THE STRATIGRAPHY AND PALAEONTOLOGY OF THE ORDOVICIAN TO DEVONIAN ROCKS OF THE AREA NORTH OF DORNES (NEAR FIGUEIRÓ DOS VINHOS), CENTRAL PORTUGAL.

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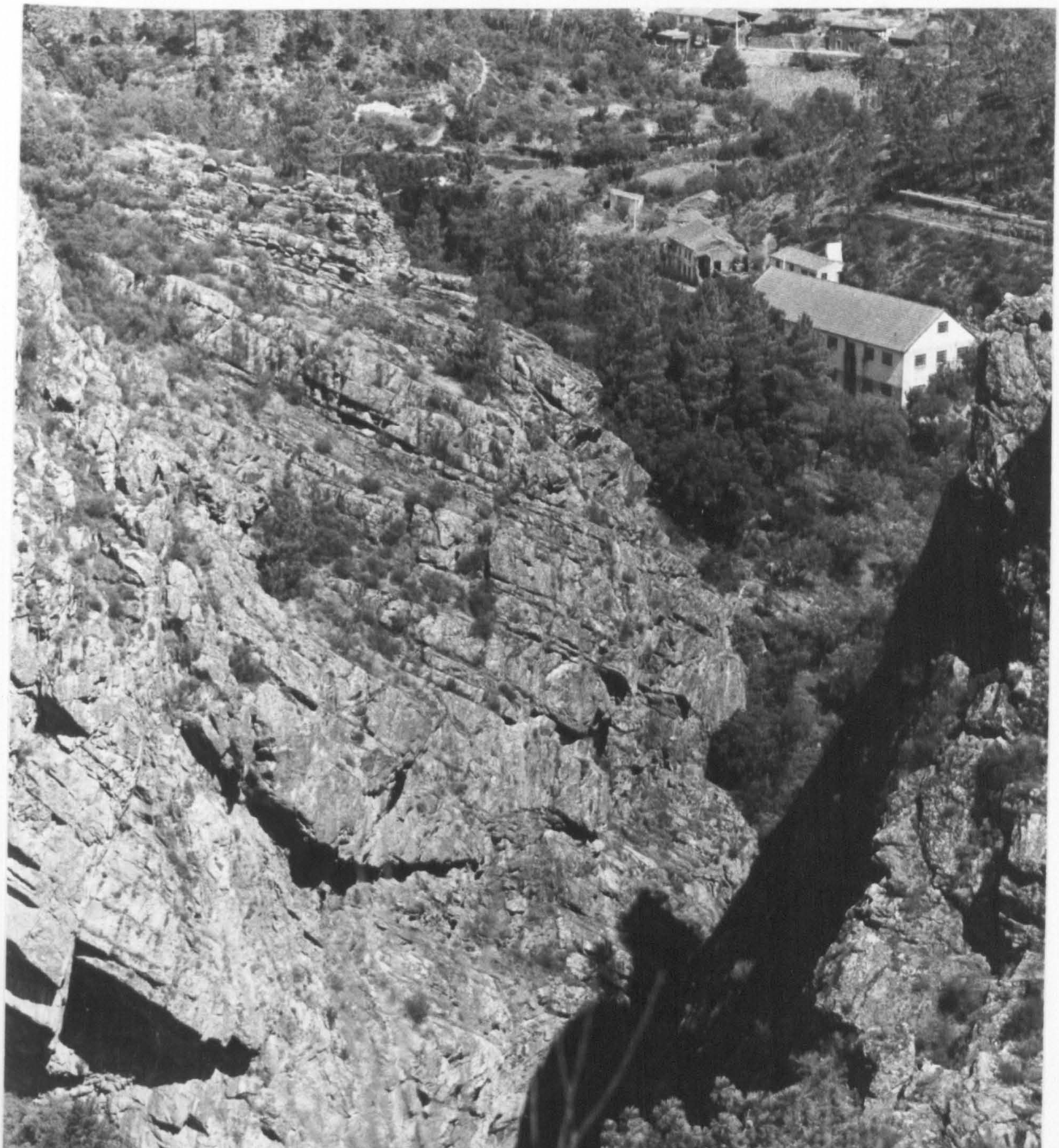

The gorge of the Ribeira de Alge at Ponte de S. Simão, 4km west of Figueiró dos Vinhos (18435 32757). The quartzites of the Serra do Brejo Formation (Arenig) are exposed on the eastern limb of an anticline which has been breached by the river.

Summary

The Ordovician, Silurian and lower Devonian rocks of the Dornes area (near Figueiró dos Vinhos), in central Portugal, form a continuous sedimentary sequence approximately 1450m thick. Folded Pre-Ordovician "Complexo xisto-grauvaquico" (CXG) is unconformably overlain by a transgressive quartzite, mudstone and greywacke succession of four Ordovician formations which are locally shelly and graptolitic. These formations are: Serra do Brejo Formation, Brejo Fundeiro Formation, Monte da Sombadeira Formation and Monte do Carvalhal Formation. The Ordovician rocks are conformably overlain by a Silurian sequence of graptolitic mudstones passing upwards into sandstones; these beds include the Vale da Ursa Formation, Foz da Serta Formation, Vale do Serrão Formation, Serra da Mendeira Formation and part of the Serra do Luação Formation. The Devonian rocks are represented by part of the Serra do Luação Formation and the Dornes formation, a sandstone-mudstone sequence passing up into shelly limestones.

Most of the Ordovician faunas are described and discussed including sixteen species of trilobite, five species of brachiopod and eleven ichnospecies of trace fossil. Faunal lists of material identified by specialists in the fields of Ordovician and Silurian graptolites, Ordovician echinoderms, Devonian brachiopods and Silurian microfossils are also given. The Ordovician faunas belong to the <u>Selenopeltis</u> Province and show close links with those of Spain, France, Morocco and Bohemia. The correlation and palaeogeography of the Dornes area is discussed with emphasis on the Ordovician Period in the Ibero-Armorican area.

Geological maps at a scale of 1:25,000 (with 1:10,000 scale maps of selected areas) are presented for the area north of Dornes which was geologically mapped at a scale of 1:10,000. Within this area a broad NNW-SSE trending syncline of Lower Palaeozoic rocks is described. This syncline is bounded on the east by an unconformable junction with the Pre-Ordovician CXG and on the west by thrust areas of gneiss and mica schist. Two granite masses are intruded into the eastern limb and the western limb is partially concealed by Triassic strata. The main folding faulting and igneous activity within the area may be attributed to the Hercynian orogeny.

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I. INTRODUCTION

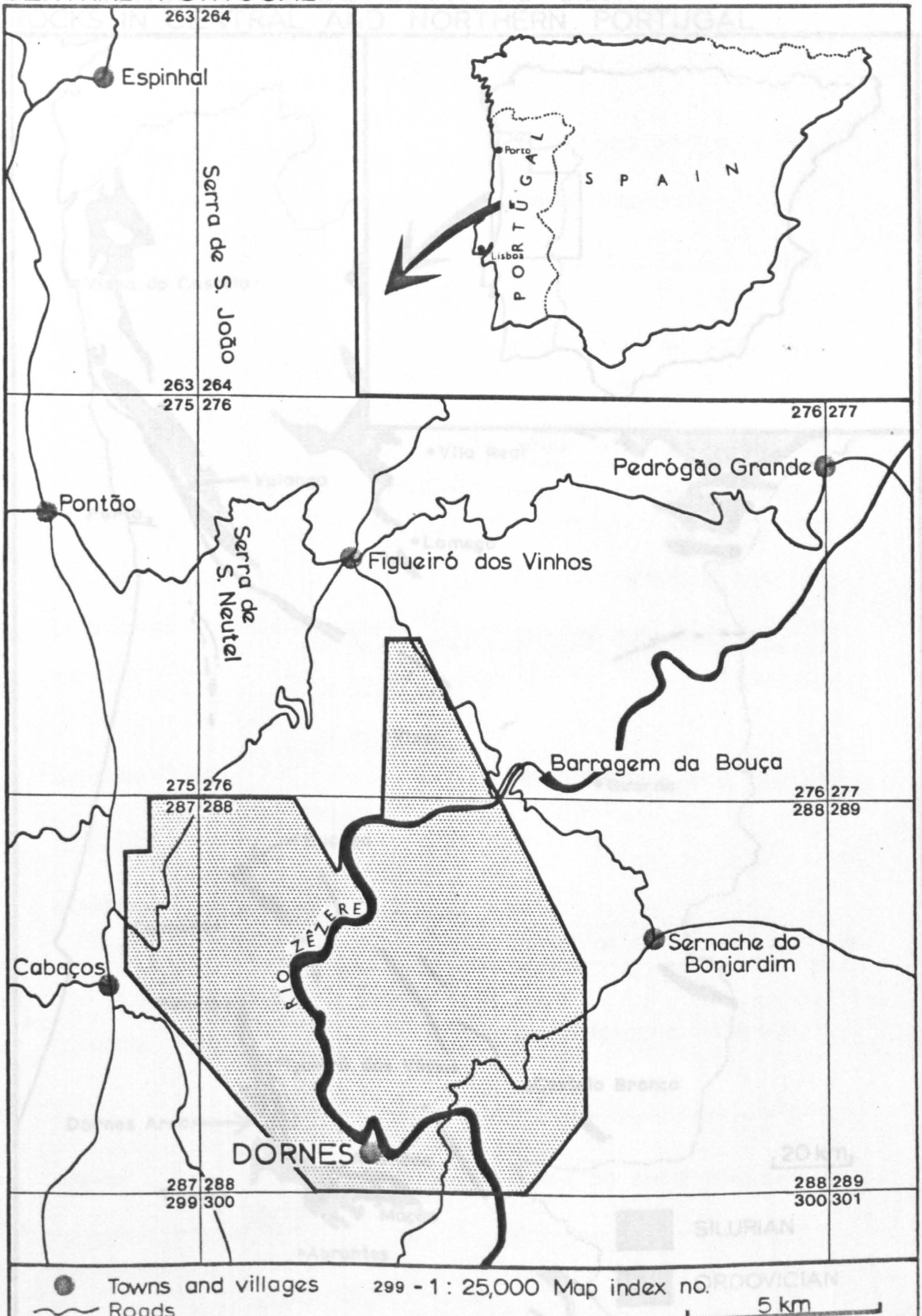
1. Location

The study area is situated in central Portugal, about 50km south-south-east of Coimbra, at the juncture of three provinces; Beira Litoral, Beira Baixa and Ribatejo (fig. 1). From the village of Dornes in the south to within 4km of Figueiró dos Vinhos in the north, the mapped area extends for about 110 square kilometres, but additional road sections were also examined north of the area. Four 1:25,000 scale Carta Militar de Portugal topographic maps (numbers 275, 276, 287 and 288) cover the area and these were obtained with the aid of the British Embassy in Lisbon. The area is also included in the 1:50,000 scale Carta Corográfica de Portugal maps (Figueiró dos Vinhos - 23B and Ferreira do Zêzere - 23D) which are generally available.

2. Geological setting

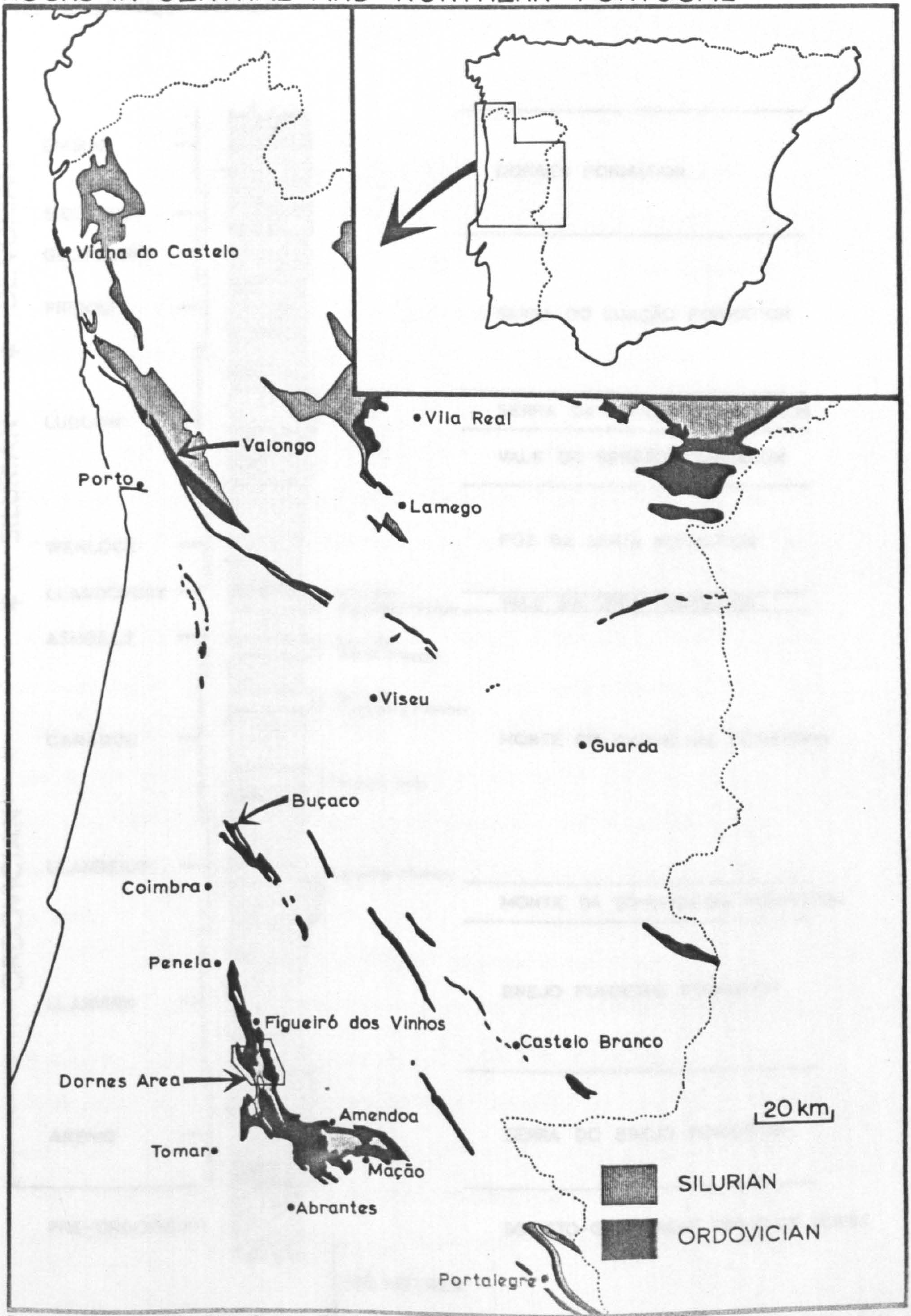
The Dornes area forms part of a curvilinear syncline of Lower Palaeozoic rocks which extends from near Mação in the south-east to Penela in the north (fig. 2). Between Dornes and Figueiró dos Vinhos the syncline is broad and has a NNW-SSE trend; it is bounded on the east by an unconformable junction with the Pre-Ordovician "Complexo xisto-grauvaquico" (Teixeira, 1972) and on the west by thrust areas of gneiss and mica schist. Two granite masses are intruded into the eastern limb and the western limb is partially concealed by Triassic strata. The Ordovician, Silurian and lower Devonian rocks of the Dornes area form a sequence approximately 1450m thick. Ten formations and four members have been recognised (fig. 3) and deposition in a slowly subsiding platform area is suggested. The

LOCATION OF THE DORNES AREA IN CENTRAL PORTUGAL FIG. 1



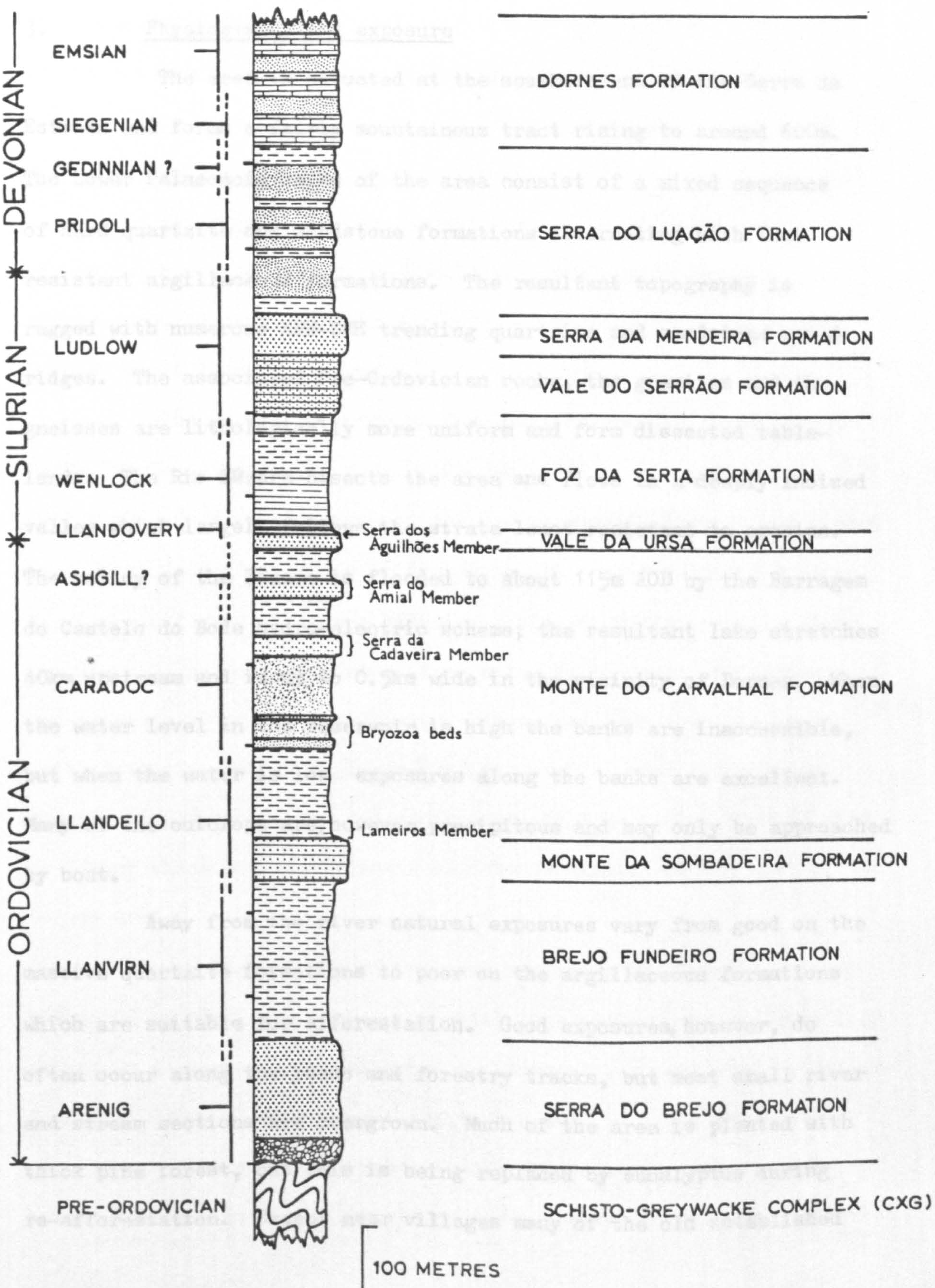
DISTRIBUTION OF ORDOVICIAN AND SILURIAN ROCKS IN CENTRAL AND NORTHERN PORTUGAL

FIG. 2



Based on the 1:1000 000 Carta Geológica de Portugal 1968

GENERALISED STRATIGRAPHICAL SEQUENCE IN THE DORNES AREA. FIG. 3



LEGEND: FIG. 59

main folding, faulting and igneous activity within the area may be attributed to the Hercynian orogeny.

3. Physiography and exposure

The area is situated at the southern end of the Serra da Estrela and forms a fairly mountainous tract rising to around 600m. The Lower Palaeozoic rocks of the area consist of a mixed sequence of hard quartzite and sandstone formations alternating with less resistant argillaceous formations. The resultant topography is rugged with numerous NNW-SSE trending quartzite and sandstone cored ridges. The associated Pre-Ordovician rocks, the granites and the gneisses are lithologically more uniform and form dissected table-lands. The Rio Zêzere bisects the area and flows in a deeply incised valley which largely follows the strata least resistant to erosion. The valley of the Zêzere is flooded to about 115m AOD by the Barragem do Castelo do Bode hydro-electric scheme; the resultant lake stretches 40km upstream and is up to 0.5km wide in the vicinity of Dornes. When the water level in the reservoir is high the banks are inaccessible, but when the water is low exposures along the banks are excellent. Many of the outcrops are, however, precipitous and may only be approached by boat.

Away from the river natural exposures vary from good on the massive quartzite formations to poor on the argillaceous formations which are suitable for afforestation. Good exposures, however, do often occur along the roads and forestry tracks, but most small river and stream sections are overgrown. Much of the area is planted with thick pine forest, but this is being replaced by eucalyptus during re-afforestation. Except near villages many of the old established olive groves are in states of neglect and are also being replaced by eucalyptus. Forestry and collecting pine resin are the main industries, farming being little above subsistence level. Most villages are surrounded by intensively cultivated fields and very small terraced fields are common in many of the valleys.

4. History of previous research

Although it is the largest area of Lower Palaeozoic rocks in central Portugal, the Mação-Penela syncline, which includes the Dornes area, has been largely neglected by geologists in favour of Buçaco, about 40km to the north.

The earliest record of the Lower Palaeozoic rocks of the Mação-Penela syncline was made by Sharpe (1849). His geological sketch map of Portugal, north of the Tagus, showed schistes and slates in a broad belt from Porto in the north, to Abrantes in the south. He also noted that the Lower Silurian schistes; "after running along the Serra de Busaco, pass about four miles to the east of Coimbra, and continue along the little river Dueca, and then down the lower part of the Zezere to the Tagus near Abrantes". Four years later Ribeiro (1853) noted that red sandstones could be traced from Coimbra to Tomar; these are the Triassic sandstones exposed on the west of the Dornes area.

A geological map of Portugal was shown in Paris by Delgado & Ribeiro in 1867, but it was not until nearly thirty years later that the first accurate Carta Geológica de Portugal was published by Delgado & Choffat (1899). They showed the Dornes area as Lower Palaeozoic strata with gneisses and Triassic rocks in the west, Cambrian and granites in the east. Delgado's exhaustive work in Portugal culminated in 1908, when he published his "Système Silurique du Portugal"; a classic study often quoted in its original form, and used as a basis for subsequent works by many students of Portuguese geology. For the Mação-Penela syncline he gave details for the area around Amendoa, and presented the following summary for the "Silurique inferieur" (Delgado, 1908, p. 75):

Ordovicien supérieur	Quartzites et schistes culminants	115m
	Schistes à *Orthis Berthoisi*	202m
Ordovicien moyen	Schistes à *Homalonotus*	107m
	Schistes à *Didymograptus*	212m
Ordovicien inférieur	Quartzites à Bilobites	82m
	Quartzites à *Scolithus*	71m

The details for the "Silurique supérieur" strata (Delgado op. cit., pp. 76-77) for the same area are translated below.

(4) Sandstones, quartzites and sandy siltstones, very well stratified in alternating beds; more than 135m.

(3) Quartzites and mudstones, very well stratified and laminated like the Slates of Gâfete in the Serra de Portalegre; at least 150m.

(2) Mudstones, soft, sandy and cleaved with many ellipsoidal nodules containing *Orthoceras*, *Cardiola* and *Monograptus*; thickness not given.

(1) Mudstones, soft, sandy and cleaved with *Monograptus* and *Orthoceras*; the mudstones appear concordant on the quartzites at the top of the "Silurique inferieur"; thickness not given.

In addition to details of all the major Lower Palaeozoic areas Delgado (op. cit., pp. 234-235) presented a chart showing the correlation of the Portuguese Ordovician and Silurian rocks.

Further correlations and a re-appraisal of the Portuguese Lower Pālaeozoic rocks were presented by Costa (1931). He added to the observations of Delgado (op. cit.) and recognised all the standard British Ordovician and Silurian series in Portugal.

Few modern works refer to the Amendoa area and the Mação - Penela syncline, fewer still to the area around Dornes. Thadeu (1949) was however an exception, and in his study of Ordovician trilobites he included a description of Synhomalonotus lusitanicus n. sp., from the south-east of the Dornes area. Conde (1966) made a detailed study of the basal Ordovician quartzites in the Amendoa - Mação area, and Romariz (1972) noted the basal conglomerates near Amendoa; Romariz (1962 & 1971) also noted that Wenlock graptolites occurred in these areas. Perdigão (1967) described Devonian fossils from near Dornes, and Teixeira & Thadeu (1967) gave a synopsis of the Portuguese Devonian including some details of the Dornes sequence.

Several general works have been published on the Pre-Ordovician rocks of Portugal, and both Schermerhorn (1955) and Bard et al. (1972b) gave details of the lithology, structure and age of these beds. Structural syntheses for Iberia were presented by Bard et al. (1972a & 1973) and by Matte & Ribeiro (1975); these give broad impressions of the structure in central Portugal, but no detailed works have been published. Recently Thadeu (1977) clarified the current knowledge of igneous and structural events in Portugal with his paper on Hercynian paragenetic units.

No 1:50,000 scale geology map of the Dornes area has yet been published, but the area to the north was under survey by Dr. G. Pereira of Coimbra University between 1972 and 1975. The only geological maps of Portugal currently available which include the Dornes area are: the Carta Geológica de Portugal (1968) and the Carta Tectónica de Portugal (Ribeiro et al., 1972) both at a scale of 1:1000,000, and the Carta Geológica de Portugal (Teixeira, 1972) at a scale of 1:500,000. Other maps also giving some details of the Dornes area are: the mapa tectonico de la Peninsula Ibérica (Julivert et al., 1972a) at a scale of 1:1000,000 and a geólogical map of south-east Iberia by Teixeira & Garcia de Figuerola (1975) at a scale of 1:500,000.

5. Purpose of study and method of procedure

This work was undertaken to study the Lower Palaeozoic rocks of the Dornes area in central Portugal. The aim of the study was to make a geological map and elucidate the stratigraphy, structure and palaeogeography of these rocks. This also involved identifying the trilobites, brachiopods and trace fossils. The other fossil groups were kindly identified by outside specialists.

The fieldwork was undertaken during the three summers between 1972 and 1974; over nine months were spent in Portugal. In the first field season transport was by motorcycle, but a Landrover was used for the subsequent seasons. The journey from Sheffield to the area (or vice versa) took four days. By using the Southampton to Bilbao ferry the driving for each journey was reduced to about 1000km each way. In the first season accommodation was by tent on recognised campsites, but the hotel in Figueiró dos Vinhos was also used for three weeks. In the second and third field seasons the

Landrover, which was fitted with a bed and a cooker, provided the accommodation. A typical week in the field involved six days field-work living "rough" in the Landrover camped next to the Rio Zêzere at Ponte do Vale da Ursa. Sundays were usually spent on the campsite in Tomar where domestic chores like washing clothes were undertaken. Provisions were replenished on Monday mornings before returning to the field. The only problems encountered in the field were mechanical breakdowns which resulted in the loss of about two weeks fieldwork.

Maps of the area at a scale of 1:25,000 were obtained in the first field season; these were photographically enlarged at Sheffield to give base maps at a 1:10,000 scale for the subsequent field seasons.

During the first summer in Portugal Dr. Romano introduced me to both the geology of northern Portugal and the Serviços Geológicos de Portugal. Permission was obtained from the Serviços Geológicos to undertake the study and four weeks were spent in the field area between Dornes and Figueiró dos Vinhos. During this period three road sections were measured, two in the north and one in the south of the proposed mapping area. It was planned to complete the 250 sq. km. of mapping between these sections in the next two years. The mapping, however, proved to be more complex than at first thought and only 110 sq. km. were eventually mapped. The area between the southern and northern road sections was therefore never completed. Details of the northern road sections are given in Appendix 4.

In the second and third field seasons mapping progressed at about 4 sq. km. per week. Nine field note books were completed and fossils were collected from nearly 200 localities. The mapping technique was to log all the road and track sections and to follow the outcrops from where they crossed the carriage-ways. The intervening areas were then traversed and any other outcrops mapped. The exposures adjacent to the Rio Zêzere were also logged, but this often involved hiring a boat to reach them. Air photographs were unfortunately not available for use in the field, but four days were spent at the Serviços Geológicos in Lisbon studying them. The photographs were at a scale of about 1:32,000 and showed the positions of some quartzite and sandstone formations; the degree of tree cover meant the photographs were of limited use. It was however possible to plot on many of the new forestry tracks and roads, which had been built since the Rio Zêzere H.E.P. scheme was constructed.

In the field sections were measured and photographed wherever the exposure was reasonable. The camera used was a 35mm Zenit B with either a 58mm Helios or a 28mm Vivitar lens. Most of the photographs were taken for monochrome prints, but some colour slides were also taken. Fossils which were collected were labelled with consecutive locality numbers using a waterproof felt tip pen, they were then wrapped and stored in labelled bags. Rock specimens were also labelled with felt tip pen, but each sample was characterised by the page number and letter of the notebook in which it was recorded. Standard notations were used in the field; grain sizes were measured according to Wentworth (1922) and bedding thicknesses were recorded using the classification of Ingram (1954). The stratigraphy was established according to the International Subcommission on Stratigraphic Classification (Hedberg, 1972) and the International Stratigraphic Guide (Hedberg, 1976).

Between field seasons much of the time at Sheffield was spent preparing and describing the collected fossils and rock specimens. Identification and interpretation of the rocks was supplemented by thin section studies of approximately 120 slides. Most of the fossils were cleaned using a "Burgess Vibrotool" fitted with a point or a chisel head; dental scrapers, scalpels and needles were also used. A flexible drive burr was also employed for cutting away large fragments of rock. A few fossils were cleaned in an ultrasonic bath and many of the trace fossils were prepared with a sandblaster. Most measurements were taken using a travelling microscope with the fossils held in the correct orientation by plasticine. Some of the very large specimens were measured with vernier calipers. The very small specimens were measured with an eye piece graticule in a zoom binocular microscope. Casts were taken of external moulds of some fossils using Silcoset 100, but plasticine was also used in a few instances. Most of the fossils were photographed using an Edixa 35mm S.L.R. camera fitted with either a 50mm Edixa lens or a 58mm Helios lens; extension tubes were fitted to give the correct magnification. The camera was held firm on a copying stand and the focusing was effected by raising or lowering the specimen on a laboratory jack stand. Illumination was by "Anglepoise" lamps with a high intensity spot lamp giving the directional illumination. All the specimens were whitened using ammonium chloride before photographing; glare from some of the specimens was reduced by placing slightly opaque plastic rings around them to diffuse the light. Unless otherwise stated, the terminology used in describing the faunas is that used in the Treatise on Invertebrate Palaeontology (Moore, 1959 and 1965; Häntzschel, 1975).

During the final year in Sheffield most of the stratigraphical sections were drawn up; the brachiopods, trace fossils and most of the trilobites were described and most of the photography was completed. The remainder of the work which included most of the writing, the diagrams, plates, maps and references was mainly completed during evenings and weekends, after leaving Sheffield in late 1975 for full time employment.

6. Acknowledgements

This project was suggested and supervised by Dr. M. Romano to whom I give my greatest thanks for his constant advice and encouragement, both during the past eight years of research and the previous three years of undergraduate study. My greatest thanks also go to Professor L.R. Moore who first introduced me to geology and who proposed me for an Edgar Allen Research Scholarship from Sheffield University to finance this study. I thank Sheffield University for this award and for the undergraduate and post-graduate facilities it provided.

I wish to thank the Serviços Geológicos in Lisboa for their permission to undertake the study and give special thanks to Dr. J. Perdigão for his help. My thanks also go to Dr. G. Pereira of Coimbra University for his assistance when I first started field work in Portugal.

Many specialists and experts have assisted me by identifying fossils and this study would have been incomplete without their work. I am indebted to the following people: Dr. R. Addison (trinucleid trilobites), Dr. G. Booth (micropalaeontology), Mr. K. Dorning (micropalaeontology), Dr. C.R.C. Paul (echinoderms), Professor D. Skevington (Ordovician graptolites), Dr. R.B. Rickards (Silurian graptolites), Dr. V.G. Walmsley (Devonian faunas). I also thank Dr. L.G. Love for studying the pyrite nodules.

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For technical help at Sheffield I thank Mr. B. Piggot (photography), Mr. G. Mulhearn (thin sections) and all the other staff under the guidance of Mr. G.S. Bryant for their assistance. For technical support since I left Sheffield, and some time off towards completing the writing up of this research, I am indebted to my current employers, the Institute of Geological Sciences. I wish to thank Mr. E.G. Smith for his advice and the photographic staff under Mr. K.E. Thornton for their help with the photographic plates and map reduction.

Lastly I thank the two ladies who have helped me to finish the work; Mrs. M. Townsend for typing the thesis so neatly and my wife Barbara for reading the manuscript and encouraging me to complete the study.

II. STRATIGRAPHY

1. The Pre-Ordovician Schisto-Greywacke Complex (CXG)

i. General character

The Schisto-Greywacke Complex of the Dornes area consists of a very thick sequence (probably several kilometres) of greywackes and mudstones with subordinate volcanic beds. These strata which are unconformably overlain by the Serra do Brejo Formation of part Arenig age, are of possible Cambrian age. In accordance with current usage the term Schisto-Greywacke Complex ("Complexo Xisto-Grauvâquico" in Portugese) is abbreviated to CXG.

ii. Topography and distribution

The monotonous greywacke, siltstone and mudstone sequence of the CXG has much less lithological variation than is found in the overlying rocks. The CXG consequently forms a smooth tableland topography cut by deep, steep sided valleys. The flattish areas between the valleys have fertile soil, support a prosperous farming community and are generally more densely populated.

The CXG crops out along the eastern side of the area from Serra da Quinta in the south to Serra do Douro in the north. The CXG also occurs north of the study area to the north of Figueirô dos Vinhos. The CXG is however missing between Serra dos Mindeiros and Aldeia Cimeira, and also in the vicinity of Figueirô dos Vinhos, where it is displaced by granitic intrusions. West of the area small enclaves of CXG have been incorporated as fault slices which crop out near the summit of Serra de S. Paulo and to the west of Ribeira do Braz.

iii. Name

Teixeira (1955) refers to the pre-Ordovician rocks as "complexo xisto-grauváquico ante-ordoviciano"; more recent works by Romariz (1972) and Bard *et al.* (1972b) also refer to the CXG as "rochas do complexo xisto grauváquico" and "complexe schisto-grauwackeux ante-ordovicien" respectively; in the latter work this term is abbreviated to CXG. Because it is in current usage by geologists working in Iberia the abbreviated term CXG is retained for the Schisto-Greywacke Complex.

Delgado and Choffat (1899, Carta Geológica de Portugal) originally divided the CXG into two sequences, "Z (Precambrico e Archaico)" and "Cb^1 (Cambrico)". Delgado (1907) later revised this classification by referring the Cb^1 sequence to the Pre-Cambrian. At the same time he recognised that the Cb^1 sequence passed down into the underlying "Z (Archean)" sequence by a gradual increase of metamorphism; a point also noted by Schermerhorn (1955 and 1959). In Delgado (1908) the Cb^1 subdivision is referred to variably in the Buçaco region as "schistes précambriens du grand affleurement de la Beira" and as "Precambrique supérieur".

Teixeira (1955) introduced the term "complexo xisto-grauváquico ante-ordoviciano" but Schermerhorn (1955) designated the CXG as the "Beira Schists", "to use a short non-committal provincial name" (Schermerhorn, 1959).

Although the term Schisto-Greywacke Complex (CXG) is retained in this work it must however be noted that in strict accordance with the International Subcommission on Stratigraphic Classification (1972) the CXG should be given a lithostratigraphic name after a type section. From the brief study of the CXG presented here formal proposal of a lithostratigraphic name is inappropriate, but the CXG would be better referred to as the "Beira Supergroup" or the "Beira Complex".

iv. Description

No type section has been designated for the CXG within the area, because only a narrow tract was mapped and nowhere within the area has the top or bottom of the complex been recognised. Because it is soft-weathering the CXG is generally poorly exposed, but good sections do occur, along the main road south-east of Sernache do Bonjardïn (19234, 31308 to 19253, 31422), along the track to the north of Sta. Maria Madalena (19146, 31468 to 19260, 31478) and north-east of Olival Grande (19212, 31604 to 19266, 31636).

Along all three of these sections similar strata are exposed. The coarsest rocks are medium-grained, grey coloured (commonly weathering white or pink-mauve), usually highly feldspathic, greywackes. These greywackes form medium to thick beds sporadically, forming sequences up to 20m thick with few or no siltstone and mudstone partings. Elsewhere similar greywackes form a few beds within dominantly siltstone and mudstone sequences. The most common sedimentary structures in the CXG are graded bedding (plate 1, fig. 1) and small scale (less than 5cm high) cross-lamination which is prevalent in the siltstones and mudstones (plate 19, figs.3 & 4). Generally the bedding interfaces for all the lithologies are even and no depositional bottom structures or biogenic structures are found within the area. Some sections did however show penecontemporaneous processes resulting in load casts and flame structures (plate 1, figs. 1 & 2).

The maximum grain size of the greywackes rarely exceeds medium-grained and no pebble horizons were found. The even, parallel-sided nature of the beds with little or no bottom scour (sole-marks or washouts) and the graded bedding suggests deposition from turbidity currents which have lost most of their erosive power. Furthermore, the widespread occurrence of regular and thin graded beds of which the pelitic units dominate over the arenitic ones, plus the lack of coarse-grained sediments and sole-marks, indicate that the CXG in the Dornes area belongs to a distal turbidite facies (Walker, 1970).

At Serra de S. Paulo (18651, 31329) a bed of probable volcanic origin occurs within the CXG. The rock is a pale green, glassy, tuff composed of very fine-grained quartz and sericite with a few ? shards up to 1mm long; about 5 percent of euhedral and subhedral quartz crystals (up to 0.5mm across) are present and the rock has a marked cleavage.

v. Thickness

It is impossible to say how thick the CXG is within the mapped area. The sections where younging directions could be studied (Sernache do Bonjardin road section, and Olival Grande) show the presence of at least several hundred metres of intensely folded and faulted strata.

Schermerhorn (1955) applied top and bottom criteria to the CXG over a large area in the vicinity of Viseu (approximately 100km north-north-east of Dornes). He showed the complex to have a minimum thickness of between 2 and 2.5km, but suggested that a much greater thickness was present. From observations in recent road cuttings near Sernache do Bonjardin the CXG appears to be of a similar nature throughout the area. The Geological Map of Portugal (Teixeira, 1972, Carta Geológica de Portugal scale 1:500,000) shows that there is a very wide expanse of CXG stretching north-east from the Sernache do Bonjardin area. It is therefore suggested that within the Dornes - Sernache do Bonjardin area the CXG is probably in the order of several kilometres thick.

vi. Age

No macrofossils have been found in the CXG within the Dornes area. Several unweathered samples of mudstone were however examined for microfossils (by G. Booth of Sheffield University), but these samples yielded only carbonaceous fragments.

The Portuguese CXG has only once yielded fossils, these were found in the area of Marão 60km east of Porto (Ribeiro et al., 1962 and Teixeira et al., 1964) where a new species of Lingulella of pre-Ordovician age was recorded. This indicates that the CXG at Marão is of post Pre-Cambrian age, a fact which reinforces the ideas of Schermerhorn (1955) who suggested a Cambrian or possibly infra-Cambrian age for the Beira Schists (CXG) in central Portugal. This conclusion was based on broad correlations by tracing the unfossiliferous CXG into the fossiliferous Cambrian strata in the north and south of Spain.

Bard et al. (1972b) also consider the CXG to be of Cambrian age and give as their reasons:

- The presence of Lingulellinae
- The comparable lithology which is similar to some of the Cambrian facies in the Iberian penninsular, in particular the Cantabrican area and the south-east of Portugal, which contain limestones and dolomites similar to those found in the CXG in the north and south-east of Portugal.
- The distribution of the CXG which occurs exactly in the area where there is no recognised Cambrian strata.
- The nature of the cover which is always of lower Ordovician age, but never of Cambrian age.
- The nature of the substratum which is always of Pre-Cambrian metamorphic basement.

From the evidence outlined above it is probable that the CXG is at least part Cambrian in age. The angular unconformity with the overlying Serra do Brejo Formation (of part Arenig age) shows that the CXG was affected by a period of folding followed by denudation. This culminated with peneplanation and the transgression of the lower Ordovician quartzites.

2. Serra do Brejo Formation

i. General character

The Serra do Brejo Formation is a transgressive sequence of upwards fining quartz arenites and orthoconglomerates about 150m thick. These form the basal Ordovician rocks of part Arenig age and are characterised by the Skolithos and Cruziana ichnofacies.

ii. Topography and distribution

The Serra do Brejo Formation forms a major escarpment trending north-north-west for 14km along the eastern side of the area and northwards a further 11km to Serra de S. João (plate 4 fig. 1). Frequently the escarpment is offset by north-east to south-west trending strike - slip faults resulting in several distinct serras. From south to north these are: Serra da Quinta, Serra do Casal, Serra do Porto dos Fusos, Serra do Brejo, Serra dos Mindeiros, Serra dos Coriscos and Serra do Douro. The formation is also represented in the west of the area at the Serra de S. Paulo.

iii. Name

The formation is named after the two escarpments within the area which are both called Serra do Brejo.

iv. Type section

Nowhere within the study area is there a completely exposed section through the Serra do Brejo Formation; the type section is therefore formed by a combination of two sections. The lower part of the type section at Serra do Casal (a) is situated about 1km south-east of the southern Serra do Brejo, and the upper part of the type section at Olival Grande (b) is situated about 1km south of the northern Serra do Brejo.

(a) Serra do Casal (19206, 31326 to 19194, 31325) fig. 4

On the Serra do Casal the base of the formation is marked by a strong break of slope. The lowest 67m of the formation is nearly completely exposed, but from 67 to 113m exposure is only about 50 per cent. The top part of the formation, between 113m and 150m above the base, is not exposed and the top of the formation is marked by a slight break of slope.

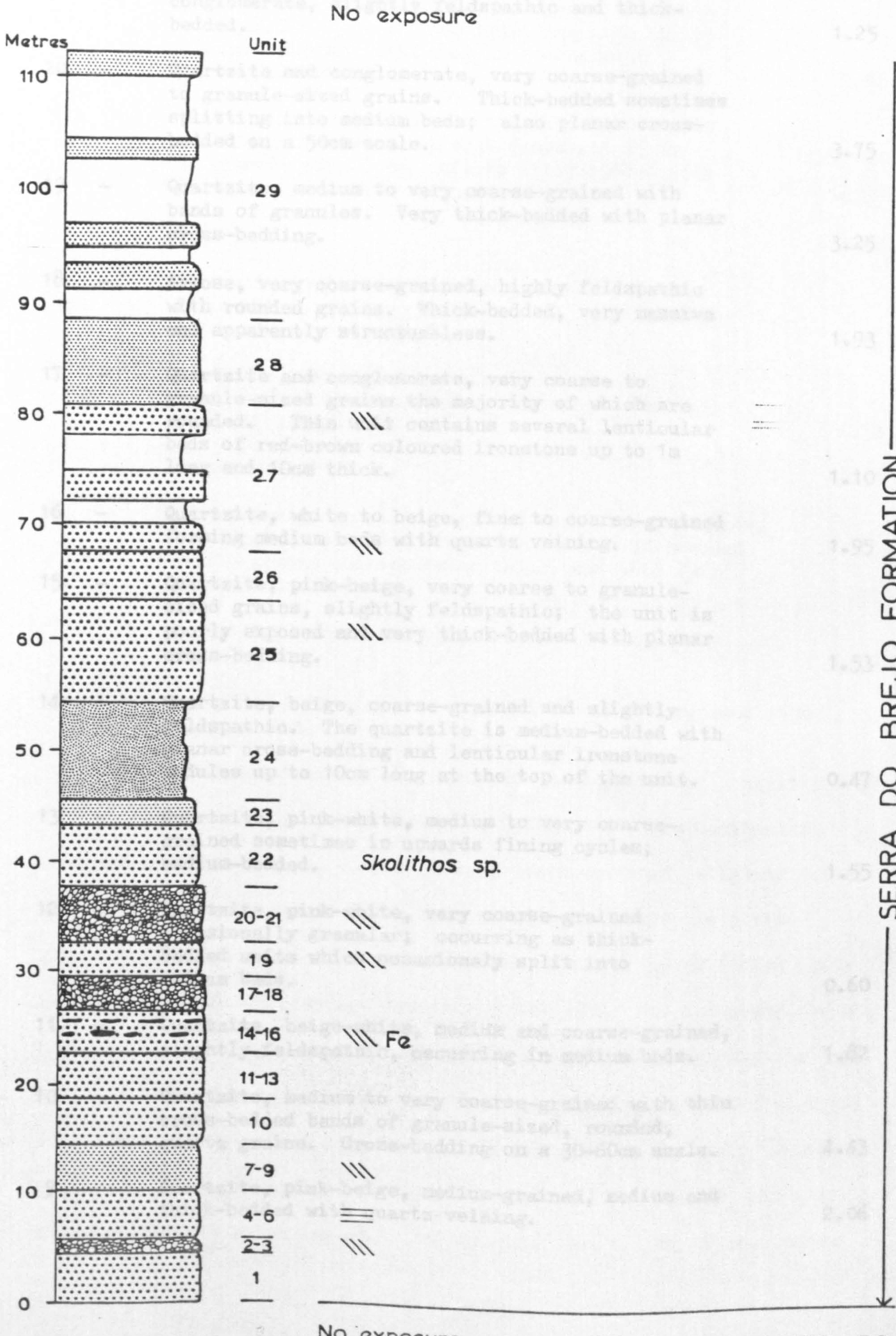
This sequence is divided into 30 units (fig. 4) which from top to bottom are:

– slight break of slope marking the top of the formation –

		metres
30 –	No exposure	47.00
29 –	Quartzite, medium to fine-grained, slightly feldspathic and thick-bedded; poorly exposed.	24.00
28 –	Quartzite, white, fine and very fine-grained, very thick, massively bedded.	8.00
27 –	Quartzite, coarse-grained, thick-bedded with faint cross-bedding; poor exposure between the thick beds.	13.00
26 –	Quartzite, white, coarse-grained and very coarse-grained, slightly feldspathic. The quartzite is massive and sometimes splits into very thick beds.	4.30
25 –	Quartzite, grey, coarse and very coarse-grained, thick and very thick-bedded; some beds with faint cross-bedding.	9.00
24 –	Sandstone, white to beige, fine-grained dominantly of quartz, very thick-bedded; the sandstone is soft weathering.	9.00
23 –	Quartzite, beige, fine-grained, slightly feldspathic, thick-bedded forming massive units.	2.30
22 –	Quartzite and conglomerate, coarse to granule-sized grains in layers; feldspathic. Poorly exposed, thick bedding with occasional very thin beds. Skolithos linearis Haldeman, 1840 common; fossil locality 69.	5.80

SERRA DO BREJO FORMATION. Type section, lower part. FIG. 4

Serra do Casal (19206 31326 to 19194 31325)



LEGEND: FIG. 59

21	-	Quartzite, very coarse-grained to granule conglomerate, slightly feldspathic and thick-bedded.	1.25
20	-	Quartzite and conglomerate, very coarse-grained to granule-sized grains. Thick-bedded sometimes splitting into medium beds; also planar cross-bedded on a 50cm scale.	3.75
19	-	Quartzite, medium to very coarse-grained with bands of granules. Very thick-bedded with planar cross-bedding.	3.25
18	-	Arkose, very coarse-grained, highly feldspathic with rounded grains. Thick-bedded, very massive and apparently structureless.	1.93
17	-	Quartzite and conglomerate, very coarse to granule-sized grains the majority of which are rounded. This unit contains several lenticular beds of red-brown coloured ironstone up to 1m long and 10cm thick.	1.10
16	-	Quartzite, white to beige, fine to coarse-grained forming medium beds with quartz veining.	1.95
15	-	Quartzite, pink-beige, very coarse to granule-sized grains, slightly feldspathic; the unit is poorly exposed and very thick-bedded with planar cross-bedding.	1.53
14	-	Quartzite, beige, coarse-grained and slightly feldspathic. The quartzite is medium-bedded with planar cross-bedding and lenticular ironstone nodules up to 10cm long at the top of the unit.	0.47
13	-	Quartzite, pink-white, medium to very coarse-grained sometimes in upwards fining cycles; medium-bedded.	1.55
12	-	Quartzite, pink-white, very coarse-grained occasionally granular; occurring as thick-bedded units which occasionaly split into medium beds.	0.60
11	-	Quartzite, beige-white, medium and coarse-grained, slightly feldspathic, occurring in medium beds.	1.82
10	-	Quartzite, medium to very coarse-grained with thin cross-bedded bands of granule-sized, rounded, quartz grains. Cross-bedding on a 30-60cm scale.	4.43
9	-	Quartzite, pink-beige, medium-grained, medium and thick-bedded with quartz veining.	2.06

8	-	Quartzite, beige, medium-grained, slightly feldspathic; the quartzite occurs as a massive very thick unit sometimes splitting into thick and medium beds; the unit is veined with crystalline quartz.	1.50
7	-	Quartzite, medium-grained, slightly feldspathic with sporadic dark grey rock fragments of up to granule size. The unit is thick-bedded with faint planar cross-bedding.	0.80
6	-	No exposure	0.60
5	-	Quartzite, medium and coarse-grained, slightly feldspathic. The quartzite occurs in thick beds which are quartz veined.	2.15
4	-	Quartzite, very coarse-grained, feldspathic, occurring in massive, thick beds which show faint, parallel lamination.	1.70
3	-	No exposure.	0.40
2	-	Conglomerate, granule sized and very coarse-grained. The conglomerate is dominantly composed of rounded quartz grains and occurs as thick beds with faint planar cross-bedding.	1.35
1	-	Quartzite, very coarse-grained, massive and very thick-bedded.	4.40
	-	Sharp break of slope - pre-Ordovician CXG exposed 150m further east.	
	-	Total thickness of the Serra do Brejo Formation	about 150.00

The lowest 38m of the formation (units 1-21) are dominantly composed of thick-bedded, coarse to very coarse-grained, slightly feldspathic quartz arenites. These beds often contain granule orthoconglomerate layers which frequently occur in planar cross-bedded units in which the top set beds are commonly eroded off. The orthoconglomerate horizons are usually formed of well rounded vein quartz fragments set in a fine-grained quartz sand matrix. The cross-bedding indicates that the depositional current was dominantly from the south-south-east. Within this part of the formation units 14 and 17 contain irregular, elongate ironstone lenses which are up to 1m long and 10cm thick. These lenses are red-brown in colour and composed of coarse sandstone cemented with limonite; they occur parallel to the bedding and appear to be syn-depositional.

Unit 22 contains numerous poorly preserved burrows of Skolithos linearis Haldeman. The thickness of the Skolithos bearing beds found in this section is much less than in many other areas, especially in the Serra da Quinta to the south and the Serra do Brejo to the north.

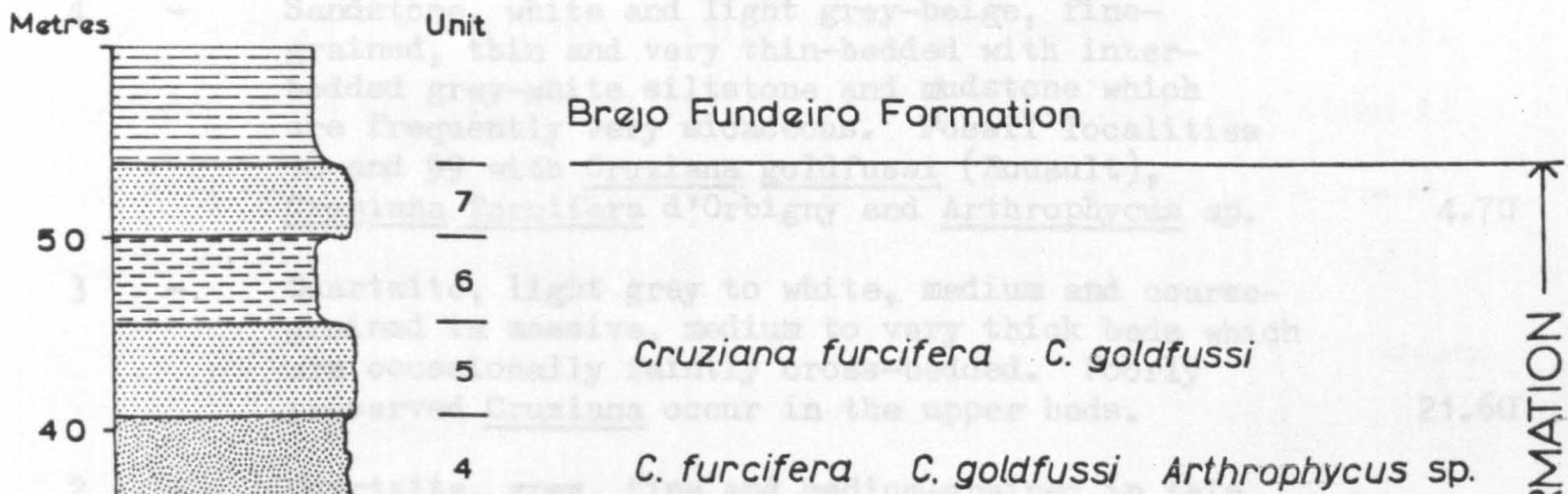
The remainder of the formation that is exposed consists mainly of thick-bedded, coarse-grained quartz arenites which pass upwards into fine-grained beds. Only about 60 percent of the upper beds are exposed, and the areas of no exposure probably conceal thinner or softer beds. The upper part of the exposed sequence is very similar to the lowest beds in the sequence exposed at Olival Grande. Combining the exposed parts of the Olival Grande and the Serra do Casal sequences gives a thickness of 155m for the formation, which is very close to that calculated for the complete sequence at Serra do Casal.

(b) Olival Grande (19146, 31619 to 19152, 31622), fig. 5

The top 52m of the formation and the contact with the overlying Brejo Fundeiro Formation are well exposed at Olival Grande (plate 3). The base of the measured section starts at the bottom of the cliff where the stream runs parallel to the strike of the beds (plate 3); the section is shown in figure 5 and is divided up into 7 units which from top to bottom are:

		metres
-	Brejo Fundeiro Formation; mudstones and siltstones, grey, laminated and thinly bedded containing fossils at fossil localities 190 and 191 which yielded Neseuretus (Neseuretus) tristani (Brongniart), Mucronaspis cf. macrophtalma (Brongniart) and Didymograptus murchisoni Zone graptolites. The lowest beds of the unit contain occasional thin beds of fine-grained, beige sandstone with ?Planolites.	

SERRA DO BREJO FORMATION. Type section, upper part. FIG. 5
Olival Grande (19146 31619 to 19152 31622)



LEGEND: FIG 59

7	-	Top of the Serra do Brejo Formation taken at the top of the upper quartzite bed. Quartzite, light grey, fine-grained occurring in thin and medium beds with partings of light grey-beige silty sandstone.	3.70
6	-	Siltstone, light grey with occasional horizons of thin-bedded, fine-grained quartzite.	4.75
5	-	Quartzite, light grey, fine-grained in medium and thick beds which are occasionally slightly banded. Fossil locality 100 containing *Cruziana goldfussi* (Rouault), *Cruziana furcifera* d'Orbigny and *Cruziana* sp. indet.	4.80
4	-	Sandstone, white and light grey-beige, fine-grained, thin and very thin-bedded with inter-bedded grey-white siltstone and mudstone which are frequently very micaceous. Fossil localities 98 and 99 with *Cruziana goldfussi* (Rouault), *Cruziana furcifera* d'Orbigny and *Arthrophycus* sp.	4.70
3	-	Quartzite, light grey to white, medium and coarse-grained in massive, medium to very thick beds which are occasionally faintly cross-bedded. Poorly preserved *Cruziana* occur in the upper beds.	21.60
2	-	Quartzite, grey, fine and medium-grained in thin and medium beds.	2.00
1	-	Quartzite, light grey, medium-grained in massive thick beds.	10.00
	-	Total thickness of the upper part of the Serra do Brejo Formation exposed	51.55

The beds of unit 1 are very similar to those of unit 29 exposed at the top of the Serra do Casal section. Unit 4 in the sequence described above has a very distinctive lithology, the quartzites being interbedded with grey and white micaceous siltstone and mudstone. This lithology commonly occurs near the top of the Serra do Brejo Formation and beds of identical lithology occur at fossil locality 62 on the western flank of the Serra do Porto dos Fusos. At Olival Grande units 4 and 5 have yielded abundant trace fossils preserved as hypichnial ridges (Martinsson, 1970) and these include: *Cruziana furcifera* d'Orbigny, *Cruziana goldfussi*

(Rouault) and Arthrophycus sp. The Cruziana indicate a probable Arenig age, but the species also range down into the topmost part of the Tremadoc (Crimes, 1975a).

v. Comparison of the type section with the other sections and outcrops

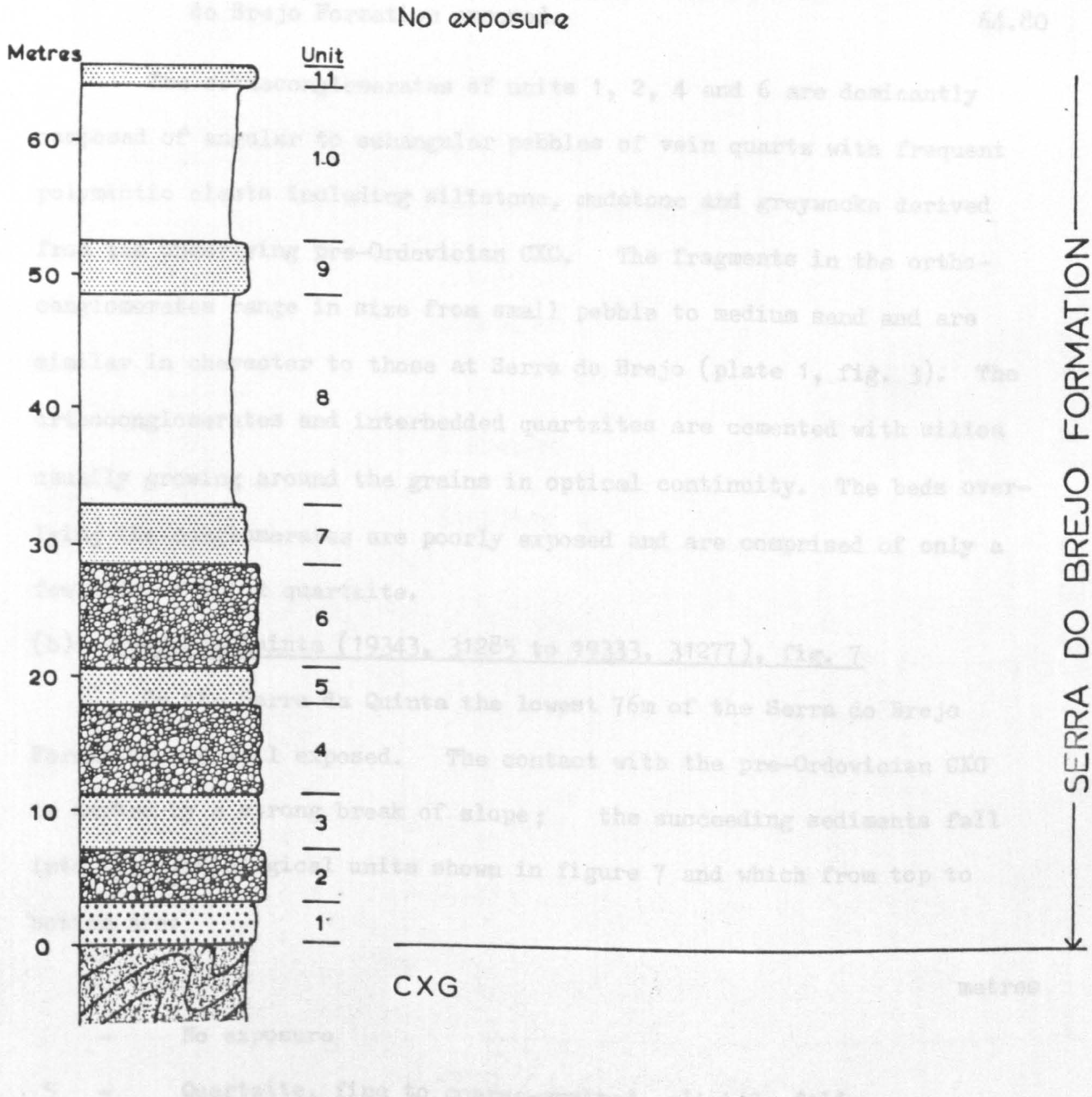
(a) Sta. Maria Madalena (19194, 31453), fig. 6

The church of Sta. Maria Madalena lies approximately half-way between the sections measured at Serra do Casal and Olival Grande. The church stands on an east-west trending ridge capped by the lowest 65m of the Serra do Brejo Formation which forms the eastern limb of an open syncline. The section can be divided into 11 units which are shown in figure 6, but only the bottom 22m of the section is completely exposed; from top to bottom the units are:

			metres
	-	No exposure	
11	-	Quartzite, white, fine-grained in thin and very thin beds.	1.00
10	-	No exposure	12.00
9	-	Quartzite, white-beige, very fine-grained in thick beds.	4.00
8	-	No exposure	15.40
7	-	Quartzite, white, fine-grained and slightly feldspathic occurring in thick and very thick beds.	4.50
6	-	Orthoconglomerate with pebble sized clasts dominantly of vein quartz, but with occasional pebbles of greywacke and siltstone. The orthoconglomerate is thick-bedded and massive with well developed jointing.	8.00
5	-	Quartzite, poorly exposed; sheared and recrystallised.	2.40
4	-	Orthoconglomerate as above (unit 6), but interbedded with thick and very thick beds of medium and coarse-grained quartzite.	6.50
3	-	Quartzite, white, fine to medium-grained, slightly feldspathic occurring in thin and medium beds.	4.00

SERRA DO BREJO FORMATION.
Sta. Maria Madalena (19194 31453)

FIG. 6



LEGEND: FIG 59

2	–	Orthoconglomerate, composed of quartz pebbles and forming very massive, thick beds.	4.00
1	–	Quartzite, white, coarse-grained and slightly feldspathic occurring in medium to thick beds interbedded with medium to thick beds of angular quartz pebble orthoconglomerate.	3.00
	–	Slight break of slope below which poorly exposed quartz veined greywackes and siltstones of the pre-Ordovician CXG crop out.	
	–	Total thickness of the lower part of the Serra do Brejo Formation exposed.	64.80

The orthoconglomerates of units 1, 2, 4 and 6 are dominantly composed of angular to subangular pebbles of vein quartz with frequent polymictic clasts including siltstone, mudstone and greywacke derived from the underlying pre-Ordovician CXG. The fragments in the orthoconglomerates range in size from small pebble to medium sand and are similar in character to those at Serra do Brejo (plate 1, fig. 3). The orthoconglomerates and interbedded quartzites are cemented with silica usually growing around the grains in optical continuity. The beds overlying the conglomerates are poorly exposed and are comprised of only a few beds of thick quartzite.

(b) Serra da Quinta (19343, 31285 to 19333, 31277), fig. 7

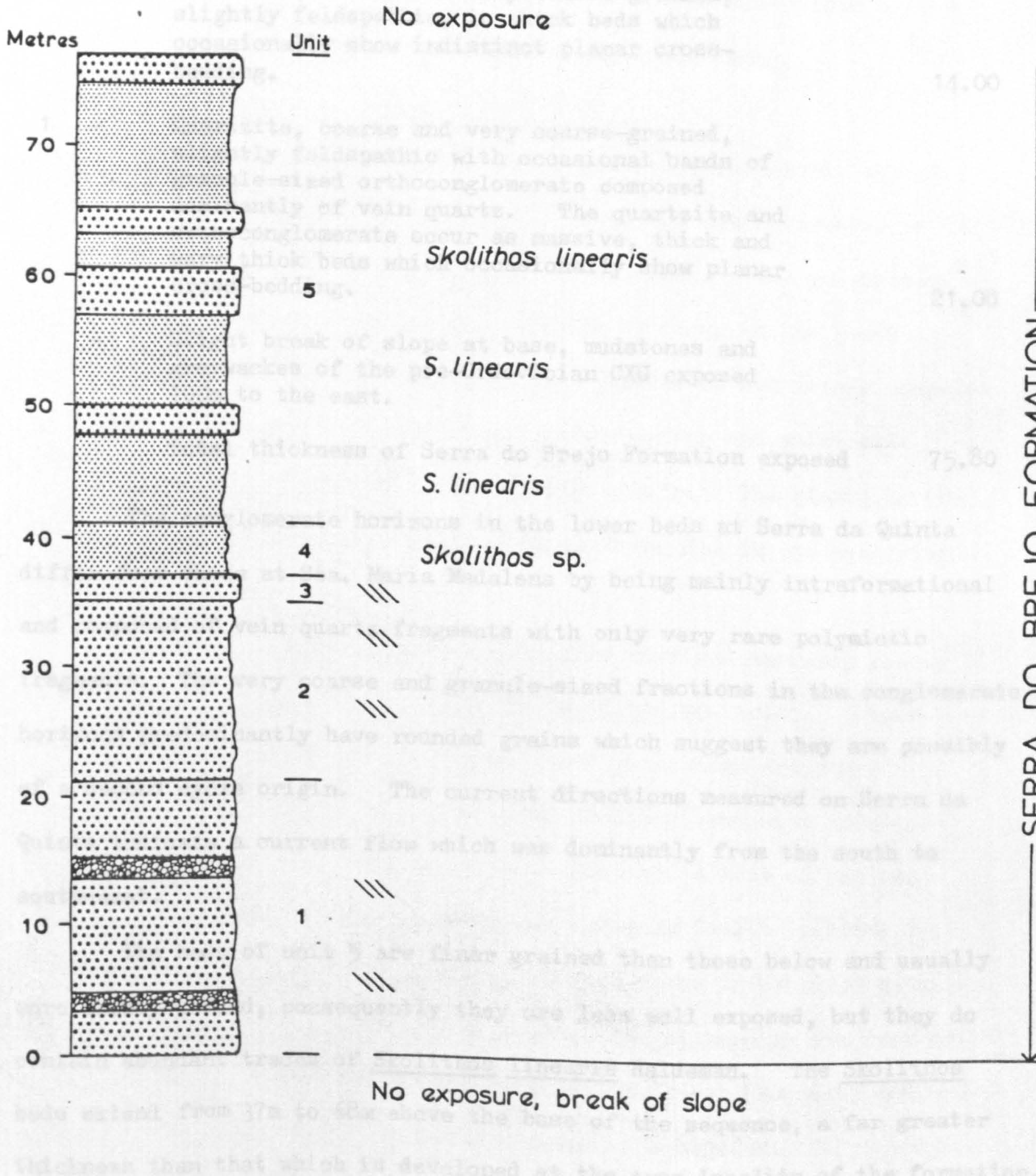
On the Serra da Quinta the lowest 76m of the Serra do Brejo Formation are well exposed. The contact with the pre-Ordovician CXG is marked by a strong break of slope; the succeeding sediments fall into five lithological units shown in figure 7 and which from top to bottom are:

			metres
	–	No exposure	
5	–	Quartzite, fine to coarse-grained, slightly feldspathic in medium and thick beds. The lower part of the unit is poorly exposed. The unit contains frequent beds with *Skolithos linearis* Haldeman at fossil localities 63 and 64.	36.00

SERRA DO BREJO FORMATION

Serra da Quinta (19343 31285 to 19333 31277)

FIG. 7



LEGEND: FIG 59

4	-	Quartzite, fine and medium-grained in thin beds with abundant Skolithos sp. in burrows up to 7mm in diameter.	3.00
3	-	Quartzite, very coarse-grained with bands of quartz granules, slightly feldspathic, forming one very thick bed which has large scale planar cross-bedding indicating a current direction from the south-east (plate 2, figs. 2 and 4).	1.80
2	-	Quartzite, coarse and very coarse-grained, slightly feldspathic, in thick beds which occasionally show indistinct planar cross-bedding.	14.00
1	-	Quartzite, coarse and very coarse-grained, slightly feldspathic with occasional bands of granule-sized orthoconglomerate composed dominantly of vein quartz. The quartzite and orthoconglomerate occur as massive, thick and very thick beds which occasionally show planar cross-bedding.	21.00
	-	Slight break of slope at base, mudstones and greywackes of the pre-Ordovician CXG exposed 100m to the east.	
		Total thickness of Serra do Brejo Formation exposed	75.80

The conglomerate horizons in the lower beds at Serra da Quinta differ from those at Sta. Maria Madalena by being mainly intraformational and composed of vein quartz fragments with only very rare polymictic fragments. The very coarse and granule-sized fractions in the conglomerate horizons predominantly have rounded grains which suggest they are possibly of a second cycle origin. The current directions measured on Serra da Quinta indicate a current flow which was dominantly from the south to south-east.

The beds of unit 5 are finer grained than those below and usually more thinly bedded, consequently they are less well exposed, but they do contain abundant traces of Skolithos linearis Haldeman. The Skolithos beds extend from 37m to 68m above the base of the sequence, a far greater thickness than that which is developed at the type locality of the formation.

The remaining part of the Serra do Brejo Formation is poorly exposed on the dip slope of the Serra da Quinta escarpment. At fossil locality 23 two specimens of Cruziana furcifera d'Orbigny were found in thinly bedded, fine-grained, quartzites interbedded with micaceous, silty, sandstones and mudstones. This lithology is very similar to that of the flaggy Cruziana bearing beds which form unit 4 at Olival Grande and which also occur at Porto dos Fusos.

(c) Serra do Porto dos Fusos (19126, 31475)

The escarpment of Serra do Porto dos Fusos is heavily wooded and the exposures of the Serra do Brejo Formation are restricted to the crest of the ridge and a road cutting to the south. The quartzites exposed on this escarpment are very similar to those to the south on Serra do Casal and Serra da Quinta. The quartzites are mainly composed of thick beds which often show planar cross-bedding and which are composed of coarse to granule-sized quartz clasts. The clasts in the basal beds are angular, but they become more rounded in the overlying strata.

Trace fossils are restricted to rare vertical burrows, poorly preserved, and tentatively assigned to Skolithos sp. indet. Exposures on the Porto dos Fusos road to the south of this ridge are poor. The outcrop is frequently disturbed by minor faulting, and well developed jointing, but the sequence appears to be similar to that of the type section. Near the village of Porto dos Fusos at fossil locality 62, thinly bedded, fine-grained, white quartzites occur interbedded with white weathering, micaceous mudstones which are exposed in the core of an anticline. These beds yielded Cruziana goldfussi (Rouault) and are very similar to unit 4 of the Olival Grande type section.

(d) Serra do Brejo (19167, 31705)

The Serra do Brejo gives its name to the formation which is splendidly exposed there, but where only the type section for the upper part of the formation at Olival Grande may be accurately measured. The basal conglomerates are very similar to those at Sta. Maria Madalena and are composed of angular pebbles of vein quartz with a few polymict fragments, set in a coarse sand matrix which is often stained red with haematite (plate 1, fig. 3). The overlying beds are mainly composed of thick, coarse-grained, planar cross-bedded quartzites; the cross-bedding indicates deposition from currents which came from the south and west. Skolithos bearing beds of quartzite are common in the lower part of the sequence, but the poor exposure of them affords little indication as to their thickness. The upper part of the sequence is developed as a Cruziana facies which forms the upper part of the type section situated at Olival Grande (see 2, iv, (b)). The upper part of the sequence also crops out in scattered exposures on the dip slope of the Serra. Several exposures reveal linguiod (plate 2, fig. 3) and straight crested ripple marks in beds associated with Cruziana; this characteristic is similar to that displayed by beds exposed next to the Rio Zêzere (see following section).

(e) Serra dos Mindeiros to the Rio Zêzere (19089, 31826 to 18950, 31932) fig. 8.

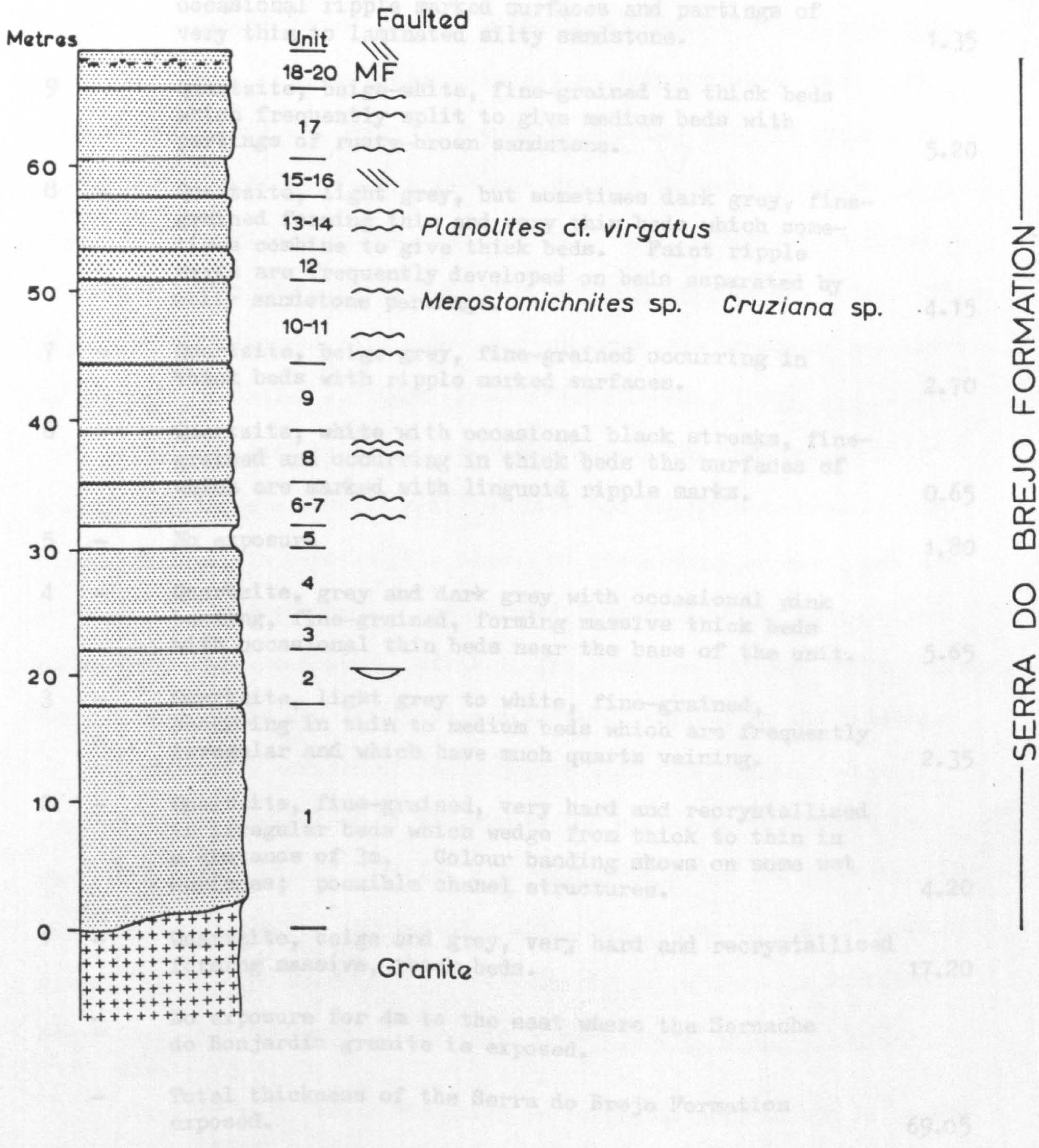
The Serra do Brejo Formation is poorly exposed on Serra dos Mindeiros, but further north towards the gorge of the Rio Zêzere the exposure improves (plate 1, fig. 4). From Serra dos Mindeiros northwards the bottom of the quartzite sequence forms the roof of the Sernache do Bonjardin granite (plate 20, figs. 3 and 4). The thermal metamorphism from the granite has recrystallised all the lower beds and quartz veining is frequently well developed; this tends to obliterate many of the sedimentological and ichnological features. In the gorge of the Rio Zêzere, exposures of the quartzites are more accessible and a section 52 metres thick is exposed (plate 1, fig. 4; plate 20, figs. 3 and 4); this sequence is divided into 20 units which are listed below from top to bottom and which are also shown in figure 8.

			metres
	–	Top contact faulted against the Brejo Fundeiro Formation.	
20	–	Quartzite, massive, but splitting into thin beds some of which show cross-bedding on a 5–10cm scale. A mud-flake conglomerate is developed in the lower beds.	1.00
19	–	Quartzite, white, fine-grained in a massive and thick bed with planar cross-bedding which suggests deposition by a current coming from the south-east.	1.05
18	–	Quartzite, white, fine-grained in a massive thick bed which thins slightly northwards.	1.10
17	–	Quartzite, light grey, fine and medium-grained in thick beds which occasionally split into medium and laminated beds. Faint ripple marks on the top surfaces of some beds.	5.90
16	–	Quartzite, white, fine-grained in medium and thick beds with cross-bedding on a 10cm scale.	1.20
15	–	Quartzite, light grey-white, fine-grained, massive and thick-bedded.	1.75
14	–	Quartzite, grey, fine-grained in thick beds with faint ripple marks and laminated quartzite partings.	2.85
13	–	Quartzite, grey, fine to medium-grained in thick, massive beds. Numerous traces of Planolites cf. virgatus (Hall). The traces are 1.5 to 2.0cm in diameter, sinuous and frequently turn and cross each other.	1.30
12	–	Quartzite, grey with dark grey banding, medium to fine-grained and occurring in massive thick beds.	2.30

SERRA DO BREJO FORMATION

Rio Zêzere near Almegue (18958 31933 to 18950 31927)

FIG. 8



LEGEND: FIG 59

11 -	Quartzite, light grey to white, in thin and medium beds with siltstone partings. The surfaces of many beds are marked with assymmetrical ripples which suggest that the current of deposition came from the north. The top surfaces of many beds show <u>Cruziana</u> preserved as partially infilled epichnial grooves (Martinsson, 1970). One bedding plane is traversed by the large arthropod walking track <u>Merostomichnites</u> sp. indet.	5.35
10 -	Quartzite, light grey and beige in thin beds with occasional ripple marked surfaces and partings of very thin to laminated silty sandstone.	1.35
9 -	Quartzite, beige-white, fine-grained in thick beds which frequently split to give medium beds with partings of rusty-brown sandstone.	5.20
8 -	Quartzite, light grey, but sometimes dark grey, fine-grained forming thin and very thin beds which sometimes combine to give thick beds. Faint ripple marks are frequently developed on beds separated by silty sandstone partings.	4.15
7 -	Quartzite, beige-grey, fine-grained occurring in thick beds with ripple marked surfaces.	2.70
6 -	Quartzite, white with occasional black streaks, fine-grained and occurring in thick beds the surfaces of which are marked with linguoid ripple marks.	0.65
5 -	No exposure	1.80
4 -	Quartzite, grey and dark grey with occasional pink banding, fine-grained, forming massive thick beds with occasional thin beds near the base of the unit.	5.65
3 -	Quartzite, light grey to white, fine-grained, occurring in thin to medium beds which are frequently irregular and which have much quartz veining.	2.35
2 -	Quartzite, fine-grained, very hard and recrystallised in irregular beds which wedge from thick to thin in a distance of 3m. Colour banding shows on some wet surfaces; possible chanel structures.	4.20
1 -	Quartzite, beige and grey, very hard and recrystallised forming massive, thick beds.	17.20
-	No exposure for 4m to the east where the Sernache do Bonjardin granite is exposed.	
-	Total thickness of the Serra do Brejo Formation exposed.	69.05

Within unit 1 the quartzites are strongly recrystallised by the metamorphism of the Sernache do Bonjardin granite and only the major bedding units can be discerned. Unit 2 is also strongly recrystallised, but is composed of beds which frequently wedge and thin over short distances; these beds are possibly channel structures. Many of the bedding surfaces within units 7, 8, 11 and 14 are ripple marked with assymmetrical ripples which have wavelengths of between 5 and 11cm. These ripples suggest deposition from currents which came from the north and the west; a few bedding planes are developed with linguoid ripple marks similar to those exposed on Serra do Brejo (plate 2, fig. 3). One ripple marked slab in unit 11 is traversed by a large example of the arthropod walking track Merostomichnites sp. indet. This is associated with indeterminate Cruziana which are unusually preserved as partially infilled epichnial grooves (Martinsson, 1970).

Unit 20, next to the fault at the top of the sequence, is thin-bedded, but forms a massive unit in which the lowest beds contain mud-flake conglomerate bands. The clasts of these conglomerate bands are composed of flat, subangular and rounded fragments of micaceous silt-stone in a quartz sandstone matrix. The rock has a wackestone texture and all the clasts are flattened and aligned parallel to the bedding.

The basal contact of the sequence with the granite is not exposed on the south bank of the river, but on the north bank it is sharp and uneven (plate 20, fig. 4); assimilation of the quartzite into the granite is obvious and partly assimilated blocks of quartzite occur within the granite near the contact with the Serra do Brejo Formation.

(f) Serra dos Coriscos to Serra do Douro (19051, 32054 to 18892, 32392)

The Serra do Brejo Formation is poorly exposed on the Serra dos Coriscos which is heavily wooded. For 3km north from the Rio Zêzere the basal contact of the formation is with the roof of the Sernache do Bonjardin granite which has recrystallised or assimilated the lower beds (plate 20, fig. 4). Where beds low in the formation are preserved they are frequently composed of pebble conglomerates in thick beds, similar to those seen further south. North of the granite towards the Serra do Douro the basal contact of the formation is erosional, with the development of a granule conglomerate resting with a strong angular unconformity upon pre-Ordovician CXG. The conglomerate is dominantly composed of angular vein quartz with a few polymictic fragments of greywacke and siltstone set in a limonitic or haematitic quartz sand matrix. North of the Rio Zêzere to the Serra do Douro no beds of the Skolithos ichnofacies have yet been recorded, but poorly exposed beds containing abundant Cruziana furcifera d'Orbigny and a few examples of Rusophycus sp. indet. are found at fossil localities 123, 124 and 134 near the contact with the Brejo Fundeiro Formation.

(g) Serra de S. Paulo (19646, 31330)

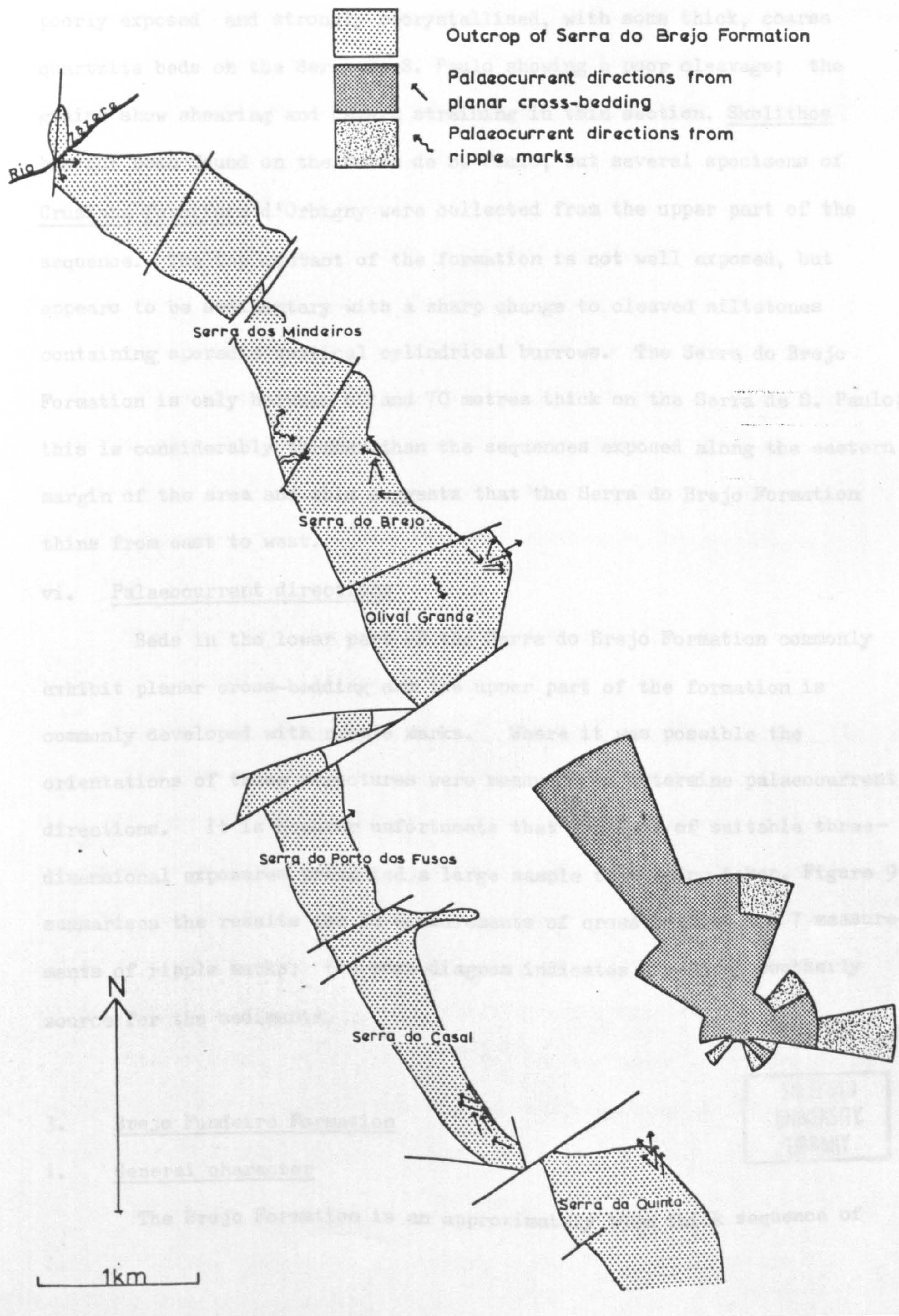
The rocks in the west of the area are more highly deformed than in the east and a strong cleavage is developed even in some of the quartzites. Despite this the resistant trace fossils Cruziana furcifera d'Orbigny and Cruziana sp. indet. are found on the ridge of Serra de S. Paulo. Since these Cruziana have only been found within the Serra do Brejo Formation elsewhere in the area, it appears reasonable to conclude that the sequence at Serra de S. Paulo also belongs to this formation and that it has been thrust onto the Monte do Carvalhal Formation.

On the crest of the ridge a very thick, recrystallised, pebble orthoconglomerate forms the base to the formation. This conglomerate overlies strongly cleaved and metamorphosed greywacke, siltstone and

SERRA DO BREJO FORMATION

FIG. 9

Palaeocurrent directions



tuff of the pre-Ordovician CXG which have also been thrust onto the Monte do Carvalhal Formation. The overlying quartzite sequence is poorly exposed and strongly recrystallised, with some thick, coarse quartzite beds on the Serra de S. Paulo showing a poor cleavage; the grains show shearing and severe straining in thin section. Skolithos has not been found on the Serra de S. Paulo, but several specimens of Cruziana furcifera d'Orbigny were collected from the upper part of the sequence. The top contact of the formation is not well exposed, but appears to be sedimentary with a sharp change to cleaved siltstones containing sporadic vertical cylindrical burrows. The Serra do Brejo Formation is only between 60 and 70 metres thick on the Serra de S. Paulo; this is considerably thinner than the sequences exposed along the eastern margin of the area and this suggests that the Serra do Brejo Formation thins from east to west.

vi. Palaeocurrent directions

Beds in the lower part of the Serra do Brejo Formation commonly exhibit planar cross-bedding and the upper part of the formation is commonly developed with ripple marks. Where it was possible the orientations of these structures were measured to determine palaeocurrent directions. It is however unfortunate that the lack of suitable three-dimensional exposures prevented a large sample from being taken. Figure 9 summarises the results for 26 measurements of cross-bedding and 7 measurements of ripple marks; the rose diagram indicates a general southerly source for the sediments.

3. Brejo Fundeiro Formation

i. General character

The Brejo Formation is an approximately 190m thick sequence of fossiliferous mudstones and siltstones which conformably overlies the Serra do Brejo Formation, and which is overlain by the arenaceous Monte do Sombadeira Formation. Professor Skevington identified the graptolites and dates the lowest part of the Brejo Fundeiro Formation as Llanvirn, possibly the upper part of the Didymograptus bifidus Zone; the top of the formation is probably Lower Llandeilo.

ii. Topography and distribution

The soft lithology of the Brejo Fundeiro Formation means it usually forms low lying and valley areas. Along the east of the study area it crops out parallel to, and a little to the west of, the Serra do Brejo Formation. The tract of land occupied by the Brejo Fundeiro Formation runs in a north-north-west direction through: Moinhos da Ribeira, Brejo Fundeiro, Porto dos Fusos, Brejo da Correia (plate 4, fig. 2), Paraiso and northwards along the Ribeira da Prudencial.

iii. Name

The Brejo Fundeiro Formation is named after the village of Brejo Fundeiro 500m north of the type section.

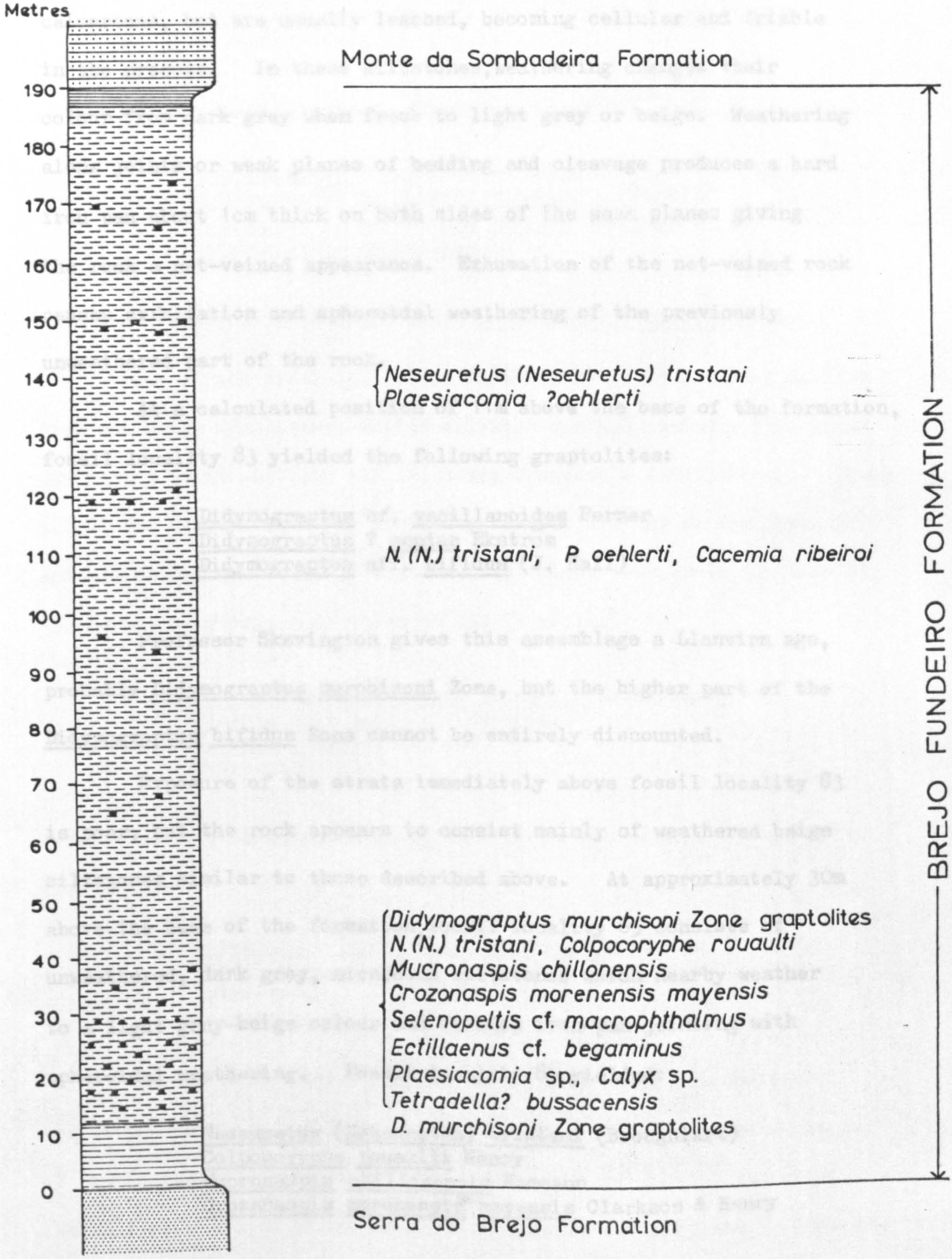
iv. Type section: Brejo Fundiero (19136, 31386 to 19092, 31347), fig.10

The type section of the Brejo Fundeiro Formation is about 190m thick and approximately 80 percent exposed (fig. 10), however, much of the exposure is loose ploughed up rock recently prepared for forestation. Although this disrupts many exposures it makes fossil collecting easier giving good palaeontological evidence throughout the sequence. Observations of the ploughing showed that very little material was transported.

The base and lowest few metres of the formation are not exposed, but the base is indicated by the break of slope marking the top of the Serra do Brejo Formation. The lowest beds of the Brejo Fundeiro Formation

BREJO FUNDEIRO FORMATION. Type section FIG. 10

Brejo Fundeiro (19136 31386 to 19092 31347)



LEGEND: FIG. 59

are composed of laminated siltstones and mudstones. These beds frequently contain nodule horizons; the nodules are possibly calcareous, but are usually leached, becoming cellular and friable in the process. In these siltstones, weathering changes their colour from dark grey when fresh to light grey or beige. Weathering along joints or weak planes of bedding and cleavage produces a hard iron pan about 1cm thick on both sides of the weak planes giving the rock a net-veined appearance. Exhumation of the net-veined rock causes exfoliation and spheroidal weathering of the previously unweathered part of the rock.

At a calculated position of 11m above the base of the formation, fossil locality 83 yielded the following graptolites:

Didymograptus cf. vacillanoides Perner
Didymograptus ? acutus Ekström
Didymograptus aff. bifidus (J. Hall)

Professor Skevington gives this assemblage a Llanvirn age, probably Didymograptus murchisoni Zone, but the higher part of the Didymograptus bifidus Zone cannot be entirely discounted.

Exposure of the strata immediately above fossil locality 83 is poor, but the rock appears to consist mainly of weathered beige siltstones similar to those described above. At approximately 30m above the base of the formation, fossil locality 85 consists of unweathered, dark grey, micaceous siltstones which nearby weather to a light grey-beige colour and develop iron-pan jointing with spheroidal weathering. Fossil locality 85 yielded:

Neseuretus (Neseuretus) tristani (Brongniart)
Colpocoryphe rouaulti Henry
Mucronaspis chillonensis Hammann
Crozanaspis morenensis mayensis Clarkson & Henry

Selenopeltis cf. macrophthalmus (Klouček)
Ectillaenus cf. bergaminus Whittard
Plaesiacomia sp. indet
Tetradella ? bussacensis (Jones)
Calyx sp. (identified by Dr. C. Paul)
no microfossils (G. Booth)

In addition to these Professor Skevington identified:

Didymograptus ? artus Elles and Wood
Didymograptus murchisoni murchisoni (Beck)
Didymograptus murchisoni geminus (Hisinger)
Didymograptus spinulosus Perner

This assemblage is of Llanvirn age; Didymograptus murchisoni Zone.

The strata overlying fossil locality 85 is composed of massive grey and beige weathering, banded siltstones, which commonly have iron-pan coated joint surfaces and which are frequently fossiliferous. These siltstones persist from 70m above the base to the top of the formation and are calculated to be 117m thick. At about 110m above the base of the formation fossil localities 66 and 77 yielded:

Neseuretus (Neseuretus) tristani (Brongniart)
Plaesiacomia oehlerti (Kerforne)
Cacemia ribeiroi (Sharpe).
Ostracodes

Fossil locality 68 situated about 140m above the base of the formation also yielded:

Neseuretus (Neseuretus) tristani (Brongniart)
Plaesiacomia ? oehlerti (Kerforne)
Ostracodes
Indeterminate bivalves.

At the top of the formation there is a rapid interbedded transition to black and dark grey mudstones which comprise the top 3m of the formation. These mudstones typically have small scale cross-lamination, wash-out structures and flame structures (plate 5, fig. 2).

The top of the formation is about 190m above the base and is taken at the bottom of the first sandstone bed in the Monte da Sombadeira Formation which sharply overlies the banded mudstones.

v. Comparison of the type section with other sections and outcrops

(a) Brejo do Correia (19127, 31655 to 19091, 31639) and (19075, 31679 to 19055, 31659), fig. 11

The lower part of the Brejo Fundeiro Formation and the contact with the Serra do Brejo Formation are exposed about 500m south-south-east of Brejo do Correia (19126, 31654) and also at Olival Grande (19148, 31618). The Brejo Fundeiro Formation is marked by a sharp contact with the top quartzite bed of the Serra do Brejo Formation. The basal 4m of the Brejo Fundeiro Formation are formed of dark grey, thin bedded, siltstones with occasional very thin beds of very fine-grained sandstone. These sandstones commonly show horizontal and vertical burrows of up to 5mm in diameter. The succeeding sediments lack the sandstone horizons and are composed of laminated to thin bedded, dark grey mudstones and siltstones which weather to a beige colour. Approximately 8m above the base of the formation fossil localities 190 and 191 yielded:

Neseuretus (*Neseuretus*) *tristani* (Brongniart)
Mucronaspis cf. *macrophtalma* (Brongniart)
Indeterminate bivalves
Ostracodes including *Ctenobolbina* sp. indet. and *Tetradella* sp. indet.

