Table 4.1

Location, grid reference and associated literature	General description and lithology
1. Fewston (Disused Quarry) Outcrops 1.1-1.6: SE 18479 54821 Wilson, A.A. (1977) The Namurian Rocks of the Fewston Area. *Transactions of the Leeds Geological Association*, 9, No. 1, 1-42.	Disused quarry with extensive grass cover displaying fragmented sandstone outcrops with variable texture; poorly defined foresets, sets and cosets, due to the processes of weathering and erosion. Elevation of central outcrop is ~188 m O.D.; main outcrop view is towards 360˚ (Fig. 4.4 Location 1). Outcrops 1.1-1.6: Coarse-grained to granular sandstone, predominantly quartz grains; highly spherical; sub-rounded; moderately to well sorted.

Identified sub-Facies, sedimentary structures and bounding surfaces of note

Outcrop 1.1 [~0.6 m (H)]: **1.** *Sl-hpx <2.0 m (Sp); low to high-angle-inclined foresets forming medium-scale planar cross-bedding; ~0.60 m thick set;

Outcrop 1.2 [~0.4 m (H)]: **1.** *Sl-hpx <2.0 m (Sp); low to high-angle-inclined foresets forming medium-scale planar cross-bedding; ~0.40 m thick set;

Outcrop 1.3 [~1.3 m (H)]: **1.** Stsx <1.5 m (St); small to medium-scale cross-cutting trough cross-bedding <1.5 m trough width; poorly defined ~0.50 m thick set; **2.** *Ss-lp-lag (Gh); small to large pebble lag deposit; ~0.02 m thick; likely forms base of overlying set (in part) and fifth-order bounding surface; 3. *Sl-hpx <2.0 m (Sp); low to high-angle-inclined foresets forming medium to large-scale planar cross-bedding; ~0.75 m thick set;

Outcrop 1.4 [~1.5 m (H)]: **1.** *Stsx <1.5 m (St); small to medium-scale cross-cutting trough cross-bedding <1.5 m trough width; ~0.36 m thick set; **2.** *Sl-hpx <2.0 m (Sp); low to high-angle-inclined foresets forming large-scale planar cross-bedding; ~1.10 m thick set;

Outcrop 1.5 [~1.0 m (H)]: **1.** *Sl-hss <1.0 m (Sl); low to high-angle-inclined foresets forming ~0.09 m thick sub-horizontal set of planar cross-bedding;

Outcrop 1.6 [~1.25 m (H)]: **1.** *Ss-lp-lag (Gh); small to large pebble lag deposit; ~0.02 m thick; likely forms base of overlying set (in part) and fifth-order bounding surface; **2.** *Sl-hpx <2.0 m (Sp); low to high-angle-inclined foresets forming medium-scale planar cross-bedding; ~0.52 m thick set; **3.** ~0.30 m thick coset of *Sl-hss <1.0 m (Sl); low to high-angle-inclined foresets forming ~0.10 m thick sub-horizontal sets of small-scale (<1.5 m) trough cross-bedding, poorly defined.

Interpretation

Outcrops 1.1-1.6 likely represent a relatively broad and deep laterally stacked channel fill elements displaying predominantly westerly palaeocurrents (Fig. 4.4 Location 1). Lag deposits (Ss-lp-lag) likely represent basal flood deposits and high-flow stage (cf. Coleman, 1969; Bristow, 1987, 1993a; Ashworth et al., 2011). Lag deposits may also denote the location of channel thalweg/axial regions (Fidolini et al., 2013; Ghinassi et al., 2014), where relatively larger bedforms develop (Reesink & Bridge, 2009; Ashworth et al., 2011; Reesink et al., 2014). Facies Sl-hpx <2.0 m likely represent net sediment (dune) deposition during falling-flow stage (cf. Coleman, 1969; Bristow, 1987, 1993a; Ashworth et al., 2011) for sets <1.0 m, or either downstream migration of a transverse bar (2D macroform, part of) (cf. Smith, 1972), or a lobate unit bar component (2D mesoform, part of) (cf. Bridge & Lunt, 2006; Ashworth et al., 2011); a set thickness ≥1.00 m likely denotes unit bars, rather than dunes (Bridge & Lunt, 2006). Similarly, Sambrook Smith *et al*. (2006) interpret sets >0.5 m, which possess inclined (i.e. ≤ angle-of-repose) cross-stratification, as a consequence of bar migration.

The preserved set thickness of ~1.10 m for facies Sl-hpx <2.0 m suggests that the maximum barform thickness was ~3.30 m (cf. Leclair, 2011). Therefore, given that bar heights may adjust between half and bankfull depth, the depth of host channel was probably between 3.30 m and 6.60 m, respectively (cf. Bristow, 1987; Bridge, 2003; Reesink et al., 2014). Such facies may also account for localised thalweg migration and alterations in flow direction (Fig. 4.4 Location 1); cf. Coleman, 1969; Bristow, 1987; Ashworth et al., 2011). Facies Stsx <1.5 m and Sl-hss <1.0 m likely represent downstream or lateral-accretion of 3D and 2D mesoforms, respectively, within a relatively shallow thalweg region of a low sinuosity channel (cf. Bristow, 1988, 1993a; Ghinassi et al., 2009; Miall, 2010b; Reesink et al., 2014), or deposition may have been related to bar top vertical-accretion of a channel bar, primarily due to dune stacking and relative shallow flow depth above the host bar (cf. Best et al., 2003; Bridge & Lunt, 2006; Sambrook Smith et al., 2006). Similarly, preservation of consecutive cross-laminated sets inevitably encompasses a measure of net deposition and subject to the inclination of their host bed most sets will climb at a similar angle (Leeder, 1982).

Table 4.2

Location, grid reference and associated literature	General description and lithology
2. Sandy Gate Road (Disused Quarry) Outcrop 2.1: SE 15120 59230 Wilson, A.A. (1977) The Namurian Rocks of the Fewston Area. *Transactions of the Leeds Geological Association*, 9, No. 1, 1-42.	Rough pasture with evidence of landfill probably at the location of a former quarry; only evidence of the Lower Brimham Grit is a small partly exposed block at grid reference SE 15120 59230, probably a remnant of disused quarry. Elevation of Outcrop 2.1 is ~280 m O.D.; main outcrop view is towards 250˚ (Fig. 4.4 Location 2). Outcrop 2.1: Coarse to very coarse-grained sandstone with 2-5% granule content (variable), predominantly quartz grains; highly spherical; sub-rounded; moderately to well sorted.

Identified sub-Facies, sedimentary structures and bounding surfaces of note

Outcrop 2.1 [~1 (H) x 1 (D) x 2 m (W)]: **1.** *Stmx 1.5-3.0 m (St); medium-scale trough cross-bedding 1.5–3.0 m trough width; shallow trough profile; ~0.50 m thick set (trough) with poorly defined foresets.

Interpretation

Although limited, Outcrop 2.1 likely represents the south-westerly migration (Fig. 4.4 Location 2) and subsequent deposition of medium-scale 3D mesoforms likely facilitated by a flood event (rising-flow stage) and associated falling-flow stage, respectively (Coleman, 1969; Bristow, 1987, 1993a; Ashworth et al., 2011). The size of cross-bedding implies downstream-accretion within a relatively broad and deep channel with dune migration near to the channel thalweg/axis; large dunes tend to develop towards deeper channel thalweg regions within relatively broad/deep channels (cf. Reesink & Bridge, 2009; Ashworth et al., 2011; Reesink et al., 2014).

Table 4.3

Location, grid reference and associated literature	General description and lithology
3. Nell Stones Outcrops 3.1: SE 14708 59309 3.2: SE 14644 59282 Hudson, R.G.S. (1937) The Millstone Grit succession of the Simonseat Anticline, Yorkshire. *Proceedings of the Yorkshire Geological Society*, 23, 319-349.	Randomly distributed sandstone outcrops with variable texture located along the crest and flanks of a hillside which forms a topographic high. Two outcrops examined, both with poor outcrop detail (e.g. foreset/sets), due to the processes of weathering and erosion. Possibility that examined outcrops may have been subjected to cambering which would influence azimuth-dip angles. Elevation of Outcrops 3.1 and 3.2 is ~271 m O.D.; main outcrop view is towards 180˚ (Fig. 4.4 Location 3). Outcrops 3.1-3.2: Coarse-grained to granular sandstone with ~2% small pebble content (variable), predominantly quartz grains; highly spherical; sub-rounded; moderately to well sorted.

Identified sub-Facies, sedimentary structures and bounding surfaces of note

Outcrop 3.1 [~2 (H) x 3 (D) x 3 m (W)]: **1.** ~2.00 m thick coset of *Stsx <1.5 m (St); small to medium-scale cross-cutting trough cross-bedding <1.5 m trough width with variable up to ~0.30 m thick troughs exhibiting signs of de-watering i.e. flame structures, soft sediment deformation (facies Ssd); set bounding surfaces are poorly defined and appear sub-horizontal; base of coset forms a sub-horizontal and irregular contact with underlying set;

Outcrop 3.2 [~2 (H) x 3 (D) x 2.5 m (W)]: **1.** ~1.40 m thick coset of *Sl-hss <1.0 m (Sl); low to high-angle-inclined foresets forming ~0.15 m thick sub-horizontal sets; **2.** *Sl-hpx <2.0 m (Sp); low to high-angle-inclined foresets forming large-scale planar cross-bedding; ~1.00 m thick set exhibiting signs of de-watering i.e. dish and flame structures, soft sediment deformation (facies Ssd).

Interpretation

Outcrop 3.1: Predominantly north to north-westerly (Fig. 4.4 Location 3) downstream migration of 3D mesoforms which may have formed along the crest or front/tail of a migrating bar (macroform) (cf. Allen, 1982; Haszeldine, 1983b; Miall, 2010b; Ashworth *et al.*, 2011). Dune height (~1.10 m) implies moderate sediment input into a relatively deep channel (~3.20 m deep) subjected to turbulent flow conditions, likely influenced by high-flow stage which facilitated dune migration and the formation of down-climbing dunes (cf. Bristow, 1988, 1993a; Reesink & Bridge, 2009; Ghinassi, 2011); collectively such mesoforms may form unit bars (cf. Sambrook Smith *et al.*, 2006; Reesink & Bridge, 2009). Evidence of soft sediment deformation (i.e. dish and flame structures, facies Ssd) implies loss of grain stability (liquefaction) within unconsolidated water laden sediments, probably facilitated by sudden overburden through rapid sediment deposition post flood and/or syn-sedimentary tectonic activity post deposition (cf. Barnhardt & Sherrod, 2006; Hubert-Ferrari *et al.*, 2017).

Outcrop 3.2: The north-westerly (Fig. 4.4 Location 3) downstream migration of stacked sets (facies Sl-hss <1.0 m) likely indicate recurring bedform migration, probably as a train of dunes over the crest or front/tail of a larger bar (macroform) (cf. Allen, 1982; Haszeldine, 1983b; Miall, 2010b; Ashworth *et al.*, 2011), thereby forming components of a larger host dune coset (cf. Haszeldine, 1983b). A cumulative coset thickness of ~1.40 m indicates a maximum unit bar/dune height and channel depth of ~1.80 m and ~3.60 m, respectively (cf. Reesink & Bridge, 2009; Leclair, 2011). Individual set thicknesses (~0.15 m) suggest limited sediment input (i.e. dune height of ~0.50 m) into a relatively shallow channel (~1.60 m deep), likely influenced by high-flow stage which facilitated the formation of down-climbing dunes (cf. Bristow, 1988, 1993a; Reesink & Bridge, 2009; Ghinassi, 2011). Subsequent deposition of facies Sl-hpx <2.0 m likely represent net sediment deposition during falling-flow stage (cf. Coleman, 1969; Bristow, 1987, 1993a; Ashworth *et al.,* 2011) of a lobate unit bar (3D mesoform) (cf. Bridge & Lunt, 2006; Ashworth *et al.*, 2011); a set thickness ≥1.00 m likely denotes unit bars (Bridge & Lunt, 2006). Similarly, Sambrook Smith *et al.* (2006) interpret sets >0.5 m, which possess inclined (i.e. ≤ angle-of-repose) cross-stratification, as a consequence of bar migration. A preserved set thickness of ~1.00 m suggests a maximum barform thickness of ~3.00 m (cf. Leclair, 2011) and depth of host channel of between 3.00 m and 6.00 m, respectively (cf. Bristow, 1987; Bridge, 2003; Reesink *et al*., 2014). Evidence of soft sediment deformation (i.e. dish and flame structures, facies Ssd), see above interpretation.

Table 4.4

Location, grid reference and associated literature	General description and lithology
4. Far Comb Hill Outcrops 4.1-4.3: SE 13910 59371 Hudson, R.G.S. (1937) The Millstone Grit succession of the Simonseat Anticline, Yorkshire. *Proceedings of the Yorkshire Geological Society*, 23, 319-349. Reid, C. T. (1996) *The Alportian and Kinderscoutian (Namurian) of North Yorkshire: the sedimentary response to eustatic variation.* Unpublished Doctoral thesis, University of Keele.	Three main outcrops are situated down and along the relatively steep north western flank of Far Comb Hill. The outcrops possess variable texture and outcrop detail (e.g. foresets/sets) is generally poor, due to the processes of weathering and erosion. Examined outcrops may have been subjected to cambering, which together with the effects of jointing may have influenced azimuth-dip angles. Elevation of central outcrop is ~240 m O.D.; main outcrop view is towards 110˚ (Fig. 4.4 Location 4). Outcrops 4.1-4.3: Coarse-grained to granular sandstone with ~2% small pebble content (variable), predominantly quartz grains; highly spherical; sub-rounded; moderately to well sorted.

Identified sub-Facies, sedimentary structures and bounding surfaces of note

Outcrop 4.1 [Lower section; ~4 (H) x 4 (D) x 4 m (W)]: **1.** ~2.50 m thick coset group of *Sl-hss <1.0 m (Sl); low to high-angle-inclined foresets forming <1.0 m thick sub-horizontal sets; cosets vary in thickness from 0.50-0.75 m; sets vary in thickness from 0.15–0.25 m; probably small to medium-scale (<1.5 m) trough cross-bedding, poorly defined; **2.** ~0.40 m thick coset of Sl-hss <1.0 m (Sl); low to high-angle-inclined foresets forming ~0.10 m thick sub-horizontal sets; probably small-scale (<1.5 m) trough cross-bedding, poorly defined; **3.** Sl-hpx <2.0 m (Sp); low to high-angle-inclined foresets forming medium to large-scale planar cross-bedding; ~0.70 m thick set;

Outcrop 4.2 [Central section; ~5 (H) x 4 (D) x 6 m (W)]: **1.** *Sl-hhs <1.0 m (Sh); low to high-angle-inclined foresets forming ~0.70 and 0.80 m thick horizontal sets of planar cross-bedding with evidence of reactivation surfaces; **2.** *Ss-lp-lag (Gh); small to large pebble lag deposit; intermittent lag deposit ~0.02 m thick; likely forms base of overlying coset (in part); **3.** ~3.60 m thick coset group of *Sl-hss <1.0 m (Sl); low to high-angle-inclined foresets forming <0.20 m thick sub-horizontal sets; ~0.50, 0.50, 1.10, 0.80 and 0.60 m thick cross-cutting cosets; <0.20 m thick sets likely represent small-scale (<1.5 m) trough cross-bedding, poorly defined; **4. ***Stsx <1.5 m (St); small to medium-scale cross-cutting trough cross-bedding <1.5 m trough width; ~0.50 m thick down-climbing trough set; **5.** ~0.30 m thick coset of *Sl-hhs <1.0 m (Sh); low to high-angle-inclined foresets forming ~0.10 m thick horizontal sets of small-scale (<1.5 m) trough cross-bedding, poorly defined;

Outcrop 4.3 [Upper section; ~1.5 (H) x 2 (D) x 4 m (W)]: **1.** *Sl-hpx <2.0 m (Sp); low to high-angle-inclined foresets forming large-scale planar cross-bedding; ~1.10 m thick set; **2.** *Sl-hpx <2.0 m (Sp); low to high-angle-inclined foresets forming small to large-scale planar cross-bedding; ~0.40 m thick set; **3.** ~0.20 m coset of *Sl-hhs <1.0 m (Sh); low to high-angle-inclined foresets forming ~0.10 m thick horizontal sets of small-scale (<1.5 m) trough cross-bedding, poorly defined.

Interpretation

Outcrop 4.1: Although palaeocurrent measurements are limited, sediment deposition appears to have been influenced by south-easterly palaeocurrents towards the base of the outcrop (Fig. 4.4 Location 4). The variable thickness and sub-horizontal sets associated with facies Sl-hss <1.0 m imply variable sediment input, flow velocity and downstream-accretion, respectively, of 3D mesoforms (cf. Coleman, 1969; Bristow, 1987, 1993a; Collinson *et al.*, 2006; Ashworth *et al.,* 2011). Individual sets may also form components of a larger host dune coset (cf. Haszeldine, 1983b). Facies Sl-hpx <2.0 m implies sediment deposition was influenced by increasing channel depth likely facilitated by a flood event (high-flow stage) and subsequent net sediment (dune) deposition during waning flow (low-flow stage) (cf. Coleman, 1969; Bristow, 1987, 1993a; Ashworth *et al.,* 2011).

Outcrop 4.2: Variable south-westerly foreset azimuth-dips associated with facies Sl-hhs <1.0 m (Fig. 4.4 Location 4) implies that the base of the outcrop was likely formed by transverse bars (2D macroforms) (cf. Smith, 1972) that may form a continuation of Outcrop 4.1, although such bar heights coincide with dune heights (Ashworth *et al.*, 2011). The intermittent lag deposit (Ss-lp-lag) likely represents scouring (Miall, 2010b) or winnowing (cf. Collinson *et al.,* 2006) processes with no obvious evidence of a fifth-order channel surface. Variable southerly to westerly palaeocurrents associated with Sl-hss <1.0 m (Fig. 4.4 Location 4) implies downstream migration of stacked sets (3D mesoforms) which indicate recurring bedform migration probably as a train of laterally-accreting dunes over the front/tail of a larger bar (macroform) (cf. Allen, 1982; Haszeldine, 1983b; Bristow, 1993b; Miall, 2010b; Ashworth *et al.*, 2011); individual sets may also form components of a larger host dune coset (cf. Haszeldine, 1983b). A dune height of ~0.70 m implies limited sediment input into a relatively deep channel (~2.20 m deep) likely influenced by high-flow stage which facilitated the formation of down-climbing dunes; facies Stsx <1.5 m also suggests downstream dune migration (cf. Bristow, 1988, 1993a; Reesink & Bridge, 2009; Ghinassi, 2011). Relatively shallow channel conditions (~1.10 m deep) associated with facies Sl-hhs <1.0 m implies waning flow, aggradation of 3D mesoforms and channel fill (cf. Cant & Walker, 1976; Ashworth *et al.*, 2011; Reesink *et al.*, 2014).

Outcrop 4.3: Facies Sl-hpx <2.0 m implies substantial increase in channel depth and net sediment input, likely facilitated by a flood event with sediment migration and aggradation influenced by high and low-flow stages, respectively (Coleman, 1969; Bristow, 1987, 1993a; Ashworth *et al.,* 2011). The size of cross-bedding (~1.10 m thick set) implies either downstream migration of a transverse bar (2D macroform, part of) (cf. Smith, 1972), or a lobate unit bar component (2D mesoform, part of); a set thickness ≥1.00 m likely denotes unit bars, rather than dunes (Bridge & Lunt, 2006). Similarly, Sambrook Smith *et al.* (2006) interpret sets >0.5 m, which possess inclined (i.e. ≤ angle-of-repose) cross-stratification, as a consequence of bar migration. The predominantly westerly palaeocurrents (Fig. 4.4 Location 4) may have been generated by net sediment deposition during falling-flow stage causing localised thalweg migration and alterations in flow direction (cf. Coleman, 1969; Bristow, 1987; Ashworth *et al.*, 2011). Alternatively, fault/tectonic (syn-sedimentary) activity and/or subsidence along the North Craven Fault may have influenced palaeocurrents through lateral tilting (cf. Kane *et al.*, 2010; Fidolini *et al.*, 2013). Subsequent facies Sl-hpx <2.0 m and Sl-hhs <1.0 m likely represent a gradual decrease in the channels flow and sediment load capacity, influenced by a waning flow and channel fill (cf. Cant & Walker, 1976; Ashworth *et al.*, 2011; Reesink *et al.*, 2014). Stacked sets separated by first-order set boundaries indicate repeated bedform migration probably as a train of dunes over a larger bar surface (Miall, 2010b; cf. Ashworth *et al.*, 2011). Similarly, preservation of consecutive cross-laminated sets inevitably encompasses a measure of net deposition and subject to the inclination of their host bed most sets will climb at a similar angle (Leeder, 1982). Further, although limited in number, the shallow inclined (≤13°) first-order and second-order bounding surface dips, relating to Location 4, may correspond to channels possessing high width to depth ratios (cf. Bristow, 1993a).

Table 4.5

Location, grid reference and associated literature	General description and lithology
5. Hood Crag Outcrops 5.1-5.3: SE 13594 59221 Reid, C. T. (1996) *The Alportian and Kinderscoutian (Namurian) of North Yorkshire: the sedimentary response to eustatic variation.* Unpublished Doctoral thesis, University of Keele.	Three main outcrops form a ~35 m broken line of irregular and blocky/jointed sandstone crags in open moorland along the north eastern flank of Whit Moor. The crags appear to form part of a line of intermittent outcrops that extend across the valley towards the disused quarry at Location 2. Outcrop components examined moving from the eastern (left) to the western (right) section of the outcrop, in a general line trending ~060˚ towards 240˚, which extends for ~35 m. Examined outcrops possess variable texture and outcrop detail (e.g. foresets/sets) is generally poor, due to the processes of weathering and erosion. Elevation of central outcrop is ~260 m O.D.; main outcrop view is towards 160˚ (Fig. 4.4 Location 5). Outcrops 5.1-5.3: Coarse-grained to granular sandstone with ~2% small pebble content (variable), predominantly quartz grains; highly spherical; sub-rounded; moderately to well sorted.

Identified sub-Facies, sedimentary structures and bounding surfaces of note

Outcrop 5.1 [Eastern section; ~3 (H) x 3 (D) x 4 m (W)]: **1.** ~1.70 m thick coset of *Stmx 1.5-3.0 m (St); medium-scale cross-cutting trough cross-bedding 1.5–3.0 m trough width; variable set thickness from 0.35–0.50 m and irregular sharp contacts; **2.** ~1.40 m coset of *Sl-hss <1.0 m (Sl); low to high-angle-inclined foresets forming 0.10–0.15 m thick sub-horizontal sets; poorly defined;

Outcrop 5.2 [Central section; ~3 (H) x 3 (D) x 4 m (W)]: **1.** ~0.80 m coset of inferred Sl-hss <1.0 m (Sl); low to high-angle-inclined foresets forming 0.10–0.15 m thick sub-horizontal sets; very poorly defined; **2.** ~1.50 m coset of *Sl-hss <1.0 m (Sl); low to high-angle-inclined foresets forming 0.10–0.15 m thick sub-horizontal sets; poorly defined; **3.** ~1.30 m coset of *Sl-hss <1.0 m (Sl); low to high-angle-inclined foresets forming 0.10–0.15 m thick sub-horizontal sets; poorly defined;

Outcrop 5.3 [Western section; ~2 (H) x 1 (D) x 3 m (W)]: **1.** ~0.40 m coset of Sl-hss <1.0 m (Sl); low to high-angle-inclined foresets forming 0.10–0.15 m thick sub-horizontal sets; poorly defined; **2.** ~0.90 m coset of *Sl-hss <1.0 m (Sl); low to high-angle-inclined foresets forming 0.10–0.15 m thick sub-horizontal sets; poorly defined; **3.** ~0.50 m coset of Sl-hss <1.0 m (Sl); low to high-angle-inclined foresets forming 0.10–0.15 m thick sub-horizontal sets; poorly defined.