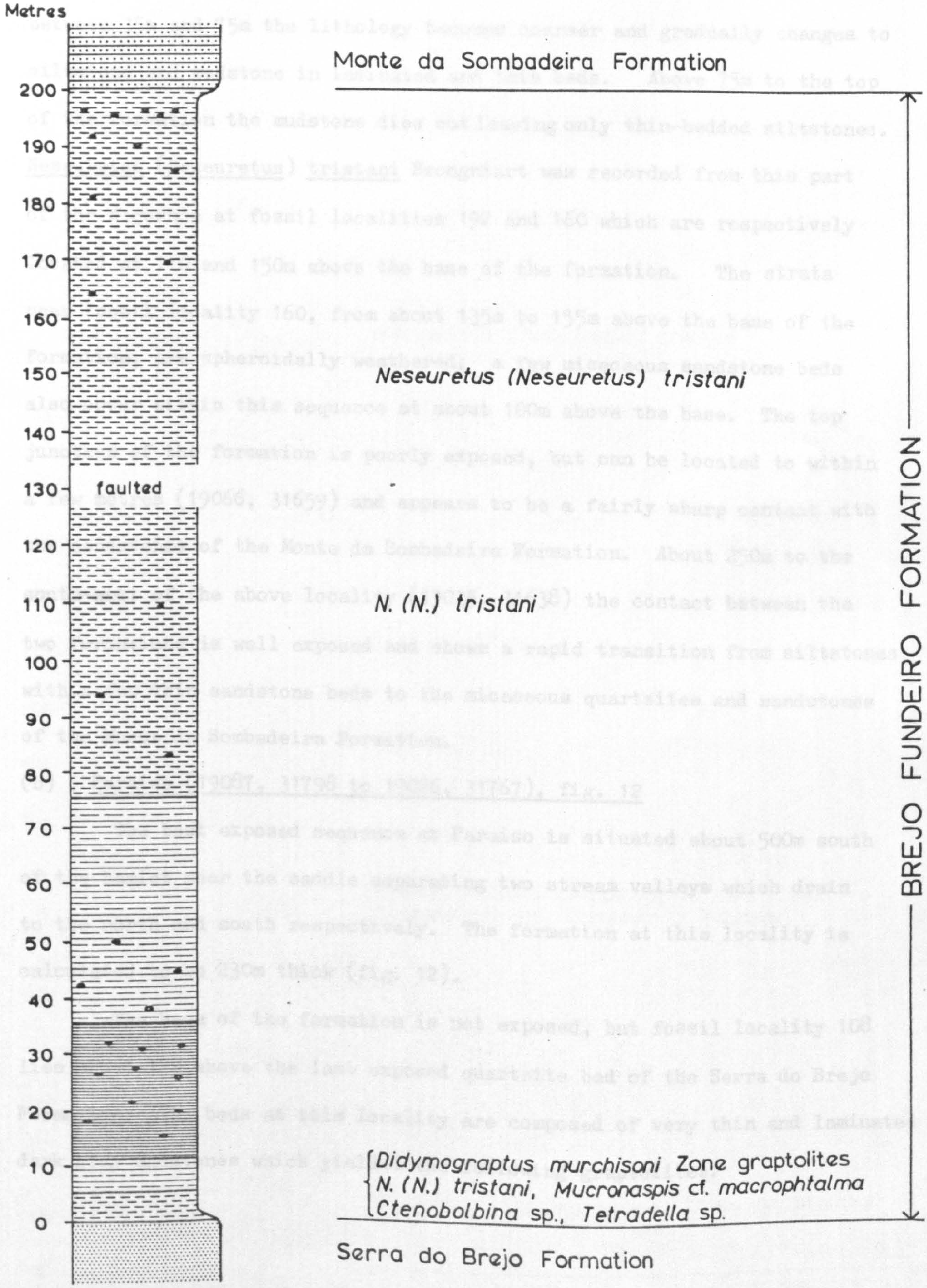
These localities also yielded graptolites which Skevington identified as:

Didymograptus aff. *bifidus* (J. Hall)
Didymograptus *geminus* (Hisinger)
Didymograptus *geminus* ? *latus* Ekström
Didymograptus ex. gr. *murchisoni* (Beck)

This graptolite assemblage is Llanvirn, *Didymograptus* *murchisoni* Zone.

BREJO FUNDEIRO FORMATION FIG. 11

Brejo da Correia (19127 31655 to 19091 31639) & (19075 31679 to 19055 31659)



LEGEND: FIG. 59

From 11m to 35m above the base of the formation the beds are composed of laminated and banded grey mudstone which weathers spheroidally; between 35m and 75m the lithology becomes coarser and gradually changes to siltstone and mudstone in laminated and thin beds. Above 75m to the top of the formation the mudstone dies out leaving only thin-bedded siltstones. Neseuretus (Neseuretus) tristani Brongniart was recorded from this part of the sequence at fossil localities 192 and 160 which are respectively located at 110 and 150m above the base of the formation. The strata near fossil locality 160, from about 135m to 155m above the base of the formation, are spheroidally weathered; a few micaceous sandstone beds also occur within this sequence at about 100m above the base. The top junction of the formation is poorly exposed, but can be located to within a few metres (19066, 31659) and appears to be a fairly sharp contact with the sandstones of the Monte da Sombadeira Formation. About 250m to the south-west of the above locality (19035, 31638) the contact between the two formations is well exposed and shows a rapid transition from siltstones with a few thin sandstone beds to the micaceous quartzites and sandstones of the Monte da Sombadeira Formation.

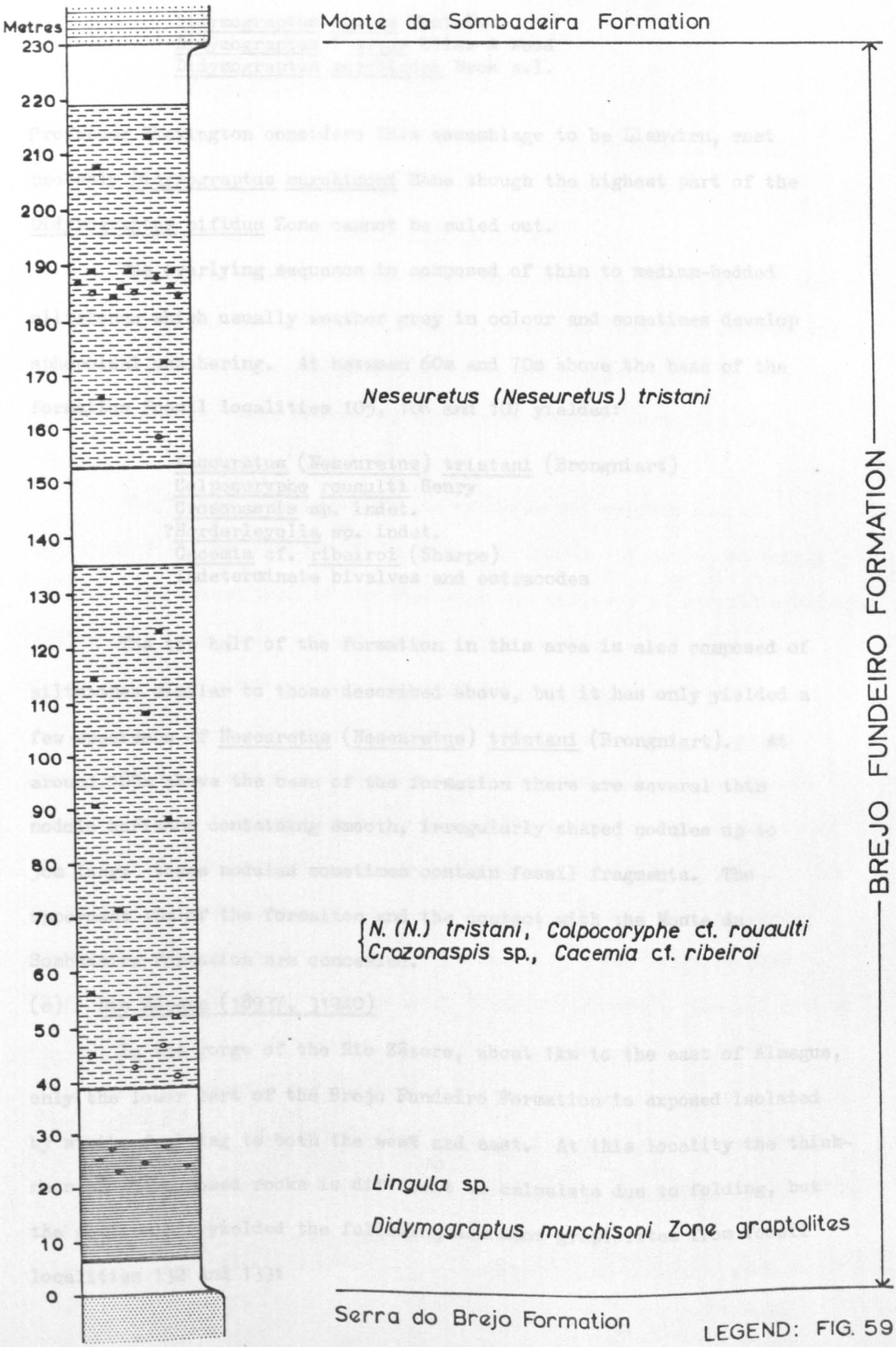
(b) Paraiso (19087, 31798 to 19026, 31767), fig. 12

The best exposed sequence at Paraiso is situated about 500m south of the hamlet near the saddle separating two stream valleys which drain to the north and south respectively. The formation at this locality is calculated to be 230m thick (fig. 12).

The base of the formation is not exposed, but fossil locality 108 lies about 12m above the last exposed quartzite bed of the Serra do Brejo Formation. The beds at this locality are composed of very thin and laminated dark grey mudstones which yielded the following graptolites:

BREJO FUNDEIRO FORMATION FIG. 12

Paraiso (19087 31798 to 19026 31767)



LEGEND: FIG. 59

<u>Didymograptus</u> <u>acutus</u> Ekström
<u>Didymograptus</u> ? <u>artus</u> Elles & Wood
<u>Didymograptus</u> <u>murchisoni</u> Beck s.l.

Professor Skevington considers this assemblage to be Llanvirn, most probably <u>Didymograptus</u> <u>murchisoni</u> Zone though the highest part of the <u>Didymograptus</u> <u>bifidus</u> Zone cannot be ruled out.

The overlying sequence is composed of thin to medium-bedded siltstones which usually weather grey in colour and sometimes develop spheroidal weathering. At between 60m and 70m above the base of the formation fossil localities 105, 106 and 107 yielded:

<u>Neseuretus</u> (<u>Neseuretus</u>) <u>tristani</u> (Brongniart)
<u>Colpocoryphe</u> <u>rouaulti</u> Henry
<u>Crozonaspis</u> sp. indet.
?<u>Horderleyella</u> sp. indet.
<u>Cacemia</u> cf. <u>ribeiroi</u> (Sharpe)
Indeterminate bivalves and ostracodes

The top half of the formation in this area is also composed of siltstones similar to those described above, but it has only yielded a few specimens of <u>Neseuretus</u> (<u>Neseuretus</u>) <u>tristani</u> (Brongniart). At around 185m above the base of the formation there are several thin nodule horizons containing smooth, irregularly shaped nodules up to 5cm long; these nodules sometimes contain fossil fragments. The uppermost 10m of the formation and the contact with the Monte da Sombadeira Formation are concealed.

(c) <u>Rio Zêzere (18937, 31940)</u>

In the gorge of the Rio Zêzere, about 1km to the east of Almegue, only the lower part of the Brejo Fundeiro Formation is exposed isolated by strike faulting to both the west and east. At this locality the thickness of the exposed rocks is difficult to calculate due to folding, but the section has yielded the following abundant graptolites from fossil localities 132 and 133:

Didymograptus ? *artus* Elles & Wood
Didymograptus aff. *bifidus* (J. Hall)
Didymograptus ? *geminus* (Hisinger)
Didymograptus *speciosus* Ekström

Professor Skevington dates this assemblage as Llanvirn, *Didymograptus murchisoni* Zone.

(d) Prudencial (18985, 32036 to 18896, 32034)

The Brejo Fundeiro Formation is more complete at Prudencial than it is next to the Rio Zêzere, but the formation is less well exposed and most of the outcrops occur as a coating on the dip slope of the Serra do Brejo Formation. Near Prudencial the Brejo Fundeiro Formation has a calculated thickness of about 220m.

The bottom contact of the formation is not exposed but the position of it can be inferred to within 3m and it appears to be fairly sharp. The lowest beds of the formation are composed of very thin-bedded, medium grey, mudstones and siltstones which weather to a beige colour. These beds frequently contain traces of ? *Planolites*. At fossil locality 130, situated about 40m above the base of the formation, *Didymograptus murchisoni* Zone graptolites similar to those found near the Rio Zêzere were collected (Identified by Professor Skevington). The remainder of the formation excluding the top 30m is composed mainly of siltstones with occasional fine-grained sandstone beds in the middle of the sequence. *Neseuretus* (*Neseuretus*) *tristani* Brongniant with a few indeterminate brachiopods and bivalves were the only fossils recovered. The top contact of the formation is not exposed, but the upper 30m are composed of dark grey banded siltstones and mudstones similar to those at the type section (plate 5, fig. 2). About 20m below the top of the formation these beds contain nodule horizons and which have also yielded *Neseuretus* (*Neseuretus*) *tristani* (Brongniart).

4. Monte da Sombadeira Formation

i. General character

The Monte da Sombadeira Formation is a 51m thick sequence of very poorly fossiliferous quartzites, sandstones and silty sandstones which are characteristically highly micaceous. The formation is of probable Lower to Middle Llandeilo age.

ii. Topography and distribution

The Monte da Sombadeira Formation is composed of sandstones and quartzites, therefore it tends to form lines of hills and ridges next to the valley formed by the Brejo Fundeiro Formation. The Monte da Sombadeira Formation is however thin, and overlain by siltstones, so that frequently the hills are low and the formation poorly exposed. From south to north the formation crops out at: Lameiros, Monte da Sombadeira, Brejo Cimeiro, Serra do Vale da Menina, along the eastern flank of Serra da Prata and along the west side of the Ribeiro do Prudencial valley.

iii. Name

The Monte da Sombadeira Formation takes its name from the hill to the north of the road cutting where the type section is exposed 700m south of Brejo Fundeiro.

iv. Type section; Monte da Sombadeira (19088, 31337 to 19096, 31347), fig. 13.

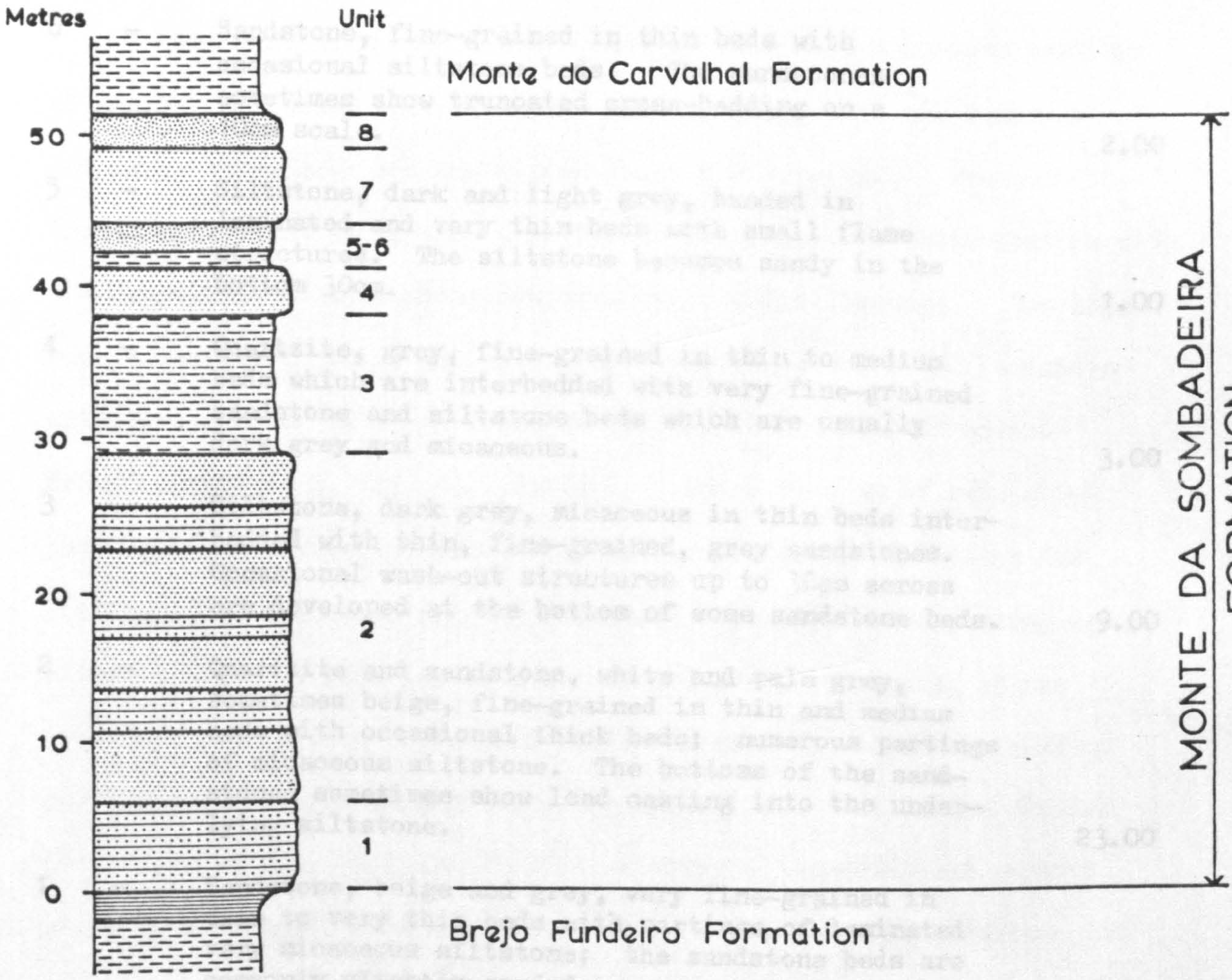
The type section shows a complete sequence exposed in the cutting where the main road winds its way through the formation to the south-east of Monte da Sombadeira (plate 4, fig. 4). This section can be divided into 8 units (fig. 13) which show the following sequence from top to bottom:

metres

- Monte do Carvalhal Formation; siltstone, beige in thin beds; weathered with the frequent development of iron pan along jointing.

MONTE DA SOMBADEIRA FORMATION. Type section FIG. 13

Monte da Sombadeira (19088 31337 to 19096 31347)



LEGEND: FIG. 59

8	–	Sandstone and siltstone, fine-grained in thin beds which pass down into medium beds. The top contact is sharp with the overlying formation and the junction is taken at the top of the highest sandstone bed in the Monte do Sombadeira Formation	2.00
7	–	Quartzite, white to light grey, fine-grained in thin to medium beds with partings of micaceous siltstone, mudstone and sandstone. The silty beds frequently wedge out and some show fine cross-bedding.	5.00
6	–	Sandstone, fine-grained in thin beds with occasional siltstone beds. The sandstones sometimes show truncated cross-bedding on a 10cm scale.	2.00
5	–	Siltstone, dark and light grey, banded in laminated and very thin beds with small flame structures. The siltstone becomes sandy in the bottom 30cm.	1.00
4	–	Quartzite, grey, fine-grained in thin to medium beds which are interbedded with very fine-grained sandstone and siltstone beds which are usually dark grey and micaceous.	3.00
3	–	Siltstone, dark grey, micaceous in thin beds interbedded with thin, fine-grained, grey sandstones. Occasional wash-out structures up to 30cm across are developed at the bottom of some sandstone beds.	9.00
2	–	Quartzite and sandstone, white and pale grey, sometimes beige, fine-grained in thin and medium beds with occasional thick beds; numerous partings of micaceous siltstone. The bottoms of the sandstones sometimes show load casting into the underlying siltstone.	23.00
1	–	Sandstone, beige and grey, very fine-grained in thin to very thin beds with partings of laminated very micaceous siltstone; the sandstone beds are commonly slightly graded.	6.00
	–	Brejo Fundeiro Formation; siltstone and mudstone, black and dark grey with small scale cross-lamination, wash-out structures and flame structures (plate 5, fig. 2).	
	–	Total thickness of the Monte da Sombadeira Formation	51.00

The base of the Monte da Sombadeira Formation shows a sudden change in lithology from the monotonous siltstones and mudstones of the

Brejo Fundeiro Formation. The initial sedimentation which forms unit 1 contains abundant mica rich layers which are up to 1mm thick and composed of mica flakes up to 2mm in diameter. The sandstone beds commonly show slight grading and the combination of this with the mica rich layers suggests deposition by settling of the sediment from suspension during periods of quiescence (Reineck and Singh, 1973).

The overlying 23m of beds (unit 2) also have micaceous partings of similar character to unit 1, but much thinner, with the dominant sediments being grey and white fine-grained quartzites. The next 12m formed by units 3 and 4 show a return to finer grained sedimentation with the deposition of more micaceous sandstones and siltstones. The upper part of unit 5 contains delicate flame structures and small loadcasts which are similar to those found at the top of the Brejo Fundeiro Formation (plate 5, fig. 2). Units 6, 7 and 8 form 9m of beds which pass from sandstones and quartzites at the bottom to sandstones and siltstones at the top. Many of the quartzites show cross-bedding on a 10cm scale. A locality in a stream bed about 100m south of the type section, in this upper part of the formation, showed one bedding surface covered with straight-crested symmetrical oscillation ripples (Pettijohn et al., 1972, p. 358) of wavelength 5cm developed in dark grey, fine-grained, micaceous sandstone. The top of the formation and the base of the Monte do Carvalhal Formation is taken on top of the highest sandstone bed of the Monte da Sombadeira Formation.

v. Comparison of the type section with other sections and outcrops

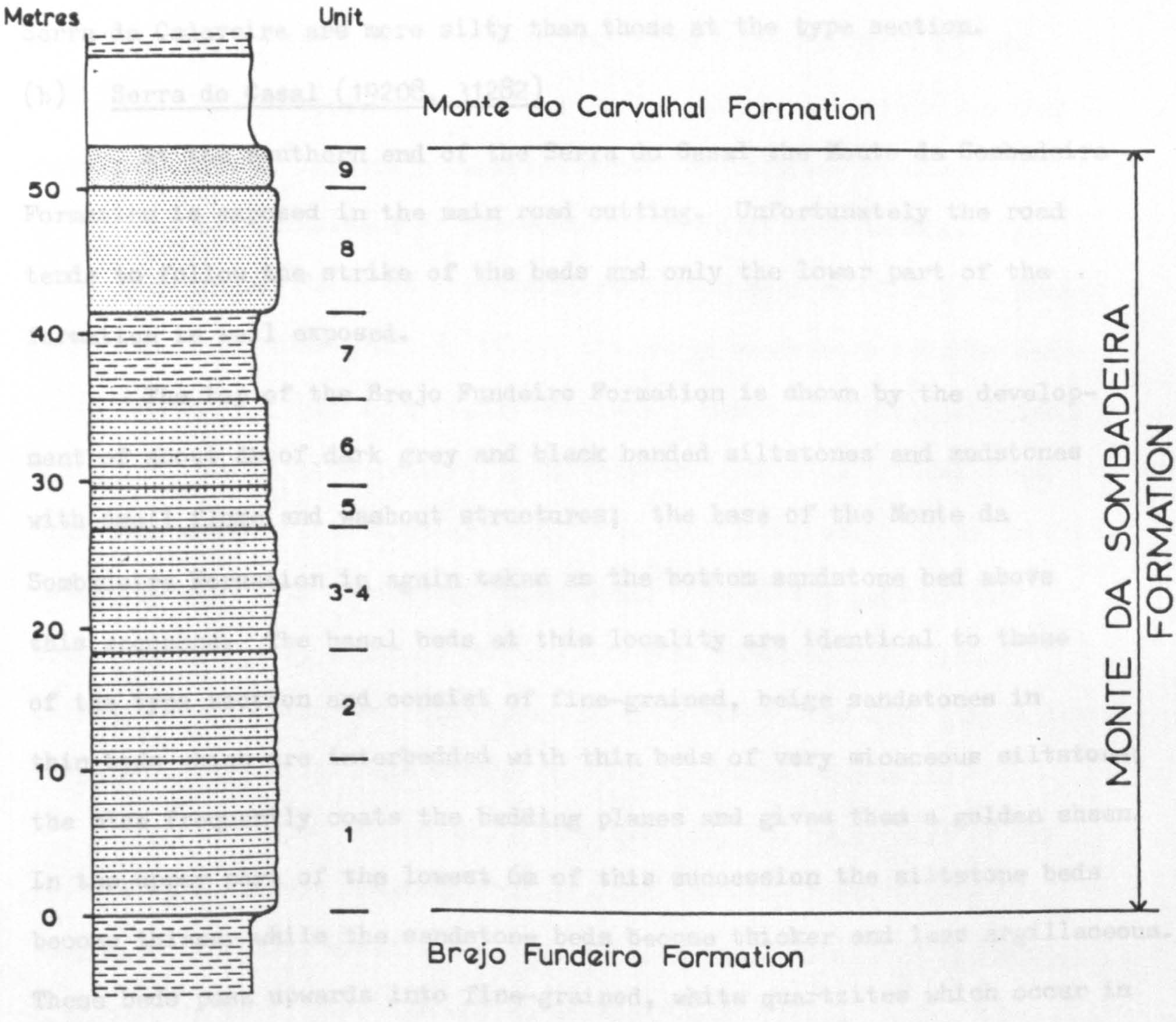
(a) Serra da Cadaveira (19020, 31404 to 19026, 31409) fig. 14.

Although it is situated only 1km north-west of the type section, the sequence at Serra da Cadaveira is worth noting because it is one of the few places in the area, apart from the type section, where an almost complete sequence through the Monte da Sombadeira Formation can be seen. The exposure is reasonable because the strata is dipping more or less vertically and a track runs across the formation at this locality. The formation is shown in figure 14 and can be divided into 9 units which are from top to bottom:

			metres
	- ?	Monte do Carvalhal Formation; no exposure, area covered with quartzite boulders. Siltstone exposed 6m away.	
9	-	Sandstone and quartzite, beige and grey respectively, fine-grained and micaceous in thin beds.	3.00
8	-	Quartzite, light grey, fine-grained and micaceous in thick and medium beds.	8.50
7	-	Siltstone and sandstone, grey and micaceous. The sandstone is fine-grained and both lithologies occur in thin and very thin beds.	5.75
6	-	Sandstone, beige, very fine-grained, silty and micaceous in thin and very thin beds with partings and very thin beds of siltstone.	6.00
5	-	Sandstone, beige, very fine-grained and micaceous in thin and very thin beds; poorly exposed in places.	3.10
4	-	Sandstone, beige, fine-grained and micaceous occurring as one thick bed.	0.40
3	-	Sandstone, beige, very fine-grained and micaceous in thin and very thin beds with occasional medium beds.	8.00
2	-	Sandstone, beige, very fine-grained silty and very micaceous in massive, medium and thick beds which are poorly exposed.	7.50
1	-	Sandstone, beige and light grey, fine-grained and micaceous in medium and thick beds with a few thin beds; sharp contact at base.	10.50
	-	Brejo Fundeiro Formation; siltstone, grey and micaceous in thin and very thin beds.	
	-	Total thickness of Monte da Sombadeira Formation	52.75

MONTE DA SOMBADEIRA FORMATION FIG. 14

Serra da Cadaveira (19020 31404 to 19026 31409)



LEGEND: FIG. 59

The similarities in thickness and lithology between this section and the type section are marked. In both sections the lower beds of the formation are highly micaceous and mica covered bedding planes abound. Both sections also have quartzite units in the upper parts of the sequences. The middle part of the sequence at Serra da Cadaveira is however more sandy than its counterpart at the type section; conversely the lower beds at Serra da Cadaveira are more silty than those at the type section.

(b) Serra do Casal (19208, 31282)

At the southern end of the Serra do Casal the Monte da Sombadeira Formation is exposed in the main road cutting. Unfortunately the road tends to follow the strike of the beds and only the lower part of the formation is well exposed.

The top of the Brejo Fundeiro Formation is shown by the development of about 4m of dark grey and black banded siltstones and mudstones with small flame and washout structures; the base of the Monte da Sombadeira Formation is again taken as the bottom sandstone bed above this sequence. The basal beds at this locality are identical to those of the type section and consist of fine-grained, beige sandstones in thin beds which are interbedded with thin beds of very micaceous siltstone; the mica frequently coats the bedding planes and gives them a golden sheen. In the upper part of the lowest 6m of this succession the siltstone beds become thinner while the sandstone beds become thicker and less argillaceous. These beds pass upwards into fine-grained, white quartzites which occur in medium beds with laminated partings of micaceous siltstone. This part of the sequence is poorly exposed in the strike section and is also frequently folded and faulted. The top of the formation in this locality is poorly exposed, but appears to consist of a rapid interbedded transition from the thin sandstones of the Monte da Sombadeira Formation into the siltstones of the overlying Monte do Carvalhal Formation which is locally developed as the highly fossiliferous Lameiros Member.

(c) Serra do Vale da Menina (19037, 31637 to 19027, 31635)

On the south-east flank of Serra da Vale da Menina about 1km south-west of Brejo da Correia the Monte da Sombadeira Formation is exposed in a road cutting made in the side of the valley. Here the formation has a thickness of about 63m. The bottom contact of the formation shows a rapid transition from the siltstones with a few thin sandstone beds of the Brejo Fundeiro Formation into the micaceous quartzites and sandstones of the Monte da Sombadeira Formation. The lower beds of the Monte da Sombadeira Formation here consist of typical beige coloured, fine-grained, silty, micaceous sandstones in thin beds; these are interbedded with highly micaceous, beige coloured, siltstones and a few beds of fine-grained, grey coloured quartzite. These lower beds pass upwards into fine-grained, grey quartzites which occur in thin to medium beds with occasional thick beds. The middle part of the formation is poorly exposed, but the top part shows a transitional passage from thin-bedded, fine-grained, grey sandstones into the weathered, beige coloured, siltstones of the Monte do Carvalhal Formation.

About 1km to the north of this section, the upper part of the formation, at fossil locality 155, yielded the only fossils from the formation. Several small slabs covered with the ostracode Ctenobolbina ? sp. indet. were collected and these slabs also yielded a few rare specimens of Neseuretus (Neseuretus) tristani (Brongniart) and one specimen of Crozonaspis morenensis cf. morenensis Hammann. In Spain Crozonaspis morenensis morenensis Hammann is regarded as being of Lower to Middle Llandeilo age (Hammann, 1974, p. 55).

(d) Serra da Prata (19015, 31804 to 19006, 31802)

The Monte da Sombadeira Formation is exposed on the east flank of the Serra da Prata 400m to the south-south-west of Paraiso; here the formation has a thickness of about 55m. The basal contact is a rapid transitional passage from the siltstones and mudstones of the Brejo Fundeiro Formation into the typical very micaceous sandstones of the Monte da Sombadeira Formation. These sandstones form the basal 4m of the sequence and are fine-grained, beige in colour and usually occur in thin beds. The overlying sequence is poorly exposed but consists of fine-grained, micaceous sandstones which are dark grey to beige in colour and which occur in thin to medium beds with occasional beds of fine-grained, grey quartzite. The middle part of the sequence is poorly exposed as steps along the footpath which runs over Serra da Prata to Sambado. The top contact of the formation is also poorly exposed and can only be located to within a few metres. The formation is overlain by dark grey siltstones of the Monte do Carvalhal Formation, which a few metres above the contact of the two formations contain abundant bryozoa.

(e) Vale do Rio Fundeiro (18896, 32026 to 18902, 32028)

At this locality the Monte da Sombadeira Formation is exposed in a cutting along a forestry track which crosses the formation. The exposure is poor in parts and the nature of the outcrop makes accurate measurement impossible. The top of the Brejo Fundeiro Formation is shown by the development of grey and dark grey banded siltstones and mudstones which occur in thin beds and which weather to a beige-brown colour. At the southern end of the exposure the siltstones and mudstones show delicate banding akin to that exposed at this level below the Monte da Sombadeira Formation at the type section (plate 5, fig. 2). The lowest beds of the formation are composed of fine-grained, beige and brown micaceous sandstone in thin and medium beds (plate 5, fig. 3). These pass upwards into thick beds of medium-grained, micaceous, grey quartzite which are folded and give little idea about their vertical thickness. The top contact of the formation is not exposed, but can be located to within a few metres.

(f) Cabeço dos Picos (18873, 32120 to 18881, 32127)

In the vicinity of Cabeço dos Picos, about 1200m north-west of Prudencial, the Monte da Sombadeira Formation is poorly exposed. Neither the bottom nor the top junctions of the formation can be seen, but their positions can be judged to within a few metres and the thickness of the formation is estimated to be about 60m. Below the formation, beige weathered siltstones of the Brejo Fundeiro Formation are exposed. The Monte da Sombadeira Formation is mainly composed of beige and red-brown coloured, fine-grained and micaceous sandstone in thin and medium beds; near the middle of the formation grey, fine-grained sandstones sometimes occur. The formation is overlain by black micaceous siltstones which yielded byrozoa, and which form the basal part of the Monte do Carvalhal Formation in this area.

5. Monte do Carvalhal Formation

i. General character

The Monte do Carvalhal Formation consists mainly of greywackes and siltstones with occasional prominant quartzite and sandstone members. The thickness of the formation varies from 345m in the east to about 490m in the west. Fossiliferous horizons occur at several positions in the formation, but lateral variation in the sequence commonly makes correlation difficult. The formation ranges in age from probable Middle Llandeilo to Upper Caradoc and possibly extends into the Ashgill, it is overlain by the Vale da Ursa Formation of probable basal Llandovery age.

ii. Topography and distribution

The siltstones of this formation are easily eroded and consequently form low land, but where they occur interbedded with greywackes, sandstones and quartzites, the formation occurs in ridges frequently with the quartzites cropping out along the crests. The Monte do Carvalhal Formation is widely distributed in the east of the area forming from south to north the ridges and hills of: Serra do Carriçal, Monte do Carvalhal, Sêrra do Amial, Serra da Cadaveira, Serra do Vale da Menina, Serra da Prata, Almegue and Cabeço dos Picos. In the west of the area the formation crops out in the hills of Serra de S. Paulo, Serra do Mercador, Vale da Lage, Serra do Luzim, Cabeça Gorda and Melroinha.

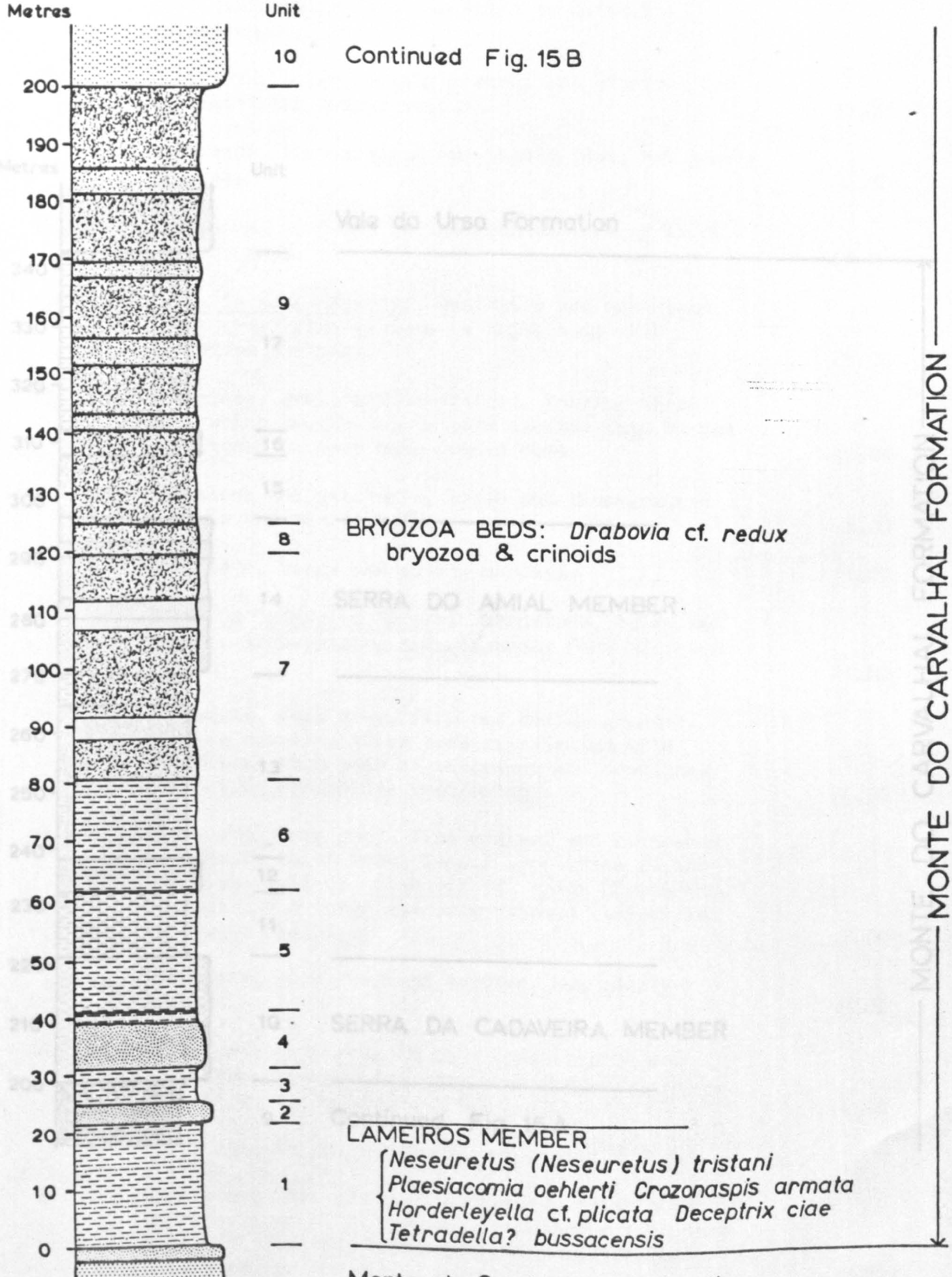
iii. Name

The formation is named after the hill of Monte do Carvalhal where the type section occurs along the road cutting on the south side of the hill.

iv. Type section; Monte do Carvalhal (19188, 31295 to 19121, 31256) fig. 15.

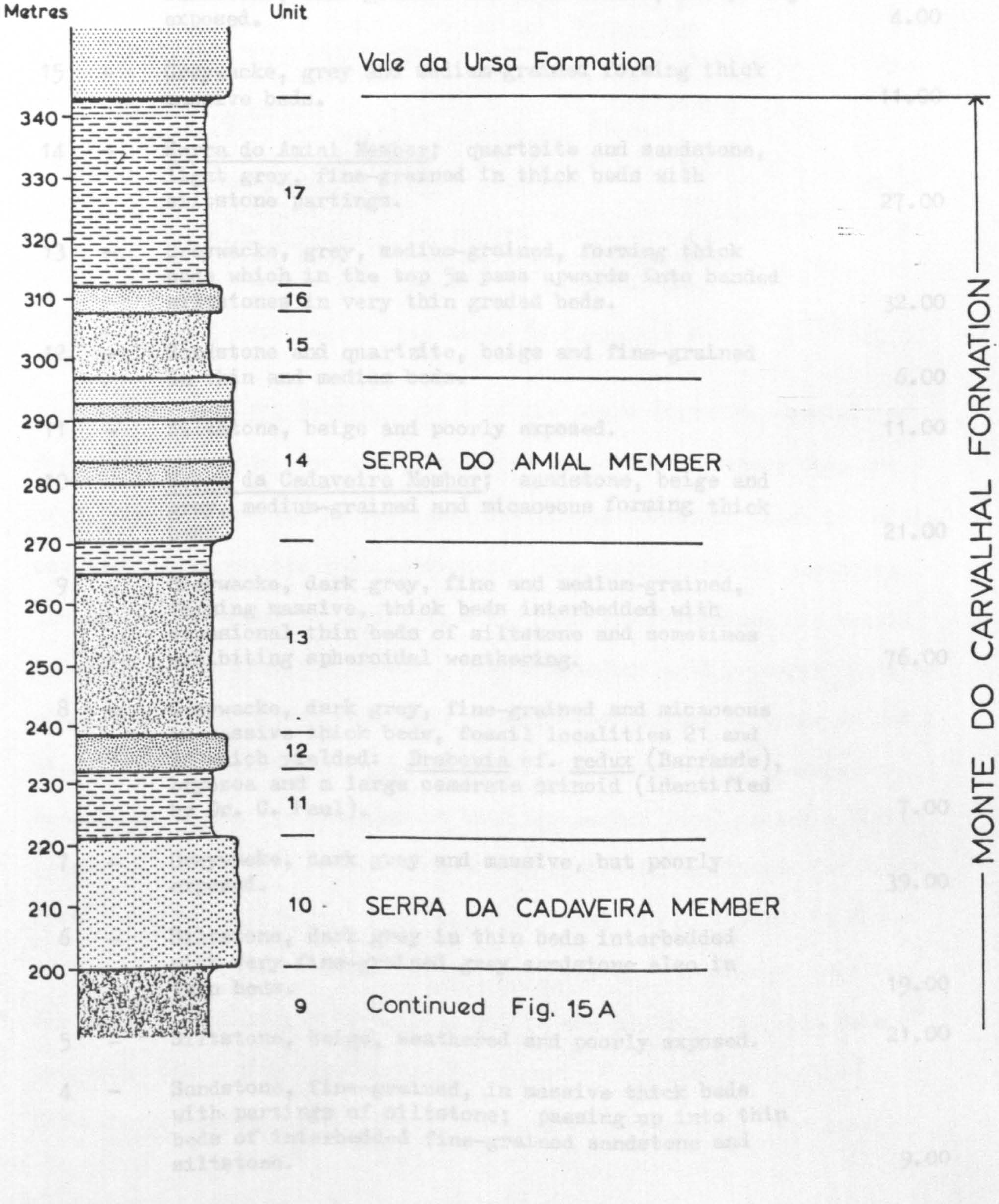
Exposure along the type section beside the disused road, to the south of Monte do Carvalhal, is generally good and 17 lithological units may be recognised in the 345m thick sequence. Three units of the formation are lithologically very distinctive and two of them may be traced throughout the area; these three units rank as members of the formation. They are unit 1 the Lameiros Member, unit 10 the Serra da Cadaveira Member and unit 14 the Serra do Amial Member. From top to bottom the units of the formation are described below and shown in figure 15.

MONTE DO CARVALHAL FORMATION. Type section, lower part. Monte do Carvalhal (19188 31295 to 19145 31272) FIG. 15 A



LEGEND: FIG. 59

MONTE DO CARVALHAL FORMATION. Type section, upper part. Monte do Carvalhal (19145 31272 to 19121 31256) FIG. 15 B



LEGEND: FIG. 59

			metres
	-	Vale da Ursa Formation; quartzite in thin beds interbedded with siltstone at the base and passing down conformably into the Monte do Carvalhal Formation.	
17	-	Siltstone, beige, slightly sandy and massive, but weathered and poorly exposed.	31.00
16	-	Sandstone, fine-grained and thin-bedded, but poorly exposed.	4.00
15	-	Greywacke, grey and medium-grained forming thick massive beds.	11.00
14	-	Serra do Amial Member; quartzite and sandstone, light grey, fine-grained in thick beds with siltstone partings.	27.00
13	-	Greywacke, grey, medium-grained, forming thick beds which in the top 5m pass upwards into banded siltstones in very thin graded beds.	32.00
12	-	Sandstone and quartzite, beige and fine-grained in thin and medium beds.	6.00
11	-	Siltstone, beige and poorly exposed.	11.00
10	-	Serra da Cadaveira Member; sandstone, beige and grey, medium-grained and micaceous forming thick beds.	21.00
9	-	Greywacke, dark grey, fine and medium-grained, forming massive, thick beds interbedded with occasional thin beds of siltstone and sometimes exhibiting spheroidal weathering.	76.00
8	-	Greywacke, dark grey, fine-grained and micaceous in massive thick beds, fossil localities 21 and 22 which yielded: Drabovia cf. redux (Barrande), bryozoa and a large camerate crinoid (identified by Dr. C. Paul).	7.00
7	-	Greywacke, dark grey and massive, but poorly exposed.	39.00
6	-	Siltstone, dark grey in thin beds interbedded with very fine-grained grey sandstone also in thin beds.	19.00
5	-	Siltstone, beige, weathered and poorly exposed.	21.00
4	-	Sandstone, fine-grained, in massive thick beds with partings of siltstone; passing up into thin beds of interbedded fine-grained sandstone and siltstone.	9.00

3	-	Siltstone, beige, weathered and poorly exposed.	6.00
2	-	Sandstone, fine-grained, forming medium beds with one bed of fine-grained, micaceous quartzite in the middle of the unit.	3.00
1	-	Lameiros Member; siltstone, beige, weathered, in thin and medium beds with occasional beds of very fine-grained beige coloured sandstone. Fossil locality 20 with frequent bedding planes covered with fossils including: Neseuretus (Neseuretus) tristani (Brongniart), Plaesiacomia oehlerti (Kerforne), Crozonaspis armata Hammann, Horderleyella cf. plicata Bancroft, Ostracodes including Tetradella? bussacensis (Jones), indeterminate gastropods and abundant bivalves including Deceptrix ciae (Sharpe).	22.00
	-	Monte da Sombadeira Formation; sandstone and siltstone, fine grained and forming thin beds; sharp contact with the overlying siltstones.	
	-	Total thickness of the Monte do Carvalhal Formation	345.00

The Lameiros Member, unit 1 of the above sequence, consists of fossiliferous siltstones with occasional sandstones. These beds are of different character to the remainder of the formation which is mainly composed of greywackes and sandstones; this member closely resembles the middle and upper parts of the Brejo Fundeiro Formation. At fossil locality 20 the Lameiros Member contains abundant well preserved fossils which are listed above (unit 1). The fossils consist of winnowed and disarticulated specimens suggesting that they represent a transported assemblage. The fossils suggest that the member is of probable Middle Llandeilo age. The Lameiros Member can be traced southwards for 2.5km from the type section to Lameiros and at least 1km northwards to Monte da Sombadeira. In the south of the area the Lameiros Member overlies the Monte da Sombadeira Formation, but in the north of the area beds of greywacke containing bryozoa, similar to unit 8 of the type section described here, overlie the Monte da Sombadeira Formation. The possible diachronous nature of the Monte da Sombadeira Formation and the significance of both the Lameiros Member and the bryozoa bearing beds are discussed in the correlation with Buçaco later in this work.

Unit 8 is made up of several thick beds of fine-grained greywacke which contain a fauna of bryozoa, crinoids and brachiopods. The fossils are all disarticulated and the bryozoa are commonly rolled and fragmented. The occurrence of these transported fossils in beds of greywacke suggest that they were carried into the area by turbidity currents. The presence of the brachiopod *Drabovia* cf. *redux* (Barrande) at fossil localities 21 and 22 in the type section, and of *Eccoptochile* (*Eccoptochile*) cf. *clavigera* (Beyrich) at a similar horizon (fossil locality 72) about 2km to the north-west of the type section indicate a lower Caradoc age. This is also suggested by the presence of *Onnia grenieri* (Bergeron) in lithologically similar material from the Mação region to the south of the Dornes area (specimens from the Museum of the Serviços Geológicos de Portugal, Lisbon).

The Serra da Cadaveira Member, unit 10 of the type section can be traced over most of the mapped area. The member has a distinctive lithology of micaceous and silty, grey and white coloured, bioturbated sandstone which is often fossiliferous (especially in the Serra do Amial section described later). About 700m south-east of the type section at fossil locality 25 this member yielded numerous specimens of *Svobodaina armoricana* Babin and Melou; it has a probable middle Caradoc age.

The Serra do Amial Member (unit 14) is a little thicker at the type section than it is at the Serra do Amial section (described later), but it is formed of similar fine-grained quartzites and sandstones in thick beds with siltstone partings. Although it is not fossiliferous this member occurring in close proximity to the Serra da Cadaveira Member forms part of a distinctive sequence which can be recognized throughout most of the area.

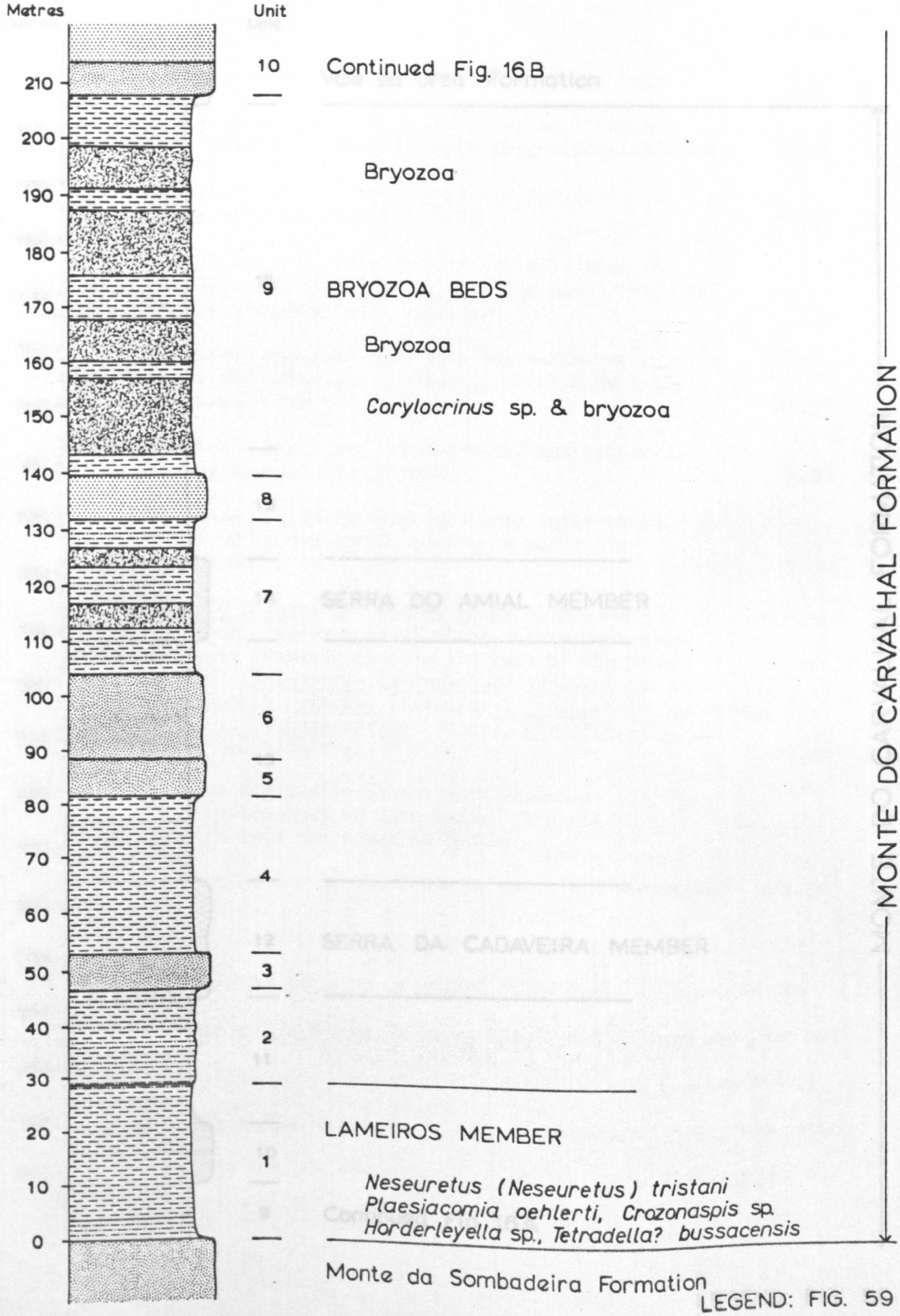
v. Comparison of the type section with other sections and outcrops

(a) Lameiros (19267, 31138 to 19197, 31132) fig. 16.

This section through the formation is situated about 1.5km south-east of the type section and is exposed along a combined stream and track section running west from Lameiros. The Monte do Carvalhal Formation along this section is 404m thick, and is very similar in character to the type section. The section may be divided into 15 lithological units (fig. 16), of which unit 1 is the Lameiros Member, unit 12 the Serra da Cadaveira Member and unit 14 the Serra do Amial Member; from top to bottom the 16 units are:

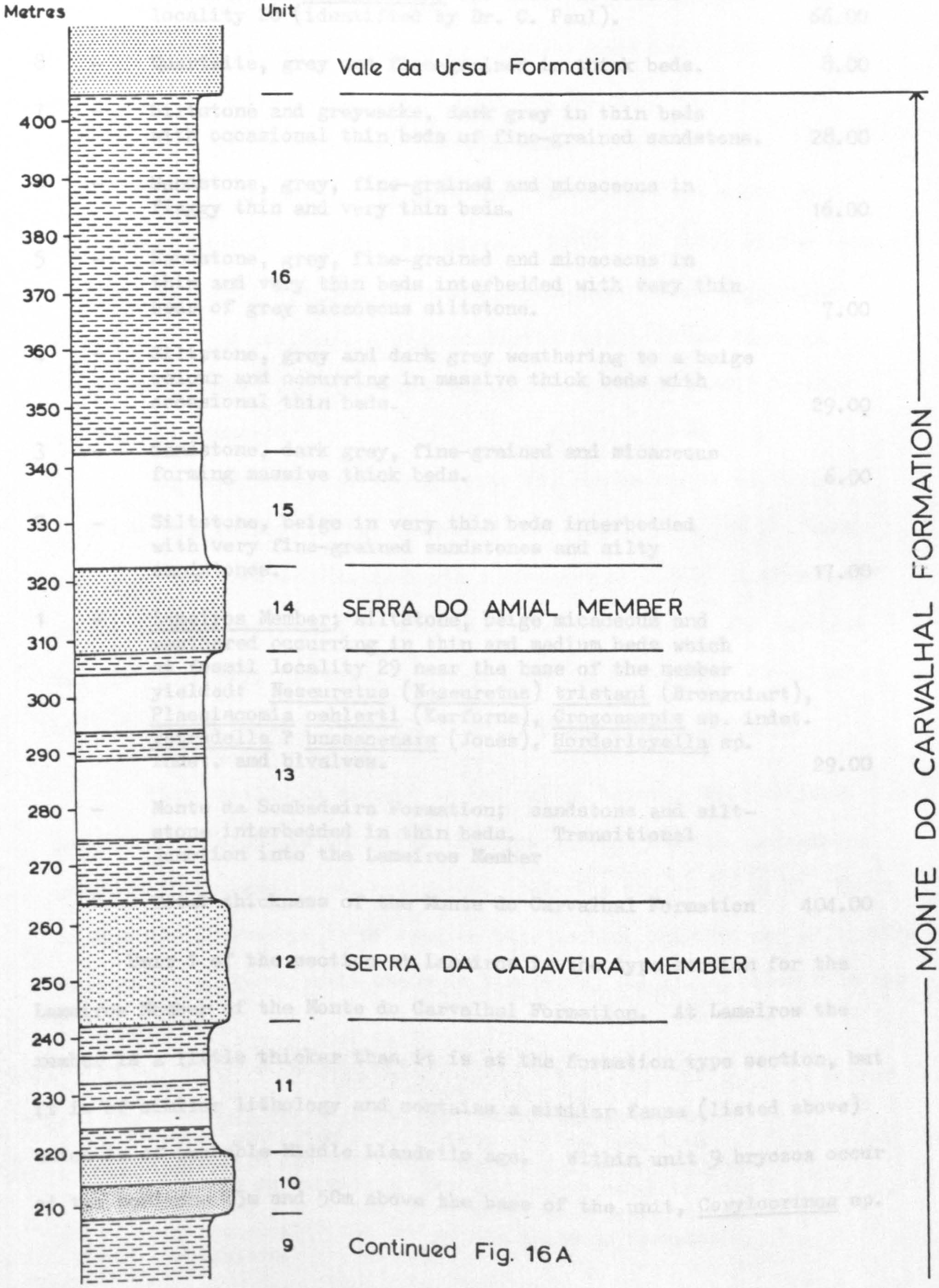
			metres
	–	Vale da Ursa Formation; sandstone and quartzite, light grey and white, fine-grained in thin and medium beds interbedded with thin and medium beds of dark grey siltstone.	
16	–	Siltstone, grey and dark grey, massive with spheroidal weathering and passing upwards into banded grey and dark grey siltstone.	64.00
15	–	No exposure.	20.00
14	–	Serra do Amial Member; quartzite, white, medium-grained forming massive, thick and very thick beds with siltstone partings.	14.00
13	–	No exposure, siltstones exposed a little way to the south.	45.00
12	–	Serra da Cadaveira Member; sandstone, white, and beige, medium-grained and micaceous forming massive medium beds.	21.00
11	–	Siltstone; very poorly exposed.	23.00
10	–	Sandstone, fine-grained and micaceous passing up into fine-grained quartzite. This sandstone forms an impersistent unit which wedges out to both the north and south	11.00

MONTE DO CARVALHAL FORMATION. Lower part. FIG. 16 A
Lameiros (19267 31138 to 19130 31132)



LEGEND: FIG. 59

MONTE DO CARVALHAL FORMATION. Upper part, Lameiros (19230 31134 to 19197 31132) FIG. 16B



LEGEND: FIG. 59

9	-	Siltstone and greywacke, dark grey weathering to a light beige colour; containing bryozoa at several horizons and Corylocrinus sp. indet at fossil locality 28 (identified by Dr. C. Paul).	66.00
8	-	Quartzite, grey and fine-grained in thick beds.	8.00
7	-	Siltstone and greywacke, dark grey in thin beds with occasional thin beds of fine-grained sandstone.	28.00
6	-	Sandstone, grey, fine-grained and micaceous in flaggy thin and very thin beds.	16.00
5	-	Sandstone, grey, fine-grained and micaceous in thin and very thin beds interbedded with very thin beds of grey micaceous siltstone.	7.00
4	-	Siltstone, grey and dark grey weathering to a beige colour and occurring in massive thick beds with occasional thin beds.	29.00
3	-	Sandstone, dark grey, fine-grained and micaceous forming massive thick beds.	6.00
2	-	Siltstone, beige in very thin beds interbedded with very fine-grained sandstones and silty sandstones.	17.00
1	-	Lameiros Member; siltstone, beige micaceous and weathered occurring in thin and medium beds which at fossil locality 29 near the base of the member yielded: Neseuretus (Neseuretus) tristani (Brongniart), Plaesiacomia oehlerti (Kerforne), Crozonaspis sp. indet. Tetradella ? bussacensis (Jones), Horderleyella sp. indet. amd bivalves.	29.00
	-	Monte da Sombadeira Formation; sandstone and siltstone interbedded in thin beds. Transitional junction into the Lameiros Member	
	-	Total thickness of the Monte do Carvalhal Formation	404.00

Unit 1 of the section at Lameiros is the type section for the Lameiros Member of the Monte do Carvalhal Formation. At Lameiros the member is a little thicker than it is at the formation type section, but it is of similar lithology and contains a similar fauna (listed above) which is of probable Middle Llandeilo age. Within unit 9 bryozoa occur at two horizons 15m and 50m above the base of the unit, Corylocrinus sp.

indet. also occurs at fossil locality 28 the lower of the two horizons. This unit probably correlates with units 7, 8 and possibly the lower part of unit 9, of the type section; similar beds containing bryozoa elsewhere in the area (see type section and Serra do Amial section) yield a fauna of probable lower Caradoc age.

Unit 12 is composed of micaceous, medium-grained sandstones which occur in beds of medium thickness. About 1 km north of the Lameiros section, at fossil locality 25, these sandstones contain Svobodaina armoricana Babin and Melou, a characteristic fossil of the Serra da Cadaveira Member; the brachiopod suggests a probable middle Caradoc age for the member.

The Serra do Amial Member (unit 14) can be traced southwards from the type section of the formation past Lameiros to the southern border of the area near Foz da Serta, a distance of 2.5km. Although the member is very persistent it does thin southwards and at the Lameiros section is is only 14m thick compared with 27m at Monte do Carvalhal.

(b) Serra do Amial (19032, 31355 to 19022, 31312) and (19076, 31307 to 19045, 31285) fig. 17

This section is exposed in the valley between Serra do Amial and Serra da Cadaveira and forms the type section for the two members which bear the names mentioned above. Only the upper half of the Monte do Carvalhal Formation is exposed in this section and this may be divided into 13 lithological units shown in figure 17, and listed below from top to bottom:

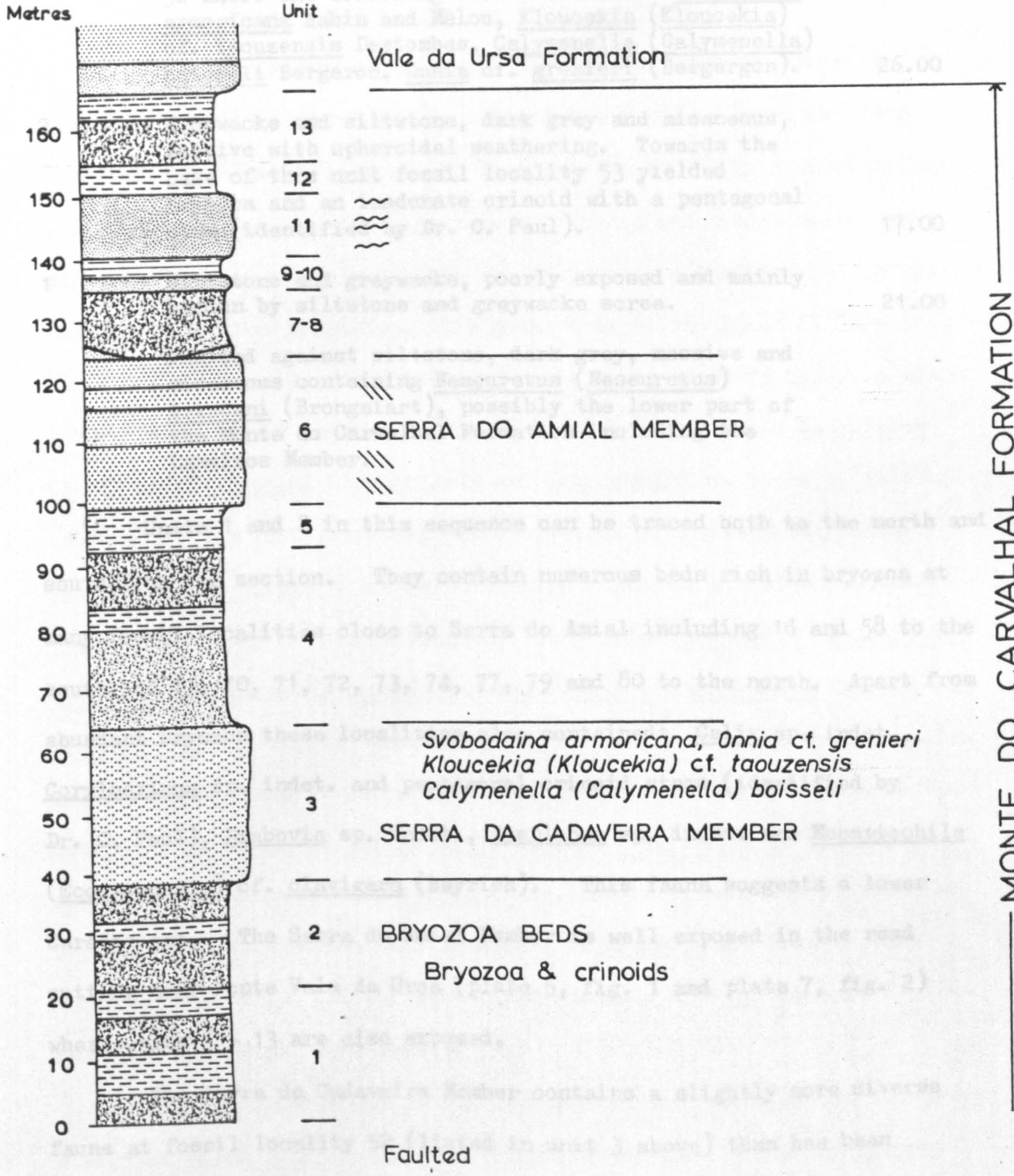
metres

– Vale da Ursa Formation; sandstone and quartzite, grey and slightly micaceous in thin beds with partings and very thin beds of siltstone. Linguoid ripple marks with an 8cm wavelength occur on some bedding planes and there is a rapid transitional junction with the top of the Monte do Carvalhal Formation.

13 -	Siltstone and greywacke, grey; the greywackes range up to fine sand grade. They are thin and medium bedded and poorly exposed, the top of the Monte do Carvalhal Formation is taken at the bottom of the first sandstone bed of the Vale da Ursa Formation.	11.00
12 -	Siltstone, beige, weathered and forming thin beds which are poorly exposed.	4.00
11 -	Sandstone, light grey and fine-grained occurring in thin beds interbedded with similar micaceous sandstones and partings of siltstone. Several bedding surfaces of the sandstones are covered with ripple marks.	10.00
10 -	Siltstone and mudstone, dark grey, interbedded in very thin to laminated beds.	4.00
9 -	Sandstone, grey and light grey, very fine-grained in thin beds interbedded with thin beds of grey siltstone.	2.00
8 -	Greywacke, dark grey, fine-grained and forming a massive, very thick unit which weathers spheroidally (plate 4, fig. 3) and which contains sporadic cubic pyrite crystals. The bottom contact of this unit is erosional in places and cuts down through parts of unit 7 to rest on unit 6.	9 - 11.00
7 -	Sandstone, fine-grained and siltstone interbedded in thin beds.	0 - 2.00
6 -	Serra do Amial Member, (plate 5, fig. 1 and plate 7, fig. 2); quartzite, grey, fine and medium-grained, massive forming thick and very thick beds which have partings and thin beds of dark grey siltstone in the bottom of the unit. The quartzites often contain planar cross-bedding on a 15 to 20cm scale.	24.00
5 -	Siltstone, dark grey and grey, micaceous with a few sandy siltstone beds. The siltstone and sandy siltstone form very thin and thin beds which towards the bop of the unit become interbedded with thin beds of grey fine and medium-grained sandstone.	7.00
4 -	Greywacke and siltstone, dark grey, micaceous, medium and thickly bedded. The greywacke beds are medium-grained at the base of the unit and become fine-grained at the top.	28.00

MONTE DO CARVALHAL FORMATION FIG. 17

Serra do Amial (19032 31355 to 19022 31312) & (19076 31307 to 19045 31285)



LEGEND: FIG. 59

3	–	Serra da Cadaveira Member; sandstone, grey, light grey and white, fine and medium-grained, micaceous and silty occurring in thick uneven beds. The sandstone weathers along joints and produces a hard brown crust. Near the top of the unit this sandstone is fossiliferous at fossil localities 12 and 52 where the following were collected: Svobodaina armoricana Babin and Melou, Kloucekia (Kloucekia) cf. taouzensis Destombes, Calymenella (Calymenella) boisseli Bergeron, Onnia cf. grenieri (Bergergon).	26.00
2	–	Greywacke and siltstone, dark grey and micaceous, massive with spheroidal weathering. Towards the base of this unit fossil locality 53 yielded bryozoa and an inadunate crinoid with a pentagonal stem (identified by Dr. C. Paul).	17.00
1	–	Siltstone and greywacke, poorly exposed and mainly hidden by siltstone and greywacke scree.	21.00
	–	Faulted against siltstone, dark grey, massive and micaceous containing Neseuretus (Neseuretus) tristani (Brongniart), possibly the lower part of the Monte do Carvalhal Formation including the Lameiros Member.	

Units 1 and 2 in this sequence can be traced both to the north and south from the section. They contain numerous beds rich in bryozoa at many fossil localities close to Serra do Amial including 16 and 58 to the south and 11, 70, 71, 72, 73, 74, 77, 79 and 80 to the north. Apart from abundant bryozoa these localities also contained: Calix sp. indet., Corylocrinus sp. indet. and pentagonal crinoid stems (identified by Dr. C. Paul), Drabovia sp. indet., Dysplanus sp. indet. and Eccoptochile (Eccoptochile) cf. clavigera (Beyrich). This fauna suggests a lower Caradoc age. The Serra do Amial Member is well exposed in the road cutting near Ponte Vale da Ursa (plate 5, fig. 1 and plate 7, fig. 2) where units 5 – 13 are also exposed.

The Serra da Cadaveira Member contains a slightly more diverse fauna at fossil locality 52 (listed in unit 3 above) than has been recorded elsewhere in the area; these fossils suggest a middle Caradoc age. Svobodaina armoricana Babin and Melou and Svobodaina sp. indet.

are very abundant at fossil locality 52 and also in the area to the west of Serra da Cadaveira where they have also been recorded at fossil localities 117, 118 and 119 within the Serra da Cadaveira Member.

(c) Serra da Prata (19007, 31802 to 18990, 31795)

At Serra da Prata the lowest part of the Monte do Carvalhal Formation is well exposed on the eastern flank of the Serra da Prata syncline. The lowest part of the formation is marked by a rapid interbedded transition from the micaceous siltstones and sandstones of the Monte da Sombadera Formation into the greywackes and siltstones of the Monte do Carvalhal Formation. The basal beds of the Monte do Carvalhal Formation are locally fossiliferous to the north of Serra da Prata where a 10cm thick bed of coquina at fossil locality 113 yielded Neseuretus (Neseuretus) tristani (Brongniart) and Crozonaspis sp. indet.; this bed is possibly the most northerly representation of the Lameiros Member. The upper beds of the Monte da Sombadeira Formation are also sometimes fossiliferous and at fossil locality 155 yielded Neseuretus (Neseuretus) tristani (Brongniart), Crozonaspis morenensis cf. morenensis Hammann and Ctenobolbina sp. indet. Numerous beds containing abundant bryozoa occur low in the sequence at Serra da Prata; from about 20m to 40m above the bottom of the Monte do Carvalhal Formation. At fossil localities 150 and 151 these beds contain Dysplanus sp. indet. in addition to abundant bryozoa, crinoid ossicles and fragments of Drabovia sp. indet. This fauna is similar to that of the bryozoa bearing beds at the type section and is of probable lower Caradoc age.

The diminished and poorly represented occurrence of the Lameiros Member at Serra da Prata and the northward decrease in the thickness of strata between the bryozoa bearing beds and the Monte da Sombadeira Formation suggests that the Monte da Sombadeira Formation is diachronous becoming younger towards the north of the area. About 90m of greywackes and siltstones forming the lower part of the Monte do Carvalhal Formation are exposed on the Serra da Prata. These are overlain by units, 20m to 30m thick, of sandstones and quartzites alternating with siltstones and greywackes; these units are poorly exposed along the crest of the Serra da Prata.

(d) Cabeço dos Picos (18861, 32094 to 18870, 32091)

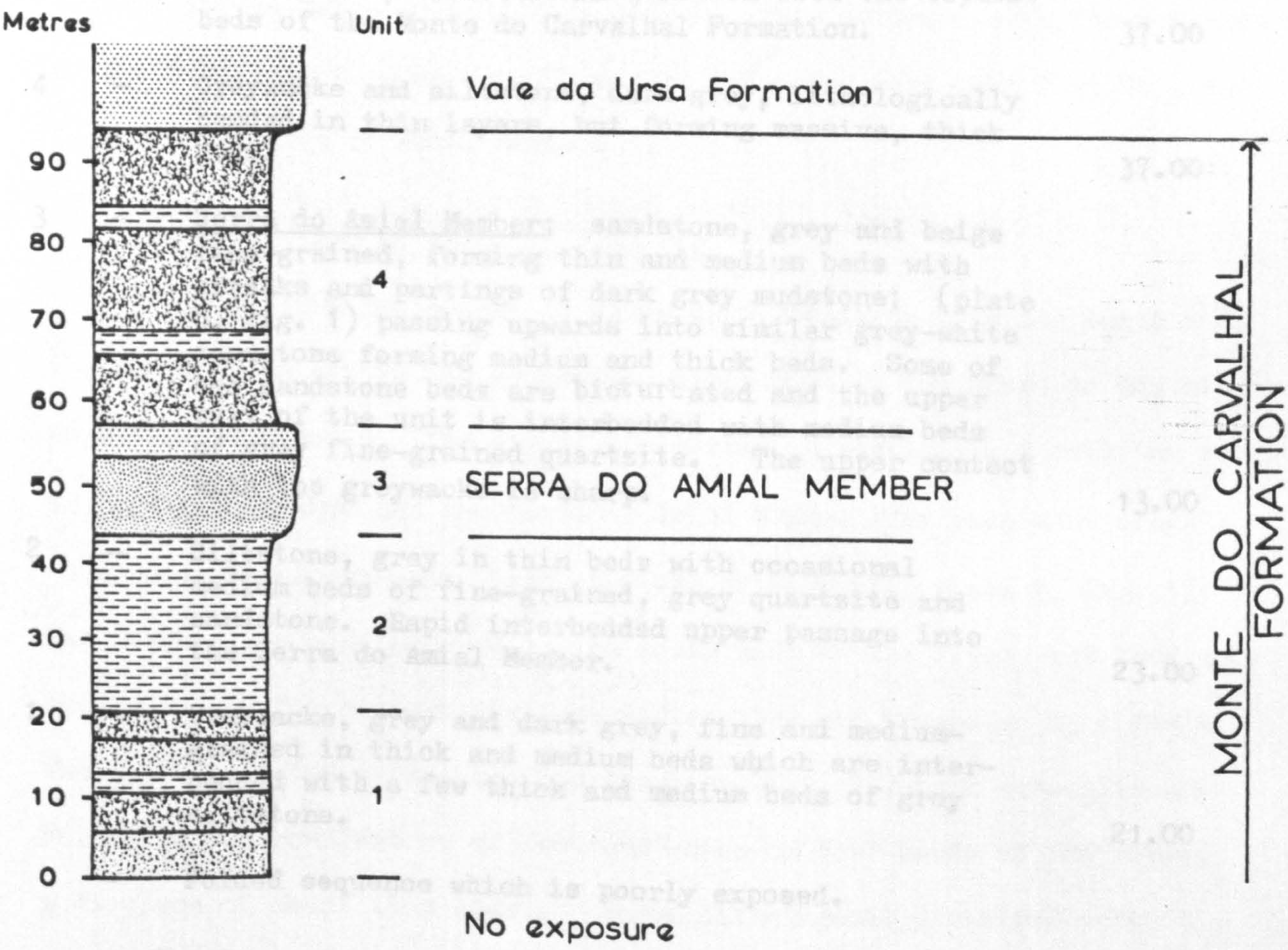
The lower part of the Monte do Carvalhal Formation is moderately well exposed at Cabeço dos Picos and is very similar to the sequence exposed at Serra da Prata. The northward decrease in thickness of the strata between the lowest bryozoa beds and the top of the Monte da Sombadeira Formation is continued and at Cabeço dos Picos it is reduced to about 10m. Fossil localities 138 and 139 in the bryozoa beds about 10m above the base of the Monte do Carvalhal Formation yielded abundant bryozoa, *Corylocrinus* sp. indet. and an indeterminate gastropod; these beds and fossils are very similar to the bryozoa beds at Serra da Prata and at the Monte do Carvalhal type section. The sequence of greywackes and siltstones which form the lower part of the formation is about 80m thick and overlain by an approximately 15m thick unit of fine-grained, white quartzite in thin beds; a comparable sequence to that at Serra da Prata.

(e) Vale da Lage (18698, 31590 to 18672, 31574) Fig. 18

At Vale da Lage, which is located to the north of Varzea de Pedro Mouro in the centre of the area, the upper part of the Monte do Carvalhal Formation with the overlying Vale da Ursa Formation are exposed in a folded and faulted sequence (plate 6 and plate 8, fig. 1). The Serra do Amial Member (plate 8, fig. 1) and the Vale da Ursa Formation form prominant crags, but other exposure is limited to the

MONTE DO CARVALHAL FORMATION FIG. 18

Vale da Lage (18698 31590 to 18672 31574)



banks of the Rio Zêzere and the forestry tracks. Four lithological divisions of the Monte do Carvalhal Formation can be recognised in this sequence; these are listed below from top to bottom and are also shown in figure 18:

			metres
	–	Vale da Ursa Formation; quartzite, grey, fine and medium-grained in thin beds passing up into thick beds. The lower part of the formation shows a rapid, interbedded, transitional junction with the topmost beds of the Monte do Carvalhal Formation.	37.00
4	–	Greywacke and siltstone, dark grey, lithologically banded in thin layers, but forming massive, thick beds.	37.00
3	–	Serra do Amial Member; sandstone, grey and beige fine-grained, forming thin and medium beds with streaks and partings of dark grey mudstone; (plate 8, fig. 1) passing upwards into similar grey-white sandstone forming medium and thick beds. Some of the sandstone beds are bioturbated and the upper part of the unit is interbedded with medium beds of grey fine-grained quartzite. The upper contact with the greywacke is sharp.	13.00
2	–	Siltstone, grey in thin beds with occasional medium beds of fine-grained, grey quartzite and sandstone. Rapid interbedded upper passage into the Serra do Amial Member.	23.00
1	–	Greywacke, grey and dark grey, fine and medium-grained in thick and medium beds which are interbedded with a few thick and medium beds of grey siltstone.	21.00
	–	Folded sequence which is poorly exposed.	

The Serra do Amial Member at Vale da Lage is thinner than it is at Serra do Amial or the Monte do Carvalhal type section. Lithologically it is similar to the member at the Monte do Carvalhal Formation type section, but the Vale da Lage sequence contains more sandstone beds and less quartzite than the member of the Serra do Amial section. The thickness and lithology of unit 4 at Vale da Lage is comparable to that of units 7-13 of the Serra do Amial section (fig. 17) and is equivalent to units 15-17 of the type section (fig. 15). The overlying Vale da Ursa Formation can be readily correlated with its type section at Vale da Ursa and to the section at Monte do Carvalhal.

Although the Vale da Lage section described above is unfossiliferous the poorly exposed folded sequence below unit 1 has yielded some bryozoa from the scree which also contained blocks of micaceous sandstone similar to that of the Serra do Cadaveira Member. This evidence with the presence of the overlying Vale da Ursa Formation indicates that unit 3 at Vale da Lage is the Serra do Amial Member.

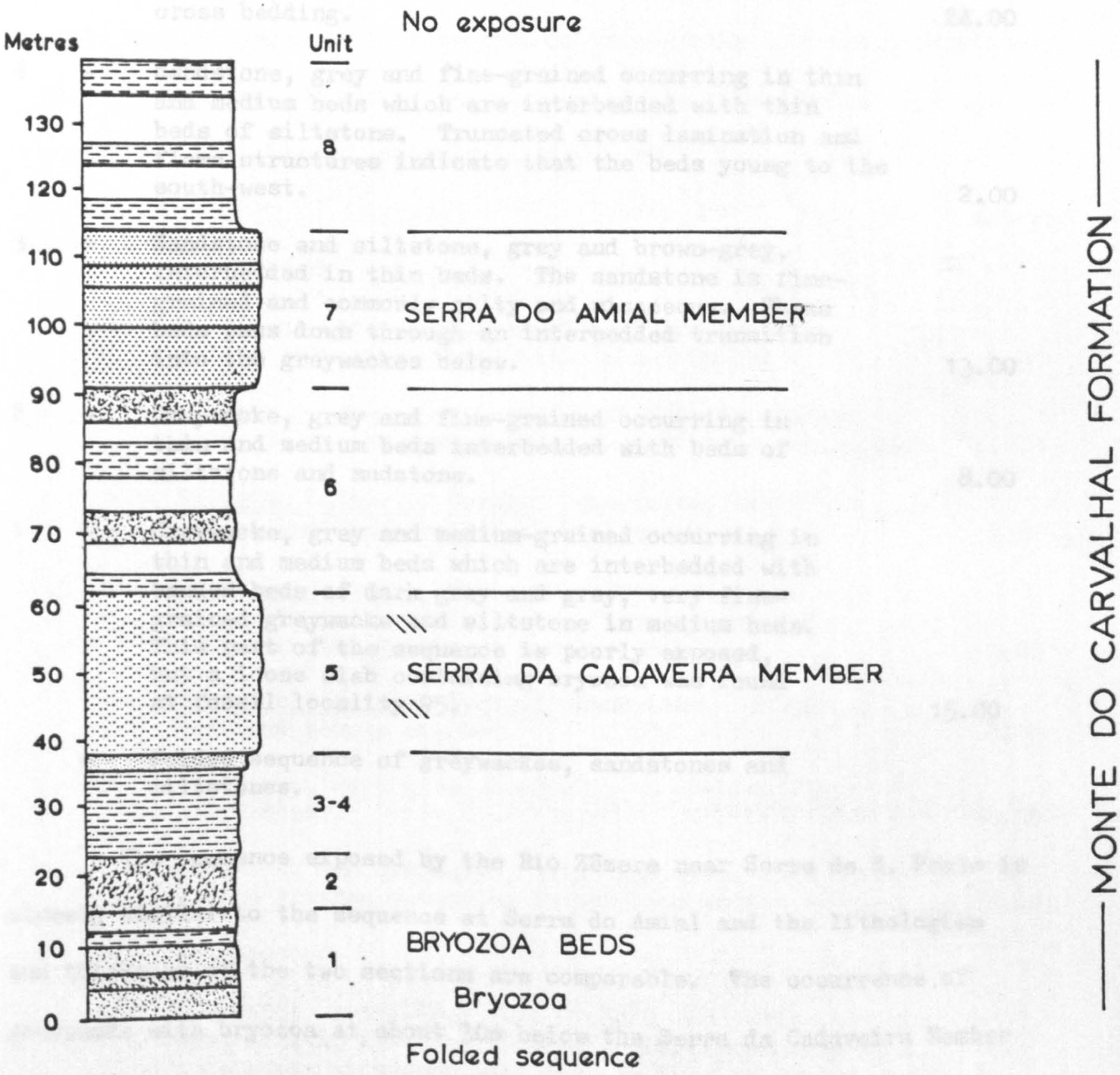
(f) Serra de S. Paulo (18723, 31285 to 18712, 31278) and (18710, 31298 to 18700, 31289) fig. 19

About 700m south-east of Serra de S. Paulo on both the north and the south banks of the Rio Zêzere the upper part of the Monte do Carvalhal Formation is exposed. The dip of the strata is vertical and both the Serra do Cadaveira Member and the Serra do Amial Member form prominent crags running up the south-east flank of Serra de S. Paulo (plate 7, fig. 1). The members are also exposed on the south side of the river, but they only strike inland for a short distance before they are truncated by a fault. The section of the strata at this location (fig. 19) is a composite one formed by the combination of sections taken on both banks of the river, a distance of about 150m apart. Eight lithological divisions were recognised at this section, these are from top to bottom:

			metres
	–	no exposure	
8	–	Siltstones; poorly exposed along a forestry track.	c25.00
7	–	Serra do Amial Member; quartzite, light grey to white with irregular dark grey banding, medium and fine-grained. The quartzite is thin to medium-bedded and passes upwards into thick and very thick massive beds at the top of the member. South of the river some of the upper beds contain scattered faint vertical cylindrical burrows 0.5cm in diameter.	23.00

MONTE DO CARVALHAL FORMATION FIG. 19

Serra de S. Paulo (18723 31285 to 18712 31278) & (18710 31298 to 18700 31289)



LEGEND: FIG. 59

6	–	No exposure; siltstones and greywackes occur poorly exposed in scattered exposures on the hillside above the section.	29.00
5	–	Serra da Cadaveira Member; sandstone, light grey, medium-grained and micaceous in places occurring in thin and medium beds with a few thick beds. The beds are separated by numerous partings of fine-grained silty sandstone and a few partings of laminated siltstone. Many of the beds have uneven wavy contacts and a few beds show faint cross bedding.	24.00
4	–	Sandstone, grey and fine-grained occurring in thin and medium beds which are interbedded with thin beds of siltstone. Truncated cross lamination and flame structures indicate that the beds young to the south-west.	2.00
3	–	Sandstone and siltstone, grey and brown-grey, interbedded in thin beds. The sandstone is fine-grained and commonly silty and micaceous. These beds pass down through an interbedded transition into the greywackes below.	13.00
2	–	Greywacke, grey and fine-grained occurring in thin and medium beds interbedded with beds of siltstone and mudstone.	8.00
1	–	Greywacke, grey and medium-grained occurring in thin and medium beds which are interbedded with banded beds of dark grey and grey, very fine-grained greywacke and siltstone in medium beds. This part of the sequence is poorly exposed, but a loose slab containing bryozoa was found at fossil locality 95.	15.00
	–	Folded sequence of greywackes, sandstones and siltstones.	

The sequence exposed by the Rio Zêzere near Serra de S. Paulo is closely similar to the sequence at Serra do Amial and the lithologies and thickness of the two sections are comparable. The occurrence of greywacke with bryozoa at about 30m below the Serra da Cadaveira Member in the Serra de S. Paulo section is also comparable with the occurrence of bryozoa at 15m and 40m below the Serra da Cadaveira Member at Serra do Amial.

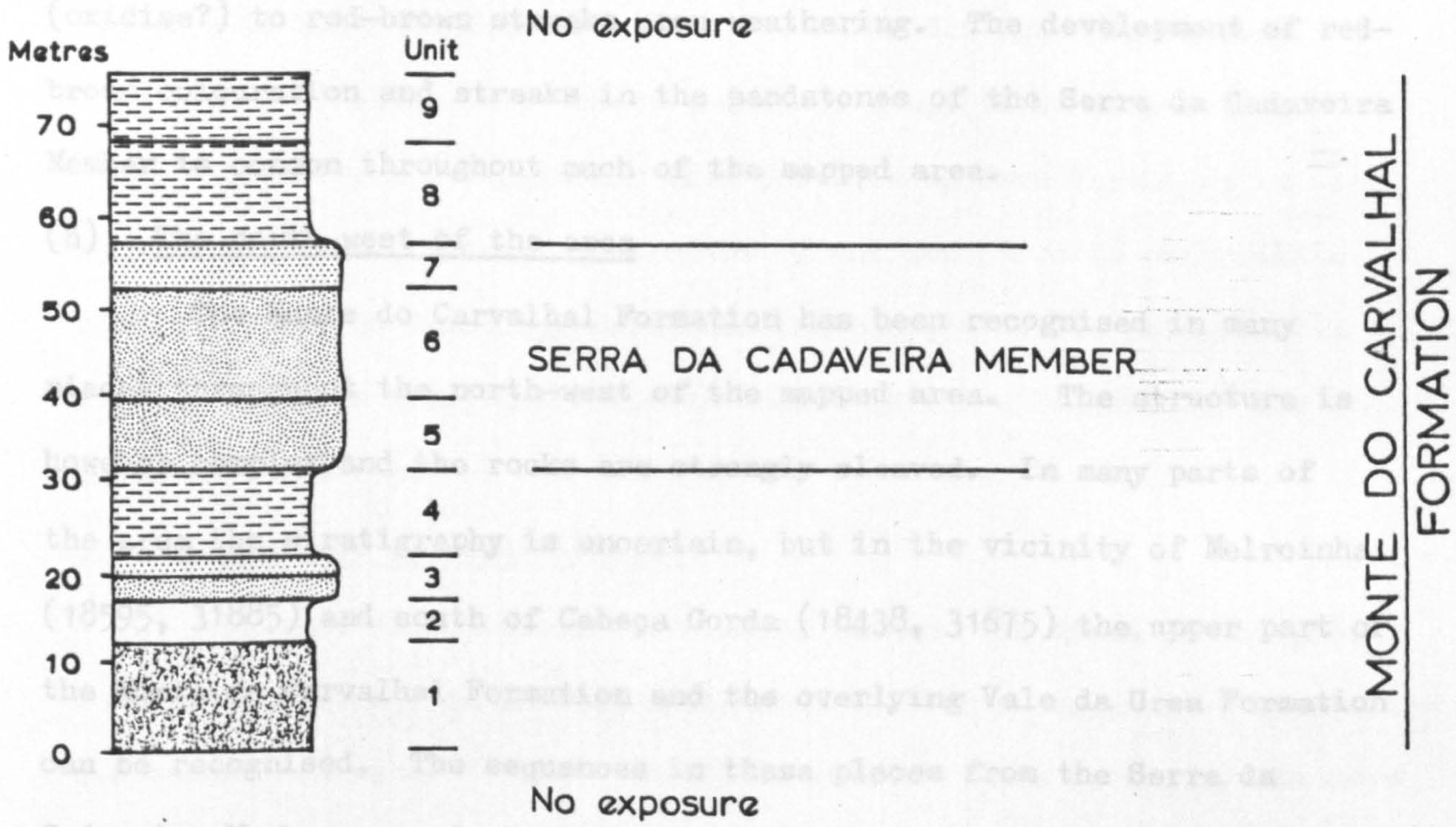
(g) Cabeço Redondo (18651, 31380 to 18647, 31373) fig. 20

The sequence at Serra de S. Paulo can be traced from the Rio Zêzere north-west for 1.5km before the sequence is truncated by a fault. About 500m north of the peak of Serra de S. Paulo at Cabeço Redondo a forestry track cutting exposes another section through the Serra do Cadaveira Member of the Monte do Carvalhal Formation. Nine lithological units were recorded at this section of which units 5, 6 and 7 form the Serra da Cadaveira Member; the nine units are listed below from top to bottom and are also illustrated in figure 20.

			metres
	-	no exposure	
9	-	Siltstone, grey weathering to a white or beige colour and occurring in thin to medium beds.	8.00
8	-	Siltstone, grey and micaceous in thin to medium beds with a few medium beds of grey sandy siltstone.	11.00
7	-	Serra da Cadaveira Member; quartzite, light grey, medium and fine-grained in medium and thick beds.	4.50
6	-	Serra da Cadaveira Member; sandstone, white with irregular red-brown streaks, fine-grained and medium bedded forming a massive unit.	12.00
5	-	Serra da Cadaveira Member; sandstone, red-brown, soft and poorly exposed.	8.00
4	-	Siltstone, dark grey, weathering to a white/light grey colour.	10.00
3	-	Sandstone and quartzite, beige and grey, fine and medium-grained occurring in thin and medium beds.	4.00
2	-	No exposure	
1	-	Greywacke, grey, very fine-grained and silty occurring in massive thick beds which pass upwards into sandy micaceous siltstone in thin to medium beds.	12.00
	-	No exposure	

MONTE DO CARVALHAL FORMATION FIG. 20

Cabeço Redondo (18651 31380 to 18647 31373)



LEGEND: FIG. 59

This section through the Serra da Cadaveira Member shows that the thickness of the member, about 25m, has remained fairly constant throughout the Serra de S. Paulo, but that slight lithological variations have occurred. The quartzite beds at the top of the member do not occur near the Rio Zêzere and units 4 and 5 at Cabeço Redondo are streaked or coloured red-brown, a phenomenon which appears to be caused by weathering. When the sandstones of the Serra do Cadaveira Member are unweathered they are commonly streaked with grey silty material which appears to change (oxidise?) to red-brown streaks upon weathering. The development of red-brown colouration and streaks in the sandstones of the Serra da Cadaveira Member is common throughout much of the mapped area.

(h) <u>The north-west of the area</u>

The Monte do Carvalhal Formation has been recognised in many places throughout the north-west of the mapped area. The structure is however complex and the rocks are strongly cleaved. In many parts of the area the stratigraphy is uncertain, but in the vicinity of Melroinha (18595, 31885) and south of Cabeça Gorda (18438, 31675) the upper part of the Monte do Carvalhal Formation and the overlying Vale da Ursa Formation can be recognised. The sequences in these places from the Serra da Cadaveira Member upwards to the top of the formation are closely similar to those exposed at Serra de S. Paulo and Vale da Lage. The strata between the bottom of the formation and the Serra da Cadaveira Member does however appear to be much thicker than it is in the east of the area. Sequences of greywacke and siltstone containing bryozoa and crinoid fragments have been mapped throughout the north-west area, but only rarely can the occurrence of these fossils be related to the positions of the Serra da Cadaveira and Serra do Amial Members. Where this is possible the thickness of strata between the bryozoa beds and the Serra da Cadaveira Member is much greater than it is in the east of the area, and a thickness for the Monte do Carvalhal Formation of around 490m is suggested.

6. Vale da Ursa Formation

i. General character

The Vale da Ursa Formation is a sequence of quartzites and sandstones between 10m and 26m thick. The formation is characterised in the top few metres by a thin, uniform and remarkably persistent sequence of black sandstones called the Serra dos Aguilhões Member. This member contains very poorly preserved graptolites of probable lower Llandovery age suggesting that the Vale da Ursa Formation is the basal Silurian sequence. The bottom of the formation is conformable upon the Monte do Carvalhal Formation and the top of the formation is overlain by dark grey, carbonaceous mudstones and siltstones of the Foz da Serta Formation.

ii. Topography and distribution

Because of the close association between the Monte do Carvalhal Formation and the Vale da Ursa Formation, this thin sequence of quartzites and sandstones tends to occur in the flanks of ridges formed by the more resistant and thicker members of the Monte do Carvalhal Formation. The Vale da Ursa Formation is exposed to the east of the area, occurring from south to north at: Serra do Carriçal, Serra dos Aguilhões, Vale da Ursa, Serra do Esphinaço, Serra do Carvalhal, Serra da Lagoa and Cabeço dos Picos. In the centre and west of the area the formation occurs at: Cabeço da Pena, east of Varzea de Pedro Mouro, Vale da Lage and Melroinha.

iii. Name

The formation is named after Vale da Ursa about 2.5km east of Dornes where the type section is located next to Ponte Vale da Ursa, the main road bridge over the Rio Zêzere.

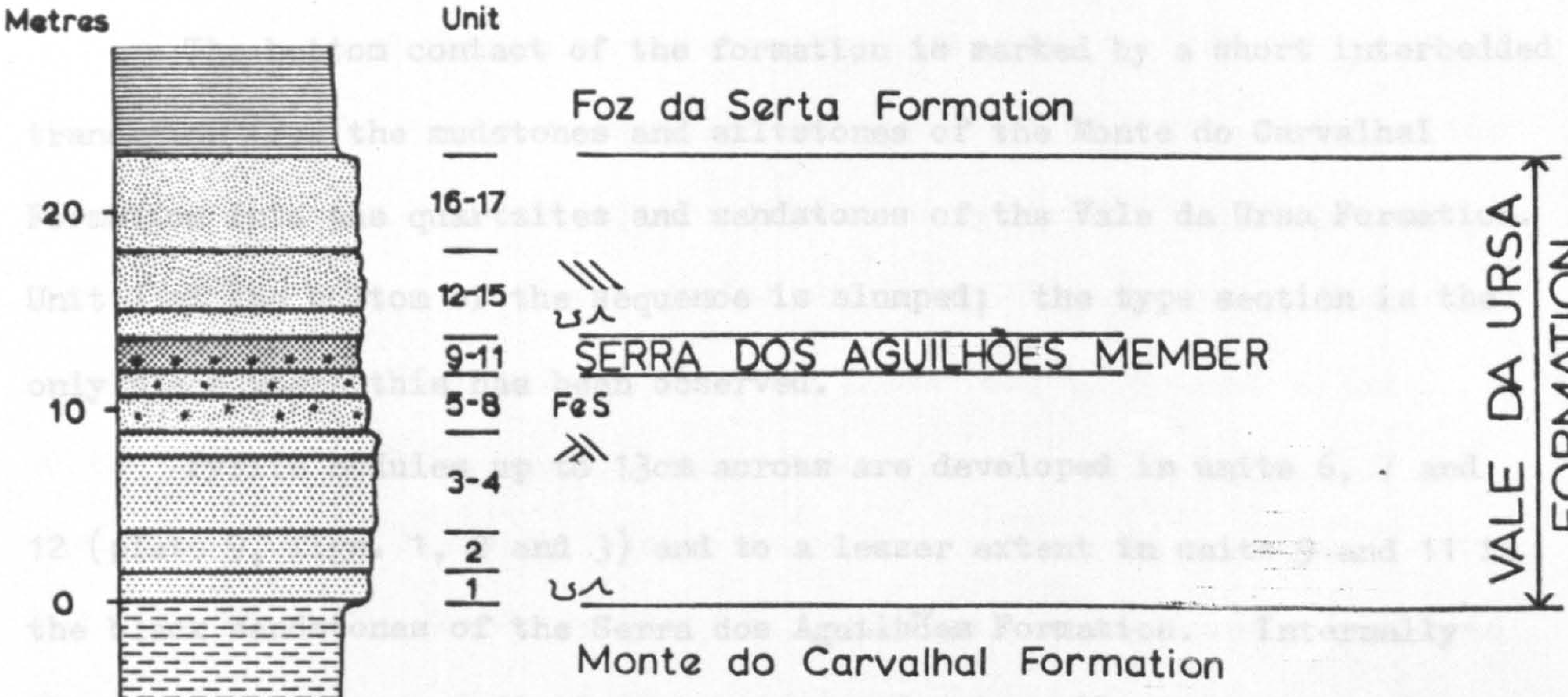
iv. Type section; Ponte Vale da Ursa (19006, 31208 to 19025, 31211) fig. 21.

The type section is located next to Ponte Vale da Ursa where it is exposed in a combined valley, road cutting and quarry section. The formation at the type section is about 22m thick, subdivided into 17 lithological units of which units 9, 10 and 11 are the dominantly black sandstones of the Serra dos Aguilhões Member. The sequence is shown in figure 21 and is listed below from top to bottom.

			metres
	-	Foz da Serta Formation; mudstone and siltstone, dark grey to black, carbonaceous and often graptolitic. At 12m above the top of the Vale da Ursa Formation these mudstones yielded graptolites of middle Wenlock age; Sheinwoodian, ridgidus to ellesae Zones inclusive.	
17	-	Sandstone, black, fine-grained and silty in thin and very thin beds which show both massive and laminated internal structures. Ripple drift cross lamination, common particularly in the upper parts of some beds; the lamination is more pronounced in the lower parts of some beds. Horizontal burrows 1-2mm in diameter occur in some beds, no branching was seen in the burrows which are laterally impersistant.	5.00
16	-	Sandstone, dark grey to black, hard and massive in thin and medium beds with partings of micaceous siltstone.	0.24
15	-	Sandstone, black, fine-grained and pyritic in thin to medium beds with partings of siltstone.	0.95
14	-	Sandstone, grey, fine-grained in thin beds with very thin beds of silty sandstone. Load casts and flame structures occur along the junctions of the beds. Lamination is quite common and cross-bedding occurs in 5 cm sets.	0.95
13	-	No exposure.	c1.00
12	-	Sandstone, black, fine-grained in medium beds which alternate with thin beds of micaceous siltstone. Pyrite nodules generally a few centimetres long scattered throughout the unit.	1.45

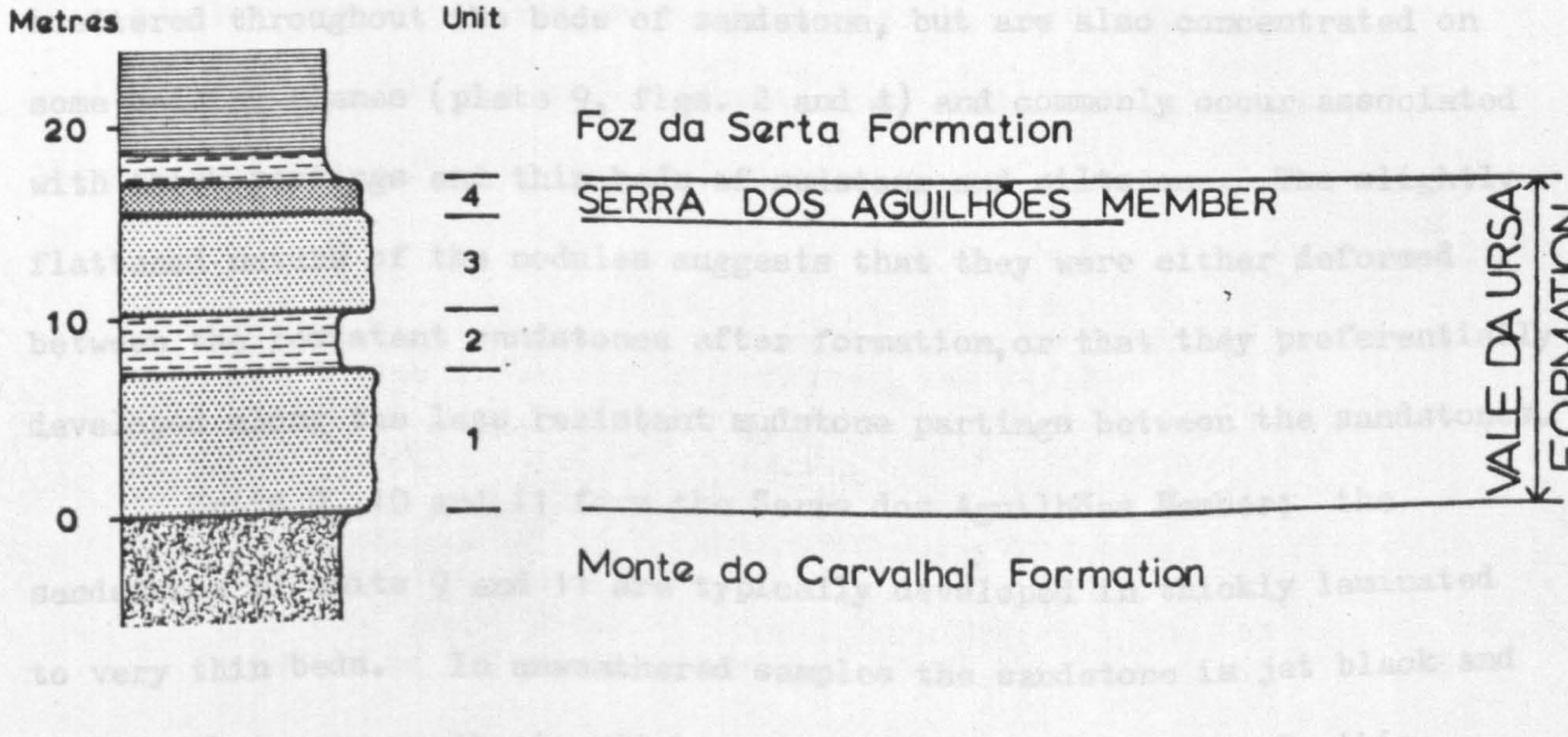
11	-	<u>Serra dos Aguilhões Member</u>; sandstone, black, fine-grained, micaceous and carbonaceous in laminated and very thin beds with poorly preserved biserial graptolites of ?basal Llandovery age (plate 8, fig. 3). Frequent pyrite bands and poorly developed pyrite nodules especially on bedding planes (plate 7, fig. 3 and plate 8, fig. 2).	0.65
10	-	<u>Serra dos Aguilhões Member</u>; siltstone, black micaceous and soft in laminated beds.	0.05
9	-	<u>Serra dos Aguilhões Member</u>; sandstone, black, fine-grained, micaceous and carbonaceous very similar to unit 11 (plate 7, fig. 3).	0.85
8	-	No exposure.	0.50
7	-	Sandstone, light grey, fine-grained in thin and medium beds which are internally trough cross-bedded on a 0.5cm to 1cm scale. Pyrite nodules up to 13cm in diameter occur especially in the bottom part of this unit (plate 9, figs. 1, 2 and 3).	0.70
6	-	Sandstone, light grey, fine-grained in thin and medium beds alternating with thin and very thin beds of dark grey mudstone. Pyrite nodules as above occur within this unit (plate 9, figs. 1, 2 and 3).	1.20
5	-	Mudstone and siltstone, dark grey and micaceous in thin beds.	0.50
4	-	Quartzite, light grey, fine-grained in thin and medium beds some of which show faint trough cross-bedding in the upper parts of the beds.	1.00
3	-	Quartzite, light grey, fine-grained in thin and medium beds interbedded with thin and very thin beds of dark grey mudstone and laminated mudstone. There are also interbedded thin beds of sandstone which show small scale cross-bedding.	3.70
2	-	Quartzite, light grey, fine-grained in thin to medium beds which are interbedded with thin beds of siltstone and mudstone. Some of the quartzites have irregular bases which are probably load cast with flame structures.	2.30
1	-	Slumped beds; quartzite, as above with siltstones and mudstones as above. All the beds are dislocated and many form randomly orientated balls and pillows in the mudstone/siltstone matrix.	1.40

VALE DA URSA FORMATION. Type section FIG. 21
Ponte Vale da Ursa (19006 31208 to 19025 31211)



LEGEND: FIG. 59

VALE DA URSA FORMATION FIG. 22
Serra do Esphinaço (19077 31287 to 19074 31284)



LEGEND: FIG. 59

- Monte do Carvalhal Formation; siltstone and mudstone, grey and micaceous with a few thin beds of sandstone.

- Total thickness of the Vale da Ursa Formation 22.44

The bottom contact of the formation is marked by a short interbedded transition from the mudstones and siltstones of the Monte do Carvalhal Formation into the quartzites and sandstones of the Vale da Ursa Formation. Unit 1 at the bottom of the sequence is slumped; the type section is the only place where this has been observed.

Pyrite nodules up to 13cm across are developed in units 6, 7 and 12 (plate 9, figs. 1, 2 and 3) and to a lesser extent in units 9 and 11 in the black sandstones of the Serra dos Aguilhões Formation. Internally these nodules have a radiating structure and externally the surface is composed of closely crowded pyrite cubes up to 5mm across (plate 9, fig. 3). Dr. L.G. Love (University of Sheffield [pyrite ref. no. F434]) kindly examined the nodules and by using reflection microscope techniques found that the pyrite enclosed quartz sand grains. Dr. L.G. Love concluded that the nodules were a secondary replacement which could have occurred at any time from early diagenesis to a tectonic episode. The nodules occur scattered throughout the beds of sandstone, but are also concentrated on some bedding planes (plate 9, figs. 2 and 4) and commonly occur associated with thick partings and thin beds of mudstone and siltstone. The slightly flattened nature of the nodules suggests that they were either deformed between the resistant sandstones after formation, or that they preferentially developed along the less resistant mudstone partings between the sandstones.

Units 9, 10 and 11 form the Serra dos Aguilhões Member; the sandstones of units 9 and 11 are typically developed in thickly laminated to very thin beds. In unweathered samples the sandstone is jet black and pyritic, but upon weathering it becomes light grey or beige. In thin section the sandstone is seen to be composed of very fine to fine-grained, angular to sub-angular quartz with a small amount of coarse silt grade quartz. Altered feldspars form 4 to 5 percent of the rock, muscovite 2 to 3 percent and tourmaline is a common accessory mineral; the muscovite usually occurs along the bedding planes which gives the rock its fissility. The grains are supported in an opaque matrix which is mainly carbonaceous, but which also contains some very fine-grained pyrite; this weathers out as yellow streaks when the fresh rock is exposed to the atmosphere. The Serra dos Aguilhões Member is also notable because it yields the oldest Silurian fossils found within the area. At fossil locality 10 in the quarry by Ponte Vale da Ursa the sandstone has yielded indeterminate biserial graptolites which Dr. Rickards considered to be of probable basal Llandovery age. The top of the formation is taken at the top of unit 17, the sandstones of which are overlain by the poorly exposed black mudstones of the Foz da Serta Formation.

v. Comparison of the type section with other sections and outcrops

(a) Serra do Esphinaço (19077, 31287 to 19074, 31284) fig. 22

The Serra do Esphinaço section is located about 1km north of the type section and is exposed in a combined track and valley section on the north-east side of Serra do Esphinaço. Four units can be recognised and these are shown in figure 22; from top to bottom these are:

			metres
	–	Foz da Serta Formation; siltstones, beige in thin beds; the siltstone is weathered and poorly exposed.	
4	–	Serra dos Aguilhões Member; sandstone, light grey and fine-grained in laminated to very thin beds. The sandstone is weathered and contains indeterminate biserial graptolites at fossil locality 19. The top contact of the member is sharp.	1.60

3	–	Quartzite, grey, fine-grained in thin and medium beds interbedded with thin beds of grey siltstone.	5.00
2	–	Siltstone, grey; poorly exposed.	3.00
1	–	Quartzite, grey and fine-grained in thin to medium beds with siltstone partings; the bottom contact of the unit is sharp.	7.00
	–	Monte do Carvalhal Formation; greywacke, grey, fine to medium-grained and massive. The greywacke weathers spheroidally.	
		Total thickness of the Vale da Ursa Formation	16.60

The Vale da Ursa Formation is thinner at Serra do Esphinaço than it is at the type section; there are however many similarities between the two sections. The bottom parts of both sections are dominantly composed of quartzite, but at the type section the siltstone and mudstone partings are thicker. The lower quartzites of both sections are overlain by a unit of mudstone (unit 5 of the type section and unit 2 above); this unit is much thicker at Serra do Esphinaço. The overlying quartzites at Serra do Esphinaço are interbedded with thin beds of siltstone and similarly the sandstones at the type section are interbedded with mudstone, however, the pyrite nodules are missing from this unit at Serra do Esphinaço. The black laminated sandstones of the Serra dos Aguilhões Member are of remarkably constant thickness between the two localities and at Serra do Esphinaco also contain very poorly preserved, indeterminate, biserial graptolites. The sandstone sequence overlying the Serra dos Aguilhões Member at the type section is not developed at this section at Serra do Esphinaço.

(b) Serra do Esphinaço (19101, 31277 to 19095, 31268) fig. 23

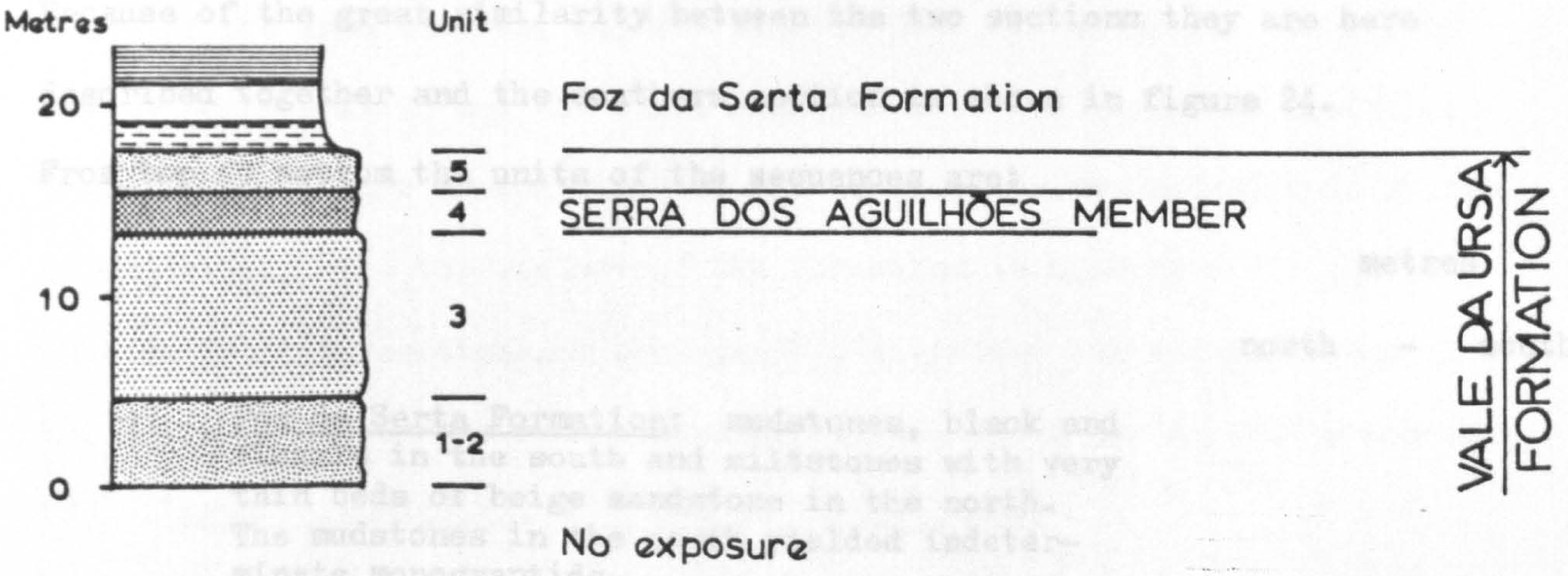
This other section exposed on the Serra do Esphinaço is located on the ridge of the serra about 1km north-east of the type section. Exposure is along an old established forestry track and at this locality the Vale da Ursa Formation is about 17m thick, it can be divided into five units (fig. 23) which are from top to bottom:

			metres
	-	Foz da Serta Formation; siltstones, beige and grey, weathered and poorly exposed.	
5	-	Sandstone, fine to medium-grained and silty forming an irregular mass with no signs of bedding.	2.00
4	-	Serra dos Aguilhões Member; sandstone, light grey, fine-grained and weathered. The sandstone forms thick laminated and very thin beds.	2.00
3	-	Quartzite, grey and fine-grained forming thick beds with occasional fine and medium beds. There are also occasional siltstone partings with a few pyrite nodules.	8.40
2	-	Sandstone, light grey, fine-grained and micaceous forming a massive unit with faint traces of bedding.	4.20
1	-	Quartzite, fine-grained forming one medium bed.	0.25
	-	No exposure; Monte do Carvalhal Formation, mudstones exposed about 10m below unit 1.	
	-	Total exposed thickness of the Vale da Ursa Formation.	16.85

The thickness of the Vale da Ursa Formation at this locality is very similar to that of the other Serra do Esphinaço section to the north and the sequence shows lithological similarities to both the northern section and the type section. The siltstone unit in the middle of the formation at the other sections is not present on the ridge, but unit 3 containing the pyrite nodules is very similar to that of the type section. The Serra dos Aguilhões Member is identical and of similar thickness to that of the type section, but it has weathered to a light grey colour. Unit 5 at the top of the formation is formed by a very thick bed of fine to medium-grained silty sandstone; this has some similarity to the silty sandstones found at the top of the type section.

VALE DA URSA FORMATION FIG. 23

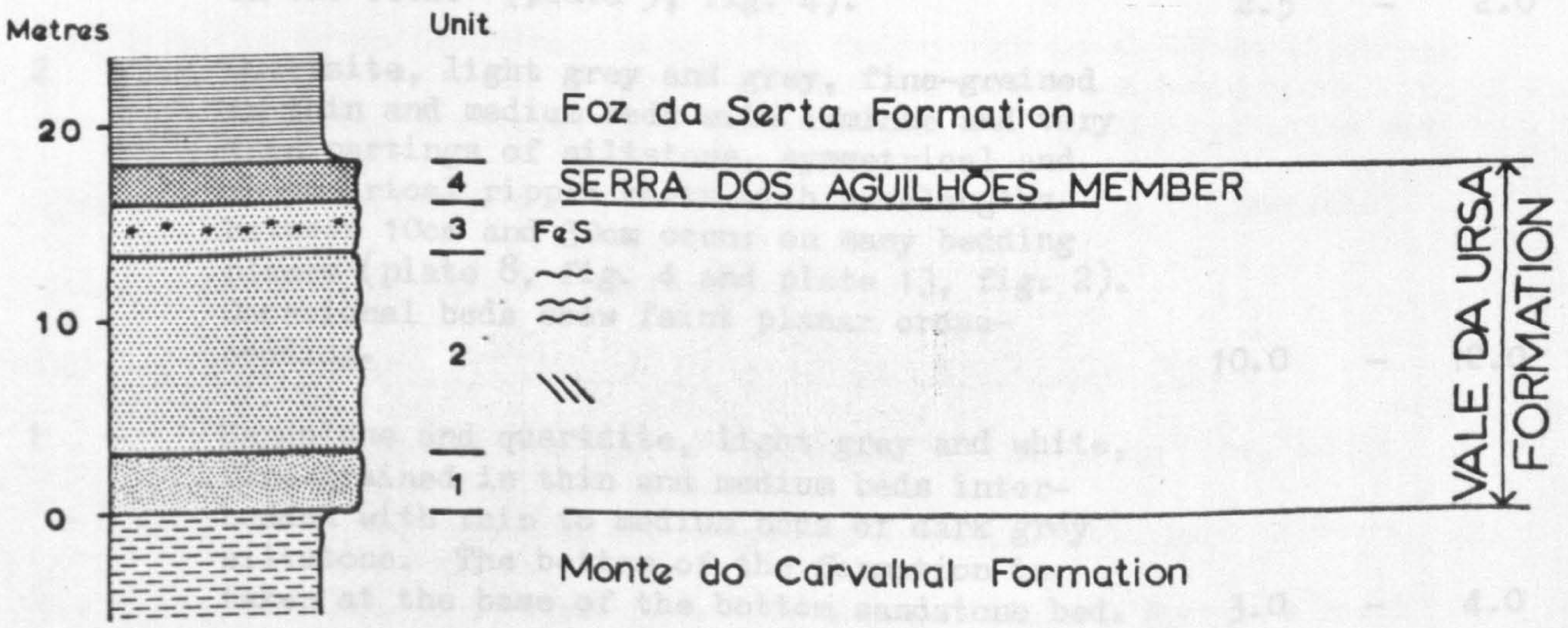
Serra do Esphinaço (19101 31277 to 19095 31268)



LEGEND: FIG. 59

VALE DA URSA FORMATION FIG. 24

Vale Salgueiro (19171 31143 to 19176 31151)



LEGEND: FIG. 59

(c) Vale Salgueiro; north (19171, 31143 to 19176, 31151), south (19202, 31116 to 19195, 31115) fig. 24

Two sections are exposed on Serra do Carriçal about 400m apart and near Vale Salgueiro about 1.75km south-east of the type section. Because of the great similarity between the two sections they are here described together and the southern section is shown in figure 24. From top to bottom the units of the sequences are:

		metres north	–	south
–	Foz da Serta Formation; mudstones, black and fissile in the south and siltstones with very thin beds of beige sandstone in the north. The mudstones in the south yielded indeterminate monograptids.			
4 –	Serra dos Aguilhões Member; sandstone, dark grey, fine-grained and very micaceous, forming laminated and very thin beds. The sandstone weathers to a light grey colour. Fossil locality 26 in the north yielded indeterminate biserial graptolites considered by Dr. Rickards to be of possible low Llandovery age.	2.0	–	1.5
3 –	Quartzite, light grey and grey, fine-grained in thin and medium beds with very thin beds and partings of siltstone containing pyrite nodules. In many places the pyrite nodules have weathered out and open cavities are left in the rock. (plate 9, fig. 4).	2.5	–	2.0
2 –	Quartzite, light grey and grey, fine-grained in thin and medium beds with laminae and very thin partings of siltstone, symmetrical and assymetrical ripple marks with wavelengths between 10cm and 30cm occur on many bedding planes (plate 8, fig. 4 and plate 13, fig. 2). Occasional beds show faint planar cross-bedding.	10.0	–	12.0
1 –	Sandstone and quartzite, light grey and white, fine-grained in thin and medium beds interbedded with thin to medium beds of dark grey siltstone. The bottom of the formation is taken at the base of the bottom sandstone bed.	3.0	–	4.0

- Monte do Carvalhal Formation; siltstone, grey and dark grey, banded.

- Total thickness of the Vale da Ursa Formation 17.5 - 19.5

The basal beds of the formation at Vale Salgueiro are similar to those of the type section, but the slumped beds are missing. The pryite nodule beds (unit 3) and the black sandstones of the Serra dos Aguilhões Member (unit 4) are more or less identical to their equivalent beds at the type section. The top contact of the formation is however different to that at the type section and the variable siltstone and mudstone beds of the Foz da Serta Formation lie directly on the Serra dos Aguilhões Member.

(d) Serra da Lagoa (18935, 31439 to 18933, 31439)

At Serra da Lagoa about 2.5km north-north-east of the type section, in a small quarry excavated for building stone, the Vale da Ursa Formation is partially exposed. The top and bottom of the formation are not exposed, but two units of the formation can be distinguished. The upper unit is the Serra Aguilhões Member which is about 2.5m thick and composed of grey, weathered, fine-grained sandstones in laminated to thin beds. At fossil locality 120 this unit yielded indeterminate biserial graptolites named by Dr. Rickards as ?Climacograptus and ?Glyptograptus suggesting either a low Silurian or an Ordovician age. The lower unit is about 8m thick and composed of medium and thick beds of grey coloured quartzites which are fine and medium-grained and which are sometimes slightly feldspathic; these quartzites are poorly exposed.

(e) Cabeço da Pena (18731, 31430 to 18730, 31423) fig. 25.

This section is located on the ridge of Cabeço da Pena, south of Varzea de Pedro Mouro and about 4km north-west of the type section. The section at Cabeço da Pena is poorly exposed along a forestry track and along the ridge. The formation can be divided into four units which are listed below from top to bottom; this sequence is also shown in figure 25.

			metres
	–	Foz da Serta Formation; siltstones, grey and beige; poorly exposed.	
4	–	Serra dos Aguilhões Member; sandstone, light grey, fine-grained forming laminated, very thin and thin beds. The sandstone is strongly weathered and shows traces of indeterminate ?graptolites.	1.00
3	–	Quartzite, white and light grey, fine-grained in thin and medium beds with very thin siltstone partings.	4.00
2	–	Siltstone, beige; weathered and poorly exposed.	2.00
1	–	Quartzite, white and light grey, fine-grained in medium and thin beds with siltstone partings.	3.00
	–	Monte do Carvalhal Formation; siltstone and mudstone, dark grey and micaceous with occasional thin beds of fine-grained sandstone; poorly exposed.	
	–	Total thickness of the Vale da Ursa Formation, approximately	10.00

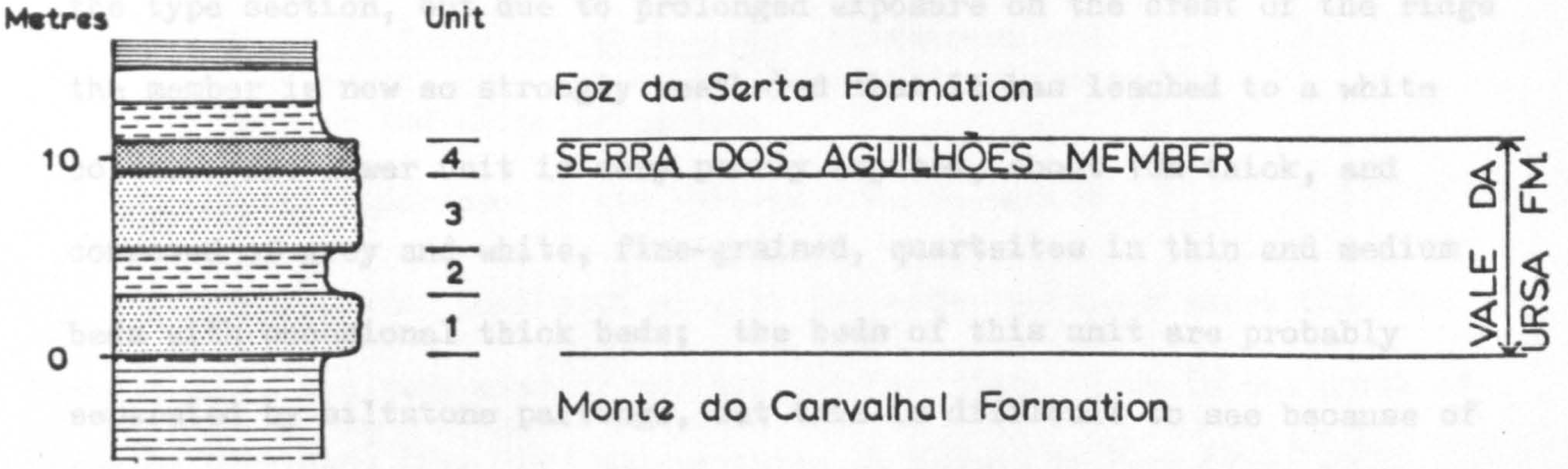
The quartzite - siltstone - quartzite progression of this sequence capped by the Serra dos Aguilhões Member is identical to that for the section to the north of Serra do Esphinaço (fig. 22), but at Cabeço da Pena the formation is much thinner. The Serra dos Aguilhões Member is again a remarkably constant marker horizon of similar character to the equivalent units at the type section.

(f) Serra do Vale (18755, 31518 to 18752, 31515)

On the Serra do Vale located about 400m east of Varzea de Pedro Mouro and 5km north-east of the type section the Vale da Ursa Formation is partially exposed on a forestry track which runs along the top of the ridge. The exposure is poor and consequently only the more resistant rock is exposed and only two lithological units can be seen. The upper unit is the

VALE DA URSA FORMATION FIG. 25

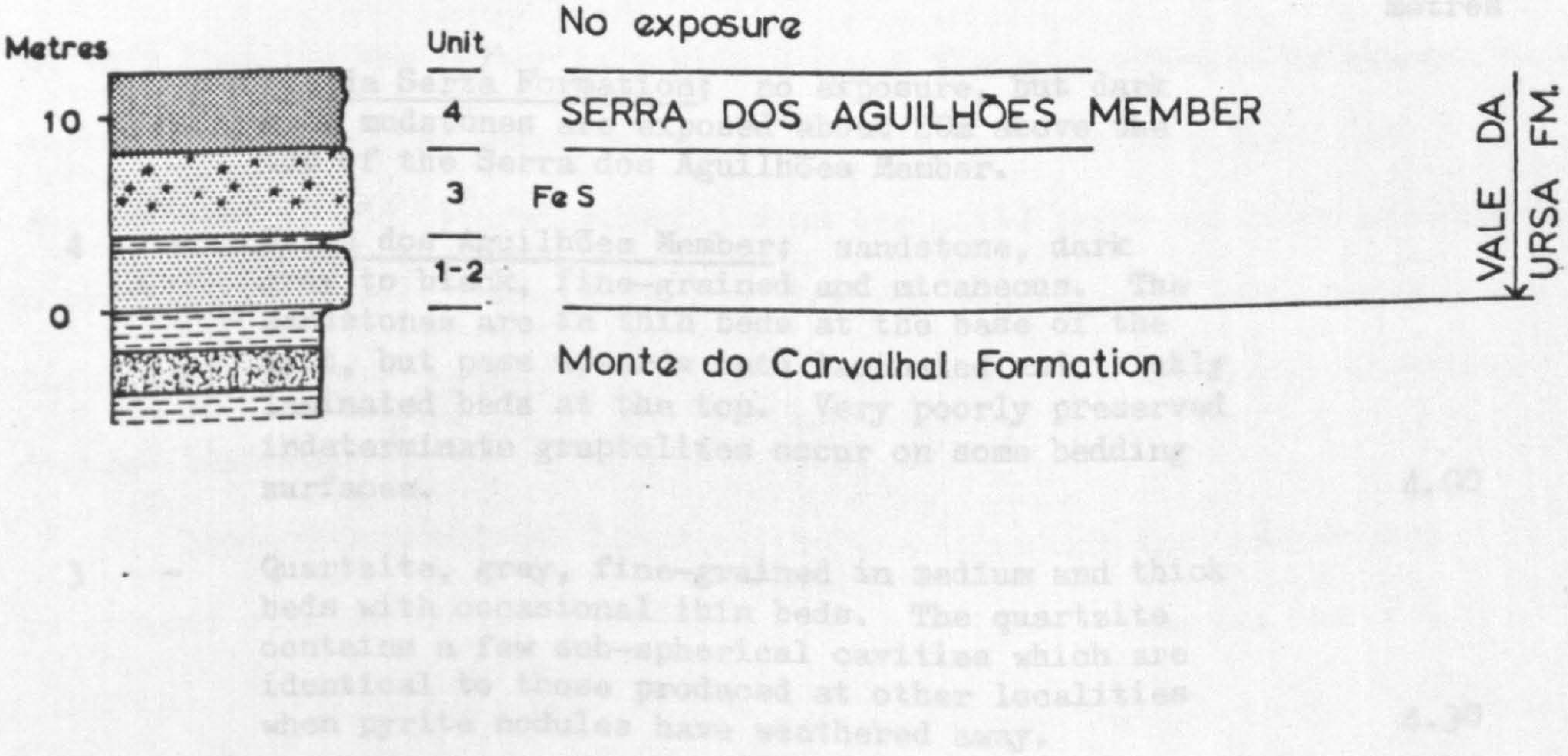
Cabeço da Pena (18731 31430 to 18730 31423)



LEGEND: FIG. 59

VALE DA URSA FORMATION FIG. 26

Melroinha (18565 31903 to 18566 31898)



LEGEND: FIG. 59

Serra dos Aguilhões Member of which about one metre of beds are poorly exposed. These consist of laminated and very thin beds of fine-grained sandstone which at fossil locality 164 contain indeterminate ?graptolites. The Serra dos Aguilhões Member is again of similar lithology to that of the type section, but due to prolonged exposure on the crest of the ridge the member is now so strongly weathered that it has leached to a white colour. The lower unit is very poorly exposed, about 10m thick, and composed of grey and white, fine-grained, quartzites in thin and medium beds with occasional thick beds; the beds of this unit are probably separated by siltstone partings, but this is difficult to see because of the poor nature of the exposure.

(g) Melroinha (18565, 31903 to 18566, 31898) fig. 26

The Vale of Ursa Formation is exposed on the western flank of Melroinha about 8.5km north-west of the type section. The exposure is along a forestry track which cuts through the steeply dipping beds. The mudstone and siltstone sequences above and below the formation are poorly exposed, but where the resistant arenaceous beds have been cut exposure is good. The formation can be divided into four units which are listed below from top to bottom and which are also shown in figure 26:

			metres
	–	Fóz da Serta Formation; no exposure, but dark grey mudstones are exposed about 20m above the top of the Serra dos Aguilhões Member.	
4	–	Serra dos Aguilhões Member; sandstone, dark grey to black, fine-grained and micaceous. The sandstones are in thin beds at the base of the unit, but pass upwards into laminated and thickly laminated beds at the top. Very poorly preserved indeterminate graptolites occur on some bedding surfaces.	4.00
3	–	Quartzite, grey, fine-grained in medium and thick beds with occasional thin beds. The quartzite contains a few sub-spherical cavities which are identical to those produced at other localities when pyrite nodules have weathered away.	4.30

2	-	Siltstone, dark grey and micaceous in laminated and very thin beds; the siltstone weathers to a light grey colour.	0.30
1	-	Quartzite, light grey, fine-grained in very thin and thin beds with occasional medium beds. There are occasional siltstone partings and many of the bedding planes are covered with mica.	2.80
	-	Monte do Carvalhal Formation; siltstones and greywackes, grey and beige, frequently micaceous; massive and slightly banded.	
	-	Total thickness of the Vale da Ursa Formation	11.40

Comparison of this section with the other sections shows that the lower 3 units are very similar to, but thinner than, those to the north of Serra do Esphinaço (fig. 22) and to those at Cabeço da Pena (fig. 25). Unit 4 the Serra dos Aguilhões Member is however much thicker than at Serra do Esphinaço or Cabeço da Pena, but the member is of identical lithological character.

(f) Vale Fundeiro (18844, 31994)

To the east of Vale Fundeiro one of the most northerly observed exposures of the Vale da Ursa Formation is located about 8km north-north-east of the type section. The formation is poorly exposed, but debris from an adit cut for water shows that the Serra dos Aguilhões Member is present and consists of laminated and very thin beds of black fine-grained sandstone. At this locality the member is within a short distance overlain by black carbonaceous mudstones which belong to the Foz da Serta Formation. At fossil locality 143 (tipped material from the adit) these mudstones yielded a profilic graptolite fauna which Dr. Rickards considers to be of probable basal Wenlock age - centrifugus Zone (or just possibly, but highly doubtful, highest Llandovery).

About 500m south of this locality the Serra dos Aguilhões Member is exposed adjacent to the Rio Zêzere (18853, 31950). Here the member is underlain by several metres of poorly exposed quartzites which are light grey, fine-grained and which occur in thin beds with assymmetrical ripple marks of wavelength 9–11cm.

7. Foz da Serta Formation

i. General character

The Foz da Serta Formation is a sequence of dark coloured mudstones and siltstones with thin-bedded sandstones mainly restricted to the middle part of the formation. The mudstones of the formation are easily weathered, consequently nowhere within this area can a straightforward sequence be found from the Vale da Ursa Formation below to the Vale do Serrão Formation above. The thickness of the Foz da Serta Formation is probably in the order of between 140m and 200m, although in some places it could be as little as 100m. The formation has yielded numerous graptolites which have all been kindly identified by Dr. R.B. Rickards and which indicate that the age of the formation ranges from topmost Llandovery to topmost Wenlock and possibly into the Ludlow (fig. 29).

ii. Topography and distribution

Because of the soft nature of the mudstones, the Foz da Serta Formation commonly occurs along valleys between ridges formed by the quartzites of the Vale da Ursa and Monte do Carvalhal Formations. The Rio Zêzere follows the Foz da Serta Formation in many parts of the area. The lithological uniformity of the formation means that when it occurs in wide folded tracts of land it forms relatively flat areas which are commonly low lying and have fertile soil; these areas are consequently very popular for farming. Such flat areas occur around Foz da Serta, Mendeira, Varzea de Pedro Mouro, Aldela Velha, Sambado and Almegue.

iii) Name

The formation is named after the village of Foz da Serta in the south-east corner of the area where the lower boundary-stratotype and the lower part of the formation are exposed.

iv) Type section

Because of the structural complexity of the Foz da Serta Formation a section reasonable enough to be designated a type section is not available. However, in accordance with the International Subcommission on Stratigraphic Classification (1972, terminology and usage ruling 2.4) boundary-stratotypes for the formation are described and a description of the intervening strata with estimated thicknesses. are also given.

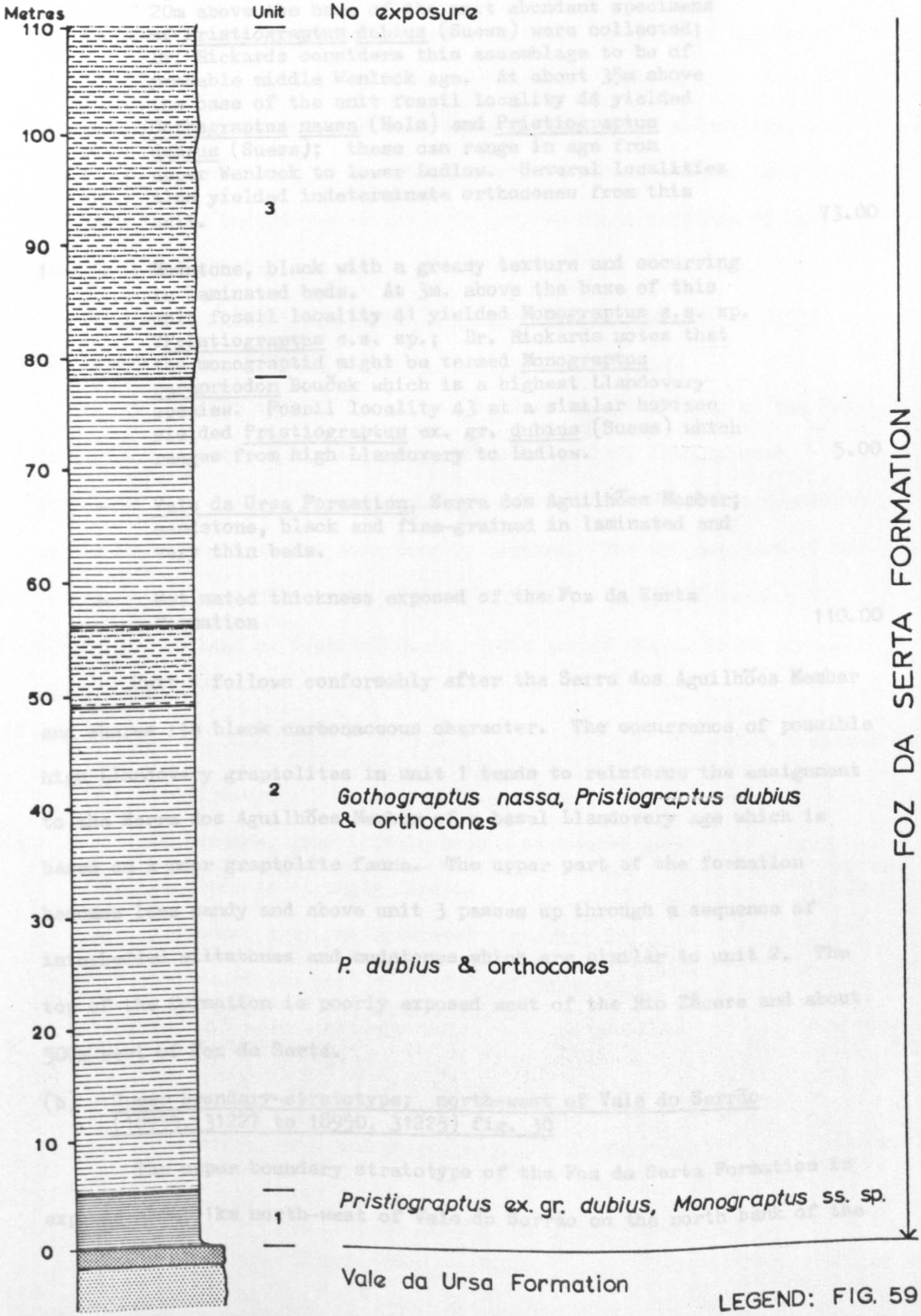
(a) Lower boundary-stratotype; Foz da Serta (19186, 31117 to 19141, 31095) fig. 27

At Foz da Serta the lower boundary-stratotype and the underlying Vale da Ursa Formation are well exposed to the east and north-east of the village. The overlying sequence is strongly folded, sheared and faulted and the thickness of formation is difficult to estimate, but may be in the order of about 180m. It is, however, obvious that the lower part of the formation is composed of mudstones and siltstones and these pass upwards into a sequence of sandstones, mudstones and siltstones. This exposed part of the formation can be subdivided into 3 units which with their estimated thicknesses are described below and shown in figure 27.

			metres
	–	No exposure	
3	–	Sandstone and siltstone, beige and grey; the sandstone is fine-grained, silty and the two lithologies occur interbedded in thin and very thin beds.	32.00

FOZ DA SERTA FORMATION. Lower boundary-statotype FIG. 27

Foz da Serta (19186 31117 to 19141 31095)



LEGEND: FIG. 59

2	-	Mudstone and siltstone, dark grey and black in laminated and very thin beds interbedded with occasional thin beds and thin sequences of fine -grained sandstone. At fossil locality 45 about 20m above the base of the unit abundant specimens of Pristiograptus dubius (Suess) were collected; Dr. Rickards considers this assemblage to be of probable middle Wenlock age. At about 35m above the base of the unit fossil locality 44 yielded Gothograptus nassa (Holm) and Pristiograptus dubius (Suess); these can range in age from upper Wenlock to lower Ludlow. Several localities also yielded indeterminate orthocones from this unit.	73.00
1	-	Mudstone, black with a greasy texture and occurring in laminated beds. At 3m. above the base of this unit fossil locality 41 yielded Monograptus s.s. sp. ?Pristiograptus s.s. sp.; Dr. Rickards notes that the monograptid might be termed Monograptus parapriodon Bouček which is a highest Llandovery species. Fossil locality 43 at a similar horizon yielded Pristiograptus ex. gr. dubius (Suess) which ranges from high Llandovery to Ludlow.	5.00
	-	Vale da Ursa Formation, Serra dos Aguilhões Member; sandstone, black and fine-grained in laminated and very thin beds.	
	-	Estimated thickness exposed of the Foz da Serta Formation	110.00

Unit 1 follows conformably after the Serra dos Aguilhões Member and shares its black carbonaceous character. The occurrence of possible high Llandovery graptolites in unit 1 tends to reinforce the assignment to the Serra dos Aguilhões Member of a basal Llandovery age which is based on a poor graptolite fauna. The upper part of the formation becomes less sandy and above unit 3 passes up through a sequence of interbedded siltstones and mudstones which are similar to unit 2. The top of the formation is poorly exposed west of the Rio Zêzere and about 500m west of Foz da Serta.

(b) Upper boundary-stratotype; north-west of Vale do Serrão (18955, 31227 to 18950, 31225) fig. 30

The upper boundary stratotype of the Foz da Serta Formation is exposed about 1km north-west of Vale do Serrão on the north bank of the

Rio Zêzere, where it crops out adjacent to the water, below the lower crag of the Vale do Serrão Formation (plate 11, fig. 1). The upper boundary-stratotype is shown by figure 30 which illustrates the lower part of the overlying Vale do Serrão Formation. This section shows a sharp conformable junction between the grey, micaceous siltstones, in laminated to thin beds, of the Foz da Serta Formation and the laminated and very thinly bedded quartzites with grey mudstone partings of the Vale do Serrão Formation.

v. Comparison of the type section with other sections and outcrops

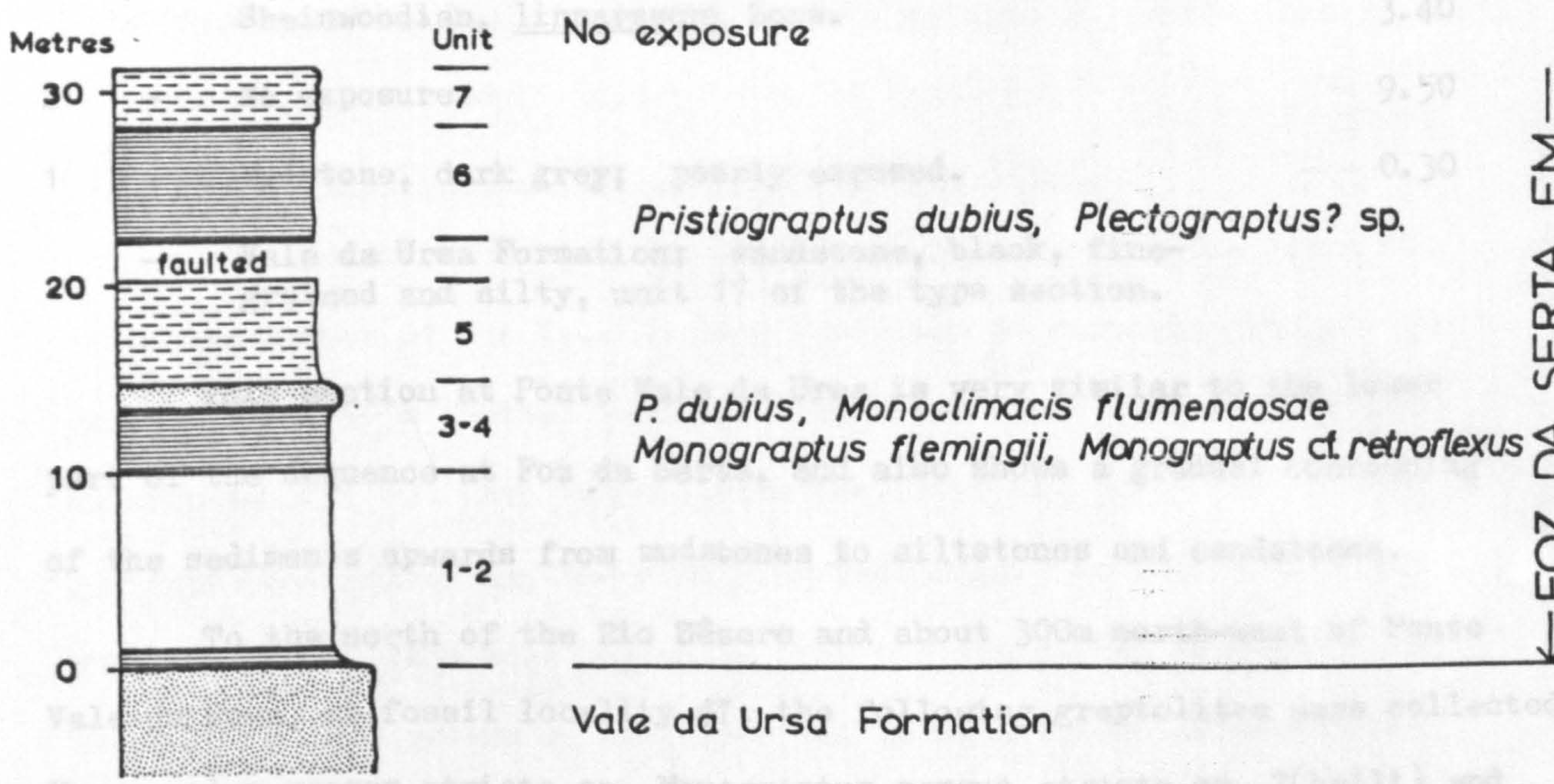
(a) Vale da Ursa (19024, 31213 to 19050, 31204) fig. 28

About 150m east of Ponte Vale da Ursa the lower part of the Foz da Serta Formation is exposed along a track section. Approximate thickness can however only be given for the bottom part of the formation as the overlying beds are structurally complex. The exposed part of the formation can be divided into 7 units, but it is faulted between units 5 and 6; the loss or duplication of strata across the fault is probably negligible.

			metres
	–	No exposure	
7	–	Siltstones, grey in thin beds interbedded with grey, fine-grained, micaceous sandstones; the sequence is strongly folded.	Approx. 3.00
6	–	Mudstone, grey and weathered occurring in laminated beds. Fossil locality 40 at the bottom of the unit yielded Pristiograptus dubius (Suess) and Plectograptus? sp. Dr. Rickards considers these to be of probable middle Wenlock age.	Approx. 6.00
	–	Fault	
5	–	Siltstone, grey and purple – grey; weathering spheroidally.	Approx. 7.40

FOZ DA SERTA FORMATION — FIG. 28

Vale da Ursa (19024 31213 to 19050 31204)



LEGEND: FIG. 59

4	–	Sandstone, grey and fine-grained occurring as two medium beds separated by a medium bed of mudstone which is black and greasy with polished listric surfaces. At fossil locality 38 these mudstones yielded: *Pristiograptus dubius* (Suess), *Monoclimacis flumendosae* (Gortani) and *Monograptus flemingii* (Salter). Dr. Rickards considers this assemblage to be of undoubted middle Wenlock age; Sheinwoodian *ridgidus* to *ellesae* Zones inclusive.	1.00
3	–	Mudstone, black, hard and porcellanous, breaking with a conchoidal fracture. The mudstone is very carbonaceous and at fossil locality 39 near the top of the unit yielded abundant specimens of *Pristiograptus dubius* (Suess), plus a few specimens of *Monoclimacis flumendosae* (Gortani) and *Monograptus* cf. *retroflexus* Tullberg. Dr. Rickards considers this assemblage to be middle Wenlock; Sheinwoodian, *linnarssoni* Zone.	3.40
2	–	No exposure	9.50
1	–	Mudstone, dark grey; poorly exposed.	0.30
	–	Vale da Ursa Formation; sandstone, black, fine-grained and silty, unit 17 of the type section.	

This section at Ponte Vale da Ursa is very similar to the lower part of the sequence at Foz da Serta, and also shows a gradual coarsening of the sediments upwards from mudstones to siltstones and sandstones.

To the north of the Rio Zêzere and about 300m north-west of Ponte Vale da Ursa, at fossil locality 47, the following graptolites were collected: *Monograptus sensus stricto* sp., *Monograptus sensus stricto* sp. ?(*halli*) and *Pristiograptus nudus* (Lapworth). Dr. Rickards notes that these fossils tend to indicate the Llandovery *turriculatus* Zone. This locality is about 8m above the top of the Vale da Ursa Formation and a Llandovery age reinforces the possible Llandovery age suggested for the Serra dos Aguilhões Member of the Vale da Ursa Formation.

(b) South of Cabeço da Pena (18772, 31394 to 18755, 31378)

To the south of Cabeço da Pena the Serra dos Aguilhões Member of the Vale da Ursa Formation is exposed in the bottom of the valley. Nearby dark grey mudstones at fossil locality 97, located about 20m above the Vale da Ursa Formation, have yielded several specimens considered by Dr. Rickards to be ?Pristiograptus dubius (Suess); if they are dubius they have a range from the top of the riccartonensis Zone to the Ludlow. About 130m south-west of this locality, fossil locality 96 yielded graptolites identified by Dr. Rickards as: Pristiograptus sp., Pristiograptus jaegeri Holland et al. and cf. Monograptus ludensis (Murchison); these specimens are Wenlock, possibly the ludensis Zone of the Homerian stage. Because these beds are structurally complex it is difficult to say how far above the Vale da Ursa Formation this locality is situated, but it would appear to be at least 40m.

(c) Cabeço dos Picos (18846, 31994 to 18841, 31993)

On the north bank of the Rio Zêzere near Almegue the Serra dos Aguilhões Member of the Vale da Ursa Formation is exposed; it is also exposed about 500m further north at Cabeço dos Picos. At the northern outcrop an adit cut into the hillside for water has penetrated the Serra dos Aguilhões Member and the overlying mudstones. At fossil locality 143 abundant graptolites were collected from the tip at the adit entrance. Although the collection of such material is open to contamination and mixing of different horizons the material collected was all the same lithology and appeared to come from a horizon within about 5 metres of the top of the Serra dos Aguilhões Member. This locality yielded abundant specimens identified by Dr. Rickards as: Retiolites geinitzianus (Barrande), Monograptus vamerina (Nicholson) s.l. and Cyrtograptus sp.; a few specimens of Monograptus cf. priodon, ?Monograptus priodon and ??Monograptus capillaceus were also collected. Dr. Rickards gives this assemblage an almost certain basal Wenlock age, probably the centrifugus Zone of the Sheinwoodian, but he notes that the assemblage might possibly be highest

Llandovery (but that this is highly doubtful). The main fossil horizon collected from the tip was in some places developed as a 1-2mm thick lamina of graptolitic material which has compacted and carbonised to produce a coal complete with cleat jointing. Vague graptolite outlines were observed imprinted on the surface of the coal, but the degree of carbonisation had obliterated most of the detail.

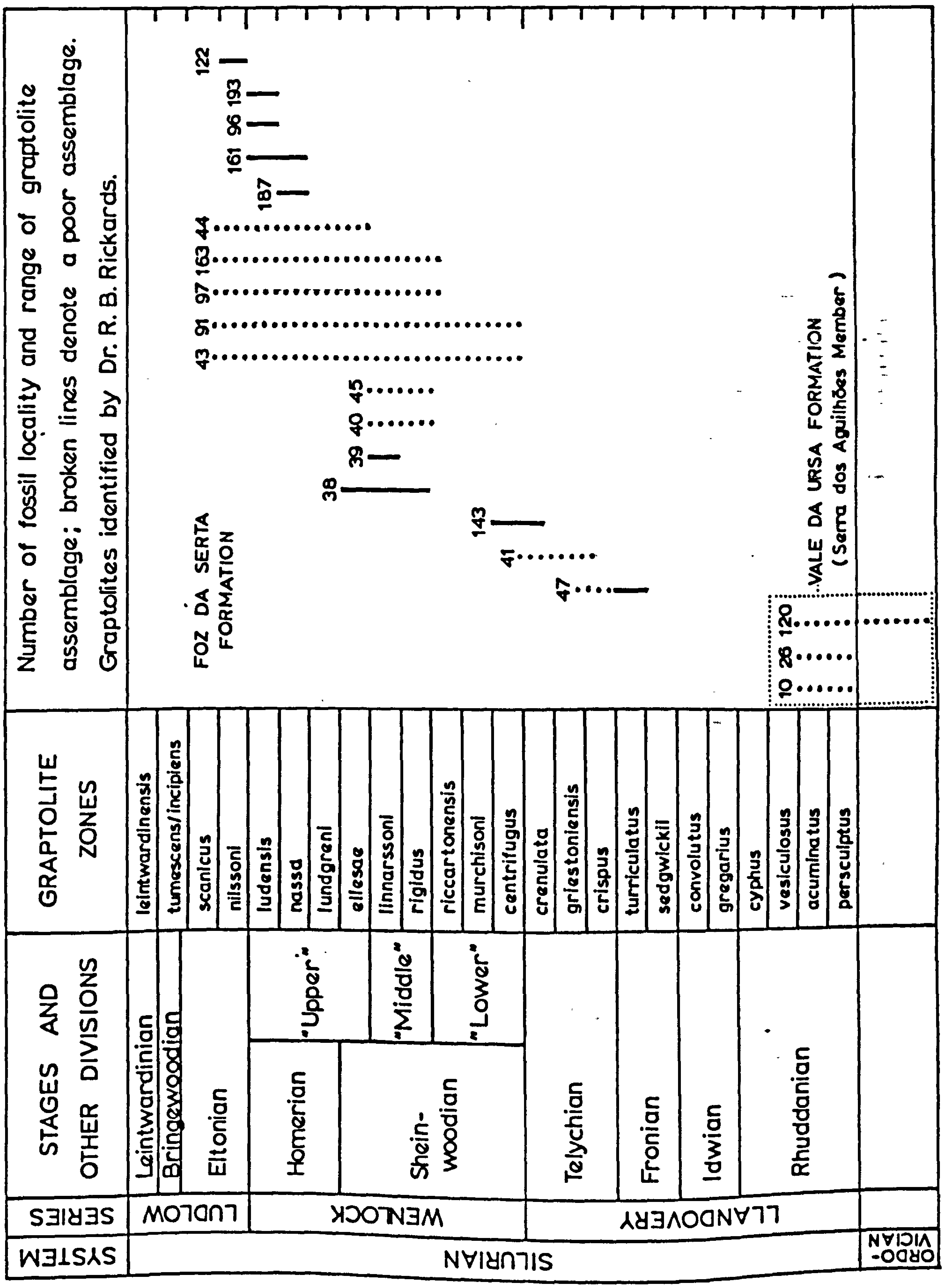
About 70m to the north and probably at a slightly higher stratigraphical position fossil locality 42 in dark grey mudstone yielded one very poor specimen of ?? Pristiograptus dubius (Suess).

(d) The area in general. Fig. 29.

The complexly folded nature of the Foz da Serta Formation precludes any accurate measurement of the formation. Throughout the complete area it is however possible to recognise three broad lithological units within the formation. The lower unit is the equivalent of units 1 and 2 described for the lower boundary-stratotype at Foz da Serta. The lower beds are always developed as mudstones and these pass upwards into mudstones and siltstones; this part of the formation is probably between 50m and 70m thick. The middle unit is developed as interbedded siltstones and sandstones similar to unit 3 at Foz da Serta. This lithology can be recognised in many places throughout the area, but it is always intensely folded. The folding shown at Sambado (plate 13, fig. 3 and plate 15, figs. 1-3) is typical and similarly folded sequences are also found at Foz da Serta, Vale da Ursa and west of Almegue. The middle part of the sequence is probably between 40m and 60m thick. The top unit of the formation is dominantly composed of mudstones and siltstones and is probably between 50m and 70m thick. Near the top of the formation sporadic thin quartzite beds become interbedded with the mudstones and there is a rapid transitional contact with the lower beds of the Vale do Serrão Formation.

GRAPTOLITE ASSEMBLAGE RANGES FOR THE VALE DA URSA & FOZ DA SERTA FORMATIONS

FIG. 29



The age ranges of the graptolite assemblages collected from the Foz da Serta Formation and the Vale da Ursa Formation (Fig. 29) show that, despite the lack of definite zonal graptolites from the lundgreni, riccartonensis, murchisoni, griestoniensis and crispus Zones, the Llandovery above the turriculatus Zone, the complete Wenlock Series and the basal Ludlow is represented by the Foz da Serta Formation.

8. Vale do Serrão Formation

i. General character

The Vale do Serrão Formation is an approximately 72m thick sequence of alternating laminated to very thinly bedded quartzites and mudstones (plate 10, fig. 2, plate 13, fig. 1 and plate 14, fig. 3). The bottom of the formation is marked by a sharp contact with the siltstones and mudstones forming the top of the Foz da Serta Formation. The top of the formation is taken at the base of the lowest quartzite bed of the Serra da Mendeira Formation. The Vale do Serrão Formation is of probable lower Ludlow age.

ii. Topography and distribution

The laminated quartzites and mudstones of the Vale do Serrão Formation are frequently well cemented and often form fairly massive crags such as those below Serra da Mendeira (plate 11, fig. 1). Elsewhere and without the protection of the Serra da Mendeira Formation, the Vale do Serrão Formation is eroded into fairly steep-sided strike ridges with sharply rounded tops (left hand end of plate 10, fig. 1). The Vale do Serrão Formation covers a considerable expanse in the central and southern parts of the area where from south to north it forms: Serra da Balança, part of Serra da Luação and parts of Serra da Molhadinha and Serra da

Mendeira (plate 11, fig. 1). The formation is also exposed to the west and south of Dornes and also in several small fault bounded areas at Serra da Lagoa, Moinhos and Sambado.

iii. Name

The Vale do Serrão Formation is named after the village of Vale do Serrão about 2km east of Dornes. The formation is exposed to the west, south and north of the village.

iv. Type section

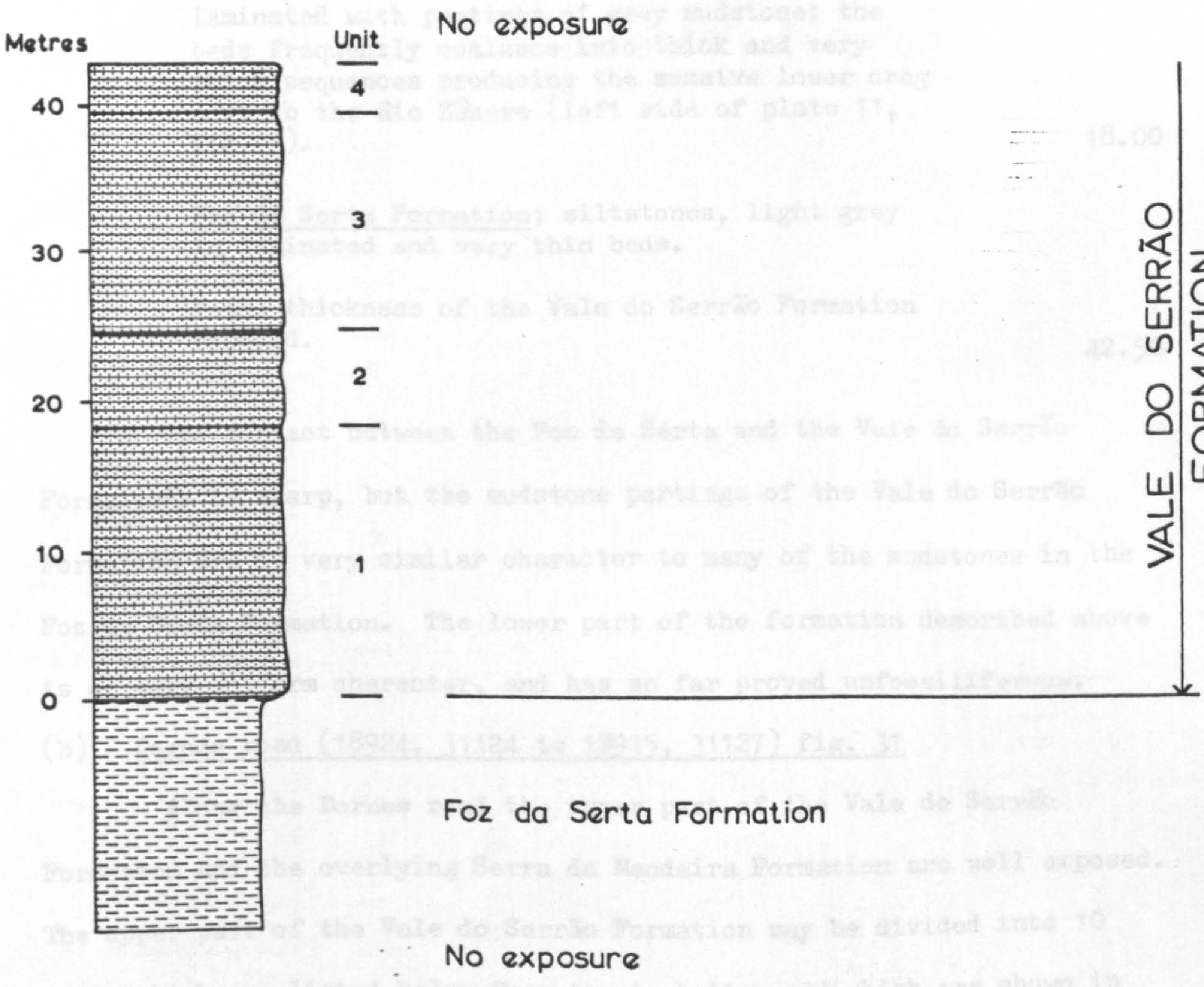
Nowhere within the area is there a continuous well exposed sequence through the Vale do Serrão Formation. A composite type section can however be constructed by the combination of; (a) a section through the bottom half of the formation to the north of Vale do Serrão and (b) a section through the top half of the formation situated about 1km south of (a) and exposed along the Dornes road to the north of Serra do Luação.

(a) North of Vale do Serrão (18945, 31215 to 18936, 31224) fig. 30

To the north of Vale do Serrão on the north bank of the Rio Zêzere the lowest 43m and bottom contact of the Vale do Serrão Formation are exposed (plate 11, fig. 1). The formation can be traced in a north-west direction almost continuously to Serra da Mendeira and can be lithologically correlated with the section through the Vale do Serrão Formation (b) exposed on the Dornes road. North of Vale do Serrão the sequence may be divided into four units listed below from top to bottom and shown in figure 30.

			metres
	–	No exposure; top of hill.	
4	–	Quartzite, light grey-white and fine-grained in very thin beds interbedded with laminae of light grey to purple mudstone; this unit is poorly exposed.	3.00

VALE DO SERRÃO FORMATION. Type section, lower part. FIG. 30
FOZ DA SERTA FORMATION. Upper boundary-statotype.
North. of Vale do Serrão (18945 31215 to 18936 31224)



LEGEND: FIG. 59

3	–	Quartzite, light grey-white and fine-grained in laminated beds frequently with partings of light grey and purple-grey mudstone. These quartzites form the upper crag north of Vale do Serrão (left side of plate 11, fig. 1) and the crag below Serra da Mendeira (right side of plate 11, fig. 1). This unit correlates with unit 2 of the Dornes road section (b)	15.00
2	–	Quartzite, light grey-white and fine-grained forming regular laminated beds with interbedded laminae of light grey mudstone.	6.50
1	–	Quartzite, light grey-white, fine-grained and laminated with partings of grey mudstone; the beds frequently coalesce into thick and very thick sequences producing the massive lower crag next to the Rio Zêzere (left side of plate 11, fig. 1).	18.00
	–	Foz da Serta Formation; siltstones, light grey in laminated and very thin beds.	
	–	Total thickness of the Vale do Serrão Formation exposed.	42.50

The contact between the Foz da Serta and the Vale do Serrão Formations is sharp, but the mudstone partings of the Vale do Serrão Formation are of very similar character to many of the mudstones in the Foz da Serta Formation. The lower part of the formation described above is of very uniform character, and has so far proved unfossiliferous.

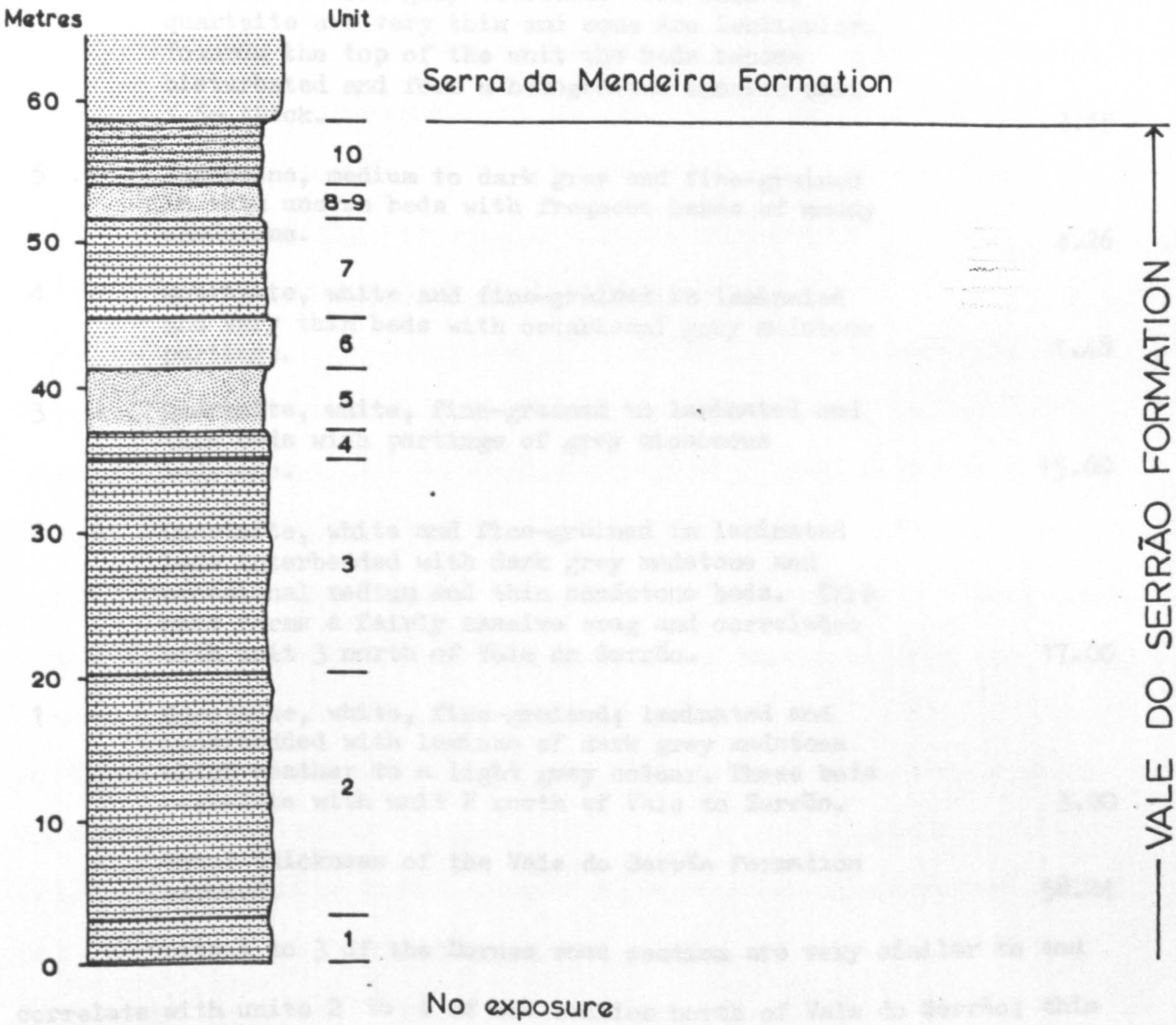
(b) Dornes road (18924, 31124 to 18915, 31127) fig. 31

Along the Dornes road the upper part of the Vale do Serrão Formation and the overlying Serra da Mendeira Formation are well exposed. The upper part of the Vale do Serrão Formation may be divided into 10 units which are listed below from top to bottom and which are shown in figure 31:

metres

– Serra da Mendeira Formation; quartzite, light grey and fine to medium-grained; the lower beds are thin and very thin, but form thick sub-units. The quartzite beds have partings of mudstone which are frequently disrupted and contorted by bioturbation; flame structures are also present.

VALE DO SERRÃO FORMATION. Type section, upper part. FIG. 31
Dornes road (18924 31128 to 18915 31127)



LEGEND: FIG. 59

10	-	Sandstone, light grey and fine-grained in very thin and thin beds with interbedded laminae of dark grey mudstone.	4.47
9	-	Sandstone, dark grey and fine-grained forming a very massive unit.	1.15
8	-	Sandstone, dark grey and hard forming lenticles (?boudins) in a mudstone matrix.	1.20
7	-	Quartzite, white, fine-grained, thin and very thinly bedded with laminae of dark grey mudstone.	6.73
6	-	Quartzite, white and fine-grained with bands and laminae of dark grey mudstone; the beds of quartzite are very thin and some are lenticular. Towards the top of the unit the beds become bioturbated and form a homogeneous massive unit 1.5m thick.	3.15
5	-	Sandstone, medium to dark grey and fine-grained in thin uneven beds with frequent bands of muddy sandstone.	4.26
4	-	Quartzite, white and fine-grained in laminated and very thin beds with occasional grey mudstone partings.	1.48
3	-	Quartzite, white, fine-grained in laminated and thin beds with partings of grey micaceous mudstone.	15.60
2	-	Quartzite, white and fine-grained in laminated beds interbedded with dark grey mudstone and occasional medium and thin sandstone beds. This unit forms a fairly maasive crag and correlates with unit 3 north of Vale do Serrão.	17.00
1	-	Quartzite, white, fine-grained; laminated and interbedded with laminae of dark grey mudstone which weather to a light grey colour. These beds correlate with unit 2 north of Vale do Serrão.	3.00
	-	Total thickness of the Vale do Serrão Formation exposed.	58.24

Units 1 to 3 of the Dornes road section are very similar to and correlate with units 2 to 4 of the section north of Vale do Serrão; this gives the formation a combined thickness of about 77 metres. From unit 4 upwards of the Dornes road sequence the beds show a gradual increase in thickness culminating with the massive quartzites which form the base of the Serra da Mendeira Formation. The beds at the top of the Vale do Serrão Formation here form a conformable, but rapid passage into the Serra da Mendeira Formation. This appears to be the case over the whole area, but the situation is often confused by the Vale do Serrão Formation frequently being strongly folded below the massive beds of the Serra da Mendeira Formation.

The Vale do Serrão Formation has yielded microfossils considered by K. Dorning (Sheffield) to be of Wenlock or lower Ludlow age (see Appendix 2 for faunal list of microfossils identified). These microfossils and the occurrence of basal Ludlow graptolites at the top of the underlying Foz da serta Formation suggest that the Vale do Serrão Formation is probably of lower Ludlow age.

v. Comparison of the type section with other outcrops

(a) Dornes and West of Serra da Mendeira

From Serra da Faisca south of Dornes north to the west side of Serra da Mendeira the Vale do Serrão Formation is exposed faulted against the Dornes Formation; in the south the overlying Serra da Mendeira Formation is also faulted against the Dornes Formation. Nearly all the exposures of the Vale do Serrão Formation in this area are of fine-grained, laminated and very thinly bedded quartzites and mudstones which are commonly intensely folded (plate 14, fig. 3 and plate 17, fig. 3). South of Dornes the top contact of the Vale do Serrão Formation with the Serra da Mendeira Formation is exposed (18878, 31027); and consists of a rapid interbedded transition from laminated quartzites and mudstones into medium and thin-bedded, fine to medium-grained quartzites (see Serra da Mendeira Formation, (9, v, a). West of Serra da Mendeira the basal beds of the Vale do Serrão Formation form a sequence of resistant quartzites which produce a prominant crag (18773, 31313) above mudstones of the Foz da Serta Formation; the beds of this crag are similar to unit 1 of the type section (8, iv, a) north of Vale do Serrão.

(b) Serra da Lagoa (18936, 31454)

On the hill of Serra da Lagoa a small area of laminated quartzites occurs overlying siltstones and mudstones of the Foz da Serta Formation which are exposed to the west of the hill. The southern and northern margins of the outcrop are faulted against older strata and the sequence is folded and poorly exposed, but the lithology is identical to the lower part of the Vale do Serrão Formation elsewhere.

(c) Moinhos (19000, 31590)

To the east of Moinhos another fault bounded enclave of the Vale do Serrão Formation is exposed. The sequence is folded into a tight north-south trending syncline between two transcurrent faults. Approximately 40m of laminated white quartzites and grey mudstones, passing up into very thinly bedded and laminated quartzites with mudstone partings, are exposed. The sequence overlies mudstones and siltstones of the Foz da Serta Formation, but exposure is poor and the exact nature of the contact between them and the Vale do Serrão Formation is uncertain.

(d) Sambado (18913, 317430)

The Vale do Serrão Formation is exposed about 300m north-east of Sambado where it forms a ridge running northwards for about 600m. A maximum possible thickness of about 60m is exposed and this is composed of white laminated quartzites with mudstone partings and a few lenticular and uneven very thin beds of white quartzite. Because of poor exposure little else can be concluded about the sequence, but to the east the bottom contact of the Vale do Serrão Formation appears to be conformable on mudstones of the Foz da Serta Formation and to the west the formation is faulted against mudstones also of the Foz da Serta Formation.

9. Serra da Mendeira Formation

i. General character

The Serra da Mendeira Formation is an approximately 50m thick sequence of massive quartzites and sandstones. The formation conformably overlies the Vale do Serrão Formation and is conformably overlain by the interbedded sandstones and siltstones of the Serra da Luação Formation. The Serra da Mendeira Formation is probably of lower or middle Ludlow age.

ii. Topography and distribution

The Serra da Mendeira Formation is a massive resistant sequence and consequently forms high ridges and peaks. The formation has only been identified in the south of the area where it forms the ridges of Serra do Luação (plate 10, fig. 1), Serra da Faisca, Serra da Molhadinha and the resistant cap rock to the Serra da Mendeira peak (plate 11, fig. 1).

iii. Name

The formation is named after Serra da Mendeira located about 2km north of the type section and 2km north-north-east of Dornes.

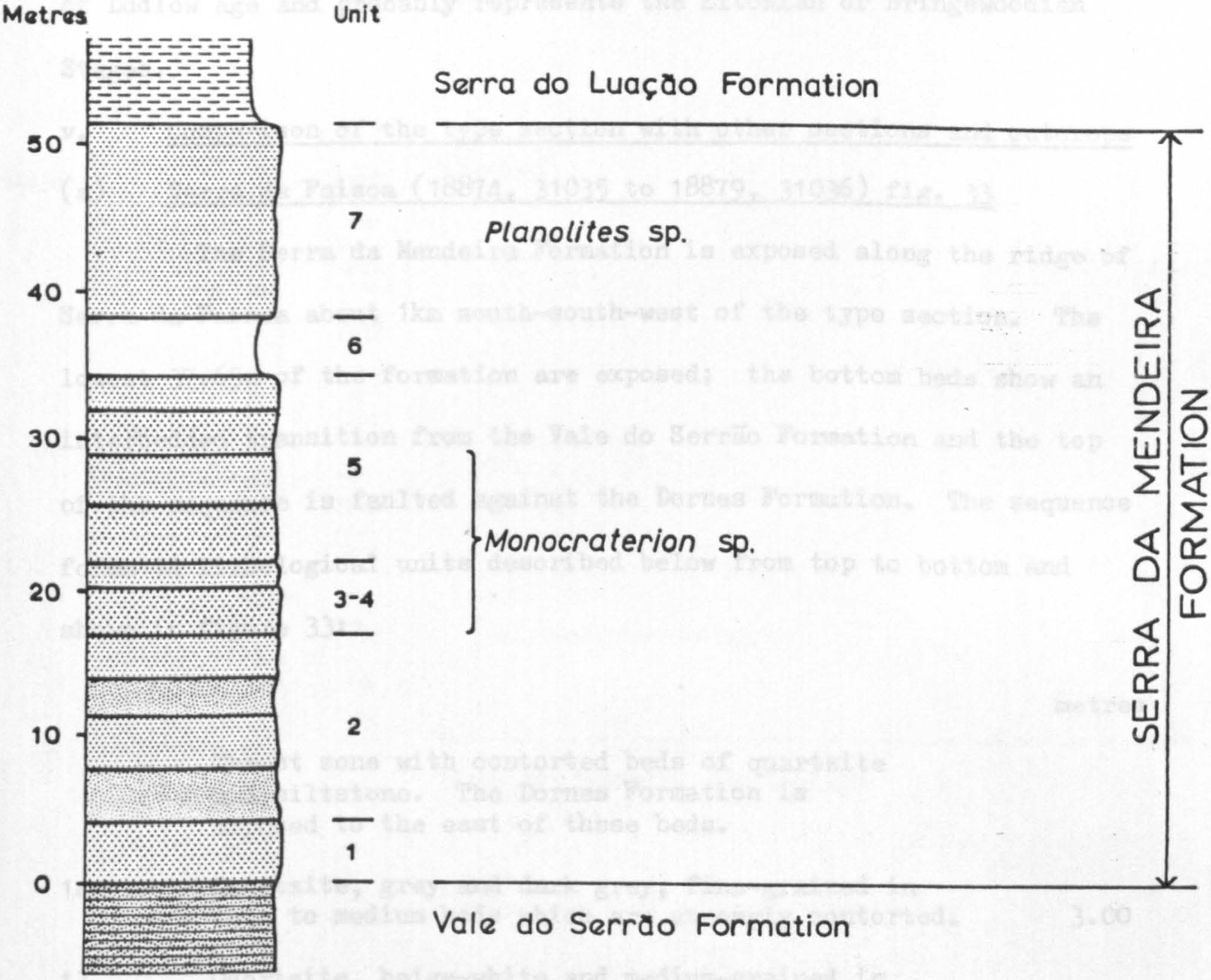
iv. Type section; Dornes road (18914, 31127 to 18910, 31126) fig. 32

The type section is well exposed along the Dornes to Vale do Serrão road where the road passes through a cutting in the massive quartzites and sandstones (plate 10, fig. 1). The base of the Serra da Mendeira Formation is taken at the bottom of the lowest quartzite bed which overlies the sandstones forming the top of the Vale do Serrão Formation. The top of the formation is taken at the base of the first thick siltstone unit above the quartzites and sandstones of the Serra da Mendeira Formation. The intervening sequence at the type section may be divided into 7 units in figure 32 and listed below from top to bottom:

Unit		Description	metres
	–	Serra do Luação Formation; unit 1, siltstone grey, weathering to a brown colour and forming very thin and laminated beds.	
7	–	Quartzite, light grey banded with dark grey, fine-grained in thin and very thin beds; a few beds show grading from fine-grained sandstone upwards to siltstone; sporadic ?*Planolites* occur within this unit.	13.15
6	–	No exposure	3.70
5	–	Quartzite, grey-white and grey, fine to medium-grained in thin and medium beds which sometimes combine to give thick beds. *Monocraterion* are abundant in the lower half of the unit and the bottom 6cm contains numerous mudstone clasts forming a mud-flake conglomerate which also contains abundant *Monocraterion*.	12.60
4	–	Sandstone, grey to dark grey and fine-grained in medium beds with sporadic *Monocraterion* in the top 15cm.	1.48
3	–	Quartzite, white to light grey with dark grey banding, fine to medium-grained and medium-bedded with sporadic burrows of *Monocraterion*.	3.05
2	–	Quartzite and sandstone, white and light green respectively; both are fine-grained in thin and medium beds with partings and thin beds of grey mudstone. Many of the arenaceous beds are load cast and some beds in the unit show slight boudinage.	13.05
1	–	Quartzite, light grey and fine to medium-grained in thin and very thin beds forming massive, thick sub-units. The quartzite beds have mudstone partings which are frequently disrupted and contorted by bioturbation and flame structures.	4.05
	–	Vale do Serrão Formation; unit 10, sandstone, light grey and fine-grained in thin and very thin beds with interbedded laminae of dark grey mudstone.	
	–	Total thickness of the Serra da Mendeira Formation	48.03

SERRA DA MENDEIRA FORMATION. Type section. FIG. 32

Dornes road (18914 31127 to 18910 31126)



LEGEND: FIG. 59

The upper part of the Vale do Serrão Formation is of probable lower Ludlow age. Microfossils (see appendix 2, sample S.2) identified by K. Dorning (Sheffield), from the overlying Serra do Luação Formation about 25m above the top of the Serra da Mendeira Formation, give a probable Leintwardinian or Whitcliffian age for that part of the sequence. This evidence therefore suggests that the Serra da Mendeira Formation is of Ludlow age and probably represents the Eltonian or Bringewoodian Stages.

v. Comparison of the type section with other sections and outcrops

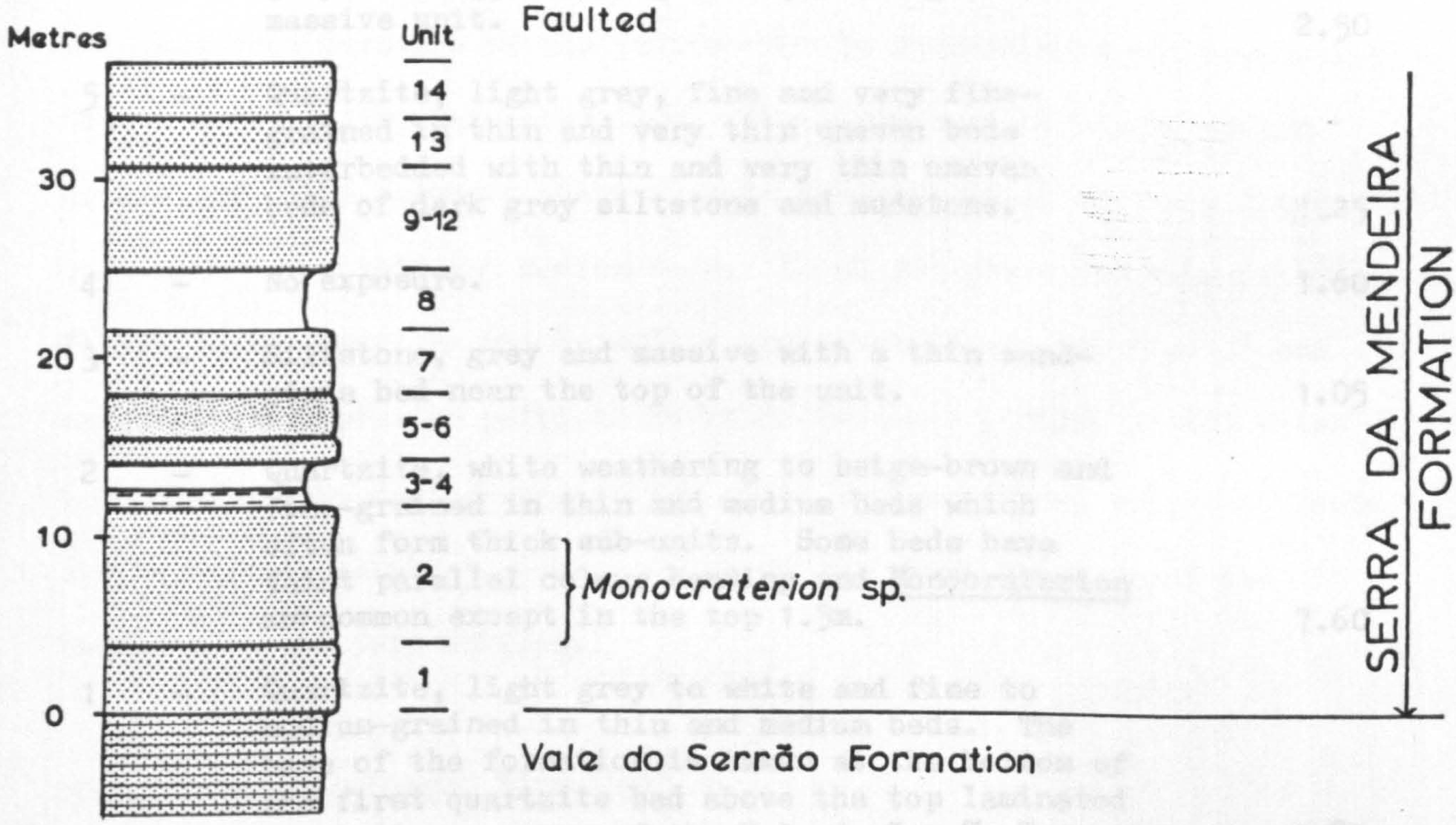
(a) Serra da Faisca (18874, 31035 to 18879, 31036) fig. 33

The Serra da Mendeira Formation is exposed along the ridge of Serra da Faisca about 1km south-south-west of the type section. The lowest 37.65m of the formation are exposed; the bottom beds show an interbedded transition from the Vale do Serrão Formation and the top of the sequence is faulted against the Dornes Formation. The sequence forms 14 lithological units described below from top to bottom and shown in figure 33:

			metres
	–	Thrust zone with contorted beds of quartzite and siltstone. The Dornes Formation is exposed to the east of these beds.	
14	–	Quartzite, grey and dark grey, fine-grained in thin to medium beds which are strongly contorted.	3.00
13	–	Quartzite, beige-white and medium-grained in very thick beds which show occasional parallel colour banding.	2.55
12	–	Quartzite, white, weathering to beige, very fine-grained in thin and medium beds which sometimes combine together into thick sub-units.	1.50
11	–	Quartzite, pink-white and fine-grained in thin to very thin beds with siltstone partings.	1.80

SERRA DA MENDEIRA FORMATION FIG. 33

Serra da Faisca (18874 31035 to 18879 31036)



LEGEND: FIG. 59

10	–	Quartzite, white weathering to beige and fine-grained; the unit forms two beds of which the upper one is thick and the lower one very thick.	1.45
9	–	Quartzite, white and fine-grained in very thin beds which are colour banded and have siltstone partings.	2.00
8	–	No exposure.	3.80
7	–	Quartzite, white and medium-grained in medium beds with dark grey, parallel and contorted banding which suggests that some of the beds have slumped.	3.60
6	–	Sandstone, dark grey with slight, very dark grey banding, medium-grained, forming a massive unit.	2.50
5	–	Quartzite, light grey, fine and very fine-grained in thin and very thin uneven beds interbedded with thin and very thin uneven beds of dark grey siltstone and mudstone.	1.25
4	–	No exposure.	1.60
3	–	Siltstone, grey and massive with a thin sandstone bed near the top of the unit.	1.05
2	–	Quartzite, white weathering to beige-brown and fine-grained in thin and medium beds which often form thick sub-units. Some beds have faint parallel colour banding and <u>Monocraterion</u> are common except in the top 1.5m.	7.60
1	–	Quartzite, light grey to white and fine to medium-grained in thin and medium beds. The base of the formation is taken at the bottom of the first quartzite bed above the top laminated quartzite sequence of the Vale do Serrão Formation.	3.85
	–	<u>Vale do Serrão Formation</u>; quartzite, white and fine-grained in laminated and thickly laminated beds with thin and medium beds of quartzite (as in unit 1 above) interbedded with the upper part of the sequence.	
	–	Total thickness of the Serra da Mendeira Formation exposed.	37.65

In overall character this sequence is very similar to that of the type section, but unit 2 of the type section is not developed. The upper units (numbers 3–13 of the Serra da Faisca section) are more varied than units 6 and 7 of the type section and contain thicker quartzite beds with more siltstone beds.

(b) Serra da Mendeira (18879, 31340)

The Serra da Mendeira Formation forms a resistant cap rock to the Serra da Mendeira and protects the Vale do Serrão Formation below. The lowest two-thirds of the Serra da Mendeira Formation is exposed and the bottom contact with the Vale do Serrão Formation is also exposed to the north-east of the serra. The bottom contact consists of a rapid interbedded transition from the laminated quartzites with mudstone partings of the Vale do Serrão Formation to the quartzites of the Serra da Mendeira Formation. The lower beds of the formation consist of white coloured quartzites in massive, thick and very thick beds with a few thin and medium beds. About 30m above the base of the formation the beds are mainly medium and thick (plate 10, fig. 3) and near the triangulation point on Serra da Mendeira (18870, 31340) these beds contain abundant Monocraterion and a horizon of mud pellets; these are both features which also occur about 20m above the base of the sequence at the type section.

10. Serra do Luação Formation

i. General character

The Serra do Luação Formation is an approximately 200m thick sequence of interbedded sandstones, siltstones and quartzites. The formation conformably overlies the quartzites of the Serra da Mendeira Formation and is conformably followed by the Dornes Formation. The Serra do Luação Formation ranges in age down from middle or upper Ludlow to Gedinnian or lower Siegenian.

ii. Topography and distribution

The formation contains a number of resistant arenaceous units which with the massive Serra da Mendeira Formation produce a steep rounded ridge which trends northwards from Serra do Luação (plate 10, fig. 1) through the Serra da Molhadinha to the south-west of Serra da Mendeira.

iii. Name

The formation is named after the Serra do Luação about 1km south-east of Dornes; the type section is situated on the north flank of this serra.

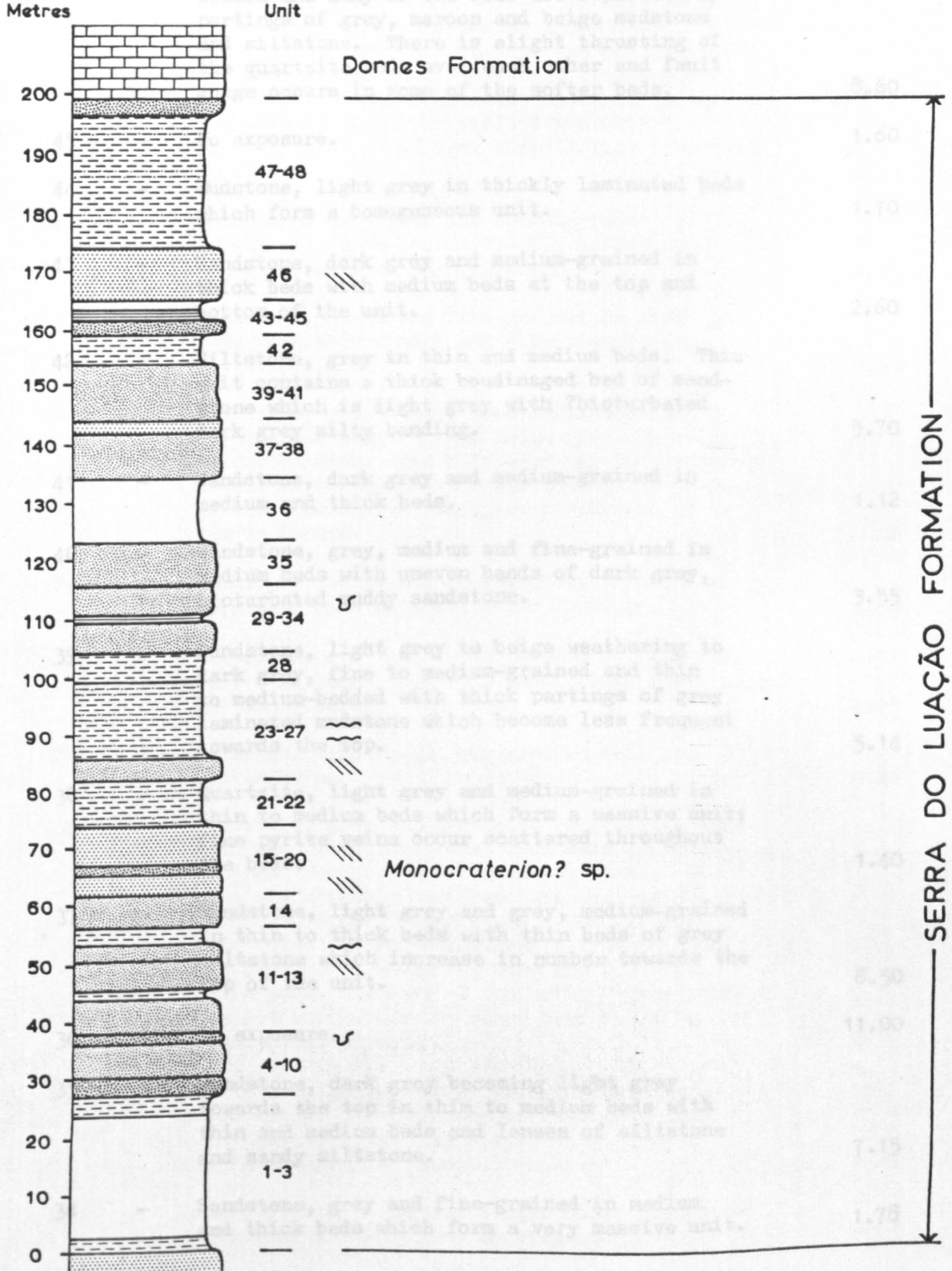
iv. Type section; Dornes road (18910, 31126 to 18885, 31104) fig. 34

The type section is well exposed along the road running east from Dornes and to the north of Serra do Luação (plate 10, fig. 1). The base of the formation is taken at the bottom of the first thick siltstone sequence above the Serra da Mendeira Formation and the top of the formation is taken at the base of the bottom limestone of the Dornes Formation. The intervening sequence is divided into 48 units which are listed below from top to bottom and which are shown in figure 34.