Interpretation

Predominantly south to south-westerly (Fig. 4.4 Location 5) migratory bedforms that likely developed within a relatively shallow channel (cf. Ashworth *et al.*, 2011), possibly on the surface of a larger sand flat (cf. Cant & Walker, 1976, 1978). Alternatively, although slightly sub-horizontal, the cosets of facies Sl-hss <1.0 m may represent the downstream migration of small-scale unit bars (cf. Sambrook Smith *et al.*, 2006; Reesink & Bridge, 2009) and the latter stages of a channel fill sequence (cf. Reesink *et al.*, 2014), possibly influenced by high-flow stage which facilitated the formation of down-climbing dunes (cf. Bristow, 1988, 1993a; Reesink & Bridge, 2009; Ghinassi, 2011). Such bedforms are also associated with a series of distinct depositional episodes (cf. Collinson *et al.,* 2006) of assembled sets divided by first-order set boundaries which indicate repeated bedform migration probably as a train of dunes (dune stacking) which may have formed components of a channel bar top (cf. Bristow, 1993b; Best *et al.*, 2003; Bridge & Lunt, 2006; Mumpy *et al*., 2007; Miall, 2010b; Ashworth *et al.*, 2011); preservation of consecutive cross-laminated sets inevitably encompasses a measure of net deposition and most sets will climb at a similar angle/dip to that of their host bed (Leeder, 1982). The maximum dune height of 1.80 m and channel depth of 5.40 m (cf. Reesink & Bridge, 2009; Leclair, 2011) relating to facies Stmx <1.5-3.0 m likely represent downstream migration and accretion of 3D mesoforms towards the channel thalweg/axis of a relatively broad and deep channel where large dunes tend to develop (cf. Reesink & Bridge, 2009; Ashworth *et al.*, 2011; Reesink *et al.*, 2014). Such facies were probably generated by flood events with sediment migration and aggradation influenced by high and low-flow stages, respectively (Coleman, 1969; Bristow, 1987, 1993a; Ashworth *et al.,* 2011).

Further, the relatively shallow inclined (mainly ≤10°) first-order bounding surface dips relating to facies Sl-hss <1.0 m likely denote that the host channel was relatively broad and shallow. Such an interpretation corresponds with McCabe's (1977) observation that distributary channel dips were in the region of ≤10° and Bristow (1987, 1993a) arguing that bounding surfaces, with very low depositional dips, correspond to channels possessing high width to depth ratios. Further, Outcrops 5.1-5.3 are dominated by a coarse-grained to granular sandstone which coincides with Coleman's (1969) observation that rivers with significant quantities of coarse sediment are representative of broad, flat, island-obstructed fluvial systems, although the term bar-obstructed is more appropriate (sensu Bridge, 2003).

Table 4.6

Location, grid reference and associated literature	General description and lithology
6. Duke's Hill Outcrops 6.1-6.3: SE 13755 58066 Reid, C. T. (1996) *The Alportian and Kinderscoutian (Namurian) of North Yorkshire: the sedimentary response to eustatic variation.* Unpublished Doctoral thesis, University of Keele.	Randomly distributed sandstone crags which extend for ~80 m along the southern flank of Duke's Hill; outcrop components examined moving from the eastern (left) to the western (right) section of the outcrop, in a general line trending ~080˚ towards 260˚; three individual crags extending for ~17 m were examined. The crags possess a variable texture with relatively poor outcrop detail (e.g. foreset/sets), due to the processes of weathering and erosion. Possibility that examined crags may have been subjected to cambering, which would influence azimuth-dip angles. Elevation of Outcrops 6.1-6.3 is ~245 m O.D.; main outcrop view is towards 180˚ (Fig. 4.4 Location 6). Outcrops 6.1-6.3: Coarse-grained to granular sandstone with ~2% small pebble content (variable), predominantly quartz grains; highly spherical; sub-rounded; moderately to well sorted.

Identified sub-Facies, sedimentary structures and bounding surfaces of note

Outcrop 6.1 [Eastern section; ~2 (H) x 3 (D) x 3 m (W)]: **1.** Stmx 1.5-3.0 m (St); medium-scale cross-cutting trough cross-bedding 1.5–3.0 m trough width; ~0.50 m thick set; poorly defined; **2.** ~1.40 m coset of *Sl-hss <1.0 m (Sl); low to high-angle-inclined foresets forming 0.10–0.20 m thick sub-horizontal sets of planar cross-bedding; poorly defined sets with evidence of reactivation surfaces; **3.** Ssb (S-); ~1.10 m thick structureless bed with evidence of horizontal jointing;

Outcrop 6.2 [Central section; ~2 (H) x 1.5 (D) x 1.5 m (W)]: **1.** Ssb (S-); ~0.50 m thick structureless bed; poorly defined; **2.** ~1.10 m coset of *Sl-hss <1.0 m (Sl); low to high-angle-inclined foresets forming 0.10–0.20 m thick sub-horizontal sets of planar cross-bedding; poorly defined sets; **3.** Stmx 1.5-3.0 m (St); medium-scale cross-cutting trough cross-bedding 1.5–3.0 m trough width; ~0.55 m thick set; poorly defined set;

Outcrop 6.3 [Western section; ~2 (H) x 3 (D) x 3 m (W)]: **1.** ~0.70 m coset of Sl-hss <1.0 m (Sl); low to high-angle-inclined foresets forming 0.20–0.25 m thick sub-horizontal sets of planar cross-bedding; poorly defined sets; **2.** *Sl-hpx <2.0 m (Sp); low to high-angle-inclined foresets forming medium-scale planar cross-bedding; variable foresets up to 0.04 m thick with granules defining foreset base; ~0.60 m thick set; **3.** Stmx 1.5-3.0 m (St); small to medium-scale cross-cutting trough cross-bedding 1.5–3.0 m trough width; ~0.30 m thick set; poorly defined; **4.** *Sl-hpx <2.0 m (Sp); low to high-angle-inclined foresets forming small to medium-scale planar cross-bedding; ~0.40 m thick set.

Interpretation

Outcrops 6.1-6.3 represent predominantly south to south-easterly (Fig. 4.4 Location 6) downstream migratory bedforms.

Outcrop 6.1 and 6.2 likely represent in channel migration of 3D and 2D mesoforms, facies Stmx 1.5-3.0 m and Sl-hss <1.0 m, respectively. Facies Stmx 1.5-3.0 m likely represent downstream migration and accretion of 3D mesoforms that developed towards the thalweg/axis of a relatively broad and deep channel (cf. Reesink & Bridge, 2009; Ashworth *et al.*, 2011; Reesink *et al.*, 2014). Such facies were probably generated by flood events with sediment migration and aggradation influenced by high and low-flow stages, respectively (Coleman, 1969; Bristow, 1987, 1993a; Ashworth *et al.,* 2011). Facies Sl-hss <1.0 m (2D mesoforms) suggests migratory bedforms that likely developed within a relatively shallow channel (cf. Ashworth *et al.*, 2011), possibly on the surface of a larger sand flat (cf. Cant & Walker, 1976, 1978). Such bedforms are also associated with a series of distinct depositional episodes (cf. Collinson *et al.,* 2006) i.e. sets divided by first-order set boundaries which indicate repeated bedform migration probably as a train of dunes (dune stacking) which may have formed components of a channel bar top (cf. Bristow, 1993b; Best *et al.*, 2003; Bridge & Lunt, 2006; Mumpy *et al*., 2007;Miall, 2010b; Ashworth *et al.*, 2011) and may also form components of a larger host dune coset (cf. Haszeldine, 1983b).) or small-scale unit bars (cf. Sambrook Smith *et al.*, 2006; Reesink & Bridge, 2009). Shallow channel conditions also imply waning flow, aggradation and channel fill (cf. Cant & Walker, 1976; Ashworth *et al.*, 2011; Reesink *et al.*, 2014); preservation of consecutive cross-laminated sets inevitably encompasses a measure of net deposition and most sets will climb at a similar angle/dip to that of their host bed (Leeder, 1982).

Outcrop 6.3: See above interpretations relating to facies Sl-hss <1.0 m and Stmx 1.5-3.0 m. Deposition of facies Sl-hpx <2.0 m implies substantial increase in channel depth and net sediment input, likely facilitated by a flood event with sediment migration and aggradation influenced by high and low-flow stages, respectively (Coleman, 1969; Bristow, 1987, 1993a; Ashworth *et al.,* 2011). The size of cross-bedding suggests downstream-accretion within a relatively broad and deep channel with dune migration near to channel thalweg/axis (cf. Reesink & Bridge, 2009; Ashworth *et al.*, 2011; Reesink *et al.*, 2014).

Table 4.7

Location, grid reference and associated literature	General description and lithology
7. Harrie's Dam Outcrops 7.1-7.3: SE 13277 57902 7.4: SE 13296 57960 Reid, C. T. (1996) *The Alportian and Kinderscoutian (Namurian) of North Yorkshire: the sedimentary response to eustatic variation.* Unpublished Doctoral thesis, University of Keele. This study.	Lower section of fragmented sandstone crags (tors) associated with Harrie's Dam and adjacent Gill House Crags situated ~100 m to the east on the north western flank of Peat Hill. The crags possess a variable texture with relatively poor outcrop detail (e.g. foreset/sets), due to the processes of weathering, erosion and algal growth. Located to the rear of main outcrop (Outcrop 7.4), Outcrops 7.1-7.3 extend intermittently for ~50 m in a southerly direction, adjacent to Green Sike which flows into Harrie's Dam. Elevation of Outcrops 7.1-7.4 is ~243 m O.D.; main outcrop view is towards 158˚ (Fig. 4.4 Location 7). Outcrops 7.1-7.4: Coarse-grained to granular sandstone with ~2% small to medium pebble content (variable), predominantly quartz grains; generally low sphericity; angular to sub-angular; poor to moderately sorted.

Identified sub-Facies, sedimentary structures and bounding surfaces of note

Outcrop 7.1 [~2.5 (H) x 5.5 m (W)]: **1.** ~1.40 m coset of *Sl-hpx <2.0 m (Sp); low to high-angle-inclined foresets forming ~0.65 and 0.75 m thick sub-horizontal sets of medium to large-scale planar cross-bedding; poorly defined foresets; **2.** ~0.50 m coset of Stsx <1.5 m (St); small-scale cross-cutting trough cross-bedding <1.5 m trough width; ~0.15 m thick sets; poorly defined sets and foresets;

Outcrop 7.2 [~1.5 (H) x 4.5 m (W)]: **1.** Sl-hpx <2.0 m (Sp); low to high-angle-inclined foresets forming ~0.30 m thick sub-horizontal set of small to medium-scale planar cross-bedding; poorly defined foresets; **2.** ~0.50 m coset of *Sl-hss <1.0 m (Sl); likely small-scale trough cross-bedding <1.5 m trough width; ~0.10 m thick sub-horizontal cross-cutting sets; poorly defined; **3.** ~0.50 m coset of *Sl-hpx <2.0 m (Sp); low to high-angle-inclined foresets forming ~0.15 m thick sub-horizontal sets of small-scale planar cross-bedding; poorly defined foresets;

Outcrop 7.3 [~1.5 (H) x 4.5 m (W)]: **1.** ~1.40 m thick coset group of *Sl-hss <1.0 m (Sl); likely small-scale trough cross-bedding <1.5 m trough width; ~0.80 and 0.60 m thick sub-horizontal cross-cutting cosets with 0.10-0.15 m thick sub-horizontal cross-cutting sets; poorly defined foresets;

Main Outcrop 7.4 [~5.2 (H) x 6.0 (D) x 4.0 m (W)]: **1.** Ssb (S-); ~0.30 m thick structureless bed with no obvious evidence of internal structures such as sets and foresets; **2.** *Stmx 1.5-3.0 m (St); medium-scale trough cross-bedding 1.5–3.0 m trough width; ~0.55 m thick set (trough); poorly defined foresets; **3.** ~1.60 m thick coset of *Stmx 1.5-3.0 m (St); medium-scale trough cross-bedding 1.5–3.0 m trough width; sub-horizontal cross-cutting sets vary in thickness from 0.60-0.40 m; poorly defined foresets; **4.** ~2.80 m thick coset group of *Sl-hss <1.0 m (Sl); low to high-angle-inclined foresets; five cross-cutting sub-horizontal cosets varying in thickness i.e. ~0.90, 0.40, 0.55, 0.55 and 0.40 m; cosets consist of 0.10–0.15 m thick sub-horizontal cross-cutting sets; likely poorly defined trough cross-bedding; **5.** *Stmx 1.5-3.0 m (St); large-scale trough cross-bedding 1.5–3.0 m trough width; ~1.00 m thick set (trough) with poorly defined foresets.

Interpretation

Outcrops 7.1-7.3 represent predominantly south-westerly (Fig. 4.4 Location 7) downstream migratory bedforms with temporal variation in channel depth. Cosets bedforms with multiple individual sets (e.g. Sl-hss <1.0 m) may also form components of a larger host dune coset (cf. Haszeldine, 1983b). Facies Sl-hpx <2.0 m likely represent flood events with an increase in channel depth/flow and net sediment input, thereby likely facilitating sediment migration and aggradation of 2D mesoforms influenced by high and low-flow stages, respectively (Coleman, 1969; Bristow, 1987, 1993a; Ashworth *et al.,* 2011). The size of cross-bedding suggests downstream-accretion within a relatively broad and deep channel with dune migration near to the channel thalweg/axis (cf. Reesink & Bridge, 2009; Ashworth *et al.*, 2011; Reesink *et al.*, 2014). Facies Sl-hss <1.0 m also suggests downstream migration of relatively small-scale 3D, or 2D, dunes (Bristow, 1988, 1993a; cf. Collinson *et al.*, 2006). The relatively shallow channel conditions associated with facies Sl-hss <1.0 m implies waning flow, aggradation and channel fill (cf. Cant & Walker, 1976; Ashworth *et al.*, 2011; Reesink *et al.*, 2014).

Outcrop 7.4 represents more variable southerly to westerly (Fig. 4.4 Location 7) downstream migratory bedforms with temporal variation in channel depth. Facies Stmx <1.5-3.0 m likely denote repeated downstream migration and accretion of 3D mesoforms towards the thalweg/axis of a relatively broad/deep channel, as reflected by the their relative set thicknesses (cf. Reesink & Bridge, 2009; Ashworth *et al.*, 2011; Reesink *et al.*, 2014). Such facies were probably generated by flood events with sediment migration and aggradation influenced by high and low-flow stages, respectively (Coleman, 1969; Bristow, 1987, 1993a; Ashworth *et al.,* 2011). Subsequent deposition of facies Sl-hss <1.0 m suggests migratory bedforms that likely developed within a relatively shallow channel (cf. Ashworth *et al.*, 2011), possibly on the surface of a larger sand flat (cf. Cant & Walker, 1976, 1978). Such bedforms are also associated with a series of distinct depositional episodes (cf. Collinson *et al.,* 2006) of assembled sets divided by first-order set boundaries which indicate repeated bedform migration probably as a train of dunes (dune stacking) which may have formed components of a larger bar top (cf. Bristow, 1993b; Best *et al.*, 2003; Bridge & Lunt, 2006; Miall, 2010b; Ashworth *et al.*, 2011). Similarly, multiple individual sets may form components of a larger migrating host dune coset (cf. Haszeldine, 1983b). Correspondingly, preservation of consecutive cross-laminated sets inevitably encompasses a measure of net deposition and subject to the inclination of their host bed most sets will climb at a similar angle (Leeder, 1982). The upper most facies of Stmx 1.5-3.0 m likely represent a subsequent flood event and return to high-flow stage, see above interpretation. The variable palaeocurrents likely represent a migrating thalweg and/or mid-channel bar cosets correlated to facies Stmx 1.5-3.0 m and Sl-hss <1.0 m, respectively. Sediment deposition during falling-flow stage may facilitate localised thalweg migration and alterations in flow direction (cf. Coleman, 1969; Bristow, 1987; Ashworth *et al.*, 2011). Alternatively, the variable palaeocurrent azimuths imply dune-scale bedforms may have migrated obliquely over, around and down a curved barform front/tail (cf. Haszeldine, 1983b). Further, although limited in number, the relatively shallow inclined (mainly ≤10°) first and second-order bounding surface dips relating to Location 7 may denote that the host channel was relatively broad and shallow. Such an interpretation corresponds with McCabe's (1977) observation that distributary channel dips were in the region of ≤10° and Bristow (1987, 1993a) arguing that bounding surfaces, with very low depositional dips, correspond to channels possessing high width to depth ratios. Further, Location 7 is dominated by a coarse-grained to granular sandstone which coincides with Coleman's (1969) observation that rivers with significant quantities of coarse sediment are representative of broad, flat, island-obstructed fluvial systems, although the term bar-obstructed is more appropriate (sensu Bridge, 2003).

Table 4.8

Location, grid reference and associated literature	General description and lithology
8. Gill House Crags Outcrop 8.1: SE 13371 57994 Hudson, R.G.S. (1937) The Millstone Grit succession of the Simonseat Anticline, Yorkshire. *Proceedings of the Yorkshire Geological Society*, 23, 319-349.	Upper section of fragmented sandstone crags (tors) associated with Gill House Crags situated on the north western flank of Peat Hill and adjacent to the outcrops relating to Harrie's Dam located ~100 m to the west. The crags possess a variable texture with relatively poor outcrop detail (e.g. foreset/sets), due to the processes of weathering and erosion. Elevation of Outcrop 8.1 is ~255 m O.D.; main outcrop view is towards 158˚ (Fig. 4.4 Location 8). Outcrop 8.1: Medium-grained to granular sandstone with ~5% small pebble content (variable), predominantly quartz grains; generally low to high sphericity; sub-rounded to rounded; moderately to well sorted.

Identified sub-Facies, sedimentary structures and bounding surfaces of note

Outcrop 8.1 [~4.5 (H) x 8.0 (D) x 3.7 m (W)]: **1.** ~2.10 m thick coset group of *Sl-hpx <2.0 m (Sp); low to high-angle-inclined foresets; four cross-cutting sub-horizontal cosets varying in thickness i.e. ~0.55, 0.45, 0.50 and 0.50 m; cosets consist of 0.10–0.15 m thick sub-horizontal cross- cutting sets; likely poorly defined planar cross-bedding; **2.** ~0.25 m thick coset of *Sl-hss <1.0 m (Sl); likely small-scale trough cross-bedding <1.5 m trough width; ~0.05 m thick sub-horizontal cross-cutting sets; poorly defined very low-amplitude cross-bedding; evidence of Calamites fossil remnant at base; **3.** ~0.60 m thick coset of *Sl-hss <1.0 m (Sl); likely small-scale trough cross- bedding <1.5 m trough width; coset consists of 0.10–0.15 m thick sub-horizontal cross-cutting sets; poorly defined cross-bedding; **4.** ~0.60 m thick coset of *Sl-hss-of <1.0 m (Sl); likely small-scale oblique trough cross-bedding <1.5 m trough width; coset consists of 0.10–0.15 m thick sub-horizontal cross-cutting sets; poorly defined cross-bedding; **5.** ~0.90 m thick coset of Sl-hhs <1.0 m (Sh); likely small-scale trough cross-bedding <1.5 m trough width forming ~0.10 m thick cross-cutting horizontal sets; poorly defined cross-bedding; **6.** ~0.30 m thick coset of Sl-hss <1.0 m (Sl); likely small-scale trough cross-bedding <1.5 m trough width; coset consists of ~0.10 m thick sub-horizontal cross-cutting sets; poorly defined cross-bedding; **7.** Stsx <1.5 m (St); small to medium-scale cross-cutting trough cross-bedding <1.5 m trough width; ~0.30 m thick set; poorly defined foresets; base forms fifth-order bounding surface representing a chute channel; **8.** ~1.50 m thick coset of *Sl-hpx <2.0 m (Sp); low to high-angle-inclined foresets forming four sub-horizontal cross-cutting sets varying in thickness i.e. ~0.60, 0.40, 0.50 and 0.40 m; foresets vary in thickness from ~0.02-0.03 m; planar cross- bedding with evidence of reactivation surfaces.

Interpretation

Although palaeocurrent data varies from an easterly to south-westerly direction, the general palaeocurrent direction appears to be towards the southeast (Fig. 4.4 Location 8); the variable range of azimuths suggest dune-scale bedforms may have migrated obliquely over, around and down a curved barform front/tail (cf. Haszeldine, 1983b).

Individual sub-horizontal sets of Sl-hpx <2.0 m likely form components of a larger host dune coset (cf. Haszeldine, 1983b), influenced by high-flow stage which facilitated the formation of down-climbing dunes (cf. Bristow, 1988, 1993a; Reesink & Bridge, 2009; Ghinassi, 2011). Such cosets may represent migratory mid-channel bar bedform components (cf. Reesink & Bridge, 2009) that likely formed within a multi-channelled fluvial system (cf. Reesink *et al*., 2014) and/or small-scale migrating unit bars (cf. Sambrook Smith *et al.*,2006; Reesink & Bridge, 2009), which in turn likely form components of a much larger host compound bar (cf. Allen, 1982; Bridge, 2003; Bridge & Lunt, 2006; Sambrook Smith *et al.*, 2006; Ashworth *et al.*, 2011), although such component coset/unit bar heights coincide with dune heights (Ashworth *et al.*, 2011). The sub-horizontal second-order coset/unit bar bounding surface contacts are likely third-order erosional surfaces (cf. Miall, 2010b; Ielpi *et al*., 2014). Such contacts denote a component of lateral coset (mesoform) accretion and growth of the host compound bar (macroform) through lateral and downstream-accretion (cf. Bridge & Lunt, 2006), alternating between a south-easterly and south-westerly direction, as the main bar (macroform) migrated south-eastwards downstream.

An average coset thickness of ~0.50 m implies that the host channel was ~1.80 m deep (cf. Reesink & Bridge, 2009; Leclair, 2011). The ~0.05 m thick sets related to the ~0.25 m thick coset of Sl-hss <1.0 m implies flow conditions were sufficiently shallow (~0.50 m deep; cf. Reesink & Bridge, 2009; Leclair, 2011) to subdue dune formation and generate very low relief dunes (cf. Bristow, 1993a); preservation of low-angle dune morphology is facilitated by dune stoss and crest erosion, during high flow-stage, and deposition of eroded sediment in the dune's trough (Hendershot *et al.*, 2016). Low-angle bedforms may be attributed to the migration of low-amplitude (near horizontal) sand waves/dunes, or low-relief dunes associated with parallel laminations, both are concomitant with the transitional zone between lower and upper flow regimes and very shallow fluvial systems (cf. Smith, 1971; Todd, 1996); generally foreset gradients decline as a flow regime intensifies, vice versa (cf. Smith, 1972). The relative shallow channel conditions also imply waning flow, aggradation of 3D mesoforms and channel fill (cf. Cant & Walker, 1976; Ashworth *et al.*, 2011; Reesink *et al.*, 2014). Further coset deposition relating to facies Sl-hss <1.0 m and Sl-hss-of <1.0 m likely represent a return to deeper channel conditions and additional compound bar accretion and migration, as detailed above.

The relative shallow channel conditions (~1.10 m deep; cf. Reesink & Bridge, 2009; Leclair, 2011) relating to the subsequent deposition of facies Sl-hhs <1.0 m and Sl-hss <1.0 m imply waning flow, aggradation of 3D mesoforms and channel fill (cf. Cant & Walker, 1976; Ashworth *et al.*, 2011; Reesink *et al.*, 2014). Such bedforms may also form a series of distinct depositional episodes (cf. Collinson *et al.,* 2006) i.e. sets divided by first-order set boundaries, indicating repeated bedform migration probably as a train of dunes (dune stacking) that may have formed components of a larger bar top (cf. Bristow, 1993b; Best *et al.*, 2003; Bridge & Lunt, 2006; Miall, 2010b; Ashworth *et al.*, 2011). The base of facies Stsx <1.5 m forms a fifth-order bounding surface (cf. Miall, 2010b) and likely represents a chute channel generated as a result of falling-stage flow and bar top incision, due to overflow from the main channel as the flow rate subsided (cf. Bristow, 1987, 1993; Ashworth *et al.*, 2011). Subsequent deposition of facies Sl-hpx <2.0 m implies continued south-easterly downstream migration, increase in net sediment input and channel depth, facilitated by a flood event and subsequent deposition of relatively larger dunes (2D mesoforms), during waning flow (low-flow stage) (cf. Coleman, 1969; Bristow, 1987, 1993a; Ashworth *et al.,* 2011). Further, the presence of Calamites remnants implies rapid deposition which facilitated fossil preservation; if propagated locally the presence of Calamites vegetation would have promoted channel bank and/or channel bar stability.