Unit		Description	metres
	–	Dornes Formation; limestone, dolomitic, grey and coarsely crystalline occurring as a massive unit composed of very thick beds.	
48	–	Sandstone, grey weathering to a rust colour, medium-grained and calcareous in thin and medium beds with thin beds of light grey siltstone.	1.80
47	–	Siltstone, grey in thin and very thin beds with occasional thin beds of sandstone. The unit is poorly exposed and yielded fragments of ?Leptostrophia sp. and an ?athyrid from about 15m above the base of the unit.	23.00

SERRA DO LUAÇÃO FORMATION. Type section. FIG. 34

Dornes road (18910 31126 to 18885 31104)



LEGEND: FIG. 59

46	-	Quartzite, grey and colour banded in shades of grey, fine-grained forming medium and thick beds which commonly combine to form thick sub-units. Some of the beds are planar cross-bedded and many of the beds are separated by partings of grey, maroon and beige mudstone and siltstone. There is slight thrusting of the quartzite beds over each other and fault gouge occurs in some of the softer beds.	8.60
45	-	No exposure.	1.60
44	-	Mudstone, light grey in thickly laminated beds which form a homogeneous unit.	1.70
43	-	Sandstone, dark grey and medium-grained in thick beds with medium beds at the top and bottom of the unit.	2.60
42	-	Siltstone, grey in thin and medium beds. This unit contains a thick boudinaged bed of sandstone which is light grey with ?bioturbated dark grey silty banding.	5.70
41	-	Sandstone, dark grey and medium-grained in medium and thick beds.	1.12
40	-	Sandstone, grey, medium and fine-grained in medium beds with uneven bands of dark grey, bioturbated muddy sandstone.	3.55
39	-	Sandstone, light grey to beige weathering to dark grey, fine to medium-grained and thin to medium-bedded with thick partings of grey laminated mudstone which become less frequent towards the top.	5.14
38	-	Quartzite, light grey and medium-grained in thin to medium beds which form a massive unit; fine pyrite veins occur scattered throughout the beds.	1.40
37	-	Sandstone, light grey and grey, medium-grained in thin to thick beds with thin beds of grey siltstone which increase in number towards the top of the unit.	8.50
36	-	No exposure.	11.00
35	-	Sandstone, dark grey becoming light grey towards the top in thin to medium beds with thin and medium beds and lenses of siltstone and sandy siltstone.	7.15
34	-	Sandstone, grey and fine-grained in medium and thick beds which form a very massive unit.	1.78

33	-	Sandstone and mudstone, beige-brown and dark grey respectively. The sandstone is fine-grained and both lithologies occur in medium and thin beds with the mudstone beds decreasing towards the top of the unit which is composed of medium-bedded sandstones. Many of the beds in this unit are bioturbated and the bottoms of the beds are frequently load cast. Sample S.9 collected from 3m above the base of this unit yielded microfossils (see appendix 2) of post Whitcliffian (Pridoli) age.	6.80
32	-	Sandstone, dark grey and medium-grained in medium and thick beds with thin siltstone and mudstone beds and partings.	1.30
31	-	Sandstone, beige and fine-grained in thin beds interbedded with and bioturbated with siltstone.	0.90
30	-	Quartzite, grey-beige, medium-grained and forming one massive very thick bed with slight colour banding. The bottom of the bed contains a band of irregularly shaped lenticular pellets of brown weathered ferruginous mudstone up to 3cm in length.	1.08
29	-	Sandstone, beige and fine-grained in thin and very thin beds with siltstone partings.	0.50
28	-	Siltstone, grey and colour banded in thin and very thin beds with occasional flame structures and small vertical burrows.	4.75
27	-	Sandstone, rust-brown coloured in thin and medium beds.	0.48
26	-	Siltstone, grey weathering to beige-brown and laminated with occasional thin beds of fine-grained, rust-brown coloured sandstone. The beds are slightly contorted and the resistant beds are slightly boudinaged. Two samples were collected for microfossils from this unit, S.4 from 5.10m above the base and S.8 from 3.10m above the base of the unit; these samples yielded acritarchs but there were no diagnostic forms (see appendix 2).	7.80
25	-	Siltstone, grey in thin laminae and laminae with occasional thin beds of dark grey fine-grained sandstone with ripple marked upper surfaces and fine cross lamination.	4.90
24	-	Fault breccia; angular fragments of laminated sandstone and dark grey mudstone.	0.60

23	-	Sandstone, light grey with dark grey streaks, fine and medium-grained in medium and thick beds with streaks of silty material depicting flame structures, cross bedding and vertical burrows.	3.46
22	-	Mudstone and siltstone grey-green and grey with occasional mica rich laminae and faint vertical burrows. Sample S.4 yielded acritarchs (see appendix 2), but there were no diagnostic forms.	3.55
	-	Fault; probably minor.	
21	-	Siltstone, grey weathering to brown-beige and very thinly bedded with occasional thin silty sandstone beds.	5.00
20	-	Quartzite, light grey and grey, medium-grained in medium and thick beds.	1.99
19	-	Sandstone, light grey weathering to dark grey, medium and fine-grained in thin and medium beds interbedded with very thin and laminated beds of mudstone and siltstone.	1.13
18	-	Sandstone, dark grey and medium-grained forming a thick massive unit showing faint cross-bedding.	0.60
17	-	Quartzite, beige and sandstone, dark grey, both fine-grained in thin and very thin uneven beds with partings and beds of dark grey siltstone. Numerous ?Monocraterion and horizontal burrows.	3.83
16	-	Sandstone, grey, beige and brown weathering to a rust colour, medium-grained and massive in colour banded thick beds. The top bed is faintly cross-bedded and ?Monocraterion burrows occur throughout the unit.	1.72
15	-	Quartzite, light grey and colour banded, interbedded with dark grey sandstone both occurring in medium and occasionally thin beds. Many of the sandstone beds are bioturbated and have inclusions of mudstone.	3.52
14	-	Sandstone, grey and dark grey in thin beds which occasionally form medium-bedded sub-units. The unit contains numerous partings and occasional thin beds of dark grey siltstone; siltstone pellets also occur in the lower parts of some beds.	5.70

13	–	Siltstone, grey and dark grey weathering to a beige colour. The siltstone occurs in thin beds with occasional very thin beds of sandstone; horizontal cylindrical burrows up to 1cm in diameter also occur within the unit. Sample S.3 from about 1m above the base of the unit yielded chitinozoa, acritarchs and miospores (see appendix 2), but there were no diagnostic forms.	2.75
12	–	Sandstone, light grey and grey, fine-grained in very thin uneven beds passing up into thin beds with a medium bed at the top.	3.03
11	–	Sandstone, dark grey and fine-grained in thin and very thin beds with occasional medium beds alternating with partings and thin beds of green-grey and grey-beige mudstone and siltstone. Bioturbation occurs mainly in the form of horizontal burrows up to 0.5cm across with no apparent pattern; the burrows move up and down within the sediment and the beds at the top of the unit are ripple marked and cross-bedded.	12.46
10	–	Sandstone, grey and medium-grained in a thick bed with a slightly load cast bottom surface.	0.44
9	–	Sandstone, beige-brown and fine-grained forming a medium bed.	0.20
8	–	Sandstone, dark grey, medium-grained and slightly colour banded; this unit has a slightly erosional load cast base with up to 15cm of beds at the top of unit 7 cut out.	1.05
7	–	Sandstone, grey-white and fine-grained in thin and very thin beds with very thin and thin beds of dark grey and green-grey mudstone which decrease in number upwards; many of the beds are bioturbated.	2.90
6	–	Sandstone, grey-white and fine-grained in thin and medium beds alternating with thin and very thin beds of bioturbated mudstone and siltstone. The sandstone beds weather to a dark grey colour in the surface layers.	2.80
5	–	Sandstone, dark grey and medium-grained forming a massive unit which occasionally splits into thin beds.	1.04
4	–	Sandstone, dark grey, fine and medium-grained, ferruginous with black mudstone pellets at the tops of some beds and in the lower parts of others. The bases of the beds with pellets are erosional and there are about 20 percent of mudstone and siltstone partings similar to those below.	2.30

3	-	Siltstone, grey and micaceous in thin and very thin beds with up to 40 percent of grey, fine-grained ferruginous sandstone in thin and very thin beds. Sample S.2 from about 1.20m above the base of the unit yielded chitinozoa, acritarchs and miospores (see appendix 2) of probable Leintwardinian or Whitcliffian age.	3.50
2	-	No exposure	21.65
1	-	Siltstone, grey weathering to brown and occurring in very thin and laminated beds.	2.00
	-	Serra da Mendeira Formation; quartzite, light grey; unit 7 of the formation type section.	
		Total thickness of the Serra do Luação Formation	199.32

The Serra do Luação Formation has proved only sparsely fossiliferous and very little of the collected material provided a definite age. Microfossil samples prepared and identified by K. Dorning (Sheffield) showed that sample S.2 from about 25m above the base of the formation contained an assemblage of chitinozoa, acritarchs and miospores (see appendix 2) of probable Leintwardinian or Whitcliffian age. Sample S.9 collected from about 110m above the base of the formation yielded a good assemblage of acritarchs and miospores considered by K. Dorning to be of probable post-Whitcliffian (Pridoli) age. This evidence with the lower or middle Ludlow age assigned to the underlying Serra da Mendeira Formation (see 9, iv) and the occurrence of Siegenian and Emsian macrofossils in the overlying Dornes Formation (see 11, iv) indicate that the Serra do Luação Formation probably ranges in age from middle or upper Ludlow to upper Gedinnian or lower Siegenian.

v. Comparison of the type section with other sections and outcrops

(a) Serra do Molhadinha (18899, 31143 to 18885, 31139) fig. 35

The Serra da Molhadinha section is situated on the south flank of the serra, on the north bank of the Rio Zêzere, parallel to and about

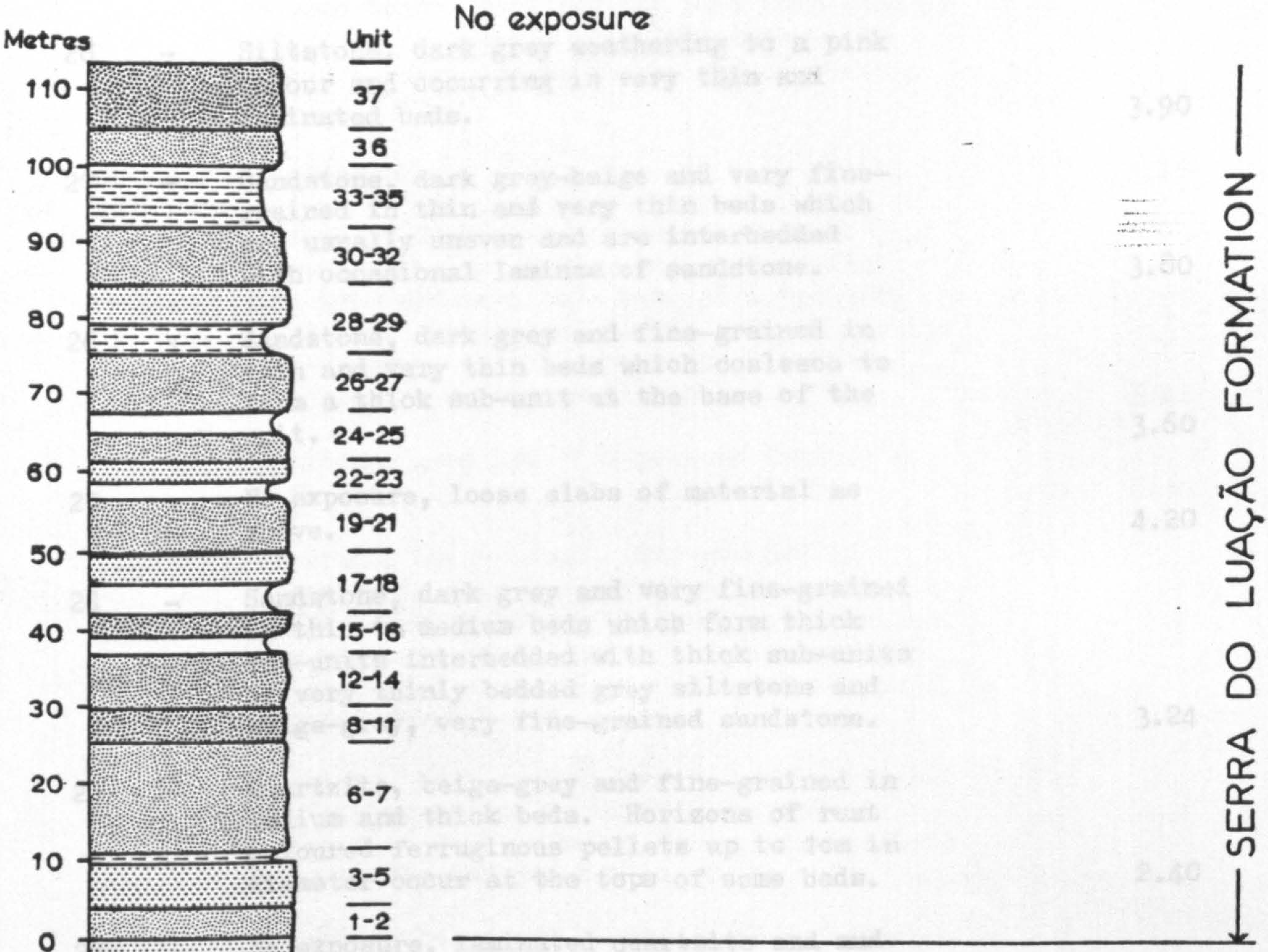
200m from the Dornes road section (10, iv). The sequence does not show the complete formation and the top contact is not exposed. The section does however show some variation in lithology and illustrates that some horizons are more persistant than others. The exposed sequence is 112m thick and may be divided into 37 units which are shown in figure 35 and which are listed below from top to bottom.

Unit		Description	metres
	–	No exposure	
37	–	Sandstone, dark grey and medium-grained in irregular and uneven beds of medium thickness. The sandstones often form massive sub-units.	8.60
36	–	Sandstone, brown-grey and very fine-grained in thin and very thin beds interbedded with thin and very thin beds of brown-grey siltstone. A few beds contain pellets of siltstone within the sandstone and there are occasional interbedded, laminated bands of siltstone and very fine-grained sandstone.	4.24
35	–	Siltstone and sandy siltstone, beige-grey and massive breaking into very thin and thinly laminated beds.	2.77
34	–	Siltstone, dark grey and laminated to very thin-bedded forming very thick sub-units interbedded with frequent very thin to medium beds of dark grey, medium-grained sandstone. The bottom part of the lowest sandstone bed contains rust coloured ferruginous pellets up to 2.5cm across.	4.75
33	–	Siltstone, brown to dark grey in very thin and irregularly laminated beds. Near the top of this unit there is one thin boudinaged bed of dark grey very fine-grained sandstone.	1.25
32	–	Sandstone, dark grey and fine-grained in thin beds. The bottom bed of this unit contains balls, up to 3cm across, of porcellanous dark grey siltstone which occur near the base of the bed.	0.48
31	–	Sandstone, dark grey and fine-grained in thin and very thin, uneven beds with laminated to very thin partings and beds of grey siltstone.	5.40

SERRA DO LUAÇÃO FORMATION

FIG. 35

Serra da Molhadinha (18899 31143 to 18885 31139)



LEGEND: FIG. 59

30	-	Sandstone, dark grey to grey and very fine-grained in thin and medium sub-units which split into very thin to laminated beds. The sandstone is interbedded with occasional medium sub-units of grey, micaceous siltstone in very thin and laminated beds.	1.62
29	-	Quartzite, light grey and vitreous, fine to medium-grained forming uneven thin and medium beds with thin laminar partings of mudstone. Sometimes the quartzite beds combine to form a very massive unit.	4.90
28	-	Siltstone, dark grey weathering to a pink colour and occurring in very thin and laminated beds.	3.90
27	-	Sandstone, dark grey-beige and very fine-grained in thin and very thin beds which are usually uneven and are interbedded with occasional laminae of sandstone.	3.80
26	-	Sandstone, dark grey and fine-grained in thin and very thin beds which coalesce to form a thick sub-unit at the base of the unit.	3.60
25	-	No exposure, loose slabs of material as above.	4.20
24	-	Sandstone, dark grey and very fine-grained in thin to medium beds which form thick sub-units interbedded with thick sub-units of very thinly bedded grey siltstone and beige-grey, very fine-grained sandstone.	3.24
23	-	Quartzite, beige-grey and fine-grained in medium and thick beds. Horizons of rust coloured ferruginous pellets up to 1cm in diameter occur at the tops of some beds.	2.40
22	-	No exposure, laminated quartzite and mudstone in the scree.	2.40
21	-	Sandstone, grey and grey beige, very fine-grained and often silty forming thin and very thin beds.	1.40
20	-	Sandstone, grey and medium-grained forming very thin to medium beds.	3.25
19	-	Sandstone, grey-green and medium-grained forming a massive very thick bed. This unit contains occasional small cubic pyrite crystals up to 1mm across.	1.60

18	-	Sandstone and quartzite, light grey, grey and beige, fine and medium-grained, often vitreous forming thin to medium beds which pass upwards into thick beds.	3.35
17	-	No exposure, massive sandstone? exposed below water.	3.60
16	-	Sandstone, grey and medium-grained occurring in thin and medium beds. The sandstone weathers to a dark grey colour in the surface layer and angular pellets of siltstone occur in some beds; partings and very thin beds of beige-grey siltstone are also common. A pellet horizon occurs at the top of the top bed.	3.38
15	-	No exposure.	1.20
14	-	Sandstone, dark grey and medium-grained forming thick and medium beds interbedded with thin and very thin beds of beige-grey siltstone. Occasional darker grey more silty pellets occur in the sandstone, but these are hard and do not weather out.	3.42
13	-	Sandstone, grey and fine-grained forming a thick bed.	0.40
12	-	Sandstone, beige-brown, fine-grained and micaceous in thin beds which pass up into thin and medium beds of beige-grey sandstone. Near the base of the unit there is one thin siltstone bed containing granule-sized rust coloured ferruginous pellets.	3.55
11	-	Sandstone, dark grey and grey, medium-grained and forming medium to thick beds. Pellet horizons of rust coloured ferruginous pellets occur at the top and bottom of the unit.	1.09
10	-	Sandstone, beige and medium-grained in thin and medium beds with occasional very thin beds of beige, fine-grained planar cross-bedded quartzite. Irregular silty horizons pick out balling in some beds caused by load casting.	1.50
9	-	Sandstone, dark grey and fine to medium-grained forming a massive unit which partially splits into medium and thick beds.	0.90
8	-	Sandstone, dark grey, fine-grained and slightly silty forming thin and medium beds which are sometimes uneven.	1.10

7	-	Sandstone, beige, fine-grained and silty in thin to laminated beds interbedded with laminae and thin beds of siltstone and occasional medium beds of siltstone.	13.50
6	-	Sandstone, dark grey to black and fine to medium-grained forming thick beds.	1.00
5	-	Siltstone, beige-grey and slightly micaceous forming laminated and very thin beds which coalesce to form a massive unit which weathers spheroidally.	1.30
4	-	Quartzite, dark grey-green and fine-grained; very thickly bedded.	1.88
3	-	Quartzite, dark grey and medium-grained forming thin beds with occasional laminae of beige fine-grained sandstone and dark grey siltstone.	4.20
2	-	Sandstône, beige-grey and very fine-grained forming thin and medium beds which pass upwards into thin and medium beds of quartzite with faint horizontal burrows in the upper beds.	3.05
1	-	Siltstone and sandstone grey and very fine-grained both occurring in laminated beds.	1.40
	-	Serra da Mendeira Formation; quartzite, beige-grey and fine-grained in thick beds which pass upwards into medium and thin beds. The quartzite beds are banded with dark grey silty material and contain faint furrows plus occasional pellets which were probably caused by bioturbation.	
	-	Total thickness of the Serra do Luação Formation exposed.	112.67

This section on the north bank of the Rio Zêzere may be correlated with the Serra do Luação Formation type section by means of two lithologically distinctive units. Unit 10 of the above section contains beds which are load cast and which probably correspond with unit 8 of the type section. Unit 34 above has a bottom sandstone bed which contains rust coloured ferruginous pellets; similar pellets also occur in unit 30 of the type section. The thickness of beds between the two units mentioned above at the type section is 69m and to the north at the Serra da Molhadinha section the thickness is 70m. This observation suggests that although two faults are recorded in the type section (between units 21 and 22, and unit 24) their effect on the thickness of the sequence is probably negligible.

11. Dornes formation (informal)

i. General character

The Dornes formation is composed of a sequence of limestones, sandstones and mudstones with nearly every intermediate lithology between the three end members. The formation is of restricted extent and is generally poorly exposed. No precise thickness is available because the formation is intensely faulted and without marker horizons with which to correlate, but it is probably at least 140m thick and probably no more than 200m thick. The formation has yielded brachiopods identified by Dr. V.G. Walmsley (Swansea) and considered to be of Siegenian and Emsian age.

ii. Topography and distribution

In general the lithological units of this formation are easily weathered and readily eroded. Where the formation is protected from severe erosion by the close proximity of the Serra do Luação Formation, in the south of the area it forms a coll, and to the north is eroded into a steep sided valley running along the western flank of the Serra do Luação. To the east of Dornes the formation is followed for nearly 1km by the Rio Zêzere which is deeply incised, but the valley is now flooded by the Barragem do Castelo do Bode hydro-electrictric scheme, so that only small parts of the formation are exposed between the high and low water marks. To the north of the Rio Zêzere near Dornes the Dornes formation is faulted and sandwiched between part of the Vale do

Serrão Formation and the Serra do Luação Formation; these formations protect it so that it forms high land which slopes steeply to the river. Outside of this 3km long strip around Dornes the formation has not been observed within the study area.

iii. Name

The Dornes formation is named after the village of Dornes in the south of the area and in whose environs the best exposures of the Dornes formation are situated. The name given to this formation is informal because the upper boundary-stratotype is not seen within the mapped area and consequently item 2.14,(d),(3) of the Stratigraphic Guide (International Subcommission on Stratigraphic Classification, 1972) requiring "Description of boundaries in detail; boundary stratotypes; reasons for choice; character of adjacent units; stratigraphic relations", cannot be adhered to. Because the Dornes formation is an informal stratigraphic unit items 1.8 and 5.10 of the above mentioned guide also rule and the initial letter of the word formation is written in lower case.

iv. Type section

No adequate type section is exposed for the complete Dornes formation, therefore ruling 2.4 on stratotypes (International Subcommission on Stratigraphic Classification, 1972) is followed which states "In the case of nearly horizontal or poorly exposed rocks, it may not be practicable to designate any one adequate unit-stratotype section, and instead the unit may be defined only be designated upper and lower boundary-stratotype sections and by such other outcrop sections as may occur in the type locality." In the vicinity of Dornes the lower boundary-stratotype and a faulted sequence about 160m thick are exposed, but this faulting prevents the exact character of the complete formation from being determined and the top contact of the formation is also faulted which prevents the upper boundary-stratotype from being defined.

(a) Lower boundary-stratotype, Dornes road (18995, 31105), fig. 34

The lower boundary-stratotype of the formation is moderately well exposed next to the sharp bend in the Dornes - Vale do Serrão road about 650m south-east of Dornes Church. The basal beds of the Dornes formation are exposed overlying the Serra do Luação Formation in the core of a syncline. Immediately to the west-south-west of the syncline the Dornes formation is faulted against beds of the Serra do Luação Formation which dip in the opposite direction. Only the lowest 5.2m of the Dornes formation is exposed; this and the lower boundary-stratotype are shown in figure 34 for the Serra do Luação Formation. The following sequence occurs:

		metres
-	No exposure	
-	Dornes formation; limestone, dolomitic and grey when fresh, the rock is coarsely crystalline, but it weathers to a rust-brown colour and becomes soft in the weathered zone. The limestone occurs in massive very thick beds with uneven stylolitic contacts.	5.2
-	Serra do Luação Formation; unit 43, sandstone, grey weathering to a rust colour, medium-grained and calcareous in thin and medium beds with thin beds of light grey siltstone.	

The sequence overlying the limestone is very poorly exposed and the valley where the Dornes formation crops out is heavily wooded, however, fossils collected at fossil locality 90 and those collected by Delgado (now in the collection of the Serviços Geológicos de Portugal museum) show that the Dornes formation extends south to the southern edge of the area. Dr. V.G. Walmsley (Swansea) kindly identified the specimens collected from fossil locality 90 which contained a ?bivalve and specimens of Plebejochonetes plebejus (Schnur); loose material from the same locality contained Chonetes sp. and probable Platyorthis circularis. These brachiopods have an age range from the Middle Siegenian to the Upper Emsian. This locality also yielded large ornamented ostracodes which are currently being identified.*

(b) North of the Rio Zêzere at Dornes (18843, 31195 to 18821, 31195), fig. 36

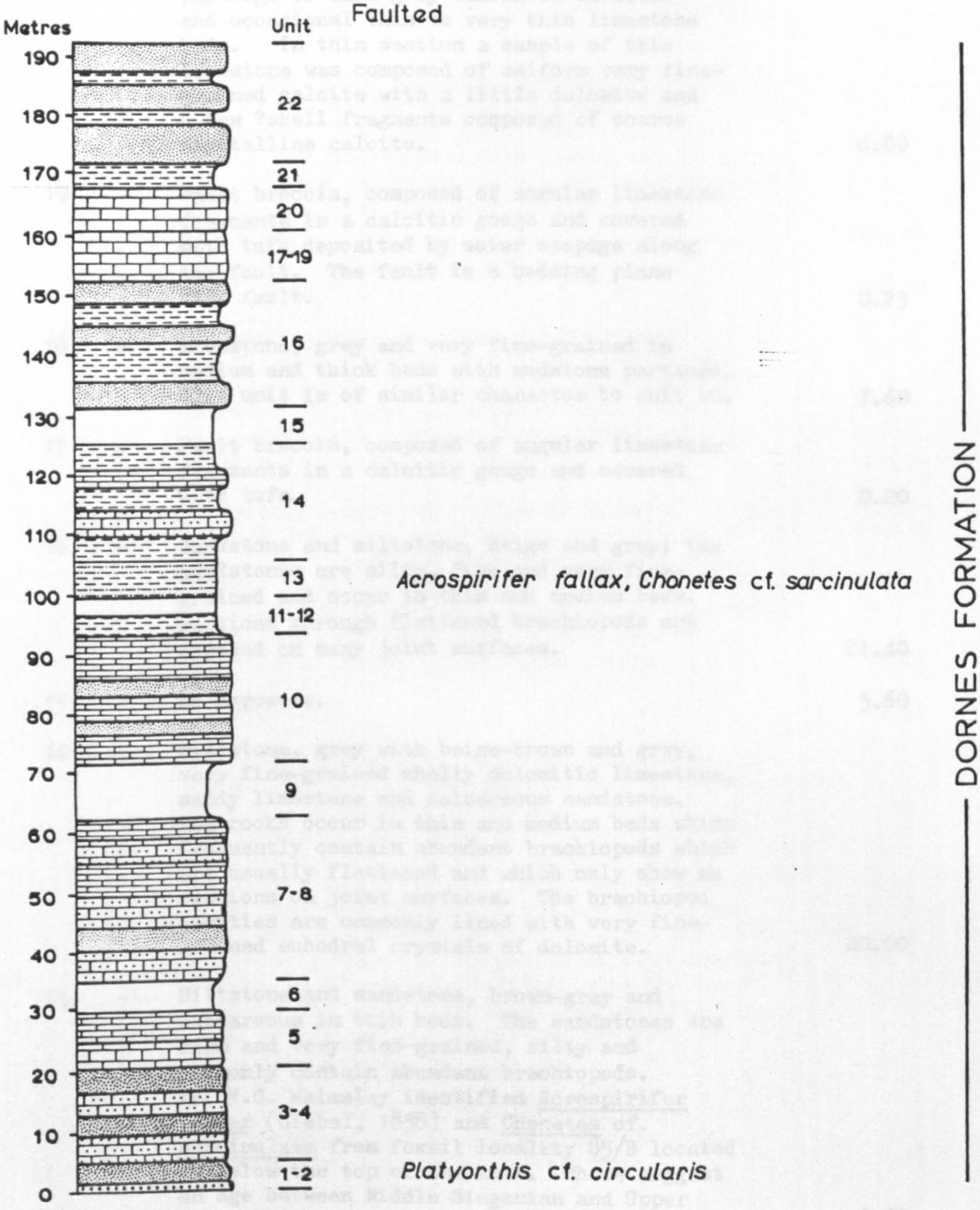
To the north of the Rio Zêzere at Dornes a section about 220m long and 195m thick is exposed through part of the Dornes formation. To the east of the section the beds are not exposed and to the west the Dornes formation is faulted against the Vale do Serrão Formation. This sequence in the Dornes formation is faulted by three approximately north-south trending faults, but because no marker horizons were found within the sequence it is difficult to ascertain which beds have been removed or repeated by the faulting. From west to east and top to bottom the sequence may be divided into 22 units described below and shown in figure 36.

			metres
	–	Vale do Serrão Formation; quartzite, white and very fine-grained in laminated beds with partings of grey mudstone.	
	–	Fault, not exposed, but inferred from the change in lithology and altitude of the strata.	
22	–	Sandstone, and siltstone, brownish grey and dark grey; the sandstones are fine-grained and both lithologies occur in thin and medium beds. Parts of the unit are poorly exposed.	20.00

* These identifications have not yet been received.

DORNES FORMATION FIG. 36

North of the Rio Zêzere at Dornes (18843 31195 to 18821 31195)



LEGEND: FIG. 59

21	-	No exposure	4.00
20	-	Limestone, slightly dolomitic, grey and very fine-grained in medium and thick beds with partings of dark grey laminated mudstone and occasional thin to very thin limestone beds. In thin section a sample of this limestone was composed of uniform very fine-grained calcite with a little dolomite and a few ?shell fragments composed of coarse crystalline calcite.	6.80
19	-	Fault breccia, composed of angular limestone fragments in a calcitic gouge and covered with tufa deposited by water seepage along the fault. The fault is a bedding plane slip fault.	0.25
18	-	Limestone, grey and very fine-grained in medium and thick beds with mudstone partings. This unit is of similar character to unit 20.	7.60
17	-	Fault breccia, composed of angular limestone fragments in a calcitic gouge and covered with tufa.	0.20
16	-	Sandstone and siltstone, beige and grey; the sandstones are silty, fine and very fine-grained and occur in thin and medium beds. Sections through flattened brachiopods are exposed on many joint surfaces.	21.40
15	-	No exposure.	5.60
14	-	Siltstone, grey with beige-brown and grey, very fine-grained shelly dolomitic limestone, sandy limestone and calcareous sandstone. The rocks occur in thin and medium beds which frequently contain abundant brachiopods which are usually flattened and which only show as sections on joint surfaces. The brachiopod cavities are commonly lined with very fine-grained euhedral crystals of dolomite.	20.00
13	-	Siltstone and sandstone, brown-grey and calcareous in thin beds. The sandstones are fine and very fine-grained, silty and commonly contain abundant brachiopods. Dr. V.G. Walmsley identified _Acrospirifer fallax_ (Giebel, 1858) and _Chonetes_ cf. _sarcinulata_ from fossil locality 85/B located 1m below the top of the unit. These suggest an age between Middle Siegenian and Upper Emsian.	6.00

12	-	Fault breccia and poorly exposed folded strata similar to unit 11.	2.30
11	-	Siltstone, grey and calcareous in laminated and very thin beds with a few beds of mudstone and limestone.	3.40
10	-	Limestone, beige and grey, coarsely crystalline and slightly dolomitic with sporadic shell fragments. The limestone occurs in thin to medium beds interbedded with medium and thin beds of grey and beige calcareous sandstone plus laminae and very thin beds of light grey mudstone.	21.80
9	-	No exposure.	9.40
8	-	Limestone, beige and grey, coarsely crystalline and slightly dolomitic interbedded with grey and beige sandy limestones and calcareous sandstones. All three lithologies occur in thin and medium beds commonly with laminae and very thin beds of light grey mudstone.	26.30
7	-	Limestone, beige-grey, slightly dolomitic, fine-grained and sandy occurring in very thin beds with impersistent and irregular laminae of mudstone. In thin section this rock contained about 25 percent of fine-grained, angular to subrounded quartz sand and 10 percent of silt grade clay minerals in streaks up to 0.5mm across.	1.20
6	-	No exposure	4.40
5	-	Limestone, beige-grey, fine and medium-grained, slightly dolomitic occurring in thin to medium beds with occasional thick beds. All the beds are uneven and many have stylolitic contacts. The bottom bed is unevenly laminated and is possibly a laminated algal mat. Three samples taken from this unit (from the top middle and base) and thin sectioned were all composed of irregularly shaped interlocking calcite crystals with up to 20 percent of dolomite in the lowest sample. The bottom bed which was possibly of algal mat origin was texturally the same as the other samples.	9.00
4	-	Sandstone, dark grey to black, medium-grained and calcareous in thin and medium beds with laminated and thin beds of siltstone.	1.36

3	–	Sandstone, light grey, medium-grained and calcareous with beds of sandy limestone. The two lithologies occur in medium and thick beds with partings of grey micaceous siltstone.	13.90
2	–	Sandstone, brown and medium-grained occurring in thin and medium beds which at fossil locality 86, 2.5m above the base of the unit, yielded <u>Platyorthis</u> cf. <u>circularis</u> identified by Dr. V.G. Walmsley and ranging in age from Siegenian to Emsian.	4.50
1	–	Quartzite, light grey to white, coarse-grained and massive.	1.10
	–	No exposure.	

The base of the Dornes formation occurs at a calculated position about 20m east of unit 1 described above. About 300m south at fossil locality 82 beds low in the Dornes formation are composed of laminated and very thinly bedded, slightly calcareous, very fine-grained sandstones with partings of grey calcareous mudstone. At this locality the beds are extensively borrowed and contain both vertical and horizontal cylindrical burrows up to 0.8cm in diameter.

(c) Dornes (18838, 31152 to 18833, 31156)

Between the Dornes church cemetery wall east to a few metres below the high water mark of the Rio Zêzere reservoir about 18m of strata belonging to the Dornes formation are exposed. Massive limestones are exposed just below the high water level (plate 11, fig. 2) and these are overlain by sandstones and quartzites. The short sequence exposed is:

		metres
–	No Exposure	
–	Quartzite, light grey and fine-grained in medium and thick beds.	3.50

–	Sandstone, white and fine-grained with streaks of dark grey mudstone. The sandstone occurs in medium and thick beds which are uneven and poorly exposed especially in the lower part of the unit.	About 3.00
–	Limestone, dolomitic, grey, crystalline and fine to medium-grained. The limestone occurs in thick and medium beds with partings, thin beds and one medium bed of light grey and grey laminated mudstone. The upper beds in this unit are poorly exposed.	8.00
–	Limestone, (plate 11, fig. 1) dolomitic, grey-beige and cream-beige, fine to medium-grained and massive in very thick beds with occasional thin laminae of mudstone which commonly occur between stylolitic contacts. A thin section taken from the top bed of the unit was composed of crystalline dolomitic limestone with about 70 percent of fossil fragments including ? bryozoa and pelmatozoan fragments. Two other sections taken from the middle and base of the unit were composed of homogeneous crystalline dolomitic limestone.	4.25
–	No exposure, water in reservoir.	

No fossils were collected from this sequence, but specimens of spiriferid brachiopods from "100m a N57°E da Igreja de Dornes" are in the collections of the Serviços Geologicos Museum Lisbon. These were collected from about 25m below the base of the sequence described above.

(d) South-west of Serra da Mendeira (18806, 31265)

At fossil locality 51 about 1km south-west of Serra da Mendeira the Dornes formation is composed of thinly bedded, brown, silty sandstones and siltstones which are underlain by medium and thick beds of grey fine-grained quartzites; about 15m west of fossil locality 51 the Dornes formation is faulted against laminated quartzites belonging to the Vale do Serrão Formation. Abundant brachiopods were collected at fossil locality 51 and these were identified by Dr. V.G. Walmsley as Acrospirifer fallax (Giebel 1858), Chonetes sarcinulata and

Chonetes cf. sarcinulata which suggests an Upper Siegenian to Lower Emsian age. In the same belt of rock, but about 400m further north beige-brown sandy siltstones at fossil locality 48 yielded a poorly preserved spiriferid and Chonetes sp. considered by Dr. Walmsley to be close to the forms collected at fossil locality 51.

The Devonian rocks of the Dornes area are also mentioned by Teixeira and Thadeu (1967) who record Chonetes plegejus Schnur and Chonetes sarcinulatum (Schloth) which are also recorded above in this current work. In addition they record "Spirifer" rouseau Roualt which is very similar to Acrospirifer fallax (Giebel 1858) also recorded above. Other species mentioned by Texeira and Thadeu (op. cit.) from the Devonian of Dornes are Leiopteria pseudolaevis (Oehl.) and the trilobite Asteropyge (Metacanthina) barrandei (Oehl.). They note that this fauna resembles those found at Sao Félix de Laundos and at Serra de Sao Mamede which have a "coblencian" age. House (1975, 250) equates the Coblencian as being equivalent with the Emsian, but Gignoux (1955) regards the Coblencian as being equivalent to the Siegenian and Emsian; either interpretation fits with the ages given by Dr. Walmsley for the material cited in this current work.

12. Triassic

i. General character

The Triassic rocks consist of a coarse clastic sequence of red beds which rest with a marked unconformity on the older sediments and metamorphic rocks of the Dornes area.

ii. Topography and distribution

The Triassic strata are restricted in extent to the western side of the area. Here they form a deeply dissected, westerly dipping escarpment. The soils on the escarpment are poor and in several places natural mixed woodland has escaped re-afforestation.

iii. Name

The small area of Triassic rocks mapped in the Dornes area is poorly exposed and only the bottom part of the sequence was recorded. Application of a formal stratigraphical name to the sequence is beyond the scope of this current work and the beds are therefore referred to the Triassic, as shown by Teixeira (1972) on the Carta Geológica de Portugal.

iv. Description

No type section or proper name has been designated for the sequence within the area because only a small tract was mapped. The Triassic rocks rest with a marked angular unconformity on gneiss, mica-schist, CXG and Lower Palaeozoic rocks. The basal beds consist of angular to sub-rounded polymict conglomerates which reflect the underlying bedrock. The surface of the unconformity is uneven and represents a varied topography with a relief of at least 50m. The combination of the present rugged topography superimposed over the burial landscape has resulted in several inliers of basement rocks and outliers of Triassic rocks being formed. The Triassic rocks are at least 100m thick and are mainly composed of coarse-grained red, brown and buff-coloured sandstones with similarly coloured conglomerates. The clasts in the conglomerates are composed mainly of sandstone and vein quartz with scattered polymict fragments. Mudstone and siltstone beds are also present in small amounts and these are dominantly red in colour. The most common sedimentary structures present are large infilled channels (plate 11, fig. 3) and cross-bedding.

The uneven nature of the unconformity and the red colouration of the mainly locally derived sediments suggest that deposition occurred in a terrestrial environment. The sedimentary structures indicate rapid erosion and active deposition in a high energy environment, and formation of these beds in a rapidly denuding landscape with flash floods is likely.

v. Age

No fossils were found in the red beds, but they are shown to be of Triassic age by Teixeira (1972).

III. STRUCTURE

1. Introduction

The Lower Palaeozoic sequence, which forms the main part of the mapped area, rests unconformably on the CXG (isoclinally folded pre-Ordovician greywackes and mudstones) which was openly folded prior to the Arenig. The Lower Palaeozoic sequence occurs as a broad, approximately NNW - SSE trending syncline, with Devonian strata in the middle and Ordovician strata along the flanks; within this syncline numerous major folds also occur. In the west of the area thrust faulting has produced klippen of metamorphic and Lower Palaeozoic rocks with associated tighter folding along the western flank of the syncline. The syncline is obliquely crossed by numerous wrench faults with lateral displacements of up to 1km. Normal faulting parallel to the axis of the syncline is also common and reverse faults, forming an imbricate structure associated with the thrusting, occur in the west of the area. Two granite bodies are present intruded into the eastern limb of the syncline. Gently dipping Triassic conglomerates and sandstones rest unconformably on the folded and faulted sequences in the west of the area and suggest a Hercynian age for the main tectonic episode.

The sequence of structural events is summarised overleaf.

Minor movements on pre-existing faults and gentle folding

Triassic conglomerate and sandstone deposition

Unconformity, Carboniferous - Permian missing

Movements along previously established wrench, normal and reverse faults

Granite intrusion

Normal faulting

Conjugate faulting

Thrust and reverse faulting

Wrench faulting

Folding

Ordovician, Silurian and Devonian deposition

Unconformity, late Cambrian to early Ordovician missing

Folding

CXG, greywacke and mudstone deposition

In the following descriptions the terminology applied to the folded strata is that of Fleuty (1964).

2. Pre-Ordovician structure

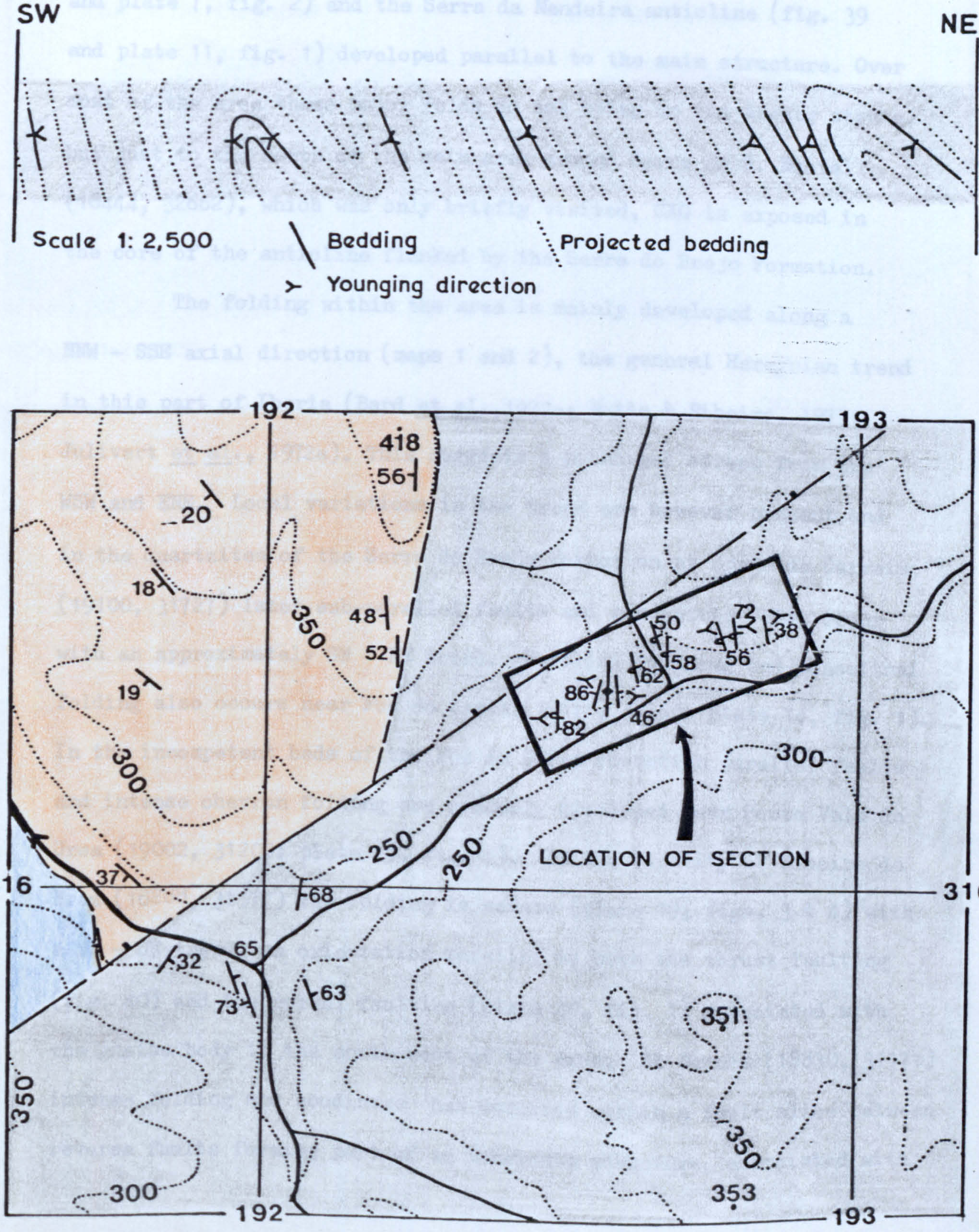
Several outcrops close to the unconformity between the Serra do Brejo Formation and the CXG show that beds in the CXG dip more steeply than the adjacent quartzites. In areas away from fault zones the strike of both sequences is however similar. Unfortunately, the actual surface of the unconformity is not exposed within the main mapped area, but to the north at Serra de S. João (plate 4, fig. 1; 18403, 33497) steeply dipping CXG was observed passing beneath massive quartzites of the Serra do Brejo Formation.

Well exposed sections in the CXG at Olival Grande (19270, 31642), Casal Madalena (19250, 31427) and Santa Maria Madalena (19175, 31475) show that in numerous places the CXG is overturned. In the 400m long section at Olival Grande (19270, 31642; fig. 37) over one-half of the beds are inverted, but Ordovician strata exposed 1km to the west is generally the right way up. It is therefore reasonable to conclude that the CXG was at least openly folded in pre-Ordovician times. The combination of pre-Ordovician and Hercynian folding results in isoclinal structures. The near vertically dipping and commonly overturned attitudes of the beds along with the younging information (plate 1, figs. 1 and 2) typifies isoclinal folding. Associated with the isoclinal folding considerable shearing has occurred within the axial regions of the folds so that very few fold culminations were observed. No re-folded folds were observed, except locally in the vicinity of major faults. The parallelism between the intensely folded CXG and the more openly folded Lower Palaeozoic sequences suggests that the pre-Ordovician structures were probably sub-parallel to the later Hercynian structures, but were considerably tightened during the Hercynian orogeny.

Only one cleavage was observed in the folded CXG and it was approximately axial planar, although slight fanning was observed in many places. On the steep limbs of the isoclinal folds the cleavage and bedding are in most instances almost parallel. These folding and cleavage relationships suggest that the Hercynian movements tightened pre-existing folds rather than refolded them and that the cleavage was developed during this later folding.

CXG STRUCTURE AT OLIVAL GRANDE; FIG. 37

Possible reconstruction of folding



Scale 1: 10,000

LEGEND: FIG. 60

3. Hercynian structure

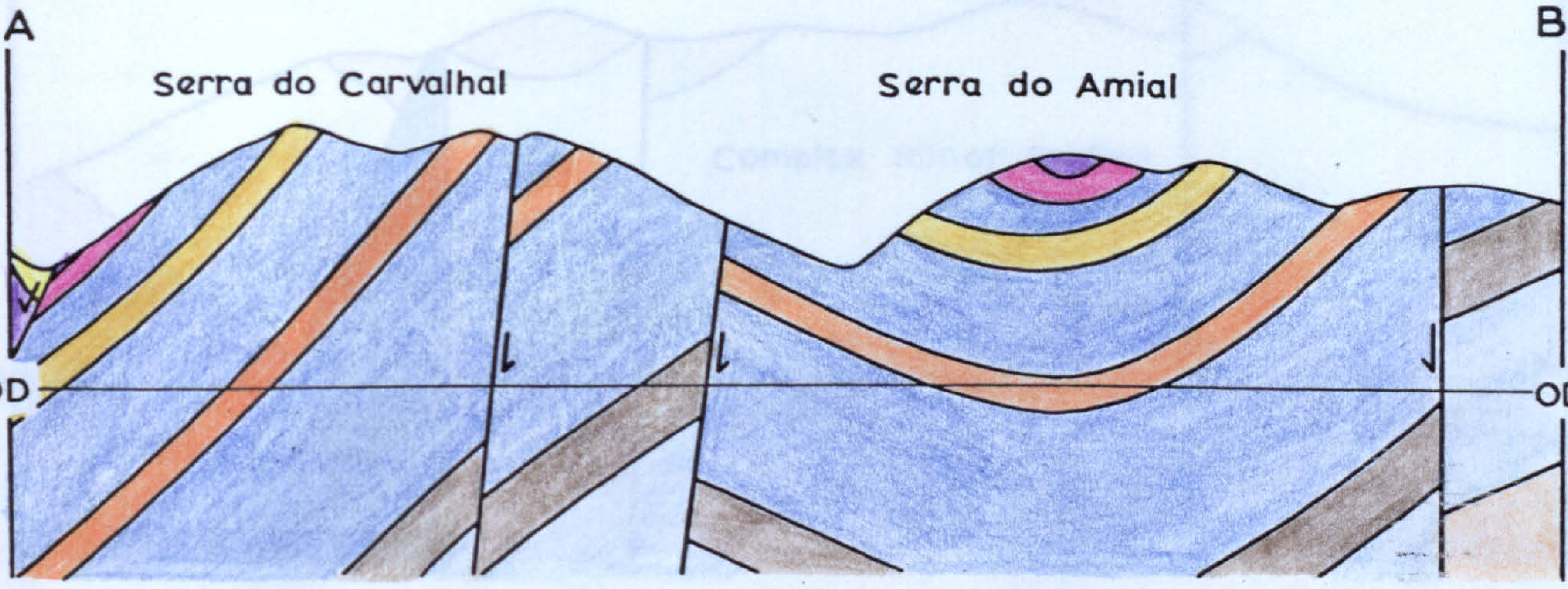
i. Folding

The Lower Palaeozoic rocks occur as a broad syncline with numerous major folds, such as the Serra do Amial syncline (fig. 38 and plate 7, fig. 2) and the Serra da Mendeira anticline (fig. 39 and plate 11, fig. 1) developed parallel to the main structure. Over most of the area these major folds do not bring up the Arenig strata, but just to the north of the main area around Serra de S. Nuetel (18444, 32662), which was only briefly visited, CXG is exposed in the core of the anticline flanked by the Serra do Brejo Formation.

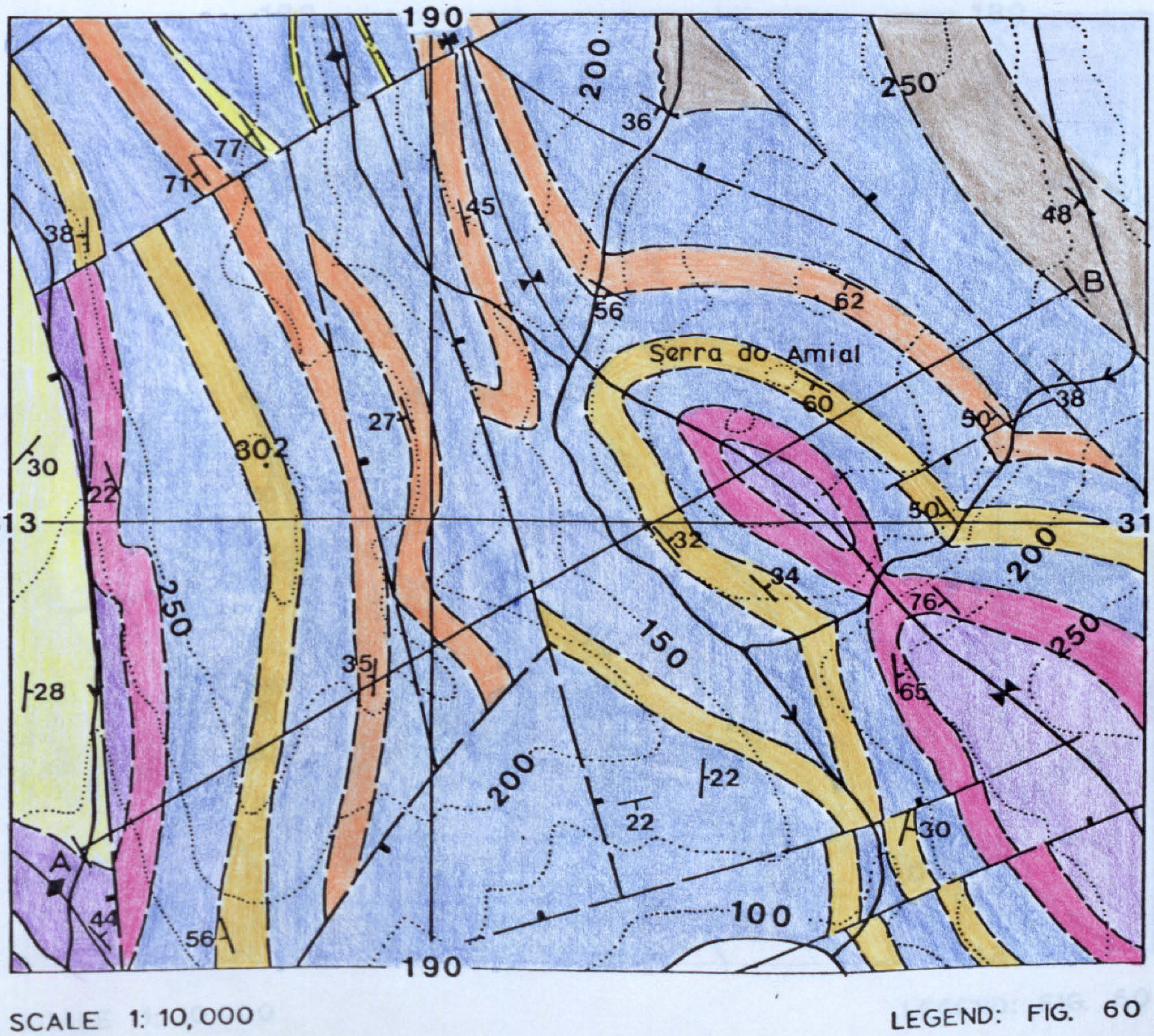
The folding within the area is mainly developed along a NNW – SSE axial direction (maps 1 and 2), the general Hercynian trend in this part of Iberia (Bard et al.,1972a; Matte & Ribeiro, 1975; Julivert et al., 1972a). This suggests a principal stress from the WSW and ENE. Local variations in the trend are however present and in the quartzites of the Serra do Brejo Formation at Brejo da Correia (19100, 31727) later sub-parallel faults and concentric folds occur with an approximately SW – NE trend. Parallel faulting and monoclinal folding also occurs near Foz da Serta (19171, 31160; plate 14, fig. 1). In the incompetent beds of the Foz da Serta Formation parallel faults and intense chevron folding are commonly developed near Ponte Vale da Ursa (19002, 31200; plate 19, fig. 1). In the vicinity of Ribeira do Braz (18288, 31577) the folding is severe (plate 19, figs. 3 & 4) with a NW – SE trend, an orientation parallel to both the thrust faulting (fig. 40) and the normal faulting (plate 20, fig. 1) associated with the gneiss body in the south-west of the area. At Dornes (18830, 31171) intense folding and boudinage has occurred within a fault slice between reverse faults forming part of an imbricate structure, associated with

STRUCTURE OF SERRA DO CARVALHAL & SERRA DO AMIAL

FIG. 38



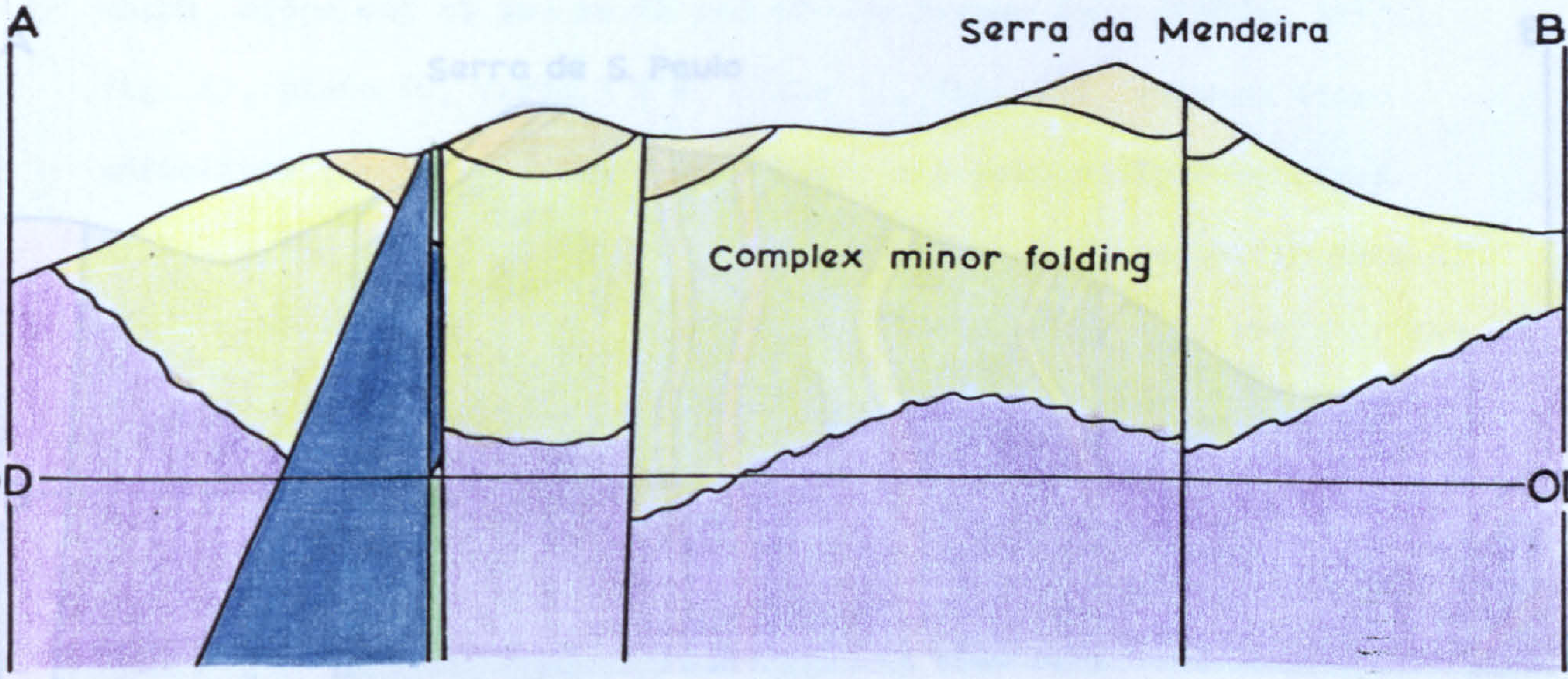
SCALE 1: 10,000



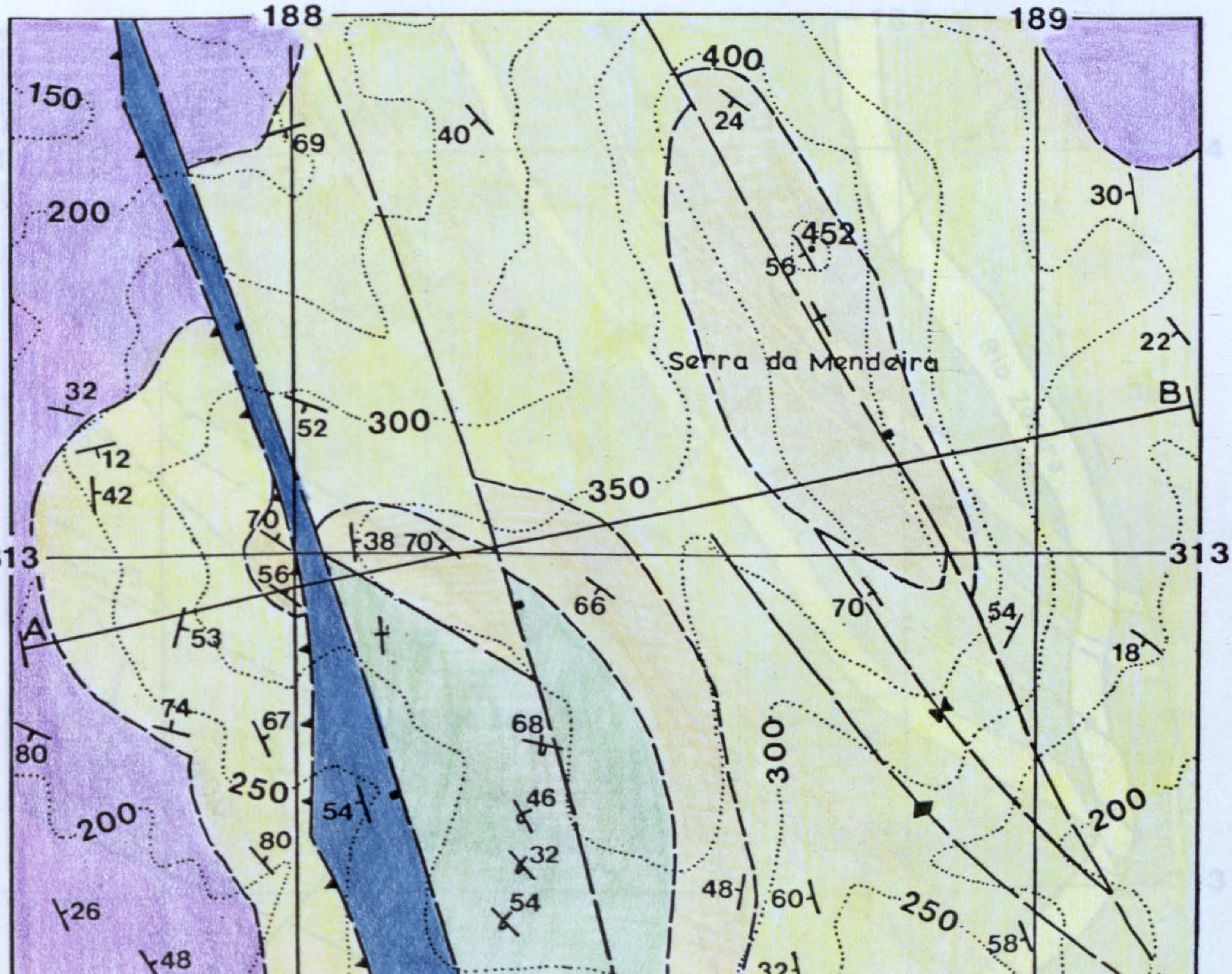
SCALE 1: 10,000

LEGEND: FIG. 60

STRUCTURE OF SERRA DA MENDEIRA FIG. 39



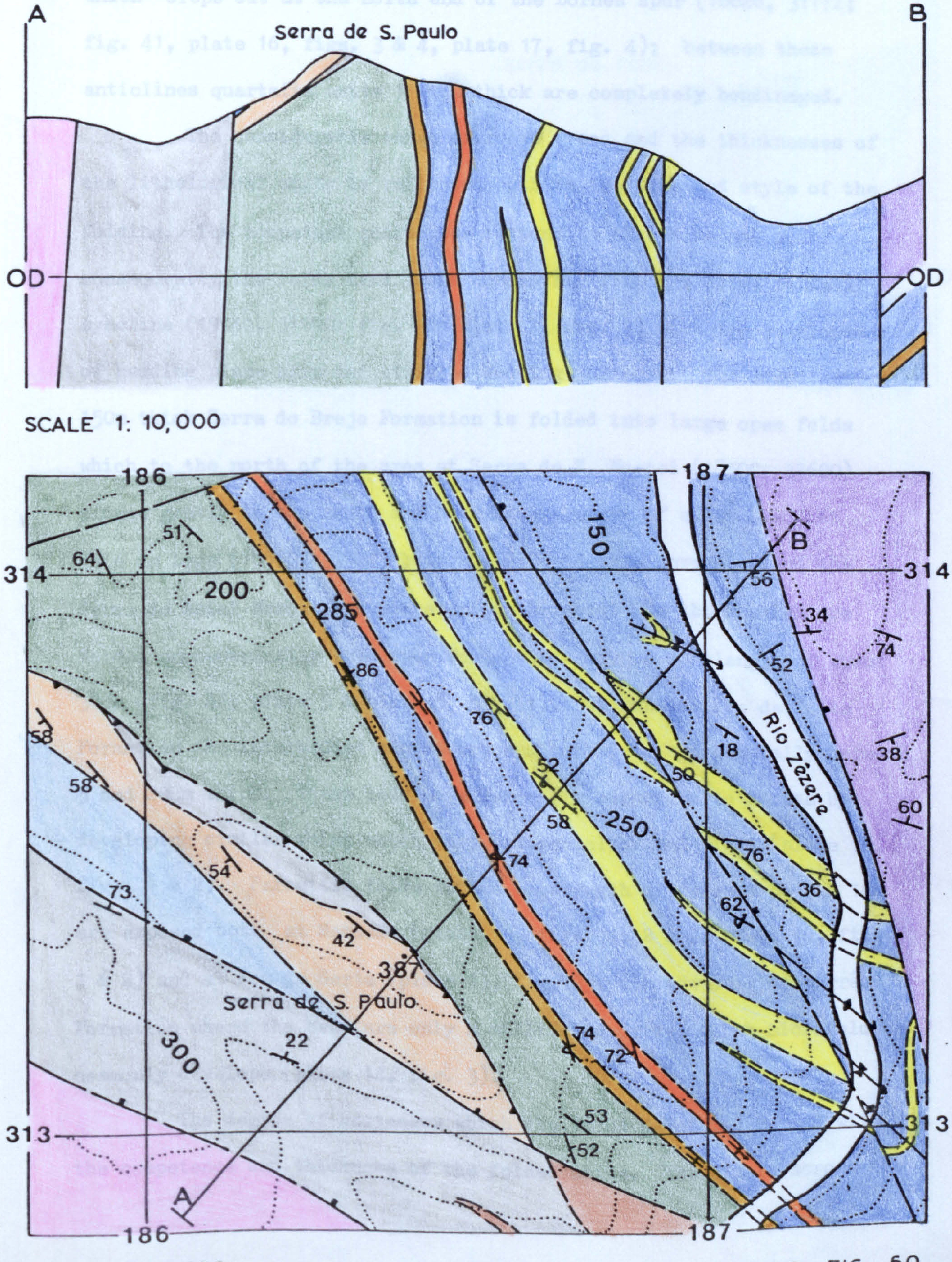
SCALE 1: 10,000



SCALE 1: 10,000

LEGEND: FIG. 60

STRUCTURE OF SERRA DE S. PAULO FIG. 40



SCALE 1: 10,000 LEGEND: FIG. 60

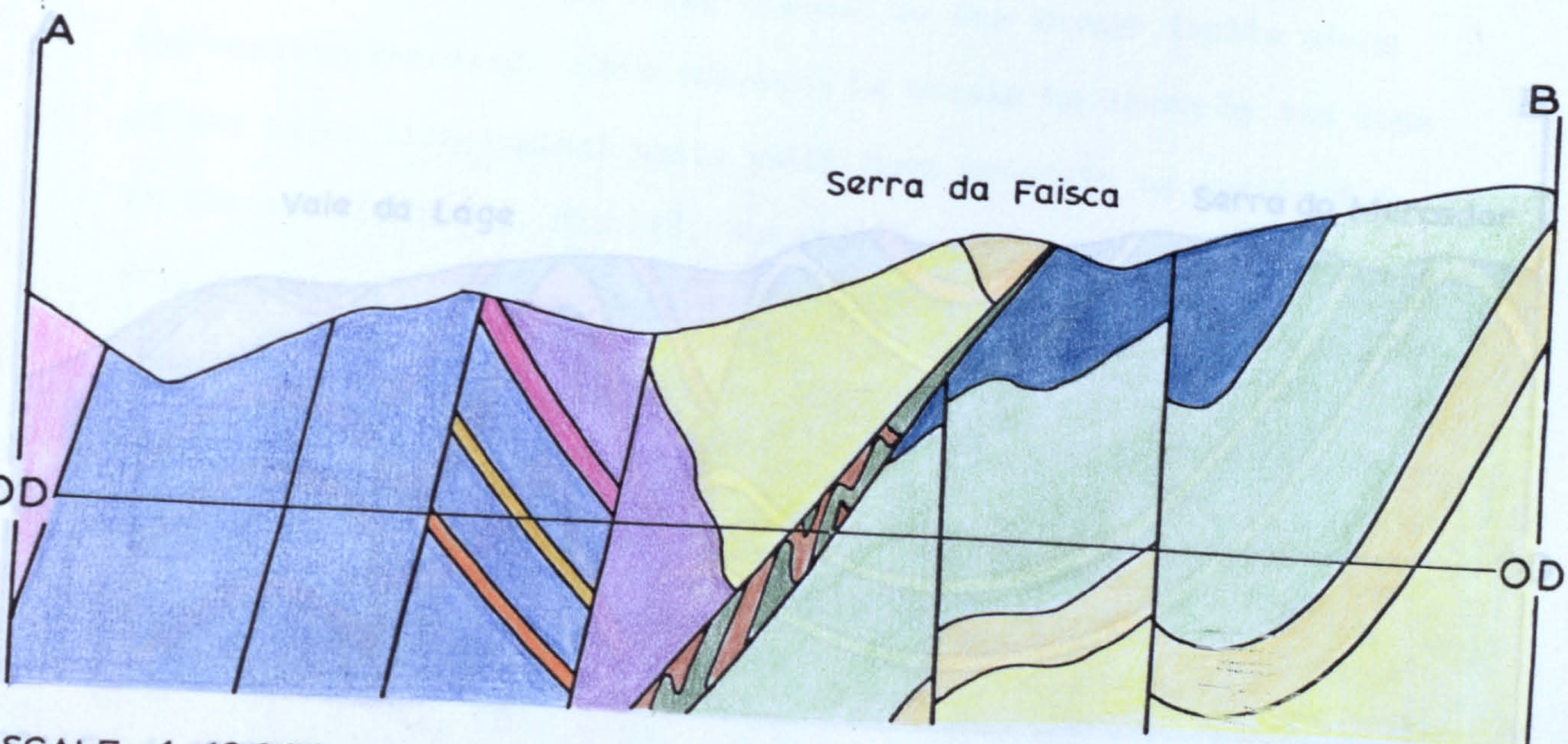
the thrust faulting in the west of the area. Within the fault slice two tight anticlines are exposed including the main Dornes anticline which crops out at the north end of the Dornes spur (18828, 31172; fig. 41, plate 16, figs. 3 & 4, plate 17, fig. 4); between these anticlines quartzite units 1 - 4m thick are completely boudinaged.

The considerable range of rocks types and the thicknesses of the lithological units is reflected both in the size and style of the folding. The competent quartzites respond to stress as one unit, consequently, the folds tend to be concentric like the Serra do Amial syncline (19062, 31290; fig. 38; plate 7, fig. 2) with the development of bedding plane slip and striated bedding surfaces. The competent 150m thick Serra do Brejo Formation is folded into large open folds which to the north of the area at Serra de S. Nuetel (18500, 32600) plunge gently to the south and have a wavelength of about 2km. At Vale da Lage (18660, 31584) both the Vale da Ursa Formation and the Serra do Amial Member are competent units about 20m thick which are folded concentrically into open folds which have a wavelength of about 300m (fig. 42; plate 5 & plate 8, fig. 1). Within the Foz da Serta Formation the interbedded sandstones and mudstones are generally between 5 and 20cm thick. These beds have generally responded to stress by developing similar folds which vary between close and tight (plate 16, figs. 1 & 2). Parasitic folds with a wavelength of between 3m and 10m are exposed both at Sambado (plate 15, figs. 1, 2 & 3; plate 16, figs. 1 & 2) and at Foz da Serta (plate 13, fig. 3). In the Vale do Serrão Formation where the beds are only a millimetre or two thick microfolding commonly develops (plate 14, fig. 3).

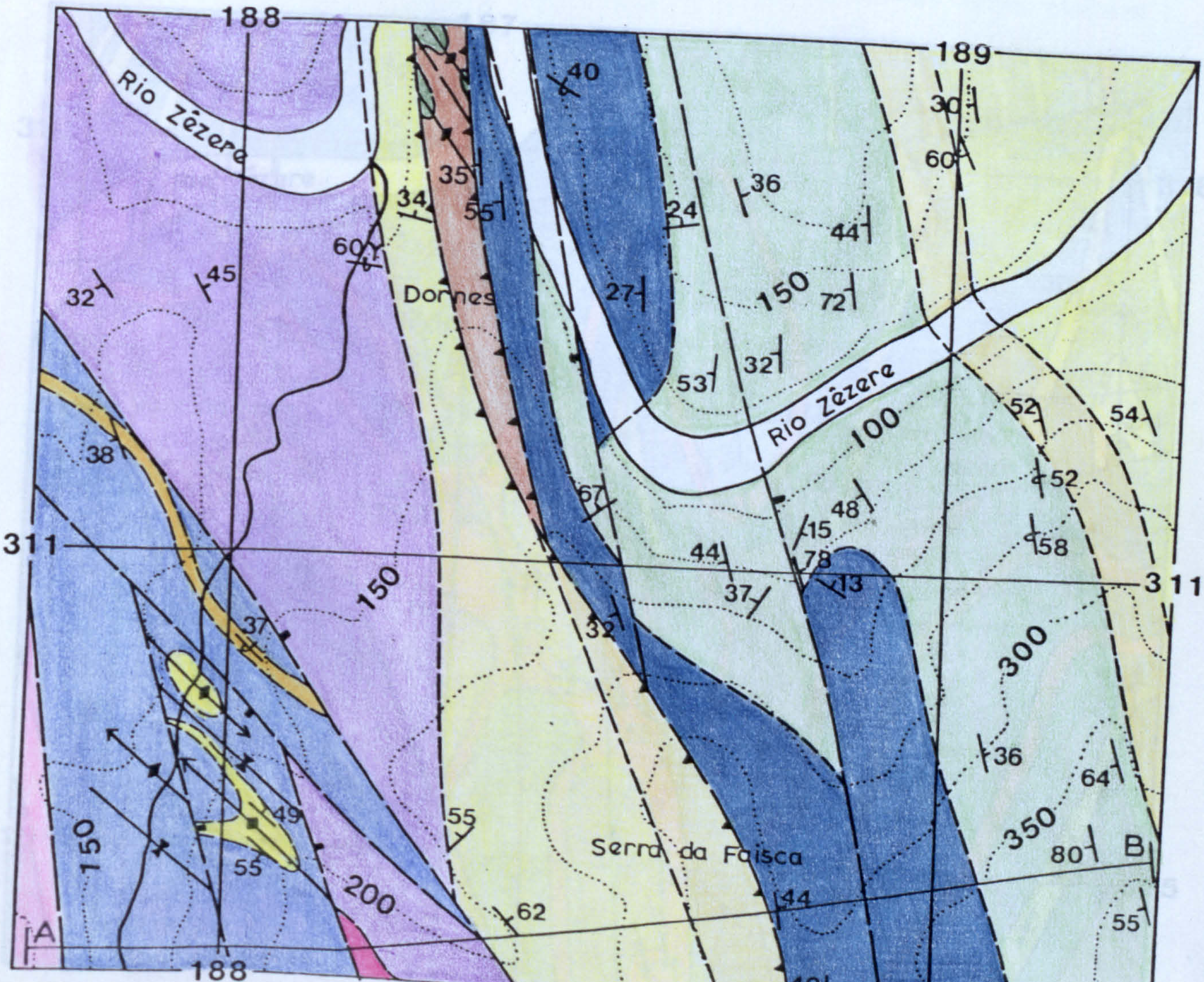
The degree of acuteness which the folds developed varies with the competence and thickness of the folded units. The strain across the

STRUCTURE OF SERRA DA FAISCA AND THE DORNES AREA

FIG. 41



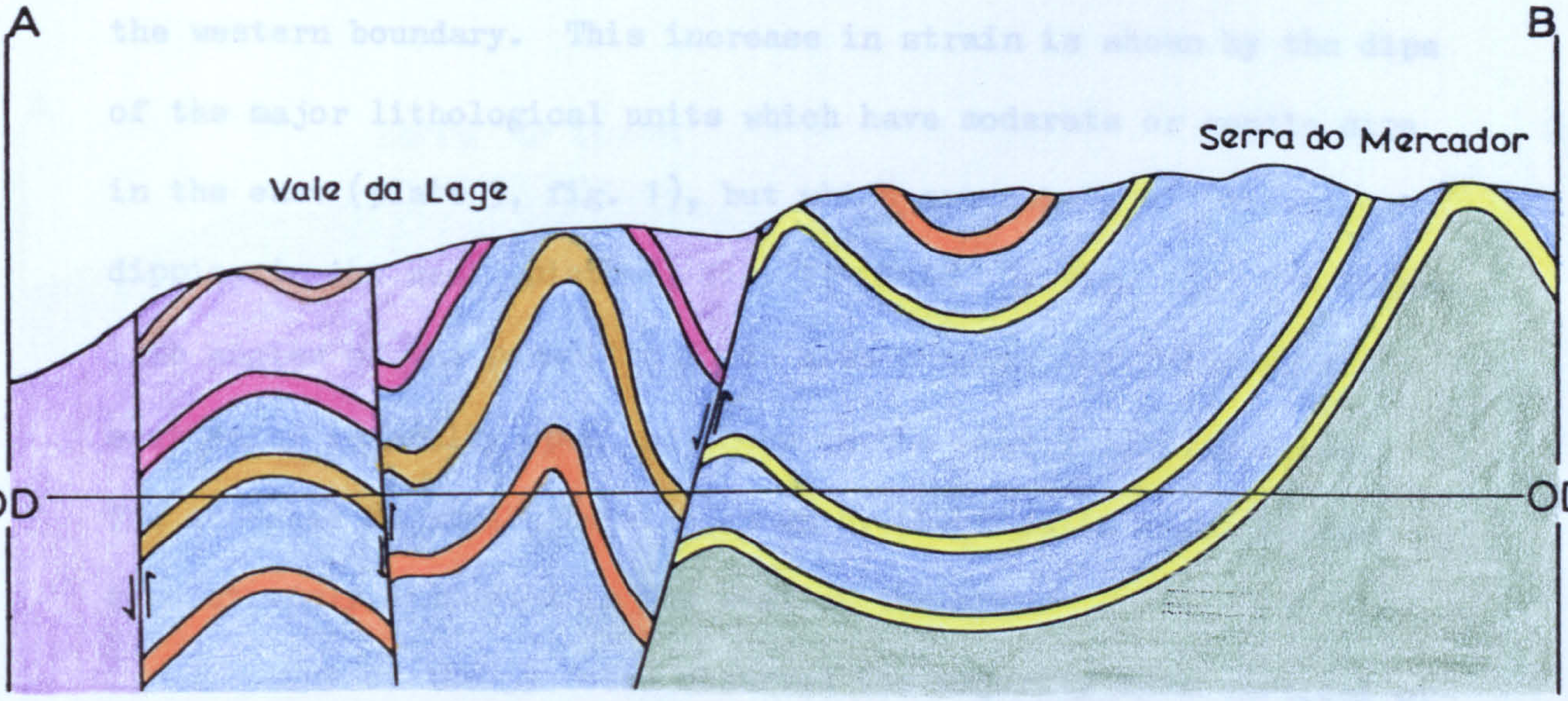
SCALE 1: 10,000



SCALE 1: 10,000

LEGEND: FIG. 60

STRUCTURE OF VALE DA LAGE AND SERRA DO MERCADOR — FIG. 42



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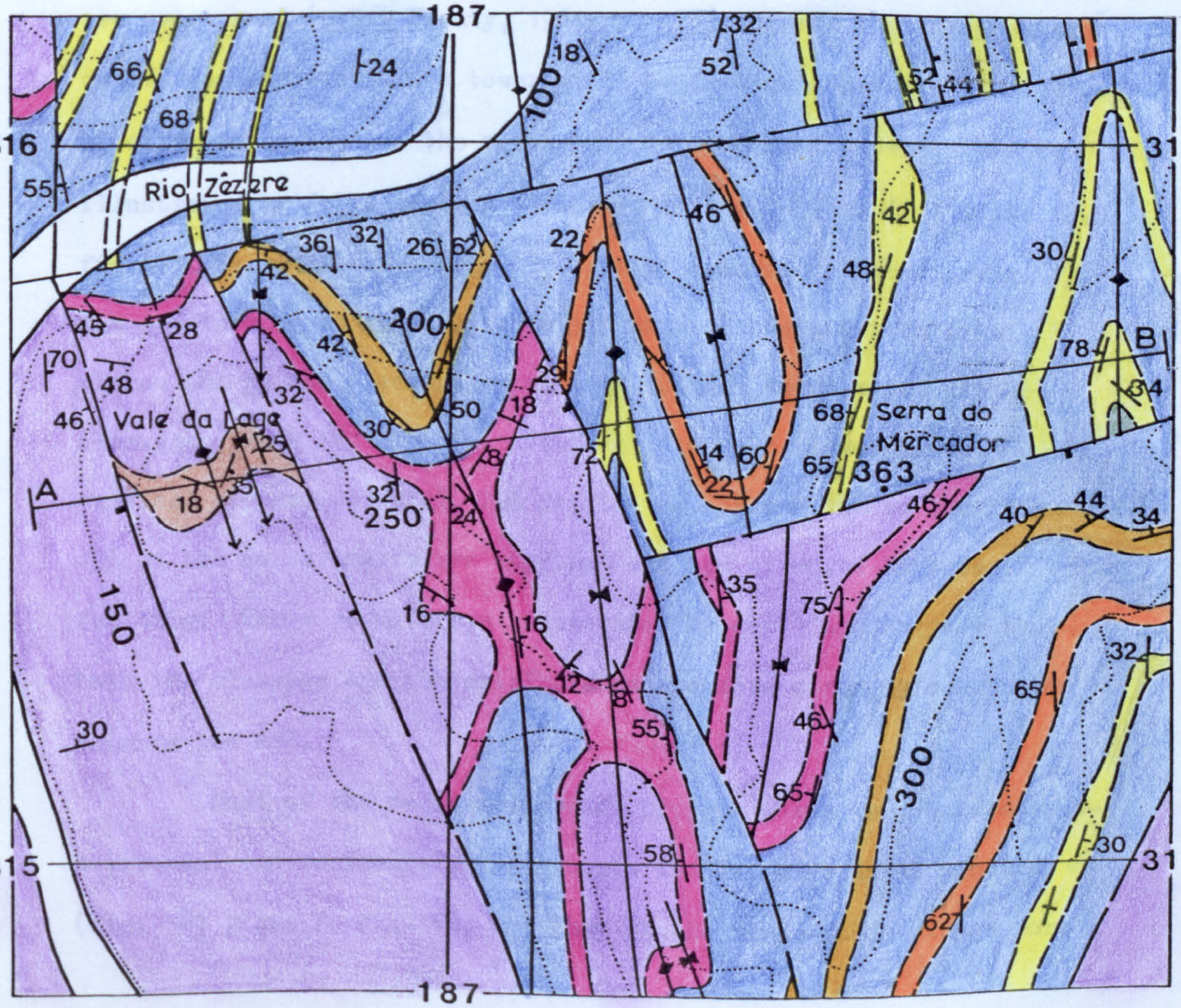


SCALE 1: 10,000

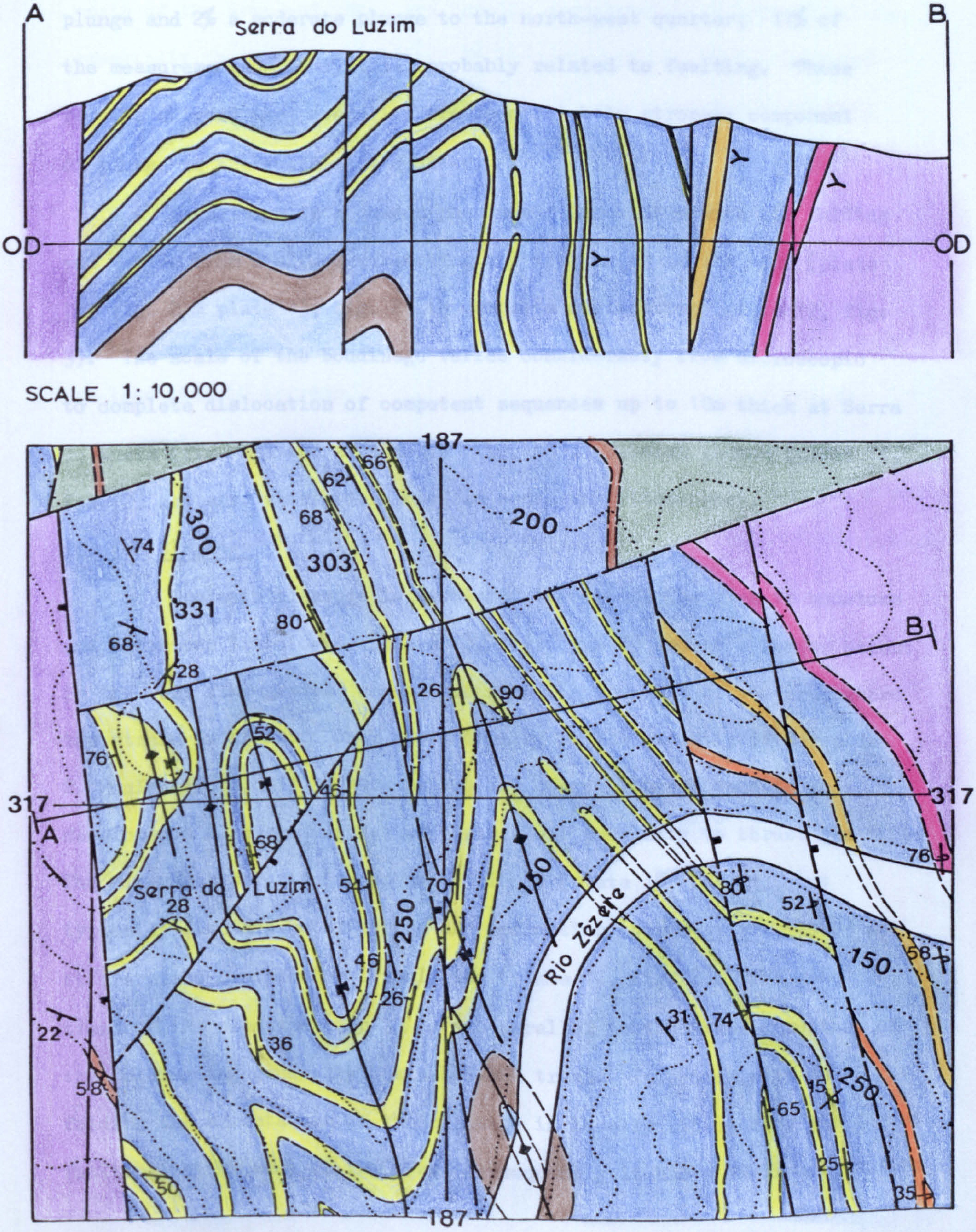
LEGEND: FIG. 60

area however is not homogeneous and increases from east to west becoming greatest in the areas closest to the thrust faults along the western boundary. This increase in strain is shown by the dips of the major lithological units which have moderate or gentle dips in the east (plate 5, fig. 1), but which are nearly all steeply dipping in the west (plate 7, fig. 1; plate 10, fig. 1). The inter-limb angles of the parasitic folds also change, the folds in the east being generally open and those in the west generally close. The increase in strain is also shown by the fossils which become more strongly distorted in the west of the area.

Out of the 59 folds observed the majority have vertical or upright axial planes, but where they are inclined almost equal numbers are overturned (sensu Fleuty, 1964, p. 476) towards the north-east quarter as are overturned towards the south-west quarter; the degree of overturning towards the north-east is however greater. This is illustrated by folds seen on the Serra do Luzim (fig. 43 & plate 12, fig. 1), Serra da Prata (fig. 44) and at Sambado (plate 15, fig. 1). The overturning is shown by both the dips of the observed axial planes and by the cleavage which approximates to an axial planar cleavage (plate 18, fig. 1). From 239 cleavage measurements 36% are vertical or near vertical, 29% dip to the WSW and 16% to the ENE; 19% of the measurements are atypical and are affected by later faulting. These results are illustrated by map 3 and suggest that both the cleavage and the axial planes are more strongly overturned towards the ENE.

Most of the major folds have plunges which vary between sub-horizontal and horizontal, for example the Serra do Amial syncline (fig. 38; plate 7, fig. 2), but many of the minor folds plunge more

STRUCTURE OF SERRA DO LUZIM FIG. 43



SCALE 1: 10,000 LEGEND: FIG. 60

steeply. Observations of these minor folds (map 2) show that 20% are horizontal or sub-horizontal; 27% have a gentle plunge and 16% a moderate plunge to the south-east quarter, while 24% have a gentle plunge and 2% a moderate plunge to the north-west quarter; 11% of the measurements are atypical, probably related to faulting. These results suggest that overall there is a slightly stronger component of plunge to the south-east quarter.

Boundinage is a common phenomenon associated with the folding and varies from a slight stretching and fracturing of the beds (plate 12, fig. 2 & plate 13, fig. 2) to complete dislocation (plate 12, fig. 3). The scale of the boudinage varies considerably from microscopic to complete dislocation of competent sequences up to 10m thick at Serra do Luzim (fig. 43) and at Almegue (fig. 45). Tension gashes (plate 14, fig. 2) are also widely developed in sandstone lithologies.

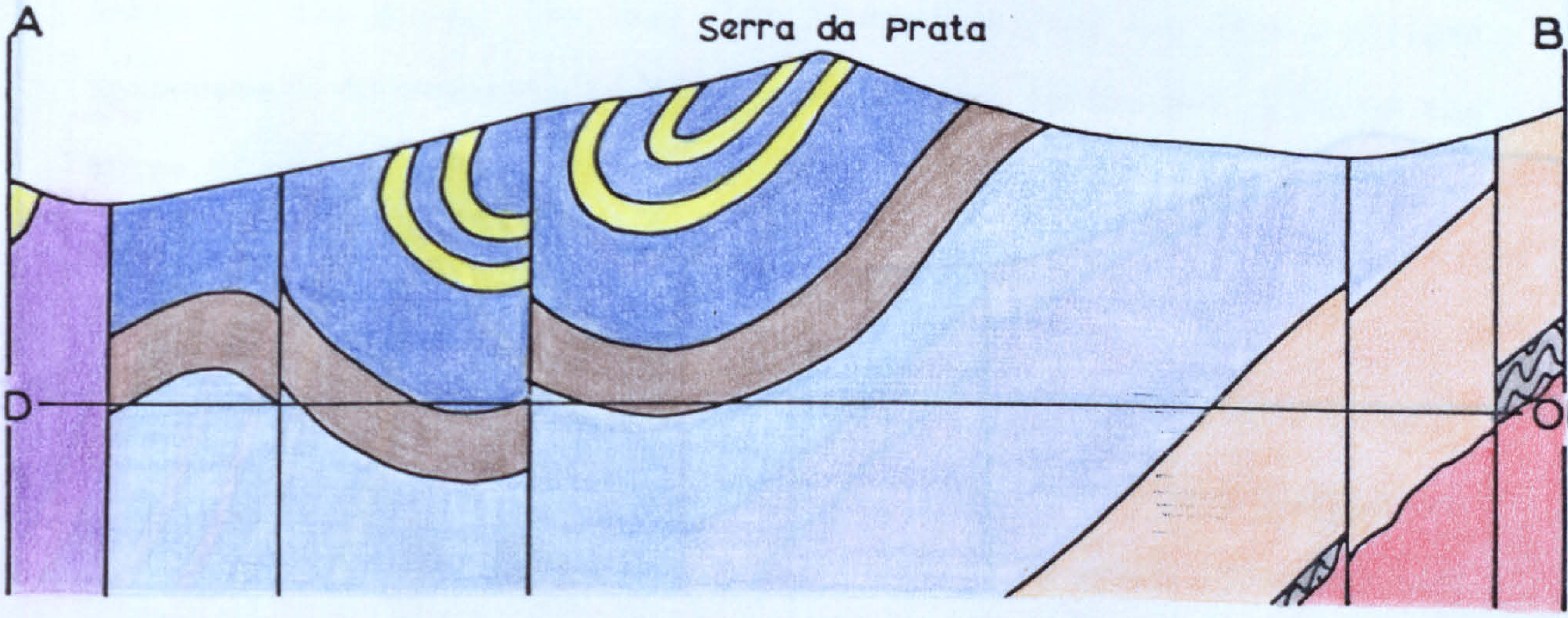
ii. <u>Cleavage</u>

One main cleavage is developed throughout the area in mudstone and siltstone lithologies (plate 18, figs. 1 & 2) and to a lesser extent in the very fine-grained sandstones found in the west of the area where the strain is higher. Only exceptionally in the vicinity of Serra de S. Paulo (18625, 31313) have medium and coarse-grained sandstones developed a cleavage because of their close proximity to thrust faulting. The cleavage approximates to axial planar (plate 18, fig. 1), but typically displays both fanning and refraction (Hobbs <u>et al</u>., 1976) as it traverses contrasting lithologies (plate 17, fig. 2). The general trend of the cleavage (map 3) is sub-parallel to the axial direction of the folding and generally has a NNW-SSE trend. In common with the folding the orientation of the cleavage is locally affected by the thrust faulting in the west of the area, consequently it has a NW-SE orientation in the vicinity of Ribeira do Braz (18500, 31400) and a north-south orientation in the vicinity of Arega (18535, 31877). Numerous atypical orientations of both cleavage and bedding have been observed in many parts of the area and these are usually associated with later faulting, especially the wrench faulting. It is also probable that some local areas have suffered slight or even moderate post-cleavage tightening of the folds affecting both the dip and strike of the cleavage; indeed, it is difficult to see how else localised areas of inverted bedding (i.e. north of Serra do Mercador; 18790, 31670) with the cleavage dipping at a low angle of about 30 degrees (plate 12, fig. 4 & plate 13, fig. 4) could have been produced in an area where cleavage seldom dips at less than 60 degrees.

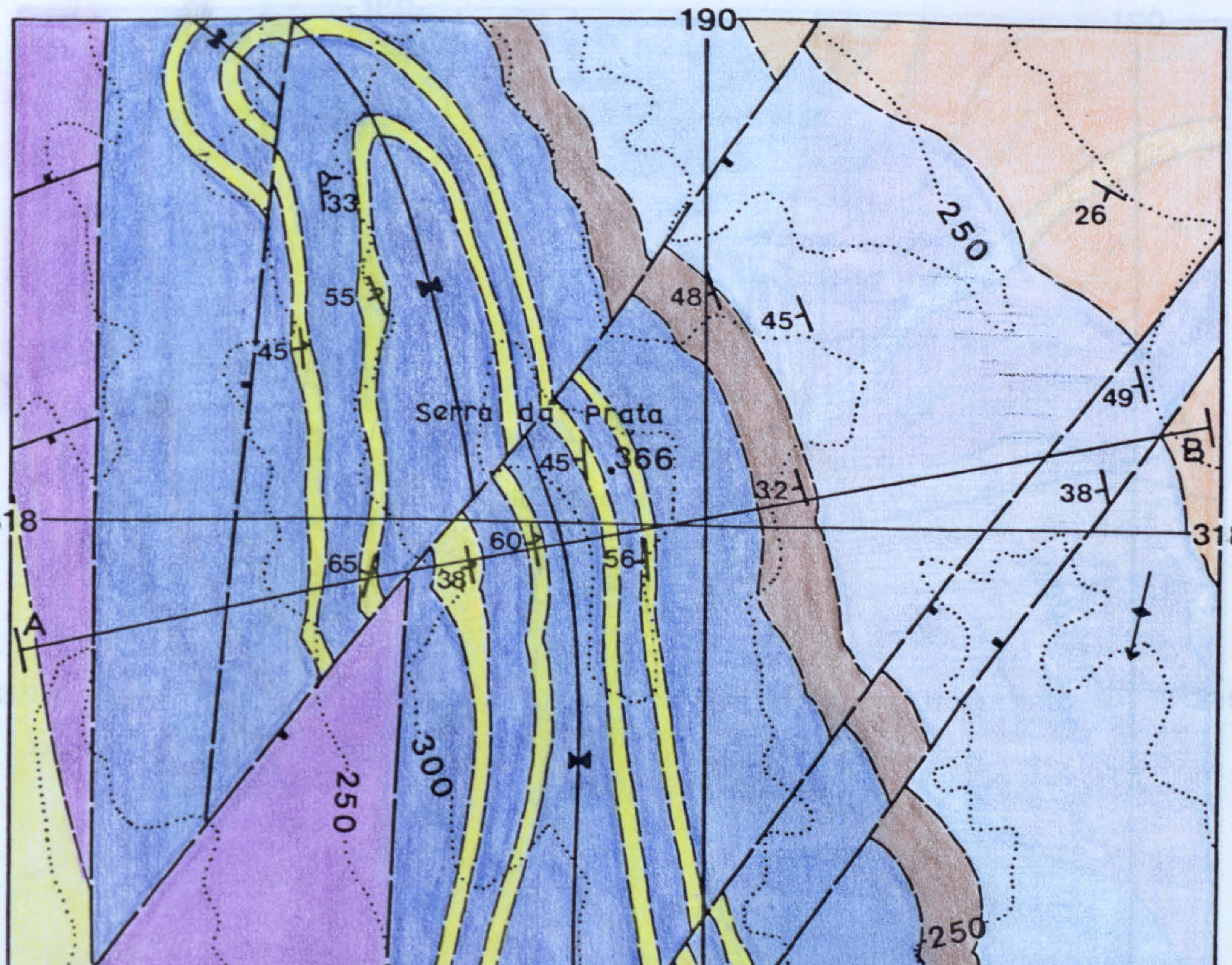
Small areas with crenulation and fracture cleavages (sensu Hobbs et al., 1976) are also developed, but their occurrence is patchy. These later cleavages tend also to be sub-parallel to known fault trends (plate 17, fig. 1 & plate 18, fig. 3).

The change in the tightness of the folding indicates that the strain increases across the area from east to west. Laboratory measurements of distorted fossils also reinforces this observation and the cleavage is more penetrative and slaty in the west. In the east of the area trilobites preserved in silty mudstones at fossil localities 85, 105 and 106 are relatively undistorted and have strain ellipsoid ratios (using the Wellman, 1962 method; or the Ramsay, 1967 method for single forms of known relative shape) of between 1 : 0.81 and 1 : 0.92. In the west fossils in similar lithologies are barely recogniseable beyond an order level and approximate strain ellipsoid ratios of greater than 1 : 0.3 are estimated. The strain is however dependent on lithology, consequently in the west of the area trilobites within beds of fine-

STRUCTURE OF SERRA DA PRATA FIG. 44



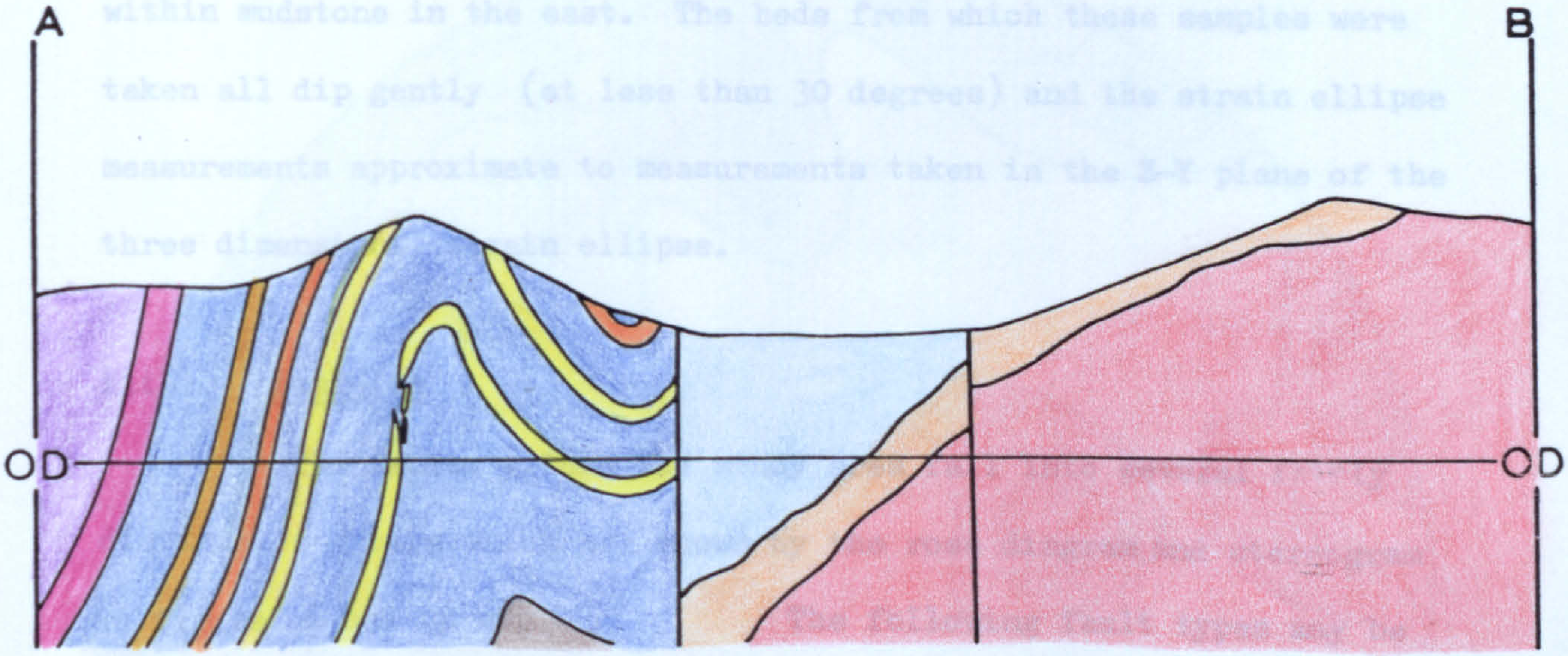
SCALE 1: 10,000



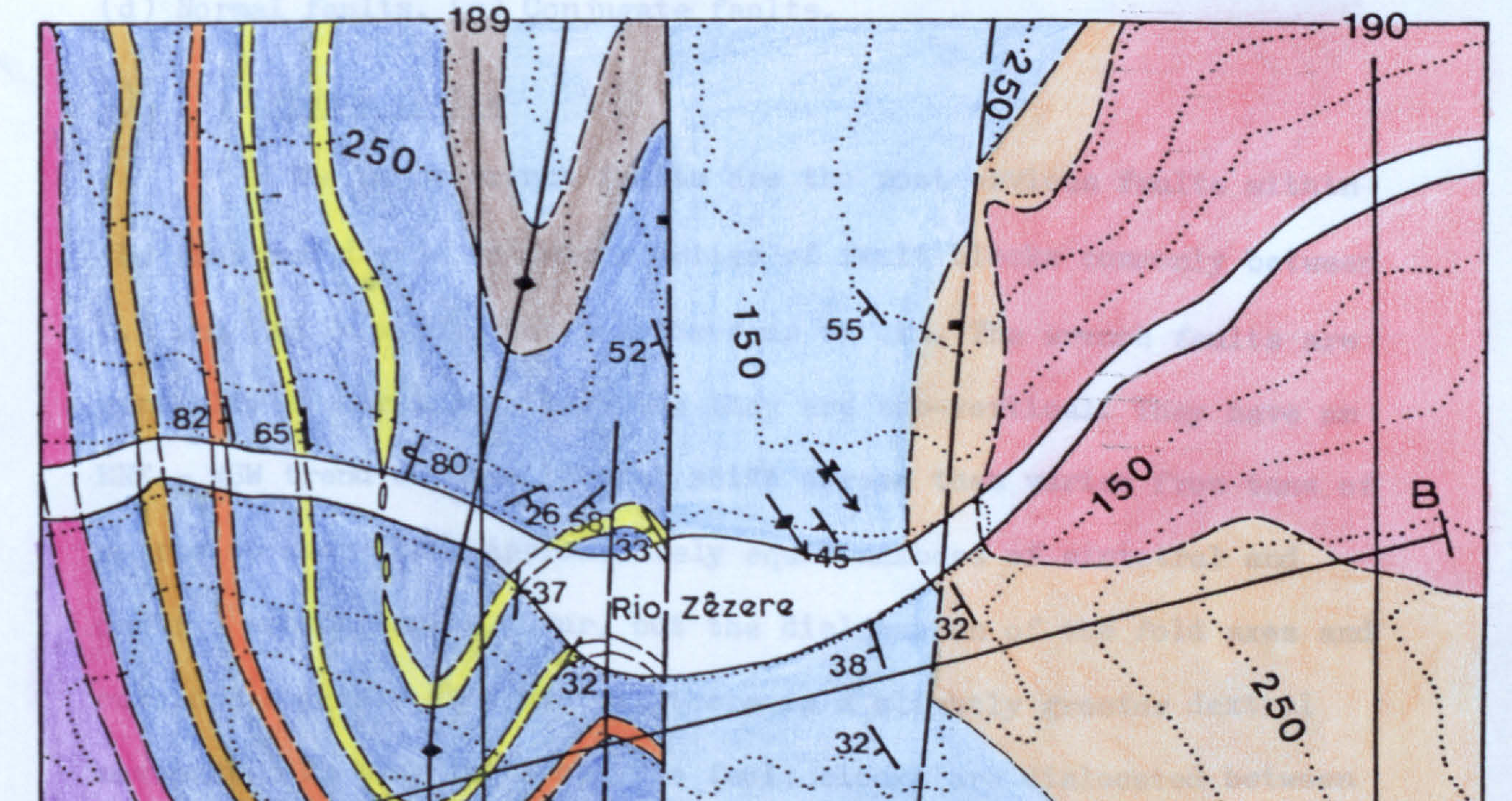
SCALE 1: 10,000

LEGEND: FIG. 60

THE STRUCTURE OF THE ALMEGUE AREA FIG. 45



SCALE: 1: 10,000



SCALE 1: 10,000

LEGEND: FIG. 60

grained sandstone at locality 175 have a strain ellipse ratio of between 1 : 0.7 and 1 : 0.89 a figure similar to those for specimens preserved within mudstone in the east. The beds from which these samples were taken all dip gently (at less than 30 degrees) and the strain ellipse measurements approximate to measurements taken in the Z-Y plane of the three dimensional strain ellipse.

iii. Faulting

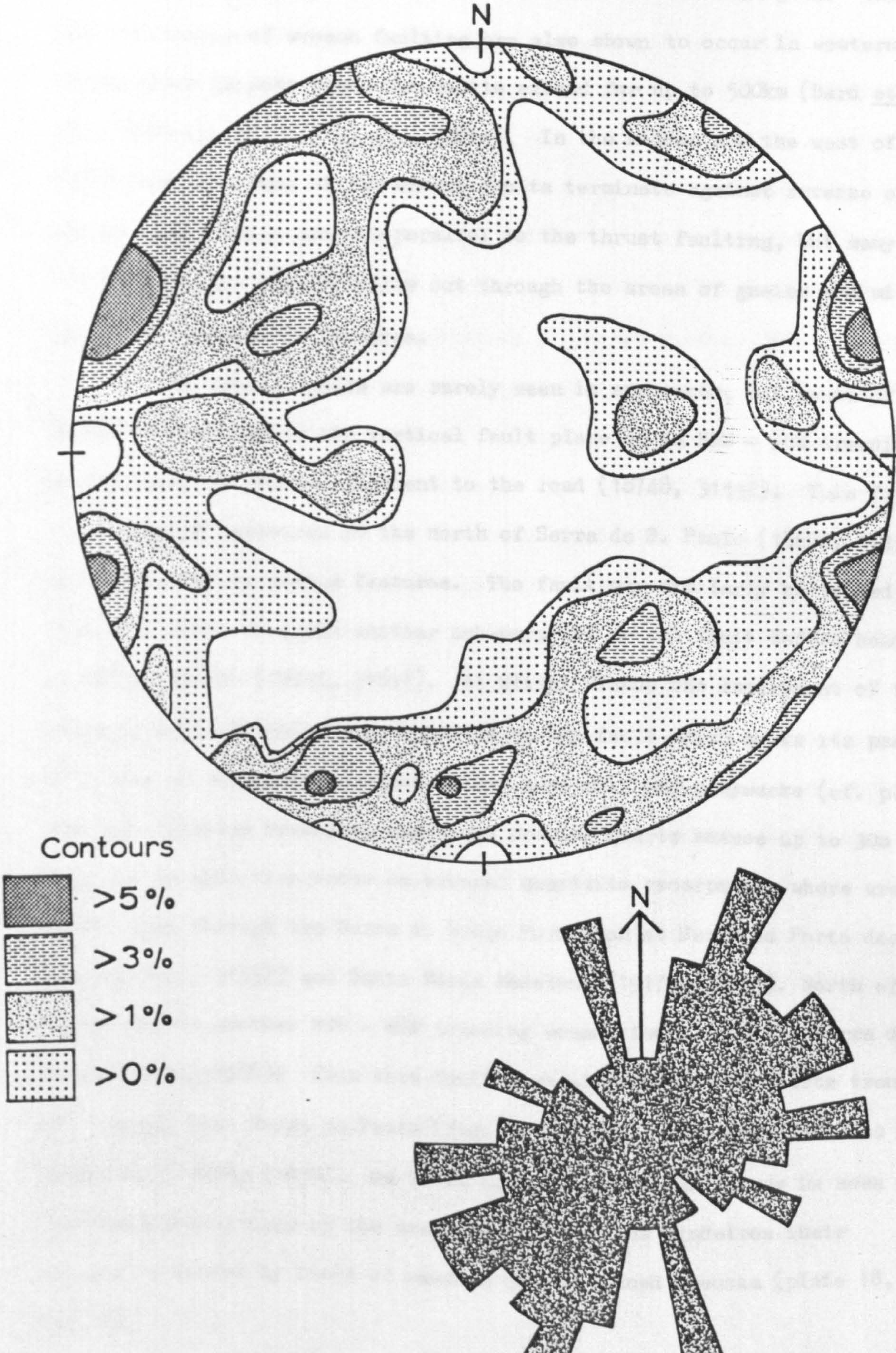
The faults within the study area fall into several fairly distinctive groups which are shown by the rose diagram and stereogram in figure 46 and by map 2 . The following fault types may be distinguished: (a) Wrench faults, (b) Thrust faults, (c) Reverse faults, (d) Normal faults, (e) Conjugate faults.

a) Wrench faults

The major wrench faults are the most obvious faults within the area and divide it into a series of fault blocks commonly between 0.5 and 2km in width, but sometimes up to 4km. The wrench faults are generally linear indicating that they are sub-vertical. They have an ENE - WSW trend and the lateral shift across them varies from tens of metres to over 1km. Approximately equal numbers of sinistral and dextral wrench faults occur, but the dislocation of the fold axes and outcrops suggests that overall there is a slightly greater dextral movement. In many instances the fault blocks are dislocated between sinistral and dextral wrench faults and the movement is accommodated by differential folding within adjacent fault blocks. Some of the wrench faults pass eastwards into the CXG, but many bifurcate or progress into minor wrench faults which make an angle of between 40 and 50 degrees to the main fault trend. Usually these minor faults

STEREOGRAM (pole-diagram contoured in %) & ROSE DIAGRAM FOR 135 FAULT PLANES

FIG. 46



have a NNE - SSW trend and a lateral movement of less than 300m. The same two trends of wrench faulting are also shown to occur in western Iberia where in some cases the faults extend for up to 500km (Bard et al., 1972a and Julivert et al., 1972a). In the middle and the west of the Dornes area many of the wrench faults terminate against reverse or normal faults which are sub-parallel to the thrust faulting, but many of the prominent wrench faults cut through the areas of gneiss and mica schist in the west of the area.

The wrench faults are rarely seen in exposures, but south of Varzea de Pedro Mouro the vertical fault plane of an ENE - WSW trending wrench fault is exposed adjacent to the road (18748, 31452). This fault may be traced westwards to the north of Serra de S. Paulo (18622, 31417) by a series of truncated features. The fault may similarly be traced eastwards where it joins another sub-parallel wrench fault before heading to Olival Grande (19215, 31617). At Olival Grande the escarpment of the Serra do Brejo Formation is truncated by the fault which marks its passage by a line of brecciated, quartz-veined quartzite and greywacke (cf. plate 18, fig. 4). Similar breccias, sometimes forming quartz masses up to 30m long and 5m wide, also occur on several quartzite escarpments where wrench faults pass through the Serra do Brejo Formation at Serra do Porto dos Fusos (19127, 31557) and Santa Maria Madelena (19173, 31451). North of Olival Grande another ENE - WSW trending wrench fault cuts the Serra do Brejo (19170, 31688); from this fault several minor wrench faults trend ENE through both Serra da Prata (fig. 44; 18980, 31826) and Serra dos Mindeiros (19078, 31838). On Serra da Prata these faults may be seen on the aerial photographs of the area and on Serra dos Mindeiros their passage is marked by lines of massive quartz-veined breccia (plate 18, fig. 4).

b) <u>Thrust faults</u>

The topmost part of Serra de S. Paulo (18646, 31332) is composed of *Cruziana* bearing quartzites belonging to the Serra do Brejo Formation. These quartzites and a small wedge of CXG rest with a marked angular relationship on the stratigraphically younger and steeply dipping beds of the Monte do Carvalhal Formation. A thrust faulted relationship is clearly implied (fig. 40), but the actual fault surface is not exposed. Near the fault, rocks in the overthrust block are however very strongly cleaved and beds of quartzite have developed a cleavage (18678, 31270 and 18666, 31284). At Serra de S. Paulo the *Cruziana* are obliquely distorted and quartzite beds well away from the probable fault plane bear a surface lineation, but the underthrust beds of the Monte do Carvalhal Formation are only moderately cleaved.

Along the western side of the area, in both the south and the north, areas of gneiss and mica schist occur as probable overthrust blocks. In the north-west around Arega (18377, 31972) the metamorphic rocks cap the high land and have an outcrop which is consistent with a klippe structure. In the south-west around Beco (18660, 31172) the gneiss and mica schist is bounded to the north and east by fairly straight faults. Those to the north-east of Beco are sub-vertical (plate 20, fig. 1), probably have a slight wrench movement, and post-date the thrust faulting (fig. 40). East of Beco the metamorphic rocks are reverse faulted against Ordovician and Silurian strata (fig. 41). Sub-parallel reverse faults occur near the edge of the metamorphic rocks and form part of the imbricate structure associated with the thrust faulting.

c) Reverse faults

Reverse faulting is mainly restricted to the west of the area where it is closely related to the thrust faulting with which it forms an imbricate structure. The reverse faults generally have a N-S to NNW-SSE trend. The most notable of these faults runs from Varzea de Pedro Mouro (18753, 31452) in the north, SSE through Dornes (18827, 31056) to Serra da Faisca (18882, 31042) in the south. Along the length of the westerly dipping fault older beds to the west are faulted up against younger beds to the east, commonly juxapositioning Silurian and Devonian, or Silurian and Ordovician strata. In the vicinity of Dornes the fault splits into several sub-parallel faults bounding a slice of intensely folded quartzites and mudstones. Within this fault slice massive units of Devonian quartzite up to 4m thick are boudinaged and sequences of quartzite are folded into tight folds of which the Dornes anticline (18828, 31172) is the best exposed (fig. 41, plate 16, figs. 3 & 4, plate 17, fig. 4). Beds of the Vale do Serrão Formation immediately west of the faulting are also severely folded into tight similar folds (plate 17, fig. 3).

d) Normal faults

Normal faults occur with two trends in the area; the general N-S to NNW-SSE trend and a few, restricted to the south-west, with a NW-SE trend (map 2 and fig. 46). These normal faults vary in throw from a few metres, such as those near Monte da Sombadeira (19090, 31350, plate 19, fig. 2), to several hundred metres such as the fault east of Almegue (18920, 31900; fig. 45).

Normal faults with an approximately N-S trend are generally restricted between wrench faults and consequently extend for between a few hundred metres to several kilometres. These normal faults are very numerous and commonly result in the repetition of the same sequence several times within a block bounded by wrench faults; this is the situation at Vale da Lage (18663, 31577; fig. 39, plate 6). The normal faults with a N-S to NNW-SSE trend share their orientation with the reverse faults and it is probable that some of them represent a later movement in the opposite direction along pre-existing reverse faults. Many of the normal faults are however steeply dipping or sub-vertical and must be independent of the reverse faulting. Prolonged movements along normal faults with this trend is shown by the existence east of Almegue (18951, 31926) of a recent fault scarp breccia associated with a normal fault (plate 20, figs. 2 & 3).

Only a few faults with a NW-SE trend occur within the area and these are mainly restricted to the south-west corner. Here, near Ribeira do Braz (189479, 31387), the gneiss and mica schist is bounded by a major fault which is paralleled by another fault 300m away to the north-east. These faults are straight, sub-vertical (fig. 40 & plate 20, fig. 1) and possibly have a slight wrench component on their movement. Post Triassic movement on the northern fault is shown by the juxa-positioning of Triassic sandstones against probable CXG near Cabaços (18281, 31594; plate 20, fig. 1), but the more southerly fault does not affect the Triassic strata.

e) Conjugate faults

Stereographic representation (fig. 46) of all the observed fault planes shows that two groups of NW-SE trending faults dipping at between 40 and 50 degrees occur as a conjugate set. These conjugate faults have a similar orientation to many of the observed kink bands and conjugate kink bands occurring in the laminated sandstones and mudstones of the Vale do Serrão Formation in the south of the area (plate 13, fig. 1). It is possible that these faults and kinks occurred during the late stages of the main phase of folding and faulting because they occur in approximately the 45 degree position with respect to the principal stress (Sherbon Hills, 1963, p. 239).

f) Sequence of faulting

Because exposure within the area is generally only poor to moderate it is very difficult to determine the order in which the faulting occurred, but no re-folded fault surfaces were observed indicating that most of the faulting post-dated the folding. The probable sequence of events of the main phase of folding and faulting was:

1. Deposition of Lower Palaeozoic sequences.
2. Folding with the initiation of wrench faults.
3. Thrust faulting with the development of reverse faults and intense folding to produce an imbricate structure along the thrust front; formation of conjugate faults and shears.
4. Relaxation after the thrust faulting with the development of normal faulting.
5. Movement along previously established wrench, normal and reverse faults with slight tightening of folds within individual fault blocks.
6. Post Triassic movements on many of the pre-existing faults.

iv. Metamorphic rocks

Areas of gneiss and mica schist occur both in the north-west of the area around Arega (18450, 31900) and in the south-west of the area around Beco (18600, 31150); at both these occurrences the metamorphic rocks are thrust on to the sedimentary sequences. The gneisses and mica schists are usually highly weathered. These rocks have a marked schistosity (map 3) which has a trend sub-parallel to both the folding, cleavage, thrust and reverse faulting in the adjacent sedimentary rocks. Around Beco this is a NW-SE trend and around Arega it is in general a N-S trend. In general the areas of mica schist grade into the areas of gneiss, but at the other extreme areas of mica schist with poorly preserved sedimentary banding, cross-cutting the schistosity, have also been observed. The age of these metamorphic rocks is not apparent.

v. Granites

Two granites are exposed within the area. The southern one crops out between Serra dos Mindeiros (19115, 31835) in the south and Aldeia Cimeira (19000, 32270) in the north. The northern granite is centred around Figueirô dos Vinhos (18772, 32600) and was only briefly visited when the road sections in the north were measured. Both granites form high plateaux which are deeply incised by steep-sided river valleys. The granites are deeply weathered and even in the gorge of the Rio Zêzere (18970, 31945) no fresh samples were seen. The weathering is so extensive that even road cuttings 10m deep near Figueirô dos Vinhos (18730, 32500) are cut exclusively in the weathered zone. Most of the minerals in the granites are weathered and only the quartz remains held in a rotten brown matrix of clay minerals. In the gorge of the Rio Zêzere (18970, 31945) the southern granite is less weathered than elsewhere and both quartz and mica survive, but the feldspars are altered and green in colour. In the gorge the granite is coarse-grained, but it becomes finer towards the uneven and cross-cutting contact with the quartzites of the Serra do Brejo Formation (18956, 31939; plate 20, fig. 4). Near the granite-quartzite contact, both at this locality and near Aldeia Cimeira (19004, 32261), xenoliths of quartzite and possibly of CXG occur within the granite; emplacement of the southern granite appears to have involved both chemical assimilation and magmatic stoping. Both granites have assimilated the greywackes and siltstones of the CXG more readily than the quartzites of the Serra do Brejo Formation which appear to have formed a partial barrier to the granite emplacements. Consequently the granites crop out to the east of the quartzite escarpment and do not penetrate it. It is possible that the granite was already rich in silica and would not assimilate the pure quartzite of the Serra do Brejo Formation as readily as it did the feldspathic greywackes of the CXG. Priem _et al_. (1970) show that in the north of Portugal discordant, allochthonous granite plutons were intruded at about the time of the Carboniferous-Permian boundary. A similar age for the granites of the Dornes area is probable and Teixeira (1972) indicates them to be of post-Stephanian age.

vi. Metamorphism

The metamorphic effect of the granites is variable, but around the southern granite where it is in contact with the CXG a belt of metamorphism about 0.75km wide occurs. This belt extends from Serra dos Mindeiros (19087, 31840) south to Serra do Brejo (19153, 31745) and generally occurs as extensive spotting which is more prominent in the mudstone lithologies. The spotting consists of minute crystals in radiating clusters which have preferentially developed along the bedding planes. These crystals are indeterminate from thin sections. Similarly spotted mudstones also occur in localised areas east of Serra do Porto dos Fusos (19145, 31513) and north of Serra da Quinta (19325, 31336) suggesting the presence of granite at shallow depth in these areas. Where the southern granite is in contact with the massive quartzites of the Serra do Brejo Formation the belt of metamorphism is very narrow. In the gorge of the Rio Zêzere near Almegue (18953, 31930) approximately the lowest 20m of quartzite are recrystallised (plate 20, fig. 4) and well preserved Cruziana occur only 80m from the contact. Mudstones of the Brejo Fundeiro Formation overlying the quartzite and probably less than 100m from the granite are unaffected; it appears that the quartzite acted as a partial barrier to the metamorphism.

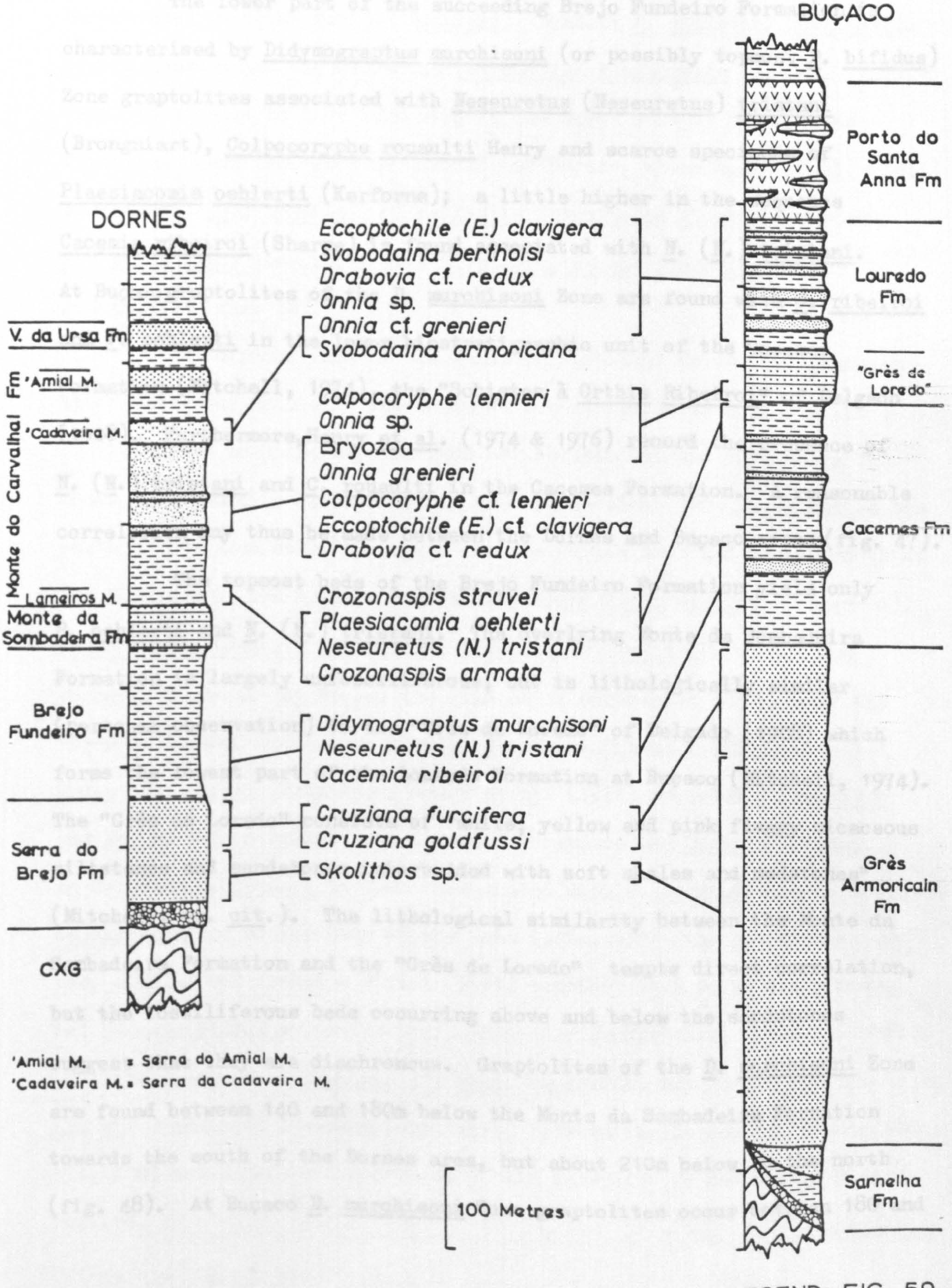
IV. CORRELATION

1. The correlation between the Dornes and Buçaco areas (fig. 47)

The Buçaco area is situated about 30km north-north-east of Coimbra and about 70km north of the Dornes area (fig. 2). Although there are considerable differences in thickness the lithological sequence and faunas of the two areas show many similarities (figs. 47 & 48).

In the Dornes area Ordovician deposition commenced with the conglomerates and quartzites of the Serra do Brejo Formation, but at Buçaco conglomeratic red beds of the Sarnelha Formation (0 - 120m thick) precede the main quartzites of the Grès Armoricain Formation (Henry et al., 1974). These red beds have yielded a specimen of Cruziana furcifera d'Orbigny from the upper part of the formation (Delgado, 1908; p. 44) suggesting a probable upper Tremadoc or Arenig age for these beds. Both the Serra do Brejo Formation (150m) and the Grès Armoricain Formation (650m) are lithologically similar transgressive sequences and both have the same ichnofacies developed. The middle part of the Serra do Brejo Formation and the lowest three-quarters of the Buçaco sequence are typified by the occurrence of Skolithos, (Delgado, 1908). Skolithos is however, a long ranging facies controlled ichnogenus of little value for correlation (Seilacher, 1967; Alpert, 1974). The upper beds in both areas are typified by Cruziana also a facies controlled trace fossil, but one which is stratigraphically useful (Crimes, 1968, 1969, 1970a, 1975a & c; Seilacher, 1970; Crimes & Marcos, 1976; Baldwin, 1977b). The top 40m of the Serra do Brejo Formation yielded Cruziana furcifera d'Orbigny and C. goldfussi (Rouault), two ichnospecies which Delgado (op. cit.) also recorded from the "Quartzites à Bilobites" (the topmost 130m of the Grès Armoricain Formation) at Buçaco. The Cruziana along with graptolites in the overlying mudstones suggest a probable upper

CORRELATION BETWEEN DORNES AND BUÇACO FIG. 47



LEGEND: FIG. 59

Arenig or possibly lower Llanvirn age for the upper part of the Serra do Brejo Formation.

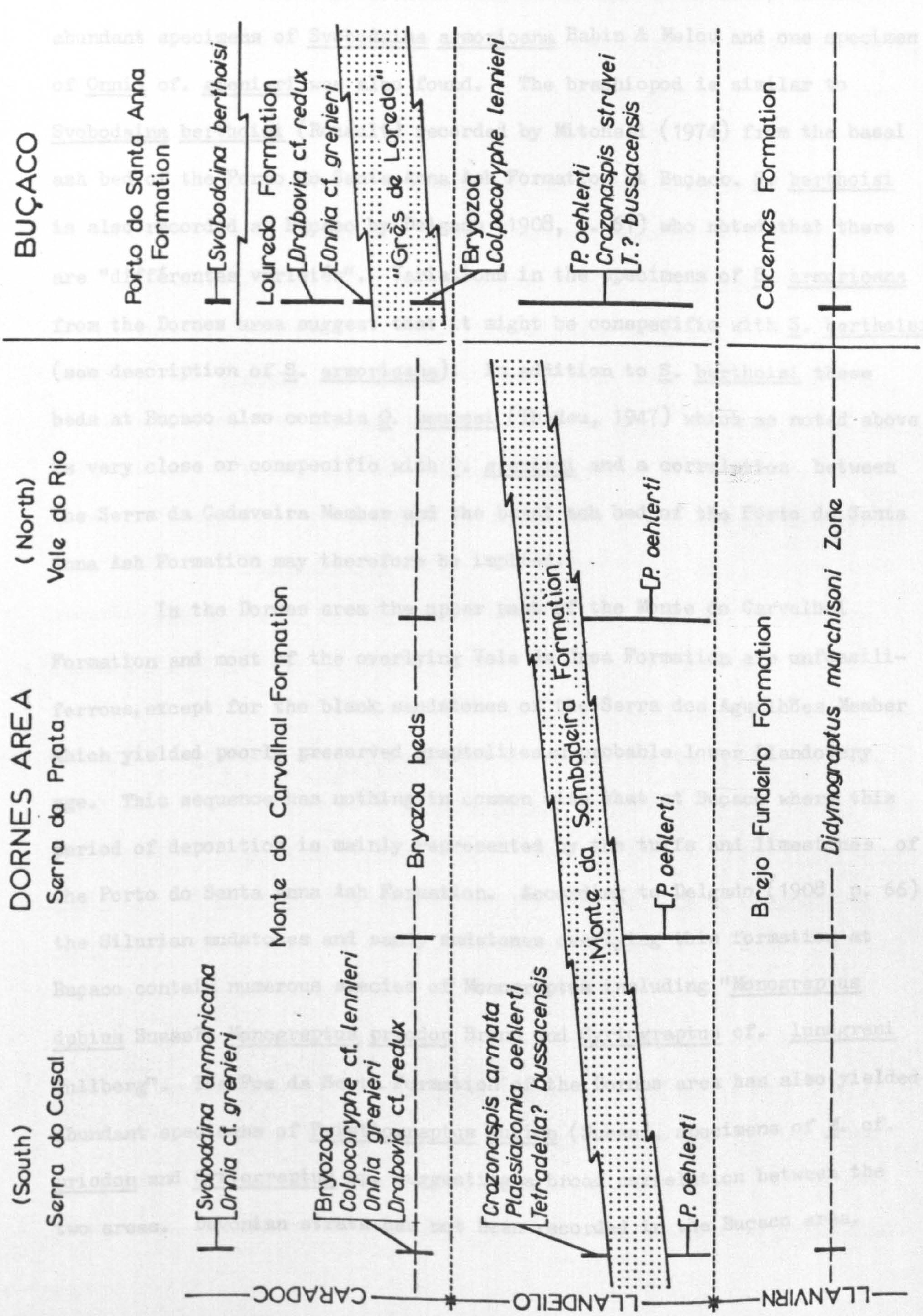
The lower part of the succeeding Brejo Fundeiro Formation is characterised by Didymograptus murchisoni (or possibly topmost D. bifidus) Zone graptolites associated with Neseuretus (Neseuretus) tristani (Brongniart), Colpocoryphe rouaulti Henry and scarce specimens of Plaesiacomia oehlerti (Kerforne); a little higher in the sequence Cacemia ribeiroi (Sharpe) is found associated with N. (N.) tristani. At Buçaco graptolites of the D. murchisoni Zone are found with C. ribeiroi and P. oehlerti in the lower biostratigraphic unit of the Cacemes Formation (Mitchell, 1974), the "Schistes à Orthis Ribeiroi" of Delgado (1908). Furthermore, Henry et al. (1974 & 1976) record the presence of N. (N.) tristani and C. rouaulti in the Cacemes Formation. A reasonable correlation may thus be made between the Dornes and Buçaco areas (fig. 47).

The topmost beds of the Brejo Fundeiro Formation yield only P. oehlerti and N. (N.) tristani. The overlying Monte da Sombadeira Formation is largely unfossiliferous, but is lithologically similar (personal observation) to the "Grès de Loredo" of Delgado (1908) which forms the lowest part of the Louredo Formation at Buçaco (Mitchell, 1974). The "Grès de Loredo" consists of "white, yellow and pink flaggy micaceous siltstones and sandstones interbedded with soft shales and mudstones" (Mitchell, op. cit.). The lithological similarity between the Monte da Sombadeira Formation and the "Grès de Loredo" tempts direct correlation, but the fossiliferous beds occurring above and below the sandstones suggest that they are diachronous. Graptolites of the D. murchisoni Zone are found between 140 and 180m below the Monte da Sombadeira Formation towards the south of the Dornes area, but about 210m below in the north (fig. 48). At Buçaco D. murchisoni Zone graptolites occur between 180 and

and 250m below the "Grès de Loredo". Furthermore, the Lameiros Member directly above the Monte da Sombadeira Formation in the south of the Dornes area contains N. (N.) tristani, abundant P. oehlerti, Crozonaspis armata Hammann and the ostracode Tetradella? bussacensis (Jones). This fauna is similar to that occurring in the upper part of the Cacemes Formation below the "Grès de Loredo" at Buçaco, where Henry et al. (1974) recorded N. (N.) tristani, P. oehlerti, Crozonaspis struvei Henry and T.? bussacensis associated with Glyptograptus teretiusculus Zone graptolites (fig. 48).

The bryozoa beds of the Monte do Carvalhal Formation reinforce the diachronous nature of the Monte da Sombadeira Formation. In the south of the Dornes area the bryozoa beds are between 160 and 200m above the Monte da Sombadeira Formation; in the middle about 100m above and in the north of the area only 20m above. In the Dornes area and to the south of the Dornes area the bryozoa beds have yielded Onnia grenieri (Bergeron), Colpocoryphe lennieri (Bergeron), Drabovia cf. redux (Barrande) and abundant bryozoa. At Buçaco the chamositic oolites at the base of the "Grès de Loredo" contain a similar fauna and Mitchell (1974) recorded Onnia cf. seunesi (Kerforne), Henry et al. (1974) recorded C. lennieri and Dr. M. Romano (pers. comm.) recorded bryozoa and Onnia sp. indet. In Brittany O. seunesi is found associated with O. grenieri in the Schistes de Raguenez and at the base of the Grès de Kermeur; the two species are very similar and Arnaud & Pillet (1971) consider them to be synonymous, but Hammann (1976a) maintains their separate identities. These trilobites plus the presence of Drabovia cf. redux in the Louredo Formation (Mitchell, op. cit.) indicate a strong correlation between the Dornes and Buçaco areas (fig. 48) and a marked diachronism of the sandstone formations is clearly implied.

THE DIACHRONISM OF THE MONTE DA SOMBADEIRA FORMATION and the possible correlation with the Buçaco area. FIG. 48



The silty micaceous sandstones which form the Serra da Cadaveira Member of the Monte do Carvalhal Formation in the Dornes area, contain abundant specimens of Svobodaina armoricana Babin & Melou and one specimen of Onnia cf. grenieri was also found. The brachiopod is similar to Svobodaina berthoisi (Rouault) recorded by Mitchell (1974) from the basal ash bed of the Porto do Santa Anna Ash Formation at Buçaco. S. berthoisi is also recorded at Buçaco by Delgado (1908, p. 61) who noted that there are "différentes variétés". Variations in the specimens of S. armoricana from the Dornes area suggest that it might be conspecific with S. berthoisi (see description of S. armoricana). In addition to S. berthoisi these beds at Buçaco also contain O. seunesi (Thadeu, 1947) which as noted above is very close or conspecific with O. grenieri and a correlation between the Serra da Cadaveira Member and the basal ash bed of the Porto do Santa Anna Ash Formation may therefore be implied.

In the Dornes area the upper part of the Monte do Carvalhal Formation and most of the overlying Vale da Ursa Formation are unfossiliferrous, except for the black sandstones of the Serra dos Aguilhões Member which yielded poorly preserved graptolites of probable lower Llandovery age. This sequence has nothing in common with that at Buçaco where this period of deposition is mainly represented by the tuffs and limestones of the Porto do Santa Anna Ash Formation. According to Delgado (1908, p. 66) the Silurian mudstones and sandy mudstones overlying this formation at Buçaco contain numerous species of Monograptus including "Monograptus dubius Suess?, Monograptus priodon Bronn and Cyrtograptus cf. lundgreni Tullberg". The Foz da Serta Formation of the Dornes area has also yielded abundant specimens of Pristiograptus dubius (Suess), specimens of M. cf. priodon and Cyrtograptus sp. suggesting a broad correlation between the two areas. Devonian strata has not been recorded in the Buçaco area.

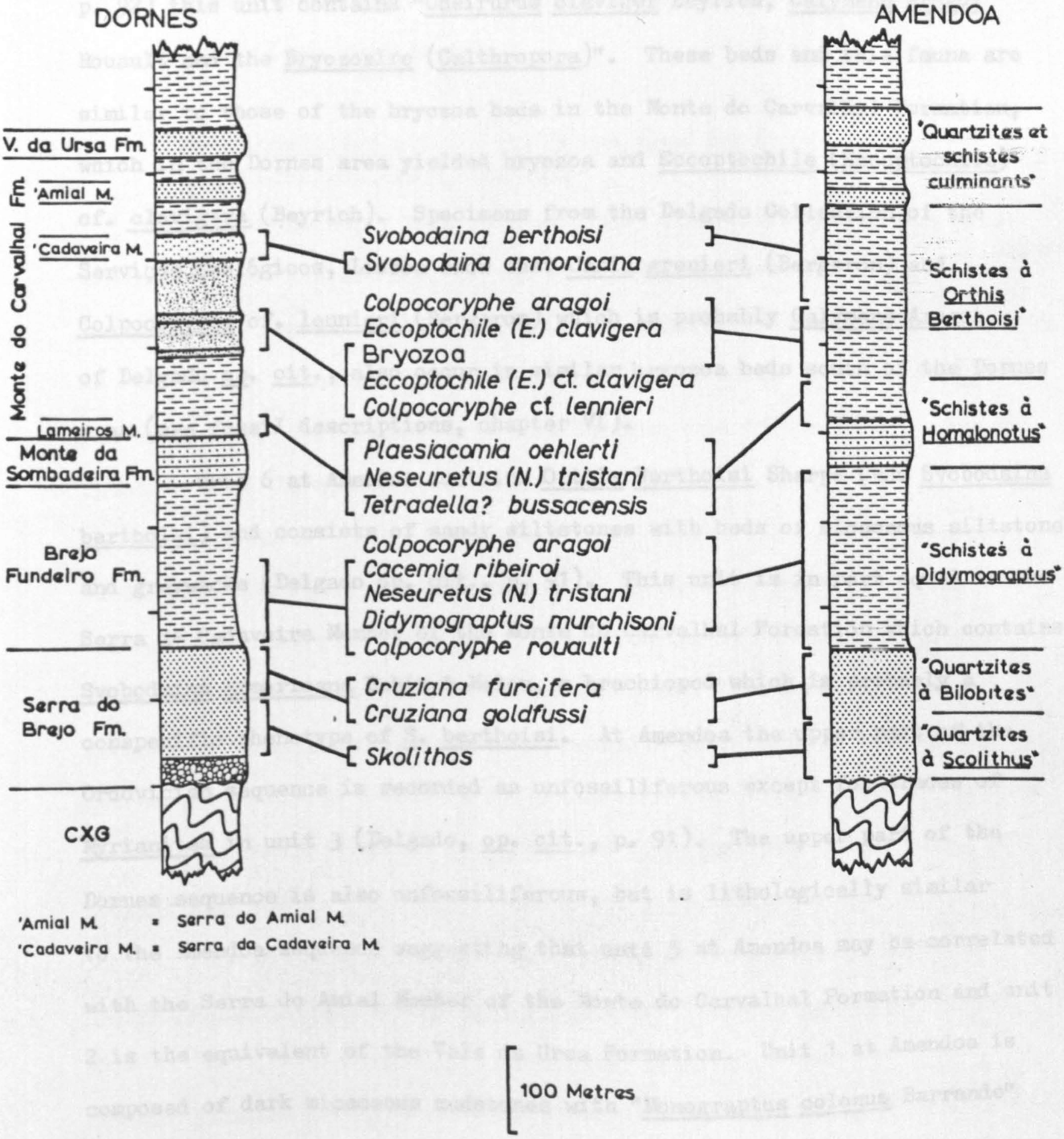
2. The correlation between the Dornes and Amendoa areas (fig. 49)

The Amendoa area is about 20km south-east of Dornes and linked to it by a continuous outcrop of Ordovician and Silurian strata (Teixeira, 1972); lithologically and faunally the two areas show many similarities (fig. 49).

The Serra do Brejo Formation of the Dornes area is of similar thickness and facies (fig. 49) to the combined "Quartzites à Scolithus" and "Quartzites à Bilobites" which Delgado (1908, p. 93, units 12 and 13) described from Amendoa. His faunal list includes Cruziana goldfussi (Rouault) and Cruziana furcifera d'Orbigny, both ichnospecies occur in the Dornes area. The Amendoa area furnishes no extra evidence to precisely date the marine transgression, but the ichnospecies of Cruziana in the upper beds suggest it is Arenig. Overlying the quartzites at Amendoa are the "Schistes à Didymograptus" from which Delgado (op. cit., p. 93, unit 11) recorded Didymograptus murchisoni Beck and Orthis ribeiroi Sharpe (now Cacemia ribeiroi). D. murchisoni occurs in the lower part of the Brejo Fundeiro Formation of the Dornes area and C. ribeiroi in the middle of the formation suggesting a close correlation between the two areas. In the upper part of the "Schistes à Didymograptus" Delgado (op. cit. p. 93, unit 10) recorded Homalonotus (Plaesiacomia) Oehlerti Kerforne (now Plaesiacomia oehlerti) and Calymene Tristani Brongniart (now Neseuretus (Neseuretus) tristani); these are both species which are common in the upper part of the Brejo Fundeiro Formation.

The Monte da Sombadeira Formation which overlies the Brejo Fundeiro Formation is of similar thickness and lithology to unit 9 of the Amendoa sequence (Delgado op. cit., p. 92). This unit is 53m thick and composed of very micaceous, fine-grained sandstones, quartzites and greywackes. Delgado included units 8 and 9 in the "Schistes à Homalonotus

CORRELATION BETWEEN DORNES AND AMENDOA FIG. 49



LEGEND: FIG. 59

Oehlerti" from which he recorded a fauna similar to that of the Lameiros Member and lower part of the Monte do Carvalhal Formation in the Dornes area.

Unit 7 at Amendoa is composed of massive grey micaceous mudstones with ochre spotting, sporadic patches of green oolitic mudstone and frequent beds of quartzite and sandstone. According to Delgado (op. cit., p. 92) this unit contains "Cheirurus claviger Beyrich, Calymene Aragoi Rouault and the Bryozoaire (Calthropora)". These beds and this fauna are similar to those of the bryozoa beds in the Monte do Carvalhal Formation, which in the Dornes area yielded bryozoa and Eccoptochile (Eccoptochile) cf. clavigera (Beyrich). Specimens from the Delgado Collection of the Serviços Geológicos, Lisboa show that Onnia grenieri (Bergeron) and Colpocoryphe cf. lennieri (Bergeron), which is probably Calymene Aragoi of Delgado op. cit., also occur in similar bryozoa beds south of the Dornes area (see fossil descriptions, chapter VI).

Unit 6 at Amendoa contains Orthis Berthoisi Sharpe (now Svobodaina berthoisi) and consists of sandy siltstones with beds of micaceous siltstone and greywacke (Delgado op. cit., p. 91). This unit is in part equal to the Serra da Cadaveira Member of the Monte do Carvalhal Formation which contains Svobodaina armoricana Babin & Melou, a brachiopod which is probably a conspecific phenotype of S. berthoisi. At Amendoa the upper part of the Ordovician sequence is recorded as unfossiliferous except for traces of Myrianites in unit 3 (Delgado, op. cit., p. 91). The upper part of the Dornes sequence is also unfossiliferous, but is lithologically similar to the Amendoa sequence suggesting that unit 5 at Amendoa may be correlated with the Serra do Amial Member of the Monte do Carvalhal Formation and unit 2 is the equivalent of the Vale da Ursa Formation. Unit 1 at Amendoa is composed of dark micaceous mudstones with "Monograptus colonus Barrande"

(Delgado, op. cit., p. 91) and correlates with the Foz da Serta Formation of the Dornes area in which ?Saetograptus colonus (Barrande) occurs. The upper Silurian sequence of the Amendoa area is given by Delgado (op. cit., p. 76 and 84-86) in less detail than the preceding sequences, but lithological units equivalent to the Vale do Serrão and Serra da Mendeira Formations are described. They are however much thicker in the Amendoa area than in the Dornes area (fig. 49). Devonian strata is not recorded in the Amendoa area.

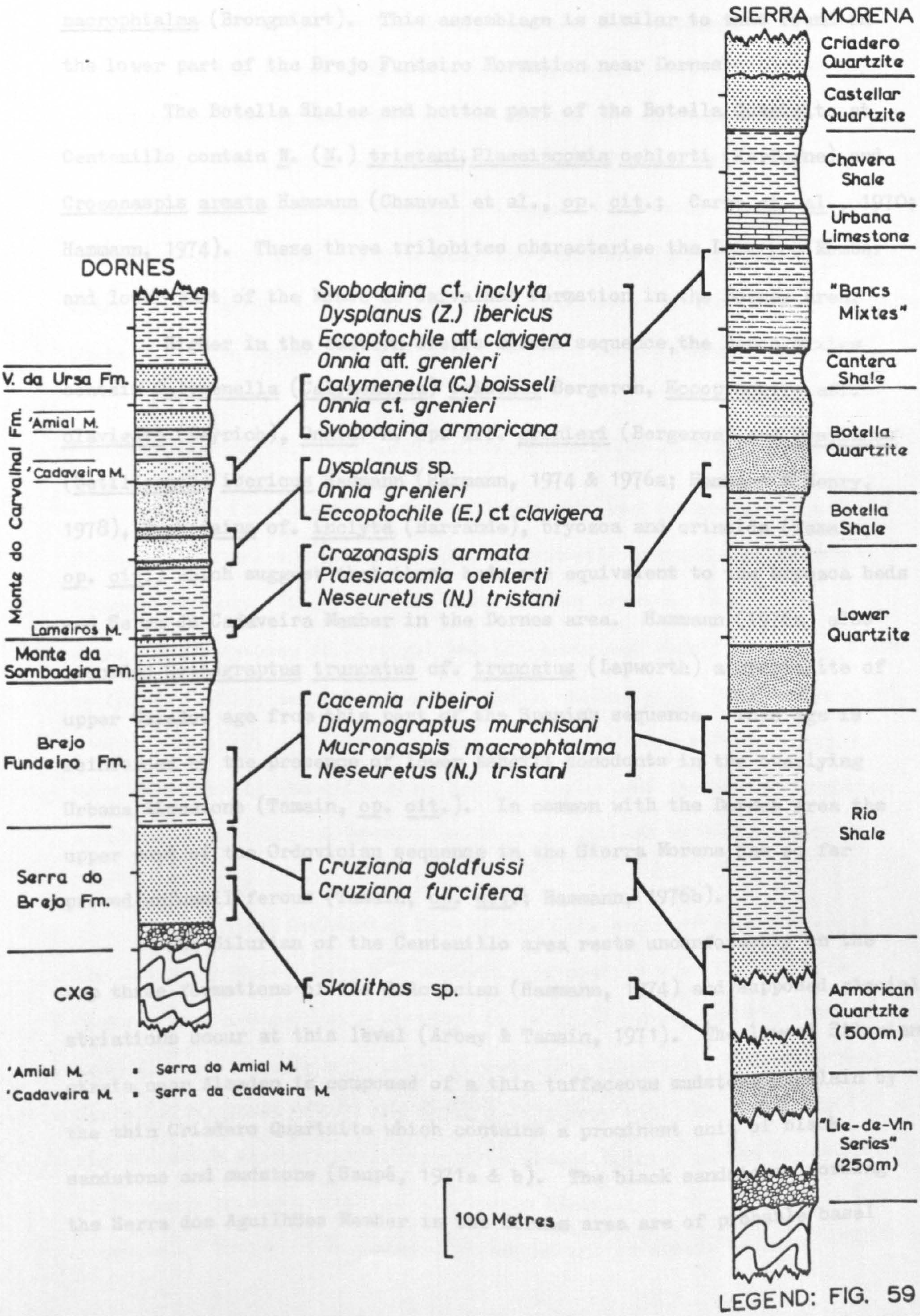
3. The correlation between the Dornes area and the Eastern Sierra Morena, Spain (Fig. 50)

Since the early work of Born (1918) the Sierra Morena has been extensively studied and most of the more important Ordovician works are summarised by Hammann (1974 & 1976b). The generalised section in figure 50 is based on the sequence in the Centenillo and Almaden areas about 300km ESE of Dornes. This sequence is much thicker than in the Dornes area and compares with the sequence at Buçaco.

The basal Ordovician quartzites at Centenillo (mid-way between Ciudad Real and Jâen) are underlain by conglomeratic red beds of the lie-de-vin series (Chauvel et al., 1969; Tamain, 1971; Hammann op. cit. which are like the Sarnelha Formation at Buçaco. The overlying Grès Armoricain Formation illustrates the relative uniformity of the Arenig quartzites in Iberia (Escorza, 1977) and like the Serra do Brejo Formation at Dornes contains both the Skolithos and Cruziana ichnofacies with C. goldfussi and C. furcifera (Tamain, op. cit., Escorza, op. cit.).

The Rio Shales which succeed the quartzites contain both the Didymograptus bifidus and D. murchisoni Zones (Tamain, op. cit.; Arbin et al., 1978) with Neseuretus (Neseuretus) tristani (Brongniart) and Cacemia ribeiroi (Sharpe) recorded from the same sequence by Born (1918);

CORRELATION BETWEEN DORNES AND THE EASTERN SIERRA MORENA FIG. 50



towards the top of these shales Hammann (1974) also recorded Mucronaspis macrophtalma (Brongniart). This assemblage is similar to that found in the lower part of the Brejo Fundeiro Formation near Dornes.

The Botella Shales and bottom part of the Botella Quartzite at Centenillo contain N. (N.) tristani, Plaesiacomia oehlerti (Kerforne) and Crozonaspis armata Hammann (Chauvel et al., op. cit.; Carre et. al., 1970; Hammann, 1974). These three trilobites characterise the Lameiros Member and lower part of the Monte do Carvalhal Formation in the Dornes area.

Higher in the eastern Sierra Morena sequence, the Bancs mixtes contain Calymenella (Calymenella) boisseli Bergeron, Eccoptochile aff. clavigera (Beyrich), Onnia? n. sp. aff. grenieri (Bergeron) and Dysplanus (Zetillaenus) ibericus Hammann (Hammann, 1974 & 1976a; Hammann & Henry, 1978), Svobodaina cf. inclyta (Barrande), bryozoa and crinoids (Tamain, op. cit.) which suggest that these beds are equivalent to the bryozoa beds and Serra do Cadaveira Member in the Dornes area. Hammann (1976a) also recorded Orthograptus truncatus cf. truncatus (Lapworth) a graptolite of upper Caradoc age from this part of the Spanish sequence. This age is reinforced by the presence of lower Ashgill conodonts in the overlying Urbana Limestone (Tamain, op. cit.). In common with the Dornes area the upper part of the Ordovician sequence in the Sierra Morena has so far proved unfossiliferous (Tamain, op. cit.; Hammann, 1976b).

The Silurian of the Centenillo area rests unconformably on the top three formations of the Ordovician (Hammann, 1974) and supposed glacial striations occur at this level (Arbey & Tamain, 1971). The lowest Silurian strata near Almaden is composed of a thin tuffaceous mudstone overlain by the thin Criadero Quartzite which contains a prominent unit of black sandstone and mudstone (Saupé, 1971a & b). The black sandstones forming the Serra dos Aguilhões Member in the Dornes area are of probable basal

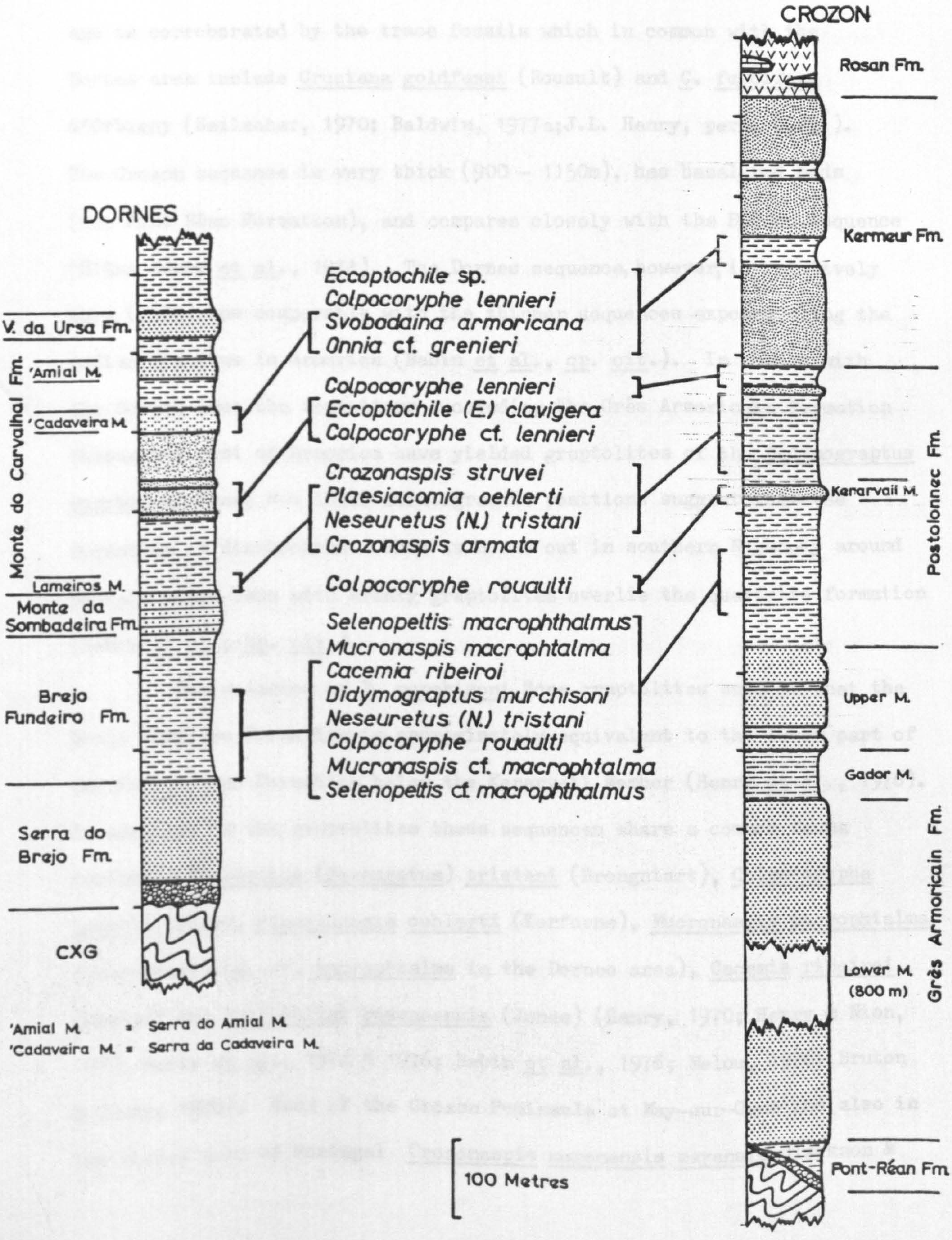
Llandovery age and might be equivalent to the black sandstone at Almaden, to which a lower or middle Llandovery age has been assigned by Saupé (1971a). In the Dornes area the succeeding upper Llandovery and Wenlock strata is dominantly mudstone, but at Almaden the equivalent beds are interbedded with sandstones and tuffs (Saupé, 1971b). The Ludlow and Pridoli of both Dornes and Almaden are mainly of a sandy facies and the Gedinnian of both areas is of a mudstone/sandstone facies (Saupé, op. cit.). Limestones similar to the Dornes formation, however, do not occur at Almaden where Siegenian deposition was of a quartzite facies (Saupé, op. cit.)

4. Correlation between the Dornes area and the Armorican Massif (fig. 51)

Born (1918) noted that the Ordovician successions and faunas of Portugal, central Spain and the Armorican Massif contain many common characteristics. Since then the similarities between the Ordovician faunas and sequences of Portugal and the Armorican Massif have been shown by Coates (1966), Henry & Morzadec (1968), Bishop et al. (1969), Bard et. al. (1972a), Babin et al. (1976), Romano (1976) and Henry & Romano (1978). More specifically the uniformity between Buçaco and the median Armorican syncline, especially at Crozon, has been emphasised by Henry and Thadeu (1971) and Henry et al. (1974 & 1976).

The basal Ordovician beds of the Grés Armoricain Formation in the Armorican Massif have been extensively studied over the past few years. They are generally accepted to be diachronous, but the lack of adequate body fossils make exact correlations difficult. Chauvel & Le Corre (1971), Doré (1972) and Babin et al. (op. cit.) show that the the formation varies in thickness from almost nothing in the north-east of Normandy to about 1000m in the Crozon Peninsula; they also show that a quartzite facies is not always developed and mudstones occur at the

CORRELATION BETWEEN DORNES AND THE CROZON PENINSULA FIG. 51



LEGEND: FIG. 59

same level in the eastern Armorican Massif (fig. 51). Where body fossils have been found in the Grès Armoricain Formation (Deuff & Chauvel, 1970; Henry, 1971) an Arenig age has been indicated; this age is corroborated by the trace fossils which in common with the Dornes area include Cruziana goldfussi (Rouault) and C. furcifera d'Orbigny (Seilacher, 1970; Baldwin, 1977a;J.L. Henry, pers. comm.). The Crozon sequence is very thick (900 - 1150m), has basal red beds (the Pont Réan Formation), and compares closely with the Buçaco sequence (815m; Henry et al., 1974). The Dornes sequence, however, is relatively thin (150m) and comparable with the thinner sequences exposed along the median syncline in Armorica (Babin et al., op. cit.). In common with the Dornes area the formations succeeding the Grès Armoricain Formation throughout most of Armorica have yielded graptolites of the Didymograptus murchisoni Zone, but their stratigraphic positions suggest that the formation is diachronous. This is borne out in southern Normandy around Mortain where beds with Arenig graptolites overlie the quartzite formation (Babin et al., op. cit.).

The presence of D. murchisoni Zone graptolites suggest that the Brejo Fundeiro Formation is approximately equivalent to the lower part of the Postolonnec Formation below the Kerarvail Member (Henry et al., 1976). In addition to the graptolites these sequences share a common fauna including; Neseuretus (Neseuretus) tristani (Brongniart), Colpocoryphe rouaulti Henry, Plaesiacomia oehlerti (Kerforne), Mucronaspis macrophtalma (Brongniart) (M. cf. macrophtalma in the Dornes area), Cacemia ribeiroi (Sharpe) and Tetradella? bussacensis (Jones) (Henry, 1970; Henry & Nion, 1970; Henry et al., 1974 & 1976; Babin et al., 1976; Melou, 1976; Bruton & Henry, 1978). East of the Crozon Peninsula at May-sur-Orne and also in the Dornes area of Portugal Crozonaspis morenensis mayensis Clarkson &

Henry is present in beds of D. murchisoni Zone age (Clarkson & Henry, 1970).

The Monte da Sombadeira Formation is largely unfossiliferous and cannot be directly correlated with the sequences in the Armorican Massif. It is also diachronous in Portugal (see correlation between the Dornes and Buçaco areas), but in the south of the Dornes area it does occur at approximately the same stratigraphical position as the Kerarvail Member in the Postolonnec Formation; a direct correlation is however not implied. The Lameiros Member and lowest part of the Monte do Carvalhal Formation in the Dornes area contain a rich fauna including abundant specimens of N. (N.) tristani and P. oehlerti with Crozonaspis armata Hammann (and possibly with Crozonaspis struvei Henry; J.-L. Henry pers. comm.). This association is similar to that occurring at the top of the Postolonnec Formation, where C. struvei occurs with N. (N.) tristani and P. oehlerti associated with graptolites of the Lower Llandeilo Glyptograptus teretiusculus Zone (Henry et al., 1976).

The bryozoa beds of the Monte do Carvalhal Formation near Dornes contain Colpocoryphe cf. lennieri (Bergeron) Eccoptochile (Eccoptochile) cf. clavigera (Beyrich) and Onnia grenieri (Bergeron), a similar faunal assemblage to that of the "Schistes de Raguenez" in the Grès de Kermeur Formation of the Crozon Peninsula (Henry et al., 1974; Babin et al., 1976; J.-L. Henry pers. comm.) where O. cf. grenieri, C. lennieri and Eccoptochile sp. indet. occur. This Armorican sequence also contains Svobodaina armoricana Babin & Melou, 1972 a brachiopod which is found with O. cf. grenieri in the Serra da Cadaveira Member of the Monte do Carvalhal Formation in Portugal. The bryozoa beds and Serra da Cadaveira Member of the Monte do Carvalhal Formation may therefore be approximately correlated with the "Schistes de Raguenez" in the Grès de Kermeur Formation of the Crozon Peninsula.

The topmost part of the Monte do Carvalhal Formation including the Serra do Amial Member has yielded no fossils in the Dornes area, but the Serra dos Aguilhões Member of the overlying Vale da Ursa Formation has produced poor biserial graptolites of probable basal Llandovery age. In the Armorican massif the upper Ordovician sequences are sparsely fossiliferous and difficult to correlate. Supposed Ashgill horizons are recorded (top of the Saint-Germain-sur Ille Formation, top of the Rosan Formation and the "Pelites à fragments" of Normandy), but Babin et al., (1976) express doubt about their true ages. Only at Domfront have sandstones overlying the "Pélites à fragments" yielded fossils with an upper Ashgill or basal Llandovery age; elsewhere the lowest Silurian horizons recorded are in the middle Llandovery. It is therefore difficult to accurately correlate these sequences between Armorica and Portugal, but it is likely that the upper part of the Monte do Carvalhal Formation (below the Serra do Amial Member) is the equivalent of the Rosan and Cosquer formations in the Crozon Peninsula. It is also probable that the topmost part of the Monte do Carvalhal Formation (Serra do Amial Member and above) is the equivalent of the glacio-marine "Pélites à fragments" in Normandy, and that the Vale da Ursa Formation is the approximate equivalent of the "Grès Culminant" at Domfront (Dangeard and Doré, 1971). Graptolites of Wenlock age are abundant in the Foz da Serta Formation in Portugal and correlate with the sequence with the Wenlock in Armorica which is generally composed of graptolitic mudstones with local limestone beds (Lardeux et al., 1977; Durand, 1977). Around Dornes the Ludlow and Pridoli are represented by the top of the Foz da Serta Formation, the Vale do Serrão Formation, the Serra da Mendeira Formation and most of the Serra do Luação Formation; this mixed sequence of sandstones, quartzites and mudstones is a similar facies to that developed during this period over much of the Armorican Massif. Similarly the Lower Devonian sequences of both areas have calcareous beds in the upper Gedinnian and Siegenian (Lardeux op. cit., Durand op. cit.).

4. Correlation of the Dornes area with the standard European chronostratigraphic series (fig. 52).

In the lower part of the Ordovician sequence the Portuguese strata may be readily correlated with the standard European series. The Serra do Brejo Formation of the Dornes area is developed with both the Skolithos and Cruziana ichnofacies and contains Cruziana furcifera d'Orbigny and Cruziana goldfussi (Rouault). This formation resembles strata of Arenig age in Wales, much of Europe and north Africa, from which the same trace fossil assemblages have been recorded (Crimes, 1968, 1969, 1970a & b, 1975a & c; Seilacher 1970).

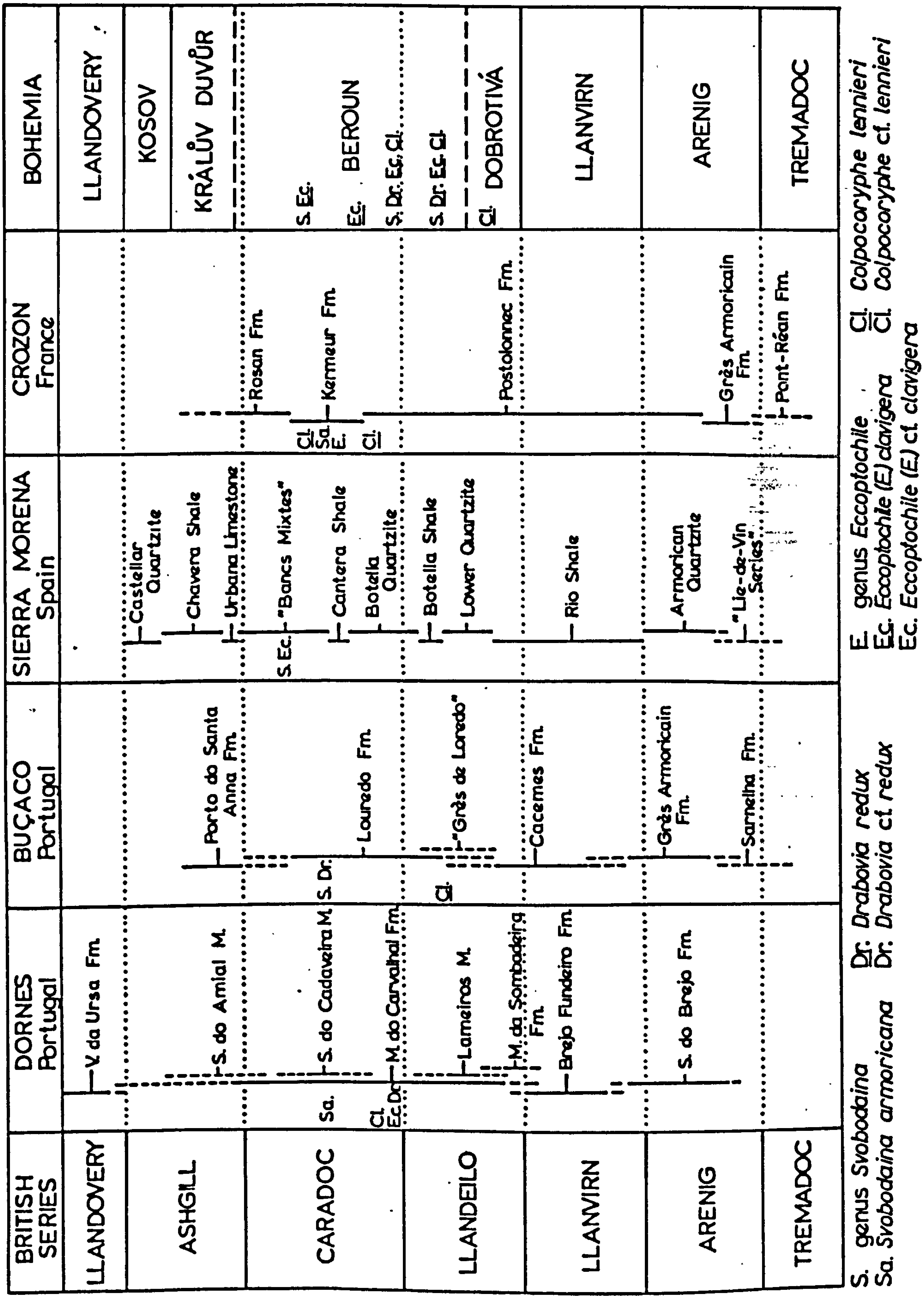
The overlying Brejo Fundeiro Formation is readily correlated with the type sequence of the Llanvirn Series by the occurrence of abundant pendent Didymograptus murchisoni Zone graptolites. Skevington (1974) suggested that the distribution of Llanvirn graptolites was climatically controlled and that the similar pendent faunas of both Wales and Portugal belong to the cold water Atlantic Province. This province occurs as a broad circum-polar belt, but the associated trilobites have more restricted distributions. Whittington (1966 & 1973) and Whittington & Hughes (1972 & 1973) showed the presence of several trilobite provinces during the Ordovician including the Selenopeltis province. Within this province strong faunal ties existed in the Arenig and Llanvirn between central Britain, France, Iberia, Czechoslovakia and Morocco. These ties are reflected in the common occurrence of the trilobite genera Neseuretus, Ectillaenus and Selenopeltis in the Dornes area, Wales, Iberia, France and Bohemia.

During and after the Llandeilo the Anglo-Welsh trilobite fauna of the _Selenopeltis_ province began to evolve along difference lines from the Iberian, French, Bohemian and Moroccan faunas (Whittington & Hughes, 1972). Consequently, the faunal ties became weaker and direct correlation of the Anglo-Welsh Llandeilo, Caradoc and Ashgill type sequences with those of southern Europe is difficult except where rare graptolite marker bands occur. The brachiopods also show similar provinciality and the separate identity of the southern European brachiopods has been noted by Spjeldnaes (1967), Williams (1973 & 1976) and Havlíček (1976). The consequence of this developing provinciality is that the faunas occurring in the Lameiros Member of the Monte do Carvalhal Formation are generally dissociated from the Anglo-Welsh faunas except for the occurrence of the brachiopod _Horderleyella_ cf. _plicata_ Bancroft. This part of the sequence, however, correlates with the upper part of the Cacemes Formation at Buçaco (see Dornes-Buçaco correlation) which contains graptolites of the Lower Llandeilo _Glyptograptus teretiusculus_ Zone and permits a tentative correlation between Dornes and the standard series to be established. Higher in the sequence trilobites from the Monte do Carvalhal Formation include species of _Dysplanus_, _Eccoptochile_, _Colpocoryphe_ and _Kloucekia_ which, with _Onnia grenieri_ (Bergeron) and the associated brachiopods _Svobodaina_ and _Drabovia_, have strong Armorican, Bohemian and Moroccan affinities. These trilobites and brachiopods allow only indirect correlations to be made with the Welsh sequences via Armorica and Bohemia (fig.52), but permit the Caradoc to be broadly identified. In the Dornes area the Ashgill has not yet been positively identified, but the upper 90m of the Monte do Carvalhal Formation are by inference of an Ashgill age.

The basal Silurian of the Dornes area is tentatively recognised by the occurrence of generally indeterminate biserial graptolites in the

PROBABLE CORRELATION OF THE DORNES, BUÇACO, SIERRA MORENA AND CROZON SEQUENCES WITH THE BRITISH AND BOHEMIAN SERIES.

FIG. 52



Serra dos Aguilhões Member of the Vale da Ursa Formation. The overlying Foz da Serta Formation, however, contains abundant graptolites which show little provinciality (Rickards, 1976) and allow direct correlation to be made with the British series. The Llandovery above the turriculatus Zone, most of the zones in the Wenlock, and the nilssoni Zone at the bottom of the Ludlow are present in the Foz da Serta Formation (fig. 29). Microfossils from the Vale do Serrão Formation were identified by K. Dorning who suggested that they were of probable Ludlow age. He also considered that the lower part of the Serra do Luação Formation ranges in age from middle to upper Ludlow into the Pridoli. Brachiopods identified by Dr. V.G. Walmsley and correlated with Rheinland faunas suggest that the upper part of the Serra do Luação Formation is of Gedinnian or Lower Siegenian age and that the overlying Dornes formation is of a Siegenian to Emsian age.

V. PALAEOGEOGRAPHY

1. Introduction

The presence of faunal provinces during the Ordovician is noted in the previous chapter. These provinces were partly controlled by the climate (Spjeldnaes, 1961 & 1967) and reinforce the palaeomagnetic evidence used to position the south Ordovician palaeo-pole. This pole has been located in central north Africa for the early Ordovician (Smith et al., 1973) and geographically north of Africa for the middle Ordovician (Scotese et al., 1979). These positions are approximately accordant with the position of the late Ordovician south pole suggested by the distribution of glacial deposits (see Ashgill palaeogeography described later). It may therefore be concluded that during Ordovician times France, Iberia, Bohemia north Africa and southern Turkey were probably covered by a common sea (Dean, 1975) and were situated in cold to polar latitudes. This sea was independent of other seas where different faunal provinces co-existed, but the environmental discontinuities between the faunal provinces are unknown and might have been a function of climate, distance, land barriers, deep oceans or ocean currents (Ross, 1975). Limestones are commonly present in the Silurian of Iberia and France (Walter, 1972; Cocks & McKerrow, 1973; Paris & Robardet, 1977; Lardeux, 1977) and a warmer palaeoclimate than that of the Ordovician may be inferred. This amelioration of the climate may be explained by the movement of Iberia and France towards the palaeo-equator, so that during the Silurian they occupied tropical or warm temperature temporate latitudes (Scotese et al., 1979). By Devonian times Iberia and France were in tropical latitudes (House, 1973 & 1975; Smith et al., op. cit.) and similar sequences (Paris & Robardet, op. cit.) within the same faunal province occur in both areas (Boucot et al., 1967).

Bullard et al. (1965) suggested that prior to the Atlantic continental drift Iberia was closer to Armorica and the bay of Biscay was closed. This concept has since been verified by the palaeomagnetic evidence of Girdler (1965) and Van der Voo (1967 & 1969). The probable mechanism of the movement which opened the Bay of Biscay was summarised by Ferragne & Vigneux (1978) who showed that the Bay is a post Triassic feature and probably formed during the Eocene. The Lower Palaeozoic palaeogeography of Iberia and France must therefore be considered with the Bay of Biscay closed and the two regions in their relative pre-Atlantic positions. In these positions their geology matches around the arc of the Ibero-Armorican virgation (Bard et al., 1972; Matte & Ribeiro, 1975; Ries, 1979) and some lithofacies and biofacies are concentric to the virgation (Bard et al., op. cit.; Henry et al., 1974; Romano, 1976; Henry & Romano, 1978; Hammann & Henry, 1978).

A geotectonic/palaeogeographic zonation of Iberia was proposed by Lotze (1945) and variations on a similar theme producing comparable results were given by Bard et al. (op. cit.). Hammann (1976b) and Hammann & Henry (1978) use a slightly modified Iberian zonation based on Lotze's original zones. The sequence in the Dornes area is comparable to the sequences described by Hammann (op. cit.) from Zone D, the Eastlusitania - Alcudia Zone. Within this zone Hammann notes that "The Lower Palaeozoic is thick, non metamorphic; a 'sardic' disconformity at the base of the Ordovician (Tremadoc or Arenig) is always present and locally the very top is cut out by an erosional unconformity". The Dornes sequence fits into Lotze's zonation, but a critical discussion of the Iberian Lower Palaeozoic palaeogeography, within the framework of Lotze's Zones, is beyond the scope of this work and the Dornes palaeogeography is described without the constraints of this preconceived zonation.

In the following discussion of the palaeogeography only France and Iberia are generally considered. In figures 53 to 57 they are approximately located in their relative pre-Triassic positions with the Bay of Biscay closed as indicated by Bullard et al. (1965).

The International Subcommission on Stratigraphic Classification (Hedberg, 1972) noted that "Systems are generally recognised world-wide, and series usually so; but many Stages and Chronozones are of only regional application". For widespread correlations and palaeogeographic reconstructions the series therefore emerges as the most practical unit for comparison. In the following explanations and maps the variations in thickness and dominant lithology of each individual series is considered.

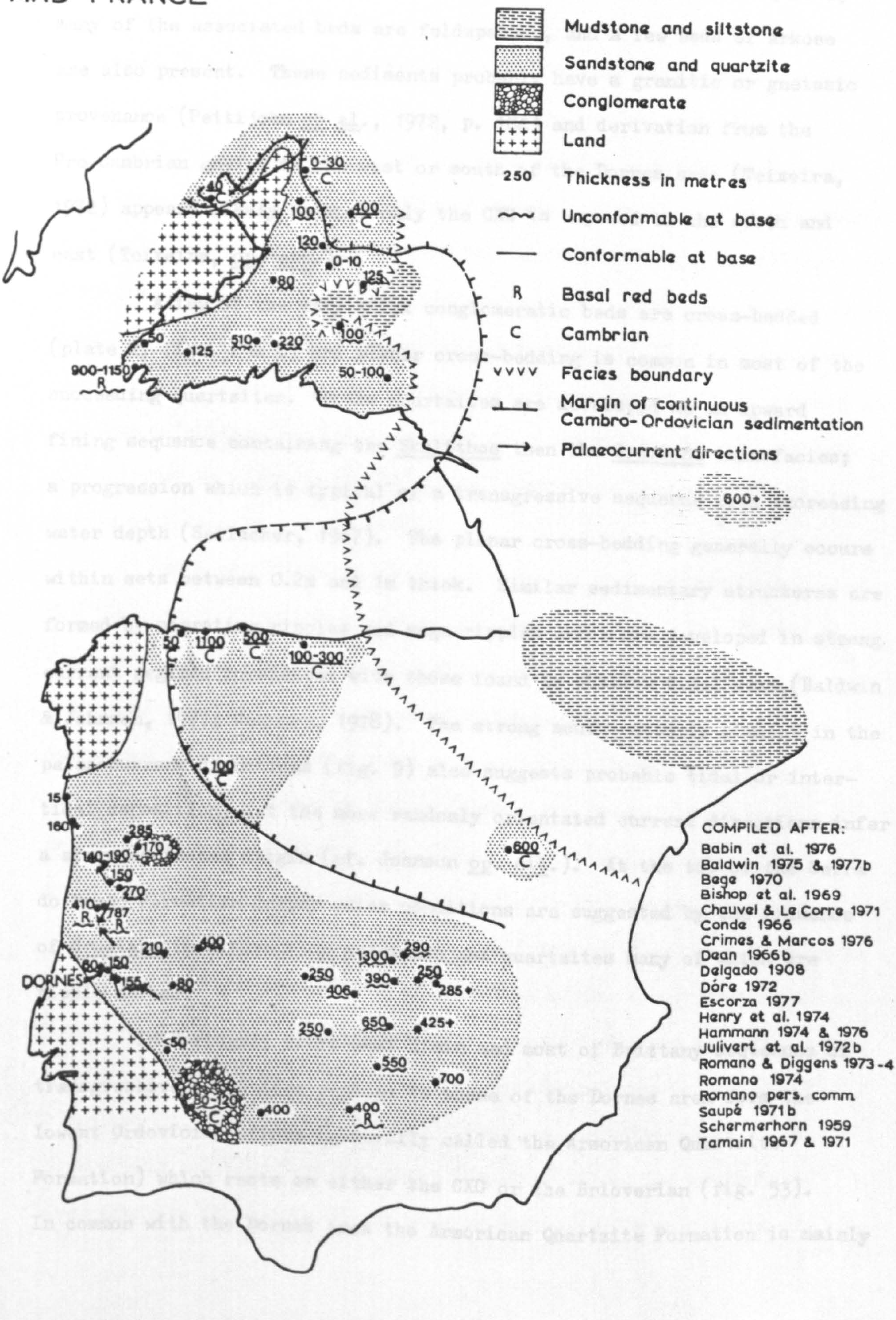
2. Arenig, fig. 53

In the Dornes area the oldest Ordovician beds belong to the Serra do Brejo Formation, a transgressive sequence of conglomerates and quartzites between 60m and 150m thick. These beds rest with a marked angular unconformity on the folded greywackes and siltstones of the CXG. The surface of the basal unconformity appears to be fairly planar and the initial sedimentation generally occurs as a thin discontinuous sequence of pebble orthoconglomerates and very coarse-grained feldspathic quartzites.

Planar unconformities may occur when rising sea level conditions inundate an already peneplaned surface (Krumbein & Sloss, 1963, p. 306). The presence of basal conglomerates in the Dornes area, however, suggest some active erosion during the transgression producing a normal marine conglomerate (Dunbar & Rodgers, 1957, p. 181). A few conglomerate beds containing fragments of greywacke derived from the underlying CXG were

ARENIG: FACIES AND THICKNESS FOR IBERIA AND FRANCE

FIG. 53



observed, but most of the Dornes conglomerates are composed of quartz, many of the associated beds are feldspathic, and a few beds of arkose are also present. These sediments probably have a granitic or gneissic provenance (Pettijohn et al., 1972, p. 184) and derivation from the Pre-Cambrian gneiss to the west or south of the Dornes area (Teixeira, 1972) appears likely because only the CXG is exposed to the north and east (Teixeira, op. cit.).

A few of the very thick conglomeratic beds are cross-bedded (plate 2, figs. 2 & 4) and planar cross-bedding is common in most of the succeeding quartzites. These quartzites are developed as an upward fining sequence containing the Skolithos then the Cruziana ichnofacies; a progression which is typical of a transgressive sequence with increasing water depth (Seilacher, 1967). The planar cross-bedding generally occurs within sets between 0.2m and 1m thick. Similar sedimentary structures are formed by migrating ripples and mega-ripples which are developed in strong current regimes consistent with those found in shallow tidal seas (Baldwin & Johnson, 1977; Johnson, 1978). The strong south-easterly element in the palaeocurrent directions (fig. 9) also suggests probable tidal or inter-tidal deposition, but the more randomly orientated current directions infer a storm dominated origin (cf. Johnson op. cit.). At the top of the Serra do Brejo Formation deeper water conditions are suggested by the presence of Cruziana in alternating mudstones and quartzites many of which are ripple-marked.

In Portugal, south-west Spain and most of Brittany sequences of transgressive quartzites similar to those of the Dornes area form the lowest Ordovician strata (generally called the Armorican Quartzite Formation) which rests on either the CXG or the Brioverian (fig. 53). In common with the Dornes area the Armorican Quartzite Formation is mainly of Arenig age, but local red beds of possible Tremadoc age precede it at Buçaco, the Crozon Peninsula (Henry et al., 1974) and Centenillo (Hammann, 1976b). In both northern Spain and much of Normandy, however, the Ordovician quartzites conformably follow the Cambrian (fig. 53). The same progression of ichnofacies, with similar sedimentary facies, are developed in the vast majority of these conformable and unconformable sequences suggesting that the water became progressively deeper throughout Armorica and Iberia during the lower Ordovician. Exceptions have however been found by Baldwin (1975) and Baldwin & Johnson (1977) who noted minor regressive cycles within the transgressive sequences of northern Spain and the Crozon Peninsula. Similar minor regressive phases may also explain the alternating Cruziana and Skolithos ichnofacies recorded from the Montes de Toledo by Escorza (1977).

Rapid variations in thickness from 15m to 1150m have been noted for the Arenig quartzites of Iberia and Armorica (fig. 53). These thickness variations, however, generally occur without altering the progression of the ichnofacies which suggests that different local subsidence rates occurred. Areas such as Buçaco (815m), the Crozon Peninsula (1150m), Montes de Toledo (1300m) and Luaca (1100m) stand out as sites of rapid subsidence, but Dornes (60 – 150m), Valongo (190m) and north of Rennes (80m) received only relatively thin deposits.

Most transgressive sequences are diachronous and the diachronism of the Santa Justa Formation (the equivalent of the Armorican Quartzite Formation at Valongo) was illustrated by Romano & Diggens (1973-4). The widespread diachronism of the Armorican Quartzite Formation is also illustrated by the age of the upper formational boundary which is of lower Arenig age near Cordoba, Spain (Hammann, 1976b) and of probable lower Llanvirn age in the Dornes area of Portugal. In most parts of

Iberia and Armorica the Arenig/Llanvirn boundary approximates to the top of the Armorican Quartzite Formation, consequently where no detailed palaeontological information is available a similar position for the series boundary is generally assumed (Babin et al., 1976; Hammann, 1976b). This assumption has largely been used in the construction of figures 53 and 54.

The distribution of the Arenig quartzites and mudstones (fig. 53) suggests that during this epoch land areas existed in central Normandy, western Galicia and south-west Portugal. The concept of land in south-west Portugal is reinforced by the westward thinning of the Serra do Brejo Formation and the occurrence of slumped conglomerates south of Badajoz (Hammann, op. cit.). The probable provenance of the sediments reinforces this interpretation which is the opposite to that proposed by Conde (1966). The rapid northward thinning of the Arenig sequences in northern Portugal between Apúlia (160m; Romano, 1974) and Viana do Castelo (15m; M. Romano, pers. comm.) along with the rapid westward attenuation of the Galician sequences (Bege, 1970; Julivert et al., 1972b) point towards a land area in western Galicia, In Normandy the Arenig quartzites also thin dramatically onto an upstanding land area and are overlapped by the subsequent Llanvirn sediments (Doré, 1972; Renouf, 1974).

Arenig sandstones and quartzites with similar ichnofacies to those of the Ibero-Armorican sequences are widespread. Comparable strata have been recorded from Wales (Crimes, 1970b), north Africa (Bennacef et al., 1971; Beuf et al., 1971), Turkey (Dean, 1975), Jordan (Selley, 1970) and Newfoundland (Seilacher & Crimes, 1969; Bergström, 1976); all illustrating the widespread extent of the Arenig transgression.

3. Llanvirn, fig. 54

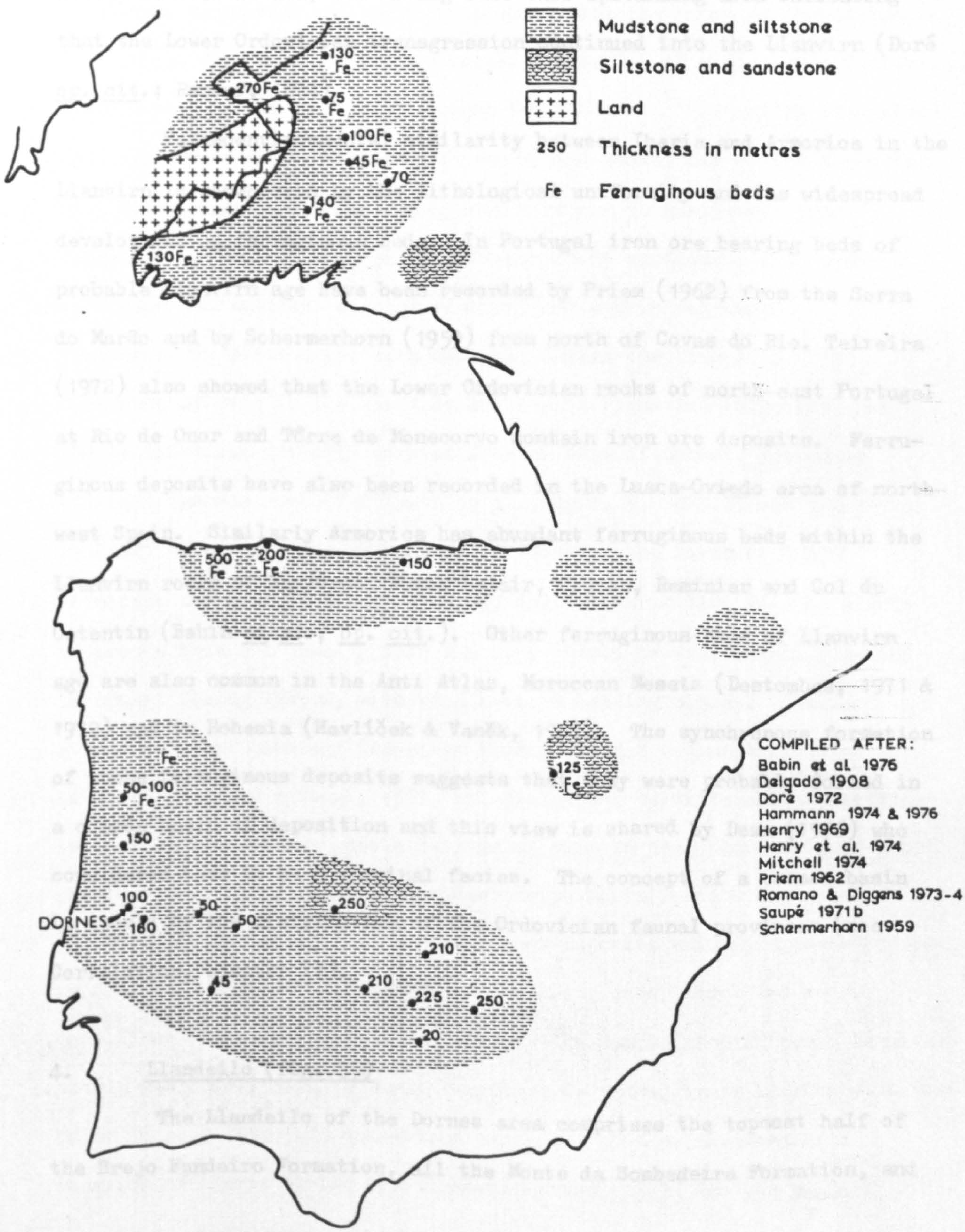
In the Dornes area the Llanvirn Series is approximately 90m thick. The topmost quartzite and mudstone beds of the Serra do Brejo Formation are probably of Llanvirn age, but the majority of the series is contained within the Brejo Fundeiro Formation and consists of mudstones and siltstones. These mudstones and siltstones vary from fissile to massive with slight lithological banding and are similar to the argillaceous rocks formed within the middle and outer parts of shelf seas (Johnson, 1978). Greensmith (1971, p. 416) also showed that similar lithologies are currently being deposited on the deeper parts of the continental shelf around Britain. Similar well laminated argillaceous rocks are usually deposited in water more than 20-50m deep (Allen, 1970). The majority of the probable benthic fossils in the Llanvirn mudstones and siltstones of the Dornes area are nearly all disarticulated and winnowed. The planktonic forms are however commonly complete suggesting that much of the shelly material was transported into the area, possibly during times of storm.

The Llanvirn Series in Iberia is generally similar to that of the Dornes area and developed as a sequence of mudstones and siltstones between 50 and 200m thick (fig. 54). In places where the Arenig sequences are thick the trend has generally continued into the Llanvirn; consequently around Luaca the Llanvirn Series is about 500m thick and south of Cuidad Real about 250m thick. Conversely where the Arenig sequences are thin the Llanvirn sequence is usually thin; this is shown at Badajoz where the Armorican Quartzite Formation is 80 – 120m thick and the Llanvirn strata about 45m thick (Hammann, 1976b). The apparent uniformity of the Llanvirn sediments in Iberia make it impossible to predict where land areas existed.

The Armorican Llanvirn is similar to that of Iberia and is dominantly composed of siltstones and mudstones between 45 and 130m thick

LLANVIRN: FACIES AND THICKNESS FOR IBERIA AND FRANCE

FIG. 54



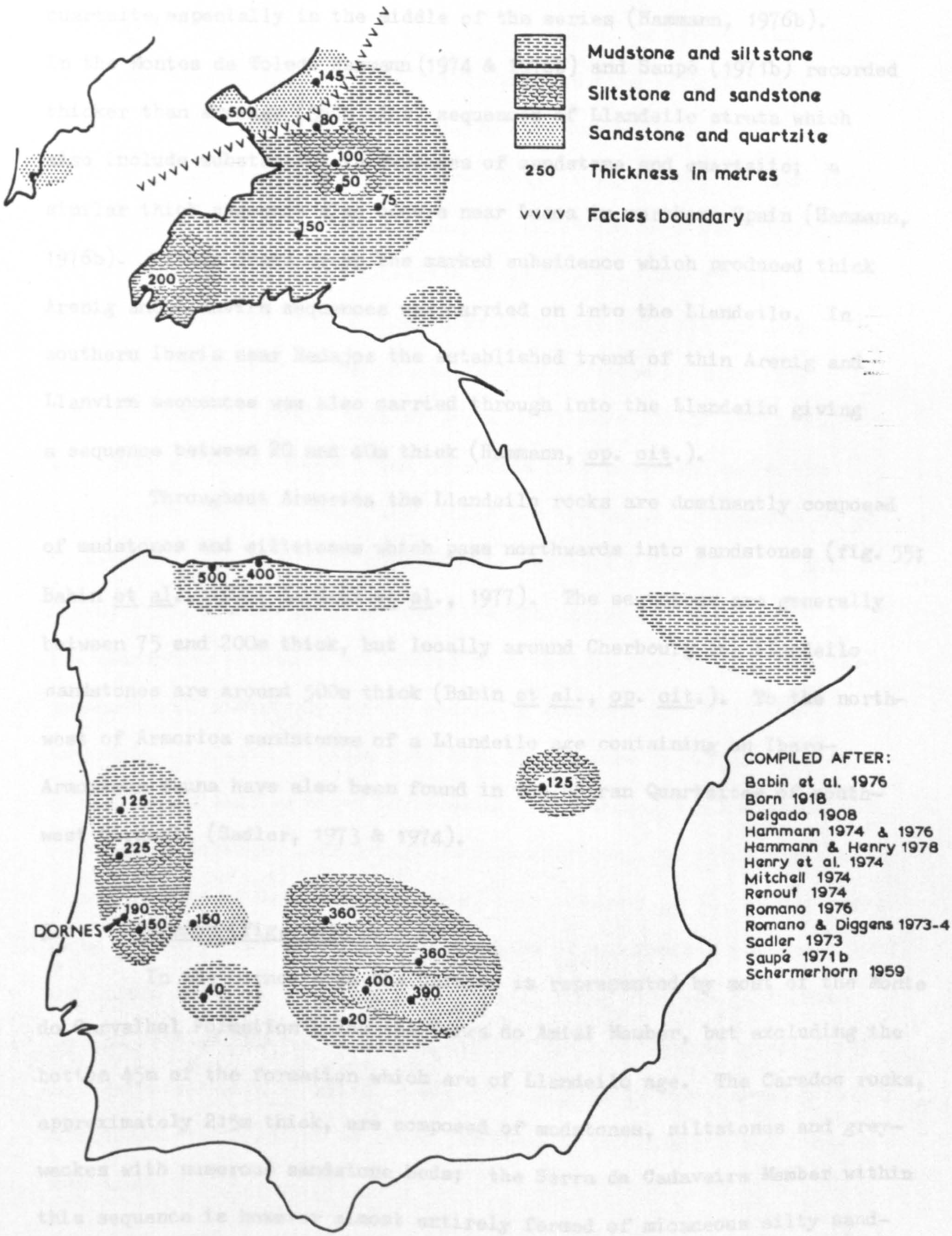
with local thickening to 270m south of Cherbourg (Babin et al., 1976; Lardeux et al., 1977). The local land area or swell noted for the Arenig in central Normandy persisted into the Llanvirn (Doré, 1972). The Llanvirn strata however overlap the Arenig onto this upstanding area indicating that the Lower Ordovician transgression continued into the Llanvirn (Doré op. cit.; Renouf, 1974).

Palaeoenvironmental similarity between Iberia and Armorica in the Llanvirn is shown both by the lithological uniformity and the widespread development of ferruginous beds. In Portugal iron ore bearing beds of probable Llanvirn age have been recorded by Priem (1962) from the Serra do Marão and by Schermerhorn (1959) from north of Covas do Rio. Teixeira (1972) also showed that the Lower Ordovician rocks of north-east Portugal at Rio de Onor and Tôrre de Monecorvo contain iron ore deposits. Ferruginous deposits have also been recorded in the Luaca-Oviedo area of north-west Spain. Similarly Armorica has abundant ferruginous beds within the Llanvirn rocks of May/Orne, Menez Belair, Crozon, Reminiar and Col du Cotentin (Babin et al., op. cit.). Other ferruginous beds of Llanvirn age are also common in the Anti Atlas, Moroccan Meseta (Destombes, 1971 & 1972) and in Bohemia (Havlíček & Vaněk, 1966). The synchronous formation of these ferruginous deposits suggests that they were probably formed in a common basin of deposition and this view is shared by Dean (1976) who considered them to be a marginal facies. The concept of a common basin is upheld by the distribution of the Ordovician faunal provinces (see Correlation, chapter IV).