Table 4.9

Location, grid reference and associated literature	General description and lithology
9. Green Sike Stream Outcrop 9.1: SE 13166 57739 This study.	Fragmented outcrop with the roots of a Beech tree running through the outcrop. The outcrop is adjacent to Green Sike which flows into Harrie's Dam (Table 4.7). Moorland north of the outcrop is covered by dense bracken and to the south managed moorland faces Cough and is strewn with numerous boulders of Lower Brimham Grit; various sizes up to ~2.0 m long x 1.5 m wide x 1.0 m high. The outcrop possesses a variable texture with relatively poor outcrop detail (e.g. foreset/sets), due to the processes of weathering and erosion, consistent with that of the Lower Brimham Grit. Elevation of Outcrop 9.1 is ~250 m O.D.; main outcrop view is towards 360˚ (Fig. 4.4 Location 9). Outcrop 9.1: Coarse-grained to granular sandstone, predominantly quartz grains; generally low sphericity; angular to sub-angular; poorly sorted and poorly cemented.

Identified sub-Facies, sedimentary structures and bounding surfaces of note

Outcrop 9.1 [~7.0 (H) x 8.0 (D) x 20.0 m (W)]: **1.** Stmx 1.5-3.0 m (St); medium to large-scale trough cross-bedding 1.5–3.0 m trough width; ~0.90 m thick set (trough); poorly defined foresets; sharp irregular contact with overlying coset; **2.** ~1.00 m thick coset of Stmx 1.5-3.0 m (St); medium-scale trough cross-bedding 1.5–3.0 m trough width; two ~0.50 m thick cross-cutting sets; sharp irregular contact between sets; poorly defined foresets; **3.** *Sl-hpx <2.0 m (Sp); low to high-angle-inclined foresets forming ~0.60 m thick sub-horizontal set of medium-scale planar cross-bedding; moderate to poorly defined foresets; sharp and relatively horizontal contact with underlying coset; **4.** ~2.00 m thick coset group of Sl-hss <1.0 m (Sl); low to high-angle-inclined foresets; five cross-cutting sub-horizontal (**~5**˚) cosets varying in thickness i.e. ~0.50, 0.50, 0.40, 0.30 and 0.30 m; cosets consist of 0.10–0.15 m thick sub-horizontal cross-cutting sets; likely poorly defined small-scale trough cross-bedding; sharp contact between cosets.

Interpretation

Palaeocurrent data relating to facies Sl-hpx<2.0 m imply that a southerly palaeocurrent prevailed during deposition (Fig. 4.4 Location 9). The relative bedform size relating to facies Stmx 1.5-3.0 m and Sl-hpx <2.0 m, imply a temporal increase in palaeo-discharge and increased rate of dune migration and accumulation, probably facilitated by repeated flood events (cf. Coleman, 1969; Bristow, 1987, 1993; Ashworth *et al.*, 2011), as relatively large sandy bedforms are indicative of flood events (cf. Cant & Walker, 1978; Ashworth *et al.*, 2011; Reesink *et al.*, 2014). Such facies were likely deposited along a channel base, rather than host barforms (cf. Cant & Walker, 1976; Ashworth *et al.*, 2011; Reesink *et al.*, 2014). The maximum dune height associated with facies Stmx 1.5-3.0 m and Sl-hpx <2.0 m, implies that the host channel was relatively deep, between 5.40-9.72 m deep (cf. Cant & Walker, 1978; Reesink & Bridge, 2009; Leclair, 2011), as deep channels generally possess larger dune bedforms (cf. Reesink & Bridge, 2009; Ashworth *et al.*, 2011; Reesink *et al.*, 2014).

The deposition of facies Sl-hss <1.0 m suggests migratory bedforms that likely developed within a relatively shallow channel (cf. Ashworth *et al.*, 2011), possibly on the surface of a larger sand flat (cf. Cant & Walker, 1976, 1978). Alternatively, individual sub-horizontal sets of Sl-hss <1.0 m may form components of a larger host dune coset (cf. Haszeldine, 1983b), influenced by high-flow stage which facilitated the formation of down-climbing dunes (cf. Bristow, 1988, 1993a; Reesink & Bridge, 2009; Ghinassi, 2011). Such cosets may represent migratory mid-channel bar bedform components (cf. Reesink & Bridge, 2009) that likely formed within a multi-channelled fluvial system (cf. Reesink *et al.*, 2014) and/or small-scale downstream migrating unit bars (cf. Sambrook Smith *et al.*, 2006; Reesink & Bridge, 2009), which in turn likely form components of a much larger host compound bar (cf. Allen, 1982; Bridge, 2003; Bridge & Lunt, 2006; Sambrook Smith *et al.*, 2006; Ashworth *et al.*, 2011), although such component coset/unit bar heights coincide with dune heights (Ashworth *et al.*, 2011). Such bedforms may also form a series of distinct depositional episodes (cf. Collinson *et al.,* 2006) i.e. sets divided by first-order set boundaries, indicating repeated bedform migration probably as a train of dunes (dune stacking) that may have formed components of a larger bar top (cf. Bristow, 1993b; Best *et al.*, 2003; Bridge & Lunt, 2006; Miall, 2010b; Ashworth *et al.*, 2011) and the latter stages of a channel fill sequence (cf. Reesink *et al.*, 2014).

Table 4.10

Location, grid reference and associated literature	General description and lithology
10. Peat Hill Outcrops 10.1: SE 13793 57882 10.2: SE 13718 57858 This study.	Two relatively small outcrop remnants ~50 m apart, likely from a disused quarry which is now part of rough/managed grassland near to the southern boundary of Peat Hill and adjacent to Round Hill. The outcrops possess a variable texture with relatively poor outcrop detail (e.g. foreset/sets), due to the processes of weathering and erosion, consistent with that of the Lower Brimham Grit. Elevation of Outcrop 10.1 and 10.2 is ~260 and 263 m O.D., respectively; main outcrop views are towards 280˚ and 270˚, respectively (Fig. 4.4 Location 10). Outcrops 10.1-10.2: Coarse-grained to granular sandstone with ~2% small pebble content (variable), predominantly quartz grains; generally low to high sphericity; sub-rounded to rounded; moderately sorted.

Identified sub-Facies, sedimentary structures and bounding surfaces of note

Outcrop 10.1 [~1.5 (H) x 2.0 (D) x 6.0 m (W)]: **1.** ~0.50 m thick coset of Stmx 1.5-3.0 m (St); medium-scale trough cross-bedding 1.5–3.0 m trough width; two ~0.25 m thick sets (troughs); poorly defined foresets; sharp horizontal contact between sets; **2.** ~0.50 m thick coset of *Sl-hss <1.0 m (Sl); likely small-scale trough cross-bedding <1.5 m trough width; coset consists of ~0.10 m thick sub-horizontal cross-cutting sets; poorly defined cross-bedding;

Outcrop 10.2 [~0.7 (H) x 1.6 (D) x 2.5 m (W)]: **1.** ~0.70 m thick coset of *Sl-hhs <1.0 m (Sh); likely small-scale trough cross-bedding <1.5 m trough width; coset consists of ~0.10 m thick horizontal cross-cutting sets; poorly defined cross-bedding.

Interpretation

Although limited and in parts inferred, the palaeocurrent appears to migrate from a south-easterly direction towards the southwest, as you move up the sequence from Outcrop 10.1 to Outcrop 10.2 (Fig. 4.4 Location 10).

Outcrop 10.1: The facies association suggest that initially the fluvial channel supported relatively large bedform (Stmx 1.5-3.0 m) migration and accumulation, probably facilitated by flood events (cf. Coleman, 1969; Bristow, 1987, 1993; Ashworth *et al.*, 2011). Whereas, the ensuing facies Sl-hss <1.0 m implies readjustment to relatively shallow channel conditions associated with waning flow, aggradation of 3D mesoforms and channel fill (cf. Cant & Walker, 1976; Ashworth *et al.*, 2011; Reesink *et al.*, 2014). Such bedforms are also associated with high-flow stage which facilitated the formation and downstream migration of down-climbing dunes (cf. Bristow, 1988, 1993a; Reesink & Bridge, 2009; Ghinassi, 2011).

Outcrop 10.2: The relatively shallow channel conditions associated with facies Sl-hhs <1.0 m (~1.00 m deep; cf. Reesink & Bridge, 2009; Leclair, 2011) implies waning flow, aggradation of 3D mesoforms and channel fill (cf. Cant & Walker, 1976; Ashworth *et al.*, 2011; Reesink *et al.*, 2014). Such bedforms are also associated with a series of distinct depositional episodes (cf. Collinson *et al.,* 2006) of assembled sets divided by first-order set boundaries which indicate repeated bedform migration probably as a train of dunes (dune stacking) which may have formed components of a larger bar top (cf. Bristow, 1993b; Best *et al.*, 2003; Bridge & Lunt, 2006; Miall, 2010b; Ashworth *et al.*, 2011).

The shallow inclined (≤10°) first-order bounding surface dips (Outcrop 10.1), may correspond to channels possessing high width to depth ratios (Bristow, 1993a) and down-climbing dunes may represent small-scale unit bars (cf. Sambrook Smith *et al.*, 2006; Reesink & Bridge, 2009); and the relatively coarse-grained to granular sandstone texture associated with Location 10 coincides with Coleman's (1969) observation that rivers with significant quantities of coarse sediment are representative of broad, flat, island-obstructed fluvial systems, although the term bar-obstructed is more appropriate (sensu Bridge, 2003).

Table 4.11

Location, grid reference and associated literature	General description and lithology
11. Hard Pits Outcrops 11.1: SE 14049 57050 11.2: SE 14019 57021 11.3: SE 13994 57013 11.4: SE 13881 56969 11.5: SE 13443 56962 11.6: SE 13410 56950 (Estimated) 11.7: SE 13485 56980 11.8: SE 13822 57227 Jones, T.W. (1943) The geology of the Beamsley Anticline. *Proceedings of the Leeds Philosophical Society*, 4, Part 2, 146-166.	Fragmented scattered outcrops which may be traced north and northwest towards Peat Hill and Green Sike, Locations 10 and 9, respectively. The main section of the outcrop straddles the boundary wall at the southern end of Hard Pits, adjacent to Spittle Ings House. The examined outcrops rest within managed moorland on Hard Pits, the outcrops south of the boundary wall adjacent to Spittle Ings House were not examined. The outcrops examined extend ~700 m to the west and ~300 m to the northwest of outcrop 11.1. The outcrops possess a variable texture with relatively poor outcrop detail (e.g. foreset/sets), due to soft sediment deformation (Ssd), weathering and erosion. Elevation of Outcrops 11.1-11.8 is ~300, 304, 304, 304, 302, 302, 303 and 290 m O.D., respectively; main outcrop views are towards 348˚, 320˚, 020˚, 164˚, 020˚, 190˚, 100˚, and 040˚, respectively (Fig. 4.4 Location 11). Outcrop 11.1: Medium to coarse-grained sandstone, predominantly quartz grains; generally high sphericity; sub-angular; very well sorted; Outcrop 11.2: Medium to coarse-grained sandstone, predominantly quartz grains; generally high sphericity; sub-rounded; well sorted; Outcrop 11.3: Medium to coarse-grained sandstone, predominantly quartz grains; generally high sphericity; sub-rounded; well sorted; Outcrop 11.4: Medium to coarse-grained sandstone, predominantly quartz grains; generally high sphericity; sub-rounded to rounded; well sorted; Outcrop 11.5: Medium to very coarse-grained sandstone with ~2% small pebble content (variable), predominantly quartz grains; generally high sphericity; sub-rounded to rounded; moderately to well sorted; Outcrop 11.6: Very coarse-grained to granular sandstone with 5-10% small pebble content (variable), predominantly quartz grains; generally high sphericity; sub-rounded to rounded; moderately sorted; Outcrop 11.7: Coarse-grained to granular sandstone with 2-5% small pebble content (variable), predominantly quartz grains; generally high sphericity; sub-rounded to rounded; moderately to well sorted; Outcrop 11.8: Coarse-grained to granular sandstone with ~2% small pebble content (variable), predominantly quartz grains; generally high sphericity; sub-rounded to rounded; well sorted.

Identified sub-Facies, sedimentary structures and bounding surfaces of note

Outcrop 11.1 [~1.4 (H) x 2.3 (D) x 4.0 m (W)]: **1.** ~0.60 m thick coset of Sl-hss <1.0 m (Sl); likely small-scale trough cross-bedding <1.5 m trough width; coset consists of ~0.10 m thick sub-horizontal cross-cutting sets; poorly defined cross-bedding exhibiting signs of soft sediment deformation (Ssd); **2.** ~0.60 m thick cosets of *Ssd (Sd); likely small-scale trough cross-bedding <1.5 m trough width; coset consists of ~0.10 m thick sub-horizontal cross-cutting sets; poorly defined cross-bedding exhibiting signs of de-watering i.e. flame structures, primary facies Ssd (Sd);

Outcrop 11.2 [~1.4 (H) x 2.5 (D) x 5.6 m (W)]: **1.** ~0.50 m thick set of Ssd (Sd); likely medium-scale trough cross-bedding 1.5-3.0 m trough width; poorly defined set bounding surface; poorly defined cross-bedding exhibiting signs of intense de-watering i.e. flame structures, primary facies Ssd; **2.** ~0.60 m thick set of *Ssd (Sd); likely medium-scale trough cross-bedding 1.5-3.0 m trough width; poorly defined set bounding surface; poorly defined cross-bedding with signs of intense de-watering i.e. flame structures, primary facies Ssd;

Outcrop 11.3 [~2.0 (H) x 3.0 (D) x 4.0 m (W)]: **1.** Stmx 1.5-3.0 m (St); medium to large-scale trough cross-bedding 1.5–3.0 m trough width; ~0.70 m thick set (trough); poorly defined irregular contact with overlying set; poorly defined cross-bedding exhibiting signs of Ssd; **2.** Stsx <1.5 m (St); small to medium-scale cross-cutting trough cross-bedding <1.5 m trough width; ~0.30 m thick set; poorly defined set bounding surface; poorly defined cross-bedding exhibiting signs of Ssd; **3.** *Stsx <1.5 m (St); small to medium-scale cross-cutting trough cross-bedding <1.5 m trough width; ~0.45 m thick set; poorly defined set bounding surface; poorly defined cross-bedding exhibiting signs of Ssd;

Outcrop 11.4 [~0.9 (H) x 3.0 (D) x 4.0 m (W)]: **1.** ~0.45 m thick coset of *Sl-hss <1.0 m (Sl); likely small-scale trough cross-bedding <1.5 m trough width; coset consists of ~0.10 m thick sub-horizontal cross-cutting sets; poorly defined cross-bedding exhibiting signs of Ssd; **2.** ~0.45 m thick coset of *Sl-hss-of <1.0 m (Sl); likely small-scale oblique trough cross-bedding <1.5 m trough width; coset consists of ~0.10 m thick sub-horizontal cross-cutting sets; poorly defined cross-bedding exhibiting signs of Ssd;

Outcrop 11.5 [~2.0 (H) x 3.0 (D) x 20.0 m (W)]: **1.** Stmx 1.5-3.0 m (St); medium to large-scale trough cross-bedding 1.5–3.0 m trough width; ~1.00 m thick set (trough); poorly defined cross-bedding exhibiting signs of Ssd; poorly defined irregular contact with overlying set; **2.** Stmx 1.5-3.0 m (St); medium to large-scale trough cross-bedding 1.5–3.0 m trough width; ~1.00 m thick set (trough); poorly defined cross-bedding exhibiting signs of Ssd;

Outcrop 11.6 [~1.1 (H) x 3.0 (D) x 1.5 m (W)]: **1.** ~1.10 m thick coset of *Sl-hss <1.0 m (Sl); low to high-angle-inclined foresets forming ~0.30, 0.30 and 0.40 m thick sub-horizontal sets of small to medium-scale planar cross-bedding; poorly defined foresets; sharp sub-horizontal contact between sets;

Outcrop 11.7 [~1.7 (H) x 3.0 (D) x 2.5 m (W)]: **1.** ~1.10 m thick coset group of Sl-hss <1.0 m (Sl); low to high-angle-inclined foresets; two cross-cutting sub-horizontal cosets varying in thickness i.e. ~0.50 and 0.60 m; cosets consist of predominantly ~0.10 m thick sub-horizontal cross-cutting sets; likely poorly defined trough cross-bedding; poorly defined set and coset bounding surfaces; **2.** ~0.50 m thick coset of *Sl-hss-of <1.0 m (Sl); likely small-scale oblique planar cross-bedding; coset consists of predominantly ~0.10 m thick sub-horizontal cross-cutting sets; poorly defined cross-bedding; poorly defined set and coset bounding surfaces;

Outcrop 11.8 [~1.0 (H) x 2.0 (D) x 3.0 m (W)]: **1.** ~1.00 m thick coset of *Sl-hss-of <1.0 m (Sl); likely small-scale oblique trough cross-bedding <1.5 m trough width; coset consists of predominantly ~0.10 m thick sub-horizontal cross-cutting sets; poorly defined cross-bedding; poorly defined set bounding surface.

Interpretation

Although limited, set palaeocurrent data in relation to Outcrops 11.1-11.8 appear to vary between westerly and northerly flow direction; similarly, foreset and in parts inferred foreset data appear more varied with flow directions towards the west, east and south (Fig. 4.4 Location 11). Such palaeocurrent data imply that deposition may have been influenced by lateral-accretion and/or dune-scale bedform migration obliquely over, around and down a curved barform front/tail (cf. Haszeldine, 1983b).

Although Outcrop 11.8 has an elevation of ~290 m O.D., the remaining Outcrops (11.1-11.7) possess elevations within ~2.0 m of each other, implying they are all horizontally related; similarly, Outcrops 11.1-11.5 possess varying levels of soft sediment deformation (liquefaction), suggesting they were influenced by water saturation and subsequent event(s) that triggered de-watering processes, for example sudden overburden through rapid sediment deposition post flood and/or syn-sedimentary tectonic activity post deposition (cf. Barnhardt & Sherrod, 2006; Hubert-Ferrari *et al.*, 2017). Although tectonic activity cannot be totally discounted, due to the areal extend of soft sediment deformation (~600 m), evidence to suggest that sudden overburden of sediment may have been a triggering event is implied by Outcrop 11.2, which appears to possess flames structures that are orientated in a westerly direction. This suggests a rapid influx and sediment deposition from an easterly direction likely destabilised the underlying water saturated sediment, causing the escaping water to be squeezed out in a similar direction to that of overburden deposition (i.e. towards the west); foreset data implies that the palaeocurrent was towards the northwest.

Generally, the examined outcrops represent intermittent components of a multi-channel braided fluvial system (cf. Reesink *et al*., 2014) with a likely north-westerly trend. The more westerly outcrops (Outcrops 11.5-11.7) possess coarser sediments and larger bedforms (i.e. Outcrop 11.5) which suggests that the fluvial system had a stronger palaeocurrent and deeper channel towards the west, respectively. The outcrops record the presence of two second-order channels partitioned by mid-channel bars (cf. Bristow, 1987). Channels are represented by Outcrops 11.2-11.3 and Outcrop 11.5, respectively. The relative set thicknesses of the facies associated with the first channel Outcrops11.2-11.3 (e.g. Stmx 1.5-3.0 m, ~0.70 m thick), imply that the maximum dune height and channel depth was ~2.50 m and ~7.60 m, respectively (cf. Reesink & Bridge, 2009; Leclair, 2011). Such dune sets likely developed towards the thalweg/axis; large dunes tend to develop towards the channel thalweg; the size of cross-bedding also implies downstream-accretion within a relatively broad and deep channel (cf. Reesink & Bridge, 2009; Ashworth *et al.*, 2011; Reesink *et al.*, 2014). A similar scenario is envisaged for the second channel Outcrop 11.5 where the size of cross-bedded sets (~1.00 m) implies downstream migration and aggradation of a unit bar component (3D mesoform, part of); a set thickness ≥1.00 m likely denotes unit bars, rather than dunes (Bridge & Lunt, 2006). Similarly, Sambrook Smith *et al.* (2006) interpret sets >0.5 m, which possess inclined (i.e. ≤ angle-of-repose) cross-stratification, as a consequence of bar migration. A preserved set thickness of ~1.00 m equates to a maximum barform height of ~3.00 m (cf. Reesink & Bridge, 2009; Leclair, 2011). Therefore, given that bar heights may adjust between half and bankfull depth, the depth of host channel was probably between ~3.00 m and ~6.00 m, respectively (cf. Bristow, 1987; Bridge, 2003; Reesink *et al.*, 2014).

Outcrops 11.1 and 11.4 likely represent downstream and lateral-accretion of mid-channel bars, the components of which possibly consisted of bar top, margin or tail facies e.g. Sl-hss <1.0 m. The relative facies set thickness of ~0.10 m imply that the maximum dune height and channel depth was ~0.35 m and ~1.10 m, respectively (cf. Reesink & Bridge, 2009; Leclair, 2011). Dune height also implies limited sediment input, likely influenced by high-flow stage which facilitated the formation of down-climbing dunes and downstream dune migration (cf. Bristow, 1988, 1993a; Reesink & Bridge, 2009; Ghinassi, 2011). The relatively shallow channel conditions associated with facies Sl-hss <1.0 m may also imply waning flow, aggradation of 3D and/or 2D mesoforms and channel fill (cf. Cant & Walker, 1976; Ashworth *et al.*, 2011; Reesink *et al.*, 2014). Such facies may also be associated with a series of distinct depositional episodes (cf. Collinson *et al.,* 2006) of assembled sets divided by first-order set boundaries which indicate repeated bedform migration probably as a train of dunes (dune stacking) which may have formed components of a larger bar top (cf. Bristow, 1993b; Best *et al.*, 2003; Bridge & Lunt, 2006; Miall, 2010b; Ashworth *et al.*, 2011). During falling-flow stage conditions, mid-channel bars may control channel flow patterns as they become increasingly exposed and gradually divide and divert the main channel flow around bar margins, rather than over bar surfaces (Collinson, 1970, 1996; cf. Reesink et al., 2014). Topographic lows adjacent to bar margins may limit falling-stage currents that flow between bars (Collinson, 1970; cf. Reesink *et al*., 2014), thereby facilitating lateral-accretion by promoting deposition along bar margins (Collinson, 1970, 1996), which may account for the presence of facies Sl-hss-of <1.0 m. Further, palaeocurrent data (Fig. 4.4 Location 11) and facies (e.g. Sl-hss <1.0 m and Sl-hss-of <1.0 m) associated with Outcrops 11.6-11.8 suggest that deposition may have been related to bar top vertical and/or upstream-accretion associated with the bar head and/or mid-bar section of a mid-channel bar, primarily due to dune stacking and relative shallow flow depth above the host bar (cf. Best *et al.*, 2003; Bridge & Lunt, 2006; Mumpy *et al*., 2007). Similarly, preservation of consecutive cross-laminated sets inevitably encompasses a measure of net deposition and subject to the inclination of their host bed most sets will climb at a similar angle (Leeder, 1982).

Further, the shallow inclined (predominantly ≤14°) first-order bounding surface dips may correspond to channels possessing high width to depth ratios (Bristow, 1993a) and down-climbing dunes may represent small-scale unit bars (cf. Sambrook Smith *et al.*, 2006; Reesink & Bridge, 2009); alternatively, individual sub-horizontal sets of facies Sl-hss <1.0 m may form components of a larger host dune coset (cf. Haszeldine, 1983b), influenced by high-flow stage which facilitated the formation of down-climbing dunes (cf. Bristow, 1988, 1993a; Reesink & Bridge, 2009; Ghinassi, 2011).