4. Llandeilo (fig. 55)

The Llandeilo of the Dornes area comprises the topmost half of the Brejo Fundeiro Formation, all the Monte da Sombadeira Formation, and approximately the lowest 45m of the Monte do Carvalhal Formation including the Lameiros Member. This sequence, approximately 185m thick, is composed of siltstones and mudstones with the exception of the very micaceous sandstones and quartzites which form the Monte da Sombadeira Formation. The argillaceous sediments are mainly of a shelf sea facies similar to that which existed during the Llanvirn. The influx of coarse detrital material in the planar cross-bedded sandstones of the Monte da Sombadeira Formation, however, suggests a return to shallower water conditions. Similar, but probably diachronous sandstones also occur at Buçaco and Amendoa (see correlation) and a minor regressive-transgressive phase might have occurred during the Llandeilo. The abundance of mica in the Monte da Sombadeira Formation indicates that the sediment was probably derived from an area of schist, gneiss or plutonic igneous rock (Pettijohn et al., 1972, p. 302). These sediments probably have a similar provenance to those of the Serra do Brejo Formation and a southerly or westerly derivation is likely. The highly micaceous beds are usually thin and very thinly bedded, commonly graded in upward fining cycles, with mica covered bedding planes. Similar graded beds are commonly deposited from suspended sediment after periods of storm (Reineck & Singh, 1973) and production by differential settling is also implied by the concentrations of mica in the upper parts of the graded beds. Above the Monte da Sombadeira Formation the coquinas of the Lameiros Member are similar to placer deposits which are concentrated in shelf sea or tidal flat environments, both under tidal and storm conditions (Reineck & Singh, op. cit.). The composition of these coquinas with a moderately rich, but not very diverse fauna, is in keeping with the polar to cool temporate conditions suggested by the palaeomagnetic location of Iberia during the Llandeilo (Ross, 1975; Scotese et al., 1979).

LLANDEILO: FACIES AND THICKNESS FOR IBERIA AND FRANCE — FIG. 55



Throughout most of Iberia the Llandeilo beds are generally composed of between 100 and 200m of siltstones and mudstones (fig. 55), which frequently contain appreciable sequences of sandstone and quartzite, especially in the middle of the series (Hammann, 1976b). In the Montes de Toledo Hammann (1974 & 1976b) and Saupé (1971b) recorded thicker than average (360m plus) sequences of Llandeilo strata which also include substantial thicknesses of sandstone and quartzite; a similar thick sequence also occurs near Luaca in northern Spain (Hammann, 1976b). Within these areas the marked subsidence which produced thick Arenig and Llanvirn sequences was carried on into the Llandeilo. In southern Iberia near Badajoz the established trend of thin Arenig and Llanvirn sequences was also carried through into the Llandeilo giving a sequence between 20 and 40m thick (Hammann, op. cit.).

Throughout Armorica the Llandeilo rocks are dominantly composed of mudstones and siltstones which pass northwards into sandstones (fig. 55; Babin et al., 1976; Lardeux et al., 1977). The sequences are generally between 75 and 200m thick, but locally around Cherbourg the Llandeilo sandstones are around 500m thick (Babin et al., op. cit.). To the north-west of Armorica sandstones of a Llandeilo age containing an Ibero-Armorican fauna have also been found in the Gorran Quartzites of south-west Cornwall (Sadler, 1973 & 1974).

5. Caradoc (fig. 56)

In the Dornes area the Caradoc is represented by most of the Monte do Carvalhal Formation below the Serra do Amial Member, but excluding the bottom 45m of the formation which are of Llandeilo age. The Caradoc rocks, approximately 215m thick, are composed of mudstones, siltstones and grey-wackes with numerous sandstone beds; the Serra da Cadaveira Member within this sequence is however almost entirely formed of micaceous silty sand-stones.

The Lower Caradoc rocks of the Dornes area contain numerous bryozoa beds. These beds generally occur as graded units composed of fine to medium grained greywacke and contain the abundant fragmented remains of bryozoa, crinoids, brachiopods and a few trilobites. The greywacke beds usually vary in thickness from thin to medium and generally have conformable non-erosive contacts with the preceding units. Deposition from turbidity currents is suggested, but the lack of sole markings indicates that the currents were weak and probably of low density and velocity (Reineck & Singh, 1973). The transport of fragile bryozoa for long distances by turbidity currents has been proved by Lagaai (1973) and the deposition of storm or hurricane induced graded greywacke beds within a continental shelf environment was noted by Hayes (1967). The sediments both above and below the bryozoa beds are of a shelf sea facies and the usual continental slope or abyssal plane turbidite environments (Reineck & Singh, op. cit.; Rupke, 1978) are not applicable to the Portuguese greywacke beds. The widespread abundance of bryozoa rich beds of Caradoc age, and the occurrence of limestones in the generally mudstone and siltstone sequences of southern Iberia have been interpreted by Hammann (1976b) to indicate a shallow water environment. Greywackes are however also recorded in southern Iberia near Córdoba (Hammann, op. cit.) and the "Bancs mixtes" of Centenillo (Tamain, 1967; Chauvel et al., 1969) appear to be a similar facies to the bryozoa beds of the Amendoa (Delgado, 1908) and Dornes areas of Portugal. It appears likely that the Portuguese bryozoa rich greywackes (and possibly the southern Spanish greywackes) were deposited within basins in a continental shelf environment possibly with local swells acting as sites for bryozoa accumulation and limestone formation.

The Serra da Cadaveira Member of the Dornes sequence overlies the bryozoa beds and consists of sandstones which are usually bioturbated, sometimes cross-bedded, and which contain a rich brachiopod fauna, a few trilobites and bryozoa. These sandstones characteristically contain abundant articulated specimens of the brachiopod Svobodaina armoricana Babin & Melou and are similar to shelf sea sandstones described by Reineck & Singh (op. cit.) and Johnson (1978). The Serra da Cadaveira Member is overlain by unfossiliferous greywackes and mudstones which were probably deposited from turbidity currents in a similar manner to the bryozoa beds.

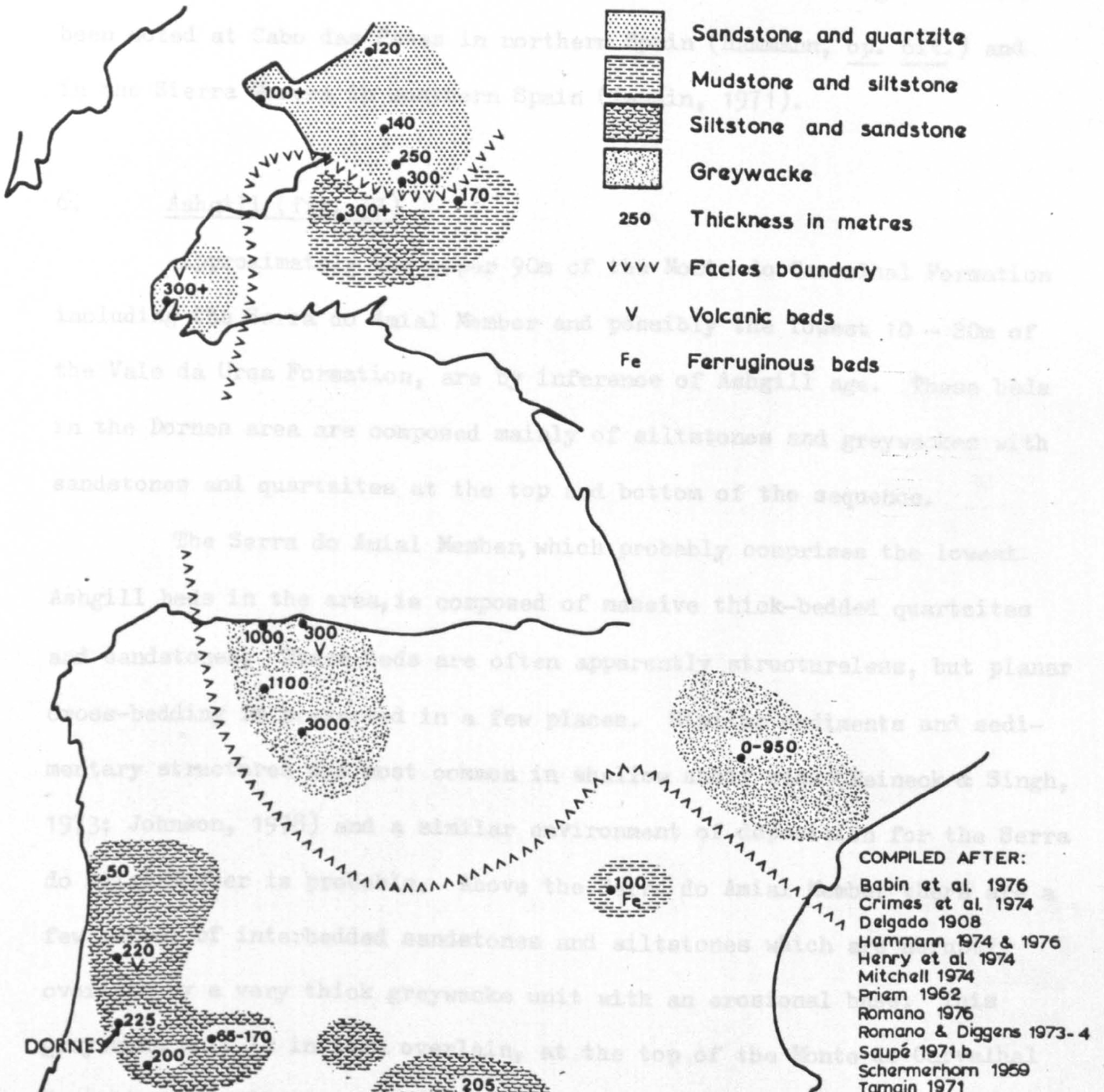
In southern Iberia the Caradoc rocks are mainly between 170 and 280m thick (fig. 56). The subsidence which locally preserved thick Arenig, Llanvirn and Llandeilo sequences was less obvious in the Caradoc and only slight thickening occurs in most of the former downwarps. The trend producing thin sequences south of Badajoz was however maintained giving only 50m of Caradoc strata (Hammann, op. cit.).

In contrast to southern Iberia marked subsidence during the Caradoc occurred in both north-west and north-east Spain. In the Cantabrian mountains between 1000 and 3000m of greywackes were laid down down (Marcos, 1974; Crimes et al., 1974) and about 1000m of similar beds were deposited in the Pyrenees (Hammann, op. cit.). The turbidites of the Cantabrian mountains had a southerly derivation (Crimes et al., op. cit.) and were presumably fed with sediment from the shelf sea area of southern Iberia.

The Caradoc rocks of Armorica are generally of a similar shelf sea facies to those of southern Iberia. They consist mainly of mudstone and sandstone sequences between 100 and 300m thick (fig. 56), but probable shelf margin deposits were also recorded near Mayenne (Babin et al., 1976). Volcanic lavas and tuffs are present in the Caradoc sequences of both

CARADOC: FACIES AND THICKNESS FOR IBERIA AND FRANCE

FIG. 56



Armorica and Iberia. These volcanic rocks are represented in the Crozon Peninsula by the Rosan Formation (Henry et al., 1974) and a comparable volcano-sedimentary sequence occurs at Buçaco in Portugal (Mitchell, 1974; Henry et al., op. cit.). Volcanic rocks of Caradoc age have also been noted at Cabo das Penas in northern Spain (Hammann, op. cit.) and in the Sierra Morena in southern Spain (Tamain, 1971).

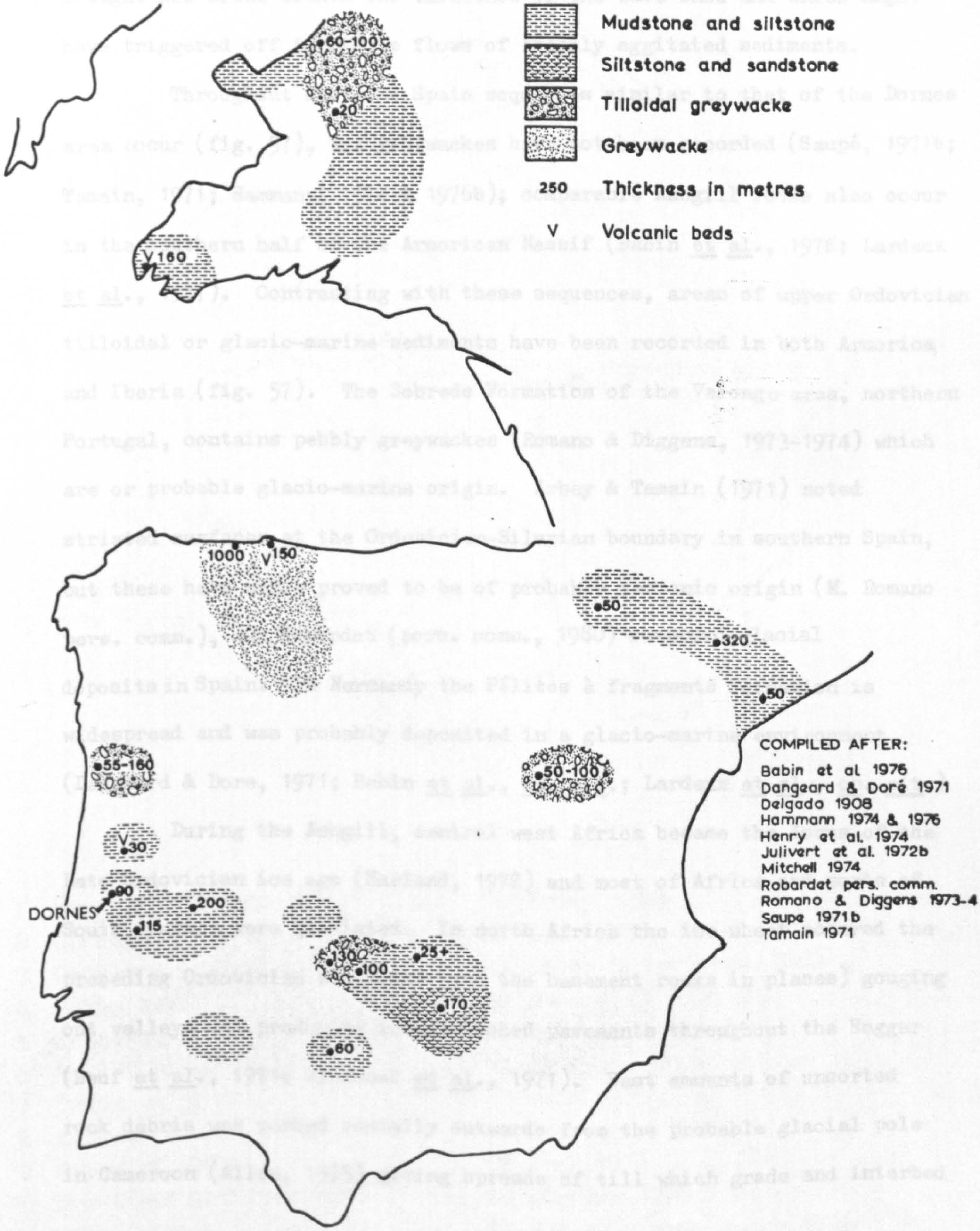
6. Ashgill (fig. 57)

Approximately the upper 90m of the Monte do Carvalhal Formation including the Serra do Amial Member and possibly the lowest 10 - 20m of the Vale da Ursa Formation, are by inference of Ashgill age. These beds in the Dornes area are composed mainly of siltstones and greywackes with sandstones and quartzites at the top and bottom of the sequence.

The Serra do Amial Member, which probably comprises the lowest Ashgill beds in the area, is composed of massive thick-bedded quartzites and sandstones. These beds are often apparently structureless, but planar cross-bedding is preserved in a few places. Similar sediments and sedimentary structures are most common in shallow shelf seas (Reineck & Singh, 1973; Johnson, 1978) and a similar environment of deposition for the Serra do Amial Member is probable. Above the Serra do Amial Member there are a few metres of interbedded sandstones and siltstones which are abruptly overlain by a very thick greywacke unit with an erosional base. This greywacke unit is in turn overlain, at the top of the Monte do Carvalhal Formation, by siltstones and sandstones with interbedded greywackes. The sandstones in this sequence are often ripple-marked and the lower sandstones and quartzites of the overlying Vale da Ursa Formation are of probable shelf sea origin. The presence of greywacke beds might appear anomalous, but a storm/hurricane induced mechanism of formation

ASHGILL: FACIES AND THICKNESS FOR IBERIA AND FRANCE

FIG. 57



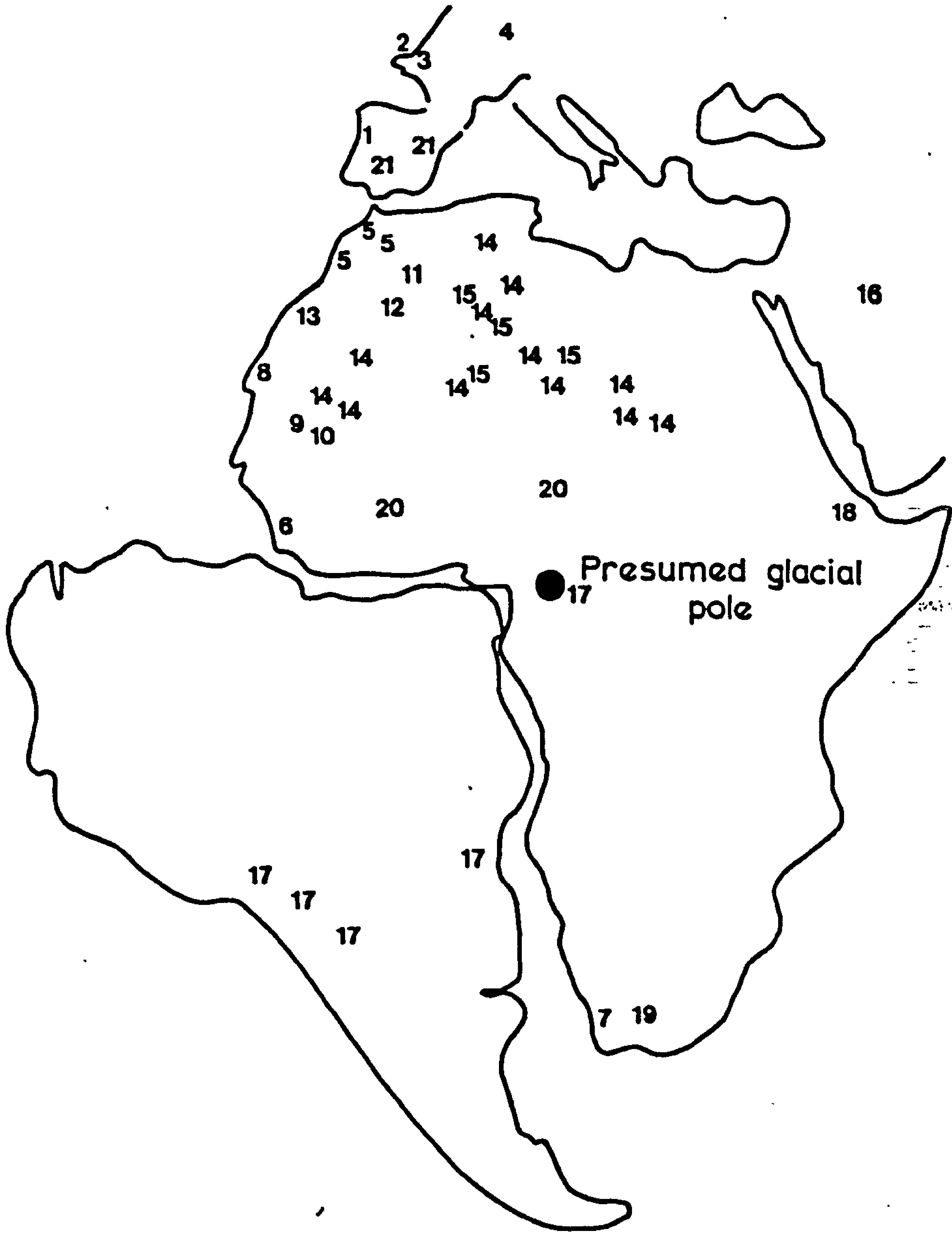
as suggested earlier for the bryozoa beds might explain their occurrence. Formation of greywackes might also have been enhanced by the drop in sea level towards the end of the Ashgill (McKerrow, 1979) which would have brought new areas within the influence of the wave base and which might have triggered off turbidite flows of freshly aggitated sediments.

Throughout southern Spain sequences similar to that of the Dornes area occur (fig. 57), but greywackes have not been recorded (Saupé, 1971b; Tamain, 1971; Hammann, 1974 & 1976b); comparable Ashgill rocks also occur in the southern half of the Armorican Massif (Babin _et al._, 1976; Lardeux _et al._, 1977). Contrasting with these sequences, areas of upper Ordovician tilloidal or glacio-marine sediments have been recorded in both Armorica and Iberia (fig. 57). The Sobredo Formation of the Valongo area, northern Portugal, contains pebbly greywackes (Romano & Diggens, 1973-1974) which are or probable glacio-marine origin. Arbey & Tamain (1971) noted striated surfaces at the Ordovician-Silurian boundary in southern Spain, but these have since proved to be of probable tectonic origin (M. Romano pers. comm.), and Robardet (pers. comm., 1980) recorded glacial deposits in Spain. In Normandy the Pélites à fragments Formation is widespread and was probably deposited in a glacio-marine environment (Dangeard & Dore, 1971; Babin _et al._, _op. cit._; Lardeux _et al._, _op. cit._)

During the Ashgill, central west Africa became the locus of the Late Ordovician ice age (Harland, 1972) and most of Africa and parts of South America were glaciated. In north Africa the ice sheet scoured the preceding Ordovician sediments (and the basement rocks in places) gouging out valleys and producing ice-scratched pavements throughout the Hoggar (Beuf _et al._, 1971; Bennacef _et al._, 1971). Vast amounts of unsorted rock debris was pushed radially outwards from the probable glacial pole in Cameroon (Allen, 1975) giving spreads of till which grade and interbed

DISTRIBUTION OF PROBABLE LATE ORDOVICIAN GLACIAL DEPOSITS

FIG. 58



1 Romano & Diggens 1973-74
2 Lardeux *et al.* 1977
3 Dangeard & Doré 1971
4 Sdzuy 1971
5 Destombes 1968, 1971, 1972
6 Reid & Tucker 1972
7 Cocks *et al.* 1970
8 Bronner & Sougy 1969
9 Dia *et al.* 1969
10 Biju-Duval & Gariel 1969
11 Arbey 1968
12 Gevin 1966, Gevin *et al.* 1968
13 Sougy & Lecorché 1963
14 Beuf *et al.* 1966, 1971
15 Debyser *et al.* 1965
16 Mc Clure 1978
17 Allen 1975
18 Dow *et al.* 1971
19 Lock 1973
20 Dennison 1976
21 Robardet pers. comm. 1980

with marine and fluvio-glacial deposits; the distribution of the Ordovician glacial deposits is shown by figure 58. Sediment carried by large icebergs was borne away from the main ice sheet to form rafted tillites such as those recorded by Schenk (1971) at the base of the White Rock Formation in Nova Scotia. This mode of origin might also explain the Pélites â fragments Formation in Normandy and the probable dropstones in the Sobredo Formation of northern Portugal.

The inference from the distribution of glacial and glacio-marine deposits is that the Dornes area was situated within circum-polar waters on the periphery of the Late Ordovician ice sheet. The probable Ashgill sediments of the Dornes area have proved to be unfossiliferous and Delgado (1908) found no fossils in the equivalent beds at Amendoa. Unfossiliferous sediments are likely to be formed under floating ice sheets and the attendant sediments of wet based glaciers include siltstones, sandstones, mudstones and turbidites (Carey & Ahmed, 1961). The palaeoenvironment was perhaps also unsuitable because of the very low salinity associated with an actively melting ice sheet or the very high salinity bottom waters produced by the accretion of both ice sheets and pack ice (Gill, 1973; Anderson, 1972). At the top of the Monte do Carvalhal Formation there is an apparently continuous passage into the sandstones and quartzites of the Vale da Ursa Formation. These beds are often ripple-marked, cross-bedded and probably reflect the shallow water conditions associated with the Late Ordovician glaciation.

7. Llandovery

In the Dornes area the Serra dos Aguilhões Member of the Vale da Ursa Formation and the lowest beds of the succeeding Foz da Serta Formation yielded Llandovery graptolites, indicating that the series is represented by approximately 16m of beds. No obvious non-sequences were observed in the field and these beds are generally carbonaceous and pyritic. Within this sequence the black sandstones of the Serra dos Aguilhões Member are all fine and very fine-grained, well laminated and micaceous with numerous poorly preserved graptolites occurring on the bedding planes. Reineck & Singh (1973) described numerous environments in which evenly laminated sands occur and it appears most likely that these beds were deposited from storm induced suspension clouds within a generally euxinic basin. Tourmaline is abundant in the black sandstones of the Serra dos Aguilhões Member and is probably the iron rich variety Schorl. This variety commonly occurs in granites (Deer et al., 1966) and a similar form has a pegmatic origin (Krynine, 1946). The abundance of tourmaline in some of these Portuguese beds suggests first cycle derivation with a probable granitic or pegmatitic provenance. The overlying mudstones of the Foz da Serta Formation are also highly carbonaceous; the sequence is thin and suggests very slow deposition in a euxinic environment probably similar to the bituminous shale facies of the British Jurassic (Johnson, 1978).

A Llandovery sequence similar to that of the Dornes area has also been described from the Vicinity of Almaden in Spain. Here Saupé (1971a) recorded the "Quartzite du criadero", a 75m thick sequence which includes 0.5m of "Grès noir" and which is overlain by mudstones of probable upper Llandovery age. In common with the Dornes area tourmaline is the main heavy mineral in the "Quartzite du criadero" (Saupé, op. cit.). The "Gres noir" is similar to the Serra dos Aguilhões Member in the Dornes area and probably occupies a similar stratigraphical position. Throughout most of Iberia the Llandovery sediments are also thin and consist of mudstones and sandstones which are rich in pyrite (Walter, 1972).

In the Dornes and Almaden areas the thin Llandovery sequences are probably para conformable (Dunbar & Rodgers, 1957) on the Ordovician. In Armorica the Llandovery sediments are also thin, they are however composed mainly of sandstones and a stratigraphical break occurs between the Ordovician and Silurian throughout most of the region (Bishop et al., 1969; Lardeux et al., 1977; Durand, 1977).

Evidence for the terminal Ordovician ice age is strong (see Ashgill palaeogeography), but the influence of the ice age probably lingered into the Llandovery. Eustatic sea level rises, probably caused by the melting ice caps have been recorded in both the basal Llandovery and the basal upper Llandovery (Berry & Boucot, 1973; McKerrow, 1979). These sea level rises appear to equate with periods of slow pyritic and carbonaceous sedimentation in the Dornes area. The abundance of graptolites and organic matter in the Portuguese sediments suggest a rich planktonic biota, perhaps blanketing the surface like the weed of the Sargasso Sea (Bulman, 1957), and effectively damping any influence of wave action on the bottom sediments, stopping light and restricting oxygen circulation to produce euxinic bottom conditions. Deep water is not implied and bituminous shales may characterise fairly shallow water environments often associated with marine transgressions (Hallam, 1967).

8. Wenlock

The dark coloured mudstones of the Foz da Serta Formation have yielded graptolites from most of the biozones present in the Wenlock Series (fig. 29; Basset et al., 1975). This suggests that continuous deposition of mudstones, with some sandstones in the middle, occurred throughout the Wenlock in the Dornes area. The thickness of this strata is difficult to determine because of the intensely folded nature of the beds, but the Wenlock appears to be between 130 and 190m thick. The mudstones are often laminated and generally less carbonaceous than the Llandovery mudstones. The sandstones are sometimes ripple drift cross-bedded and were probably deposited in a shelf environment; a restricted environment is however also suggested by the lack of benthic marine organisms in these beds.

The Wenlock Series of the Dornes area and strata throughout much of Europe and north Africa are generally developed as a fairly uniform sequence of platform mudstones (Cocks & McKerrow, 1973). Walter (1972) also noted similar sequences in these parts, but additionally mentions local swells or land areas in northern Spain and north-western Armorica. Although the Wenlock Series is fairly uniform in its development Saupé (1971b) recorded an anomalous sequence at Almaden where lavas and pyroclastic rocks are interbedded with the sediments. Slight variations also occur in Armorica where limestones are locally present in the upper part of the Wenlock sequence (Walter, op. cit.; Lardeux et al., 1977).

9. Ludlow

The basal Ludlow in the Dornes area has only tentatively been recognised by the occurrence of a few poorly preserved graptolites from the upper part of the Foz da Serta Formation. The upper boundary of the Ludlow has however been proved by the presence of microfossils. The upper few metres of the Foz da Serta Formation, the Vale do Serrão Formation, the Serra da Mendeira Formation and the bottom 30 - 80m of the Serra do Luação Formation are of Ludlow age.

The Vale do Serrão Formation, a characteristic striped sequence of alternating mudstone and quartzite laminae is similar to the rhythmic deposits formed by strong tidal action in shallow water; these sediments are most common in intertidal flats and river estuaries (Reineck & Singh, 1973). The scarce occurrence of bioturbation in the Portuguese beds suggests that the environment changed rapidly and very few burrowing organisms became established. The individual laminae in the striped beds can commonly be traced for several metres, but the uniformity and basin-wide continuity of glacial varves are not present and the laminae do not show the upward fining which typifies both varved beds and storm sand layers (Reineck & Singh, op. cit.). The Vale do Serrão Formation forms an upward coarsening sequence which culminates with the quartzites of the Serra da Mendeira Formation. These quartzites contain abundant Monocraterion which is characteristic of the shallow water Skolithos facies (Seilacher, 1967) and a sandy, mid tidal flat environment might be suggested. The overlying Serra do Luação Formation is developed as a heterolithic upward fining sequence. Bioturbation is widespread and Monocraterion? is very common; ripple marks, cross-bedding, load casts and flame structures are abundant. Many of the thicker sandstone and quartzite beds in this sequence have erosional bases and mud flake conglomerate bands are common; ferruginous beds also occur near the base of the formation. Similar heterolithic facies with comparable sedimentary structures and mud flake conglomerates may occur in mid tidal flat environments (Klein, 1977); shallow water is also suggested by the Skolithos facies trace fossils. The shallow water Ludlow sequence of the Dornes area reflects the late Ludlow eustatic regression recorded by McKerrow (1979).

The Ludlow sequence described by Carls (1977) from the Eastern Iberian Chains is lithologically similar to that of the Dornes area. The Spanish sequence consists of dark shales with arenaceous intercalations (Bádenas Formation) which is overlain by thick-bedded quartzites forming the lower member of the Luesma Formation; these quartzites pass upwards into alternating shales, sandstones and quartzites with ferruginous beds and phosphatic nodules. Many other Ludlow sequences in Armorica and Iberia also show the progressive development of sandy facies (Walter, 1969 & 1972; Saupé, 1971b; Durand, 1977; Lardeux, 1977).

10. Pridoli and Gedinnian

Microfossils collected from the Serra do Luação Formation indicate that it is at least partly of Pridoli age. The occurrence of Siegenian-Emsian fossils in the overlying Dornes formation suggest that the Gedinnian (if present) occurs within the upper part of the Serra do Luação Formation and that this Pridoli-Gedinnian sequence is between 120 and 170m thick. The bottom part of this sequence, interbedded quartzites, sandstones and mudstones with Monocraterion, mudstone pellets and ferruginous nodules, is similar to the upper Ludlow beds and a similar environment of deposition may be implied. The upper part of the sequence is also heterolithic, bioturbation is common and shelly fossils were recovered from the top of the formation; few environmental indicators are however present. A mid-tidal facies (Klein, 1977) is likely, but a sub-tidal shelf sea facies (Johnson 1978) is also possible.

The Dornes Pridoli-Gedinnian sequence is similar to the equivalent strata described by Carls and Gandl (1967) and Carls (1977) from the Eastern Iberian Chains. The Spanish sequence of sandstones and mudstones includes numerous ferruginous sandstone beds and ferruginous nodules are also present. Ferruginous sandstones have also been recorded by Brouwer (1967) from equivalent beds in the Cantabrian

Mountains and by Paris & Robardet (1977) from the Armorican massif. In the Dornes area the Gedinnian strata is less than 80m thick and may be missing altogether; condensed or absent Gedinnian sequences have also been recorded in many parts of Iberia (Llopis Llado _et al._, 1967; Teixeira & Thadeu, 1967) and the Armorican sequences are similarly variable (Babin et al., 1972; Lardeux _et al._, 1977).

11. Siegenian and Emsian

The Dornes formation is of probable Siegenian to Emsian age and constitutes the only calcareous strata in the area. The limestones, which are often dolomitic and which contain bedded coquinas, form part of a heterolithic sequence with mudstones and sandstones; the bedding is generally fairly regular and bioturbation is common. Similar heterolithic calcareous facies with appreciable amounts of terrigenous clastics are generally restricted to open shelf environments (Sellwood, 1978).

In common with the Dornes area most of the comparably aged sequences in Iberia and Armorica are developed as heterolithic calcareous facies, especially in the middle Siegenian (Llopis Llado _et al._, 1967; Teixeira & Thadeu, 1967; Babin _et al._, 1972; Lardeux _et al._, 1977; Paris & Robardet, 1977).

LEGEND FOR FIGURES 3-36 AND 47-51; FIG. 59
Details in parentheses refer only to figs. 3 and 47-51.

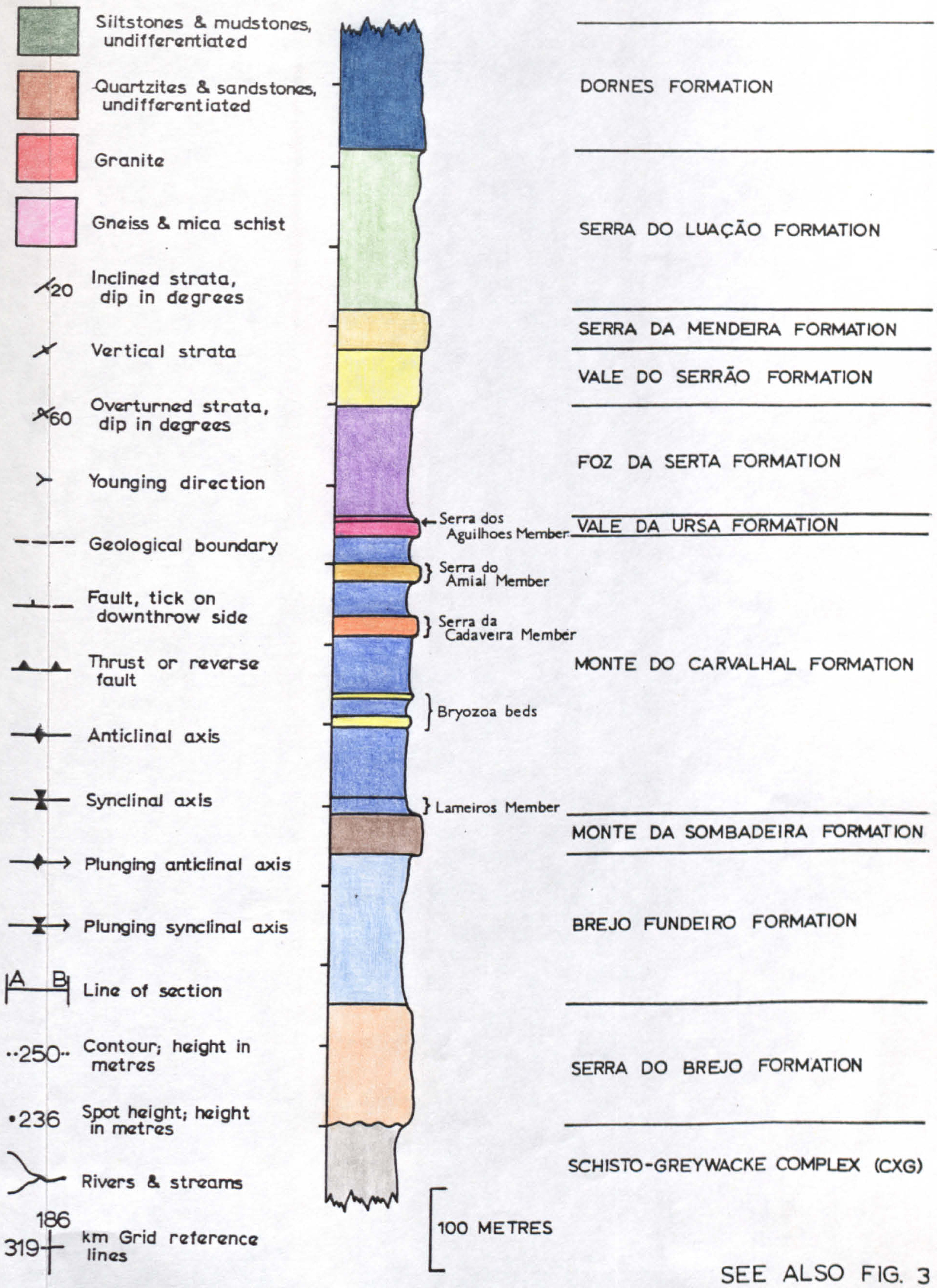
- No exposure
- Fine-grained quartzite
- Medium-grained quartzite (quartzite)
- Coarse-grained quartzite
- Conglomerate
- Fine-grained sandstone (sandstone)
- Medium-grained sandstone
- Sandstone with micaceous laminae
- Micaceous sandstone
- Carbonaceous & pyritic fine-grained sandstone
- Laminated sandstone & mudstone
- Laminated quartzite & mudstone
- Mudstone
- Mudstone & siltstone
- Siltstone
- Siltstone & sandstone
- Fine-grained greywacke
- Coarse-grained greywacke (greywacke)
- Thin-bedded limestone (limestone)
- Massive limestone
- Sandy limestone
- Folded greywacke & mudstone
- Lava & tuff
- Granite
- Trough cross-bedding
- Planar cross-bedding
- Parallel horizontal lamination
- Ripple marks
- Cut and fill structures
- Nodules
- •Fe Ironstone nodules
- •FeS Pyrite nodules
- MF Mudstone flakes
- Load casts
- Flame structures

Abbreviations :-

Fm.	Formation
M.	Member
Lst.	Limestone
Sh.	Shale
Q.	Quartzite

LEGEND AND GENERALISED VERTICAL SECTION FOR FIGS. 37-45 OF THE DORNES AREA.

FIG. 60



VI. PALAEONTOLOGY

1. Arthropoda

Class	TRILOBITA Walch, 1771
Order	PTYCHOPARIIDA Swinnerton, 1915
Suborder	ILLAENINA Jaanussun, 1959
Superfamily	ILLAENACEA Hawle & Corda, 1847
Family	ILLAENIDAE Hawle & Corda, 1847
Subfamily	BURMASTINAE Raymond, 1916
Genus	DYSPLANUS Burmeister, 1843

Type species. *Asaphus* (*Illaenus*) *centrotus* Dalman, 1827.

Dysplanus sp. indet.

Pl. 21, fig. 1.

Age and locality

Lower Caradoc, localities 72 and 151 from the bryozoa beds of the Monte do Carvalhal Formation.

Material

Two cranidia, both preserved as internal moulds. The specimen from locality 72 is severely distorted and crushed, but the specimen from locality 151 is only slightly crushed and has four poorly preserved thoracic segments attached.

Measurements (mm)

Locality	72	151
Width of cranidium	33.0 (est.)	20.7
Length of cranidium	Severely shortened	17.3
Width of axial region	18.0	8.9

Description

The cranidium is about four-fifths as long as it is wide and sub-semicircular in outline. In longitudinal profile it is dorsally strongly convex and in transverse profile it is moderately convex. The glabella is very weakly defined and has a preserved width which is a little less than one-half of the cranidial width. The axial furrows are very poorly defined and die out anteriorly; they are between one-quarter and one-half the length of the cranidium. The furrows are very slightly curved, adaxially convex and diverge very slightly forwards; the anterior part of the glabella merges into the frontal area without a break. The posterior part of the glabella on the specimen from locality 151 bears a very slight, but wide, occipital furrow which reaches almost to the posterior edge of the cranidium so that an occipital ring is hardly developed. Because of the distorted nature of one specimen and the poor preservation of the other the fixed cheeks and facial sutures are difficult to interpret. The facial sutures appear to be slightly sinuous, sub-parallel to the axial line and extend for approximately half the length of the cranidium from the posterior margin. Approximately the anterior half of each suture in front of the eye is very gently and adaxially convex. At the position of the eyes the facial sutures are strongly and abaxially convex for approximately one-quarter of their overall length. The posterior areas of the fixed cheeks on the specimen from locality 151 show slight traces of poorly preserved posterior border furrows.

Four incomplete thoracic segments are attached to the cranidium from locality 151. The axis is the same width as the posterior width of the glabella. Each axial ring is very wide and moderately convex (trans.); very short and slightly convex (sag.). The axial furrows are wide, shallow and have a gently rounded profile. The pleurae are incomplete and only the parts nearest to the axial furrows remain. These parts of the pleurae are smooth with a very slight furrow running parallel to and just in from the posterior edge.

Discussion

The specimens described above are too poorly preserved for specific designation, but agree with the generic description for Dysplanus given by Jaanusson (1954) and Moore (1959). Dysplanus may be distinguished from the other members of the Burmastinae by the shape and size of the eyes and the palpebral areas of the fixed cheeks. The shape of the glabella is also distinctive with a very weak and only slightly divergent development of the anterior parts of the axial furrows; the presence of weakly developed posterior border furrows is also typical of Dysplanus.

Snajdr (1957) established the genus Zetillaenus, but Jaanusson (1958) and Moore (1959 consider it bo be a synonym of Dysplanus. Hammann (1974) while dismissing many of the differences noted by Snajdr (op. cit.) considers differences in the posterior part of the facial suture to be strong enough to establish two subgenera Dysplanus (Dysplanus) and Dysplanus (Zetillaenus). In Dysplanus (Zetillaenus) the facial sutures go straight to the posterior border, but in Dysplanus (Dysplanus) they diverge slightly and cut the posterior border adjacent to the inner part of the genal spine. Because the Portuguese specimens are poorly preserved it is not possible to distinguish to which subgenus they belong.

The presence of a weakly developed occipital ring has been recorded for Dysplanus (Zetillaenus) ibericus Hammann (1974, pp. 51 and 52, fig. 56 and plate 3, figs. 26, 30, 33a and 33c). Hammann (op. cit.)

records his species from the upper Caradoc of Sierra Morena in Spain and includes in his synonymy the species Illaenus wahlenbergianus Barrande, 1852 recorded by Thadeu (1947) from the "Schistes a dibasiques" (Porto do Santa Anna Ash Formation of Mitchell, 1974) of the Buçaco area of Portugal. Dysplanus sp. indet. occurs in the bryozoa beds of the Monte do Carvalhal Formation in the Dornes area and the beds probably correlate with the Louredo Formation which underlies the Porto do Santa Anna Ash Formation. Dysplanus wahlenbergianus (Barrande) is recorded in Bohemia by Havlíček and Vaněk (1966) from the Králův Dvůr Formation which is considered by Havlíček and Marek (1973) to be of a lower and middle Ashgill age.

Subfamily ECTILLAENINAE Jaanusson, 1959

Genus ECTILLAENUS Salter, 1867

Type species. Illaenus perovalis Murchison, 1839.

Ectillaenus bergaminus Whittard, 1961

1961 Ectillaenus bergaminus sp. nov.; Whittard pp. 309-211, plate XXVIII, figs. 8-12; plate XXIX, figs. 1-5; plate XXX, fig. 8.

Ectillaenus cf. bergaminus Whittard, 1961

Pl. 21, figs. 2-4.

Age and locality.

Llanvirn, Didymograptus murchisoni Zone; Brejo Fundeiro Formation fossil localities 85 and 126.

Material

The material consists of an internal and complementary external mould of an almost complete specimen which has only 3 thoracic segments remaining; a complementary internal and external mould of a crushed cephalon with 10 thoracic segments attached and an internal mould of an incomplete cephalon with 8 incomplete thoracic segments attached.

Measurements (mm)

Of the three specimens, one appears to have undergone little tectonic compression and approximates to an "o-form"; the other specimens have suffered sagittal compression and approximate to "w-forms" (Henningsmoen, 1960).

	o-form	w-form	w-form
Width of cranidium	43.0	26.5	32.0 (d)
Length of cranidium	30.0	9.0	14.0 (e)
Width of thorax	64.0 (d)	37.5	34.0 (d)
Length (sag.) of pleural segment	2.4	1.5	2.0
Width of pygidium	63.0	-	-
Length of pygidium	30.0	-	-

(d) equals half measurement doubled and (e) equals an estimated measurement.

Description

The cephalon is about twice as wide as it is long and sub-semicircular in plan. In longitudinal profile it is moderately convex, even though all three specimens show signs of crushing. The curve of the profile rises sharply from the anterior border reaching a maximum height about the mid-point of the cephalon, it then remains sub-horizontal and descends slightly to the posterior border. The transverse profile is convex, but less so than the longitudinal profile. The cranidium is almost bare of structures except for weak, straight, axial furrows which extend from the posterior margin over about one-third of the sagittal length and stop abruptly. The glabella is about two-fifths the width of the cranidium; the anterior edge of the glabella is undefined and continuous with the anterior part of the cranidium. Only one specimen has a free cheek preserved, but this is displaced and slightly crushed giving no indication as to the nature of the eye. The free cheek is sub-trapezoidal in outline with the facial suture forming the longest side which is one and one-half times as long (sag.) as the width (trans.); the anterior and posterior sides converge abaxially at about 40 degrees and the lateral side is parallel to the facial suture. The posterolateral and anterolateral corners of the free cheek are sharply rounded. The facial suture extends for about one-half the length of the cephalon and is gently sigmoidal; it curves outwards from the posterior border in a gentle convex arc and then runs abaxially to form a notch around the ?small eye which is situated mid-way along the facial suture. From the front of the eye the suture runs anteriorly in a gentle abaxial arc which becomes tighter just before cutting the anterior edge of the cephalon. The eye is not preserved.

The thorax contains at least 10 thoracic segments; the axis is one-third the width of the thorax and the axial furrows converge slightly towards the rear. The axis is convex (trans.) and sharply separated by a sudden change in slope from the flat pleurae which have slightly deflexed ends. On internal moulds ventrally directed apodemes are preserved as sharp depressions situated in the axial furrow on both sides of the axis and just forward from the posterior edge of each thoracic segment. The tips of the pleurae are sharply truncated with tightly rounded corners and lateral margins which diverge abaxially backwards at about 15 degrees from the axis.

The pygidium is semicircular in outline and about twice as wide as it is long. It is dorsally convex (sag. and trans.) with a flattish axial area. The pygidium is slightly crushed and details of an axis can hardly be seen, but the faint axial furrows appear to converge posteriorly at about 40 degrees and to extend over one-third of the pygidial length (exsag) from the anterior margin; the posterior margin of the axis is undefined. From the three incomplete specimens it is shown that the species is isopygous with at least 10 thoracic segments.

On external moulds the ornament on the cranidium consists of roughly sub-parallel and closely spaced terrace lines which occasionally and randomly bifurcate over most of the surface. The lines are arranged sub-parallel to the anterior and posterior cranidial edges and become more closely spaced and less regular postero-laterally (plate 21, fig. 3a) Following the terminology of Miller (1973), the terrace lines generally have an escarpment profile and the lower parts of the dip slopes are perforated by numerous pits; occasional random pits are also present on the wider dip slopes of the anterior terrace lines. The ornament on the free cheeks anteriorly consists of terrace lines which are sub-parallel to the anterior edges of the cheeks, these lines fan slightly from the antero-lateral corner of the cheek and have numerous pits developed on the lower parts of the dip slopes; posteriorly the terrace lines pass into an ornament of random, closely spaced pits (plate 21, fig. 3b).

The central axial parts of the thoracic segments carry terrace lines which are sub-parallel to the anterior and posterior edges of the segment; laterally these curve backwards and stop just short of the axial furrow. On the pleurae the terrace lines run anterolaterally from the axis with which they make an angle of about 75 degrees; distally these terrace lines run sub-parallel (trans.) to the anterior and posterior edges of the pleurae. The dip slopes of the terrace lines are less marked and bear smaller pits than those ornamenting the cephalic and pygidial regions.

The pygidium is anteriorly ornamented with frequent, but less distinct terrace lines than those of the cephalon; the style is however similar. Posteriorly and laterally the terrace lines become wavy, narrower and shorter with new lines arising by frequent intercalation. The size of the pits on the lower parts of the dip slopes is similar to those found on the cephalon. The terrace lines run more or less parallel to the edge of the pygidium, but turn abruptly downwards towards the anterolateral corners of the pygidium.

Discussion

These specimens agree with the description of Ectillaenus bergaminus Whittard, 1961, except for the shape of the free cheeks which in the Portuguese specimen are more angular and trapezoidal in shape compared to the triangular shape with rounded genal angles of Whittard's paratypes. The shape of the pygidium is slightly broader in the Portuguese specimen.

Ectillaenus cf. bergaminus differs from Ectillaenus cunicularis Whittard, 1961 which has a more regular ornament and a more pronounced axis on the pygidium. Ectillaenus perovalis (Murchison, 1839) and its closely related form Ectillaenus hughesi (Hicks, 1875) differ from E. cf. bergaminus by overall dimensions and by having an irregular pitted ornament on the pygidium. Ectillaenus katzeri (Barrande, 1856) has eyes which are set well forward and free cheeks which are crescent-shaped (Jaanusson, 1954; p. 577, fig. 18); Whittard (1961, p. 215), however, notes that the eyes of E. katzeri are set midway along the facial suture a feature also shown by E. cf. bergaminus from Portugal. Whittard (1961) also notes that Ectillaenus parabolinas (Novák and Perner, 1918) is characterised by a markedly triangular cephalon and that Ectillaenus benignensis (Novák and Perner, 1918) is a synonym of E. hughesi, furthermore he considers Ectillaenus sarkaensis (Novák and Perner, 1918) to be a probable junior synonym of E. hughesi.

Ectillaenus bergaminus is recorded from the Upper Arenig of Shropshire and it is conceivable that a closely related species might persist into the Llanvirn of Portugal especially since other species of Ectillaenus are found as high as the Ashgill in Sweden and Bohemia (Whittard, 1961).

Suborder TRINUCLEINA Swinnerton, 1915

Family TRINUCLEIDAE Hawle and Corda, 1847

Subfamily MARROLITHINAE Hughes, 1971

Genus ONNIA Bancroft, 1933

Type species. Cryptolithus superbus Bancroft, 1929.

Onnia grenieri (Bergeron, 1893)

Pl. 22, figs. 1-7.

1893 Trinucleus grenieri Bergeron, pp. 45-46, pl. VI, figs. 5-6. non. 1894.

1895 Trinucleus grenieri Bergeron; Oehlert, p. 306, pl. II, fig. 3.

1900 Trinucleus Grenieri Bergeron; Kerforne, pp. 783-4 and 789.

1948 Cryptolithus Grenieri Bergeron; Dreyfuss, p. 54 pl. IX, fig. 1.

1966 Cryptolithus grenieri (Bergeron); Coates, p. 84, fig. 5 a–e.

1968a Cryptolithus grenieri (J. Bergeron, 1894); Pillet and Robardet, p. 179.

1968b Cryptolithus grenieri (Bergeron, 1894); Pillet Robardet, pp. 66, 69–70, 73, fig. 2, pl. 1, fig. 1 a–g.

1969 Cryptolithus grenieri (Bergeron, 1893); Pillet and Robardet, pp. 16–17, pl. figs. 1–5.

1970 Cryptolithus grenieri (Bergeron, 1893); Pillet and Robardet, pp. 11–12, pl. figs. 1–6.

1971 Onnia grenieri (Bergeron, 1894); Arnaud and Pillet, pp. 157–158, pl. 2, figs. 1–11.

1972 Onnia grenieri (Bergeron); Babin & Melou, p. 92.

1975 Onnia grenieri (Bergeron, 1894); Hughes, Ingham and Addison, p. 574; authorship attributed to Bergeron, 1893 on p. 593.

Age and locality

Lower Caradoc; the specimens are from the J.F.N. Delgado collection (7–6–1886) housed in the Serviços Geológicos Museum, Lisbon. The specimens were collected from "1700m a N57° E de pyr de Queixopera, Mação" about 30km south-east of the Dornes area. The specimens are associated with bryozoa, Colpocoryphe cf. lennieri (Bergeron, 1893) and Drabovia cf. redux (Barrande, 1848). The same bryozoa and brachiopod also occur in lithologically identical material, within the bryozoa beds of the Monte do Carvalhal Formation, in the Dornes area.

Material

One almost complete, undistorted, internal mould of a cephalon preserved in a nodule and two incomplete, internal moulds of cephala, preserved in mudstone.

Measurements (mm)

Maximum width (trans.) of cephalon (1 & 3)	14.0
Length (sag.) of cephalon (1)	6.5
Length (sag.) of glabella (1)	6.0
Maximum width (trans.) of glabella (1)	4.8
Anterior width (sag.) of fringe (2)	2.0
Maximum lateral width of fringe (2)	3.0

(1) With occipital ring vertical

(2) Along surface of fringe

(3) Half measurement doubled

Description

The cephalon is sub-semicircular in outline with rounded postero-lateral corners and has a width of about twice the sagittal length. The glabella is clavate with a maximum width where the axial furrows reach the fringe. The glabella is strongly inflated with a maximum height above the fixed cheeks similar to the maximum width of the glabella; the frontal part of the glabella overhangs the fringe. The occipital furrow is narrow (sag. and exsag.) and well defined. The occipital ring is narrow and dorsally convex (exsag.); transversely it is strongly arched. The genal lobes are roughly quadrant-shaped with the axial furrows and the posterior border furrows making an angle of about 80 degrees; the anterior corners and postero-lateral corners of the lobes are sharply rounded and dorsally the genal lobes are strongly convex (exsag. and trans.). The posterior borders are poorly preserved, but appear to be narrow and separated from the genal lobes by narrow (exsag.), straight, posterior border furrows directed abaxially. The surfaces of the glabella and the genal lobes are smooth.

The fringe is of medium width and narrowest in front of the glabella increasing to a maximum width at the positions of the R11 and R12 pits. The anterior and left-hand part of the fringe has the upper lamella preserved, but the right hand part is broken to reveal the lower lamella. The girder is difficult to distinguish, but the assumed E_1 pits are more numerous than the I_1 pits indicating that the girder is between these arcs; the first internal pseudogirder (between the I_1 and I_2 arcs) is not particularly obvious but is better developed than the girder (Dr. R. Addison pers. comm.). The notation applied to the fringe pits is essentially that proposed by Bancroft (1929, pp. 69-72) but incorporating modifications introduced by Ingham (1974) and Hughes, Ingham and Addison (1975). Hughes _et al._ (_op. cit._) demonstrate that in _Onnia_ the girder has previously been mistaken for the first internal pseudogirder and that _Onnia_ has only one E arc and not two as indicated by Moore (1959). Hughes _et al._ (_op. cit._) also consider the inner arc I_n to be a complete primary arc with I_1 appearing next and successive arcs being introduced between I_1 and I_n. Using this notation (and with grateful assistance from Dr. R. Addison) the following fringe formula is derived:

The postero-lateral corners of the fringe are incomplete and consequently the complete number of pits in each arc is not known, but the fringe formula is:

E_1: $R_o - R_{18+}$

I_1: $R_o - R_{16+}$

I_2: $R_2 - R_{14}$ or R_{15}

I_3: $R_6 - R_{13}$

I_n: $R_o - R_{17+}$

I_4 or F pits: R_{11} and R_{12}

On the well preserved left-hand side of the fringe for which the above formula is given the E_1 pits fall along radii, but on the less complete right hand side they are more numerous and out of alignment with the other fringe pits. Most of the pits are of similar moderate size, but many of the pits in I_n, I_3 and I_4 or F are smaller; slightly larger pits are developed in the postero-lateral parts of the I_1 and I_2 arcs.

Discussion

The relative development of the girder and the first internal pseudogirder on the specimen described above are not particularly obvious, but the first internal pseudogirder is better developed than the girder which is a characteristic of Onnia (Dr. R. Addison pers. comm., Ingham, 1974 and Hughes et al. 1975; p.542, fig. 3(d) and pp. 574-75). The Portuguese specimen is very similar to the type specimen of O. grenieri figured by Bergeron (1893, pl. vi, fig. 5). The description and general fringe formula of the Portuguese specimen is also very close to that for Onnia grenieri described by Coates (1966, fig. 5 a-d.), Arnaud and Pillet (1971) and Pillet and Robardet (1969; pl., figs. 1-3). Other similarities noted include the glabellar shape and the enlargement of the I pits in I_1 and I_2 arcs in the lateral and postero-lateral areas of the fringe. The vestige of an occipital spine shown in the French specimens (Pillet and Robardet; 1968b, p. 73, fig. 2 and 1969, pl., figs. 1-3) and described by Coates (1966, p. 85) is not seen in the Portuguese specimen in which the posterior edge of the occipital ring is poorly preserved.

O. grenieri has been widely recorded in the Manche Province of Normandy (Pillet and Robardet 1968a, 1968b, 1969, 1970 and Babin et al. 1976) where it occurs in Lower Caradoc strata. It has also been recorded in the Coëvrons syncline where it is associated with the brachiopod

Svobodaina armoricana (Babin *et al.*, *op.cit.*) and also from the Redon-Angers syncline (Arnaud and Pillet 1971, and Babin *et al.*, *op. cit.*); both occurrences are in lower Caradoc rocks. In Spain Hammann (1976 a) records the closely related form *O.* ? n. sp. aff. *grenieri* (Bergeron, 1893) from upper Caradoc strata in the eastern Sierra Morena. Hammann (*op. cit.*) notes that the differences between O. ? n. sp. aff. *grenieri* and both *O. grenieri* and *O. seunesi* (Kerforne, 1900) are difficult to find because the material from western France is not well described; however, he considers both *O. grenieri* and *O. seunesi* to be valid species of *Onnia*. The shape of the fringe and development of the pits in the Portuguese specimen are closer to that of the French material described by Arnaud and Pillet (1971) than the Spanish material described by Hammann (*op. cit.*). In Morocco Destombes (1971) records *O.* cf. *grenieri* (Bergeron) from upper Caradoc rocks east of Casablanca.

Onnia cf. *grenieri* (Bergeron, 1893)

Pl. 22, fig. 8.

Age and locality

Lower to middle Caradoc; locality 52 in the Serra da Cadaveira Member of the Monte do Carvalhal Formation.

Material

The material consists of one internal mould of a left hand genal lobe with the fringe attached; the anterior part of the fringe and the genal angle are missing.

Measurements (mm)

Estimated length of cephalon	8.0
Maximum width of genal lobe approximately at mid point (trans.)	4.0

Width of fringe anterior to the axial furrow	2.0
Maximum width of fringe adjacent to posterior border	3.0

All the above measurements were taken with the fringe horizontal.

Description

The glabella is missing but the shape of the fringe and orientation of the axial furrow suggests that the glabella was clavate. The genal lobe is dorsally convex and sub-triangular in plan with the posterior border furrow making an angle of 80° with the axial furrow. The lateral margin of the genal lobe is abaxially curved and both the anterior and the postero-lateral corners are rounded. The posterior border is broken, but the posterior border furrow is moderately wide and straight. The surface of the genal lobe is ornamented with a faint, flat, granular ornament.

The fringe is of medium width, narrowest anteriorly and expanding posteriorly to become widest at the genal angle. Since the anterior part of the fringe is missing no pit count is possible. The girder is situated with only one arc of pits (E_1) external to it and the first internal pseudogirder is moderately well developed; three I arcs are present:- I_1, I_2 and I_n. The E_1 pits are more numerous, more closely spaced, and smaller than the pits of the I_1 and I_2 arcs and a few small F pits are present to the rear of the postero-lateral corner of the genal lobe. The E_1 arc has approximately 18 pits compared with 13 pits for the same length of arc in the I_1 arc.

Discussion

The fragmentary nature of the specimen prevents a precise specific identification, but the position of the girder; the anterior development of the first internal pseudogirder and the more numerous pits in the E_1 arc agree with the revised diagnosis of Onnia (Ingham, 1974 and Hughes et al., 1975). The Portuguese specimen is similar to Onnia ? n. sp. aff. grenieri (Bergeron, 1893) described by Hammann (1976a) and is very close to the specimen figured in plate 2, fig. 12. The Portuguese specimen is also fairly similar to O. grenieri figured in Bergeron (1893), Pillet and Robardet (1968b and 1969) and Arnaud and Pillet (1971).

In the Dornes area O. cf. grenieri occurs associated with Svobodaina armoricana Babin and Melou, 1972, Calymenella (Calymenella) boisseli Bergeron, 1890 and Kloucekia (Kloucekia) cf. taouzensis Destombes, 1972. In western France Onnia grenieri and Svobodaina armoricana occur together in the Caradocian rocks of the Coëvrons syncline (Babin et al., 1976). In Spain Hammann (1976a) records O. ?. n. sp. aff. grenieri associated with Calymenella (Calymenella) boisseli in the upper Caradoc rocks of the Sierra Morena and in Morocco Destombes (1971) records O. cf. grenieri and Calymenella aff. boisseli in upper Caradoc rocks from east of Casablanca.

Order PHACOPIDA Salter, 1864

Suborder CHEIRURINA Harrington and Leanza, 1957

Family CHEIRURIDAE Salter, 1864

Subfamily CYRTOMETOPINAE Öpik, 1937

Genus ECCOPTOCHILE Hawle and Corda, 1847

Type species. Cheirurus claviger Beyrich, 1845

<u>Eccoptochile</u> (<u>Eccoptochile</u>) <u>clavigera</u> (Beyrich, 1845)

1845 <u>Cheirurus</u> <u>claviger</u> Beyrich, p. 13, figs. 2 & 3.

1852 <u>Cheirurus</u> <u>claviger</u> Beyrich; Barrande, pl. 40, figs. 1-12, pl. 42, fig. 1.

1908 <u>Cheirurus</u> <u>claviger</u> Beyrich; Delgado, pp. 57, 80 and 92.

1918 <u>Cheirurus</u> <u>claviger</u> Barr; Born, p. 352.

1947 <u>Cheirurus</u> <u>claviger</u> Beyrich; Thadeu, pp. 228-9, pl. 3, figs. 2 & 3.

1947 <u>Eccoptochile</u> (<u>Eccoptochile</u>) <u>clavigera</u> <u>clavigera</u> (Beyrich), 1845; Prantl & Přibyl, p. 26, pl. VI, figs. 1 & 2.

1956 <u>Eccoptochile</u> (<u>Eccoptochile</u>) <u>clavigera</u> (Beyrich, 1845); Šnajdr, pp. 507-508, pl. III, fig. 10 and pl. V, fig. 8.

1959 <u>Eccoptochile</u> (<u>Eccoptochile</u>) <u>clavigera</u> (Beyrich); Moore, pp. 0.435 and 0.434, fig. 3, a, b & c.

1961 <u>Eccoptochile</u> <u>clavigera</u> (Beyrich, 1845); Curtis, p. 8.

1966 <u>Eccoptochile</u> (<u>Eccoptochile</u>) <u>clavigera</u> (Beyrich); Havlíček & Vaněk, pp. 53, 55, 57, 58, 66 and pl. X, fig. 5.

<u>Eccoptochile</u> (<u>Eccoptochile</u>) cf. <u>clavigera</u> (Beyrich, 1845)

Pl. 22, fig. 9.

<u>Age and locality</u>

<u>Eccoptochile</u> (<u>Eccoptochile</u>) cf. <u>clavigera</u> is of lower Caradoc age and was collected at locality 72 from the bryozoa beds of the Monte

do Carvalhal Formation. It was found associated with Corylocrinus sp. and bryozoa. Elsewhere similar beds have yielded Onnia grenieri (Bergeron, 1893) and Drabovia cf. redux (Barrande, 1848).

Material

One incomplete glabella preserved as an internal mould; the specimen is flattened and obliquely distorted.

Measurements

The glabella is 39mm wide and 30mm long, but most of the frontal glabellar lobe and much of the left hand lateral glabellar lobes are folded under the rest of the specimen.

Description

The glabella is severely and obliquely distorted making its true shape difficult to determine. Visual examination and reorientation of the specimen suggests that the glabella was roughly rectangular with an approximately semicircular frontal glabellar lobe. The distortion of the specimen has made it strongly and asymmetrically convex both sagittally and transversely, with the front and much of the left hand side of the glabella folded under. The axial furrows are approximately parallel and three pairs of lateral glabellar furrows are present. The frontal glabellar lobe is about two-fifths the length of the glabella. The front two pairs of lateral glabellar lobes are each a little less than one-fifth the glabellar length, with the pre-occipital lobe a little more than one-fifth the glabellar length. The lateral glabellar furrows are directed adaxially and curve slightly to the rear away from the axial furrows; each lateral glabellar furrow extends for about one-third of the glabellar width. The adaxial ends of the 1p furrows curve sharply towards the occipital furrow and finish about half the length of the pre-occipital glabellar lobe from the occipital furrow. The 2p and 3p furrows are shallow, the the 1p furrows are strongly developed. On this specimen the right hand pre-occipital glabellar lobe and the occipital ring are missing. The glabella, including much of the frontal area and the lateral glabellar lobes, is ornamented with numerous small, fine, circular tubercles.

Discussion

Curtis (1961) noted that Eccoptochile (Eccoptochile) clavigera differs from the closely related form E. (E.) mariana (Verneuil and Barrande, 1855) by having a longer frontal glabellar lobe. The other differences pointed out by Curtis for distinguishing the species (eye ridges and the position of the eyes) cannot be applied to the Portuguese material because the specimen is incomplete and distorted. Measurement of the holotype of E. (E.) mariana gives a ratio of 0.36 : 1 for the ratio between the length of the frontal glabellar lobe (5mm) and the length of the glabella excluding the occipital ring (14mm). Measurement of the 4 specimens of E. (E.) mariana figured by Curtis (1961) gives a ratio of 0.33 : 1. For E. (E.) clavigera measurement of the specimens figured by Beyrich (1845; holotype), Prantl and Přibyl (1947) and Havliček and Vaněk (1966) show a ratio of 0.39 : 1 for 3 specimens. The specimen described above has a ratio of at least 0.36 : 1 excluding that part of the frontal glabellar lobe which is folded under the glabella. This suggests a closer similarity of the specimen with E. (E.) clavigera than with E. (E.) mariana. Generally the figured specimens of E. (E.) clavigera have an ornament composed of fine tubercles (Beyrich, 1845, fig. 2); Havliček and Vaněk, 1966, pl. X, fig. 5), but the holotype of E. (E.) mariana, the specimen figured by Born (1918, pl. 27, fig. 1) and most of the specimens figured by Curtis (1961) appear to be smooth except for the specimen figured by Curtis (*op. cit.*) in plate 1, fig. 2 which has a faint ornament of fine tubercles. The specimen from the Dornes area also has an ornament which are similar to those shown for *E.* (*E.*) *clavigera*.

E. (*E.*) *clavigera* has been recorded from the Libeň, Letná, Vinice and Zahorany Formations in Bohemia (Havlíček and Vaněk, 1966) which are of probable Upper Llandeilo to upper Caradoc age (Havlíček and Marek, 1973). A hypostoma and pygidium of *Eccoptochile* aff. *clavigera* (Beyrich, 1845) have also been recorded from Caradocian strata in the Sierra Morena, Spain (Hammann, 1974). In the Dornes area the occurrence of *E.* (*E.*) cf. *clavigera* in the bryozoa beds which also yielded *Drabovia* cf. *redux* suggests a probable Caradoc age. The occurrence of *Onnia grenieri* in similar beds to the south of the area suggests a lower Caradoc age for these beds.

Suborder CALYMENINA Swinnerton, 1915

Family HOMALONOTIDAE Chapman, 1890

Subfamily EOHOMALONOTIDAE Hupé, 1953

Genus CALYMENELLA Bergeron, 1890

Type species. *Calymenella boisseli* Bergeron, 1890

Calymenella (*Calymenella*) *boisseli* Bergeron, 1890

Pl. 22, fig. 10; pl. 23, figs. 1-2.

For a complete synonymy see Hammann (1976a)

1976 *Calymenella* (*Calymenella*) cf. *boisseli* Bergeron, 1890; Hammann, pp. 54-57, fig. 6. pl. 4, figs. 38-45.

Dr. J.-L. Henry, 1978 (pers. comm.) reported that both he and Dr. W. Hammann now consider the material described by Hammann (1976a) to belong to Calymenella (Calymenella) boisseli Bergeron, 1890.

Age and locality

Lower to middle Caradoc; localities 12 and 52 in the Serra da Cadaveira Member of the Monte do Carvalhal Formation.

Material

One internal mould of an incomplete cranidium and one internal mould of a pygidium; both specimens are slightly and obliquely distorted.

Measurements (mm)

Length (sag.) of cranidium	12.3
Width of cranidium across posterior border	27.0 (d)
Length (sag.) of glabella excluding occipital ring	7.5
Length (sag.) of occipital ring	1.3
Length (sag.) of frontal area	3.5
Maximum width of glabella	8.5
Length (sag.) of pygidium (anterior border vertical)	11.0
Maximum width (trans.) of pygidium	18.5
Maximum width (trans.) of axis	9.0

(d); half measurement doubled

Description

The cranidium is about twice as wide as it is long, sub-triangular in outline and with a rounded anterior angle.

The glabella is sub-trapezoidal in shape and extends for about two-thirds the length of the cranidium; it has a length which is about seven-eights of its maximum width. The axial furrows are shallow, wide and converge anteriorly; the posterior one-third of each axial furrow is very gently and adaxially convex, but the remaining two-thirds is very gently and adaxially concave. The preglabellar furrow is flexed gently forwards and the antero-lateral corners of the glabella are rounded. In longitudinal profile the glabella rises steeply from the frontal area with which it makes an angle of about 110 degrees, it then curves dorso-posteriorly to become horizontal just before the occipital furrow. In transverse profile the glabella is moderately convex though flattened medianly. Two pairs of lateral glabellar furrows are present, but both pairs are wide (exsag.) and very weak. The 1p furrows define a pair of lateral glabellar lobes each about one-third the length of the glabella. The 1p furrows are weakly sigmoidal in shape and are directed posteriorly and inwards from the axial furrows to make an angle of about 60 degrees with the axial line. Each furrow extends inwards for about one-third the width of the glabella. The 2p lobes are also about one-third the length of the glabella. The 2p furrows are short (each about one-sixth of the maximum glabellar width) and directed backwards from the axial furrows to make an angle of about 60 degrees with the axial line.

The occipital ring is about one-sixth as long (sag.) as the length of the glabella and a little wider than the maximum glabellar width. The posterior edge of the occipital ring is almost straight, but the central part of the anterior edge and the occipital furrow are arched forwards. The occipital furrow is deep and well defined laterally, but the median one-third of the furrow is shallower and wider where it is arched forwards.

The palpebral areas and anterior areas of the fixed cheeks, along with the frontal area, form an almost concentric border around the glabella; this border has a width (sag. and trans.) of about one-half the glabellar length. The frontal area is weakly differentiated into a preglabellar field and a slightly elevated anterior border which is about one-third the length (sag.) of the frontal area. The front of the anterior border is rounded (in transverse profile) and carries numerous fine broken tubercles which appear to be internal casts of fine canals perforating the anterior border. Weak eye ridges are present and extend from adjacent to the 2p furrow abaxially backwards across the fixed cheek at an angle of about 60 degrees with the axial line. The posterior areas of the fixed cheeks, which are about one-fifth (exsag.) the length (sag.) of the cranidium, are expanded abaxially to about twice the width of the fixed cheek anterior areas. The distal ends of the fixed cheeks are rounded and the posterior areas bear a wide posterior border furrow which starts at the occipital furrow and gently curves antero-laterally sub-parallel to the posterior border. The eyes and supporting palpebral lobes if any are broken.

The pygidium when viewed with the anterior border vertical is roughly triangular in shape with rounded corners and is about six-tenths as long as it is wide. In lateral and posterior views the pygidium is strongly convex and the border is slightly reflexed to form a narrow doublure. The axis measured across the anterior axial ring (trans.) is about half of the maximum pygidial width. The axis tapers posteriorly with the axial furrows converging at about 20 degrees; the posterior end of the axis is bluntly rounded and stops well short of the posterior edge of the pygidium. Six or possibly seven axial rings are present separated by shallow, fairly wide furrows. The axial rings are sub-rectangular in outline and transversely they are strongly convex. The seventh axial ring is poorly differentiated from the terminal axial piece which is approximately semi-circular in outline and strongly convex both transversely and sagittaly. The anterior axial ring carries an articulating half ring which is about half the width of the anterior axial ring. The pleural fields are strongly convex (trans.) with a smooth border which is slightly reflexed to form a narrow doublure.

Six pleurae are present and the interpleural furrows are shallow and weak; they become even weaker adjacent to the axial furrows and stop at the smooth border. The pleural furrows are deep and wide with a rounded profile, they are straight (trans.) and approximately bisect the pleurae. The pleural furrows start at the axial furrows, but stop at the smooth border which is about as wide (trans.) as the anterior axial ring (sag.). The posterior parts of the pleural fields project ventrally and surround the end of the terminal axial piece so that they form an integral part of the smooth border which posteriorly is also reflexed to form part of the doublure. Both the cranidium and the pygidium are smooth.

Discussion

The cranidium described here is similar to that of Calymenella (Calymenella) boisseli Bergeron, 1890 illustrated in Moore (1959, p. O 457, figs. 8a & 8b), except that the Portuguese specimen has a rounded frontal area and illustration 8a (op. cit.) has a strongly pointed frontal area. Other differences are that the lateral ends of the fixed cheeks in illustration 8a (op. cit.) are pointed whereas those of the Portuguese specimen are rounded; the Portuguese specimen also has definite eye ridges which are not seen in the illustration of Moore (op. cit.).

The Portuguese cranidium is however, very similar to those described by Hammann (1976a, p. 54-57; figs. 6a & 6b; pl. 4, figs. 38a, 38b, 40, 41 & 42) from the Sierra Morena in Spain and identified as C. (C.) cf. boisseli Bergeron, 1890, but now considered by Hammann to be C. (C.) boisseli (J.L. Henry pers. comm. 1978).

The Portuguese pygidium differs from the one illustrated in Moore (op. cit., fig. 8b) by having 6 or 7 axial rings instead of 10; the Portuguese specimen also has a smooth border. The Portuguese pygidium is very similar to that now assigned to C. (C.) boisseli (Hammann, op. cit. figs. 6c & d, pl. 4, figs. 44a, 44b & 45).

C. (C.) boisseli differs from C. (C.) media (Barrande, 1872) by having two pairs of very weak lateral glabellar furrows compared with three in the other species (Prantl and Přibyl, 1950, pp.126-128 and Moore, op. cit., p. 0457, fig. 9.). C. (C.) boisseli differs from C. (C.) parvula (Barrande, 1846) by having a longer frontal area and less pronounced 2p glabellar furrows (Prantl and Přibyl, 1950, pp. 128-129; Havliček and Vaněk, 1966, pl. IX, fig. 7). C. (C.) moorei Sdzuy, 1957 has a longer and more rounded frontal area than C. (C.) boisseli which can also be distinguished from C. (C.) bayani (Tromelin and Lebesconte, 1876) which has a much less pronounced anterior border to the frontal area (Hammann, 1976a).

Hammann (op. cit.) records C. (C.) boisseli from the upper part of the "Bancs mixtes" of the eastern Sierra Morena in Spain where it occurs associated with Orthograptus truncatus cf. truncatus (Lapworth, 1876) which indicates an upper Caradoc age; Onnia ? n. sp. aff. grenieri (Bergeron, 1893) is also recorded from the same sequence by Hammann (op. cit.). Within the Dornes area of Portugal C. (C.) boisseli has been found in the Serra da Cadaveira Member of the Monte do Carvalhal Formation where it is associated with Onnia cf. grenieri (Bergeron, 1893) and Svobodaina armoricana Babin & Melou, 1972 which suggest a lower or middle Caradoc age. In Morocco Calymenella aff. boisseli is also recorded by Destombes (1971, p. 251) from the east of Casablanca where it occurs associated with Calymenella aff. bayani and Onnia cf. grenieri (Bergeron) in beds which are of probable upper Caradoc age.

Family SYNHOMALONOTIDAE Kobayashi, 1960

Genus NESEURETUS Hicks, 1872

Type species. Neseuretus ramseyensis Hicks, 1872, subsequent designation by Vodges (1925, p. 106).

Subgenus NESEURETUS (NESEURETUS) Hicks, 1872

Neseuretus (Neseuretus) tristani (Brongniart, 1822)

Pl. 23, figs. 3-9; pl. 24, figs. 1-6; pl. 27, fig. 2.

1822 Calymene Tristani Brongniart, pp. 12-14, pl. I, fig. 2, A-K.

1908 Calymene Tristani Brongniart; Delgado, pp. 32-35, 41-43, 50, 51, 57, 74, 80, 89, 92, 93.

1918 Calymene Tristani Brongniart; Born, p. 348, pl. XXVI, fig. 4, a-e.

1936 Synhomalonotus tristani (Brongniart); Shirley, pp. 394, 398.

1942 Calymene Tristani Brongniart; Costa, pp. 91-93, fig. 1.

1949 Synhomalonotus Tristani Brongniart; Thadeu, pp. 5-6, pl. I, figs. 4-5.

1950 Synhomalonotus tristani (Brongniart); Termier, p. 36, pl. CXCVI, figs. 13-14.

1951 Calymene (Synhomalonotus) tristani (Brongniart); Gigout p. 288, pl. III, figs. 4-5.

1956 Synhomalonotus tristani (Brongniart); Thadeu, pp. 17-18, pl. VI, fig. 4.

1957 Synhomalonotus tristani (Brongniart); Sdzuy, pl. 1, figs. 3-4.

1960 Neseuretus tristani (Brongniart); Whittard, p. 140.

1961 Synhomalonotus tristani (Brongniart); Spjeldnaes, p. 55.

1966a Neseuretus tristani (Brongniart); Dean, p. 316.

1969 Neseuretus tristani (Brongniart, 1822); Chauvel et al., p. 619, pl. XIV, figs. 1a- 1d.

1970 Neseuretus (Neseuretus) tristani (Brongniart, 1822) Henry, pp. 5-11, pl. A, figs. 1-10 and text-figs. 1, & 2E. This paper also contains a more complete synonymy of works prior to 1955.

1970 Neseuretus tristani (Brongniart, 1822); Carré et al., pp.782-783, fig. 3.

1961 Neseuretus (Neseuretus) tristani Brongniart, 1822; Gil Cid, p. 313.

1971 Neseuretus tristani Brongniart; Tamain, pp. 405, 413

1971 Neseuretus tristani (Brongniart); Saupé, p. 361.

1974 Neseuretus (Neseuretus) tristani (Brongniart); Henry et al., p. 332, pl. X, figs. 3 & 5.

1974 Neseuretus tristani (Brongniart); Mitchell, p. 388.

1974 Neseuretus (Neseuretus) tristani (Brongniart, 1822) Sadler, pp. 75-82, pl. 9, figs. 4-12, text-fig. 3.

1976 Neseuretus tristani (Brongniart); Babin et al., pp. 362-364, 366, 370 and 374.

1977 Neseuretus (Neseuretus) tristani (Brongniart, 1822); Hammann, pl. 1, fig. 3.

Age and locality

Neseuretus (Neseuretus) tristani (Brongniart) within the Dornes area ranges in age from Llanvirn, Didymograptus murchisoni Zone to upper Llandeilo. It has been found within the Brejo Fundeiro Formation at fossil localities; 9, 56, 67, 68, 85, 105, 106, 107, 109, 110, 111, 112, 122, 125, 135, 141, 145, 147, 149, 160, 190, 191 and 192; within the Monte da Sombadeira Formation at fossil locality 155 and within the Lameiros Member and lower part of the Monte do Carvalhal Formation at localities 5, 6, 13, 14, 15, 17, 18, 20, 29, 30, 35, 55, 57, 75, 76, 78, 113, 175, 180, 182, 184 and 185.

Material

All the material except for two complete specimens (one enrolled and one outstretched) is disarticulated and winnowed. Apart from the two complete specimens the material also includes 94 cranidia, 1 cephalon, 25 free cheeks and 42 pygidia; about 80 per cent of the specimens are preserved as internal moulds and 20 per cent as external moulds.

<u>Measurements</u>

All the measurements of <u>Neseuretus</u> (<u>Neseuretus</u>) <u>tristani</u> were taken with the specimens orientated so that the posterior margin of the cranidium was vertical. Following the terminology of Temple (1975) the following measurements were taken for the cranidia and the average measurements calculated from 90 specimens are shown in brackets (mm) after each measurement.

Width of cranidium	i		(26.0)
Width between eyes	j		(18.0)
Maximum width of glabella	k		(10.5)
Length (sag.) of glabella	b		(10.0)
Length (sag.) of occipital ring	e		(1.6)
Length (sag.) of preglabellar field	f_2	f_2+g	(5.2)
Length (sag.) of anterior border	g		
Length (exsag.) from exterior border to front of eye	d_5		(11.2)

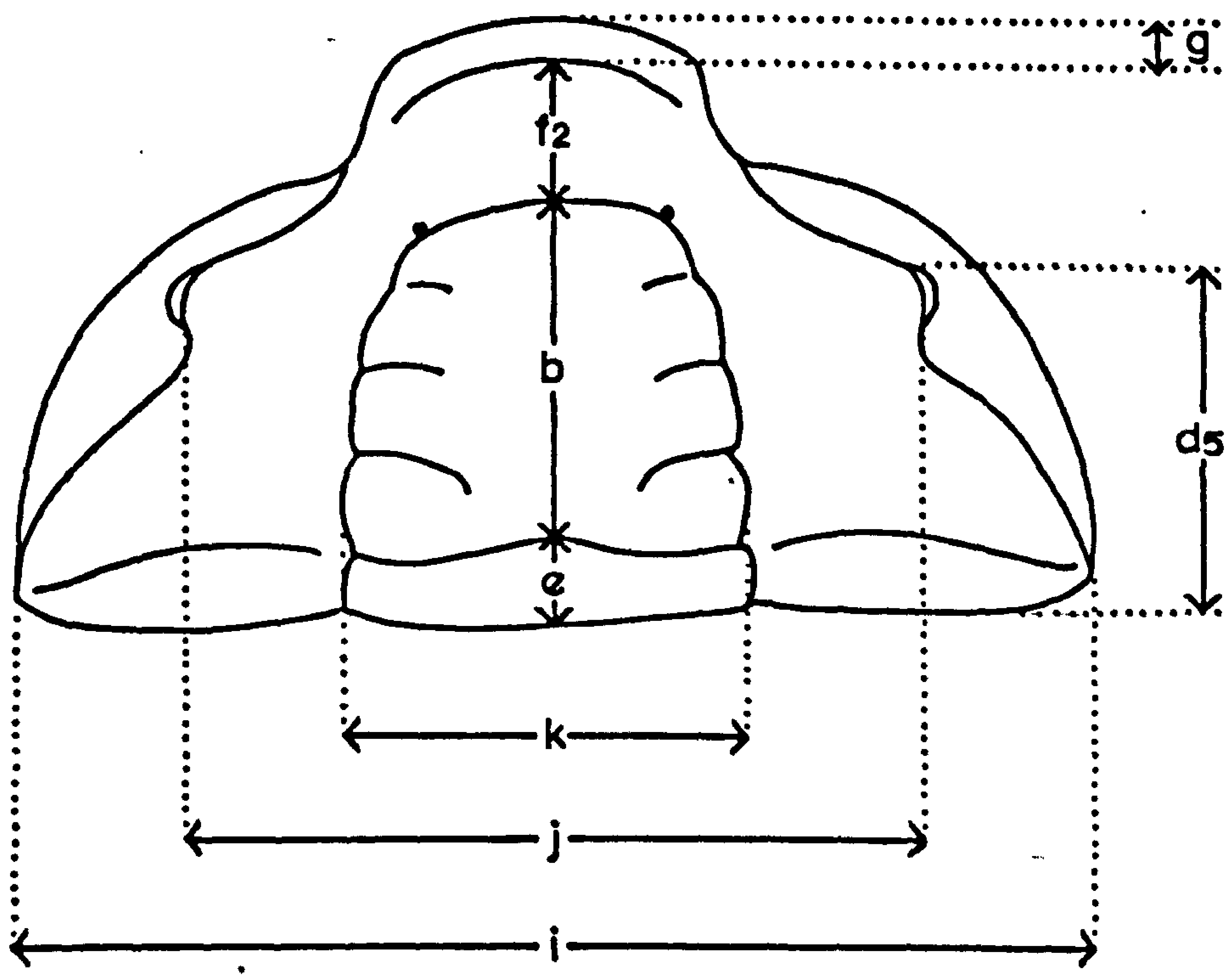
These measurements are shown in appendix 3 and summarised by the following graphs and figures: orientation of measurements (fig. 61), j against k (fig.62), $f_2 + g$ against b (fig. 63), d_5 against b (fig. 64), $b + e$ against k (fig. 65) and $e + b + f_2 + g$ against i (fig. 66).

The graphs plotted for length against length, $f_2 + g$ against b and d_5 against b, or width against width, j against k, show a good linear relationship for the measurements. The graphs plotted for lengths against widths, $b + e$ against k and $b + e + f_2 + g$ against i, show more scatter of points caused by tectonic distortion of the specimens. The single linear cluster of points for each graph indicates that, from a measurement point of view, only one species is present.

ORIENTATION OF MEASUREMENTS

FIG. 61

For *Neseuretus (Neseuretus) tristani* (Brongniart)



Measurements based on Temple (1975) and taken with plane of posterior margin vertical.

g - Length of anterior border

f_2 - Length of preglabellar field

b - Length of glabella

e - Length of occipital ring

d_5 - Length from posterior border to front of eye

k - Maximum width of glabella

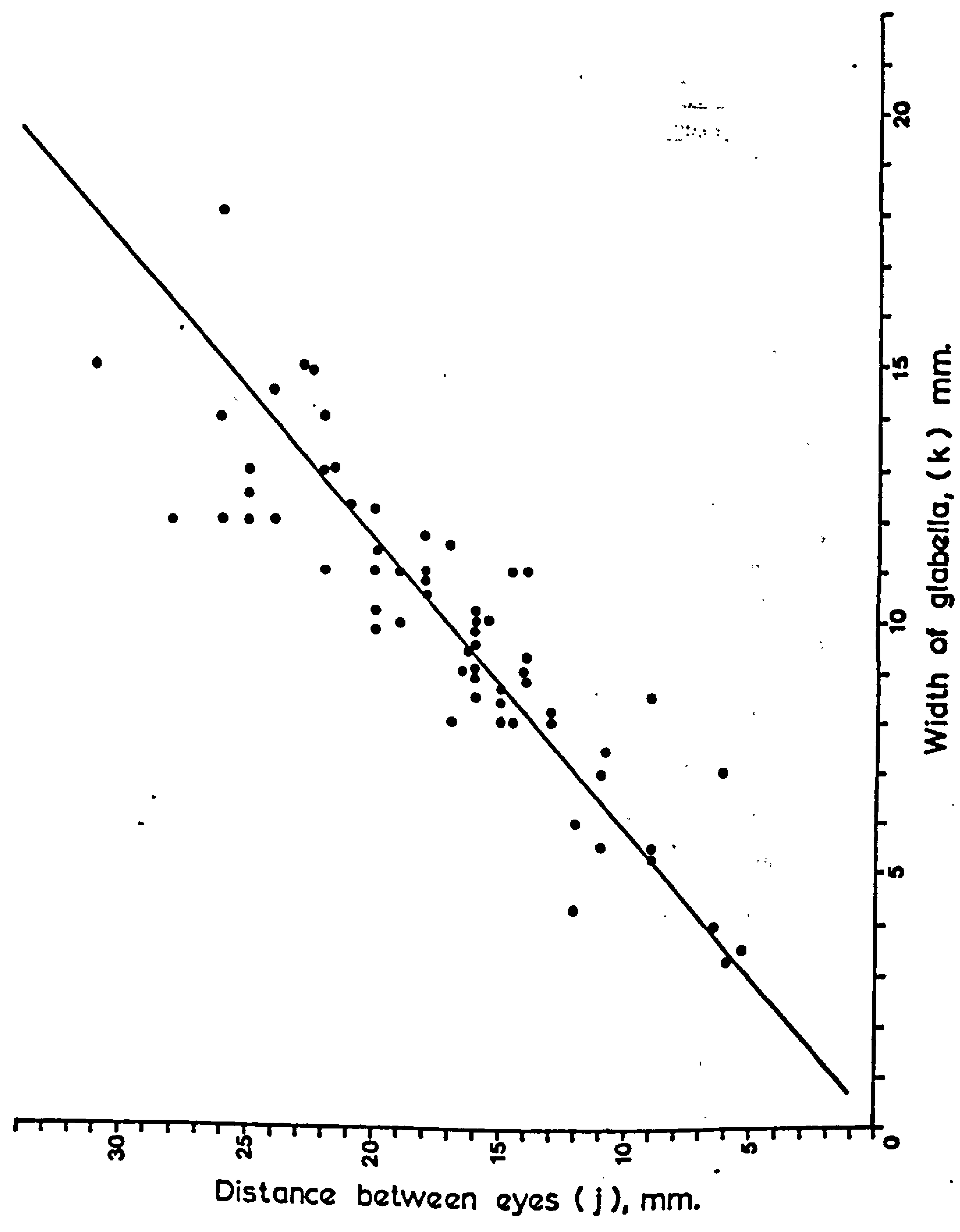
j - Width between eyes

i - Width of cranidium

GRAPH OF GLABELLAR WIDTH (k) AGAINST DISTANCE BETWEEN EYES (j)

FIG. 62

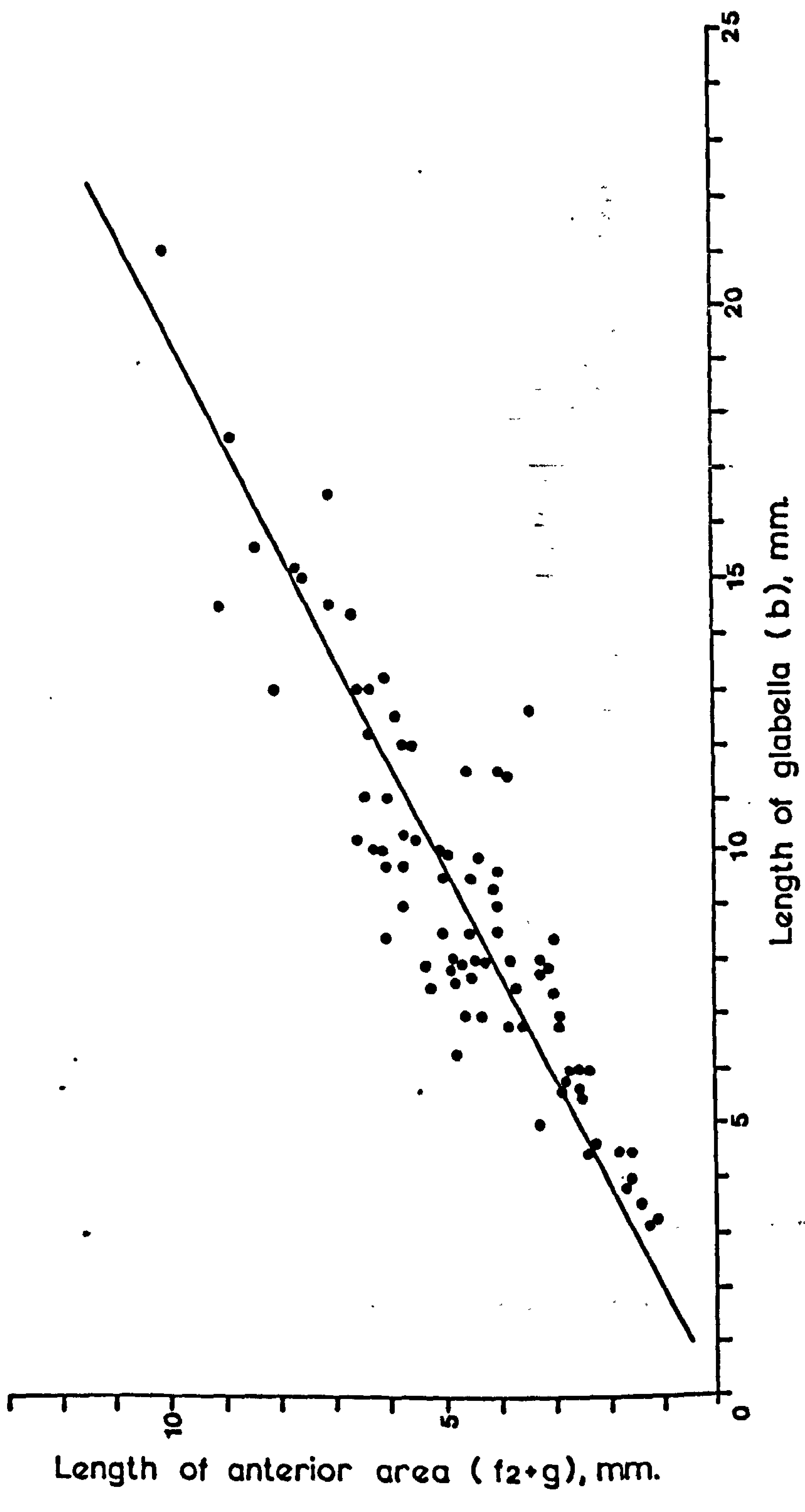
For *Neseuretus (Neseuretus) tristani* (Brongniart); 63 specimens.



GRAPH OF GLABELLAR LENGTH (b) AGAINST LENGTH OF ANTERIOR AREA (f2+g)

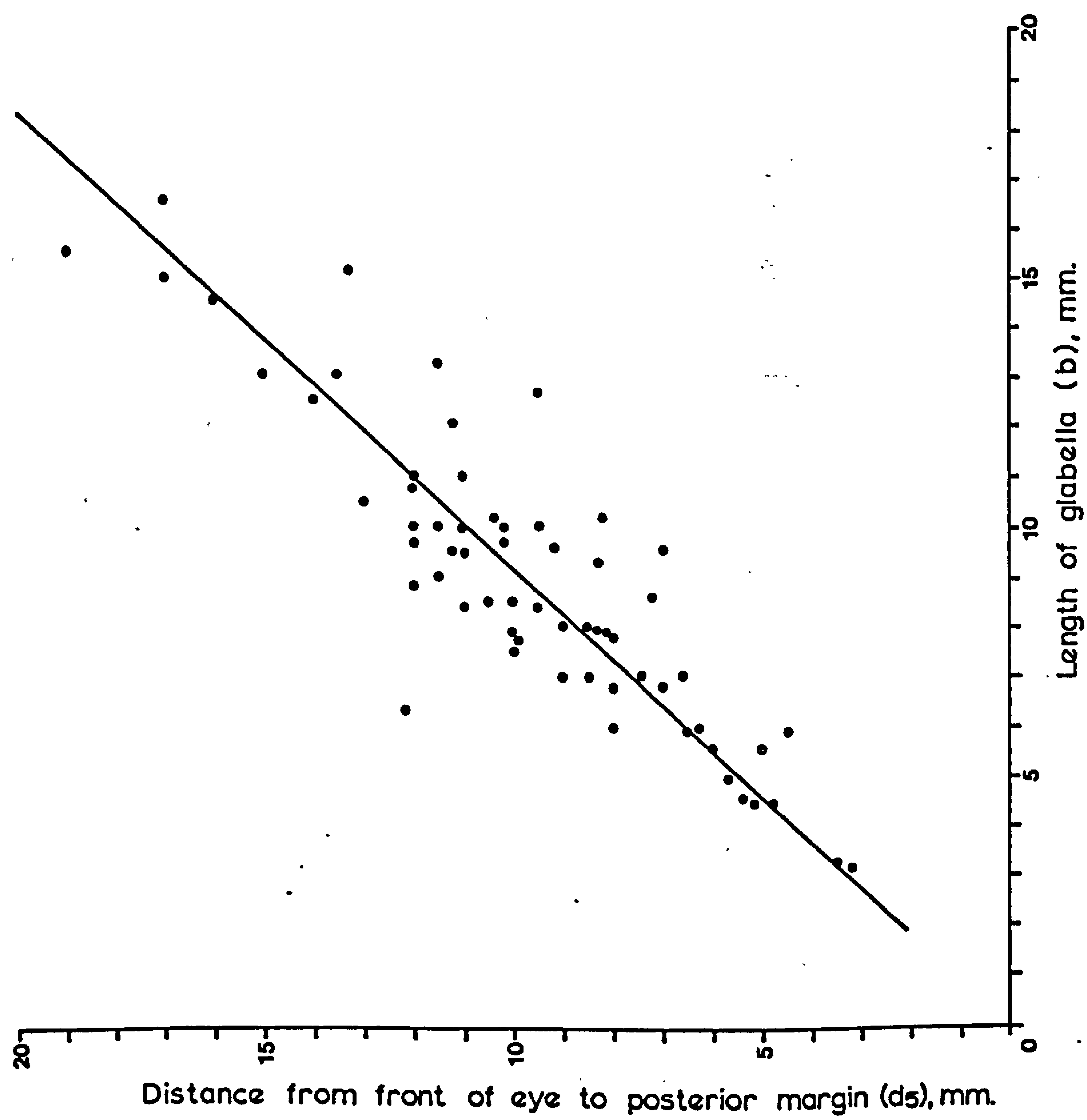
FIG. 63

For *Neseuretus (Neseuretus) tristani* Brongniart; 83 specimens



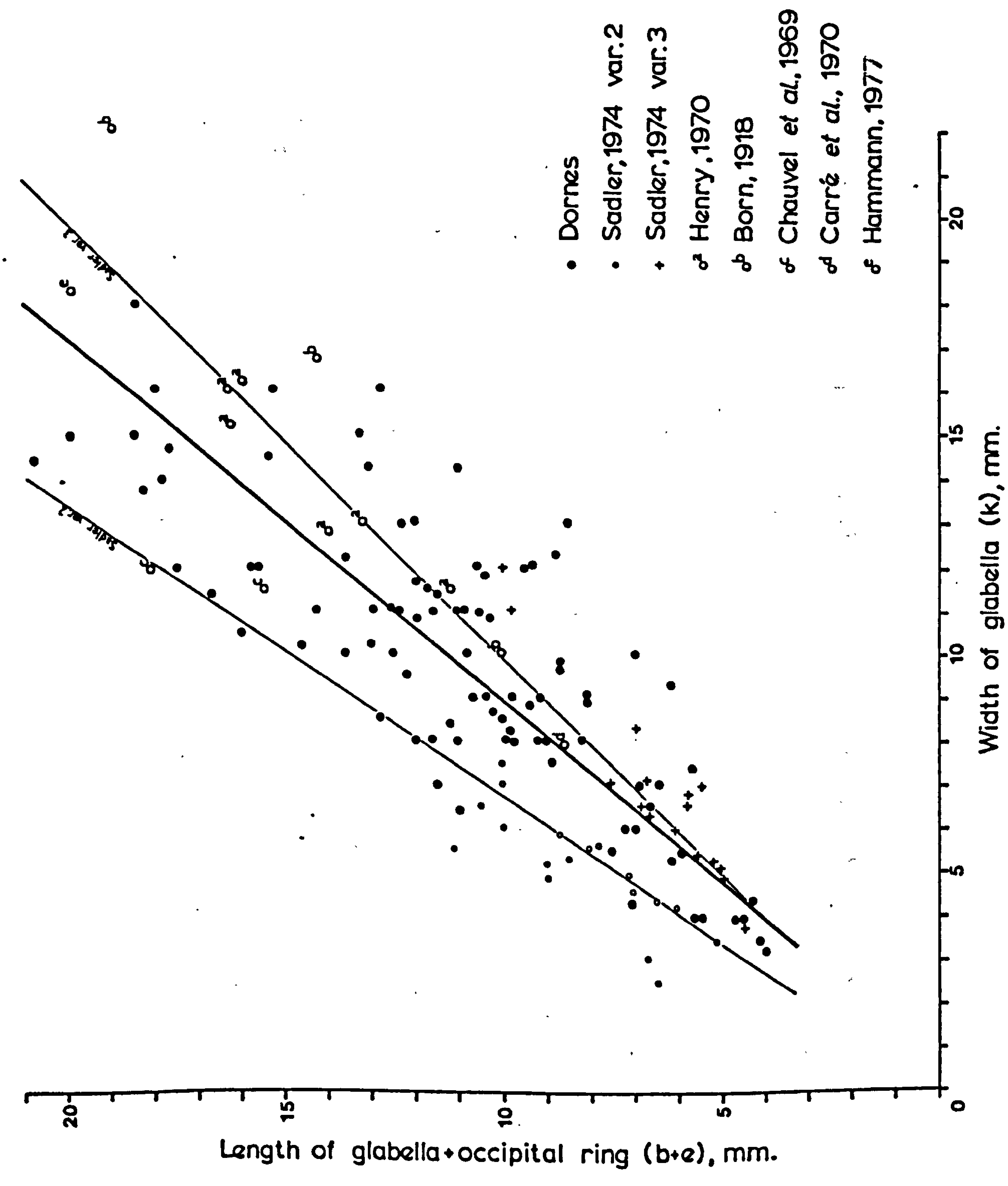
GRAPH OF GLABELLAR LENGTH (b) AGAINST DISTANCE FROM FRONT OF EYE TO POSTERIOR MARGIN (d5) FIG. 64

For *Neseuretus (Neseuretus) tristani* (Brongniart); 64 specimens



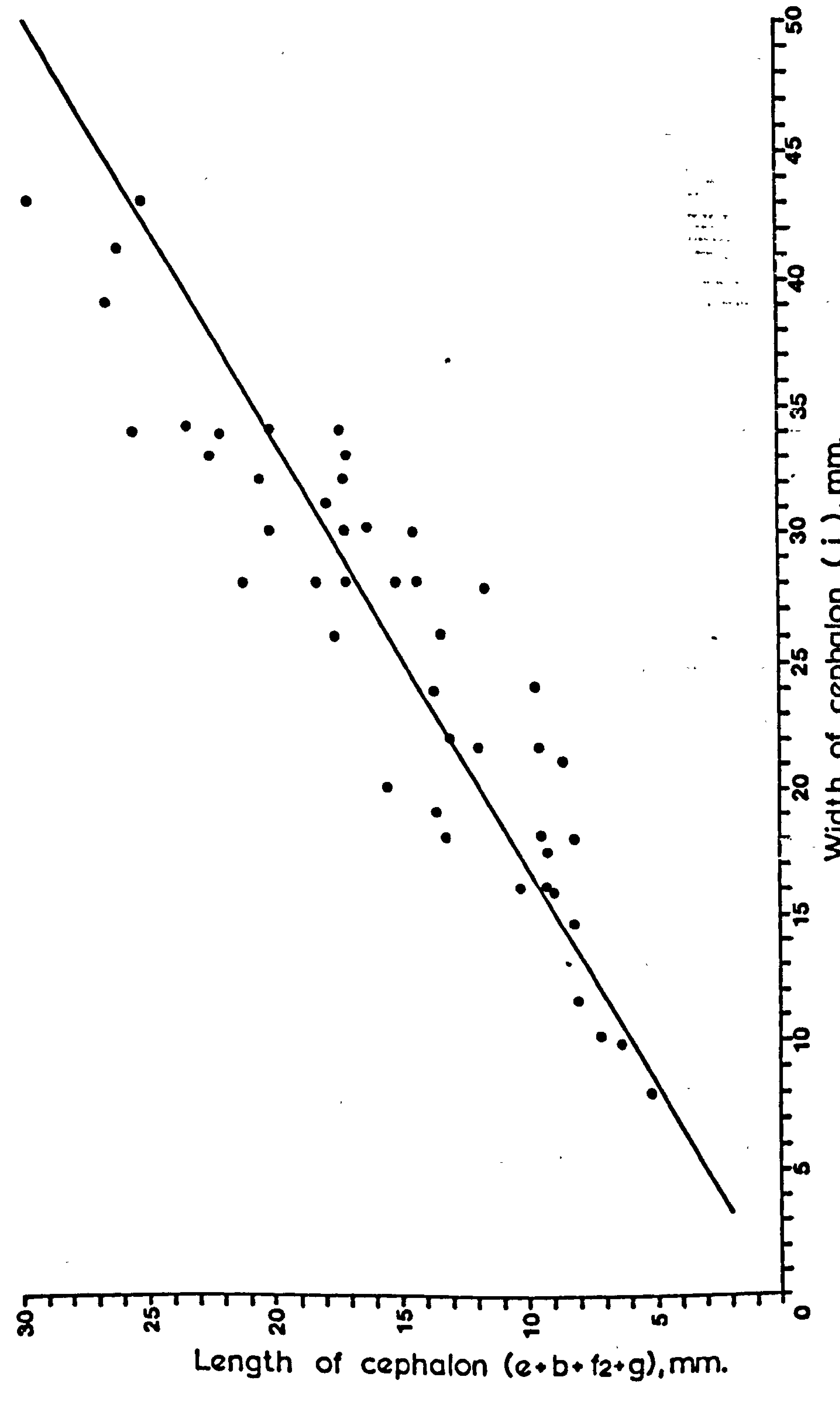
GRAPH OF GLABELLAR WIDTH (k) AGAINST LENGTH OF GLABELLA+OCCIPITAL RING (b+e) FIG. 65

For *Neseuretus (Neseuretus) tristani* (Brongniart) from Dornes (89 specimens) and comparison with previously figured specimens.



GRAPH OF CEPHALIC WIDTH (i) AGAINST CEPHALIC LENGTH (e+b+f2+g) FIG. 66

For *Neseuretus (Neseuretus) tristani* Brongniart; 46 specimens



Description

The cephalon is approximately semi-circular in outline and has a maximum width which is a little less than twice its length. The glabella is trapezoidal in outline with anteriorly convergent lateral margins and rounded corners, it has a length which is about three-fifths that of the cephalon and a maximum width which is about one-third the width of the cephalon. The anterior width of the glabella is about two-thirds of the posterior width. The axial furrows are deep and well developed as is the preglabellar furrow which also carries a well developed fossula at each end. In transverse profile the glabella is strongly arched and in longitudinal profile it is strongly convex rising abruptly from the preglabellar furrow and becoming moderately convex opposite the 1p glabellar furrows. Three pairs of lateral glabellar furrows are usually developed. The 1p furrows extend for about one-third the width of the glabella, they are moderately deep and directed adaxially backwards to make an angle of about 60 degrees to the mid-line. The 2p furrows are each about one-quarter of the maximum glabellar width in length, slightly shallower than the 1p furrows, and directed adaxially backwards to make an angle of about 85 degrees with the mid-line. The 3p furrows are short and faint, lying sub-parallel to the 2p furrows and extending adaxially for less than one-sixth of the maximum glabellar width. The 1p, 2p and 3p lateral glabellar lobes measured along the axial furrows are approximately three-sevenths, two-sevenths and one-seventh the length of the glabella respectively. The occipital furrow is deep and wide (sag.) with the lateral extremities adjacent to the preoccipital lobes being slightly deeper than the central portion; the central part of the furrow is slightly curved and anteriorly convex. Sagittally the occipital ring is about one-sixth the length of the glabella; it has a straight posterior margin and narrows slightly (exsag.) towards its lateral ends.

The frontal area (sag.) is about one-half the length of the glabella and has a maximum width which is similar to the maximum glabellar width. The anterior margin varies from near semi-circular in undistorted specimens (plate 23, fig. 3a) to bluntly rounded in slightly flattened specimens (plate 23, fig. 5). The frontal area is roughly axe-shaped with its lateral margins weakly defined by a change in surface curvature running outwards and forwards from the fossulae to the anterior margin. In longitudinal profile the frontal area slopes down and backwards towards the preglabellar furrow. A very weak anterior border furrow is also commonly present and this defines an anterior border which is sagittally about one-fifth the length of the frontal area. The anterior edge of the frontal area is rounded and reflexed so that it slopes ventrally backwards to form a continuous surface with the crescent-shaped rostral plate, from which it is separated by a well developed rostral suture (plate 23, figs.3c and 3d). Along the front of the anterior margin the exoskeleton is punctured by up to 6 more or less regular rows of canals which stand out as infillings after the original exoskeleton material has been removed; these infillings are usually broken off and resemble tubercles along the anterior margin.

The facial sutures are gonatoparian; they start at the slightly rounded genal angles and curve forwards and inwards until they are opposite the 1p lateral glabellar furrows and about half the maximum glabellar width from the axial furrows. Here they curve sharply to the front and run sub-parallel to the axial furrows before curving out and round the crescent-shaped eyes situated opposite the 3p lateral glabellar lobes. From the front of the eyes, approximately opposite the 3p lateral glabellar furrows, the suture curves gently forwards and adaxially to cut the anterior margin just outside the lateral margin of the frontal area. The posterior areas of the fixed cheeks are deflexed giving the cranidium a marked transverse convexity. The anterior areas of the fixed cheeks are also deflexed and produce a marked transverse and longitudinal convexity. The palpebral areas of the fixed cheeks are dorsally convex, rise from the axial furrows, and arch outwards to the eyes. The posterior border furrows start at the occipital furrow and run abaxially and slightly forward in a gentle curve to cut the facial suture just in from the genal angle. The posterior border furrows are very wide, of moderate depth, and form a continuous furrow from the lateral border furrows of the free cheeks. The eyes are positioned opposite the 3p lateral glabellar lobes. The eyes are crescent-shaped in outline, slightly raised, laterally convex and their length is about one-fifth that of the glabella. No visual surfaces have been preserved.

Only three specimens were found with the free cheeks in place, but many disarticulated free cheeks were collected. The free cheeks are roughly triangular in outline with a convexly curved exterior margin. The anterior section of the facial suture is gently sigmoidal and the posterior section is strongly sigmoidal joining the lateral border at the genal angle so that the border forms a pointed and posteriorly directed corner to the free cheek. The lateral border forms a continuous band about one-quarter of the width of the cheek running concentrically around the outer edge and defined by the lateral border furrow which is very wide, open, and of moderate depth. The lateral margin is rounded in section and reflexed into a doublure which is about the same width as the lateral border. Where the anterior and posterior sections of the facial suture meet at the position of the eye, the corner of the free cheek is extended into a small, slightly upturned, tab-like projection which forms part of the eye support.

The thorax is composed of thirteen segments and tapers posteriorly so that the posterior thoracic segment is about one-half the width of the anterior segment. The axis is about one-half the thoracic width and transversely arched with a strong dorsal convexity. The axial rings are roughly rectangular in outline, each about five times as wide (trans.) as it is long (sag.). The abaxial ends of each ring are rounded and bent so that they are directly slightly forwards. The durrows between the axial rings and articulating half rings are deep and wide (sag.) with a rounded profile and the articulating half rings are partially visible on the enrolled specimen. The axial furrows are deep, well defined and bear well developed ventrally directed apodemes at the posterolateral corners of each axial ring.

The pleurae are difficult to observe because they are incomplete or overlap each other considerably. Each pleura appears to be roughly parallel-sided (trans.) with a rounded abaxial end and the lateral one-third of each pleura is slightly curved towards the front. The pleurae are deflexed and dorsally convex so that their abaxial ends are almost directed ventrally. Each pleura bears a pleural furrow which is deep and wide next to the axial furrow where it starts opposite the antero-lateral corner of the axial ring. Each pleural furrow runs abaxially parallel to the sides of the pleura, but distally becomes shallow and curves gently towards the anterior edge of the pleura; the lateral ends of the pleurae are poorly preserved and it is not clear where or how the pleural furrow terminates.

The pygidium is small, triangular in outline, and about twice as wide as it is long; it has a width which is about two-fifths the the width of the cephalon. Deep axial furrows define a cone-shaped axis which is transversely strongly convex. The axis is divided into 7, possibly 8, axial rings which are approximately rectangular in outline and which become poorly defined posteriorly to merge with a large, slightly inflated, rectangular terminal axial piece. The transverse axial ring furrows are anteriorly deep and wide, but become very faint posteriorly. An articulating half ring extends from the anterior axial ring. The pleural regions are dorsally convex and strongly deflexed. There are 6 ribs on each pleural field, less in number than the axial rings. The interpleural furrows are shallow near the axial furrows and become very faint towards the lateral margins. The pleural furrows are moderately deep and wide, but become faint towards the lateral margins which in many instances are almost smooth. The ventral margin of the pygidium is sharply rounded in section and reflexed to form a narrow doublure which is wide below the terminal axial piece. The ventral margin of the pygidium is commonly punctured by several rows of canals which stand out as infillings after the original exoskeleton material has been removed; these infillings are usually broken off and resemble tubercles.

The cephalon bears an ornament of fine granules both on the internal and external moulds, a similar ornament also occurs on the reflexed part of the frontal area and the rostral plate. Commonly coarser granules or small tubercles occur on the antero-ventral part of the frontal area, these are the stubs of fine canals which penetrate the frontal area and which are noted above in the description. Additionally the central part of the glabella sometimes bears an ornament of scattered small pits. The ornament of the thorax is not well preserved, but appears to consist of fine granules on the internal moulds. The nature of the external ornament on the thorax cannot be determined from these specimens. Internal and external moulds of the pygidium bear a similar fine granular ornament to the cephalon. The ventral edge of the pygidium is perforated by fine canals similar to those found on the frontal area of the cephalon, but these are usually broken and appear as slightly larger granules or small tubercles.

Enrollment resulted in a near perfect sphere. Coaptive structures occur on the cephalon which has a beak-like rostral plate and a well developed central notch which accepts and interlocks with the terminal axial piece of the pygidium (plate 23, figs.3d & 6c). The almost smooth, unfurrowed lateral margin of the pygidium also fits neatly under the frontal part of the cephalon. The thorax tapers posteriorly, has well developed articulating half rings, and the lateral ends of the pleurae are smooth and fairly flat. During enrollment the movement of the axial rings over the articulating half rings provided the "hinge" between the thoracic segments and the tapering thorax allowed the smooth lateral parts of the pleurae to fit neatly under the adjacent anterior pleurae providing a rigid interlocking mechanism.

Discussion

In agreement with the arguments put forward by Whittard (1960, part IV, pp. 138 & 139) *Neseuretus* Hicks, 1872 is accepted as a senior synonym of *Synhomalonotus* Pompeckj, 1898. Dean (1967, p. 115) created the subgenus *Neseuretus* (*Neseuretinus*) for trilobites from the Bedinan Formation in south-eastern Turkey; it is separated from the subgenus *Neseuretus* (*Neseuretus*) by the convex form of the preglabellar field and the development of a large inflated anterior border. Consequently, the Porguguese specimens described above fall into the subgenus *Neseuretus* (*Neseuretus*).

Neseuretus (*Neseuretus*) *tristani* (Brongniart, 1822) is reviewed by Henry (1970) who selected a neotype from the type locality at Hunaudière. This neotype is accepted here and compares well with the original material figured by Brongniart (1822) except that the very strong anterior border furrow shown by Brongniart (*op. cit.*, pl. 1, fig. 2G) is only weakly developed; in the other illustrations given by Brongniart (op. cit., pl. 1, fig. 2F) the furrow is however not very obvious.

Whittard (1960), Henry (1970, p. 10 and fig. 2) and Sadler (1974, p. 82 and text-fig. 6) all point out that *N.* (*N.*) *tristani* may be separated by the longitudinal cephalic profiles from the following species of *Neseuretus* (*Neseuretus*): *N.* (*N.*) *murchisoni* (Salter), *N.* (*N.*) *ramseyensis* Hicks, *N.* (*N.*) *parvifrons* (McCoy), *N.* (*N.*) *monensis*

(Shirley) N. (N.) brevisulcus Whittard, N. (N.) bullatus Whittard N. (N.) complanatus Whittard and N. (N.) arenosus Dean. These cephalic profiles are summarised by Sadler (1974, p. 82, text-fig. 6). N. (N.) tristani is notably different from the above mentioned species because it has a posteriorly sloping (sag.) profile to the preglabellar field. N. (N.) attenuatus (Gigout) and N. (N.) antetristani Dean also have preglabellar fields which slope backwards, but N. (N.) antetristani has weaker glabellar furrows and a narrow frontal glabellar lobe which drops sharply to the preglabellar furrow; N. (N.) attenuatus resembles N. (N.) tristani by the form and convexity of the glabella, but the glabellar lobes (especially the 2p lobes) are more rectangular and the preglabellar field does not slope as strongly to the preglabellar furrow.

Sadler (1974) considers that there are three variants of Neseuretus (Neseuretus) tristani and recognises two of them from Cornwall. He considers variant 1 to be equivalent to the neotype erected by Henry (1970) and variant 3 is of similar dimensions to variant 1, but distinguished from it by the presence of a weak anterior border furrow. The Portuguese material sometimes bears a very weak anterior border furrow and is very close to the material described by Henry (op. cit.). Both the French and the Portuguese material show variations in the frontal areas which are very prone to flattening, especially when the free cheeks are missing. It is probable that the very weak anterior border furrow will not survive even slight flattening. The specimens figured by Sadler (op. cit.) have frontal areas which appear to be slightly flattened, consequently, it is possible that variants 1 and 3 are the same.

To enable comparison with the material presented by Sadler (op. cit.) the measurements of maximum glabellar width versus length of glabellar plus occipital ring (k/b + e) for the Portuguese material were plotted (fig. 65). The graph for 89 samples gives a reduced major axis line which lies between Sadler's variants 2 and 3 so that it is three times as far from variant 2 as it is from variant 3. The Portuguese material shows only one major grouping of points fairly close to the reduced major axis line, but with the addition of a fairly uniform and wide scatter caused by the effects of shear strain producing e and 1 forms (Henningsmoen, 1960). The presence of e and 1 forms is verified by the graphs comparing ratios of length to length and width to width (figs. 62,63 and 64) which show much closer groupings of points because the measurements are taken in the same direction of strain. The majority of the Portuguese material is fairly close to variants 1 and 3 of Sadler (1974), but about 20 percent of the material falls into the variant 2 grouping, however, very little of the Portuguese material plots above the variant 2 line and the large number of very elongate forms recorded by Sadler (op. cit.) are not present. This suggests that variant 2 is probably a valid entity, but that distortion of the Portuguese material as a result of shear strain has produced an apparent overlap of the groups.

Hammann (1977) has recently introduced two new species of *Neseuretus* (*Neseuretus*), *N.* (*N.*) *avus* and *N.* (*N.*) *henkei* respectively, coming from the Llanvirn and Llandeilo of Spain; he also figured what he considered to be *N.* (*N.*) *tristani* also from the Llandeilo of Spain. The two new species are only briefly described and differ from *N.* (*N.*) *tristani* mainly on the shape and convexity of the glabellae and the frontal areas. None of the specimens have the free cheeks attached and they resemble the variations of *N.* (*N.*) *tristani* caused by flattening and tectonic distortion observed in the Portuguese material. Hammann (op. cit.) does not say how many specimens his new species are based on and until more detailed descriptions are published meaningful comparison with the Portuguese material is difficult. According to Hammann *N.* (*N.*) *avus* has a pentagonal-shaped glabella and a short frontal area. Plotting the measurements of this species against the measurements of the Portuguese material shows that comparing the lengths of the glabellae plus occipital rings against the widths of the glabellae, very little of the Portuguese material approache the same dimensions as *N.* (*N.*) *avus* and those which do are generally obvious w forms (Henningsmoen, 1960) which occur with l forms on the same slabs. Comparison of the lengths of the glabellae against the lengths of the frontal areas shows that *N.* (*N.*) *avus* has the same ratio as the mean average calculated for the Portuguese material. Hammann does however note that *N.* (*N.*) *avus* has 4 pairs of lateral glabellar furrows (but only 3 pairs are clearly visible on his figure, pl. 1, fig. 1); this is not a feature shown by any of the Portuguese material and might be the only reliable criterion for separating *N.* (*N.*) *avus* from *N.* (*N.*) *tristani*. Comparing *N.* (*N.*) *henkei* (Hammann, 1977) with the Portuguese material, it has similar glabellar measurements to the Portuguese specimens of *N.* (*N.*) *tristani* (and to variants 1 and 3 of Sadler, 1974); the frontal area of *N.* (*N.*) *henkei* is however marginally longer than the average for *N.* (*N.*) *tristani*, but well within the main grouping of variation shown by the Portuguese material. The specimen of *N.* (*N.*) *tristani* figured by Hammann (*op. cit.*, pl. 1, fig. 3) has the same glabellar and frontal area dimensions as predicted for similarly sized o forms (Henningsmoen, 1960) of *N.* (*N.*) *tristani* from Portugal. The slight morphological and dimensional differences noted by Hammann (*op. cit.*) between the species *N.* (*N.*) *avus*, *N.* (*N.*) *henkei* and *N.* (*N.*) *tristani* are all vulnerable to distortion due to flattening (especially the frontal areas and glabellae) and without detailed measurements and descriptions of the new species it is impossible to subdivide the Portuguese material, furthermore the graphical presentation of the data for the Portuguese material indicates that only one species is present.

Dean and Martin (1978) describe N. (N.) vaningeni Dean, 1978 from the Arenig iron ore beds of Bell Island, eastern Newfoundland. This species is easily distinguished from N. (N.) tristani because it has a tumid frontal area postero-laterally bounded by marked anterior border furrows which are continuous with the preglabellar furrow.

N. (N.) tristani is a very common, long ranging and widespread trilobite which has been recorded throughout the southern and western parts of the Mediterranean province (Spjeldnaes, 1961) from strata of Llanvirn and Llandeilo ages. It has been recorded extensively from north-west France (Henry, 1970 and Babin et al., 1976) where it ranges from the lower Llanvirn to the upper Llandeilo. In Spain it occurs in Llanvirn and Llandeilo strata and has been noted in several places by Born (1918), Carré et al. (1970), Gil Cid (1971), Saupé (1971) and Tamain (1971). In Portugal Delgado (1908) recorded beds containing N. (N.) tristani from most of the "middle" Ordovician "Schistes à Didymograptus" and "Schistes à Homalonotus" in the Amendoa and Buçaco areas. Later works by Costa (1942) and Thadeu (1949 and 1956) also record N. (N.) tristani from beds of probable Llanvirn and Llandeilo age in many parts of Portugal. Mitchell (1974) recorded it from the upper levels of the Cacemes Formation at Buçaco which he considered to be of lower or possibly middle Llandeilo age. In Britain N. (N.) tristani has been recorded in Cornwall from the Gorran Quartzites of Llandeilo age (Sadler, 1974) and from the derived pebbles in the

Budleigh Salterton Pebble Beds (Salter, 1864). Further afield it has also been recorded from the Llandeilo rocks of Morocco (H. & G. Termier, 1950 and Gigout, 1951). Because N. (N.) tristani was so successful and ranges for a long time it has not yet proved to be of much stratigraphical use, but it appears to be restricted to the Llanvirn and Llandeilo.

Family COLPOCORYPHIDAE Hupé, 1955

Genus COLPOCORYPHE Novák in Perner, 1918

Type species: Calymene Arago Rouault, 1849

Colpocoryphe lennieri (Bergeron, 1893)

1893 Calymene lennieri nov. sp. Bergeron, pp. 43-45, pl. VI, figs. 3-4.

1956 Calymene (Colpocoryphe) grandis nov. sp.; Snajdr, pp. 501-504, 529-530, 532 and pl. III, figs. 1-9.

1966 Colpocoryphe grandis (Šnajdr); Dean, p. 141.

1966 Colpocoryphe lennieri (Bergeron, 1894) and Colpocoryphe grandis (Šnajdr, 1956); Destombes, p. 36.

1966 Colpocoryphe grandis Šnajdr; Havliček and Vaněk, pp. 30, 52-54 and pl. VIII, fig. 5.

1969 Colpocoryphe lennieri (Bergeron); Henry, pp. 13, 15 and 17.

1970 Colpocoryphe lennieri (Bergeron, 1894); Henry, p. 17.

1971 Colpocoryphe lennieri (Bergeron); Henry and Thadeu, p. 3.

1972 Colpocoryphe lennieri (Bergeron); Robardet et al., p. 122.

1974 Colpocoryphe lennieri (Bergeron); Henry et al., p. 333.

1974 Colpocoryphe lennieri; Lindström et al., p. 20.

1976 Colpocoryphe lennieri (Bergeron); Babin et al., pp. 371, 374.

Colpocoryphe cf. lennieri (Bergeron, 1893)

Pl. 24, fig. 7.

Age and locality

Lower Caradoc; the specimen is from the J.F.N. Delgado collection (7–6–1886) housed in the Serviços Geológicos Museum, Lisbon. The specimen was collected from "1700m a N57°E de pyr. de Queixopera Mação" about 30km south-east of the Dornes area. The specimen was associated with bryozoa, Onnia grenieri and Drabovia cf. redux. The same bryozoa and brachiopod also occur in lithologically identical material within the bryozoa beds of the Monte do Carvalhal Formation in the Dornes area.

Material

One incomplete cranidium preserved as an internal mould.

Measurements (mm)

Maximum width of cranidium across the posterior areas of the fixed cheeks	67.7 (estimated)
Width of glabella across posterior margin	22.0
Length of cranidium	19.0
Length of glabella	14.7
Length of glabella including occipital ring	17.2

Description

The specimen has been distorted by sagittal compression and is a "w form" (Henningsmoen, 1960, p. 207). The cranidium is about one-third as long as it is wide. The glabella is trapezoidal in outline and about half as wide across the preglabellar furrow as it is across the occipital furrow; the axial furrows are deep, well developed, and converge evenly forwards. Three pairs of lateral glabellar furrows are present. The 1p lateral glabellar lobes each have a maximum length (exsag.) of about one-third of the glabellar length. The 1p lateral glabellar furrows are deep, wide (exsag.) and each has a length which is about one-third of the maximum glabellar width. The 1p furrows point adaxially backwards and make an angle of about 45 degrees with the sagittal line. The 2p lateral glabellar lobes each has a length (exsag., measured between the adaxial ends of the 1p and 2p furrows) which is about one-third of the glabellar length. The 2p furrows are wide (exsag.) and of moderate depth. Each furrow has a length (trans.) which is about one-sixth of the glabellar length and is directed adaxially backwards to make an angle of between 80 and 85 degrees with the sagittal line. Only the right 3p lateral glabellar lobe is preserved, it is about one-quarter of the glabellar length. The 3p furrow is wide (exsag.) and very shallow; transversely the furrow is short and measures about one-third the length of each 2p furrow. The 3p furrow starts a little way in towards the axial line from the axial furrow. The glabella is dorsally strongly convex (both sag. and trans.) and the median area is fairly flat. The preglabellar furrow is well marked and slightly deeper in its central part. The occipital ring is rectangular in outline with a width (sag.) about one-quarter of the glabellar length. The occipital furrow is straight deep and wide (sag.) with a rounded profile.

Only an incomplete left fixed cheek and the frontal area are preserved in addition to the glabella. The posterior area of the fixed cheek is approximately equal in width to the maximum glabellar width. The posterior edge is straight, but the anterior edge is convex towards the front and directed abaxially slightly backwards from opposite the 2p lateral glabellar furrow. Only the left palpebral area of the fixed cheek is poorly preserved and it appears to be about equal in width to about one-quarter of the posterior glabellar width. The frontal area is about one-third the length of the glabella and a little wider than the maximum glabellar width. The frontal area is directed sharply downwards and is not very apparent in dorsal view. In anterior view the central part of the frontal area is cut away to form a central notch about one-half the length and one-half the width of the frontal area. The lobes of the frontal area either side of the notch have rounded ends. The specimen is an internal mould and is essentially smooth, but the frontal area carries small scattered tubercles.

Discussion

Destombes (1966, p. 36) and Henry (1969, p. 17 and 1970, p. 17) all consider that Colpocoryphe grandis (Šnajdr, 1956) is a junior synonym of Colpocoryphe lennieri (Bergeron, 1893). Henry (1970) notes that C. lennieri "semble au premier abord identique a C. grandis: les quelques faibles differences relevêes sont insignifiantes et ne pourraient justifier qu'une distinction subspêcifique". This synonymy emphasised by Destombes (op. cit.) is important for the establishment of stratigraphic correlation between Bohemia, Morocco, western France and Iberia.

Colpocoryphe cf. lennieri from Dornes is very similar to C. lennieri figured by Bergeron (1893), but the effects of sagittal compression on the Portuguese specimen make absolute specific identification difficult. The Portuguese material is also comparable with the material figured for C. grandis by Šnajdr (1956) and Havliček and Vaněk (1966).

C. lennieri has a very similar glabellar form and segmentation to C. rouaulti Henry, 1970, but can be separated from it by the characteristics of the anterior notch of the cephalon which in C. lennieri is less marked and more open. C. inopinata Vaněk, 1965 differs from C. lennieri by its anteriorly narrow glabella and by the weak development of the glabellar furrows. C. bohemica (Vaněk, 1965) is separated from C. lennieri by the position of the eyes which are set well forwards and give very long (ex sag.) posterior areas to the fixed cheeks; it is also distinguished by the pre-occular branches of the facial suture which are strongly convergent. C. thorali Dean, 1966(b) is distinguished from C. lennieri mainly by its more elongate, less squat and bell-shaped glabella. C. salteri (Rouault, 1851) redescribed by Henry (1970, pp. 18-22) and C. lusitanica (Thadeu, 1949) are very similar and both differ from C. lennieri by having a strongly tapering and dorsally more convex glabella with shorter (trans.) 2p lateral glabellar furrows.

C. arago (Rouault, 1849) has in the past been extensively recorded throughout Armorica, Spain, Portugal and Morocco, but as Henry (1970, pp. 12-13) points out, although it is a valid species having a holotype and published description, the holotype is very poor and defies comparison with any other material. As a consequence of the difficulties of comparing material with C. arago Henry (op. cit. pp. 13-18) erected the species C. rouaulti to include most of the recordings of C. arago. C. arago has been extensively recorded in Portugal by Delgado (1908) and is usually misquoted as "Calymene Aragoi Rou." (Delgado, op. cit. p. 33, 35, 41, 43, 48, 50, 57, 70, 89, 92 and 93). C. arago recorded by Delgado (op. cit., p. 57) from the "Ordovicien supérieur; Schistes culminants and Grès de Loredo" of Buçaco is probably C. lennieri, but C. arago recorded from the "Ordovicien moyen; schistes à Homalonotus Oehlerti and Schistes a Orthis Ribeiroi" of Buçaco, or similar beds in Amendoa area (Delgado op. cit., p. 80) is probably C. rouaulti.

C. lennieri has been recorded from the base of the Louredo Formation at Buçaco in the oolitic phosphato-chloritic beds and also from the upper part of the Postolonnec Formation in the Armorican massif (Henry et al., 1971, and Lindström et al., 1974). In Bohemia the junior synonym C. grandis has been recorded by Šnajdr (1956) and Havlíček and Vaněk (1966) from the Dobrotiva, Libeň and Letná Formations which indicates that C. lennieri ranges from the lower Llandeilo to the lower Caradoc in Bohemia (Havlíček and Marek, 1973), but is restricted to the lower and middle Caradoc in Portugal and Armorica.

Colpocoryphe rouaulti Henry, 1970.

Pl. 24, figs. 8-9.

For a complete synonymy of works before 1966 see Henry 1970.

1969 Colpocoryphe rouaulti n. sp., Henry p. 13.

1970 Colpocoryphe rouaulti nov. sp., Henry, pp. 13-18, pl. B, figs. 1-8 and pl. C, fig. 1.

1971 Colpocoryphe rouaulti Henry, 1970; Gil Cid, pp. 313 and 314.

1973 Colpocoryphe rouaulti Henry, 1970; Clarkson & Henry, pp. 117, 118, fig. 10 and fig. 11.

1974 Colpocoryphe rouaulti Henry; Henry et al., p. 332.

1974 Colpocoryphe rouaulti; Lindström et al., p. 20.

1976 Colpocoryphe rouaulti Henry; Babin et al., pp. 370, 373 & 374.

1976 Colpocoryphe rouaulti; Henry et al., p. 279.

1977 *Colpocoryphe rouaulti* Henry; Henry & Romano, p. 335.

1978 *Colpocoryphe rouaulti* Henry; Bruton & Henry, p. 900.

Age and locality

Llanvirn, *Didymograptus murchisoni* Zone. One specimen of a cranidium was loaned from the J.F.N. Delgado collection housed in the Serviços Geológicos Museum, Lisbon and was collected from the Brejo Fundeiro Formation, 250 metres south of Brejo Fundeiro; two additional cranidia were also collected nearby at locality 85. A cephalon was also found to the north of the area at locality 5 probably also in the Brejo Fundeiro Formation.

Material

Three cranidia preserved as internal moulds and one cephalon preserved both as an internal and an external mould.

Measurements (mm)

Locality 5:-		
Width (trans.) of cephalon	11.7	
Length (sag.) of cephalon	5.7	
Locality 85:-		
Width (trans.) of cranidium	8.5 (est.)	12.7
Length (sag.) of cranidium	3.0	5.0
Museum specimen:-		
Width (trans.) of cranidium	29.0 (est.)	
Length (sag.) of cranidium	17.7	
Posterior width of glabella	11.5	
Length (sag.) of glabella	9.5	

Description

The cephalon is approximately semi-circular in outline when viewed dorsally; its width measured along the posterior border furrow is about equal to double the length (sag.). The glabella is trapezoidal in outline, about two-thirds as wide across the preglabellar furrow as it is across the occipital furrow. The axial furrows are deep and well developed. The glabellar carries three pairs of lateral glabellar furrows. The preoccipital glabellar furrows (1p) are large, deep and each of a length which is about one-third the maximum glabellar width. These furrows are oblique, well formed and directed adaxially backwards to make an angle of 60 degrees with the axis. The median lateral glabellar furrows (2p) are deep and well developed; they are directed adaxially and slightly backwards, and each has a length of about one-third the glabellar width at that point. The anterior lateral glabellar furrows (3p) are very weakly developed, about one quarter the glabellar width at that point, and directed adaxially and slightly forwards. The 1p, 2p and 3p glabellar lobes are approximately one-third, two-ninths and two-ninths the length of the glabella respectively. The preglabellar furrow is well developed and one specimen (5, external) has traces of slight fossulae. The glabella is moderately to strongly convex (both sag. and trans.) and the area between the 1p and 2p lobes is fairly flat. The occipital furrow is deep, straight and well developed with the lateral extremities adjacent to the preoccipital lobes being slightly deeper than the axial portion. The occipital ring is about one-quarter the length of the glabella when viewed dorsally.

The frontal area is about one-quarter the length of the glabella and equal in width to the maximum glabellar width. The frontal area points sharply downwards and is not very apparent in dorsal view. In anterior view the central part of the frontal area is cut away to form a rounded notch of about one-third the width and half the length of the frontal area. The lobes of the frontal area at either side of the notch have rounded ends formed by the facial sutures curving and cutting the anterior margin adjacent to the notch.

The facial sutures are gonatoparian. They start at the slightly rounded genal angles and curve forwards and inwards until they are opposite the 1p glabellar furrows. Here they curve sharply to the front and run forwards sub-parallel to and about one-third the maximum glabellar width out from the axial furrows. At their anterior extremities the facial sutures curve sharply towards the axis, then backwards, delineating the rounded lobes of the frontal area and cutting the cephalic margin on either side of the central notch. The posterior areas of the fixed cheeks are deflexed making the cranidium strongly convex (trans.). The posterior border furrows start at the occipital furrow, arch slightly forwards then back to finish just short of the genal angles. The furrows are of moderate depth, but become wider and shallower towards the genal angles. The palpebral areas of the fixed cheeks are inclined inwards towards the axial furrows. The anterior areas of the fixed cheeks curve forwards and downwards to merge with the anterior area. The eyes are positioned opposite the 2p furrows. They are crescentic in outline, slightly raised, laterally convex, and their length is about one quarter that of the glabella. No visual surfaces have been preserved.

Only one specimen (from locality 5) has the free cheeks intact. They are roughly triangular in outline with a convexly curved exterior margin. The specimen has been slightly crushed, and the lateral parts of the cheeks have been partly folded under the cephalon. Moderately strong lateral border furrows are present defining narrow lateral borders to the free cheeks; these borders and furrows finish approximately in front of the axial furrows. The furrows and borders have probably been emphasised by the crushed nature of the specimen.

Only one complete thoracic segment and one part of a segment are preserved attached to the specimen from locality 5. The maximum width of the thorax is slightly narrower than the maximum width of the cephalon. The axis is about one-third the width of the thorax and in transverse section it is dorsally strongly convex; the axial furrows are deep and well defined. The axial rings are roughly rectangular in outline and each is about five times as wide (trans.) as long (sag.). The abaxial ends of each ring are rounded and curve very slightly forwards. The furrows between the axial rings and the articulating half rings are deep and wide (sag.) with a rounded profile; the articulating half rings cannot be seen because they are concealed by the occipital ring and the axial rings. The pleurae are incomplete and overlap each other considerably. Each pleura appears to be parallel-sided with a rounded abaxial end. The pleurae are strongly deflexed giving the thorax a marked dorsal convexity and the distal one-third of each pleura is curved very slightly towards the front. Each pleura bears a pleural furrow which is deep and wide next to the axial furrow where it starts opposite the antero-lateral corner of the axial ring. The furrow runs abaxially parallel to the sides of the pleura, but distally becomes shallow and curves towards the antero-lateral corner of the pleura.

Traces of a very fine granular ornament are present on internal moulds of the central glabellar lobe, the occipital ring, both the free and fixed cheeks and the axial rings of the thorax.

Discussion

Henry (1970) considered Colpocoryphe arago (Rouault, 1849) to be a valid species having a published description, figure and type locality, but the specimen is poor and excludes comparison with the specimens. Consequently, Henry (op. cit.) established the species Colpocoryphe rouaulti to include many of the synonyms of C. arago. The Portuguese specimens described above compare well with the description given for C. rouaulti, but several minor differences are apparent. The specimens described here have only three pairs of lateral glabellar furrows of which the front (3p) furrows are very weakly developed. Henry described C. rouaulti as having four pairs of lateral glabellar furrows of which the front two pairs (3p and 4p) are very weakly developed (Henry, 1970, p. 15 and pl. B, figs. 2a, 2c and 8). The lack of the very faint 4p furrows on the Portuguese specimens is probably due to the small size of the specimens and the state of preservation. The lateral border furrows along the edges of the free cheeks are not obvious in Henry's photographs (pl. B, figs. 1b, 2a and 2b), but are mentioned by him in his description. On the specimen from locality 5 they appear to be very well developed, but the specimen is obviously slightly crushed which might explain the differences.

C. rouaulti differs from the closely related species C. lennieri (Bergeron, 1893) mainly by having a narrower and more marked anterior notch in the anterior area. C. rouaulti may be distinguished from C. inopinata Novak in Perner, 1918 and C. bohemica (Vaněk, 1965) by the position of the eyes which are much further forwards in these species. C. thorali Dean, 1966(b) can be distinguished from C. rouaulti by the shape of the glabella which is more elongate and bell-shaped in the former. C. salteri (Rouault, 1851) redescribed by Henry (1970, pp. 18–11. pl. C, figs. 2–6 and text-fig. 4) and C. lusitanica (Thadeu, 1949) are very similar species and differ from C. rouaulti by having a glabella which tapers more sharply towards the front.

In the Dornes area C. rouaulti occurs in the Brejo Fundeiro Formation associated with Didymograptus murchisoni Zone graptolites. Elsewhere in Portugal C. rouaulti occurs in the Cacemes Formation at Buçaco in rocks of a Llanvirn or Llandeilo age (Henry et al., 1974). Gil Cid (1971) also records C. rouaulti from Llandeilo strata in the area south-east of Toledo in Spain. In the Armorican massif C. rouaulti ranges in age from Llanvirn to Llandeilo and occurs in the Postolonnec Formation, the Traveusot Formation and the Angers Slate Formation (Henry 1970, Henry et al., 1974 and Babin et al., 1976).

Genus PLAESIACOMIA Hawle & Corda, 1847

Type species. Plaesiacomia rara Hawle & Corda, 1847

Plaesiacomia oehlerti (Kerforne, 1900)

Pl. 24, figs. 10–12; pl. 25, figs. 1–8;
pl. 27, fig. 1; pl. 30, figs. 3–5 & 7.

1900 Homalonotus (Plaesiacomia) oehlerti n. sp.; Kerforne p. 784, pl. XIII, figs. 1 & 2.

1908 Homalonotus (Plaesiacomia) oehlerti Kerforne; Delgado, pp. 27, 33, 34, 41–43, 50, 57, 69, 74, 80, 89, 92 & 159.

1966a Plaesiacomia oehlerti (Kerforne); Dean, pp. 135–140, pls. 1–3.

1968 Plaesiacomia oehlerti (Kerforne); Henry & Morzadec, pp. 158–159, figs. A & B.

1970 Plaesiacomia oehlerti (Kerforne); Carré et al., pp. 778–9, pl. XXV, figs. 4, 5, 7 & 8.

1971 Plaesiacomia oehlerti (Kerforne); Henry & Thadeu, p. 1345.

1972 Plaesiacomia oehlerti (Kerforne); Robardet et al., p. 121–122, fig. 4, E & F, pl. XVIII, fig. 11.

1974 Plaesiacomia oehlerti; Lindström et al., pp. 20–21.

1974 Plaesiacomia oehlerti (Kerforne); Henry et al., p. 332, pl. X, figs. 6 & 7.

1974 Plaesiacomia oehlerti; Mitchell, p. 388.

1976 Plaesiacomia oehlerti (Kerforne); Babin et al., pp. 363, 364 & 370.

1976 Plaesiacomia oehlerti; Henry et al., p. 279.

Age and locality

In the Dornes area Plaesiacomia oehlerti is abundant in the upper Llandeilo, common in the lower Llandeilo and very rare in the upper Llanvirn. Plaesiacomia sp. indet occurs associated with Didymograptus murchisoni Zone graptolites at fossil locality 85 and P. oehlerti is recorded from the upper part of the Brejo Fundeiro Formation (post Didymograptus murchisoni Zone) at fossil localities numbered 6, 56, 67, 68 and 147. Abundant specimens were collected from the Lameiros Member and the lowest 30 metres of the Monte do Carvalhal Formation at localities numbered 13, 14, 15, 17, 18, 20, 29, 30, 78, 180 and 184; the Monte da Sombadeira Formation proved almost unfossiliferous.

Material

The material consists of 6 cephala, 69 cranidia; 22 pygidia and one pygidium with a poorly preserved incomplete thorax attached. The specimens are mainly preserved as internal moulds and occasionally as external moulds.

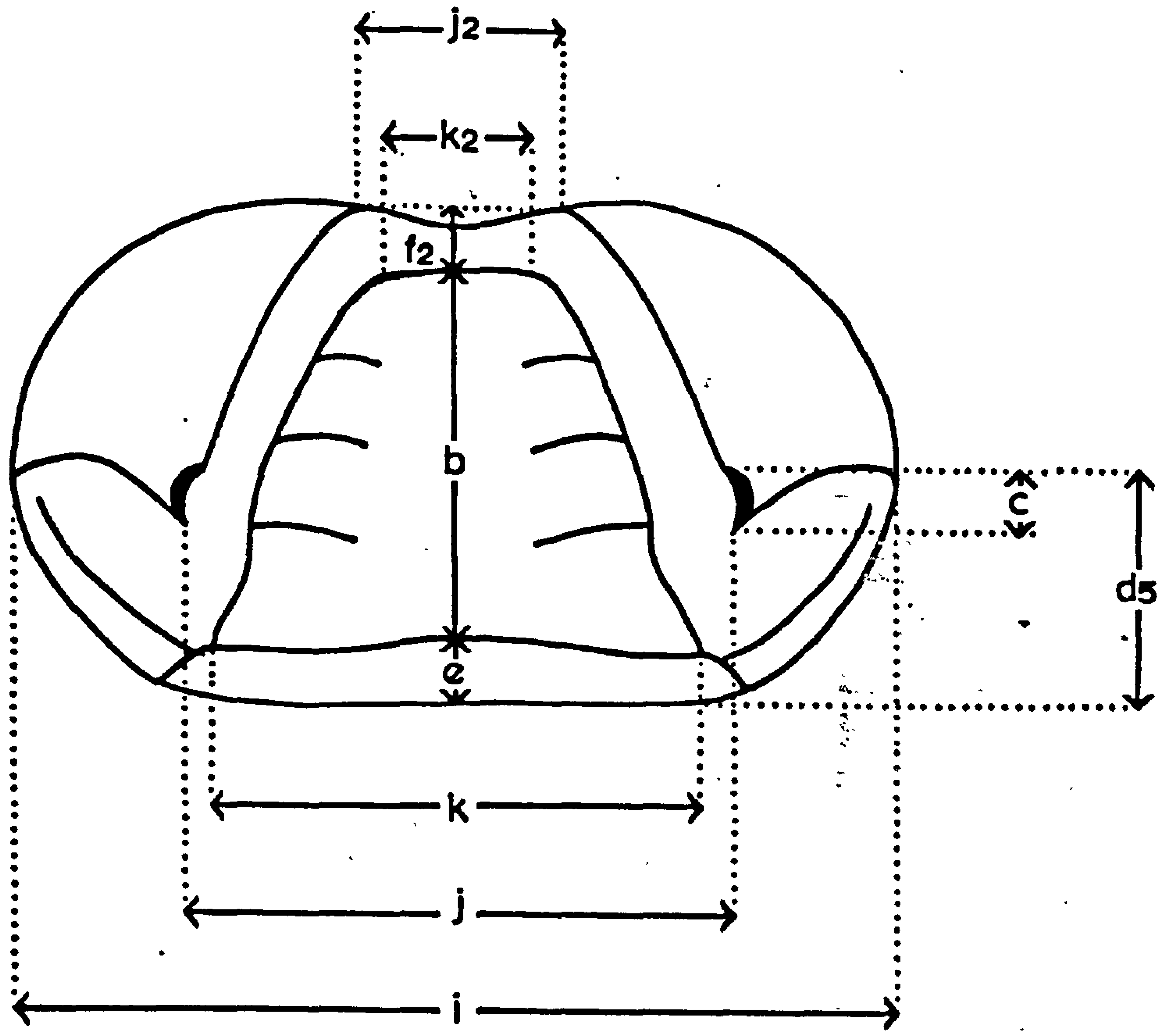
Measurements (mm)

The collected cephala vary between 4.6 and 11.6mm in width and the orientations of the detailed measurements are given in figure 67; some detailed measurments are shown graphically in figures 68–71

ORIENTATION OF MEASUREMENTS

FIG. 67

For *Plaesiacomia oehlerti* (Kerforne)



Measurements based on Temple (1975) and taken with the normal projection of the sagittal cranidial length horizontal.

f_2 - Length of preglabellar field

b - Length of glabella

e - Length of occipital ring

d_5 - Length from posterior border to front of eye

c - Length of eye

k - Posterior width of glabella

k_2 - Anterior width of glabella

j - Width between eyes

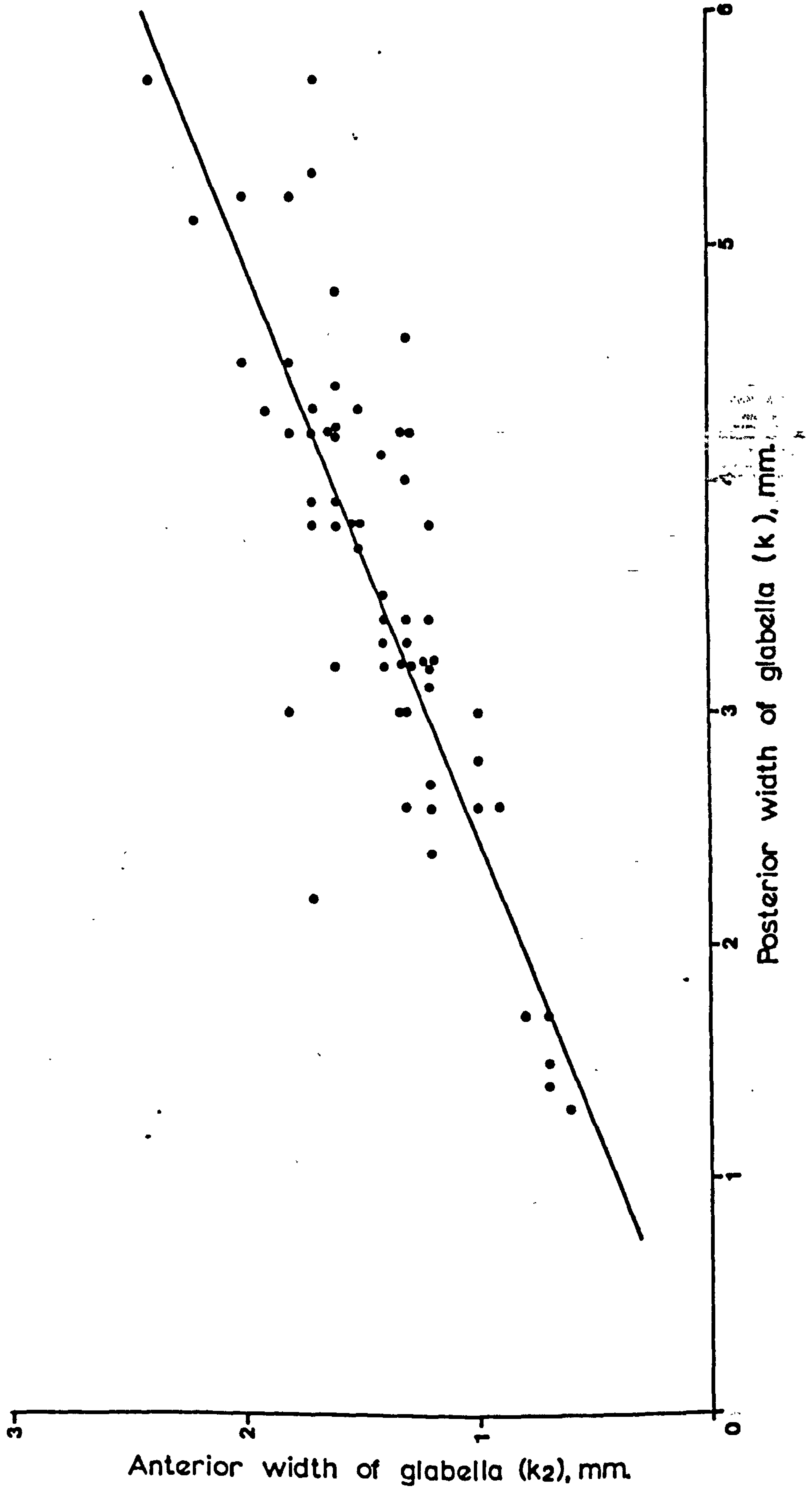
j_2 - Anterior width between facial sutures

i - Width of cranidium

GRAPH OF POSTERIOR GLABELLAR WIDTH (k) AGAINST ANTERIOR GLABELLAR WIDTH (k2)

FIG. 68

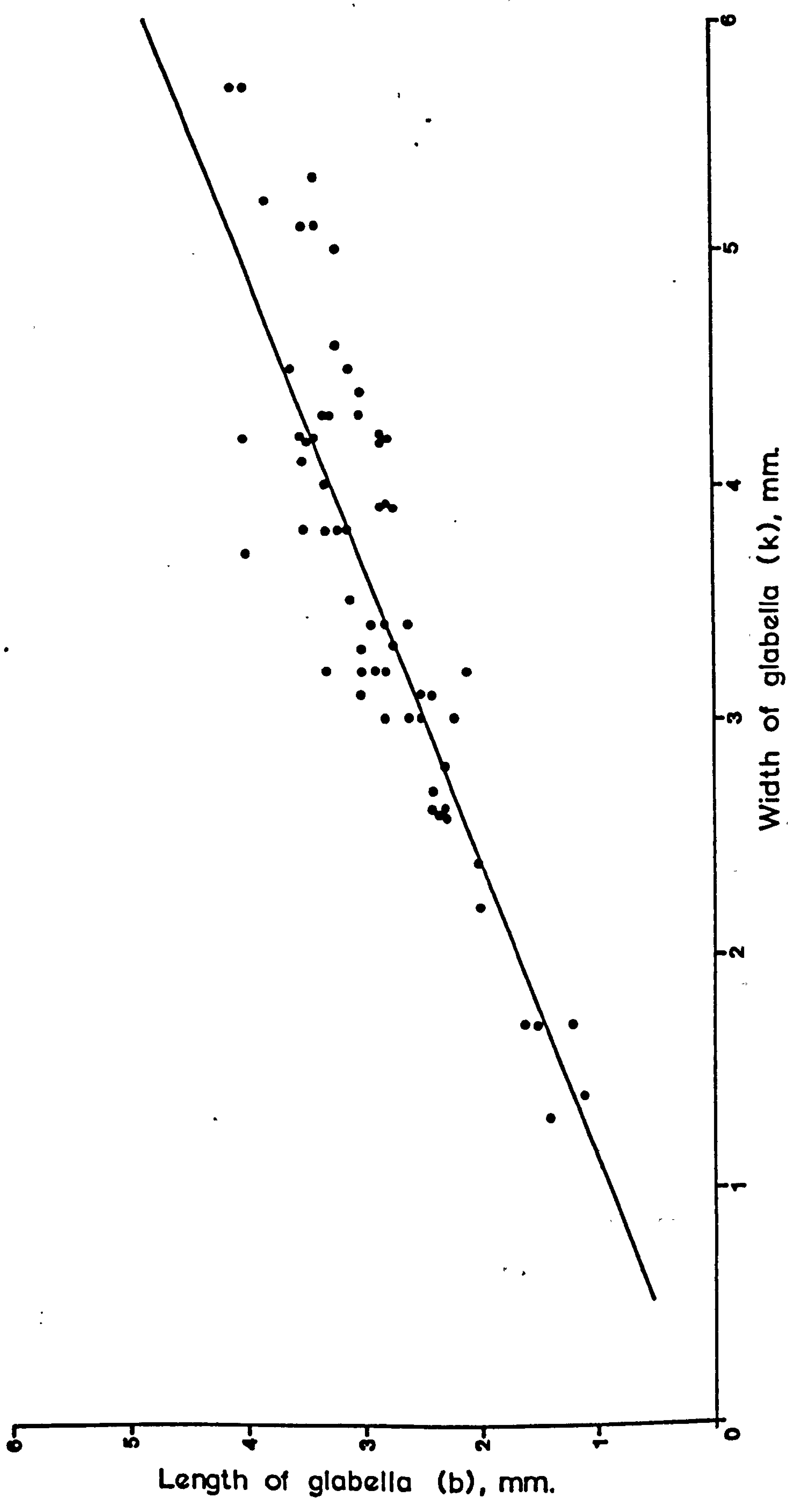
For *Plaesiacomia oehlerti* (Kerforne); 62 specimens



GRAPH OF GLABELLAR WIDTH (k) AGAINST GLABELLAR LENGTH (b)

FIG. 69

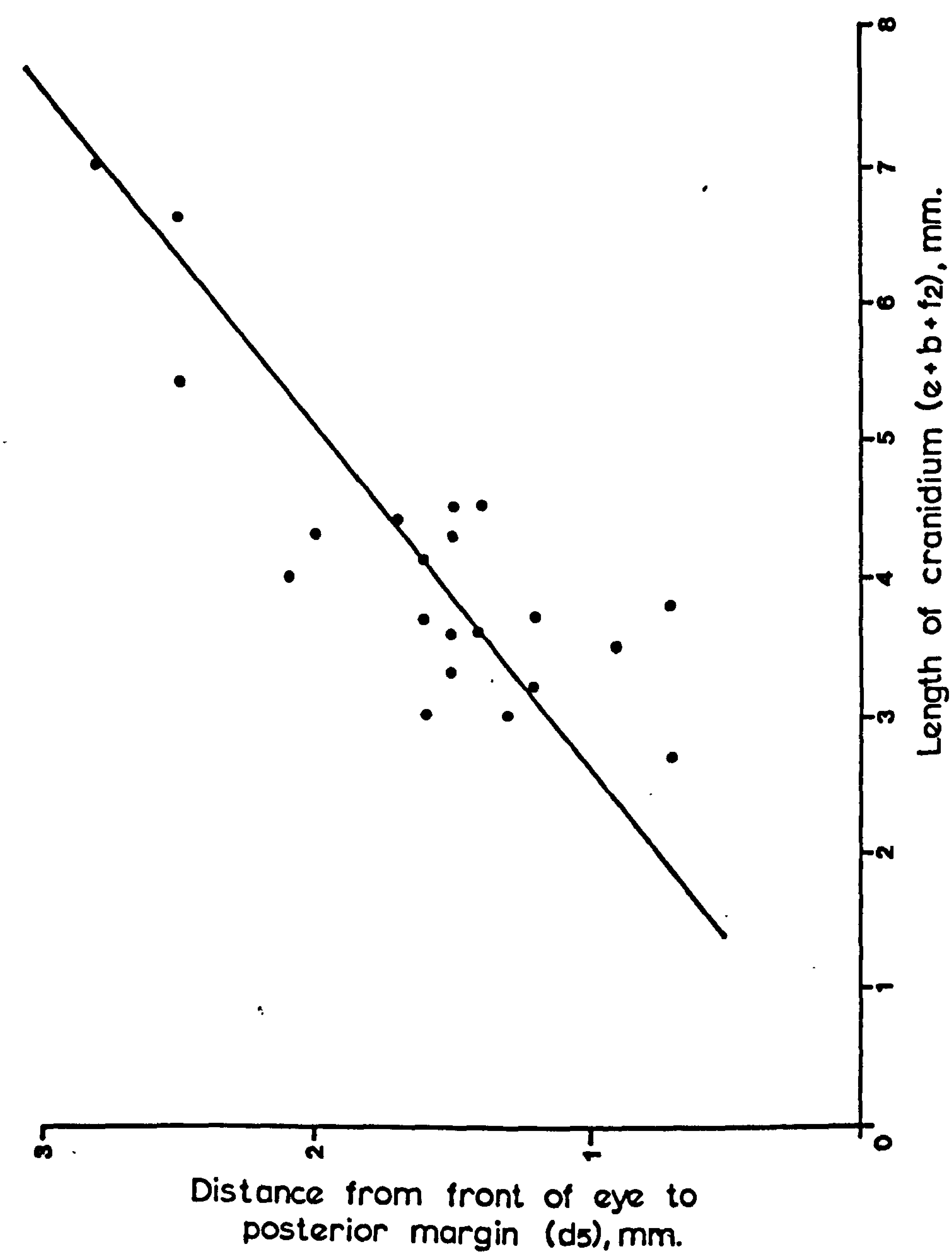
For *Plaesiacomia oehlerti* (Kerforne); 62 specimens



GRAPH OF CRANIDIAL LENGTH (e + b + f2) AGAINST DISTANCE FROM FRONT OF EYE TO POSTERIOR MARGIN (d5)

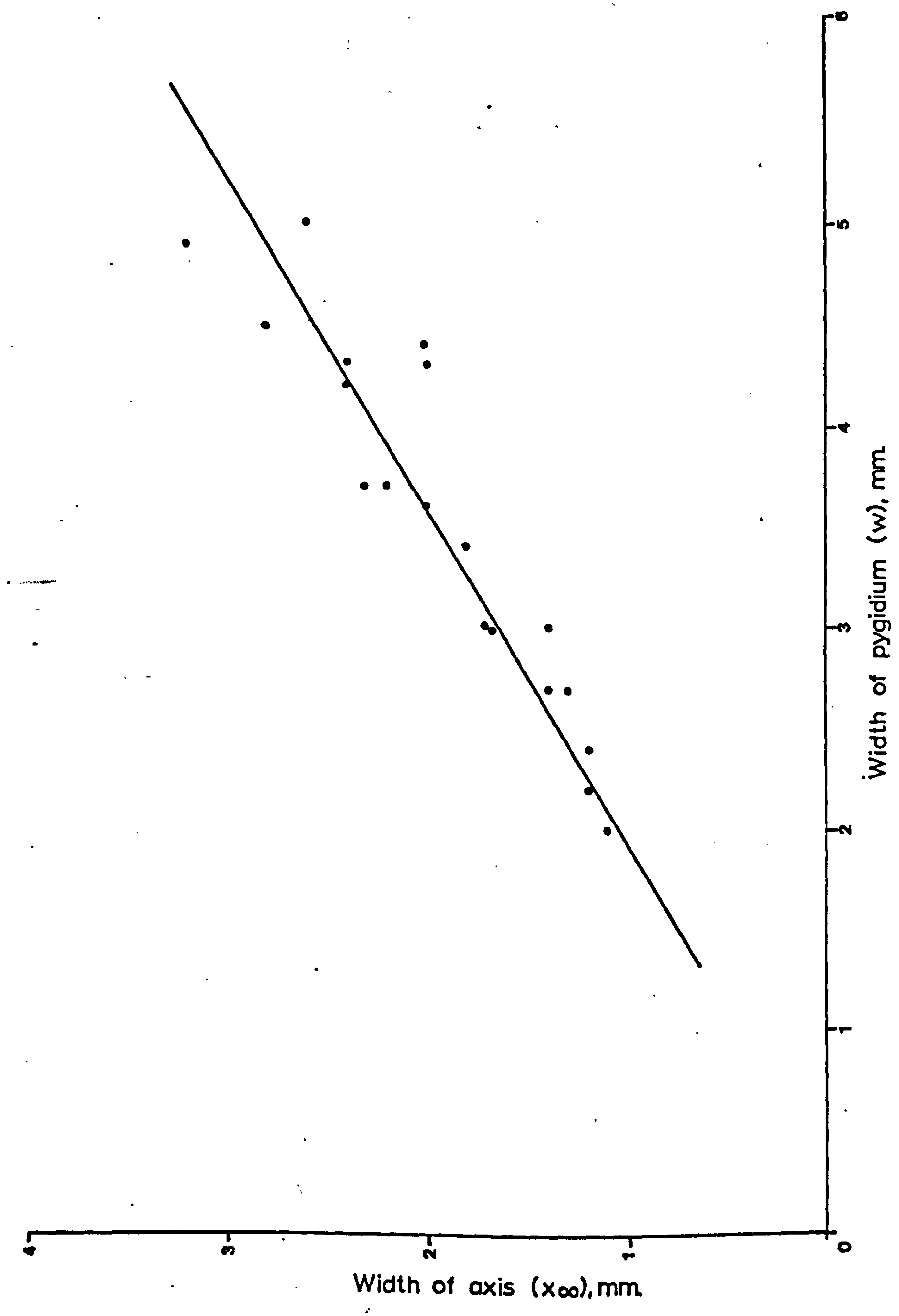
FIG. 70

For *Plaesiacomia oehlerti* (Kerforne); 21 specimens



GRAPH OF WIDTH OF PYGIDIUM (w) AGAINST WIDTH OF AXIS (x_{oo}) FIG. 71

For *Plaesiacomia oehlerti* (Kerforne); 19 specimens



and the complete details are presented in Appendix 3. The measurements are based on Temple (1975); for the cephala they are taken with the sagittal cranidial length horizontal and for the pygidia they are taken with the anterior margin vertical. The average measurements for 23 cranidia/cephala and 19 pygidia are given below:

Width of cephalon (i)	7.61
Width between eyes (j)	5.10
Posterior width of glabella (k)	4.01
Anterior width between facial sutures (j_2)	2.48
Anterior width of glabella (k_2)	1.56
Length of occipital ring (e)	0.51
Length of glabella (b)	3.09
Length of anterior border (f_2)	0.51
Length from posterior border to front of eye (d_5)	1.58
Length of pygidium (z_1)	1.56
Width of pygidium (w)	3.42
Width of axis (x_{oo})	1.93

Description

The cephalon is generally oval in shape with well rounded genal angles, the length being about one-half of the width. The cephalon has a moderate transverse convexity and is sagittally strongly convex. The glabella is generally sub-trapezoidal in shape, with the axial furrows converging forward at about fifty degrees, and with the length being two thirds of the posterior glabellar width. The anterior corners of the glabella are rounded and the posterior ones angular.

The axial furrows are straight or slightly curved abaxially except between the 1p furrows and the occipital furrow where they curve with a slight adaxial concavity. All the glabellar furrows are shallow and curve inwards and backwards at an angle of seventy degrees to the sagittal line; the 3p furrows are frequently missing. The 1p furrows are each about one-third the posterior glabellar width and the 2p and 3p furrows about one quarter of the posterior glabellar width; the central one-third of the glabella being free of furrows. The frontal glabellar lobe is about one sixth of the glabellar length. Some of the internal casts show ovoid muscle scars coinciding with the adaxial parts of the 1p and 2p furrows, otherwise the glabella is smooth. The occipital ring is narrow (sag.) and clearly differentiated from the glabella by a wide occipital furrow. The occipital ring has an anterior margin that is slightly curved and off-set slightly backwards at both ends to accommodate the basal glabellar lobes. The occipital furrow continues with a small posterior offset into the posterior border furrows which distally curve in an anterior direction, becoming shallower at the same time, and finishing just short of the lateral margins. The posterior borders are straight or slightly curved towards the front and widest (exsag.) near the occipital ring. The fixed cheeks and frontal area are smooth, together forming a concentric border around the glabella; this border has a width which is about one-sixth the length of the glabella. The posterior one-quarter of the fixed cheeks is expanded abaxially and slightly forward to form the two lobe-shaped posterior areas of the fixed cheeks; the anterior and the posterior parts of the gonatoparian facial suture meeting at about 80 degrees. Antero-laterally in front of the glabella the anterior border is expanded and forms a pair of lobe-like projections which are directed antero-ventrally. The eyes are situated opposite the 2p glabellar furrows; they are crescent-shaped in plan with rounded ends and about one-sixth the length of the glabella. They are supported by poorly developed and abaxially convex palpebral lobes; no eye ridges are developed and no visual surfaces have been found. The free cheeks are smooth and sub-triangular in outline with the lateral margins outwardly convex and the posterior margins concave. The cheeks are transversely convex in section, and no lateral border is developed.

A complete thorax has not been found here, but Dean (1966) records "probably thirteen segments". The specimen described here consists of seven thoracic segments attached to a pygidium. The axis is about two thirds the thoracic width but the pleurae have been folded under, and about one half the thoracic width as stated by Dean (op. cit.) is probably more correct. The axis is transversely arched standing higher than the pleurae. The axial rings are sub-rectangular with their lateral margins tapering forwards at an angle of about twenty degrees. The axial lobes and apodemal pits described by Dean (op. cit.) are not apparent. The articulating furrows are straight, deep and the articulating half rings appear to be only slightly smaller than the axial rings. The pleurae are not complete, only the proximal parts are present. These are straight, slightly arched (trans.) and appear to be parallel sided. A deep pleural furrow divides the pleurae into two equal parts.

The pygidium is small and twice as wide as it is long, however, many specimens are crushed and a length of two thirds the width might be a better approximation. The pygidium has a strong longitudinal and transverse convexity. Viewing the pygidium dorsally, with the anterior border vertical, it has a semicircular outline with a wide, well defined axis that at its frontal breadth is approximately half the maximum width of the pygidium. The axis is delineated by deep, slightly curved furrows which converge backwards at between twenty and thirty degrees. Most of the specimens have a smooth axis, but a few internal casts show up to four faint axial rings with small distal ovoid muscle impressions, and with the axial ring furrows better developed on the lateral parts of the axis. The anterior part of the axis of many specimens shows a well developed articulating half-ring defined by a fairly deep articulating furrow. The pleural fields are small, triangular and smooth, the anterior part of each carries a pleural furrow that is narrow and deep next to the axial furrow, and which curves slightly backwards becoming shallower laterally. Just inside from the lateral margins, and running parallel to them, the dorsal surface carries a pair of deep furrows which are anteriorly truncated by the articulating facets; posteriorly these furrows become shallower and join together below the terminal axial piece. Dean (1966a) considers the function of these deep pygidial border furrows to be vincular forming a locking mechanism during enrollment, this view is upheld.

Discussion

The material compares well with the description of Plaesiacomia oehlerti (Kerforne) given by Dean (1966a) in his revision of the genus Plaesiacomia Hawle & Corda, 1847. One difference concerns the paraglabellar areas on the cephalon. Dean (op. cit., p. 135) records "small paraglabellar areas, represented by sub-elliptical depressions of the fixigenae with the long axes parallel to the axial furrows. These are not present on the material described here, but it is possible that they may have been destroyed during deformation of the specimens. The pygidia show differences in the number of axial rings, Dean (1966a, p. 137) records none, or "no more than a suggestion of about two axial rings", but the Portuguese material described here frequently has two well defined axial rings and occasionally two more poorly defined rings. These rings have lateral muscle impressions which are small, oval in shape, and very similar to those figured by Carré et al. (1970, pl.225, fig. 8a) for P. oehlerti, except that the pygidium figured has five sets of muscle impressions. Robardet et al. (1972) do not present a photograph of a pygidium for P. oehlerti, but the drawing (p. 121, fig. 4) shows only two poorly defined axial rings. Of the other species figured by these authors, P. n. sp. aff. rara (Hawle and Corda, 1847) is shown with three rings and P.? brevicaudata (Deslongchamps, 1825) is now considered by Henry (1976) to be a species of Kerfornella. The cephala of P. oehlerti figured from the Serra do Buçaco (Henry & Morzadec, 1968; Henry et al., 1974) are identical to the material described here.

The approximately linear graphs for measurements of the Dornes material (figs. 67-71) indicate that one species is present, but figure 70 does show more scatter than the other graphs. This graph shows that eye position varies slightly, but not enough to overlap with many of the other Plaesiacomia species.

P. oehlerti may be distinguished from P. rara (Hawle & Corda, 1847), P. n. sp. aff. rara (Robardet et al., 1972) and P. hughesi Thomas, 1977 which all have their eyes set much further forward and have smooth or almost smooth glabellae. P. vacuvertis Thomas, 1977 is very similar to P. oehlerti, but the eyes of the former are set slightly further forwards and the glabella is smooth in all adult forms.

In Portugal P. oehlerti has been recorded extensively from the Cacemes Formation at Buçaco and in Armorica it occurs extensively in the Postolonnec Formation. At these localities it occurs in both Llanvirn and Llandeilo strata (Henry _et al._, 1976, p. 279), but is more abundant in the upper parts (Llandeilo) of both formations. Similarly in the Dornes area _P. oehlerti_ is generally uncommon in the upper half of the Brejo Fundeiro Formation, but abundant in the lower part of the Monte do Carvalhal Formation especially in the Lameiros Member where it is associated with _Crozonaspis armata_ Hammann, 1972. This trilobite is of an upper Llandeilo age in the Sierra Morena, Spain (Hammann, 1974) where Carré _et al._ (1972) also recorded _P. oehlerti_ in Llandeilo strata.

Suborder	PHACOPINA Struve, 1959
Superfamily	DALMANITACEA Vogdes, 1890
Family	DALMANITIDAE Vogdes, 1890
Subfamily	DALMANITININAE Destombes, 1972
Genus	CROZONASPIS Henry, 1968

Type species. _Crozonaspis struvei_ Henry, 1968

Crozonaspis armata Hammann, 1972

Pl. 25, figs. 9-10; pl. 26, figs. 1-4; pl. 27, figs. 1-2; pl. 28, fig. 4.

1972 _Crozonaspis armata_ n. sp.; Hammann, p. 375, pl. 1, fig. 12.

1974 _Crozonaspis armata_ Hammann, 1972; Hammann, pp. 63-65, figs. 20 & 23, pl. 3, figs. 31-38.

Age and locality

The species has only been found in beds of Llandeilo age. It occurs in the middle of the Brejo Fundeiro Formation at fossil locality 105 (probably lower or middle Llandeilo) and in the Lameiros Member of the Monte do Carvalhal Formation at fossil localities 20 and 175 (upper Llandeilo).

Material

The material consists of 2 cephala, 9 cranidia, 14 pygidia and one complete enrolled specimen. The specimens are mainly preserved as internal moulds, sometimes with the complementary external moulds.

Measurements (mm)

Only a few specimens were complete enough to be measured.

Locality number	20	20	105
Width of cephalon	25.0	14.5	30.0
Length of glabella (G)	10.7	6.1	14.3
Length of glabella inc. occipital ring (Gn)	12.1	7.0	16.0
Maximum width of glabella	10.9	6.3	15.7
Width across occipital ring	6.5	3.2	8.3
Length of eye (A)	4.2	2.2 & 2.6	5:2
Augen Indices (A : Gn %)	34.5	3 7.1 & 31.4	32.5

To permit comparison with other species of Crozonaspis the practice of following the terminology of Struve (1958) and use of Augen Indices (A : G and A : Gn) as employed by Henry (1968), Clarkson and Henry (1970), Clarkson and Henry (1973) and Hammann (1972 and 1974) is continued. The Portuguese specimens have an average Augen Index, A : Gn of 33.9 per cent.

Description

The cephalon is approximately semi-circular in outline when viewed dorsally and the frontal area is slightly and anteriorly pointed. The maximum width of the cephalon along the posterior margin is approximately equal to double the length. The glabella is club-shaped and expands forwards from the occipital ring. The axial furrows are straight or have a slight adaxial curvature and diverge forwards at an angle of about thirty degrees. The anterior margin of the glabella is anteriorly pointed at an angle of about 140 degrees. The length of the glabella is about six-sevenths the length of the cephalon, and it has a maximum anterior width which is about half the maximum width of the cephalon. In frontal and lateral view the glabella is convex with a flattish median area. Three pairs of lateral glabellar furrows are present. The 1p furrows define the preoccipital glabellar lobes which are about one-sixth of the glabellar length. The 1p furrows are deep and each about two-fifths the posterior glabellar width in length. They are directed adaxially and slightly to the rear. On external moulds they terminate with shallow furrows which run posteriorly parallel to the axis and almost reach the occipital furrow. The 2p furrows define the 2p lateral glabellar lobes which are about one-sixth of the glabellar length. These furrows are shallow and each about one-half of the posterior glabellar width in length. They are slightly curved, anteriorly convex, and are perpendicular to the axial line. The 2p furrows do not quite reach the axial furrows. The 3p furrows are shallow and about two-thirds of the posterior glabellar width in length. The furrows start about two-thirds the length of the glabellar from the occipital furrow and begin just inside from the axial furrows. The 3p furrows are slightly sinuous and are directed adaxially and backwards at an angle of about seventy degrees to the axis. They each terminate in about the middle of the glabella (exsag.). Central to the glabella, and positioned about three-fifths of the glabellar length from the occipital furrow, a short shallow furrow is situated. It has a length about one-eighth that of the glabella, and is slightly deeper anteriorly than posteriorly. The frontal glabellar lobe is of moderate dorsal convexity both antero-ventrally and transversely.

The occipital ring is slightly wider axially than it is at the lateral ends. It has a maximum width (sag.) of about one-sixth, and a minimum width (exsag.) of about one-tenth, that of the glabellar length. The posterior margin of the occipital ring is straight, when viewed dorsally with the posterior edge of the cephalon vertical. The central part of the occipital furrow is flexed slightly forwards. The central half of the occipital furrow is shallow and wide, but the abaxial ends are deep and narrow.

The fixed cheeks are transversely strongly convex and the facial sutures are proparian. The facial sutures border the anterior part of the glabella separating a narrow frontal area. At the antero-lateral corners of the glabella the sutures turn sharply backwards and run sub-parallel with the axial line to the anterior corners of the crescent-shaped eyes situated opposite the 3p lobes. The sutures then run along the adaxial edges of the eyes (which are abaxially convex and positioned parallel to the axial line) to the posterior corners of the eyes situated opposite the preoccipital lobes. The sutures run from the posterior edges of the eyes, curve abaxially and slightly forwards to cut the lateral margins opposite the 1p furrows. The palpebral areas rise sharply from the axial furrows and are capped by raised, well developed, crescent-shaped palpebral lobes, each of which carry a row of small pits parallel to the top edge of the eye. Very weak eye ridges run from the anterior parts of the palpebral lobes forwards and sub-parallel to the facial sutures to join the axial furrows opposite the 3p lateral glabellar furrows. The posterior areas of the fixed cheeks are convex and both bear a deep posterior border furrow which starts a little behind the lateral ends of the occipital furrow. The posterior border furrows curve outwards and slightly to the front becoming wider and shallower towards their lateral ends. The furrows become very shallow at about the width (sag.) of the occipital ring from the lateral margins where they join the very weak lateral border furrows. The postero-lateral corners of the fixed cheeks carry a pair of genal spines each about one-sixth the length of the cephalon; these are directed abaxially backwards at about forty-five degrees from the axial line.

The eyes are crescent-shaped and abaxially convex, the curvature becoming sharper towards the posterior. The eyes are situated opposite the 2p lateral glabellar lobes and aligned parallel to the axial line. The posterior part of each eye rises abruptly from the free cheek, but the anterior part slopes downwards into the cheek. The maximum height of the visual surface above the free cheek is of a similar dimension to the width of the occipital ring (sag.). Each eye is composed of at least thirty-three vertical rows of lenses with up to seven lenses per row. The lenses are circular and arranged with a hexagonal close packing pattern.

The free cheeks are roughly quadrant-shaped with the anterior and posterior parts of the facial sutures making an angle of about 80 degrees. The anterior part of the free cheek continues around the front of the glabella as an anterior border with a width (exsag.) of about one-twelfth the glabellar length. The frontal part of the anterior border is inflated across a width (trans.) of about one-eighth the width of the cephalon to produce a raised, slightly anteriorly pointed lip or 'beak' (cf. Sadler 1974, p. 90). The free cheeks slope down sharply from the eyes to the lateral border furrows which are very shallow and wide. These furrows start at the axial furrows opposite the middle of the frontal glabellar lobe and run concentrically with the lateral margin until they are opposite the 2p glabellar lobes, where the furrows curve abaxially and join the abaxial ends of the posterior border furrows.

The thorax is preserved on one enrolled and slightly crushed specimen, eleven thoracic segments are present. The thorax tapers posteriorly from the cephalon and the posterior thoracic segment is about two-thirds the width of the anterior segment. The axis is transversely arched with a strong dorsal convexity and is about one-third of the thoracic width. The central parts of the axial rings are parallel sided, but the lateral ends are slightly wider (exsag.) and curved slightly to the front. The furrows between the axial rings and the articulating half rings are deep and wide (sag.) with a rounded profile. The articulating half rings are partially visible and well developed. The pleurae are poorly preserved and their distal parts overlap each other considerably. The adaxial two-thirds of each pleura is parallel sided (trans.) and the distal parts appear to taper slightly. Each pleura is crossed by a deep pleural furrow which starts at the axial furrow opposite the anterior extremity of an axial ring and which runs outwards and backwards towards the distal extremity of the pleura. A slight and narrow furrow runs close and parallel to the posterior edge of each pleura from the axial furrow outwards for at least two-thirds the width (trans.) of the pleura.

The collected pygidia were all disarticulated except for one belonging to an enrolled and slightly crushed specimen. The pygidium is roughly semi-circular in outline, about two-thirds as long as it is wide. It has a well developed terminal axial spine, which is approximately equal in length to the maximum width of the pygidium. The antero-lateral corners of the pygidium are slightly rounded. The axis measured across the anterior axial ring (trans.) is slightly more than one-third of the maximum pygidial width. The axis tapers posteriorly with the axial furrows making an angle of about thirty degrees. The axial furrows are narrow (trans.) and of moderate depth, becoming shallower posteriorly and dying out adjacent to the terminal axial piece. Eight axial rings are present separated by moderately deep furrows. The axial rings are rectangular in outline (in dorsal view with the anterior margin vertical) and have a strong transverse dorsal convexity. The terminal axial piece is projected backwards into a long thin terminal axial spine which is roughly circular in cross-section. A well formed articulating half ring is attached to the anterior axial ring. The pleural regions are transversely convex. Five pleurae are present, but the posterior ones are poorly defined and merge into the terminal axial piece. The inter pleural furrows are weak, shallow and reach almost to the lateral margins. The pleural furrows are narrow (sag.), but moderately deep and towards the axis they are fairly straight. They start opposite the axial ring furrows and strike outwards and slightly backwards across the pleurae becoming shallower and dying out just short of the lateral margins, so that a smooth narrow border is formed to the pygidium. The postero-lateral part of each pleura is slightly inflated into a smooth, sub-oval blister which terminates against the smooth border.

On internal moulds the specimens are essentially smooth, but on latex casts of the external moulds the glabella, occipital ring and fixed cheeks are ornamented with a very fine granular ornament; in addition the fixed cheeks also bear small regularly spaced pits in their posterior areas. The anterior border, frontal area of the glabella and the lateral edges of the fixed cheeks bear a fine granular ornament which is slightly more pronounced and a little coarser than that on the rest of the cranidium. The free cheeks have a fine granular ornament with additional small pits on the elevated areas in front of and below the eyes. The pleural segments and the pygidium also have a fine granular ornament, but with slightly coarser and more pronounced granules on the border and to a lesser extent on the larger axial rings of the pygidium.

Discussion

Hammann (1974) discusses the distinguishing features of ten species of *Crozonaspis* not including *Crozonaspis peachi* Sadler (1974). Hammann (*op. cit.*) summarises the characteristic features of the crozonaspids in table 1 (page 56). From the shape and development of the glabella, the facial sutures and the anterior lip of the frontal border the Portuguese specimens fall into a group which includes *C. struvei* Henry, 1968; *C. kerfornei* Clarkson and Henry, 1970 and *C. armata* Hammann, 1972. Henry (1968), Clarkson & Henry (1970), Hammann (*op. cit.*) and Sadler (1974) all consider augen indices (A : Gn; length of eye : length of glabella including occipital ring, expressed as a percentage and first used by Struve in 1958) to be useful criteria for distinguishing between some of the species of *Crozonaspis*. From Hammann (*op. cit.*, table 1) it is clear that there is considerable overlap in the augen indices for many of the species, but by using them in conjunction with other morphological characters they help to separate closely related species. For the specimens of

C. armata described here the augen index (A : Gn) is 33.5% for 3 specimens. Hammann (op. cit.) gives the following A : Gn figures: C. struvei 25 – 39%, C. kerfornei about 25% and C. armata 30 – 32%. Henry (1968) however, gives C. struvei an A : Gn figure of 22 – 25% and Sadler (1974) gives augen indices of 23% for C. struvei and 28% for C. kerfornei. The wide range given for the augen indices of C. struvei is accounted for by Hammann (op. cit., p. 59, fig. 21) who shows that the A : Gn ratio decreases with increasing size so that the juvenile forms have the larger eyes. For specimens of C. struvei of similar size to the samples of C. armata described here the augen index is predicted from Hammann (op. cit.) to be about 26%. The augen indices for the Portuguese specimens are therefore much closer to those of C. armata than they are to C. struvei or C. kerfornei. C. armata is shown by Hammann (1972 and 1974) to have pronounced genal spines while C. struvei is shown by Henry (1968) and Hammann (1974) to have very short genal spines. All the other described species of Crozonaspis have very short or no genal spines except for C. primula Destombes, 1972 on which they are very well developed, but this species differs from C. armata by having larger eyes and more axial rings on the pygidium. One of the specimens of C. armata from the Dornes area has a genal spine which is intact and this approaches the length of those shown for the holotype of C. armata (Hammann, 1974, pl. 23, fig. 32), but are shorter than those shown in figure 23 (p. 64) and in plate 3, figure 35 for the same species. C. armata may be distinguished from C. peachi which has a wide (trans.) squat glabella and large eyes (A : Gn, 38%) which are set well away from the axial furrows and at an angle to the axial line. The specimens figured by Sadler (1974, p. 86, pl. 10, figs. 11–20) do not have genal spines, but on his reconstruction (p.89, text-fig. 9) the genal angles are left open suggesting that the genal spines might have been present. Hammann (pers. comm., 1974) considered a Portuguese specimen from locality 20 (plate 26, figs. 1a – 1e) to belong to his species C. armata mainly because of the size of the eyes and the presence of the genal spines.

C. armata is considered by Hammann (1972 and 1974) to be of upper Llandeilo age and has been recorded by him from the Sierra Morena in Spain. Within the study area it is found associated with Plaesiacomia oehlerti (Kerforne) and Neseuretus (N.) tristani (Brongniart) in the Lameiros Member of the Monte do Carvalhal Formation; this occurrence is consistent with an upper Llandeilo age. It has also been found in the middle part of the Brejo Fundeiro Formation which is probably lower or middle Llandeilo.

Crozonaspis morenensis morenensis Hammann, 1972

1972 Crozonaspis mayensis morenensis n. ssp.; Hammann, p. 375, pl. 1, fig. 13.

1974 Crozonaspis morenensis morenensis Hammann, 1972; Hammann pp. 60-62, pl. 3, figs. 39-48 and text-figs. 20 and 22.

Crozonaspis morenensis cf. morenensis Hammann, 1972

Pl. 26, fig. 5.

Age and locality

Middle or upper Llandeilo, locality 155 in the upper part of the Monte da Sombadeira Formation.

Material

One cranidium preserved both as an internal and an external mould.

Measurements (mm)

Length of glabella (G)	5.7
Length of glabella including occipital ring (Gn)	7.0
Maximum width of glabella across frontal lobe	5.3
Posterior glabellar width	3.7
Length of left palpebral lobe (A)	2.3
Length of right palpebral lobe (A)	2.4
Augen indices (A : Gn%)	31.5 to 33.0%

Description

The glabella is club-shaped and expands forwards from the occipital ring. The axial furrows are deep, fairly wide and straight diverging anteriorly at an angle of about 30 degrees. The anterior edge of the glabella is pointed towards the front at an angle of about 135 degrees. In anterior view the glabella has a strong dorsal convexity, but in lateral view it is only moderately convex. Three pairs of lateral glabellar furrows are present. The 1p lateral glabellar lobes are each about one-fifth of the glabellar length. The 1p furrows are deep and each has a length which is about two-fifths of the posterior glabellar width; they are directed adaxially from the axial furrows and point slightly backwards terminating with a slight widening of the furrows. The 2p lateral glabellar lobes are each about one-sixth of the glabellar length. The 2p furrows are shallow and each has a length which is about one-half of the posterior glabellar width. They are slightly curved, anteriorly convex, set approximately perpendicular to the axial line and positioned so they do not reach the axial furrows. The 3p lateral glabellar lobes each have a maximum length (exsag.) of about one-third the glabellar length. The 3p furrows are shallow and have a slightly sinuous shape; they start a little way in from the axial furrows and slightly anterior to the front corners of the eyes. The furrows are directed inwards and backwards so that they each make an angle of about 60 degrees with the sagittal line; each furrow finishes in the middle of the glabella (exsag.) Central to the glabella and positioned sagittally opposite the anterior ends of the 3p furrows, there is a short, shallow median furrow which has a length of about one-tenth that of the glabella.

The occipital ring is slightly wider axially than it is laterally. It has a maximum width (sag.) of about one-sixth and a minimum width (exsag.) of about one-eighth of the glabellar length. The posterior edge of the ring is fairly straight, but the anterior edge and the occipital furrow is sinuous with the lateral ends off-set slightly backwards. The central part of the occipital furrow is wide and shallow, but both ends, each for about one-quarter of the posterior glabellar width, are deep and narrow.

The fixed cheeks are incomplete; only one of the small frontal areas and both the palpebral areas of the fixed cheeks are intact; the posterior areas are broken and the genal corners are missing. The anterior parts of the facial sutures run backwards from the antero-lateral corners of the glabella, sub-parallel to the sagittal line, to the front corners of the palpebral lobes thus defining the two small triangular frontal areas to the fixed cheeks. The palpebral lobes are large (A : Gn 31.5 to 33%), crescent-shaped with rounded ends, outwardly convex, and set sub-parallel to the axial line. They are positioned with their mid-points opposite the 2p lateral glabellar furrows. The palpebral lobes are slightly raised on the strongly elevated palpebral areas of the fixed cheeks which slope sharply downwards to the axial furrows. On the right hand cheek a marked eye ridge is preserved; it runs forwards from the palpebral lobe to join the axial furrow just behind the adaxial end of the 3p furrow. Only one incomplete posterior area of a fixed cheek is preserved and this has a deep posterior border furrow which starts adjacent to the occipital ring a little behind the occipital furrow.

On the internal mould the specimen bears a fine granular ornament with additional large spaced out granules on the frontal glabellar lobe. The 2p and 3p furrows are poorly defined on the internal mould and occur as slightly raised ridges. On the complementary external mould the specimen also has a fine granular ornament, but the larger granules on the frontal glabellar lobe are only weakly developed; the 2p and 3p furrows are however moderately well developed.

Discussion

The specimen described above is very similar to _Crozonaspis morenensis morenensis_ Hammann (1972 and 1974) and shares with it eyes which are the same size (A : Gn 31.5 - 33.0% compared with 31 - 35% for the type specimens) and which are positioned in the same place parallel with the axial line and opposite the 2p lateral glabellar lobes. The Portuguese specimen does however differ from _C. morenensis morenensis_ by having a large granular decoration on the frontal glabellar lobe.

C. morenensis cf. _morenensis_ may be separated from the other species of _Crozonaspis_ by the glabellar shape, the nature of the 1p furrows and the shape and size of the eyes; these details for most of the species of _Crozonaspis_ are summarised by Hammann (1974, p. 56, table 1). _C. morenensis_ cf. _morenensis_ differs from _C. morenensis mayensis_ Clarkson & Henry, 1973 which has smaller eyes (A : Gn 25 - 31%), but which does have an ornamented frontal glabellar lobe similar to that of the Portuguese specimen described above. The eyes of C. armata Hammann, 1972 are of a similar size (A : Gn 30 - 32%) to those of the Portuguese species described above, but they are set further back and slightly further away from the glabella; in addition to this the 1p lateral glabellar furrows are deeper and wider in C. C. armata. C. kerfornei Clarkson & Henry, 1970 has smaller eyes (A : Gn about 25%) than C. morerensis cf. morenensis and the glabella of the former species is more elongated with a large frontal glabellar lobe, but this does bear a similar ornament to that found on the latter species. C. struvei Henry, 1968 has a similar glabellar shape and ornament to C. morenensis cf. morenensis, but the eyes in C. struvei are generally small (A : Gn 25-39%); they are larger in juvenile forms and have long axes which diverge backwards. C. chouberti Destombes, 1972 and C. primula (Destombes, 1972) both have larger eyes and a different glabellar shape than C. morenensis cf. morenensis. C.? incerta Deslongchamps, 1825) and C.? dujardini (Rouault, 1847) noted in Hammann (1974) also differ in glabellar shape and both have eyes which are set well forwards with their long axes diverging strongly backwards. C. peachi Sadler, 1974 differs from C. morenensis cf. morenensis by having larger eyes (A : Gn 38.7%) whose long axes diverge backwards and the frontal glabellar lobe is smooth.

C. morenensis cf. morenensis was found within the upper beds of the Monte da Sombadeira Formation at locality 155; these beds have also yielded abundant specimens of the ostracode Ctenobolbina sp. indet. and a fragmentary specimen of Neseuretus (N.) tristani (Brongniart, 1822). Hammann (1974, p. 55) suggests that C. morenensis morenensis is of a lower to middle Llandeilo age. The Monte da Sombadeira Formation is overlain by the Lameiros Member of the Monte do Carvalhal

Formation which has yielded C. armata considered by Hammann (1972 & 1974) to be of an upper Llandeilo age. The relative stratigraphical positions of the Portuguese specimens are in keeping with the observations made by Hammann (1974, p. 55).

Crozonaspis morenensis mayensis Clarkson & Henry, 1973

Pl. 26, figs. 6–7; pl. 27, fig. 1.

1973 Crozonaspis mayensis n. sp.; Clarkson & Henry, pp. 108–109, figs. 2 and 3.

1974 Crozonaspis morenensis mayensis Clarkson & Henry, 1973; Hammann, pp. 60 and 62, pl. 3, figs. 49 and 50.

1974 Crozonaspis mayensis; Babin et al., pp. 362 and 363.

Age and locality

Llanvirn, Didymograptus murchisoni Zone, Locality 85 within the Brejo Fundeiro Formation.

Material

One external mould of an almost complete cephalon and one internal mould of a fragmentary cephalon with a small part of the complementary external mould. The fragmentary cephalon was associated with a pygidium and attached thorax comprising nine thoracic segments. The pygidium and thorax occur as an internal mould with a complementary, but broken external mould.

Measurements (mm)

Length of glabella (G)	5.9	12.1 (est)
Length of glabella including occipital ring (Gn)	6.7	-
Maximum width of glabella across frontal lobe	6.9	14.1

Posterior width of glabella	4.4	-
Length of right eye (A)	2.4	4.0
Length of left eye (A)	2.3	-
Augen indices (A : Gr%)	28.7 - 29.1	
Width of pygidium across anterior margin		14.0
Anterior width of axis		5.0
Length of pygidium (excluding terminal spine)		9.7

Description

The cephalon is approximately semi-circular in outline with the frontal area slightly and anteriorly pointed; the maximum cephalic width is a little more than double the length. The glabella is club-shaped and expands forwards from the occipital ring; anterior to the 1p lateral glabellar furrows the axial furrows are straight and diverge forwards at about 45 degrees. Adjacent to the 1p lateral glabellar lobes the axial furrows have a slight outward convexity. The anterior edge of the glabella is pointed at an angle of about 140 degrees and the maximum width of the glabella across the frontal lobe is about one-half the width of the cephalon. In frontal and lateral views the glabella is of moderate dorsal convexity. Three pairs of lateral glabellar lobes are present. The 1p lateral glabellar lobes are each about one-sixth of the glabellar length. The 1p furrows are deep and each is about two-fifths of the glabellar width in length; they are directed adaxially from the axial furrows and point slightly to the rear terminating with a slight widening and deepening of the furrows. The 2p lateral glabellar lobes are each about one-sixth of the glabellar length. The 2p furrows are shallow, narrow and each is about one-half of the posterior glabellar width in length. They are slightly curved, anteriorly convex, approximately perpendicular to the axial line and start a little way in from the axial furrows; their adaxial ends are directed very slightly backwards. The 3p lateral glabellar lobes each have a maximum length (exsag.) of a little less than one-third of the glabellar length. The 3p. furrows are shallow and slightly sinuous in shape. They start at the axial furrows just in front of the anterior corners of the eyes and are directed adaxially to the rear each making an angle of about 60 degrees with the sagittal line; the 3p furrows each finish in the middle of the glabella (exsag.). Central to the glabella and positioned axially opposite the abaxial ends of the 3p furrows there is a short, shallow, ovoid-shaped furrow which is about one-eleventh the length of the glabella.

The occipital ring is slightly wider axially (sag.) than it is at the lateral ends. The ring has a maximum width (sag.) of about one-fifth and a minimum width (exsag.) of about one-tenth of the glabellar length. The posterior edge of the ring is fairly straight, but the occipital furrow is sinuous with the lateral ends each off-set slightly backwards for about one-quarter of the glabellar width. The central half of the occipital furrow is of moderate depth, but the abaxial ends are deep and narrow.