Table 4.12

Location, grid reference and associated literature	General description and lithology
12. Foulshaw Crags Outcrop 12.1: SE 14832 62690 Hudson, R.G.S. (1937) The Millstone Grit succession of the Simonseat Anticline, Yorkshire. *Proceedings of the Yorkshire Geological Society*, 23, 319-349.	Fragmented and scattered outcrop located on both the western and eastern flanks of Fosse Gill, situated within a moorland setting. The majority of visible outcrops appear disarticulated, displaced and therefore not in-sitú. The outcrops possess a variable texture with relatively poor outcrop detail (e.g. foreset/sets), due to the processes of weathering and erosion. Elevation of examined outcrop is ~310 m O.D.; overall main and examined outcrop views are towards 276˚ and 352˚, respectively (Fig. 4.4 Location 12). Outcrop 12.1: Coarse-grained to granular sandstone with 2-5% small to medium pebble content (variable), predominantly quartz grains; generally low to high sphericity; sub-angular to rounded; well to moderately sorted.

Identified sub-Facies, sedimentary structures and bounding surfaces of note

Outcrop 12.1 [~4.0 (H) x 5.5 (D) x 5.5 m (W)]: **1.** ~1.20 m thick set of Ssd (Sd); no obvious signs of internal bounding surfaces or cross-bedding; evidence of intense de-watering i.e. flame structures; **2.** ~0.50 m thick coset of *Sl-hss <1.0 m (Sl);); likely small-scale trough cross-bedding <1.5 m trough width; coset consists of ~0.10 m thick sub-horizontal cross-cutting sets; poorly defined cross-bedding; sharp sub-horizontal contact with over/underlying sets; **3.** ~2.00 m thick coset group of *Sl-hss <1.0 m (Sl); low to high-angle-inclined foresets; three cross-cutting sub-horizontal cosets varying in thickness i.e.~0.50, 0.50 and 1.00 m; cosets consist of predominantly 0.10-0.20 m thick sub-horizontal cross-cutting sets; likely poorly defined trough cross-bedding; poorly defined set and coset bounding surfaces.

Interpretation

Although limited, palaeocurrent data imply that the palaeocurrent at the time of deposition was towards the southwest (Fig. 4.4 Location 12).

Soft sediment deformation (liquefaction) at the base of the outcrop implies influence of water saturation and event(s) that triggered de-watering processes, for example sudden overburden (rapid sediment deposition) post flood event and/or syn-sedimentary tectonic activity post deposition (cf. Barnhardt & Sherrod, 2006; Hubert-Ferrari *et al.*, 2017). Evidence to suggest that a sudden overburden of sediment was the triggering event is not evident, due to the relatively small-scale overlying sets; therefore, although sudden overburden cannot be totally discounted, the effect of tectonic activity may have played a more significant role. Further, the thickness of facies Ssd (~1.20 m) likely represents net sediment deposition during falling-flow stage (cf. Coleman, 1969; Bristow, 1987, 1993a; Ashworth *et al.,* 2011), in the form of either downstream migration of a transverse bar (2D macroform, part of) (cf. Smith, 1972), or a lobate unit bar component (2D mesoform, part of) (cf. Bridge & Lunt, 2006; Ashworth *et al.*, 2011); a set thickness ≥1.00 m likely denotes unit bars, rather than dunes (Bridge & Lunt, 2006). Similarly, Sambrook Smith *et al.* (2006) interpret sets >0.5 m, which possess inclined (i.e. ≤ angle-of-repose) cross-stratification, as a consequence of bar migration.

The overlying cosets of facies Sl-hss <1.0 m, bounded by third and second-order bounding surfaces, may represent migratory mid-channel bar bedform components (cf. Reesink & Bridge, 2009) that likely formed within a multi-channelled fluvial system (cf. Reesink *et al*., 2014) and/or small-scale downstream migrating unit bars (cf. Sambrook Smith *et al.*, 2006; Reesink & Bridge, 2009), which in turn likely form components of a much larger host compound bar (cf. Allen, 1982; Bridge, 2003; Bridge & Lunt, 2006; Sambrook Smith *et al.*, 2006; Ashworth *et al.*, 2011), although such component coset/unit bar heights coincide with dune heights (Ashworth *et al.*, 2011). Alternatively, individual sub-horizontal sets of facies Sl-hss <1.0 m may form components of a larger host dune coset (cf. Haszeldine, 1983b), influenced by high-flow stage which facilitated the formation of down-climbing dunes (cf. Bristow, 1988, 1993a; Reesink & Bridge, 2009; Ghinassi, 2011). The sub-horizontal second-order coset/unit bar bounding surface contacts are likely third-order erosional surfaces (cf. Miall, 2010b; Ielpi *et al*., 2014). Such contacts denote a component of lateral coset (mesoform) accretion and growth of the host compound bar (macroform) through lateral and downstream-accretion (cf. Bridge & Lunt, 2006).

Variable set thicknesses of between 0.10-0.20 m, relating to the uppermost coset, implies a maximum coset dune/unit bar height of ~1.50 m (cf. Leclair, 2011). Therefore, given that bar heights may adjust between half and bankfull depth, the depth of host channel was probably between ~1.50 m and 3.00 m, respectively (cf. Bristow, 1987; Bridge, 2003; Reesink *et al*., 2014). Variable set thicknesses imply varying sediment input, likely influenced by a fluctuating flow stage which facilitated the formation of down-climbing dunes and downstream migration (cf. Bristow, 1988, 1993a; Reesink & Bridge, 2009; Ghinassi, 2011), likely influenced by a periodic rise and fall in flow rate generated by flood events. Deposition of dune coset/unit bar bedforms also suggests waning flow, net aggradation of 3D and/or 2D mesoforms and channel fill (cf. Cant & Walker, 1976; Ashworth *et al.*, 2011; Reesink *et al.*, 2014); similarly, preservation of consecutive cross-laminated sets inevitably encompasses a measure of net deposition and most sets will climb at a similar angle/dip to that of their host bed (Leeder, 1982).

Table 4.13

Location, grid reference and associated literature	General description and lithology
13. Old Wife Ridge (Heyshaw Moor) Outcrops 13.1: SE 15901 62665 13.2: SE 15886 62662 13.3: SE 15881 62667 13.4: SE 15880 62671 Thompson, A. T. (1957) *The structure and stratigraphy of Nidderdale between Lofthouse and Dacre*. Unpublished, Doctoral thesis, Durham University. Available at Durham E-Theses Online: http://etheses.dur.ac.uk/722/.	Fragmented and scattered outcrop located along ridgeline ~80 m north of trackway. Outcrop components are situated within a predominantly moorland setting and are partially obscured by vegetation; outcrops vary in height up to ~1.5 m and possess a variable texture with relatively poor outcrop detail (e.g. foreset/sets), due to the processes of weathering and erosion. Outcrop components examined moving from the eastern (left) to the western (right) section of the outcrop, in a general line trending ~ 070˚ towards 250˚, which extends for ~40 m. Elevation of Outcrops 13.1-13.4 is ~338 m O.D.; overall main and examined outcrop views are towards 360˚, 053˚, 068˚, 010˚ and 030˚, respectively (Fig. 4.4 Location 13). Outcrops 13.1-13.4: Coarse-grained to granular sandstone with 2-5% small to medium pebble content (variable), predominantly quartz grains; generally high sphericity; sub-rounded to rounded; well to moderately sorted.

Identified sub-Facies, sedimentary structures and bounding surfaces of note

Outcrop 13.1 [~1.5 (H) x 4.0 (D) x 6.5 m (W)]: **1.** ~1.00 m thick coset of *Sl-hhs <1.0 m (Sh); coset consists of low to high-angle-inclined foresets forming 0.10–0.15 m thick horizontal sets of likely small-scale (<1.5 m) trough cross-bedding, poorly defined cross-bedding;

Outcrop 13.2 [~1.0 (H) x 2.5 (D) x 6.0 m (W)]: **1.** ~1.00 m thick coset of *Sl-hhs <1.0 m (Sh); coset consists of low to high-angle-inclined foresets forming 0.10–0.15 m thick horizontal sets of likely small-scale (<1.5 m) trough cross-bedding, poorly defined cross-bedding;

Outcrop 13.3 [~1.0 (H) x 2.5 (D) x 5.0 m (W)]: **1.** ~0.50 m thick coset of *Sl-hhs <1.0 m (Sh); coset consists of low to high-angle-inclined foresets forming 0.10–0.15 m thick horizontal sets of likely small-scale (<1.5 m) trough cross-bedding, poorly defined cross-bedding; **2.** *Sl-hpx <2.0 m (Sp); low to high-angle-inclined foresets forming medium-scale planar cross-bedding; poorly defined foresets; ~0.50 m thick set with evidence of reactivation surface delineated by minor small to medium pebble lag (Ss-lp-lag(Gh)); sharp and horizontal contact with underlying coset and evidence of minor lag deposit with small to large pebble component;

Outcrop 13.4 [~0.7 (H) x 2.0 (D) x 5.0 m (W)]: **1.** *Sl-hpx <2.0 m (Sp); low to high-angle-inclined foresets forming medium to large-scale planar cross-bedding; poorly defined foresets; ~0.70 m thick set.

Interpretation

Palaeocurrent data implies that the depositional current varied from a south-westerly direction to a predominantly westerly direction, as you move laterally from the eastern to the western section of the outcrop (Fig. 4.4 Location 13). The change in palaeocurrent also coincides with a change in facies, from Sl-hhs <1.0 m to Sl-hpx <2.0 m and the associated channel depth.

The initial set thicknesses associated with facies Sl-hhs <1.0 m (i.e. 0.10-0.15 m) implies that the host channel was relatively shallow (~1.10-1.60 m deep) (cf. Reesink & Bridge, 2009; Leclair, 2011); in contrast the subsequent set thicknesses associated with facies Sl-hpx <2.0 m (0.50-0.70 m) implies that the host channel was much deeper (~5.60-7.60 m deep) (cf. Reesink & Bridge, 2009; Leclair, 2011). Therefore the variable flow depth suggests fluctuating amounts of sediment input and flood event influence. Facies Sl-hhs <1.0 m may represent downstream migration and net accretion of 3D mesoforms within a relatively shallow thalweg region of a low sinuosity channel (cf. Bristow, 1988, 1993a; Ghinassi *et al.,* 2009; Miall, 2010b; Reesink *et al.,* 2014), influenced by waning flow, net sediment aggradation and channel fill (cf. Cant & Walker, 1976; Ashworth *et al.*, 2011; Reesink *et al.*, 2014). Such facies may also indicate migratory bedforms that likely developed on the surface of a larger sand flat (cf. Cant & Walker, 1976, 1978) and/or they may represent the latter stages of a channel fill sequence (cf. Reesink *et al.*, 2014). Similarly, such bedforms are also associated with a series of distinct depositional episodes (cf. Collinson *et al.,* 2006) of assembled sets divided by first-order set boundaries which indicate repeated bedform migration probably as a train of dunes (dune stacking) which may have formed components of a channel bar top (cf. Bristow, 1993b; Best *et al.*, 2003; Bridge & Lunt, 2006; Mumpy *et al*., 2007; Miall, 2010b; Ashworth *et al.*, 2011). The preservation of consecutive cross-laminated sets inevitably encompasses a measure of net deposition and most sets will climb at a similar angle/dip to that of their host bed (Leeder, 1982).

The subsequent deposition of facies Sl-hpx <2.0 m implies an increase in net sediment input and channel depth, probably resulting from a flood event (high-flow stage) and the net deposition of 2D mesoforms during waning flow (low-flow stage) (cf. Coleman, 1969; Bristow, 1987, 1993a; Ashworth *et al.,* 2011). Such flood events may have also influenced thalweg migration and alterations in flow direction, as indicated in the palaeocurrent data relating to facies Sl-hpx <2.0 m (cf. Coleman, 1969; Bristow, 1987; Ashworth *et al.*, 2011). Hence, the facies associated with Outcrops 13.1-13.4 are likely associated with the downstream migration and net aggradation of relatively small scale dunes and subsequent lateral bedform migration influenced by a flood event that facilitated a minor change in thalweg and/or bedform direction and therefore channel migration/direction. The presence of a minor lag deposit at the base of facies Sl-hpx <2.0 m may represent: i. a basal flood deposit (part of) and high-flow stage (cf. Coleman, 1969; Bristow, 1987, 1993a; Ashworth *et al.*, 2011); ii. the location of a channels thalweg/axial region (Fidolini *et al.*, 2013; Ghinassi *et al.*, 2014) where relatively larger bedforms develop (Reesink & Bridge, 2009; Ashworth *et al.*, 2011; Reesink *et al.*, 2014); iii. localised scouring (Miall, 2010b); or iv. winnowing (cf. Collinson *et al.,* 2006) processes.

Table 4.14

Location, grid reference and associated literature	General description and lithology
14. Flat Crags (Heyshaw Moor) Outcrops 14.1-14.1.2: SE 15750 62770 14.2: SE 15742 62777 14.3: SE 15738 62780 14.4: SE 15735 62794 14.5: SE 15728 62802 Thompson, A. T. (1957) *The structure and stratigraphy of Nidderdale between Lofthouse and Dacre*. Unpublished, Doctoral thesis, Durham University. Available at Durham E-Theses Online: http://etheses.dur.ac.uk/722/.	Line of intermittent and fragmented outcrops located along a ridgeline situated within a predominantly moorland setting; outcrops are partially obscured by vegetation and vary in their respected dimensions; they possess a variable texture with occasional small orthoclase feldspar pebble inclusions and relatively poor outcrop detail (e.g. foreset/sets), due to processes of weathering and erosion. Outcrop components examined moving from the southeast to the northwest section, in a general line trending ~140˚ towards 320˚, which extends for ~86 m with numerous smaller boulders scatter either side of the main outcrops which may be interpreted as a fragmented ~265 m long ridgeline extension of Location 13. Old Wife Ridge. Possibility that examined outcrops may have been subjected to minor cambering which would influence azimuth-dip angles. Elevation of Outcrops 14.1-14.5 is ~333 m O.D.; main examined outcrop views are towards 360˚, 060˚, 030˚, 040˚ and 360˚, respectively (Fig. 4.4 Location 14). Outcrop 14.1 (Southeast section): Coarse-grained to granular sandstone with 2-5% small pebble content (variable), predominantly quartz grains; generally high sphericity; sub-angular to rounded; well to moderately sorted; Outcrop 14.1.1 (Central section): Medium-grained to granular sandstone with 2-5% small to medium pebble content (variable), predominantly quartz grains; generally low to high sphericity; sub-angular to well rounded; very well to poorly sorted; Outcrop 14.1.2 (Northwest section): Coarse-grained to granular sandstone with 2-5% small to medium pebble content (variable), predominantly quartz grains; generally low to high sphericity; sub-angular to rounded; very well to moderately sorted; Outcrop 14.2: Coarse-grained to granular sandstone with 2-5% small pebble content (variable), predominantly quartz grains; generally high sphericity; sub-rounded to rounded; very well to moderately sorted; Outcrop 14.3: Coarse-grained to granular sandstone with 2-15% small to large pebble content (variable), predominantly quartz grains; generally high sphericity; sub- rounded to rounded; very well to poorly sorted; Outcrop 14.4: Coarse-grained to granular sandstone with 5-10% small to medium pebble content (variable), predominantly quartz grains; generally low to high sphericity; sub-angular to rounded; moderately to poorly sorted. Outcrop 14.5: Coarse-grained to granular sandstone with 2-10% small to medium pebble content (variable), predominantly quartz grains; generally low to high sphericity; sub-rounded to rounded; well to poorly sorted.

Identified sub-Facies, sedimentary structures and bounding surfaces of note

Outcrop 14.1 [Southeast section; ~2.5 (H) x 5.0 (D) x 14.0 m (W)]: **1.** ~0.80 m thick coset of *Stmx 1.5-3.0 m (St); medium-scale cross-cutting trough cross-bedding 1.5–3.0 m trough width; variable set thickness from 0.20–0.40 m and poorly defined foresets and bounding surfaces; **2.** ~0.70 m coset of *Sl-hpx <2.0 m (Sp); low to high-angle-inclined foresets forming ~0.40 and 0.30 m thick sub-horizontal sets of small to medium-scale planar cross-bedding; poorly defined foresets and bounding surfaces; **3.** ~0.25 m thick coset of *Sl-hss <1.0 m (Sl); likely small-scale trough cross-bedding <1.5 m trough width; coset consists of ~0.10 m thick sub-horizontal sets; poorly defined cross-bedding; **4.** *Sl-hpx <2.0 m (Sp); low to high-angle-inclined foresets forming medium-scale planar cross-bedding; ~0.60 m thick sub-horizontal set; poorly defined foresets and bounding surfaces; **5.** ~0.30 m thick coset of *Sl-hss <1.0 m (Sl); likely small-scale planar cross-bedding; coset consists of ~0.10 m thick sub-horizontal sets; poorly defined foresets and bounding surfaces;

Outcrop 14.1.1 [Central section; ~2.5 (H) x 5.0 (D) x 14.0 m (W)]: **1.** Stmx 1.5-3.0 m (St); medium-scale trough cross-bedding 1.5–3.0 m trough width; ~0.30 m thick set (trough); sharp, predominantly horizontal contact with overlying coset; **2.** ~0.65 m coset of *Sl-hpx <2.0 m (Sp); low to high-angle-inclined foresets forming 0.20, 0.25 and 0.20 m thick sub-horizontal sets of small-scale planar cross-bedding; poorly defined foresets; horizontal contact with underlying set and sub-horizontal contact with overlying coset; **3.** ~0.40 m thick coset of *Sl-hss <1.0 m (Sl); likely small-scale trough cross-bedding; coset consists of 0.10-0.15 m thick sub-horizontal sets; poorly defined foresets and sub-horizontal coset bounding surfaces; **4.** *Sl-hss-of <1.0 m (Sl); low to high-angle-inclined foresets ~0.02 m thick, likely medium-scale oblique planar cross-bedding; ~0.50 m thick sub-horizontal set; poorly defined foresets and set bounding surfaces; **5.** ~0.20 m thick coset of Sl-hss <1.0 m (Sl); likely small-scale trough cross- bedding; coset consists of two ~0.10 m thick sets; sub-horizontal set and coset bounding surfaces; poorly defined low-amplitude foresets; **6.** ~0.30 m thick coset of *Sl-hss <1.0 m (Sl); likely small-scale trough cross-bedding; coset consists of three ~0.10 m thick sets; sub-horizontal set and coset bounding surfaces; poorly defined down-climbing dunes and foresets;

Outcrop 14.1.2 [Northwest section; ~2.5 (H) x 5.0 (D) x 14.0 m (W)]: **1.** ~1.50 m thick coset of *Stmx 1.5-3.0 m (St); medium-scale trough cross-bedding 1.5–3.0 m trough width; four 0.30-0.40 m thick sets (troughs); poorly defined sub-horizontal undulating contact between sets and sub-horizontal planar contact with overlying set; **2.** *Sl-hpx <2.0 m (Sp); low to high-angle-inclined foresets 0.02-0.03 m thick, forming medium-scale planar cross-bedding; ~0.40 m thick sub-horizontal set; poorly defined foresets and sub-horizontal planar contacts with over/underlying cosets; **3.** ~0.25 m thick coset of *Sl-hss <1.0 m (Sl); likely small-scale trough cross-bedding; coset consists of two 0.10-0.15 m thick sub-horizontal sets; poorly defined low-amplitude foresets; poorly defined sub-horizontal planar contact with overlying coset and underlying set; **4.** ~0.30 m thick coset of *Sl-hss <1.0 m (Sl); likely small-scale trough cross-bedding; coset consists of 0.05-0.10 m thick cross-cutting sub-horizontal sets; poorly defined foresets;

Outcrop 14.2 [~2.0 (H) x 3.0 (D) x 4.0 m (W)]: **1.** *Sl-hpx <2.0 m (Sp); low to high-angle-inclined foresets ~0.02 m thick, forming medium to large-scale planar cross-bedding; ~0.70 m thick sub-horizontal set; poorly defined foresets and sharp sub-horizontal contact with overlying coset; **2.** ~0.40 m thick coset of *Sl-hhs <1.0 m (Sh); likely small-scale trough cross-bedding; coset consists of 0.10-0.15 m thick sets; poorly defined foresets; sharp sub-horizontal contact with underlying coset; **3.** ~0.50 m thick coset of *Sl-hhs <1.0 m (Sh); likely small-scale trough cross-bedding; coset consists of 0.10-0.15 m thick sets; poorly defined foresets; poorly defined horizontal contact with underlying coset;

Outcrop 14.3 [~1.8 (H) x 4.0 (D) x 3.0 m (W)]: **1.** ~0.55 m thick coset of Sl-hss <1.0 m (Sl); likely small-scale trough cross-bedding <1.5 m trough width; coset consists of 0.15-0.20 m thick sub-horizontal sets; poorly defined cross-bedding and set bounding surfaces; **2.** *Sl-hpx <2.0 m (Sp); low to high-angle-inclined foresets ~0.03 m thick, forming small to medium-scale planar cross-bedding; ~0.30 m thick sub-horizontal set; poorly defined foresets and sharp sub-horizontal contact with underlying coset; **3.** *Stsx <1.5 m (St); small-scale trough cross-bedding <1.5 m trough width; 0.15-0.30 m thick set; poorly defined cross-bedding, set and overlying coset bounding surfaces; **4.** ~0.30 m thick coset of *Sl-hss-of <1.0 m (Sl); likely small-scale oblique trough cross-bedding <1.5 m trough width; coset consists of ~0.06 m thick sub-horizontal sets; poorly defined cross-bedding, set and coset bounding surfaces; **5.** *Sl-hpx <2.0 m (Sp); low to high-angle-inclined foresets forming small to medium-scale planar cross-bedding; ~0.30 m thick sub-horizontal set; poorly defined foresets and poorly defined sub-horizontal erosive contact with underlying coset; **6.** *Spb >15% (Gt/p); likely pebble rich small-scale trough cross-bedding <1.5 m trough width; ~0.10 m thick set; poorly defined cross-bedding and set bounding surfaces;

Outcrop 14.4 [~0.8 (H) x 3.0 (D) x 9.0 m (W)]: **1.** ~0.80 m thick coset of *Sl-hpx <2.0 m (Sp); low to high-angle-inclined foresets ~0.02 m thick, forming small to medium-scale planar cross-bedding; coset consists of three ~0.25 m thick sub-horizontal sets; poorly defined cross-bedding and set bounding surfaces;

Outcrop 14.5 [~2.0 (H) x 4.0 (D) x 4.0 m (W)]: **1.** ~0.75 m thick coset group of *Sl-hss <1.0 m (Sl); low to high-angle-inclined foresets; two sub-horizontal cosets varying in thickness i.e. ~0.40 and 0.35 m; cosets consist of predominantly ~0.10 m thick sub-horizontal cross-cutting sets; likely poorly defined trough cross-bedding; poorly defined set and coset bounding surfaces; **2.** ~0.30 m thick coset of *Sl-hss <1.0 m (Sl); low to high-angle-inclined foresets; coset consist of ~0.10 m thick sub-horizontal cross-cutting sets; likely poorly defined trough cross-bedding; poorly defined set and coset bounding surfaces; **3.** *Sl-hss-of <1.0 m (Sl); low to high-angle-inclined foresets; likely small-scale oblique planar cross-bedding; set consists of ~0.25 m thick poorly defined planar cross-bedding; poorly defined set and under/overlying coset bounding surfaces; **4.** ~0.90 m thick coset of *Sl-hhs <1.0 m (Sh); low to high-angle-inclined foresets; coset consist of 0.10-20 m thick horizontal cross-cutting sets; likely poorly defined planar and trough cross-bedding; coarser grain component delineates foreset/set boundaries – normal grading; poorly defined set and coset bounding surfaces.

Interpretation

Outcrop 14.1-14.1.2: Generally, foreset palaeocurrent data implies that, as you move up the sequence, the depositional current varies from a westerly to southerly direction; in contrast set data varies more widely from a south-westerly to a north-easterly direction, whereas coset data varies from a north-easterly to a northerly direction (Fig. 4.4 Location 14). Variable set thicknesses of between 0.05 and 0.60 m (facies Sl-hss <1.0 m and Sl-hpx <2.0 m, respectively) implies a maximum dune height and channel depth of ~2.15 m and 6.50 m, respectively (cf. Leclair, 2011). Individual sets may form components of larger host dune cosets (cf. Haszeldine, 1983b) and/or bars, therefore, given that bar heights may adjust between half and bankfull depth (cf. Bristow, 1987; Bridge, 2003; Reesink *et al.*, 2014), a bar thickness of ~2.45 m (Log 3) equates to a maximum bar height and channel depth of ~2.60 m and 5.20 m, respectively (Fig. 4.6 Location 14) (cf. Reesink & Bridge, 2009; Leclair, 2011). The 0.20–0.40 m thick basal facies represented by Stmx 1.5-3.0 m and Sl-hpx <2.0 m, respectively (Logs 1 and 2) likely represent flood events and in channel vertical-accretion (cf. Best *et al.*, 2003; Bridge & Lunt, 2006) and/or downstream-accretion within a relatively broad and deep channel with dune migration near to the thalweg/axis (cf. Reesink & Bridge, 2009; Ashworth *et al.*, 2011; Reesink et al., 2014). The overlying facies of Sl-hss <1.0 m imply limited sediment input into a relatively shallow channel, likely influenced by high-flow stage which facilitated the formation of subcritical set angles, as they migrated over a slower moving or stalled host bedform (cf. Haszeldine, 1983a, 1983b; Collinson *et al.*, 2006). Together with the underlying facies, these mesoforms may form components of small-scale downstream migrating unit bar (cf. Sambrook Smith *et al.*, 2006; Reesink & Bridge, 2009). Such unit bars likely form components of a much larger host compound bar (cf. Allen, 1982; Bridge, 2003; Bridge & Lunt, 2006; Sambrook Smith *et al.*, 2006; Ashworth *et al.*, 2011). The sub-horizontal coset/unit bar contacts are likely third-order erosional surfaces (cf. Miall, 2010b; Ielpi *et al.*, 2014), which denote a component of lateral coset (mesoform) accretion and growth of the host compound bar (macroform) through lateral and downstream-accretion (cf. Bridge & Lunt, 2006). The subsequent facies of Sl-hpx <2.0 m (~0.60 m thick set) (Logs 1 and 2) (Fig. 4.4 Location 14) suggests an increase in channel depth and dune or further unit bar deposition (cf. Bridge & Lunt, 2006; Sambrook Smith *et al.*, 2006; Ashworth *et al.*, 2011) and lateral/downstream-accretion of the host compound bar; net sediment input was likely facilitated by a flood event with sediment migration and aggradation influenced by high and low-flow stages, respectively (Coleman, 1969; Bristow, 1987, 1993a; Ashworth *et al.*, 2011). Similarly, the sequence of facies related to Log 3 and upper facies of Logs 2 and 1 (i.e. Sl-hss-of <1.0 m and Sl-hss <1.0 m, respectively), likely represent deposition of a further unit bar (Fig. 4.4 Location 14) with the uppermost facies Sl-hss <1.0 m (0.05-0.10 m thick sets) representing initial erosion and subsequent bar top vertical and/or upstream-accretion associated with the bar head and/or mid-bar section of a mid-channel bar, primarily due to dune stacking and relative shallow flow depth above the host bar (cf. Best *et al.*, 2003; Bridge & Lunt, 2006; Sambrook Smith *et al.*, 2006; Mumpy *et al.*, 2007). Further, the subcritical set and coset angles (facies Stmx 1.5-3.0 m and Sl-hss <1.0 m, respectively) imply that they migrated over a slower moving or stalled host bedform (cf. Haszeldine, 1983a, 1983b; Collinson *et al.*, 2006) and the relative shallow channel conditions above the host bar relating to facies Sl-hss <1.0 m imply waning flow, aggradation of 3D dunes and channel fill (cf. Cant & Walker, 1976; Ashworth *et al.*, 2011; Reesink *et al.*, 2014). Similarly, preservation of consecutive cross-laminated sets inevitably encompasses a measure of net deposition and subject to the inclination of their host bed most sets will climb at a similar angle (Leeder, 1982).

Preservation of low-angle dune morphology (e.g. Sl-hss <1.0 m) is facilitated by dune stoss and crest erosion, during high flow-stage, and deposition of eroded sediment in the dune's trough (Hendershot *et al.*, 2016). Such low-angle bedforms may be attributed to the migration of low-amplitude (near horizontal) sand waves/dunes concomitant with the transitional zone between lower and upper flow regimes and very shallow fluvial systems (cf. Smith, 1971; Todd, 1996); generally foreset gradients decline as a flow regime intensifies, vice versa (cf. Smith, 1972). Further, tangential (or asymptotic) foresets are promoted by fairly frail separation eddies and a high rate of sediment deposition, from suspension, beyond the slipface of a dune's lee (cf. Leeder, 1982; Bristow, 1993a; Bridge, 2003).

Outcrop 14.2: Palaeocurrent data (Fig. 4.4 Location 14) imply bedform migration towards the south and the basal facies (Sl-hpx <2.0 m, ~0.70 m thick) suggest that the maximum dune height and channel depth was ~2.50 m and ~7.60 m, respectively (cf. Reesink & Bridge, 2009; Leclair, 2011); net sediment input was likely facilitated by a flood event with sediment migration and aggradation of a 2D mesoform influenced by high and low-flow stages, respectively (Coleman, 1969; Bristow, 1987, 1993a; Ashworth *et al.,* 2011). Such facies may also indicate in channel vertical-accretion (cf. Best *et al.*, 2003; Bridge & Lunt, 2006) that likely developed towards the channel thalweg during waning flow (low-flow stage), and/or downstream-accretion within a relatively broad and deep channel with dune migration near to channel thalweg/axis (cf. Reesink & Bridge, 2009; Ashworth *et al.*, 2011; Reesink *et al.*, 2014). The overlying facies of Sl-hhs <1.0 m (i.e. 0.10-0.15 m thick sets) imply a maximum dune height and channel depth of ~0.55 m and ~1.60 m, respectively (cf. Reesink & Bridge, 2009; Leclair, 2011). The relatively shallower channel conditions related to facies Sl-hhs <1.0 m implies waning flow (low-flow stage), limited sediment input and net aggradation of 3D mesoforms and channel fill (cf. Cant & Walker, 1976; Ashworth *et al.*, 2011; Reesink *et al.*, 2014). Such bedforms may also relate to distinct depositional episodes (cf. Collinson *et al.,* 2006) i.e. sets divided by first-order set boundaries, which indicate repeated bedform migration probably as a train of dunes (dune stacking) which may have formed a component of a larger bar top (cf. Bristow, 1993b; Best *et al.*, 2003; Bridge & Lunt, 2006; Miall, 2010b; Ashworth *et al.*, 2011). Together with the underlying facies, these bedforms may form components of a downstream migrating small-scale unit bar (cf. Sambrook Smith *et al.*, 2006; Reesink & Bridge, 2009), which in turn may form a component of a larger compound bar (cf. Allen, 1982; Bridge, 2003; Bridge & Lunt, 2006; Sambrook Smith *et al.*, 2006; Ashworth *et al.*, 2011).

Outcrop 14.3: Palaeocurrent data indicate that boundary contacts (i.e. set and coset) generally dip towards the north, whereas foreset data indicate a south-westerly flow and therefore a degree of lateral-accretion (Fig. 4.4 Location 14). Such data imply that deposition may have been related to bar top vertical and/or upstream-accretion associated with the bar head and/or mid-bar section of a mid-channel bar, primarily due to dune stacking and relative shallow flow depth above the host bar (cf. Best *et al.*, 2003; Bridge & Lunt, 2006; Mumpy *et al*., 2007), where deposition was likely associated with the left of centre component of a channel bar as it migrated downstream, albeit with a component of lateral-accretion. Facies Sl-hss <1.0 m and Sl-hss-of <1.0 m likely form a distinct series of depositional episodes (cf. Collinson *et al.,* 2006) of assembled sets divided by first-order set boundaries which indicate repeated bedform migration probably as a train of dunes (dune stacking) (cf. Bristow, 1993b; Best *et al.*, 2003; Bridge & Lunt, 2006; Miall, 2010b; Ashworth *et al.*, 2011); the subcritical set and coset bounding surface angles imply that they migrated over a much slower moving host bedform (cf. Haszeldine, 1983a, 1983b; Collinson *et al.*, 2006) and the relative shallow channel conditions above the host bar related to facies Sl-hss-of <1.0 m (~0.60 m) imply waning flow, aggradation of 3D dunes and channel fill (cf. Cant & Walker, 1976; Ashworth *et al.*, 2011; Reesink *et al.*, 2014). Similarly, preservation of consecutive cross-laminated sets inevitably encompasses a measure of net deposition and subject to the inclination of their host bed most sets will climb at a similar angle (Leeder, 1982). In contrast, facies Sl-hpx <2.0 m and Stsx <1.5 m imply deposition was influenced by increasing flow depth likely facilitated by flood events (high-flow stage) and subsequent net sediment deposition during waning flow (low-flow stage) (cf. Coleman, 1969; Bristow, 1987, 1993a; Ashworth *et al.,* 2011); similarly, Spb >15% likely represents a basal flood/scour deposit and high-flow stage (cf. Coleman, 1969; Bristow, 1987, 1993a; Ashworth *et al.*, 2011), together with the two distinct episodes of Sl-hpx <2.0 m suggest that channel bar deposition was influenced by at least three flood events.

Outcrop 14.4: Limited and variable palaeocurrent data (Fig. 4.4 Location 14) indicate that the general flow during deposition was towards the southwest and the set thickness associated with facies Sl- hpx <2.0 m (~0.25) suggest a maximum dune height and channel depth of ~0.90 m and ~2.70 m, respectively. The relatively coarse grain and granular texture, pebble content and size of cross-bedding implies downstream-accretion within a relatively broad and deep channel with bedform migration near to the channel thalweg/axis (cf. Reesink & Bridge, 2009; Ashworth *et al.*, 2011; Reesink *et al.*, 2014). Facies Sl-hpx <2.0 m consists of repeated grain flow avalanche deposits (~0.02 m thick foresets; see Smith, 1972; Reesink & Bridge, 2007, 2009), with the host sets likely relating to a series of distinct depositional episodes (cf. Collinson *et al.,* 2006) of assembled sets divided by first-order set boundaries, indicating repeated bedform migration probably as a train of dunes (dune stacking) which may form components of a larger bar (macroform) top (cf. Bristow, 1993b; Best *et al.*, 2003; Bridge & Lunt, 2006; Miall, 2010b; Ashworth *et al.*, 2011); the preservation of consecutive cross-laminated sets inevitably encompasses a measure of net deposition (Leeder, 1982). The variable foreset azimuth-inclinations and angular foreset contacts related to the bedform likely represent the downstream migration and net aggradation of a transverse bar (2D macroform), rather than a longitudinal or diagonal bar (cf. Smith, 1972; Hein & Walker, 1977; Collinson *et al.,* 2006); although such bar heights coincide with dune heights (Ashworth *et al.*, 2011). Foreset variability was likely due to the lobate and asymmetrical morphology of the bar's tail and the angular foreset contacts were likely generated due to low fluid and low sediment discharge (cf. Smith, 1972; Hein & Walker, 1977; Collinson *et al.,* 2006; Bridge, 2003). Hence, facies Sl-hpx <2.0 m likely represent the accretion of a transverse bar where sediment deposition was influenced by increasing channel depth facilitated by a flood event (high-flow stage) and subsequent net sediment deposition during waning flow (low-flow stage) (cf. Coleman, 1969; Bristow, 1987, 1993a; Ashworth *et al.,* 2011).

Outcrop 14.5: Although limited and variable, palaeocurrent data (Fig. 4.4 Location 14) indicate that coset and set azimuths dip towards the west and northwest; in contrast the predominant foreset dip direction is towards the southwest, suggesting that deposition was influenced, in part, by a degree of lateral-accretion. Set thicknesses indicate variable dune thickness and related channel depth; facies Sl-hss <1.0 m imply a maximum dune height and channel depth of ~0.35 m and ~1.10 m, respectively, whereas facies Sl-hss-of <1.0 m imply a maximum dune height and channel depth of ~0.90 m and ~2.70 m, respectively (cf. Reesink & Bridge, 2009; Leclair, 2011). Therefore, variable flow depth suggests fluctuating amounts of potential sediment input and influence of flood events. Facies Sl-hss <1.0 m may represent: i. downstream-accretion of 3D mesoform within a relatively shallow thalweg region of a low sinuosity channel influenced by high-flow stage which facilitated the formation of down-climbing dunes (cf. Bristow, 1988, 1993a; Ghinassi *et al.,* 2009; Miall, 2010b; Reesink *et al.,* 2014); ii. bar top vertical-accretion component of a channel bar, primarily due to dune stacking and relative shallow flow depth above the host bar (cf. Best *et al.*, 2003; Bridge & Lunt, 2006); or iii. recurring downstream migration of 3D mesoforms, probably as a train of dunes over the crest or front/tail of a migrating channel bar (macroform) (cf. Allen, 1982; Haszeldine, 1983b; Miall, 2010b; Ashworth *et al.*, 2011). The subsequent deposition of facies Sl-hss-of <1.0 m implies an increase in net sediment input and channel depth, probably resulting from a flood event (high-flow stage) and the net deposition, through lateral-accretion, of 2D mesoforms during waning flow (low-flow stage) (cf. Coleman, 1969; Bristow, 1987, 1993a; Ashworth *et al.,* 2011). Such flood events may have also influenced thalweg migration and alterations in flow direction, as indicated in the palaeocurrent data relating to facies Sl-hss-of <1.0 m and subsequent facies Sl-hhs <1.0 m (cf. Coleman, 1969; Bristow, 1987; Ashworth *et al.*, 2011). The relative shallower channel conditions related to facies Sl-hhs <1.0 m implies waning flow, aggradation of 2D and 3D mesoforms and channel fill (cf. Cant & Walker, 1976; Ashworth *et al.*, 2011; Reesink *et al.*, 2014); preservation of consecutive cross-laminated sets inevitably encompasses a measure of net deposition and most sets will climb at a similar angle/dip to that of their host bed (Leeder, 1982).

Overall, the elevation of the fragmented ~265 m long ridgeline encompassing Old Wife Ridge (Location 13) and Flat Crags (Location 14) varies by ~5.0 m, from Outcrop 13.1 (338 m) to Outcrop 14.5 (333 m), which implies that all the outcrops are related components of a fluvial system that extended horizontally for ~ 265 m. Similarly, the general southerly to westerly palaeocurrents associated with both locations indicates that deposition was influenced by similar palaeocurrents, further suggesting a horizontal relationship. The outcrops relating to Location 13 and 14 are therefore likely to be intermittent components of a multi-channel (braided) fluvial system (cf. Reesink *et al*., 2014). Such systems encompass a hierarchy of first, second and third-order channels, i.e. main channel, main channel partitioned by bars and bar top chute channels, respectively; equally, second-order channels may subdivide channel bars (cf. Bristow, 1987; Bridge, 2003; Miall, 2010b and references there in). For example, Outcrop 14.1-14.1.2 likely represents a compound bar remnant which acted to partition the first-order main channel, thereby generating two second-order channels; the basal flood/scour deposit on the surface of Outcrop 14.3 may form the remnant base of a third-order chute channel. Further, the shallow inclined (mainly ≤12°) first-order and second-order bounding surface dips may correspond to channels possessing high width to depth ratios (Bristow, 1993a) and down-climbing dunes may denote small-scale unit bars (cf. Sambrook Smith *et al.*, 2006; Reesink & Bridge, 2009).

Table 4.15

Location, grid reference and associated literature	General description and lithology
15. High Kettle Spring Farm Outcrop 15.1: SE 26920 62414 Thompson, A. T. (1957) *The structure and stratigraphy of Nidderdale between Lofthouse and Dacre*. Unpublished, Doctoral thesis, Durham University. Available at Durham E-Theses Online: http://etheses.dur.ac.uk/722/.	Small disused quarry situated on the edge of small woodland area adjacent to a public bridleway; the outcrop is partially obscured by vegetation (i.e. trees/shrubs) and possesses a very jointed with a bulbous and blocky/jointed structure and relatively very poor outcrop detail (e.g. foreset/sets), due to processes of weathering and erosion; base of quarry is also obscured by ~1.50 m of leaf mould and associated detritus. Outcrop examined moving from the east (right) towards the northwest (left) section of the outcrop. Elevation of Outcrop is ~105 m O.D.; main outcrop view is towards ~030˚ (Fig. 4.4 Location 15). Outcrop 15.1: Coarse-grained to granular sandstone with 2-5% small to medium pebble content (variable), predominantly quartz grains; generally high sphericity; sub-rounded to rounded; very well to poorly sorted.

Identified sub-Facies, sedimentary structures and bounding surfaces of note

Outcrop 15.1 [~9.5 (H) x 5.0 (D) x 30.0 m (W)]: **1.** Eastern section; ~1.50 m thick coset of possibly *Stsx <1.5 m (St); small-scale trough cross-bedding <1.5 m trough width; very poorly defined sedimentary features i.e. set and foreset details; sharp sub-horizontal contact with overlying coset; **2.** Central section; ~1.90 m thick coset of possibly *Stsx <1.5 m (St); small-scale trough cross-bedding <1.5 m trough width; very poorly defined sedimentary features i.e. set and foreset details; sharp sub-horizontal contact with the under and overlying coset; **3.** Central section; ~1.00 m thick coset of possibly *Stsx <1.5 m (St); small-scale trough cross-bedding <1.5 m trough width; very poorly defined sedimentary features i.e. set and foreset details; sharp sub-horizontal contact with underlying coset and apparent horizontal contact with overlying set; **4.** North western section; ~3.00 m thick set of possibly *Sl-hpx >2.0 m (Sp); very large-scale planar cross-bedding; no obvious internal coset/set details; poorly defined sedimentary features i.e. foreset details; sharp apparent horizontal contact with underlying coset and overlying set; **5.** North western section; ~0.20 m thick set of *Stsx <1.5 m (St); small-scale trough cross-bedding <1.5 m trough width; poorly defined sedimentary features i.e. set and foreset details; very low-amplitude cross-bedding; sharp apparent horizontal contact with underlying set; **6.** North western section; Ss-lp-lag (Gh); small to large pebble lag deposit; intermittent lag deposit ~0.02 m thick; likely forms base of overlying set (in part); **7.** North western section; ~0.20 m thick set of Stsx <1.5 m (St); small-scale trough cross-bedding <1.5 m trough width; poorly defined sedimentary features i.e. set and foreset details; sharp sub-horizontal contact with overlying coset; **8.** North western section; ~1.50 m thick coset of *Sl-hhs <1.0 m (Sh); small-scale trough cross-bedding <1.5 m trough width; variable set thickness between ~0.10 m and 0.20 m; poorly defined sedimentary features i.e. set and foreset details; sharp sub-horizontal contact with underlying set; evidence of flute mark, groove casts and prod marks along base/underside.

Interpretation

Although limited and variable, palaeocurrent data (Fig. 4.4 Location 15) indicate that the principal depositional palaeocurrent was towards the north-northeast. The rounded morphology relating to the initial two cosets of facies Stsx <1.5 m may represent: i. downstream-accretion of 3D mesoforms within a relatively shallow thalweg region of a low sinuosity channel influenced by high-flow stage which facilitated the formation of down-climbing dunes (cf. Bristow, 1988, 1993a; Ghinassi *et al.,* 2009; Miall, 2010b; Reesink *et al.,* 2014); ii. bar top vertical-accretion component of a channel bar, primarily due to dune stacking and relative shallow flow depth above the host bar (cf. Best *et al.*, 2003; Bridge & Lunt, 2006); or iii. migratory mid-channel bar bedform components; dune set components of such cosets likely formed within a multi-channelled fluvial system (cf. Reesink *et al*., 2014) and such cosets may form individual consecutive small-scale unit bar components (cf. Sambrook Smith *et al.*, 2006; Reesink & Bridge, 2009) of a much larger compound bar (cf. Allen, 1982; Bridge, 2003; Bridge & Lunt, 2006; Sambrook Smith *et al.*, 2006; Ashworth *et al.*, 2011); similarly, cosets with multiple individual sets may also form components of a larger host dune coset (cf. Haszeldine, 1983b). Further, preservation of consecutive cross-laminated sets inevitably encompasses a measure of net deposition and subject to the inclination of their host bed most sets will climb at a similar angle (Leeder, 1982).

The third consecutive coset relating to Stsx <1.5 m may represent a further expansion of the compound bar, both vertically and laterally, primarily through dune stacking due to relative shallow flow depth above the host bar (cf. Best *et al.*, 2003; Bridge & Lunt, 2006) which likely, in turn, facilitated expansion through lateral-accretion. A reduction in accommodation space along the bar top may have contributed to lateral expansion. Evidence of lateral-accretion is implied primarily from the jointing dips associated with the partially obscured rock contiguous to the eastern section of the initial two cosets relating to facies Stsx <1.5 m, see above (Fig. 4.4 Location 15).

The overlying easterly migrating very large-scale planar tabular cross-bedding (facies Sl-hpx >2.0 m) likely represents an alternate bar (2D macroform; McCabe, 1977; Collinson, 1996; Collinson *et al.*, 2006; Miall, 2010b) and increase in palaeo-discharge. McCabe (1977) interpreted alternate bars to have formed within distributary channels between 1.0 to 2.0 km wide and 30.0 to 40.0 m deep. Similarly, the scale of facies Sl-hpx >2.0 m (~3.00 m thick) suggests that the alternate bar probably formed in a relatively deep channel (cf. Reesink & Bridge, 2009; Ashworth et al., 2011; Reesink *et al.*, 2014). The shallow inclined (12°) first-order bounding surface dip also corresponds with McCabe's (1977) observation that distributary channel dips were in the region of ≤10° and Bristow (1993a) arguing that bounding surfaces, with very low depositional dips, correspond to channels possessing high width to depth ratios. Given that bar heights may vary between half and bankfull depth (cf. Bristow, 1987; Bridge, 2003; Reesink *et al.*, 2014), the preserved thickness of facies Sl-hpx >2.0 m (~3.00 m) suggests that the bar height and therefore depth of the host channel was, at a minimum, in the region of 9.0 to 18.0 m (cf. Bristow, 1987; Bridge, 2003; Reesink *et al.*, 2014). Alternate bars may: i. be attached to and migrate obliquely to a channel bank (McCabe, 1977; Collinson, 1996; Collinson *et al.*, 2006); ii. develop as large mid-channel forms (Collinson, 1996; Collinson *et al.*, 2006); or iii. develop in scour pools related to a channel confluence (McCabe, 1977;

Collinson, 1996; Collinson *et al.*, 2006). Relative to the underlying unit, the scale of facies Sl-hpx >2.0 m implies an increase in channel depth and sediment input under laminar flow conditions. The addition of facies Sl-hpx >2.0 m within the channel was likely facilitated by a flood event and subsequent net sediment deposition (aggradation) during falling-flow stage (cf. Coleman, 1969; Bristow, 1987, 1993a; Ashworth *et al.,* 2011), which would reduce flow depth over the bar top, thereby increasing flow velocity and sediment transport (cf. Reesink & Bridge, 2009). Such conditions probably facilitated the formation of facies Stsx <1.5 m and the intervening lag deposit (facies Ss-lp-lag), which likely represents scouring (Miall, 2010b) or winnowing (cf. Collinson *et al.,* 2006) processes with no obvious evidence of a fifth-order channel surface; although, such lag deposits may also denote channel thalweg/axial regions (Fidolini *et al.*, 2013; Ghinassi *et al.*, 2014).