The facial sutures are proparian and border the anterior of the glabella separating a narrow frontal area. At the antero-lateral corners of the glabella the sutures turn sharply backwards running sub-parallel with the axial line to the front corners of the eyes situated opposite the abaxial ends of the 3p lateral glabellar furrows. The sutures run along the adaxial edges of the eyes to the posterior corners of the eyes situated opposite the 1p lateral glabellar furrows. The sutures bend abruptly from the posterior edges of the eyes and curve abaxially, with a slight forward concavity, to cut the lateral margins opposite and a little behind the 2p glabellar furrows. In transverse profile the posterior areas of the fixed cheeks are slightly deflexed. The palpebral areas of the fixed cheeks rise sharply from the axial furrows and are capped by raised, well developed, crescent-shaped, palpebral lobes. Very weak eye ridges run forwards from the anterior parts of the palpebral lobes and sub-parallel with the facial sutures to join the axial furrows at the 3p glabellar furrows. The posterior areas of the fixed cheeks are convex (trans.) and each bears a deep posterior border furrow which starts opposite the lateral ends of the occipital ring. The posterior border furrows are fairly straight, deep and wide becoming very shallow at their abaxial ends where they join the lateral border furrows. The posterior borders are narrow (exsag.) adjacent to the occipital ring and become wider abaxially reaching about one-sixth of the glabellar length in width (exsag.). The genal angles are extended into very short genal spines which point abaxially backwards at about 45 degrees from the sagittal line.

The eyes are of moderate size (A : Gn about 29%), crescent-shaped and abaxially convex with the curvature becoming slightly sharper posteriorly. The eyes are situated opposite the 2p and 3p lateral glabellar lobes and have long axes which diverge slightly backwards. The visual surfaces of the eyes rise sharply from the fixed and free cheeks and have a slight dorso-lateral convexity. The eyes are composed of small circular lenses arranged in a hexagonal close packing arrangement. It is difficult to see if a complete row of lenses is present, but at least seven and up to nine lenses a row occur. Between 25 and 30 vertical rows of lenses are estimated to make up each of the eyes.

The free cheeks are roughly sub-triangular in outline and the anterior parts of the cheeks continue around the front of the glabella as an anterior border which is ventrally reflexed to form a doublure of about one-eighth the glabellar length in width. The free cheeks slope down from the eyes to the lateral border furrows which are shallow and wide. These furrows separate the lateral borders which each have a width of about one-sixth the length of the glabella. At their posterior ends the lateral border furrows join the border furrows, anteriorly they die out just in front of the eyes.

The thorax is incompletely preserved on one enrolled and slightly crushed specimen; nine thoracic segments are present and the thorax tapers slightly backwards. The axis is about one-third of the thoracic width, it is transversely arched and has a strong dorsal convexity. The central parts of the axial rings are parallel-sided, but the lateral ends are slightly wider (exsag.) and curve slightly to the front. The furrows between the axial rings and the articulating half rings are deep and wide (sag.) with a rounded profile, at each end they terminate with an apodeme which is clearly seen on internal moulds; the articulating half rings are partially visible. Because the specimen is enrolled the distal ends of the pleurae overlap each other considerably. The pleurae are strongly deflexed, but if flattened out would each be about one and one-half times as wide (trans.) as the axial region. The adaxial two-thirds of each pleura is parallel sided and the distal part tapers very slightly to the end which is rounded. Each pleura is crossed by a deep, slightly curved, pleural furrow which starts at the antero-lateral extremity of the axial ring and runs abaxially and slightly backwards almost reaching the posterior margin of the pleura. On the distal one-quarter of the pleura the furrow curves slightly forwards to bisect the lateral end of the pleura. A slight and narrow furrow closely parallels the posterior edge of each pleura, running from the postero-lateral corner of the axial ring, slightly and adaxially backwards, to cut the posterior margin about one-third of the pleural width from the axial furrow.

The pygidium is roughly triangular in outline and about two-thirds as long as it is wide; the terminal axial spine is missing and only the broken stub remains. The axis measured across the anterior axial ring is slightly more than one-third of the maximum pygidial width. The axis tapers posteriorly with the axial furrows making an angle of about 25 degrees. The axial furrows are narrow (trans.) and of moderate depth, they become shallower posteriorly and die out adjacent to the terminal axial piece. Eight axial rings are present; anteriorly they are separated by moderately deep furrows, but posteriorly they are poorly defined. The axial rings are rectangular in dorsal view (viewed with the anterior margin vertical) and have a marked transverse dorsal convexity. The terminal axial piece is bluntly truncated with the stub of the missing terminal axial spine. An articulating half ring is present on the anterior axial ring. The pleural regions are transversely convex and deflexed. Five ribs are present, but the posterior ones are very poorly defined and merge into the terminal axial piece. The interpleural furrows are weak, shallow and stop short of the lateral margin leaving a smooth border. The pleural furrows are wide (exsag.) and moderately deep. In dorsal view (with the anterior margin vertical) they are straight starting at the front of the pleura next to the axial furrow and running abaxially slightly backwards, more or less bisecting the pleura. The pleural furrows also stop short of the margin leaving a smooth border.

The external surface of the complete cephalon is smooth, but the fragmentary specimen bears a very fine granular ornament on the frontal glabellar lobe and a slightly coarser ornament on the anterior border and the doublure. On the complete specimen the palpebral and posterior areas of the fixed cheeks (excluding the posterior and lateral borders) and the free cheeks between the bases of the eyes and the lateral border furrows bear an ornament of small fairly closely spaced pits. The internal moulds of the thorax and the pygidium have a smooth surface, but the external moulds have a very fine granular ornament on the pleurae with a slightly coarser granular ornament on the axial regions.

Discussion

The specimens described above are very similar to Crozonaspis morenensis mayensis described by Clarkson and Henry (1973) and by Hammann (1974, p. 55, fig. 20 and p. 56, table 1); characteristically the specimens have moderately sized eyes (A : Gn about 29%) with long axes that diverge slightly backwards, very short genal spines and an ornament of small pits on the genae. This subspecies differs from C. morenensis morenensis Hammann, 1972 which has larger eyes (A : Gn, 31 - 35%). C. struvei Henry, 1968; C. kerfornei Henry, 1970, C. armata Hammann, 1972 and C. rouaulti (Tromelin & Lebesconte, 1876) differ from C. morenensis mayensis mainly by having an inflated frontal beak to their anterior areas; the eyes of the first two species are also smaller, and those of C. armata and C. rouaulti slightly larger. All the other species of Crozonaspis have larger eyes than C. morenensis mayensis and the species with their augen indices are listed below: C. chouberti Destombes, 1972, A : Gn, about 41% ; C. primula (Destombes, 1972), A : Gn, 33 - 39%; *C. ?incerta* (Deslongchamps, 1825), A : Gn, 27 - 36%; *C. ?dujardini* (Rouault, 1847), A : Gn, 30 - 34%; *C. peachi* Sadler, 1974, A : Gn, 39%.

In Normandy *C. morenensis mayensis* has been recorded by Clarkson & Henry (1973) from the Llanvirn shales of May-sur-Orne, Calvados. Babin *et al.* (1976) also recorded it from the May syncline where it occurs associated with *Didymograptus murchisoni* (Beck) and *Neseuretus* (*N.*) *tristani* (Brongniart) and from the Cotentin Peninsula where it is associated with *Plaesiacomia oehlerti* (Kerforne) and *Neseuretus* (*N.*) *tristani*. *C. morenensis mayensis* occurs within the Brejo Fundeiro Formation in Portugal from strata which is of a Llanvirn, *Didymograptus murchisoni* Zone age; this occurrence is in accord with the occurrence of the trilobite in Normandy.

Genus MUCRONASPIS Destombes, 1972

Type species. *Dalmanitina* (*Mucronaspis*) *termieri* Destombes, 1973

Destombes (1972) promoted *Mucronaspis* from a subgenus to a genus and included the genus *Eodalmanitina* Henry (1965) as a junior synonym of *Mucronaspis*; Hammann (1974) and Ingham (1977) also hold this view. Babin et al. (1976), Henry and Romano (1978) and Bruton & Henry (1978) however, use the genus *Eodalmanitina*.

Mucronaspis macrophtalma (Brongniart, 1822)

1822 *Calymène macrophtalma* n. sp.; Brongniart, pp. 15-16, pl. 1, fig. 4 (non fig. 5).

1974 *Mucronaspis* *macrophtalma* (Brongniart, 1822); Hammann, pp. 41-45, fig. 13; pl. 4, fig. 67-78 and pl. 5, figs. 69-76. This paper also contains a complete synonymy of works prior to 1974 with the following correction: Delgado 1879 should be 1897.

1976 *Eodalmanitina* *macrophtalma* (Brongniart); Babin *et* *al.*, p. 370.

1978 *Eodalmanitina* *macrophtalma* (Brongniart); Bruton & Henry, p. 900.

Mucronaspis cf. *macrophtalma* (Brongniart, 1822)

Pl. 28, figs. 2-3.

Age and locality

Upper Llanvirn, *Didymograptus* *murchisoni* Zone, locality 190 within the Brejo Fundeiro Formation.

Material

Two incomplete cranidia both preserved as internal moulds; one is approximately an "o" form and the other an "l" form (Henningsmoen, 1960).

Measurements (mm)

Length of glabella (G)		6.2	4.2
Length of glabella including occipital ring (Gn)		7.7	4.9
Maximum width of glabella across frontal lobe		7.1	3.9
Posterior width of glabella		4.4	2.3
Length of palpebral lobes		2.9	-
Approximate Augen indices (A : Gn%)	about	37.5	-

Description

The glabella is club-shaped with a maximum anterior width which is a little less than twice the posterior width. The axial furrows diverge forwards at an angle of about 30 degrees and the front of the glabella is anteriorly pointed at about 150 degrees. The axial furrows are well developed and each has a slight adaxial curvature with additional adaxial kinks at the positions of the 3p lateral glabellar furrows. The glabella is slightly flattened, but still retains a moderately convex transverse profile and a slightly convex longitudinal profile. Three pairs of lateral glabellar furrows are present. The 1p lateral glabellar lobes are about one-fifth of the glabellar length. The 1p lateral glabellar furrows are straight, narrow (exsag.) and of moderate depth; the length of each furrow (trans.) is a little more than one-third of the posterior glabellar width. These furrows are angled slightly backwards each making an angle of about 80 degrees with the axial line and they each terminate adaxially with a slightly developed cross-furrow. The 2p lateral glabellar lobes are each about one-fifth of the glabellar length. The 2p furrows are narrow (exsag.), of shallow depth and anteriorly slightly convex. They are each about one-third of the posterior glabellar width in length and are directed abaxially and very slightly backwards. The 2p furrows are very weakly developed adjacent to, or stop short of, the axial furrows. The 3p lateral glabellar lobes each has a maximum length (exsag.) which is about one-third of the glabellar length. The 3p furrows are shallow, narrow (exsag.) and each has a length which is about one-half of the posterior glabellar width. These furrows start at the adaxial kinks in the axial furrows, opposite the anterior corners of the eyes, and are directed adaxially backwards to make an angle of about 60 degrees with the axial line. The 3p furrows are slightly sinuous with the abaxial half of each furrow being slightly and anteriorly convex and the adaxial half of each furrow being slightly and anteriorly concave. The frontal glabellar lobe is roughly diamond-shaped in outline with rounded acute angles.

The occipital ring has a maximum length which is a little less than one-quarter of the glabellar length. The posterior edge of the ring is slightly curved and anteriorly concave. The central part of the anterior edge and the occipital furrow are arched slightly forwards between the 1p lateral glabellar lobes. The central half of the occipital furrow is shallow and fairly open, but the abaxial ends are deep and narrow. The occipital ring has a moderate dorsal convexity, but like the glabella appears to be flattened.

The fixed cheeks of both specimens are incomplete. The palpebral areas of the fixed cheeks are roughly triangular in outline and abaxially edged by very marked palpebral lobes. These lobes are crescent-shaped, outwardly convex, and diverge backwards at between 15 and 20 degrees from the axial line. Anteriorly the palpebral lobes fit into the notches in the axial furrows situated opposite the 3p lateral glabellar furrows; the posterior ends of the palpebral lobes are situated opposite the 1p lateral glabellar furrows. The posterior areas of the fixed cheeks are incomplete except for one fairly intact specimen for which the maximum width (trans.) is about one and one-half times the posterior glabellar width. The cheek bears a fairly straight posterior border furrow which starts opposite the end of the occipital ring. This furrow defines a narrow posterior border which abaxially becomes wider (exsag.) increasing towards the genal angle until it is a similar width to the occipital ring (sag.)

Discussion

The shape and segmentation fo the glabellae of the Portuguese specimens described above are very similar to those of Mucronaspis macrophtalma (Brongniart, 1822) as re-described by Henry (1965), Henry and Nion (1970) and Hammann (1974); the material also compares well with the type material figured by Brongniart (1822, pl. 1, fig. 4). The size and shape of the palpebral lobes falls within the limits of augen indices given for M. macrophtalma by Henry (1965; A : Gn 32 - 39%) and by Hammann (1974; A : Gn 35 - 48%). For many of the described species of Mucronaspis the eyes are larger in juvenile forms; the Portuguese specimens are fairly small and the A : Gn values compare reasonably well with similarly sized material described by Hammann (1974, p. 43; graph of A against G and Gn). One difference is however apparent; the palpebral lobes of M. cf. macrophtalma each diverge backwards at between 15 and 20 degrees from the axial line, but those of the material mentioned above for Henry, Henry and Nion, Hammann and Brongniart diverge at between 10 and 15 degrees from the axial line. The specimens of M. cf. macrophtalma described above are however flattened, much of dorsal cranidial relief has been lost, and the once elevated palpebral lobes have been flattened; this might help to explain the greater divergence of the palpebral lobes.

M. cf. macrophtalma may be distinguished from most of the other species of Mucronaspis because they have larger eyes. They are listed below with their relevant augen indices (A : Gn): M. destombesi destombesi Henry, 1966 (39 - 52%); M. destombesi nava Hammann, 1972 (43 - 55%); M. chillonensis Hammann, 1972 (38 - 42%); M. termieri (Destombes, 1963) (38 - 44%). In addition to differences in augen indices the eyes of the two subspecies of M. destombesi are parallel to the axial line, M. chillonensis has slightly straighter axial furrows to the glabella and M. termieri has different glabellar furrows. M. alinfensis Destombes, 1972 has similarly sized eyes (A : Gn 36 - 39%) to those of M. cf. macrophtalma, but the 2p glabellar furrows are much narrower (trans.); M. zagoraensis Destombes, 1972 differs by having smaller eyes (A : Gn, 28 - 32%). M. greti (Destombes, 1963) was described only from a large pygidium and is beyond comparison. M. mucronata (Brongniart, 1822) and M. olini (Temple, 1952) are very similar species and Ingham (1977) considers that M. olini is a subspecies of M. mucronata. These two species both differ from M. cf. macrophtalma by having eyes which are abaxially very strongly convex and which have their long axes set parallel to the sagittal line. The eyes of M. olini are slightly smaller than those of M. cf. macrophtalma, but those of M. mucronata are of a similar size (A : Gn approximately 36%).

Henry and Nion (1970) describe M. macrophtalma from the "Schistes a Calymene" in the Armorican massif and indicate a Llanvirn or Llandeilo age. Babin et al. (1976, p. 370) note the occurrence of M. macrophtalma with "rare" Didymograptus murchisoni in the lower member of the Schistes de Postolonnec Formation within the southern limb of the Chateaulin Basin. Hamman (1974, p. 42) however, records M. macrophtalma from Navatrasierra (Montes de Toledo, Spain) and Bruton & Henry 1978 record it from le Chatellier in Brittany, both occurrences in strata of lower Llandeilo age. In the Dornes area M. cf. macrophtalma occurs associated with Didymograptus ex. gr. murchisoni (Beck) towards the base of the Brejo Fundeiro Formation, a comparable occurrence to that described by Babin et al. (op. cit.).

Mucronaspis chillonensis Hammann, 1972

Pl. 28, figs. 5-8.

1972 Mucronaspis chillonensis n. sp.; Hammann, p. 374, pl. 1, fig. 6.

1974 Mucronaspis chillonensis Hammann, 1972; Hammann, pp. 51-53, pl. 2, figs. 22-27 and text-fig. 19.

Age and locality

Llanvirn, Didymograptus murchisoni Zone. Locality 85 within the Brejo Fundeiro Formation.

Material

Three almost complete cephala preserved as internal moulds, one with the complementary external mould, and one fragmentary internal mould of a cephalon.

Measurements (mm)

Specimen no.	85/93	85/146	85/44	85/-
Max. width of cephalon	18.2(est.)	19.0	13.9	14.6(est.)
Max length of cephalon (excluding genal spines)	-	9.2	-	-
Max. width of glabella across frontal lobe	9.6(est.)	9.9(est.)	6.1	6.3
Posterior width of glabella	5.0	5.4	3.7	3.1
Length of glabella including occipital ring (Gn)	10.5	8.9	5.6	9.6
Length of glabella excluding occipital ring (G)	9.0	7.3	4.8	8.8
Length of eyes	4.5(est.)	3.4	2.3	3.9
Form l or w*	l	w	w	l
A : Gn%	43%	38%	41%	41%

* Henningsmoen, 1960

Description

The cephalon is sub-semicircular in outline and anteriorly pointed, it is a little less than twice as wide as it is long. All the material is flattened, but the cephalon appears to have been moderately convex dorsally in both transverse and sagittal sections. The posterior width of the glabella is a little more than one-quarter of the cephalic width and the axial furrows diverge anteriorly at about 30 degrees. The axial furrows are deep and of moderate width, they have a slight adaxial curvature and have slight adaxial kinks at the positions of the 3p lateral glabellar furrows adjacent to the anterior corners of the eyes. The front of the glabella is sharply pointed with slightly curved and anteriorly convex sides. The glabella is dorsally strongly convex in transverse profile and moderately convex in longitudinal profile. Three pairs of lateral glabellar furrows are present. The 1p lateral glabellar lobes are a little less than one-fifth of the glabellar length. The 1p lateral glabellar furrows are fairly straight, deep, narrow and each is about one-quarter of the posterior glabellar width in length (trans.). These furrows are angled slightly backwards to make an angle of about 80 degrees with the axial line and the abaxial end of each furrow terminates with a very short cross furrow running sub-parallel to the axial line. The 2p lateral glabellar lobes are each about one-fifth of the glabellar length. The 2p furrows are narrow (exsag.), of moderate depth and anteriorly slightly convex. Each furrow is about one-third of the posterior glabella width in length and set at about 90 degrees to the axial line; the abaxial end of each furrow is directed slightly to the rear. The 2p furrows are slightly variable and do not reach the axial furrows, or are very weakly developed adjacent to the axial furrows. The 3p lateral glabellar lobes have a maximum length (exsag.) of a little more than one-quarter of the glabellar length. The 3p furrows are each about two-thirds of the posterior glabellar width in length, of moderate depth and fairly narrow (exsag.). The 3p furrows start either at the axial furrows, or a little way in from the axial furrows, opposite the anterior corners of the eyes. These furrows are fairly straight to very slightly sinuous and have a slight anterior convexity at their abaxial ends; they are directed backwards at between 60 and 70 degrees to the axial line. The frontal glabellar lobe is roughly diamond-shaped in outline with rounded acute angles.

The occipital ring has a maximum length (sag.) of about one-fifth of the glabellar length. The posterior edge of the ring is straight, but the central half of the anterior edge and the occipital furrow are arched slightly forwards between the 1p lateral glabellar lobes. The central half of the occipital furrow is wide (sag.) and moderately deep; the abaxial ends are deep and narrow (sag.). The occipital ring has a moderate transverse dorsal convexity.

The facial sutures follow the anterior and lateral edges of the glabella to the anterior corners of the eyes situated at the abaxial ends of the 3p furrows. The sutures follow the adaxial edges of the eyes to the posterior corners of the eyes situated opposite the 1p glabellar lobes. The sutures then parallel the postero-lateral edges of the eyes and diverge abaxially curving convexly towards the front to cut the lateral cephalic margins opposite the 1p glabellar lobes. The palpebral areas of the fixed cheeks are small and slope towards the axial furrows. These areas are strongly elevated adjacent to the eyes forming very large crescent-shaped palpebral lobes which slope adaxially from the eye. The posterior areas of the fixed cheeks have a slight dorsal and tranverse convexity. The posterior border furrows are deep, wide and straight. They start opposite the lateral ends of the occipital ring and extend abaxially at about 90 degrees to the axial line stopping short of the lateral edges wherethey join the weak lateral border furrows. The posterior borders become wider (exsag.) abaxially and reach a maximum width of about one-sixth of the glabellar length. The genal angles are prolonged into marked genal spines each about one-third the length of the glabella. These spines are sub-parallel to or diverge slightly from the axial line. The lateral edges of the fixed cheeks are slightly 'waisted in' just in front of the genal spines.

The eyes are large and of about one-half the glabellar length: (A : Gn 38% to 43%). The anterior corners of the eyes are positioned opposite the abaxial ends of the 3p furrows and the posterior corners are opposite the 1p lateral glabellar lobes. The eyes have a strongly curved crescent shape and stand up sharply from the cheeks supported by the strongly developed palpebral lobes. The long axes of the eyes are sub-parallel to the axial line. The eyes have 30 vertical rows of lenses and appear to have a maximum of 9 lenses per row. The lenses are circular and arranged in a hexagonal close packing arrangement.

The free cheeks are incomplete with the narrow frontal border to the glabella largely broken. The free cheeks are sub-triangular in outline with curved edges and slope gently outwards from the eyes. A weak, shallow and wide lateral border furrow runs concentrically with the edge of the cephalon from the posterior border furrow finishing opposite the frontal glabellar lobe. The lateral edges of the cheeks are ventrally reflexed to form a doublure which anterior to the eyes is at least one-sixth of the glabellar length in width.

Most of the cephalic surfaces are devoid of ornament except for the free and fixed cheeks in the areas bordered by the eyes, the axial furrows, the posterior border furrows and the lateral border furrows; these enclosed parts of the cheeks bear an ornament of small closely spaced pits. The frontal glabellar lobe bears an ornament composed of faint widely spaced granules.

Discussion

The Portuguese specimens of M. chillonensis compare well with the type material of the species described by Hammann (1972 and 1974). The augen indices of the Portuguese and Spanish material are very similar (A : Gn, 38 - 43% and 38 - 42% respectively) and both have a similar number of lenses per eye (up to 9 lenses in 30 rows for the Portuguese material and 9 lenses in 30 - 32 rows for M. chillonensis (J.-L. Henry pers. comm.). They also have a very similar glabellar shape and segmentation, similar abaxially wide posterior borders and similar genal spines. The ornament of the frontal glabellar lobe is present in the Portuguese material, but is very faint.

M. chillonensis may be separated from most of the other species of Mucronaspis by the size of the eyes for which the augen indices (A : Gn) are given in the discussion of M. cf. macrophtalma. In addition to the eye size the number of lenses in the eyes is an identifying factor and the maximum number of lenses per row and number of rows per eye are given below for the different species of Mucronaspis: M. macrophtalma (10 x 28-30), M. destombesi destombesi (9 x 27-28), M. destombesi nava (11 x 32-33), M. termieri (8-12 x 38-40), M. alnifensis (9 x 18), M. zagoraensis (12 x 36) and M. mucronata (11 x 42) all are clearly different from those of M. chillonensis. Other differences are that the eyes of M. macrophtalma have long axes which diverge backwards, M. zagoraensis, M. mucronata and M. olini have very long genal spines and M. alnifensis and M. termieri have different glabellar segmentation, especially the 2p furrows.

Hammann (1972 & 1974) collected his specimens of M. chillonensis from one locality and no other fossils are recorded associated with them, consequently he is not certain about the age of the species. He suggests a ?Llandeilo age, but the occurrence of the Portuguese material with definite *Didymograptus murchisoni* Zone graptolites proves that the species occurs in the upper Llanvirn, it might however range into the Llandeilo as well.

Family CALMONIIDAE Delo, 1935

Subfamily ACASTINAE Delo, 1935

Genus KLOUCEKIA Delo, 1935

Type species. *Phacops phillipsi* Barrande, 1846

Subgenus KLOUCEKIA (KLOUCEKIA) Delo, 1935

Kloucekia (Kloucekia) taouzensis Destombes, 1972

1972 *Kloucekia (Kloucekia) taouzensis* n. sp.; Destombes, pp. 58-60, pl. 15 figs. 4-8, text-fig. 21.

1974 *Scotiella? taouzensis* (Destombes, 1972); Hammann, pp. 89-91, pl. 9 figs. 133-139, text-fig. 33.

Kloucekia (Kloucekia) cf. *taouzensis* Destombes, 1972

Pl. 29, figs. 1-2.

Age and locality

Lower to middle Caradoc; locality 52 in the Serra da Cadaveira Member of the Monte do Carvalhal Formation.

Material

One almost complete cephalon preserved as an internal mould with the complementary external mould to the anterior part of the cephalon.

One external mould of a fragmentary cephalon and one almost complete internal mould of a pygidium.

Measurements (mm)

Width of cephalon	12.8 (est)	19.5
Length of glabella (G)	6.3	9.8
Length of glabella including occipital ring (Gn)	-	11.7
Maximum width of glabella	6.4	9.6 (est)
Posterior width of glabella	5.0	6.5 (est)
Length of eyes (A)	2.6	4.0
Augen index (A : G)	41%	41%
Augen index (A : Gn)	-	34%
Maximum width of pygidium	13.0	
Maximum length of pydidium	9.2	

Description

The cephalon is sub-semicircular in outline, about twice as wide as it is long, with the front very slightly pointed. The cephalon is sagittally strongly convex and transversely moderately convex; in anterior view the front of the cephalon is slightly arched. The posterior width of the glabella is about four-tenths of the cephalic width and the axial furrows diverge anteriorly at about 24 degrees from each other. The axial furrows are fairly deep and almost straight except for a slight abaxial curve between the 1p and the 3p furrows. The anterior edge of the glabella is curved with a very slight medial anterior point. The glabella is dorsally convex both sagittally and transversely; three pairs of glabellar furrows are present. The 1p and 2p lateral glabellar lobes are each about one-fifth of the glabellar length. The 1p lateral glabellar furrows are straight, deep and narrow, each about one-third of the posterior glabellar width in length (trans.) and directed slightly backwards to make an angle of about 75 degrees to the axial line. The 2p lateral glabellar furrows are shallow and poorly defined, each is about one-third of the posterior glabellar width in length and positioned approximately perpendicular to the axial line. The furrows have a slight anterior convexity and start a little way in from the axial furrows. The 3p lateral glabellar lobes have a maximum length (exsag.) of about one-quarter of the glabellar length. The 3p furrows are each about one-half of the posterior glabellar width in length. They are very shallow, poorly defined, slightly sigmoidal in shape and directed posteriorly at about 65 degrees to the axial line.

The occipital ring has a maximum width (sag.) which is about one fifth of the glabellar length. The posterior edge of the ring is straight, but the central half of the anterior edge and the occipital furrow are arched forwards. The central half of the occipital furrow is shallow and moderately wide, but the abaxial ends are deep and narrow.

The fixed cheeks are fairly complete, but their posterior edges are broken. The facial sutures border the anterior edge of the glabella and turn sharply backwards at the antero-lateral corners of the glabella. Here they diverge very slightly from the axial line (exsag.) to join the anterior, adaxial corners of the eyes situated opposite the 3p lateral glabellar lobes. The sutures run along the adaxial edges of the eyes to the posterior corners of the eyes situated opposite the 1p lateral glabellar lobes. The sutures follow the rounded posterior edges of the eyes, diverge abaxially and curve convexly towards the front to cut the lateral cephalic margins a little way in front of the rounded genal angles, approximately opposite the 2p lateral glabellar lobes. The anterior areas of the fixed cheeks are of small size and merge with the axial furrows. The palpebral areas of the fixed cheeks slope slightly towards the axial furrows and are elevated slightly adjacent to the eyes to form crescent-shaped palpebral lobes. The posterior areas of the fixed cheeks slope backwards from the eyes to the posterior border furrows and the lateral parts of the cheeks are deflexed. The posterior border furrows start a little behind the occipital furrow and are deep, narrow and fairly straight. The furrows run almost to the genal angles where they become shallow and curve sharply forwards to join the weak lateral border furrows. The posterior borders are narrow adjacent to the occipital ring, but become wider (exsag.) laterally.

The eyes are incomplete, crescent-shaped, abaxially convex and have rounded anterior and posterior corners. The mid-points of the eyes are situated approximately opposite the 2p lateral glabellar lobes and the long axes of the eyes diverge backwards at about 15 degrees from the sagittal line. The visual surfaces of the eyes rise abruptly from the free cheeks and have a height similar to the length (exsag.) of the 1p lateral glabellar lobes. The augen indices (A:Gn) are about 34%. The visual surfaces are incomplete but at least 18 vertical rows of lenses are present and around 20–22 vertical rows are estimated for a complete eye; each vertical row has a maximum of 7 lenses. The lenses are circular in outline both on internal and external moulds and they are arranged in a hexagonal close packing arrangement.

The free cheeks are sub-triangular in outline and dorsally convex in profile (sag. and trans.). The anterior corners of the cheeks are extended around the front of the glabella to form a narrow (in dorsal view) anterior border. This border and the edges of the cheeks are ventrally reflexed to form a doublure which is anteriorly equal in width to about one-sixth of the glabellar length and which appears to be slightly narrower along the lateral edges of the cheeks. Each cheek bears a very weak, shallow and wide lateral border furrow.

The pygidium is sub-semicircular in outline, but the posterior edge is slightly broken. With the axial ring vertical and when viewed dorsally the pygidium is about twice as wide as it is long. It has a moderately convex profile in transverse section and a slightly convex profile in sagittal section. The axis, measured across the anterior axial ring, is about four-tenths of the pygidial width. The axis tapers posteriorly with the axial furrows making an angle of about 30 degrees with each other, but it does not reach the posterior edge of the pygdium and is bluntly terminated with a semicircular terminal axial piece. Five, possibly six axial rings are present, but only the three anterior axial rings are clearly differentiated, being separated by moderately deep furrows which are shallow medially and which have a rounded profile (sag.). In dorsal view with the anterior margin vertical the axial rings are rectangular in outline; an articulating half ring is present on the anterior axial ring. The pleural regions are slightly and transversely convex, four pairs or ribs are present, but the posterior ones are poorly defined and merge into the smooth post-axial area. The interpleural furrows are weak and shallow, but slightly more marked at their abaxial ends. The furrows stop short of the lateral margins about the width (sag.) of the anterior axial ring in from the edge leaving a smooth border separated from the pleural field by a very slight dorsal concavity. The pleural furrows are moderately deep and have a rounded profile (exsag.), they are slightly curved abaxially backwards and stop at the smooth border.

The cephalon bears an ornament of small granules which on the frontal glabellar lobe become more dense and numerous fusing together to form scattered flattish tubercles. The pygidium bears a similar ornament to the cephalon and is covered in small granules.

Discussion

The Portuguese specimens of Kloucekia (Kloucekia) cf. taouzensis Destombes, 1972 have the same overall shape, glabellar shape, glabellar segmentation and rounded genal angles as the type material of K. (K.) taouzensis described by Destombes (1972). Slight differences are however noted in the size of the eyes; Destombes (op. cit.) gives an augen index (A : Gn) of 28-30% in his description, but from his figured material an augen index (A : Gn) closer to 37-40% is calculated. This apparent discrepancy cannot be easily resolved, but the Portuguese specimens are very similar in size to his figured specimens. Hammann (1974) records an A : Gn figure of 35-40% for the species and the Portuguese specimens have an A : Gn figure of about 34% which is fairly similar. Other slight differences do occur between the Portuguese material and the Moroccan type material; Destombes (op. cit.) records a maximum of 6 eye lenses per vertical row and the glabellae of his specimens are smooth, but the Portuguese material has a maximum of 7 lenses per row and the frontal glabellar lobes bear an ornament of flattish tubercles.

The species taouzensis was originally placed in the genus and subgenus Kloucekia (Kloucekia) by Destombes (1972). The overal shape of the cephalon is fairly close to that of K. (K.) phillipsi (Barrande, 1846) the type species for the genus redescribed by Whittington 1962 and illustrated in Havliček and Vaněk (1966), but the glabella of taouzensis is slightly wider and anteriorly very slightly pointed. The furrows and segmentation of the glabella are however very close to those shown for K. (K.) phillipsi. The species taouzensis is placed by Destombes (op. cit.) in the subgenus Kloucekia (Kloucekia) Delo, 1935 because of the absence of a pygidial spine, which is a characteristic of the subgenus Kloucekia (Phacopidina) Bancroft, 1949, and because the 1p lateral glabellar furrows are angled only slightly backwards.

Hammann (1974) considers that taouzensis is probably a species of the genus Scotiella Delo, 1935 and not Kloucekia because the glabella of the former expands forwards more quickly, is more "vasen förmig" (vase-shaped) and because the pygidium is very slightly pointed. The specimens he describes as Scotiella? taouzensis (Destombes, 1972) only bear the 1p lateral glabellar furrows, a feature very akin to the genus Scotiella. In contrast, however, both the specimens described by Destombes and the Portuguese specimen show the development of weak 2p and 3p furrows, a feature more in keeping with the genus Kloucekia. In addition to this, the ornament of the frontal glabellar lobe displayed by the Portuguese material is similar to that shown by other species of Kloucekia (Kloucekia) and Kloucekia (Phacopidina) which are described in Hammann (1974) and Destombes (1972).

K. (K.) cf. taouzensis may be distinguished from K. (K.) phillipsi phillipsi (Barrande, 1846), which was redescribed by Whittington (1962), because this subspecies has straighter axial furrows, stronger glabellar furrows and a more rounded anterior margin to the cephalon. K. (K.) phillipsi euroa Dean, 1967 is essentially the same as K. (K.) phillipsi phillipsi, but the pygidium has more axial rings. K. (K.) drevermanni drevermanni Hammann, 1972 differs from K. (K.) cf. taouzensis by having very weakly developed 2p and 3p glabellar furrows and by having slightly larger eyes (A : Gn 35-40%). K. (K.) drevermanni glabra also has larger eyes (A : Gn 38-42%) than the Portuguese species, but the glabellar furrows are fairly similar; the pygidium of the Spanish species is however very distinctive and bears only 2 or 3 very indistinct axial rings. K. (K.) mimus (Salter, 1864) re-described by Sadler (1974) also has slightly larger eyes (A : Gn 37-38%) than K. (K.) cf. taouzensis, a glabella which is narrower and 3p lateral glabellar furrows which do not have a sinuous shape. K. (K.) poueytoi Destombes, 1972 also differs from K. (K.) cf. taouzensis by having slightly larger eyes (A : Gn about 41%) and a strongly rounded anterior edge to the glabella. K. (K.) robertsi (Reed, 1904) may be distinguished from K. (K.) cf. taouzensis because it has a more diamond-shaped and laterally expanded frontal glabellar lobe and eyes which almost touch the junctions of the axial furrows and the 3p lateral glabellar furrows. The augen indices (A : Gn) for this species calculated from the illustrations of Price (1974) and Ingham (1977) give a figure of between 36 and 45% showing the eyes to be larger than those of K. (K.) cf. taouzensis. The pygidium of K. (K.) robertsi is also different and has up to 10 axial rings (Ingham, 1977, pl. 27, fig. 18). K. (K.) extensa Price, 1974 is characterised by the 3p lateral glabellar lobes being the widest part of the glabella, but differs from K. (K.) cf. taouzensis by having short (trans.) 2p lateral glabellar furrows and a frontal glabellar lobe with a strongly rounded anterior margin; the pygidium is also different with at least 8 axial rings.

Destombes (1972) records K. (K.) taouzensis from the lower Caradoc, basal part of the Ktaoua Formation of the Anti Atlas Morocco. Hammann (1974) records similar material from the Caradocian rocks of the Sierra Morena in Spain. In the Dornes area K. (K.) cf. taouzensis occurs associated with Onnia cf. grenieri (Bergeron, 1893) and Calymenella (Calymenella) boisseli Bergeron, 1890. C. (C.) boisseli is recorded by Hammann 1974 associated with Onnia? n. sp. aff. grenieri (Bergeron, 1893) from upper Caradoc strata in the eastern Sierra Morena in Spain. This suggests that the Serra do Cadaveira Member of the Monte do Carvalhal Formation in the Dornes area is of an upper Caradoc age.

Order ODONTOPLEURIDA Whittington, 1959

Family ODONTOPLEURIDAE Burmeister, 1843

Subfamily SELENOPELTINAE Hawle & Corda, 1847

Genus SELENOPELTIS Hawle & Corda, 1847

Type species. Odontopleura inermis Beyrich, 1846

Selenopeltis macrophthalmus (Kloucek, 1916)

1896 Acidaspis Buchii; Crosfield & Skeat, p. 528.

1916 Acidaspis Buchi var. macrophthalma; Klouček, pp. 2, 3, 6 and 7.

1919 Acidaspis Buchi var. macrophthalma; Klouček, pp. 232, 234, 236 and 238.

1931 Acidaspis (Solenopeltis) buchi (Klouček); Whittard, p. 328.

1949 Selenopeltis buchi macrophtalma (Klouček, 1916), nov. emend.; Prantl & Přibyl, p. 177, pl. 8, figs. 1-4.

1953 Selenopeltis buchi macrophthalma (Klouček); Přibyl p. 67.

1961 Selenopeltis inermis var. macrophthalmus (Klouček); Whittard, p. 199, pl. 26, figs. 2-9.

1966 Selenopeltis buchi macrophthalma (Klouček); Havliček & Vaněk, pp. 51 and 52, pl. 7 fig. 3.

1968 Selenopeltis macrophthalmus (Klouček, 1916); Bruton pp. 65-66, pl. 11 figs. 9-13.

1973 Selenopeltis macrophtalma (Klouček, 1916); Přibyl & Vaněk, pp. 64, 66, pl. 2 fig. 1.

1976 Selenopeltis macrophthalma (Klouček, 1916); Přibyl & Vaněk, p. 14, pl. 1, fig. 4.

1978 Selenopeltis macrophthalmus (Klouček, 1916); Bruton & Henry, p. 895–896, pl. 1, figs. 2, 3, 5 & 7; text-fig. 1 & 2.

Selenopeltis cf. macrophthalmus (Klouček, 1916)

Pl. 28, fig. 9; pl. 29, fig. 3.

Age and locality

Llanvirn, Didymograptus murchisoni Zone; Brejo Fundeiro Formation, fossil locality 85.

Material

One incomplete cephalon and one fragmentary left pleura, both preserved as external moulds.

Measurements (mm)

Length (sag.) of cephalon (excluding genal spine)	21.0 (est.)
Width (trans.) of cephalon along posterior border	46.0 (est.)
Length (exsag.) of eye	5.0
Length of genal spine preserved	25.0

(est.) equals estimated measurement.

Description

The estimated length to width ratio of the cephalon (excluding the genal spine) is approximately twice as wide as long. It is roughly trapezoidal in outline although the lateral border is not preserved. The glabella is incomplete, it appears to be sub-rectangular in outline and to be about half the cephalic width. The glabella is flattish (trans.) but slightly convex (sag.). The axial furrow is very weak and occurs as a change in convexity between the glabella and the fixed cheek rather than as a distinct furrow. The lateral margin of the glabella curves gently abaxially. The glabellar lobes and furrows are poorly preserved, but a short, shallow and sub-linear shaped depression occurs opposite the anterior corner of the eye. This furrow is arranged parallel to the axial line and is positioned about one-quarter of the width of the glabella in from the axial furrow.

The fixed cheek is an open V-shape in outline. The palpebral and anterior areas, along with the anterior part of the posterior area, are slightly elevated above the glabella and have a slight to moderate convex (trans.) profile. The abaxial edge of the anterior area of the fixed cheek is marked by a strongly pronounced eye ridge and complementary furrow which curve posteriorly and abaxially, diverging from the axial furrow at an angle of about 15 degrees. Abaxial to the eye ridge the fixed cheek drops sharply to make an angle of about 90 degrees with the free cheek. The anterior part of the facial suture runs along this angle, then towards the eye it rises rapidly up to the eye ridge at the anterior corner of the eye. The palpebral lobe is crescent-shaped, it is raised slightly from the palpebral area of the fixed cheek and is continuous with the eye ridge. The facial suture runs between the outer edge of the palpebral lobe and the eye which is strongly and outwardly convex. The posterior part of the facial suture is weakly sigmoidal in shape, it curves sharply from the posterior corner of the eye and runs straight towards the postero-lateral corner of the cephalon (excluding the genal spine) then swings posteriorly to cut the posterior margin adjacent to the adaxial edge of the genal spine. The posterior area of the fixed cheek slopes down sharply from the palpebral area to the posterior border furrow which is very deep and wide with a rounded profile. This furrow runs abaxially, crossing the facial suture about half way between the eye and the posterior margin. The furrow then parallels the facial suture just on the edge of the free cheek, before it curves posteriorly to reach the posterior margin at the same point as the facial suture. The posterior border is raised into a rounded (exsag.) ridge which becomes slightly wider abaxially and simultaneously curves backwards parallel to the facial suture, the ridge ends in a short, bluntly terminated spine.

The free cheek is sub-triangular in outline with a rounded antero-lateral corner. The anterior and lateral margins are incomplete and the cheek is slightly convex (trans.). A wide shallow furrow with a rounded profile divides the free cheek from the fixed cheek and the eye, which stand elevated above the free cheek. The disposition of the visual surface suggests that the cephalon has been slightly crushed and that the furrow below the eye has been made more pronounced. The postero-lateral corner of the fixed cheek is prolonged into a genal spine which gently tapers posteriorly and which has a preserved length similar to that of the cranidium. The spine diverges at about 20 degrees from the axial line and is strongly convex in profile (trans.) even though it is slightly crushed.

The eye is about one-quarter the length of the cranidium and is crescent-shaped in dorsal view. It is also outwardly convex both in lateral and anterior views and the visual surface extends from the facial suture down to the free cheek. The eye lenses are circular and very small; they are not very well preserved, but appear to be arranged in a fairly orderly manner as a hexagonal close packing arrangement. There are an estimated 15-20 lenses per vertical row and an estimated 40-50 vertical rows.

The fragmentary left pleura is sub-rectangular in outline and about one-third as long (exsag.) as it is wide (trans.). The postero-lateral corner is extended into a gently and posteriorly tapering pleural spine which has a preserved length of about twice the length (exsag.) of the pleura; the spine has a circular section (trans.). The adaxial end of the pleura is gently and abaxially curved. The anterior edge of the pleura is raised into a slight articulating ridge about one-seventh the length (exsag.) of the pleura. A well developed ridge crosses the pleura, it starts at the inner posterior corner and gently curves antero-laterally to about two-thirds the way to the anterior edge. From here it curves sharply backwards to be continuous with the pleural spine.

The whole of the cephalon is covered with a very fine granular ornament composed of very small, closely and fairly regularly spaced tubercles numbering an estimated 100–200 per square millimetre. In addition to this ornament the free cheek (excluding the border, the eye and the genal spine) is ornamented with a wrinkled pattern of slight ridges and furrows which are roughly aligned sub-parallel to the long axis of the genal spine and which radiate slightly from the eye. The detached pleura is almost smooth, but has a trace of a very fine granular ornament.

Discussion

There has been some past controversy about the validity of the genus *Selenopeltis*; the views of Prantl & Přibyl (1949), Dean (1966), Bruton (1968), Bruton & Henry (1978) are upheld and the generic name *Polyeres* Rouault, 1847 is rejected (*nomen oblitum*). Prantl & Přibyl (*op. cit.*) consider there to be two subspecies of *Selenopeltis buchi*; *S. buchi buchi* (Barrande, 1846) and *S. buchi macrophthalmus*

(Klouček, 1916). Bruton (1968) considered the differences between the two forms to be worthy of specific rank and his views are followed here.

Bruton (op. cit.) and Whittard (1961, p. 168) both consider that S. buchi and S. macrophthalmus may be reliably separated on the form of the pygidia. Because of this the difficulty of assigning a specific name to a fragmentary cephalon and pleural lobe from Portugal is acknowledged. There are however slight differences in the free cheek ornament of the two species. S. buchi has a large granular ornament (Prantl & Přibyl, 1949, pl. 4 fig. 1 and pl. 9 fig. 2), (as does S. gallicus irroratus Bruton & Henry, 1978) but S. macrophthalmus has a much less pronounced ornament composed of fine wrinkles (Whittard, 1961, pl. 26 fig. 4); the Portuguese specimen is fairly similar to Whittard's figured material. S. binodosus Dean, 1966; S. gallicus gallicus Bruton & Henry, 1978 and S. gallicus irroratus Bruton & Henry, 1978 may be distinguished from S. macrophtalmus by their glabellar segmentation and coarse, granular glabellar ornament.

S. macrophthalmus is reported by Havliček & Vaněk (1966) and by Bruton (1968) to occur in the Šarka and Dobrotivá Formations in Bohemia. These are considered by Havliček &Marek (1973) to be of Llanvirn and lower Llandeilo ages. Bruton & Henry (1978) record the same species from the Upper Llanvirn of the Postolonnec Formation in the Crozon Peninsula and the Lower Llandeilo of the eastern Armorican Massif. In Britain Whittard (1961) records that S. macrophthalmus has been found in beds of Didymograptus extensus Zone (Arenig) and D. bifidus Zone (Lower Llanvirn) ages. In the Dornes area of Portugal S. cf. macrophthalmus is found in beds of Llanvirn age, D. murchisoni Zone; a horizon which is similar to that of the species in Bohemia and the

Crozon Peninsula. Elsewhere in Portugal Delgado (1908, pp. 35 and 57) has recorded Acidaspis Buchi Barrande from the "Schistes a Orthis Ribeiroi" of Buçaco where it is associated with D. murchisoni; it is likely that this trilobite is S. macrophthalmus. In the Amendoa area of Portugal Delgado (op. cit., p. 80) also records Acidaspis Buchi Barrande, but from the "Schistes a Orthis Berthoisi" (Caradoc); it is probable that this trilobite is S. buchi which Bruton (op. cit.) records in the Letná and Králův Dvůr Formations of Bohemia. Havlíček & Marek (1973) consider these formations to be of approximately upper Llandeilo to lower Caradoc, and lower Ashgill ages respectively.

2. Brachiopoda

Class	ARTICULATA Huxley, 1869
Order	ORTHIDA Schuchert & Cooper, 1932
Superfamily	ENTELETACEA Waagen, 1884
Family	DRABOVIINAE Havlíček, 1951
Genus	DRABOVIA Havlíček, 1951

Type species. Orthis redux Barrande, 1848

Drabovia redux (Barrande, 1848)

for a complete synonymy see Havlíček (1951)

1951 Drabovia redux (Barrande, 1848); Havlíček, pp. 117-118, pl. 9, fig. 4; pl. 10, figs. 5, 6, 8.

1965 Drabovia redux (Barrande, 1848); Moore, p. H330.

1966 Drabovia redux (Barrande, 1847); Coates, pp. 91-92, fig. 6, e, f, g and fig. 7a, b, c, d.

1977 Drabovia redux (Barrande, 1848); Havlíček, pp. 246-247 & pl. 14, figs. 1-5.

Drabovia cf. redux (Barrande, 1848)

Pl. 29, figs. 4-7, pl. 30, fig. 1.

Age and locality

Lower Caradoc, bryozoa beds within the Monte do Carvalhal Formation at fossil localities 16, 21, 22 and 50.

Material

13 external and 2 internal moulds of brachial valves; 10 internal and 4 external moulds of pedicle valves. The majority of the specimens from locality 16 are distorted.

Measurements (mm)

Only a few undistorted specimens were found; these were collected from locality 22.

Valve; pedicle (P) or brachial (B)	P	B	B
Width of the valve	12.0	11.0	9.0(d)
Length of the valve	8.0	7.0	7.0
Length of brachiophores or dental plates	1.8	2.2	1.5
Width across brachiophores or dental plates	3.5	2.9	2.3
Height of the valve	1.6	1.0	1.2

(d) is a half measurement doubled.

Description

The shells are sub-quadrate in outline about 70% as long as they are wide with obtuse to 90 degree cardinal angles. The pedicle valve is convex in profile about 20% as high as it is long, the brachial valve is slightly less convex and about 16% as high as it is long. Some pedicle valves are slightly carinate and some brachial valves medially slightly sulcate. The radial ornament is ramicostellate with 3 to 5 ribs per millimetre 5mm antero-medially to the ventral umbo. The brachial valve interarea is flat and anacline; the pedicle valve interarea is apsacline.

The teeth are supported by divergent dental plates extending anteriorly for 23% the length of the valve and making an angle of about 75 degrees to each other. The ventral muscle area is poorly distinguished, bilobed, and about 40% the length of the valve. In the majority of ventral valves the internal surface is ornamented by well developed ribs which occur even on the muscle areas.

The internal surface of the brachial valve is ornamented by faint ribs; these do not occur in the umbonal and muscle areas of the valve, but are very well developed around the antero-lateral margins of the valve. The cardinal process is formed by a posteriorly directed wedge-shaped myophore and an anteriorly pointing triangular shaft. The area surrounding the cardinal process and interior to the brachiophores is extended anteriorly into a narrow notothyrial platform, tapering and becoming lower anteriorly to finish centrally in the valve. The brachiophores are blade-like, diverge anteriorly at about 90 degrees and thicken towards the umbo. The anterior ends of the brachiophores are extended forwards and inwards as curved brachial ridges which finish about one-third the way across the valve. Well formed fulcral plates are developed parallel to the hinge line and delimit sockets which are shallow and rounded. The diductor muscle scars are small and drop-shaped, impressed either side of the myophore. The adductor muscle scars are lobe-shaped and positioned anterior to the curved brachial ridges. These muscle scars extend to the mid-point of the valve and each scar is divided, about one-third from its posterior edge, by an anteriorly convergent ridge which separates the two parts of the muscle field.

Discussion

The Portuguese specimens of Drabovia cf. redux are fairly close to those of D. redux (Barrande, 1848) as redescribed by Havlíček (1951 and 1977). The only notable difference is that the notothyrial platforms of the Bohemian material are slightly more elevated above the floor of the valve, but the figured specimens (1951; pl. 9, fig. 4, pl. 10, figs. 5, 6 & 8; 1977, pl. 14, figs. 1-5) are larger than the Portuguese material. Coates (1966) also describes D. redux, but from Normandy, the specimens he figures (fig. 6, e g and fig. 7 a-d) are similar to the Portuguese material and occur in strata which in common with the bryozoa beds of the Monte do Carvalhal Formation also contain Onnia grenieri (Bergeron, 1893). It must however be noted that Havlíček (1977) excludes the material described by Coates (op. cit.) from his synonymy of D. redux and assigns it to Drabovia sp. There are some 15 species of Drabovia most of which may be distinguished from D. redux by their coarser radial ornament or by the stronger development of their notothyrial platforms. Four species are however, fairly similar to D. redux, these are: D. dux Havlíček, 1975 which differs by having both a slight fold and sulcus, and short brachiophore supports. D. vappa Havlíček, 1975 is nearly identical to D. redux, but smaller with minute adductor muscle scars and D. trubinensis Havlíček, 1977 is also almost identical to D. redux, but is a sub-circular form. D. praedux Havlíček 1978 from the Sierra Morena in Spain (Arbin et al., 1978) is also a sub-circular form, but differs from D. redux by having very short and only slightly divergent brachiophores along with slightly stronger ribs. *D. vappa*, *D. trubinensis* and *D. redux* all occur in the Letná Formation in Bohemia, but each occurs in a different lithology and all three might represent phenotypes of *D. redux*. The Letna Formation is considered by Havlíček & Marek (1973) to be of probable upper Llandeilo to lower Caradoc age. The species is also recorded by Coates (*op. cit.*) in Normandy where it occurs with *Onnia grenieri*; this trilobite suggests a probable lower Caradoc age. Mitchell (1974) also records *D.* cf. *redux* from the middle to upper part of the Louredo Formation at Buçaco in Central Portugal, where the brachiopod is associated with *Onnia* sp. In the Dornes area the occurrence of *D.* cf. *redux* therefore appears to be very similar to the occurrence of *D. redux* elsewhere.

Family HARKNESSELLIDAE Bancroft, 1928

Genus HORDERLEYELLA Bancroft, 1928

Type species. *Horderleyella plicata* Bancroft, 1928

Horderleyella plicata Bancroft, 1928

1928 *Horderleyella plicata* n. gen. and n. sp.; Bancroft, p. 186–187, pl. 1, figs. 15–18.

1945 *Horderleyella plicata* Bancroft, 1928; Bancroft, pp. 235–237, pl. 31, figs. 4–7 and pl. 32, figs. 1–4.

1958 *Horderleyella plicata* Bancroft; Dean, pp. 197–199, 218, pl. 24, figs. 3–4.

1965 *Horderleyella plicata* Bancroft, 1928; Moore, pp. H339–H340, fig. 215, 1a–d.

1974 Horderleyella plicata Bancroft; Williams, p. 103.

1977 Horderleyella plicata Bancroft; Havlíček, p. 204.

Horderleyella cf. plicata Bancroft, 1928

Pl. 27, fig. 1; pl. 30, figs. 2-7.

Age and locality

Upper Llandeilo, locality 20 within the Lameiros Member of the Monte do Carvalhal Formation.

Material

The material consists of 8 internal and 3 external moulds of brachial valves; 7 internal and 3 external moulds of pedicle valves.

Measurements (mm)

The detailed measurements of the shells are given in appendix 3, but the mean average lengths of the measurements along with the number of specimens in brackets are given below:

Mean average length of pedicle valves (6)	5.8
Mean average width of pedicle valves (6)	7.5
Mean average length of dental plates (6)	0.8
Mean average maximum width across dental plates (6)	2.0
Mean average length of brachial valves (7)	4.7
Mean average width of brachial valves (7)	6.6
Mean average length of brachiophores (7)	0.6
Mean average maximum width across brachiophores (7)	1.0

Description

The shells are sub-quadrate in outline, with 90 degree cardinal angles. The pedicle valve is medially carinate about 76% as long as it is wide. The brachial valve is about 74% as long as it is wide; the valve is almost planar to slightly convex with a well developed median sulcus in juvenile forms, this sulcus dies out anteriorly in larger specimens. The radial ornament is fascicostellate with sub-triangular ribs numbering between 3 and 5 per millimetre 2mm antero-medially of the dorsal umbo. The radial ornament is well developed both externally and internally, but the muscle areas of the pedicle valves are only slightly ribbed.

The teeth are supported by divergent dental plates extending anteriorly for 34% the length of the valve and making an angle of between 80 and 85 degrees to each other. The ventral muscle scar is weakly differentiated, lozenge-shaped, about as wide as it is long and extending anteriorly for about 35% the length of the pedicle valve.

In juvenile forms the cardinal process is simple and blade-like, about half as long as the brachiophores which are 22% the length of the valve and diverge slightly to the anterior. In the larger valves the cardinal process is developed into a sub-oval myophore and a very weakly defined shaft; at the same time the brachiophores thicken, diverge less and become sub-parallel. The adductor scars are sub-quadrate, poorly defined and positioned posteriorly in shallow hollows in the notothyrial platform.

Discussion

The shells described above agree with the diagnosis of the genus Horderleyella given by Bancroft (1928 and 1945) and have the correct shape, short brachiophores, simple myophore and lozenge-shaped (non bilobate) ventral muscle area which typify the genus. The Portuguese specimens are very close to the type species H. plicata, but differ from the material described by Bancroft (op. cit.) which has a fairly well developed sulcus in the brachial valves of both large and small specimens. It must however be noted that the specimen of *H. plicata* figured by Dean (1958, pl. 24, fig. 4) has only a very weak sulcus and is very close to the Portuguese material. The small specimen of *H.* cf. *plicata* figured by Williams (1974, pl. 17, fig. 1) is also very similar to the Portuguese specimens.

The Portuguese *H.* cf. *plicata* may be readily distinguished from *H. corrugata* Bancroft, 1945 and *H. blanda* Havlíček, 1977 which both have much coarser ribbing. *H. corrugata* also has a well developed fold and sulcus while the cardinalia of *H. blanda* are much larger than those found in *H.* cf. *plicata*. Similarly *H. convexa* Williams, 1949; *H. lata* Williams, 1949 and *H. bouceki* Havlíček, 1951 also have larger cardinalia than the Portuguese material. *H. bouceki* additionally has much more pronounced pedicle valve muscle scars, *H. lata* has a strong fold and sulcus while *H. convexa* has a much more convex brachial valve. *H. subcarinata* MacGregor, 1961 is very similar to *H. plicata* and Williams (1974, p. 103) considers that the two species may be conspecific.

H. plicata has been recorded from the Costonian and Harnagian stages of the Caradoc in Shropshire (Bancroft, 1928 & 1945; Dean, 1958 and Williams, 1974) while the probably conspecific form *H. subcarinata* occurs in the upper Llandeilo of the Berwyn Hills in North Wales (MacGregor, 1961). In Portugal *H.* cf. *plicata* occurs associated with the trilobite *Crozonaspis armata* Hammann, 1972 which also occurs in the upper Llandeilo of the Sierra Morena in Spain; the occurrence of the two species together in Portugal indicates a probable upper Llandeilo age for the Lameiros Member of the Monte do Carvalhal Formation.

Genus SVOBODAINA Havlíček, 1951

Type species. Orthis ellipsoides Barrande, 1848

Svobodaina armoricana Babin & Melou, 1971

Pl. 20, figs. 8–13; pl. 31, figs. 1–6.

1968b Drabovia? sp.; Pillet & Robardet, p. 72, figs. 1 and 1a.

1972 Svobodaina armoricana nov. sp. Babin & Melou, pp. 87–90, pl. 9 figs. 1–5, pl. 10 figs. 1–8 and text-figs. 6–7.

1976 Svobodaina armoricana; Babin et al., pp. 365 and 371.

1977 Svobodaina armoricana Babin & Melou, 1972; Havlíček, p. 122.

Age and locality

Lower to middle Caradoc; localities 25, 52, 117, 118 and 119 within the Serra da Cadaveira Member of the Monte do Carvalhal Formation.

Material

The material consists of 30 internal and 14 external moulds of brachial valves; 21 internal and 14 external moulds of pedicle valves; 3 internal moulds of brachial and pedicle valves together.

Measurements (mm)

The detailed measurements for 49 valves are given in appendix 3; the same measurements were taken as those used by Babin & Melou (1972, p. 90, fig. 6) to enable comparison with the previously described material. The mean average lengths of the measurements along with the number of specimens in brackets are given below.

Pedicle valve length (14)	13.6
Pedicle valve width (14)	18.3
Median length of pedicle valve muscle field (14)	5.0
Maximum length of pedicle valve muscle field (14)	6.8
Width of pedicle valve interarea (14)	10.3
Brachial valve length (22)	13.9
Brachial valve width (22)	16.1
Length of brachial valve muscle field (22)	7.3
Width of brachial valve interarea (22)	8.3

Description

The shells are sub-circular in outline, dorsi-biconvex in adult specimens and biconvex in juvenile forms. The cardinal angles are obtusely developed or rounded. The pedical valve is about 15% as deep as long and has a very shallow median sulcus. The brachial valve is sub-oval about 85% as long as wide, moderately convex and about 30% as deep as long. The ventral interarea is planar, apsacline and ornamented by striae parallel to the hinge line. The dorsal interarea is analcine, shorter and much narrower than the ventral interarea. The radial ornament is ramicostellate with 4-5 costae per millimetre developed 5mm antero-medially of the dorsal umbo; each costa is triangular in section. The internal radial ornament is weakly developed except around the anterior and lateral margins which are finely costellate.

The teeth are small and triangular, supported by strong dental plates which diverge at between 70 and 80 degrees and which extend anteriorly for 20% the length of the pedicle valve. The ventral muscle field extends anteriorly for 43% of the length of the pedicle valve, and laterally for between 30% and 40% of the width. In outline the ventral muscle area varies from flabelliform to almost parallel sided with pointed antero-lateral ends. The widely splayed diductor scars sometimes enclose, and are sometimes bounded by the large adductor impressions. Despite the marked differences in the ventral muscle fields (plates 30 and 31) structural details of the pedicle valves are constant for all the specimens.

The brachiophores are triangular in outline with the postero-lateral edges diverging at 90° to each other; the oblique sockets are simple without bounding fulcral plates. The cardinal process is formed by a well developed median ridge extending 50% of the length of the shell, slightly splayed posteriorly and terminated posterolaterally by a well developed bilobed myophore; the plates of which diverge anteriorly at an angle of 140° to each other. The area between the cardinal process and brachiophores is raised forming a well developed sub-rhomboidal notothyrial platform; the lateral sides of which converge and curve gently inwards to terminate at the end of the cardinal process. The dorsal muscle area is formed by two lobe-shaped muscle scars which extend for half the length of the shell, and which frequently have transverse ribs dividing each muscle into two, sometimes three distinct areas (plates 30 and 31).

Discussion

The specimens described above agree well with the description of Svobodaina armoricana given by Babin & Melou (1972). The mean average ratios of pedicle valve length against the length of the pedicle valve muscle scars is 0.45 for the French material and 0.43 for the Portuguese material. In contrast to this the same ratio calculated from the illustrations by Havlicek (1970 and 1977) of S. ellipsoides (Barrande, 1848) - formerly S. inclyta (Barrande 1879) - is 0.64, reflecting the much larger muscle development of this species.

Approximately one-half of the Portuguese material is identical to that of S. armoricana described by Babin & Melou (op. cit.), but many of the remaining specimens show major variations in the ventral muscle scars. These are possibly phenotypes and it is interesting to note that one specimen (pl. 31, fig. 3b) has a muscle field which is narrow with an angular W-shaped anterior end. This muscle scar configuration is identical to that illustrated for S. berthoisi (Rouault) by Sharpe (1853, pl. 8, fig. 4b), which incidentally has the same pedicle valve length to muscle length ratio of 0.45 to that of S. armoricana. Sharpe (op. cit. p. 155) notes that for S. berthoisi "the specimens figured by M. Rouault are much distorted and only show the exterior for which reason the species is refigured here". Because it is the internal characteristics of the genus Svobodaina which separate the species it is probably better to consider S. berthoisi described by Sharpe (op. cit.) as a synonym of S. armoricana. This form is probably a phenotype of S. armoricana rather than a separate species or sub-species. Phenotypic variation is also shown in the musculature of S. ellipsoides described by Havlíček (1970 and 1977).

Havlíček, 1951 describes S. suburbana (Barrande 1879) as a separate species of Svobodaina, but Havlíček, 1970 considers it to be synonym of S. inclyta (Barrande, 1879) (now S. ellipsoides (Barrande, 1848)). Havlíček, 1977 however, considers S. suburbana to be a separate species only known from its brachial valves and separated from the other species of Svobodaina by its circular shape. In view of the variations in shape and musculature shown by S. armoricana and S. ellipsoides it is probable that S. suburbana is actually a slight variation of S. ellipsoides.

Svobodaina armoricana has been recorded within the Armorican Massif by Babin & Melou (1972) and by Babin et al. (1976) from the Caradoc of the Coëvrons syncline and the Grès de Kermeur Formation (middle Caradoc) of the Crozon Peninsula. In Portugal the closely related form described as S. berthoisi has been recorded from Buçaco by Sharpe (1853) and Delgado (1908, pp. 32, 39, 40, 51 & 61) who records "differentes varietes" from the "Schistes à Dalmanites Dujardini" and "Schistes culminants et schistes diabasiques". More recently Mitchell (1974) records the same species from the Porto do Santa Anna Formation in the same area. Delgado (op. cit., pp. 74, 75, 83 & 87) also records small and poorly developed specimens of S. berthoisi from the Amendoa area where it occurs in the "Ordovicien supérieur, Schistes à Orthis Berthoisi". In the Dornes area S. armoricana is associated with the trilobites Onnia cf. grenieri (Bergeron, 1893), Calymenella (Calymenella) boisseli Bergeron, 1890 and Kloucekia (Kloucekia) cf. taouzensis Destombes, 1972; this assemblage suggests a middle or possibly lower Caradoc age.

Family HETERORTHIDAE Schuchert & Cooper, 1931

Genus TISSINTIA Havlíček, 1970

Type species. Tissintia convergens Havlíček, 1970

Tissintia sp. indet.

Pl. 31, figs. 7-9; pl. 32, figs. 1-2.

Age and locality

Llandeilo, localities 8 and 135 in the Brejo Fundeiro Formation and locality 76 in the Lameiros Member of the Monte do Carvalhal Formation.

Material

The material consists of 4 internal and 2 external casts of brachial valves; 4 internal and 1 external casts of pedicle valves.

Measurements (mm)

The detailed measurements of the shells are given in appendix 3, but the mean average lengths of the measurements along with the number of specimens in brackets are given below:

Mean average length of pedicle valves (4)	5.5
Mean average width of pedicle valves (4)	8.9
Mean average length of dental plates (4)	1.2
Mean average maximum width across dental plates (4)	2.0
Mean average length of brachial valves (4)	8.3
Mean average width of brachial valves (4)	7.6
Mean average length of brachiophore bases (4)	1.3
Mean average maximum width across brachiophores (4)	1.4

Description

The shells are sub-circular in outline with rounded, obtuse cardinal angles and a plano-convex profile. The pedicle valve thickness is about 20% of the valve length with an evenly convex median zone and slightly flattened lateral areas. The brachial valve is about 90% as long as it is wide and almost planar with a shallow median sulcus which becomes less well defined towards the anterior margin. The ventral interarea is planar and apsacline, the dorsal interarea is planar and anacline. The delthirium is open, but the notothyrium is poorly preserved and of indeterminate character. The radial ornament is fascicostellate with 3-4 ribs per millimetre 5mm antero-medially of the dorsal umbo.

The teeth are small and trigonal, supported by dental plates which extend anteriorly for 22% the length of the valve and which diverge to have a spread which is about 22% the width of the valve. The ventral muscle field is not apparent.

The cardinal process varies during growth, in juvenile forms it is a simple shaft, but in larger forms it develops into a medially cleft, bilobed, ovoid myophore and anteriorly tapering shaft which dies out just behind the anterior limits of the brachiophores. The brachiophores are triangular in outline and divergent at about 90 degrees, but with sub-parallel bases. The brachiophore bases extend anteriorly for about 16% the length of the valve. The sockets are oblique and defined laterally by weak fulcral plates.

Discussion

The specimens described above have the correct shape, anteriorly divergent brachiophores which have longer bases where they meet the valve, and bilobate cardinal processes which typify the genus Tissintia Havlíček (1970, p. 14). The Portuguese material is fairly close to that of Tissintia convergens Havlíček, 1970 (especially the small specimens figured in plate 1, fig. 6), but the Moroccan species has a better developed notothyrial platform and median ridge. In common with T. convergens the sulcus of Tissintia sp. is only visible on the posterior half of the brachial valve and the cardinal process in small specimens is simple and ridge-like. The Portuguese specimens differ from the small Bohemian form Tissintia velizia Havlíček, 1977 which is characterised by long brachiophores with bases which are sub-parallel; in both valves the internal ornament is restricted to the peripheral belt and the external ribbing is coarser than that of Tissintia sp.. Tissintia immatura Williams, 1949 from the Llandeilo of Shropshire differs from Tissintia sp. by having a marked median ridge, thicker brachiophore bases and an almost smooth interior ornament. The other British species T. prototypa Williams, 1949 from the Llanvirn of the Shropshire and Llandeilo areas has much narrower brachiophores and a narrower cardinal process than the Portuguese specimens; the shape is also more rounded and the median ridge is only very slightly developed. Both T. immatura and T. prototypa differ from Tissintia sp. by having longer and thicker dental plates which diverge at less of an angle.

Williams (1974, p. 111, table 77) presents data from which the ratio of the length of the brachiophore bases against the length of the brachial valve may be calculated. The same ratios may also be calculated from the illustrations of T. convergens (Havlíček, 1970, pl. 1) and from the data for T. velizia given by Havlíček (1977, p. 114). The ratios are given below with the number of specimens in brackets:

Tissintia velizia from Bohemia (3)	0.209
Tissintia convergens from Morocco (8)	0.140
Tissintia immatura from Shropshire (4)	0.174
Tissintia prototypa from Shropshire (21)	0.158
Tissintia prototypa from Llandeilo (55)	0.136

The Portuguese specimens of Tissintia sp. give a ratio of 0.157 for 4 specimens a figure which is very close to that for T. prototypa from Shropshire; the cardinalia of this species are, however, clearly different to those of Tissintia sp. which is morphologically closer to T. convergens. Tissintia cf. convergens Havlíček, 1970 has been recorded from the Buçaco area of Portugal by Mitchell (1974) from strata which is comparable to the Brejo Fundeiro Formation of the Dornes area from which Tissintia sp. has been described. All the species of Tissintia mentioned above occur in strata of Llanvirn or Llandeilo age. In the Dornes area Tissintia sp. occurs in beds of post Didymograptus murchisoni Zone to lower or middle Llandeilo age. The occurrence of Tissintia sp. in these strata agree with the occurrences of the genus elsewhere.

Genus CACEMIA Mitchell, 1974

Type species. Orthis ribeiroi Sharpe, 1853

Cacemia ribeiroi (Sharpe, 1853)

Pl. 32, figs. 3-6 & 8.

1853 Orthis Ribeiro, N.S.; Sharpe, pp. 152-153, pl. 8, figs. 1a-1d.

1908 Orthis Ribeiroi Sharpe; Delgado, pp. 27, 30, 34, 35, 42, 43, 48, 50, 55, 61, 70, 74, 82 and 89.

1918 Orthis Ribeiroi Sharpe, 1853; Born , pp. 335-336, pl. 24, figs. 1a-1d.

1974 Cacemia ribeiroi (Sharpe, 1853); Mitchell, p. 394, pl. 1, figs. 1-6.

1976 Cacemia ribeiroi (Sharpe, 1853); Melou, pp. 698-700, pl. 3, figs. 1-15.

Age and locality

Upper Llanvirn or possibly Lower Llandeilo; fossil localities 66, 67 and 106 within the upper part of the Brejo Fundeiro Formation.

Material

The material consists of 8 internal and 2 external moulds of pedicle valves; 4 internal and 1 incomplete external moulds of brachial valves.

Measurements (mm)

The detailed measurements of the specimens are given in appendix 3, but the mean average measurements and number of specimens in brackets are given below.

Mean average length of pedicle valves (6)	8.1
Mean average width of pedicle valves (6)	13.0
Mean average length of dental plates (6)	1.4
Mean average length of pedicle valve muscle scar (6)	3.7
Mean average length of brachial valve (4)	6.8
Mean average width of brachial valve (4)	10.6
Mean average length of brachiophore bases (4)	1.0

Description

The pedicle valve is sub-semicircular in outline and is on average 57% as long as it is wide. In longitudinal and transverse profiles the valve is moderately convex and about 24% as deep as it is long. The cardinal angles are about 90 degrees in small specimens, but become alate in large specimens; the valve is medially gently carinate and the interareas are apsacline. The delthirium is wide, but closed posteriorly by an apical pedicle callist. Only small brachial valves were found, these are on average 68% as long as wide and sub-semicircular in outline. The brachial valve is essentially planar except for the development of a wide and shallow antero-medial sulcus. The interareas are anacline and the notothyrium appears to be closed. The external ornament of both valves is ramicostellate with 3-4 costellae per millimetre 5mm antero-medially on the pedicle valve. Concentric growth lines are well developed and the shell material is finely and densely punctate.

The internal moulds of the pedicle valves show that the teeth are small, triangular and supported on thin dental plates which extend anteriorly for about 15% the length of the valve and which diverge anteriorly at an angel of about 80 degrees. The fulcral plates are moderately developed parallel to the hinge line. The cardinal process of the small shells is short and triangular in outline; it tapers posteriorly, rests on a very slight notothyrial platform, and extends for about 12% the length of the valve. The internal surfaces of both valves are slightly ribbed except in the muscle and articulation areas which are usually smooth; the ribs are well developed around the lateral and anterior edges of the valves.

Discussion

The pedicle valves of the specimens described above are identical to those of *Cacemia ribeiroi* described by Sharpe (1853), Mitchell (1974) and Melou (1976). The genotype *C. ribeiroi* is characterised by its transverse outline with alate cardinal angles which distinguish it from all other heterorthid genera and species. Mitchell (*op. cit.*) does not figure a brachial valve of *C. ribeiroi*, but Melou (*op. cit.*, pl. 3, figs. 1-3 and 12-13) does and these shells have the same transverse alate outline as similarly sized pedicle valves. The Portuguese brachial valves described above are however, small and sub-semicircular in outline comparing fairly closely to the small brachial valve figured by Melou (*op. cit.*, pl. 3, figs. 14-15). Melou does not mention the internal characteristics of this juvenile form, but from the illustrations the cardinal area appears to be very similar to that of the Portuguese specimens which have a simple triangular myophore and not a bilobed myophore as described by Mitchell and Melou for larger specimens.

In the Buçaco area of Portugal Mitchell (*op. cit.*) records *C. ribeiroi* from the lower unit of the Cacemes Formation where it is associated with Didymograptus murchisoni indicating an upper Llanvirn age. In the Amendoa area of Portugal Delgado (1908) records C. ribeiroi from the "Schistes à Didymograptus" where it was also associated with D. murchisoni. In the Dornes area which lies between Buçaco and Amendoa C. ribeiroi occurs in the upper part of the Brejo Fundeiro Formation in the part of the sequence which overlies beds of D. murchisoni Zone age. In Spain Born (1918, p. 316) records abundant specimens of C. ribeiroi in beds which overlie strata containing D. murchisoni and an impoverished fauna including C. ribeiroi. The only other recorded occurrence of C. ribeiroi is from the basal part of the Postolonnec Formation in the Armorican Massif (Melou, op. cit., pp. 694 & 705) where it is associated with D. bifidus and D. murchisoni. The occurrence of C. ribeiroi in the Dornes area is therefore similar to its occurrence elsewhere.

3. Trace Fossils

Ichnogenus CRUZIANA D'Orbigny, 1842

Type ichnospecies. Cruziana rugosa D'Orbigny, 1842

Cruziana goldfussi (Rouault, 1850)

Pl. 33, fig. 3; pl. 35, figs. 1-2.

Age and locality

Arenig, Serra do Brejo Formation, fossil localities 62, 99, 100, 114 and 131.

Material

The material consists of 7 specimens and 4 fragmentary specimens all preserved as hypichnial ridges (Martinsson, 1970, p. 327).

Measurements (mm)

The measurements of the widths of the traces are listed below with the fossil locality number in parantheses; (d) denotes a half measurement doubled: (62), 40 (d); (99), 32 (d); (100), 42 (d); (114), 25, 23, 28, 30, 23; (131), 18, 9, 9.

Description

The collected traces vary in length from 30 to 90mm and in width from 8 to 42mm; in no specimen is the axial termination of the trace visible. The endopodal lobes are well developed to a depth of between 3 and 10mm and the endopodite produced V-shaped markings normally make medial angle of between 10 and 60 degrees, but in some specimens the markings become almost parallel medially. The endopodal lobes are bordered by genal grooves which form the outer margins of the trace; each groove constitutes between 5 and 10 percent the width of the track. The largest specimen from fossil locality 62 has the endopodite scratches in clusters of 2 or 3 possibly suggesting that they were formed by a trilobite with 2 or 3 claws per limb (Seilacher, 1970, p. 450).

Discussion

The preservation of Cruziana goldfussi (Rouault, 1850) as hypichnial ridges, which when they occur on the bottoms of very thin sandstone beds, show no sign of the traces on the upper surfaces of the beds suggests that they were probably formed by the infilling of open burrows. An open burrow origin for Cruziana is convincingly demonstrated by Osgood (1970), Seilacher (1970), Crimes (1970a & 1973) and Baldwin (1977a), but Birkenmajer and Bruton (1971) suggest formation along a sediment - sediment interface. All the above authors are however, unanimous in attributing the production of Cruziana to trilobites. Osgood (op. cit.) records finding trilobites resting on Rusophycus traces and also records Rusophycus occurring at the end of Cruziana. Furthermore both Seilacher (1970) and Crimes (1970) show that Rusophycus, Diplichnites and several styles of Cruziana may be produced by the same animal and conclude it to be a trilobite.

Cruziana goldfussi is common in the basal Ordovician quartzites in Iberia and is recorded in Portugal by Delgado (1885, 1887 & 1908) and Thadeu (1955). In southern Spain C. goldfussi is extensively recorded by Escorza (1977) from the Lower Ordovician (Tremadoc and Arenig) quartzites of the Sierra Morena. In northern Spain this ichnospecies is recorded from the upper Tremadoc and Arenig of the Cabos Series by Baldwin (1975 & 1977a) and by Crimes and Marcos (1976); a similar age range is also given for C. goldfussi by Crimes (1975a, p. 42, table 1). C. goldfussi is also recorded by Baldwin (1977a) from the Crozon Formation in Brittany.

Cruziana aff. goldfussi (Rouault, 1850)

Age and locality

Arenig, Serra do Brejo Formation, fossil localities 23, 60, 62, 98, 99, 100 and 103.

Material

The material consists of three specimens all preserved as hypichnial ridges (Martinsson, 1970, p. 327). The three specimens were collected from fossil locality 60, but other similar specimens were also recorded in the field from the other fossil localities listed above.

Measurements (mm)

The measurements of the widths of the traces are listed below with the fossil locality number in parantheses: (23), 10; (60), 30, 28, 32, 22, 22; (62), 50; (98), 26; (99), 15; (100), 36, 34, 32; (103), 24.

Description

The observed specimens vary in width from 15 to 50mm and are up to 140mm long. The endopodal lobes vary from poor to well developed and no endopodite V-shaped markings have been observed. The bordering genal grooves may each form up to 12 percent the width of the track.

Discussion

The specimens here assigned to *Cruziana* aff. *goldfussi* (Rouault, 1850) were generally found as hypichnial ridges on the bottom surfaces of coarse and poorly cemented quartzites. The moderately friable nature of these quartzites and lack of cement between the grains might explain the lack of fine detail preserved on the endopodal lobes of the traces. Another explanation for the smooth endopodal lobes might be that since coarser grains require faster transporting currents the bare tracks would be eroded by such currents, but not by the slower ones. Crimes (1975b, p. 44) however, presents data showing that "A current depositing even the coarsest sand is unlikely to be fast enough to erode either clay or silt" the usual excavation medium of most *Cruziana*. This data is however for moving water over sediment and fails to take account of the probable "sandblaster" effect caused by sediment laden water currents which might remove fine detail from a trace prior to it being infilled.

It is therefore likely that C. aff. goldfussi is a preservational variant of C. goldfussi.

Cruziana furcifera d'Orbigny, 1842

Pl. 36, figs. 1-2.

Age and locality

Arenig, Serra do Brejo Formation fossil localities 3, 23, 99, 100, 124, 131, 134, 169 and 170.

Material

The material consists of 9 well preserved and 2 fragmentary traces all preserved as hypichnial ridges (Martinsson, 1970).

Measurements (mm)

The measurements of the widths of the traces are listed below with the fossil locality number in parantheses; (d) denotes a half measurement doubled: (3), 30; (23), 23, 32, 38; (99), 29, 10(d), 26; (100), 45; (134), 45; (169), 38; (170), 28, 33.

Description

The collected tracks vary in length from 50 to 160mm and in width from 3.5 to 45mm; in no specimen is an axial termination visible. The endopodal lobes are well developed and vary in depth from 3 to 9mm. The endopodite produced v-shaped markings make a medial angle of between 25 and 35 degrees. In some specimens the markings become more parallel medially, but in others they form a sharp angle. The scratch marks on each endopodal lobe are sub-parallel or criss-cross at an acute angle making them very difficult to separate, but in some of the specimens they are arranged in groups of two or three. In the majority of the specimens the endopodal lobes have no bordering genal grooves, but two specimens (localities 23 & 170) have incomplete genal grooves where the excavation was deep (plate 36, fig. 1) suggesting that C. furcifera and C. goldfussi reflect behavioural patterns of the same animal.

Discussion

Cruziana furcifera is the most common Cruziana ichnospecies found within the study area and is also very abundant in many other places. C. furcifera is recorded from as far afield as Newfoundland (Bergström, 1976), Wales (Crimes, 1968, 1970a & 1975a) Portugal (Delgado, 1885, 1887 & 1908; Thadeu, 1956; Romano & Diggens, 1973-4), Spain (Tamain, 1971; Baldwin, 1975 & 1977; Crimes & Marcos, 1976; Escorza, 1977), Jordan (Selley, 1970) and the Sahara (Beuf et al., 1971). In all these places the occurrence of C. furcifera with or without C. goldfussi is generally taken to indicate an Arenig age for the sequences, but as Baldwin (1975), Crimes (1975a) and Crimes & Marcos (1976) point out C. furcifera ranges into the Tremadoc of northern Spain; it may also occur in the Llanvirn (Seilacher, 1970).

Cruziana sp. indet

Pl. 33, figs. 1-2.

Age and locality

Arenig, Serra do Brejo Formation, fossil localities 24, 60, 62, 98, 99, 100, 114, 123, 127, 169 and 170.

Material

The material conists of 10 specimens with an additional 34 specimens identified in the field. Most of the specimens are preserved as hypichnial ridges on the bottom surfaces of sandstone beds, but several specimens observed at locality 114 are unusually preserved as epichnial grooves partially infilled with sediment (Martinsson, 1970).

Measurements (mm)

The widths of the traces are listed below with the fossil locality number in parantheses:

(24), 10; (60), 10, 12; (62), 49, 25, 50, 15; (98), 45; (99), 13, 12, 29, 32, 17, 20, 31, 30, 9, 18, 16, 3.5; (100), 19, 19, 17, 6, 5, 21, 29, 25, 29, 22, 18, 28, 32, 26, 24, 26, 14; (123), 23; (127), 31; (170), 13.

Description

The traces, both those collected and those measured in the field vary from 3.5 to 50mm in width and lengths up to 50cm have been observed. All the traces are bilobed with no genal grooves and are either smooth or poorly ornamented by scratch-marks similar to those seen on *Cruziana furcifera*. Several of the collected slabs have furrows which undulate in depth and some show tracks which meander and turn. Two slabs show tracks with axial terminations where the trilobite had either started or finished furrowing in the sediment, but the lack of fine surface ornament prevents a conclusion about the direction in which it moved. In addition to the Cruziana two slabs from fossil locality 60 also contain *Rusophycus* trilobite resting traces.

Discussion

The specimens of *Cruziana* sp. indet. in common with *C.* aff. *goldfussi* generally occur in the coarse, poorly cemented quartzites and sandstones. It appears likely that *Cruziana* sp. indet is a preservational variation of *C. furcifera*, but where the fine detail has not been preserved. The reasons for the lack of fine detail are probably the same as those attributed to C. aff. goldfussi described earlier.

Ichnogenus RUSOPHYCUS Hall, 1852

Type ichnospecies. Rusophycus pudicus Hall, 1852.

Rusophycus sp. indet.

Pl. 33, fig. 5.

Age and locality

Arenig, Serra do Brejo Formation, fossil localities 60 and 124.

Material

The material consists of 3 specimens preserved as hypichnial ridges (Martinsson, 1970)

Measurements (mm)

Locality	60	124	124
Length	14	11	13
Maximum width	9.5	9	10
Maximum depth	1.5	2	3

Description

The specimens each consist of two smooth, abaxially convex, coffee-bean shaped lobes divided by a slight furrow. The two samples from locality 124 have lobes which taper slightly towards the rear and in one of the specimens the lobes converge posteriorly at about 10 degrees. The specimen from locality 60 has parallel lobes which do not taper.

Discussion

The specimens of Rusophycus described above have no surface ornament and consequently cannot accurately be assigned to any known ichnospecies. In accordance with current usage and the Treatise on Invertebrate Palaeontology (Häntzschel, 1975) the ichnogenus Rusophycus is used. It must however be noted that Seilacher (1970) considered all traces made by the same animal to be one ichnogenus and consequently preferred to class all Rusophycus ichnospecies as forms of Cruziana. The classification adopted by Seilacher does however, have the marked disadvantage that at a generic level it does not distinguish between furrows (Cruziana) and resting traces (Rusophycus).

That the trace fossil Rusophycus may be produced by a trilobite is beyond doubt and Osgood (1970) illustrates a specimen of Flexicalymene meeki in situ upon a trace of Rusophycus pudicum. The formation of Cruziana by trilobites is also indicated by this occurrence and several traces of Rusophycus concurrent with Cruziana have been described (Osgood, 1970 and Crimes, 1970a). Like Cruziana, Rusophycus appears to be a surface excavation which is infilled and preserved as a hypichnial ridge (Baldwin, 1977a).

Ichnogenus MEROSTOMICHNITES Packard, 1900

Type ichnospecies. Merostomichnites beecheri, Packard, 1900

Merostomichnites sp. indet

Pl. 33, fig. 4; pl. 34, figs. 1-2.

Age and locality

Arenig, Serra do Brejo Formation, fossil locality 114, within unit 11 of the Rio Zêzere measured section (fig. 8).

Material

The material consists of a single specimen preserved as a series of epichnial grooves (Martinsson, 1970) on the top surface of a massive quartzite slab. This slab was impossible to remove and was left in situ. It is located about 4m below high water mark in the south bank of the Rio Zêzere at fossil locality 114, grid reference (18954, 31929).

Description

The trail is 820mm long and extends to the limits of the exposed bedding plane. The left and right sides are approximately parallel, about 135mm apart and the trail describes a gently sinuous curve; there is no obvious dimorphism. The true right side of the trail consists of at least 40 imprints, but only about 10 are preserved on the left side. Individual imprints reach 24mm in length (trans.) and always show a composite structure consisting of up to 5 tooth-like impressions evenly spaced along the length. The imprints are irregularly spaced at intervals from 9 to 22mm apart. The imprints are consistently deeper and more sharply defined along one edge which is taken to be the anterior edge (Savage, 1971 p. 221).

Discussion

The lack of dimorphism suggests that the trail may be classified as the straight-ahead type where the antero-posterior axis of the animal was aligned parallel to the direction of movement (Osgood, 1970). The relatively simple trail suggests either an animal with few walking appendages, or an animal in which only some of the appendages were used in locomotion. It is not clear how many pairs of appendages were used to produce the trail since no obvious repetition or series could be recognised, however, it is possible that as few as four pairs is a likely number.

The composite nature of each imprint suggests that each walking limb was either polydactylous or bore, along its distal length, a row of spines. The depth to which the imprints are preserved suggests setae or 'hairs' could not have been responsible for the tooth-like impressions and it is more likely that short, strong spines were present. Since it is uncommon for all five impressions along the imprint to be preserved, it is probable that the animal frequently used only the distal ends of the appendages to support the body, and occasionally during a 'series' (Osgood, 1970) some limbs barely made contact with the sediment and produced a trace of delicate scratch marks from the downward projecting spines.

The direction of movement was from south to north which is almost exactly opposite to the bottom water currents which produced the asymmetric ripples over which the trail was made (the movement was from bottom to top in plate 33, figure 4 and plate 34, figure 1.

The formation of the trace by an animal with mult-clawed walking legs suggests that it was formed by an arthropod; a trilobite or eurypterid appear to be the most likely candidates.

Ichnogenus PLANOLITES Nicholson, 1873

Type ichnospecies. Planolites vulgaris Nicholson, 1873

Planolites cf. virgatus (Hall, 1847)

Pl. 33, fig. 6.

Age and locality

Arenig, Serra do Brejo Formation, fossil locality 23, and fossil locality 114 within unit 13 of the Rio Zêzere measured section (fig. 8).

This ichnospecies was also observed on a detached slab near fossil locality 114 (plate33, fig.6). All the specimens are preserved on the bottom surfaces of sandstone beds as hypichnial ridges (Martinsson, 1970).

Material

The material consists of one trace collected at fossil locality 23; other specimens were observed in the field, but were impossible to collect.

Description

The collected trace measures 100mm long and is sub-elliptical to rounded in cross-section with a diameter of between 18 and 21mm. The burrow is unbranched, has a smooth surface, and no internal structures have been seen. More complete traces have been observed in the field at fossil locality 114 where they are sinuous, between 15 and 20mm in diameter and up to 800mm long. The specimens on the loose slab nearby are between 13 and 15mm in diameter and up to 400mm long.

Discussion

Although the traces are preserved as hypichnial ridges, they are sometimes only loosely attached to the bottom surfaces of the beds and represent infills of actual burrows not casts of furrows like Cruziana. Alpert (1975, p. 518) gives a description and synonymy of Planolites virgatus (Hall, 1847) and the Portuguese specimens agree fairly well with this, but are slightly more rounded in cross-section. Häntzschel (1975, p. W95) however, notes that Planolites burrows may be cylindrical or sub-cylindrical in cross-section, but only up to 15mm in diameter; in contrast to this Crimes (1976, p. 63) describes Planolites up to 30mm wide and the Portuguese material fits within these parameters.

The presence of Planolites has little environmental significance and Crimes (op. cit.) notes that "Planolites has been recorded from all marine facies".

Ichnogenus SKOLITHOS Haldeman, 1840

Type ichnospecies. Skolithos linearis Haldeman, 1840

Skolithos linearis Haldeman, 1840

Pl. 2, fig. 1.

Age and locality

Arenig, Serra do Brejo Formation, fossil localities 61, 63, 64, 65, 69 and 128.

Material

The material consists of 6 specimens and field photographs of material from localities 61, 63, 64 and 128. The specimens occur as endichnia (Martinsson, 1970), but the casting medium is generally similar to that of the sediment in which they are formed.

Description

The burrows are cylindrical to sub-cylindrical with a diameter of between 3 and 8mm; they range in length up to 120mm long. The burrows are usually straight and perpendicular to the bedding, but are occasionally slightly curved. All the burrows observed in the field were unbranched and no terminations to any of them were seen; the collected specimens are similar. The density of the burrows varies between 300 and 2,500 per square metre.

Discussion

Alpert (1974) reviewed the ichnogenus Skolithos Haldeman, 1840 and suggested that all vertical burrows which are straight and cylindrical, between 3 and 12mm in diameter, should be included in the ichnospecies Skolithos linearis Haldeman, 1840. In common with Hallam & Swett (1966), Alpert (op. cit.) considered that factors such as the density of the burrows are not diagnostic features of the ichnospecies.

Seilacher (1967) considered that Skolithos is a typical ichnogenus of the littoral zone. Crimes (1970a & 1973) however showed that Skolithos may occur in neritic or even bathyal conditions, but the numbers of individuals will be small, and abundant closely spaced burrows (Crimes, 1976) indicate the littoral environment suggested by Seilacher (op. cit.). In the Dornes area the occurrence of S. linearis in the middle part of the Serra do Brejo Formation, overlying a sequence of transgressive conglomerates, is in accordance with the palaeo-environmental situation for Skolithos indicated by Seilacher (op. cit.); furthermore the Skolithos facies is overlian by Cruziana bearing sand-stones which Seilacher considers to be indicative of slightly deeper water. The Serra do Brejo Formation is therefore shown to be a transgressive sequence, and gradually increasing water depth may be inferred.

Skolithos sp. or S. linearis have been widely recorded from the basal Ordovician (Arenig) quartzites and sandstones of Portugal (Delgado, 1908; Romano & Diggens, 1973-4; Romano, 1974), Spain (Escorza, 1977), Brittany (Babin et al., 1976), north Africa (Beuf et al., 1971) and Wales (Crimes, 1970a & 1970b). In most of these occurrences the Skolithos facies is overlain by a Cruziana facies; the typical sequence indicated by Seilacher (op. cit.). Romano (1974), however, recorded a sequence in northern Portugal where the Skolithos facies overlies the Cruziana facies. In addition to this, personal observations of a loose block from the vicinity of Salamanca, central Spain, show that Cruziana and Skolithos may occur together on the same bedding plane.

Ichnogenus ARTHROPHYCUS Hall, 1852

Type ichnospecies. Arthrophycus harlani Conrad, 1838

Arthrophycus sp. indet

Pl. 36, fig. 3.

Age and locality

Arenig, Serra do Brejo Formation, fossil locality 99.

Material

One incomplete burrow occurring as a hypichnial ridge (Martinsson, 1970) on the bottom surface of a sandstone bed.

Description

The preserved part of the specimen is 40mm long and varies from 12 to 18mm in diameter. The burrow is sub-cylindrical and runs horizontally along the base of the sandstone. The burrow is poorly preserved, but a well developed ornament consisting of fairly regular annulae (each about 1mm wide) occurs over about one-fifth the length of the burrow. The remainder of the burrow has been worn almost smooth, but slight traces of the ornament still exist. Several sub-parallel grooves run along the length of the burrow.

Discussion

The specimen described above is very similar to the ichnogeneric description of Arthrophycus given in the Treatise on Invertebrate Palaeontology (Häntzschel, 1975). In Portugal Delgado (1885, p. 75, pl. XXXV) records 'Arthrophycus cf. Halani Hall' from south of the Dornes area at Mação. Compared with his illustration the fragmentary specimen from Dornes is very similar, except that it has more closely spaced annular rings than the specimen from Mação. Selley (1970) records Halania from the Arenig sandstones of Jordan; this ichnogenus is now regarded as a junior synonym of Arthrophycus (Häntzschel op. cit.). The specimen figured from Jordan (Selley, op. cit., pl. 2, fig. b) is also similar to the material from the Dornes area, but in common with that from Mação it has less annular rings.

The specimen of Arthrophycus sp. is preserved as a hypichnial ridge on the bottom surface of a sandstone bed, but it is only loosely attached and appears to be an infilled burrow formed along the interface between the sand above and the silt or clay below. In the Dornes area Arthrophycus sp. occurs within the Cruziana facies; it also occurs in in similar facies both near Mação and in Jordan.

Ichnogenus PALAEOPHYCUS Hall, 1847

Type ichnospecies. Palaeophycus tubularis Hall, 1847.

Palaeophycus sp. indet.

Pl. 37, fig. 1.

Age and locality

Lower to Middle Caradoc, fossil locality 195 within the Monte do Carvalhal Formation, approximately 5m below the base of the Serra da Cadaveira Member. Ludlow, fossil localities 49 and 50 within the Serra da Mendeira Formation.

Material

The material consists of 3 samples with 6 burrows preserved as hypichnial ridges (Martinsson, 1970) on the bottom surfaces of the slabs.

Description

The burrows are cylindrical to sub-cylindrical in cross-section, between 4 and 14mm in diameter, and up to 100mm long. The burrows are sub-parallel to the bedding and occasionally branch at angles of between 30 and 100 degrees, but branching at about 70 degrees is most common; both Y and T-shaped branching occurs. Where the burrows branch both limbs are of similar diameter, but interference and crossing by different sized burrows also occurs. In no specimens have the axial terminations of the burrows been observed. The walls of the burrows are generally smooth, but some show signs of burrow collapse or are slightly flattened into an ovoid profile.

Discussion

The burrows are preserved as hypichnial ridges (Martinsson, 1970), but in some instances are only loosely attached to the overlying sandstone and appear to represent burrows along the sand - mud interface. The ichnogenus Palaeophycus is considered by the Treatise on Invertebrate Palaeontology (Häntzschel, 1975) to consist of smooth, branched and unbranched, cylindrical burrows which are 3 to 15mm in diameter. Alpert (1975) however, separated Planolites from Palaeophycus stating that: "A more useful criterion for differentiation is the presence or absence of true branching. Branched burrows are Palaeophycus, unbranched, Planolites". Using these criteria the Portuguese material is best assigned to the ichnogenus Palaeophycus. Alpert (op. cit.) revised the genus Planolites and in doing so reduced the number of probable Palaeophycus ichnospecies to thirty, two, the majority of which are described in obscure and ancient papers. It thus appears that the ichnogenus is badly in need of revision.

In the Dornes area Palaeophycus occurs both in the Caradoc and the Ludlow, but the occurrence of the same trace fossil at widely separated horizons is not an unusual situation because similar burrows may be made by entirely different animals (Seilacher, 1967). Palaeophycus is also recorded from the Bathonian of Dorset where its formation is attributed to annelids (Hallam, 1970) and from the Eocene and Miocene of Poland (Ksiazkiewicz, 1970). Palaeophycus does not appear to be restricted to any particular ichnofacies.

Ichnogenus MONOCRATERION Torell, 1870

Type ichnospecies. Monocraterion tentaculatum Torrell, 1870

Monocraterion sp. indet.

Pl. 37, fig. 2.

Age and Locality

Ludlow, Serra da Mendeira Formation, fossil localities 49, 87 and 196.

Material

The material consists of 4 specimens with the burrows perserved as endichnia (Martinsson, 1970). In most of the specimens the fill of the burrows is silty mudstone and the host rock is quartzite.

Description

The burrows are vertical to sub-vertical, straight to slightly curved and of conical section. The burrows are up to 50mm long and 12mm wide at the top, tapering evenly downwards to 1mm at the bottom; a few of the burrows are very slightly flared at the top. One specimen from locality 87 has faint striae which run along the length of the burrow and the specimen from locality 49 shows that the bedding lamination in the quartzite is warped donwards adjacent to the burrows. The internal structure of the burrows consists of a straight central column which has a diameter of between 20 and 50% that of the burrow. The central column in most of the specimens is infilled with quartz sand which contrasts with the siltstone infilling the remainder of the burrow.

Discussion

The specimens of Monocraterion sp. indet. described above are similar to the description of the ichnogenus given in the Treatise on Invertebrate Palaeontology (Häntzschel, 1975); their size, trumpet shape and central column are all typical of the ichnogenus. The downward warping of the bedding planes adjacent to the burrows suggests that they were formed by the upward migration of the inhabiting organism during active sedimentation. Hallam & Swett (1966) suggested that Monocraterion and Skolithos burrows in Scotland were produced by the same burrowing animal. In the Dornes area of Portugal the two ichnospecies are however stratigraphically separated; Skolithos has so far only been found in the Serra do Brejo Formation and Monocraterion in the Serra da Mendeira Formation.