Scour and tool marks (i.e. Flute and grooves, respectively) at the base of the ensuing coset of facies Sl-hhs <1.0 m indicates that the host channel had experienced a hiatus with regard to deposition of sand grade sediment in favour of a veneer of probably mud grade sediment, sufficiently thick enough to facilitate the formation of scour and tool marks prior to their preservation promoted by the subsequent deposition of coarse to very coarse grained sediment (facies Sl-hhs <1.0 m), both of which may have been generated sequentially by the same palaeocurrent (cf. Collinson *et al.*, 2006). The variable set thickness (i.e. 0.10 to 0.20 m) and the lateral extent (~30.00 m) relating to facies Sl-hhs <1.0 m implies that the depth of host channel above the alternate bar likely varied between ~1.10 and ~2.20 m, respectively (cf. Reesink & Bridge, 2009; Leclair, 2011). Facies Sl-hhs <1.0 m may represent downstream migration and net accretion of 3D mesoforms within a relatively shallow thalweg region of a low sinuosity channel (cf. Bristow, 1988, 1993a; Ghinassi *et al.,* 2009; Miall, 2010b; Reesink *et al.,* 2014), influenced by waning flow, net sediment aggradation and channel fill (cf. Cant & Walker, 1976; Ashworth *et al.*, 2011; Reesink *et al.*, 2014). Such facies may also indicate migratory bedforms that likely developed on the surface of a larger sand flat (cf. Cant & Walker, 1976, 1978), likely generated by the underlying alternate bar and/or they may represent the latter stages of a channel fill sequence (cf. Reesink *et al.*, 2014); although such bar heights coincide with dune heights (Ashworth *et al.*, 2011). Similarly, such bedforms are also associated with a series of distinct depositional episodes (cf. Collinson *et al.,* 2006) of assembled sets divided by first-order set boundaries which indicate repeated bedform migration probably as a train of dunes (dune stacking) which may have formed surface components of the underlying alternate bar, for example (cf. Bristow, 1993b; Best *et al.*, 2003; Bridge & Lunt, 2006; Miall, 2010b; Ashworth *et al.*, 2011). The preservation of consecutive cross-laminated sets inevitably encompasses a measure of net deposition and most sets will climb at a similar angle/dip to that of their host bed (Leeder, 1982).

Table 4.16

Location, grid reference and associated literature	General description and lithology
16. High Mill – Shaw Mills Outcrop 16.1: SE 25282 62696 Thompson, A. T. (1957) *The structure and stratigraphy of Nidderdale between Lofthouse and Dacre*. Unpublished, Doctoral thesis, Durham University. Available at Durham E-Theses Online: http://etheses.dur.ac.uk/722/.	Possible face of an old abandoned quarry, very little outcrop visible ~ 2 m high and 3 m wide, depth unknown. Location overgrown with vegetation (e.g. Brambles and Ivy) and therefore only small section of outcrop visible. Outcrop appears to encompass of a predominantly fragmented fissile and friable grey shale type rock capped by a sandstone unit, not clearly visible. Relatively poor outcrop detail (e.g. foreset/sets), due to processes of weathering and erosion. Elevation of Outcrop is ~104 m O.D.; main outcrop view is towards ~350˚ (Fig. 4.4 Location 16). Outcrop 16.1: Base and main part of outcrop consists of a laminated and very fragmented fissile and friable grey shale type rock, mud/clay sized particles; surface section of outcrop capped by a medium to very coarse-grained (variable) sandstone; predominantly quartz grains; generally high sphericity; sub-rounded to rounded; moderately to well sorted.

Identified sub-Facies, sedimentary structures and bounding surfaces of note

Outcrop 16.1 [~2.0 (H) x unknown (D) x 3.0 m (W)]: **1.** Main section; ~1.50 m thick section of Sh-l (Fl); very fragmented ~0.005 m thick laminations; fissile and friable grey shale type rock; mud/clay sized particles; undulating contact with overlying unit; **2.** Surface/top section; partially visible unit likely ~0.50 m thick section of Stsx <1.5 m (St); small-scale trough cross-bedding <1.5 m trough width; very fragmented; no clear evidence of internal structures, such as sets and foresets.

Interpretation

No obvious palaeocurrent details present. Location consists of a primarily laminated grey shale type rock or mudstone (cf. Collinson *et al.,* 2006). Citing Bates & Jackson (1987), O'Brien (1996) highlights the main distinction between shales and mudstones, that is, although shales and mudstones have a similar composition and texture (i.e. a detrital argillaceous sedimentary rock), shales possess a finely laminated and fissile structure which is absent in mudstones (cf. Neuendorf *et al.,* 2011). Tucker (2001) details sediment variables such as oxicity-anoxicity, fauna and organic matter content which may influence the colour of mud sediments and therefore the colour of any subsequent shale/mudrock. For example poor organic matter preservation during normal marine conditions where oxic environments extend into the sediment may result in light grey and other colouring, whilst during euxinic conditions where anoxic environments extend throughout the sediment and well into the overlying water, excellent preservation of organic matter results in black colouring and the presence of pyrite (Iron Sulphide – FeS_2) minerals (Tucker, 2001). Schmoker (1981) also shows that grey shales possess little or no organic matter, whilst black shales possess relatively higher levels of organic matter. Therefore, the observed grey colouring of the shale at Outcrop 16.1 indicates that there is little or no preserved organic matter and the shale sediments were likely deposited in an oxic environment (e.g. fresh flowing water).

Although there is insufficient exposure to provide a definite interpretation of its formation, Thompson (1957) equates a grey shale rock within an old quarry by High Mill to the Libishaw Shales, directly overlain by the Lower Brimham Grit, thereby highlighting an erosive unconformity at the base of the Lower Brimham Grit (Thompson, 1957; cf. Reid, 1996). Hudson (1937) was the first to adopt the term Libishaw Shales (Wilson, 1957) and associate the base of the Libishaw Shales with black shales; Thompson (1957) describes the Libishaw Shales as a grey argillaceous shale (i.e. silt to clay sized sediment) with several marine bands close to its base, likely black shales. The basal fossiliferous level contains both lamellibranch (Bivalve) and goniatite (*Reticuloceras aff. Pulchellum*) fauna, goniatite fauna forms part of the *Reticuloceras eoreticulatum* zone (Thompson, 1957), i.e. $R_{1b}1$ ammonoid zone which delineates the latter stages (*ca* 320.0 Ma) of a protracted interglacial period which concluded at *ca* 319.5 Ma (Waters & Condon, 2012).

The following outline how abandoned channels could form sediment traps that may accommodate shale type laminated fills. Variable degrees of channel modifying processes generate abandoned channels including meander bend neck or chute cutoffs (High sinuosity channels) and channel-belt avulsion-abandonment of bifurcation channels (Low sinuosity channels), through disconnection from the main channel and local switching of the main channel to a neighbouring section of the floodplain (Toonen *et al.*, 2012). Such abandoned channels, and their associated depressions, form floodplain lakes which operate as sediment traps during flood events and thereby, over time, generate a layered sedimentary fill through suspended load deposition, post complete disconnection (Toonen *et al.*, 2012).

Due to temporal variations associated with the transitional stage, from initial abandonment to complete disconnection, abandoned bifurcation channel lakes may take centuries before complete disconnection, whereas oxbow lakes (i.e. meander bend neck or chute cutoffs) may take up to a decade before complete disconnection (Toonen *et al.*, 2012). Therefore, during initial disconnection accommodation space associated with abandoned bifurcation channel lakes is occupied more by proximal coarse-grained fill, which leaves less room for subsequent distal fine grained suspension load deposition (laminated fill), post complete disconnection (Toonen *et al.*, 2012). Conversely, during initial disconnection accommodation space associated with oxbow lakes is occupied less by proximal coarse-grained fill, which leaves more room for subsequent distal fine grained suspension load deposition (laminated fill), post complete disconnection (Toonen *et al.*, 2012). Further, Constantine *et al.* (2010) argue that the aggradation rate within the entrance of an abandoned channel is a function of the diversion angle between the main (active) and disconnected (abandoned) channel (Fig. 4.4 Location 16) (cf. Ishii & Hori, 2016); that is, channels with relatively high diversion angles experience rapid channel disconnection and little coarse-grained sediment deposition, whereas channels with low diversion angles experience slower channel disconnection and a high level coarse-grained sediment deposition (cf. Ishii & Hori, 2016). Toonen *et al.* (2012) equate oxbow lakes with high diversion angles and abandoned bifurcation channel lakes with low diversion angles.

Similarly, Citterio & Piégay (2009) show that former braided channels form straight and narrow lakes with relatively low sedimentation rates (e.g. ~0 to 10 $mm.yr^{-1}$), whereas former anastomosed and meandering channels form increasingly wider and sinuous channel lakes with a corresponding increase in sedimentation rates, respectively (e.g. ~4 to 10 $mm.yr^{-1}$ – anastomosed channel lakes; ~3 to 26 $mm.yr^{-1}$ – meandered channel lakes). Further, Citterio & Piégay (2009) point out that, in alluvial channels, meander bend lakes (e.g. oxbow lakes) possess some of the most effective sediment trapping characteristics, although sedimentation rates relating to oxbow lakes vary depending on their environment (Ishii & Hori, 2016).

References made to the presence of shale partings and beds associated with the Lower Brimham Grit (see Thompson, 1957; Reid, 1996) may (in part) be related to the above processes, particularly to references of thin shale partings, although they may not be able to account for the apparent areal extent of some shale deposits mentioned. Further, the shallow ramp-type shelf margin associated with the Askrigg Block and Craven Basin boundary, would have been very sensitive to temporal variations in base sea-level (Reid, 1996), which may have been influenced further by subsidence linked to syn-sedimentary tectonic activity. Such sensitivity to eustatic variations may have facilitated deposition of relatively thicker intermittent shale horizons, which likely inter-fingered with the Lower Brimham Grit to form intermittent shale deposits. The presence of chalybite nodules and thin sandstone lenses in a shale parting observed by Thompson (1957) may be evidence of such influence. Chalybite [or more generally siderite ($FeCo_3$), see Bishop *et al.*, 2001] mineralisation is related to hydrothermal alteration (Bishop *et al.*, 2001; Wenk & Bulakh, 2004) and anoxic (reducing) environments (Wenk & Bulakh, 2004), such as those related to shales.

Table 4.17

Location, grid reference and associated literature	General description and lithology
17. Rabbit Hill Farm Outcrops 17.1: SE 23492 65220 17.2: SE 23494 65254 17.3: SE 23482 65299 Thompson, A. T. (1957) *The structure and stratigraphy of Nidderdale between Lofthouse and Dacre*. Unpublished, Doctoral thesis, Durham University. Available at Durham E-Theses Online: http://etheses.dur.ac.uk/722/.	Line of intermittent fragmented blocky and jointed outcrops located within a narrow strip of woodland to the south of Rabbit Hill Farm. Adjacent land consists of predominantly managed farm and woodland with evidence of numerous boulders/blocks of Lower Brimham Grit scattered within the fields and woodland to the east and south of Rabbit Hill Farm; the majority of boulders/blocks are covered in algae, moss, lichen and are partially buried under soil cover; due to the effects of weathering and erosion, the scattered outcrops have no discernible sedimentary features e.g. foreset and/or set bounding surfaces. The main outcrops are partially obscured by vegetation and vary in their respected dimensions; they possess a variable texture and relatively poor outcrop detail (e.g. foreset/sets), due to processes of weathering and erosion, and may have been subjected to minor downward cambering towards the east. Outcrop components examined moving from the southern to the northern section, in a general line trending ~180˚ towards 360˚, which extends for ~120 m into the main woodland area. Elevation of Outcrops 17.1-17.3 is ~204; 208 and 210 m O.D., respectively; main examined outcrop views are towards 036˚, 040˚ and 164˚, respectively (Fig. 4.4 Location 17). Outcrop 17.1 (Southern section): Coarse-grained to granular sandstone with 2-10% small to large pebble content (variable; up to ~50% within lag deposit), predominantly quartz grains; generally low to high sphericity; sub-angular to rounded; well to poorly sorted; Outcrop 17.2 (Central section): Coarse-grained to granular sandstone with ~2% small pebble content (variable), predominantly quartz grains; generally low to high sphericity; sub-angular to rounded; well to moderately sorted; Outcrop 17.3 (Northern section): Coarse-grained to granular sandstone with 2-20% small to large pebble content (variable), predominantly quartz grains; generally low to high sphericity; sub-angular to rounded; moderately to poorly sorted.

Identified sub-Facies, sedimentary structures and bounding surfaces of note

Outcrop 17.1 [~3.5 (H) x 5.0 (D) x 18.0 m (W)]: **1.** ~0.50 m thick coset of *Sl-hss <1.0 m (Sl); likely small-scale trough cross-bedding; coset consists of ~0.15 m thick sub-horizontal sets; poorly defined foresets; erosive sub-horizontal contact with overlying coset; **2.** ~1.30 m thick coset of *Stsx <1.5 m (St); small to medium-scale trough cross-bedding with variable up to ~0.30 m thick troughs; exhibiting signs of coarsening up, more granules and pebbles towards the surface; poorly defined sub-horizontal contact with overlying set; **3.** *Sl-hss-of <1.0 m (Sl); low to high-angle-inclined foresets forming medium-scale oblique planar cross-bedding; ~0.45 m thick set; poorly defined cross-bedding and sub-horizontal set bounding surface with overlying lag deposit; set pinches out after ~6.00 m along width of outcrop; **4.** *Ss-lp-lag (Gh); small to medium pebble lag deposit; intermittent lag deposit ~0.04 m thick; predominantly granular with up to ~50% pebble content; likely forms base of overlying coset (in part); **5.** ~1.00 m thick coset of *Sl-hss-of <1.0 m (Sl); small to medium-scale oblique trough cross-bedding <1.5 m trough width, coarser grain/pebble component towards base of troughs; coset consists of 0.20-0.30 m thick cross-cutting sub-horizontal sets; poorly defined cross-bedding and set bounding surfaces;
6. ~0.50 m thick set of Ssd (Sd); likely small-scale cross-cutting trough cross-bedding <1.5 m trough width; poorly defined set bounding surfaces and cross-bedding; evidence of de-watering i.e. flame structures, primary facies Ssd;

Outcrop 17.2 [~2.0 (H) x 4.0 (D) x 7.0 m (W)]: **1.** ~0.90 m thick coset of *Sl-hss <1.0 m (Sl); likely small-scale trough cross-bedding <1.5 m trough width; coset consists of 0.10-0.15 m thick sub-horizontal cross-cutting sets; poorly defined cross-bedding and set bounding surfaces; **2.** ~1.00 m thick coset of *Sl-hss <1.0 m (Sl); likely small-scale trough cross-bedding <1.5 m trough width; coset consists of 0.10-0.15 m thick sub-horizontal cross-cutting sets; poorly defined cross-bedding and set bounding surfaces;

Outcrop 17.3 [~5.0 (H) x 6.0 (D) x 11.0 m (W)]: **1.** ~1.30 m thick coset of Spb >15% (Gt/p); likely pebble rich small-scale trough cross-bedding <1.5 m trough width; 0.10-0.15 m thick sets; poorly defined cross-bedding and set bounding surfaces; unit extends intermittently for ~18.0 m northwards into adjacent woodland; sub-horizontal contact with overlying lag deposit; **2.** *Ss-lp-lag (Gh); small to large pebble lag deposit; intermittent lag deposit ~0.02 m thick; likely forms sub-horizontal base of overlying coset (in part); **3.** ~0.75 m thick coset of *Sl-hss <1.0 m (Sl); likely small-scale planar cross-bedding; coset consists of 0.10-0.15 m thick sub-horizontal sets, coarser granule component concentrated towards base of sets; poorly defined foresets; sub-horizontal contact with overlying coset; **4.** ~0.65 m thick coset of *Sl-hpx <2.0 m (Sp); small to medium-scale planar cross-bedding; coset consists of 0.30-0.35 m thick sets with ~0.03 m thick foresets delineated by coarser granule component concentrated towards base of foresets; sub-horizontal undulating contact with overlying coset; **5.** ~1.00 m thick coset of *Sl-hss <1.0 m (Sl); small-scale trough cross-bedding; coset consists of 0.10-0.15 m thick sub-horizontal sets; poorly defined cross-bedding and set bounding surfaces; erosive sub-horizontal contact with overlying coset; **6.** ~1.40 m thick coset of *Stmx 1.5-3.0 m (St); medium-scale trough cross-bedding 1.5–3.0 m trough width; ~0.60 m thick sets (troughs), variable; poorly defined cross-bedding and set bounding surfaces.

Interpretation

Variable palaeocurrent data associated with Outcrop 17.1 suggest that deposition was influenced by initial westerly and subsequent easterly and south-westerly palaeocurrents, respectively; Outcrop 17.2 was influenced by southerly palaeocurrents whilst Outcrop 17.3 was influenced by south-easterly and easterly palaeocurrents, respectively (Fig. 4.4 Location 17).

Outcrop 17.1: Facies Sl-hss <1.0 m and Stsx <1.5 m may represent: i. downstream-accretion of 3D mesoforms within a relatively shallow thalweg region of a low sinuosity channel influenced by high-flow stage which facilitated the formation of down-climbing dunes (cf. Bristow, 1988, 1993a; Ghinassi *et al.,* 2009; Miall, 2010b; Reesink *et al.,* 2014); ii. bar top vertical-accretion component of a channel bar, primarily due to dune stacking and relative shallow flow depth above the host bar (cf. Best *et al.*, 2003; Bridge & Lunt, 2006); iii. recurring downstream migration of 3D mesoforms, probably as a train of dunes over the crest or front/tail of a migrating channel bar (macroform) (cf. Allen, 1982; Haszeldine, 1983b; Miall, 2010b; Ashworth *et al.*, 2011); iv. individual sub-horizontal set components of a larger host dune coset (cf. Haszeldine, 1983b); or v. small-scale downstream migrating unit bars (cf. Sambrook Smith *et al.*, 2006; Reesink & Bridge, 2009), which in turn likely form components of a much larger host compound bar (cf. Allen, 1982; Bridge, 2003; Bridge & Lunt, 2006; Sambrook Smith *et al.*, 2006; Ashworth *et al.*, 2011), although such component coset/unit bar heights coincide with dune heights (Ashworth *et al.*, 2011). Similarly, preservation of consecutive cross-laminated sets inevitably encompasses a measure of net deposition and subject to the inclination of their host bed most sets will climb at a similar angle (Leeder, 1982). Facies Sl-hss-of <1.0 m implies an increase in net sediment input and channel depth, probably resulting from a flood event (high-flow stage) with net deposition and lateral-accretion of 2D mesoforms during waning flow (low-flow stage) (cf. Coleman, 1969; Bristow, 1987, 1993a; Ashworth *et al.,* 2011). Such flood events may have also influenced thalweg migration and alterations in flow direction, as indicated in the palaeocurrent data relating to facies Sl-hss-of <1.0 m and subsequent deposition of facies Sl-hss-of <1.0 m (cf. Coleman, 1969; Bristow, 1987; Ashworth *et al.*, 2011). Further, topographic lows adjacent to bar margins may limit falling-stage currents that flow between bars (Collinson, 1970; cf. Reesink *et al*., 2014), thereby facilitating lateral-accretion by promoting deposition along bar margins (Collinson, 1970, 1996); similarly, the fluctuating easterly and westerly foreset palaeocurrent data (Fig. 4.4 Location 17) imply that deposition may have been influenced by lateral-accretion and/or dune-scale bedform migration obliquely over, around and down a curved barform front/tail (cf. Haszeldine, 1983b) and may account for the pinching out of the initial facies unit of Sl- hss-of <1.0 m. The intervening intermittent lag deposit (Ss-lp-lag) likely represents scouring (Miall, 2010b) or winnowing (cf. Collinson *et al.,* 2006) processes with no obvious evidence of a fifth-order channel surface. Soft sediment deformation (i.e. dish and flame structures) at the surface of the outcrop imply loss of grain stability (liquefaction) within unconsolidated water laden sediments, probably facilitated by sudden overburden (rapid sediment deposition) post flood event and/or syn-sedimentary tectonic activity post deposition (cf. Barnhardt & Sherrod, 2006; Hubert-Ferrari *et al.*, 2017).

Outcrop 17.2: See above interpretation relating to facies Sl-hss <1.0 m. The sub-horizontal contact between the two units of facies Sl-hss <1.0 likely represents a third-order erosional surface (cf. Miall, 2010b; Ielpi *et al*., 2014) which denotes lateral coset (mesoform) migration towards the southeast, as the main bar (macroform) migrated southwards downstream.

Outcrop 17.3: Due to the intermittent longitudinal extent (~18.00 m), grainsize component and pebble content, facies Spb >15% represents bedload transport of sediment which likely formed a mid-channel bar that acted as a core/nucleus for subsequent sediment deposition (cf. Allen, 1983) and the formation of a compound bar. Such facies were probably generated by a major flood event with sediment migration and aggradation influenced by high and low-flow stages, respectively (Coleman, 1969; Bristow, 1987, 1993a; Ashworth *et al.,* 2011). The surface lag deposit (Ss- lp-lag) likely represents scouring (Miall, 2010b) or winnowing (cf. Collinson *et al.,* 2006) processes with no obvious evidence of a fifth-order channel surface. Facies Sl-hss <1.0 m (2D mesoforms) may imply migratory bedforms that likely developed within a relatively shallow channel (cf. Ashworth *et al.*, 2011), possibly on the surface of a larger sand flat (cf. Cant & Walker, 1976, 1978). Although, it is more likely that the bedforms are associated with downstream or lateral-accretion of a series of distinct depositional episodes (cf. Collinson *et al.,* 2006) i.e. sets divided by first-order set boundaries which indicate repeated bedform migration probably as a train of dunes (dune stacking) that form components of a channel bar top vertical-accretion, influenced by a relatively shallow flow depth above the host bar (cf. Bristow, 1993b; Best *et al.*, 2003; Bridge & Lunt, 2006; Miall, 2010b; Ashworth *et al.*, 2011). Shallow channel conditions also imply waning flow, aggradation and channel fill (cf. Cant & Walker, 1976; Ashworth *et al.*, 2011; Reesink *et al.*, 2014); preservation of consecutive cross-laminated sets inevitably encompasses a measure of net deposition and most sets will climb at a similar angle/dip to that of their host bed (Leeder, 1982). The coset of facies Sl-hpx <2.0 m is constructed from repeated grain flow avalanche deposits (~0.03 m thick foresets; see Smith, 1972; Reesink & Bridge, 2007, 2009) and likely relate to sediment migration influenced by increasing channel depth facilitated by a flood event (high-flow stage) and subsequent net sediment deposition and aggradation of 2D mesoforms during waning flow (low-flow stage) (cf. Coleman, 1969; Bristow, 1987, 1993a; Ashworth *et al.,* 2011). The subsequent coset of facies Sl-hss <1.0 m likely represents downstream and/or lateral-accretion of 3D mesoforms, with similar processes to those highlighted for facies Sl-hss <1.0 m relating to Outcrop 17.2. The sub-horizontal contact with the underlying facies likely represents a third-order erosional surface (cf. Miall, 2010b; Ielpi *et al*., 2014) which denotes lateral coset (mesoform) migration towards the east, contrary to the mainly south-easterly migration of the preceding facies (Fig. 4.4 Location 17). Similarly, palaeocurrent data associated with facies Stmx 1.5-3.0 m imply that the prevailing palaeocurrent was mainly towards the east. The preserved set thickness of facies Stmx 1.5-3.0 m (~0.60 m) suggests that the maximum dune height and channel depth was ~2.15 m and ~6.50 m, respectively (cf. Reesink & Bridge, 2009; Leclair, 2011). Such dune sets and associated increase in channel depth imply that the dunes developed towards the channel thalweg/axis, overprinting the underlying compound bar. Since large dunes tend to develop towards channel thalwegs, such cross-bedding also implies downstream-accretion within a relatively broad and deep channel (cf. Reesink & Bridge, 2009; Ashworth *et al.*, 2011; Reesink *et al.*, 2014).

Table 4.18

Location, grid reference and associated literature	General description and lithology
18. Careless House Farm Outcrop 18.1: SE 25335 65113 Thompson, A. T. (1957) *The structure and stratigraphy of Nidderdale between Lofthouse and Dacre*. Unpublished, Doctoral thesis, Durham University. Available at Durham E-Theses Online: http://etheses.dur.ac.uk/722/.	Relatively small intermittent and fragmented outcrop running along the northern bank of small gully which extends down into the bed of a small stream. Stream bed appears to consist, in part, of horizontally bedded sandstone rock, which is overgrown with algae, moss and vegetation and is also covered, in the main, by cobbles. The outcrop is situated due south of Careless House Farm and is located adjacent to managed farmland. The main outcrop is partially obscured by vegetation (e.g. ivy and moss) and possesses a variable texture with relatively poor outcrop detail (e.g. foreset/sets), due to processes of weathering and erosion. Elevation of Outcrop is ~140 m O.D.; main outcrop view is towards ~310˚ (Fig. 4.4 Location 18). Outcrop 18.1: Medium-grained to granular sandstone with 5-10% small to medium pebble content (variable), predominantly quartz grains; generally low to high sphericity; sub-angular to rounded; well to poorly sorted.

Identified sub-Facies, sedimentary structures and bounding surfaces of note

Outcrop 18.1 [~2.0 (H) x 4.0 (D) x 10.0 m (W)]: **1.** *Sl-hpx <2.0 m (Sp); low to high-angle-inclined foresets (variable) forming medium-scale planar cross-bedding; ~0.40 m thick sub-horizontal set; poorly defined foresets and sharp undulating contact with overlying coset; **2.** ~0.70 m thick coset of Stsx <1.5 m (St); small-scale trough cross-bedding with variable up to ~0.20 m thick troughs; exhibiting signs of normal grading, more granules and pebbles towards base of sets; fragmented coset with poorly defined sets and foresets.

Interpretation

Although limited, both in available outcrop and palaeocurrent data, the data obtained indicate that the principal depositional palaeocurrent was towards the west (Fig. 4.4 Location 18). The full extent of Outcrop 18.1 is unknown due to the outcrop boundary being masked by soil and vegetation.

The measured visible preserved thickness of facies Sl-hpx <2.0 m (~0.40 m) suggests that the original height of the 2D mesoform, and corresponding channel depth, was at least ~1.45 m and ~4.30 m, respectively (cf. Reesink & Bridge, 2009; Leclair, 2011). The bedform likely relates to in channel downstream and/or lateral-accretion where sediment migration was facilitated by a flood event (high-flow stage) and subsequent net sediment deposition and aggradation of the 2D mesoform during waning flow (low-flow stage) (cf. Coleman, 1969; Bristow, 1987, 1993a; Ashworth *et al.,* 2011). Sediment aggradation inevitably encompasses a measure of channel fill and a reduction in overall channel depth (cf. Cant & Walker, 1976; Leeder, 1982; Ashworth *et al.*, 2011; Reesink *et al.*, 2014). Such conditions may account for the relatively reduced height of the ensuing facies of Stsx <1.5 m and a change from laminar to turbulent flow conditions, which would account for the undulating contact between the two units. The preserved thickness of facies Stsx <1.5 m (~0.20 m) suggests that the original height of the 3D mesoform and corresponding channel depth was ~0.70 m and ~2.15 m, respectively (cf. Reesink & Bridge, 2009; Leclair, 2011). The relatively coarser sediment component of facies Stsx <1.5 m denotes an increase in flow velocity and downstream progradation and migration of 3D mesoforms, possibly on the surface of a larger sand flat (cf. Cant & Walker, 1976, 1978), likely generated by facies Sl-hpx <2.0 m. Similarly, bedforms consisting of facies Stsx <1.5 m may also relate to a series of distinct depositional episodes (cf. Collinson *et al.,* 2006) of assembled sets divided by first-order set boundaries which indicate repeated bedform migration probably as a train of dunes (dune stacking) which may have formed components of a channel bar top (cf. Bristow, 1993b; Best *et al.*, 2003; Bridge & Lunt, 2006; Mumpy *et al*., 2007; Miall, 2010b; Ashworth *et al.*, 2011); preservation of consecutive cross-laminated sets inevitably encompasses a measure of net deposition and subject to the inclination of their host bed most sets will climb at a similar angle (Leeder, 1982).

Table 4.19

Location, grid reference and associated literature	General description and lithology
19. Klondike (Disused Quarry) Outcrop 19.1: SE 22346 65801 Thompson, A. T. (1957) *The structure and stratigraphy of Nidderdale between Lofthouse and Dacre*. Unpublished, Doctoral thesis, Durham University. Available at Durham E-Theses Online: http://etheses.dur.ac.uk/722/.	Relatively small solitary remnant of disused quarry situated in the northeast corner of a small field of managed farmland, original quarry has been filled in. Outcrops of Lower Brimham Grit are visible in adjoining woodland, although access and examination is not practicable, due to the amount of vegetation barring access and covering the outcrops. Similar intermittent outcrops extend eastwards form Quarry Hill for ~700 m towards North Owl; access to outcrops not granted by local farmer (Middle House Farm), due to livestock within fields. When spoken to, farmer advised that there were no open quarry sites present on his property, due to the disused quarries being filled in. The main outcrop examined is partially obscured by vegetation (e.g. ivy and moss) and possesses a variable texture with relatively poor outcrop detail (e.g. foreset/sets), due to processes of and erosion. Elevation of Outcrop is ~260 m O.D.; main outcrop view is towards ~130˚ (Fig. 4.4 Location 19). Outcrop 19.1: Coarse-grained to granular sandstone with 2-5% small pebble content (variable), predominantly quartz grains; generally low to high sphericity; sub-angular to rounded; moderately to poorly sorted.

Identified sub-Facies, sedimentary structures and bounding surfaces of note

Outcrop 19.1 [~2.2 (H) x 2.5 (D) x 6.0 m (W)]: **1.** ~2.20 m thick coset group of *Sl-hss <1.0 m (Sl); likely a combination of small-scale trough cross-bedding <1.5 m trough width and planar cross-bedding; variable ~0.40 to 0.60 m thick sub-horizontal cross-cutting cosets with 0.10-0.15 m thick sub-horizontal cross-cutting sets; poorly defined foresets.

Interpretation

The outcrop appears to have been subjected to minor cambering towards the southwest, primarily due to its apparent pitch towards the southwest. Bedding and palaeocurrent data were restored through stereographic projection, relative to the 15° dip and 200° azimuth inferred from the coset inclination relating to facies Sl-hss <1.0 m. The restored palaeocurrent data imply that deposition was influenced by palaeocurrents that were more variable than the original field data (Fig. 4.4 Location 19), although the restored azimuth means appear consistent with the south-south-westerly palaeocurrents of the original data (Fig. 4.4 Location 19). The predominant set thicknesses of 0.10-0.15 m imply that sediment input was limited and the maximum dune height and channel depth was between 0.35-0.55 m and 1.10-1.60 m, respectively (cf. Reesink & Bridge, 2009; Leclair, 2011).

The group of cosets relating to facies Sl-hss <1.0 m may represent: i. downstream-accretion of 2D and/or 3D mesoforms within a relatively shallow thalweg region of a low sinuosity channel influenced by high-flow stage which facilitated the formation of low-angle down-climbing dunes (cf. Bristow, 1988, 1993a; Ghinassi *et al.*, 2009; Miall, 2010b; Reesink *et al*., 2014); ii. bar top vertical-accretion component of a channel bar, primarily due to dune stacking and relative shallow flow depth above the host bar (cf. Best *et al.*, 2003; Bridge & Lunt, 2006); iii. migratory mid-channel bar bedform components; dune set components of such cosets likely formed within a multi-channelled fluvial system (cf. Reesink *et al.*, 2014); iv. a series of distinct depositional episodes(cf. Collinson *et al.*, 2006) of assembled sets divided by first-order set boundaries which indicate repeated downstream bedform migration, possibly as a train of dune components over the surface/crest or front/tail of a larger bar (macroform) (cf. Allen, 1982; Haszeldine, 1983b; Bristow, 1993b; Miall, 2010b; Ashworth *et al.*, 2011); or, v. the ≤05° dip angles relating to the restored data, normal grading associated with the sets/foresets and general linear appearance of the bedding sequence suggests that the sedimentary features may be similar to thin sand waves generated at very shallow fluvial depths (cf. Smith, 1971).

The low-angle bedforms imply flow conditions were sufficiently shallow to subdue dune formation and generate very low relief dunes (cf. Bristow, 1993a); preservation of low-angle dune morphology is facilitated by dune stoss and crest erosion, during high flow-stage, and deposition of eroded sediment in the dune's trough (Hendershot *et al.*, 2016). Low-angle bedforms may be attributed to the migration of low-amplitude (near horizontal) sand waves/dunes concomitant with the transitional zone between lower a and upper flow regimes and very shallow fluvial systems (cf. Smith, 1971; Todd, 1996); generally foreset gradients decline as a flow regime intensifies, vice versa (cf. Smith, 1972). Similarly, dune height also implies limited sediment input, likely influenced by high-flow stage which facilitated formation of the low-angle down-climbing dunes and downstream migration (cf. Bristow, 1988, 1993a; Reesink & Bridge, 2009; Ghinassi, 2011). The relatively shallow channel conditions may also imply waning flow and net the aggradation of 2D and/or 3D mesoforms associated with the latter stages of a channel fill sequence (cf. Cant & Walker, 1976, 1978; Ashworth *et al.*, 2011; Reesink *et al.*, 2014).

Further, the preservation of consecutive cross-laminated sets inevitably encompasses a measure of net deposition and subject to the inclination of their host bed most sets will climb at a similar angle (Leeder, 1982). Hence, with the limited data available, Outcrop 19.1 likely represents the downstream migration and accretion of relatively small-scale dune components of a larger host sand flat and channel fill.

Table 4.20

Location, grid reference and associated literature	General description and lithology
20. Jeffery Crags (Warren Forest Park) Outcrops 20.1: SE 23056 65454 20.2: SE 23044 65442 20.3: SE 23038 65422 20.4: SE 23030 65393 20.5: SE 22989 65399 Thompson, A. T. (1957) *The structure and stratigraphy of Nidderdale between Lofthouse and Dacre*. Unpublished, Doctoral thesis, Durham University. Available at Durham E-Theses Online: http://etheses.dur.ac.uk/722/.	Numerous various sized outcrops scattered throughout woodland area adopted as a static caravan park. Outcrops are generally masked (in part) by soil, vegetation (e.g. lichen, moss and algae) and detritus associated with a woodland setting. Although several outcrops appear to have been displaced, the in-sitú examined outcrops generally follow a line of intermittent fragmented crags trending 045˚-225˚ for ~70.0 m, along raised ground at the north eastern boundary of Warren Forest Park. Generally, all the examined outcrops are jointed, horizontally and vertically, weathered and possess a variable texture with relatively poor outcrop detail (e.g. foreset/sets), due to processes of weathering and erosion; the outcrops may have also been subjected to minor cambering. Outcrops examined moving from the northeast towards the southwest. Elevation of Outcrops 20.1-20.5 is ~215, 215, 214, 214 and 218 m O.D, respectively; main outcrop views are towards ~230˚, 270˚, 280˚, 270˚ and 240˚, respectively (Fig. 4.4 Location 20). Outcrop 20.1: Medium-grained to granular sandstone with ~2% small to medium pebble content (variable), predominantly quartz grains; generally high sphericity; sub-rounded to rounded; moderately to very well sorted; Outcrop 20.2: Coarse-grained to granular sandstone with 2-5% small to medium pebble content (variable), predominantly quartz grains; generally low to high sphericity; sub-angular to rounded; moderately to well sorted; Outcrop 20.3: Medium-grained to granular sandstone with 2-10% small to medium pebble content (variable), increasing towards the top of outcrop, predominantly quartz grains; generally low to high sphericity; sub-angular to rounded; moderately to very well sorted; Outcrop 20.4: Medium-grained to granular sandstone with 2-5% small to medium pebble content (variable), predominantly quartz grains; generally low to high sphericity; sub-angular to rounded; moderately to very well sorted; Outcrop 20.5: Medium-grained to granular sandstone with 5-15% small to large pebble content (variable), predominantly quartz grains; generally low to high sphericity; sub-angular to rounded; moderately to poorly sorted.

Identified sub-Facies, sedimentary structures and bounding surfaces of note

Outcrop 20.1 [~2.0 (H) x 3.0 (D) x 7.0 m (W)]: **1.** ~0.50 m thick coset of Sl-hss <1.0 m (Sl); likely small-scale trough cross-bedding; coset consists of ~0.10 m thick sub-horizontal sets; poorly defined foresets; erosive and sub-horizontal contact with overlying coset (in part) and channel base coset; **2.** ~0.40 m thick coset of *Sl-hss <1.0 m (Sl); likely small-scale trough cross-bedding; coset consists of ~0.10 m thick sub-horizontal sets; poorly defined foresets; erosive and sub-horizontal contact with overlying coset (in part) and channel base coset; **3.** ~0.75 m thick coset group of *Sl-hss <1.0 m (Sl); likely a combination of small-scale trough cross-bedding <1.5 m trough width and planar cross-bedding; variable ~0.25 m thick sub-horizontal cosets with 0.10-0.15 m thick sub-horizontal cross-cutting sets; poorly defined foresets; sharp, erosive and sub-horizontal contact (in part) with overlying set (chute channel base); **4.** ~0.40 m thick coset of *Sl-hpx <2.0 m (Sp); low to high-angle-inclined foresets forming 0.10-0.15 m thick sub-horizontal sets of small-scale planar cross-bedding; poorly defined foresets; erosive chute channel base (part of); **5.** ~0.15 m thick set of Stsx <1.5 m (St); small-scale trough cross-bedding <1.5 m trough width; poorly defined sedimentary features i.e. set and foreset details; sharp erosive chute channel base (part of); Calamites fossil remnant along base; **6.** ~1.00 m thick coset of *Sl-hpx <2.0 m (Sp); low to high-angle-inclined foresets forming ~0.20 and 0.25 m thick sub-horizontal sets of small to medium-scale planar cross-bedding; poorly defined foresets;

Outcrop 20.2 [~3.0 (H) x 3.0 (D) x 7.0 m (W)]: **1.** ~3.00 m thick coset group of *Sl-hss <1.0 m (Sl); likely small-scale trough cross-bedding <1.5 m trough width; three ~1.00 m thick sub-horizontal cross-cutting cosets with 0.10-0.25 m thick sub-horizontal cross-cutting sets, variable, increasing in thickness towards top of outcrop; poorly defined foresets;

Outcrop 20.3 [~4.0 (H) x 7.0 (D) x 13.0 m (W)]: **1.** *Ssb (S-); ~0.60 m thick structureless coset with no obvious evidence of internal structures such as foresets; two sets ~0.30 m thick; possible evidence of rip-up clast cavities up to 0.06 m long and 0.01 m high; sharp sub-horizontal contact with overlying coset; **2.** ~0.60 m thick coset of *Sl-hpx <2.0 m (Sp); low to high-angle-inclined foresets forming 0.20-0.30 m thick cross-cutting sub-horizontal sets of small to medium-scale planar cross-bedding; poorly defined foresets; sharp sub-horizontal contact with overlying coset; **3.** ~1.30 m thick coset group of *Sl-hpx <2.0 m (Sp); low to high-angle-inclined foresets; ~0.50 and ~0.80 m thick sub-horizontal cosets; cosets consist of 0.30-0.40 m thick cross-cutting sets of small to medium-scale planar cross-bedding; poorly defined foresets; erosive and sharp sub-horizontal contact with overlying coset (in part); **4.** ~0.50 m thick coset of *Sl-hss <1.0 m (Sl); likely small-scale trough cross-bedding; coset consists of ~0.15 m thick sub-horizontal cross-cutting sets; poorly defined sets and foresets; sub-horizontal contact with overlying coset; **5.** ~0.60 m thick coset of *Sl-hss <1.0 m (Sl); likely small-scale trough cross-bedding; coset consists of 0.10-0.15 m thick sub-horizontal cross-cutting sets; poorly defined sets and foresets; sub-horizontal contact with overlying coset; **6.** ~0.90 m thick coset of Sl-hss <1.0 m (Sl); likely small-scale trough cross-bedding; coset consists of 0.10-0.15 m thick sub-horizontal cross-cutting sets; poorly defined sets and foresets;

Outcrop 20.4 [~4.5 (H) x 6.0 (D) x 9.0 m (W)]: **1.** ~0.95 m thick coset of *Sl-hpx <2.0 m (Sp); low to high-angle-inclined foresets forming ~0.20 and 0.25 m thick sub-horizontal cross-cutting sets of small-scale planar cross-bedding; poorly defined foresets; sub-horizontal undulating contact with overlying set; **2.** *Stsx <1.5 m (St); small-scale trough cross-bedding <1.5 m trough width; ~0.10 m thick set; poorly defined cross-bedding, set and overlying coset bounding surfaces; **3.** ~0.70 m thick coset of *Sl-hpx <2.0 m (Sp); low to high-angle-inclined foresets forming 0.10 and 0.25 m thick sub-horizontal cross-cutting sets of small- scale planar cross-bedding; poorly defined foresets; sharp sub-horizontal contact with overlying coset; **4.** ~0.40 m thick coset of *Sl-hpx <2.0 m (Sp); low to high-angle-inclined foresets forming ~0.20 m thick sub-horizontal sets of small-scale planar cross-bedding; poorly defined foresets; sub-horizontal contact with overlying set; **5.** *Sl-hpx <2.0 m (Sp); low to high-angle-inclined foresets forming medium-scale planar cross-bedding; ~0.50 m thick sub-horizontal set; poorly defined foresets and sharp sub-horizontal contact with overlying set; **6.** *Sl-hpx <2.0 m (Sp); low to high-angle-inclined foresets forming medium-scale planar cross-bedding; ~0.60 m thick sub-horizontal set; poorly defined foresets and sharp undulating contact with overlying coset; **7.** ~1.00 m thick coset of Sl-hss <1.0 m (Sl); likely small-scale trough, or planar, cross-bedding; coset consists of ~0.10 m thick sub-horizontal cross-cutting sets; poorly defined sets and foresets;

Outcrop 20.5 [~4.0 (H) x 9.0 (D) x 14.0 m (W)]: **1.** ~0.50 m thick coset of Sl-hss <1.0 m (Sl); likely small-scale trough cross-bedding; coset consists of ~0.10 m thick sub-horizontal cross-cutting sets; poorly defined sets and foresets; coarser grain component towards base of sets and foresets – normal grading; poorly defined, likely sub-horizontal, contact with overlying coset; southern section of outcrop; **2.** ~0.50 m thick coset of *Sl-hpx <2.0 m (Sp); low to high-angle-inclined foresets forming medium-scale planar cross-bedding; coset consists of ~0.10 m thick cross-cutting high-angle sub-horizontal sets; poorly defined sets and foresets; coarser grain component towards base of sets and foresets – normal grading; poorly defined, likely sub-horizontal, contact with overlying coset; middle section of outcrop between southern section and chute channel; **3.** ~0.50 m thick coset of *Sl-hss <1.0 m (Sl); likely small-scale trough cross-bedding; coset consists of ~0.10 m thick sub-horizontal cross-cutting sets; poorly defined sets and foresets; coarser grain component towards base of sets and foresets – normal grading; mainly sharp horizontal contact with overlying coset and erosive contact (in part) with either an overlying chute channel, obstacle scour, or hydraulic scour; **4.** *Ss-lp-lag (Gh); small to large pebble lag deposit; ~1.20 m long wedge shaped deposit up to ~0.15 m thick; predominantly coarse to granular grains with up to ~33% pebble content; lag forms an erosive base of either a chute channel, obstacle scour, or hydraulic scour, with poorly defined small-scale trough cross-bedding with pebble lags forming base of troughs, imbrication and fossil remnants (likely Calamites); sub-horizontal erosive contact with adjacent coset and poorly defined contact with overlying coset; **5.** ~0.50 m thick coset of *Stsx <1.5 m (St); small-scale trough cross-bedding <1.5 m trough width; coset consists of ~0.20 m thick cross-cutting sets; poorly defined sets and foresets; poorly defined, likely horizontal, contact with overlying coset and erosive contact (in part) with dissecting chute channel; **6.** ~2.00 m thick coset group of *Sl-hss <1.0 m (Sl); likely small-scale trough or planar cross-bedding; ~0.60, 0.60 and 0.80 m thick cosets; cosets consist of ~0.20 m thick sub-horizontal cross-cutting sets of small-scale cross-bedding; poorly defined sets and foresets; erosive and poorly defined, likely sub-horizontal to horizontal contact between cosets and erosive contact (in part) with dissecting chute channel; broken sequence, contact with overlying coset obscured by ground cover; **7.** ~1.20 m thick coset of *Sl-hpx <2.0 m (Sp); low-angle-inclined foresets forming 0.20-0.40 m thick horizontal sets of small to medium-scale planar cross-bedding; poorly defined sets and foresets; coarser grain component towards base of sets and foresets – normal grading.

Interpretation

Outcrop 20.1: Palaeocurrent data relating to Outcrop 20.1 suggest that the principal depositional palaeocurrent was towards the south-southwest (Fig. 4.4 Location 20). The predominant set thicknesses for Sl-hss <1.0 m (i.e. 0.10-0.15 m) imply that sediment input was limited and the maximum dune height and channel depth was ~0.55 m and ~1.60 m, respectively (cf. Reesink & Bridge, 2009; Leclair, 2011). In contrast, The variable set thicknesses for Sl-hpx <2.0 m (i.e. 0.10-0.25 m) imply an increase in sediment input and a maximum dune height and channel depth of ~0.90 m and ~2.70 m, respectively (cf. Reesink & Bridge, 2009; Leclair, 2011).

The group of cosets relating to facies Sl-hss <1.0 m may represent: i. bar top vertical-accretion component of a channel bar, primarily due to dune stacking and relative shallow flow depth above the host bar (cf. Best *et al.*, 2003; Bridge & Lunt, 2006); or ii. migratory mid-channel bar bedform components; dune set components of such cosets likely formed within a multi-channelled fluvial system (cf. Reesink *et al*., 2014) and each coset may have formed an individual consecutive small-scale unit bar component (cf. Sambrook Smith *et al.*, 2006; Reesink & Bridge, 2009) of a much larger compound bar (cf. Allen, 1982; Bridge, 2003; Bridge & Lunt, 2006; Sambrook Smith *et al.*, 2006; Ashworth *et al.*, 2011); iii. a series of distinct depositional episodes (cf. Collinson *et al.,* 2006) of assembled sets divided by first-order set boundaries which indicate repeated downstream bedform migration, possibly as a train of dune components over the surface/crest or front/tail of a larger bar (macroform) (cf. Allen, 1982; Haszeldine, 1983b; Bristow, 1993b; Miall, 2010b; Ashworth *et al.*, 2011).

The shallow channel conditions associated with facies Sl-hss <1.0 m may also imply waning flow and net the aggradation of 2D and/or 3D mesoforms associated with the latter stages of a channel fill sequence (cf. Cant & Walker, 1976; Ashworth *et al.*, 2011; Reesink *et al.*, 2014). Further, the preservation of consecutive cross-laminated sets inevitably encompasses a measure of net deposition and subject to the inclination of their host bed most sets will climb at a similar angle (Leeder, 1982). Hence, Outcrop 20.1 likely represents the downstream migration and accretion of relatively small-sale dune components of a larger host bar. The base of facies Sl-hpx <2.0 m and Stsx <1.5 m both (in part) form a fifth-order bounding surface (cf. Miall, 2010b) and likely represent a third-order bar top chute channel (cf. Bristow, 1987; Bridge, 2003; Miall, 2010b and references there in) generated as a result of falling-stage flow (drawdown) and bar top incision, due to overflow from the main channel as the flow rate subsided (cf. Bristow, 1987, 1993; Ashworth *et al.*, 2011). Subsequent deposition of facies Sl-hpx <2.0 m implies continued southerly downstream migration, and gradual increase in net sediment input and channel depth, facilitated by flood events and deposition of relatively larger dunes (2D mesoforms), during waning flow (low-flow stage) (cf. Coleman, 1969; Bristow, 1987, 1993a; Ashworth *et al.,* 2011). Such bedforms are also associated with a series of distinct depositional episodes (cf. Collinson *et al.,* 2006) of assembled sets divided by first-order set boundaries which indicate repeated bedform migration probably as a train of dunes (dune stacking) which may have formed components of a small-scale unit bar (cf. Sambrook Smith *et al.*, 2006; Reesink & Bridge, 2009; Ashworth *et* *al.*, 2011). Correspondingly, the preservation of consecutive cross-laminated sets inevitably encompasses a measure of net deposition and most sets will climb at a similar angle/dip to that of their host bed (Leeder, 1982). Further, the presence of a Calamites remnant implies rapid deposition which facilitated fossil preservation; if propagated locally the presence of Calamites vegetation would have promoted channel bank and/or channel bar stability. The general north-south orientation of the fossil remnant (Fig. 4.4 Location 20) is a further indication that the main palaeocurrent was towards the south. The shallow inclined (mainly ≤14°) first-order and second-order bounding surface dips may correspond to channels possessing relatively high width to depth ratios (Bristow, 1993a).

Outcrop 20.2: Although limited to mainly coset and set data, the palaeocurrent relating to Outcrop 20.2 suggest that sediment deposition was likely influenced by a south-westerly palaeocurrent (Fig. 4.4 Location 20). Facies Sl-hss <1.0 m exhibits variable set thicknesses of ~0.10 m towards the base and ~0.25 m towards the surface of the outcrop; such observations imply that sediment input and flow depth increased correspondingly with a maximum dune height and channel depth of ~0.90 m and ~2.70 m, respectively (cf. Reesink & Bridge, 2009; Leclair, 2011). Although, if the cosets relating to facies Sl-hss <1.0 m represent small-scale unit bars (cf. Sambrook Smith *et al.*, 2006; Reesink & Bridge, 2009), or dune cosets (cf. Haszeldine, 1983b), the preserved coset thickness of ~1.00 m suggests that the maximum bedform thickness was ~1.65 m (cf. Leclair, 2011). Therefore, given that bar heights may adjust between half and bankfull depth, the host channel was probably between ~1.65 m and ~3.30 m deep, respectively (cf. Bristow, 1987; Bridge, 2003; Reesink *et al*., 2014).

The coset group relating to facies Sl-hss <1.0 m may represent: i. downstream-accretion of 2D and/or 3D mesoforms within a relatively shallow thalweg region of a low sinuosity channel, likely influenced by high-flow stage which facilitated the formation of down-climbing dunes (cf. Bristow, 1988, 1993a; Ghinassi *et al.,* 2009; Miall, 2010b; Reesink *et al.,* 2014); ii. bar top vertical-accretion component of a channel bar, primarily due to dune stacking and an initial relatively shallow flow depth above the host bar (cf. Best *et al.*, 2003; Bridge & Lunt, 2006); iii. migratory mid-channel bar bedform components; dune set components of such cosets likely formed within a multi-channelled fluvial system (cf. Reesink *et al*., 2014) and each coset may have formed an individual consecutive small-scale unit bar component (cf. Sambrook Smith *et al.*, 2006; Reesink & Bridge, 2009) of a much larger compound bar (cf. Allen, 1982; Bridge, 2003; Bridge & Lunt, 2006; Sambrook Smith *et al.*, 2006; Ashworth *et al.*, 2011); iv. individual sub-horizontal set components of a larger host dune coset (cf. Haszeldine, 1983b), although such component coset/unit bar heights coincide with dune heights (Ashworth *et al.*, 2011); or v. a series of distinct depositional episodes (cf. Collinson *et al.,* 2006) of assembled sets divided by first-order set boundaries which indicate repeated downstream bedform migration, possibly as a train of dune components over the surface/crest or front/tail of a larger bar (macroform) (cf. Allen, 1982; Haszeldine, 1983b; Bristow, 1993b; Miall, 2010b; Ashworth *et al.*, 2011). The initial relatively shallow channel conditions associated with facies Sl-hss <1.0 m may also imply waning flow and net the aggradation of 3D mesoforms associated with the latter stages of a channel fill sequence (cf. Cant & Walker, 1976; Ashworth *et al.*, 2011; Reesink *et al.*, 2014); subsequent deposition of thicker sets imply an increase in flow depth and dune migration along a bar surface/flank (cf. Mumpy *et al*., 2007) or dune migration near to the channel thalweg/axis (cf. Reesink & Bridge, 2009; Ashworth *et al.*, 2011; Reesink *et al.*, 2014). Further, the preservation of consecutive cross-laminated sets inevitably encompasses a measure of net deposition and subject to the inclination of their host bed most sets will climb at a similar angle (Leeder, 1982). And the sub-horizontal coset/unit bar contacts are likely third-order erosional surfaces (cf. Miall, 2010b; Ielpi *et al*., 2014) which denote a component of lateral coset (mesoform) accretion and growth of the host compound bar (macroform) through lateral and downstream-accretion (cf. Bridge & Lunt, 2006), which could also account for the variable palaeocurrent data. Although Outcrop 20.2 may represent a channel fill sequence (part of) it may also form a component of a channel bar sequence, studies conducted by Skelly *et al.* (2003) and Ashworth *et al.* (2011) (and references there in) argue that the distinction between compound bar and adjacent channel fill core deposits, in sandy braided fluvial systems, is problematic.

Outcrop 20.3: Although variable, the palaeocurrent data relating to Outcrop 20.3 suggest that the principal depositional palaeocurrent was towards the southwest (Fig. 4.4 Location 20). The relatively course grain size, texture and possible presence of rip-up clast cavities, suggest that the basal facies (Ssb) was likely deposited towards the channel thalweg region during a flood event. In contrast the grain size and texture of facies Sl-hpx <2.0 m suggests reduced flow strength and deposition at a relatively lower flow stage, compared with facies Ssb (Reesink & Bridge, 2009). The set components relating to facies Sl-hpx <2.0 m (up to 0.40 m thick) imply that the maximum dune height and channel depth was ~1.45 m and ~4.30 m, respectively (cf. Reesink & Bridge, 2009; Leclair, 2011). Such dune sets likely developed towards the channel thalweg/axis where large dunes tend to develop; the size of cross-bedding and relatively shallow inclined (mainly ≤14°) first-order bounding surface dips may correspond with downstream-accretion within a channel possessing a relatively high width to depth ratio (cf. Bristow, 1993a; Reesink & Bridge, 2009; Ashworth *et al.*, 2011; Reesink *et al.*, 2014). Further, such facies are associated with downstream migration of: i. longitudinal bars (Ghinassi *et al.,* 2009); and ii. unit bars, which may form sand flat components (cf. Cant & Walker, 1976, 1978), although such bar heights coincide with dune heights (Ashworth *et al.*, 2011). Preservation of consecutive cross-laminated sets inevitably encompasses a measure of net deposition and subject to the inclination of their host bed most sets will climb at a similar angle (Leeder, 1982). Bedload deposition is related to flow stage i.e. fine and coarse-grained cross strata accumulate at low and high-flow stage, respectively (Reesink & Bridge, 2009 and references there in). Deposition of facies Sl-hpx <2.0 m would contribute to channel fill and thereby reduce the overall channel depth and increase the flow rate over the bedform (cf. Reesink & Bridge, 2009). Such an increase in flow rate would account for the increase in grain size and pebble content associated with the cosets relating to facies Sl-hss <1.0 m; and a predominant set thickness of between 0.10-0.15 m is consistent with relatively a shallow host channel, between 1.00-1.60 m deep (cf. Reesink & Bridge, 2009; Leclair, 2011). Although, if the cosets relating to facies Sl-hss <1.0 m represent small-scale unit bars (cf. Sambrook Smith *et al.*, 2006; Reesink & Bridge, 2009), or dune cosets (cf. Haszeldine, 1983b), the preserved coset thickness of ~0.90 m suggests that the maximum bedform thickness was ~1.30 m (cf. Leclair, 2011). Therefore, given that bar heights may adjust between half and bankfull depth, the depth of host channel was probably between ~1.30 m and ~2.60 m, respectively (cf. Bristow, 1987; Bridge, 2003; Reesink *et al*., 2014), see above for facies interpretation.

Outcrop 20.4: Palaeocurrent data relating to Outcrop 20.4 suggest that the principal depositional palaeocurrent was more towards the west, compared with Outcrops 20.1-20.3 (Fig. 4.4 Location 20). Although Outcrop 20.4 appears to have been subjected to minor cambering, the principal facies relating to Outcrop 20.4 are similar to that of Outcrop 20.3. Such parallels imply continued downstream-accretion and extension of sandy bedforms for at least 30 m towards the southwest, within a channel setting possessing a relatively high width to depth ratio (cf. Bristow, 1993a; Reesink & Bridge, 2009; Ashworth *et al.*, 2011; Reesink *et al.*, 2014), see above for facies Sl-hss <1.0 m interpretation.

Outcrop 20.5: Palaeocurrent data relating to Outcrop 20.5 suggest that the depositional palaeocurrent was variable, although the principal palaeocurrent appears to have been more towards the west and southwest (Fig. 4.4 Location 20). The northerly palaeocurrents are associated with facies Ss-lp-lag, which may either form the base of a: i. chute channel; ii. hydraulic scour; or iii. obstacle scour (cf. Bristow, 1996) evidenced by the presence of fossil remnants (likely Calamites). Outcrop 20.5 is dominated by facies Sl-hss <1.0 m, see above for facies Sl-hss <1.0 m interpretation. The initial relatively shallow channel conditions associated with facies Sl-hss <1.0 m may also imply waning flow and net the aggradation of 3D mesoforms associated with the latter stages of a channel fill sequence (cf. Cant & Walker, 1976; Ashworth *et al.*, 2011; Reesink *et al.*, 2014); subsequent deposition of the thicker sets (e.g. Sl-hpx <2.0 m) imply an increase in flow depth and dune migration along a bar surface/flank (cf. Mumpy *et al*., 2007) or dune migration near to the channel thalweg/axis (cf. Reesink & Bridge, 2009; Ashworth *et al.*, 2011; Reesink *et al.*, 2014).

Overall, the elevation of the ~70 m long line of fragmented outcrops relating to Jeffery Crags varies by ~4.0 m, which implies that all the outcrops are related components of a fluvial system that migrated downstream for a minimum of 70 m. Notwithstanding that braided fluvial systems display variable flow configurations, as they migrate round over and across channel bars, the general southerly to westerly palaeocurrents associated with the outcrops indicates that deposition was influenced by similar palaeocurrents, further suggesting a downstream relationship. The outcrops are therefore likely to be intermittent components of a multi-channel (braided) fluvial system (cf. Reesink *et al*., 2014). Such systems encompass a hierarchy of first, second and third-order channels (i.e. main channel, main channel partitioned by bars and bar top chute channels, respectively; equally, second-order channels may subdivide channel bars) (cf. Bristow, 1987; Bridge, 2003; Miall, 2010b and references there in). For example, the lag deposit associated with Outcrop 20.5 may form the remnant base of a third-order chute channel deposit. Although chute channels are generated as a result of falling-stage flow (drawdown) and bar top incision, due to overflow from the main channel as the flow rate subsides (cf. Bristow, 1987, 1993; Ashworth *et al.*, 2011), they may subsequently act as conduits to facilitate the deposition of lag deposits in the form of basal flood deposits during high-flow stage (cf. Coleman, 1969; Bristow, 1987, 1993a; Ashworth *et al.*, 2011). Lag deposits may also denote the location of a: i. channel thalweg/axial region (Fidolini *et al.*, 2013; Ghinassi *et al.*, 2014); ii. hydraulic scour; or iii. obstacle scour (cf. Bristow, 1996). Hydraulic or obstacle scours are associated with circular flow patterns (cf. Bristow, 1996) which may account for northerly palaeocurrent correlated with facies Ss-lp-lag. Further, the mainly shallow inclined first-order and second-order bounding surface dips may correspond to channels possessing a relatively high width to depth ratios (Bristow, 1993a) and down-climbing dunes may represent small-scale unit bars (cf. Sambrook Smith *et al.*, 2006; Reesink & Bridge, 2009).

Table 4.21

Location, grid reference and associated literature	General description and lithology
21. Bilberry Wood (Warren Forest Park) Outcrops 21.1: SE 22727 65245 21.2: SE 22717 65244 21.3: SE 22680 65236 21.4: SE 22654 65254 21.5: SE 22674 65314 Thompson, A. T. (1957) *The structure and stratigraphy of Nidderdale between Lofthouse and Dacre*. Unpublished, Doctoral thesis, Durham University. Available at Durham E-Theses Online: http://etheses.dur.ac.uk/722/.	Numerous various sized outcrops scattered throughout woodland area adopted as a static caravan park. Outcrops are generally masked (in part) by ground cover, vegetation (e.g. lichen, moss and algae) and detritus associated with a woodland setting. Although several outcrops appear to have been displaced, the in-sitú examined outcrops generally follow a line of intermittent fragmented crags along the 230 m Ordnance Survey contour line near to the south western boundary of Warren Forest Park. Generally, all the examined outcrops are jointed, horizontally and vertically, weathered and possess a variable texture with relatively poor outcrop detail (e.g. foreset/sets), due to the processes of weathering and erosion; the outcrops may have also been subjected to minor cambering. Outcrops examined moving from the east towards the west. Elevation of Outcrops 21.1-21.5 is ~225, 225, 222, 215 and 231 m O.D, respectively; main outcrop views are towards ~040˚, 320˚, 110˚, 110˚ and 080˚, respectively (Fig. 4.4 Location 21). Outcrop 21.1: Medium-grained to granular sandstone (variable) with 2-5% small to medium pebble content (variable), predominantly quartz grains; generally high sphericity; sub-angular to rounded; moderately to well sorted; Outcrop 21.2: Medium-grained to granular sandstone (variable) with ~2% small pebble content (variable), predominantly quartz grains; generally high sphericity; sub-angular to rounded; moderately to very well sorted; Outcrop 21.3: Coarse-grained to granular sandstone (variable) with 2-5% small pebble content (variable), predominantly quartz grains; generally high sphericity; sub-angular to rounded; well to poorly sorted; Outcrop 21.4: Medium-grained to granular sandstone (variable) with 2-30% small to medium pebble content (variable), predominantly quartz grains; generally low to high sphericity; sub-angular to rounded; well to poorly sorted; Outcrop 21.5: Medium-grained to granular sandstone with 2-5% small to medium pebble content (variable), predominantly quartz grains; generally low to high sphericity; sub-angular to rounded; well to poorly sorted.

Identified sub-Facies, sedimentary structures and bounding surfaces of note

Outcrop 21.1 [~2.5 (H) x 8.0 (D) x 7.0 m (W)]: **1.** ~0.45 m thick coset of *Sl-hss <1.0 m (Sl); small-scale trough cross-bedding; coset consists of ~0.10 m thick sub-horizontal sets; poorly defined sets and foresets; sharp, erosive (in part) and poorly defined contact with overlying coset; **2.** ~0.60 m thick coset of *Stsx <1.5 m (St); likely small-scale trough cross-bedding; coset consists of ~0.10 m thick sets; poorly defined foresets; sharp and horizontal contact with overlying coset; **3.** ~0.45 m thick coset of *Sl-hpx <2.0 m (Sp); high-angle-inclined foresets forming ~0.10 m thick sub-horizontal cross-cutting sets of small-scale planar cross-bedding; coarser grain component towards base of sets and foresets – normal grading; sharp, erosive (in part) and poorly defined horizontal contact with overlying set; **4.** *Sl-hpx <2.0 m (Sp); high-angle-inclined foresets forming medium-scale planar cross-bedding; ~0.40 m thick horizontal set; coarser grain component towards base of foresets – normal grading; foresets vary in thickness up to 0.02 m thick; poorly defined horizontal contact with overlying set; **5.** *Sl-hpx <2.0 m (Sp); high-angle-inclined foresets forming medium to large-scale planar cross-bedding; ~0.80 m thick horizontal set; foresets vary in thickness up to ~0.02 m thick; sharp, erosive (in part) and poorly defined, intermittent, horizontal contact with overlying set; **6.** *Sl-hpx <2.0 m (Sp); high-angle-inclined foresets forming small to medium-scale planar cross-bedding; ~0.30 m thick horizontal set; poorly defined foresets; intermittent exposure;

Outcrop 21.2 [~3.5 (H) x 7.0 (D) x 10.0 m (W)]: **1.** ~0.90 m thick coset of Stmx 1.5-3.0 m (St); medium-scale trough cross-bedding 1.5–3.0 m trough width; two 0.40-0.50 m thick sets (troughs); poorly defined sub-horizontal contact between sets and poorly defined (in part) horizontal contact with overlying coset; **2.** ~0.30 m thick coset of *Sl-hss <1.0 m (Sl); likely small-scale trough cross-bedding; coset consists of ~0.10 m thick sub-horizontal sets; poorly defined sets and foresets; sharp and erosive contact with overlying coset; **3.** ~0.70 m thick coset of *Sl-hpx <2.0 m (Sp); high-angle-inclined foresets forming ~0.15 m thick sub-horizontal cross-cutting sets of small-scale planar cross-bedding; poorly defined foresets and sets; sharp, erosive (in part) and poorly defined horizontal contact with overlying coset; **4.** ~0.50 m thick coset of *Sl-hpx <2.0 m (Sp); high-angle-inclined foresets forming ~0.10 m thick sub-horizontal cross-cutting sets of small-scale planar cross-bedding; poorly defined foresets and sets; sharp, erosive and poorly defined (in part) sub-horizontal contact with overlying coset; **5.** ~0.40 m thick coset of *Sl-hss <1.0 m (Sl); likely very low-amplitude small-scale trough cross-bedding; coset consists of 0.05-0.10 m thick sub-horizontal sets; poorly defined sets and foresets; sharp and erosive (in part) sub-horizontal contact with overlying set, mainly poorly defined contact; **6.** *Sl-hpx <2.0 m (Sp); high-angle-inclined foresets forming medium to large-scale planar cross-bedding; ~0.90 m sub-horizontal thick set; poorly defined foresets;

Outcrop 21.3 [~4.7 (H) x 6.0 (D) x 17.0 m (W); data obtained from southern section]: **1.** ~1.00 m thick coset of *Sl-hhs <1.0 m (Sh); likely small-scale trough cross-bedding; coset consists of 0.05-0.10 m thick mainly horizontal sets; poorly defined sets and foresets; sharp and sub-horizontal contact with overlying coset; **2.** ~1.15 m thick coset group of * Stmx 1.5-3.0 m (St); low to high-angle-inclined foresets; two cross-cutting sub-horizontal cosets (dunes) varying in thickness from ~0.50 m to ~0.65 m; cosets consist of poorly defined ~0.10 m thick sub-horizontal cross-cutting sets; sharp and likely erosive horizontal contact with overlying coset; **3.** ~0.80 m thick coset of *Sl-hhs <1.0 m (Sh); likely small-scale trough cross-bedding; coset consists of 0.10-0.15 m thick mainly horizontal sets; poorly defined sets and foresets, coarser grain component towards base of sets and foresets – normal grading; poorly defined, likely, horizontal contact with overlying set;

4 *Sl-hpx <2.0 m (Sp); high-angle-inclined foresets forming medium-scale planar cross-bedding; ~0.50 m thick set; coarser grain component towards base of foresets – normal grading; foresets vary in thickness up to 0.02 m thick; evidence of reactivation surface; poorly defined, likely, horizontal contact with overlying coset; **5.** ~1.20 m thick coset of * Sl-hpx <2.0 m (Sp); small-scale planar cross-bedding; coset consists of 0.10-0.20 m thick sub-horizontal cross-cutting sets; poorly defined sets and foresets; poorly defined, likely, horizontal contact with overlying coset; **6.** ~0.40 m thick coset of *Sl-hhs <1.0 m (Sh); likely small-scale trough cross-bedding; coset consists of 0.05-0.10 m thick mainly horizontal sets; poorly defined sets and foresets; coarser grain component towards base, forming trough outline – normal grading;

Outcrop 21.4 [~7.0 (H) x 10.0 (D) x 36.0 m (W)]: **1.** ~0.80 m thick coset of Sl-hhs <1.0 m (Sh); likely small-scale trough cross-bedding; coset consists of ~0.10 m thick mainly horizontal sets; poorly defined sets and foresets – normal grading; poorly defined contact with overlying coset; **2.** ~0.45 m thick coset of *Spb >15% (Gt/p); likely pebble rich (~30% small to medium pebbles) small-scale trough cross-bedding <1.5 m trough width; ~0.15 m thick sets; poorly defined cross-bedding and set bounding surfaces; coarser grains towards trough base – normal grading; poorly defined, likely horizontal contact with overlying coset; **3.** ~0.50 m thick coset of *Stsx <1.5 m (St); small-scale trough cross-bedding <1.5 m trough width; coset consists of ~0.25 m thick down-climbing and cross-cutting sets; poorly defined sets, foresets delineated by coarser granule component towards foreset base – normal grading; poorly defined, likely horizontal contact with overlying coset; **4.** ~1.30 m thick coset of *Stsx <1.5 m (St); small-scale trough cross-bedding <1.5 m trough width; coset consists of 0.10-0.20 m thick down-climbing and cross-cutting sets; poorly defined sets and foresets; sharp (in part), likely sub-horizontal contact with overlying coset; **5.** ~1.60 m thick coset group of *Sl-hhs <1.0 m (Sh); two sub-horizontal cross-cutting cosets ~0.80 m thick; cosets consist of 0.15-0.20 m thick mainly horizontal cross-cutting sets; likely poorly defined trough cross-bedding; undulating and erosive contact between cosets; poorly defined sub-horizontal contact with overlying coset and lag deposit (in part); **6.** Ss-lp-lag (Gh); small to medium pebble lag deposit, 2.0-3.0 m long and ~0.20 m thick; concentrated towards the northern (Left) section of outcrop; predominantly coarse to granular grains (normal grading) with over 15% pebble content; lag may form erosive thalweg of a low-angle channel and likely forms base of overlying coset (in part); **7.** ~1.20 m thick coset of *Sl-hpx <2.0 m (Sp); low to high-angle-inclined foresets forming small-scale planar cross-bedding with down-climbing and cross-cutting 0.15-0.25 m thick sub-horizontal sets; poorly defined sets and foresets; coset pinches out towards the northern section (Left) of outcrop with evidence of tangential foresets, probably near to a channel thalweg; poorly defined graded contact with underlying lag deposit (in part) and sub-horizontal erosive contact with overlying coset; **8.** ~2.00 m thick coset group of *Sl-hss <1.0 m (Sl); three sub-horizontal cross-cutting cosets ~0.70 m thick; coarser grain component, and pebbles, towards coset base – normal grading; cosets consists of ~0.10 m thick down-climbing and cross-cutting sub-horizontal sets; likely poorly defined low-amplitude trough cross-bedding;

Outcrop 21.5 [~5.0 (H) x 6.0 (D) x 16.0 m (W)]: **1.** ~1.10 m thick coset of *Sl-hss <1.0 m (Sl); likely small-scale trough or planar cross-bedding; coset consists of 0.15-0.20 m thick sub-horizontal sets; poorly defined sets and foresets; sharp horizontal contact with overlying set; **2.** * Sl-hss-of <1.0 m (Sl); high-angle-inclined foresets forming medium-scale oblique planar cross-bedding; ~0.50 m thick horizontal set; poorly defined, likely, horizontal contact with overlying coset; **3.** ~0.45 m thick coset of *Sl-hss <1.0 m (Sl); small-scale trough cross-bedding <1.5 m trough width; coset consists of 0.15-0.20 m thick sub-horizontal sets delineated by ~0.03 m thick small to medium pebble lag (Ss-lp-lag (Gh)); poorly defined foresets; poorly defined horizontal contact with overlying coset; **4.** ~0.60 m thick coset of *Sl-hpx <2.0 m (Sp); low to high-angle-inclined foresets forming small to medium-scale planar cross-bedding; two ~0.30 m thick slightly sub-horizontal sets; poorly defined tangential foresets; sets pinch out towards the southern (Right) section of outcrop; poorly defined, likely, horizontal contact with overlying set; **5.** *Sl-hhs <1.0 m (Sh); small-scale trough cross-bedding <1.5 m trough width; ~0.15 m thick horizontal set; poorly defined set and low-angle foresets; set pinches out towards the southern (Right) section of outcrop; sharp (in part) horizontal contact with overlying set; **6.** *Spl/b (Sh); ~0.005 m thick planar low-angle laminations, poorly defined; ~0.15 m thick set; laminations pinch out towards the southern (Right) section of outcrop; sharp (in part) horizontal contact with overlying set; **7.** *Sl-hpx <2.0 m (Sp); low to high-angle-inclined foresets forming small to medium-scale planar cross-bedding; ~0.30 m thick horizontal set; poorly defined set and foresets; set pinches out towards the southern (Right) section of outcrop; sharp (in part) sub-horizontal and erosive contact with overlying set; **8.** *Sl-hpx <2.0 m (Sp); high-angle-inclined foresets forming large-scale planar cross-bedding; ~1.70 m thick sub-horizontal set; poorly defined foresets; evidence of possible Lepidodendron fossil remnant at base of northern (Left) section; poorly defined undulating contact with overlying coset, due to influence of soft sediment deformation (Ssd), mainly towards top section of set; **9.** ~0.80 m thick coset of *Ssd (Sd); likely medium-scale trough cross-bedding (Stmx 1.5-3.0 m); coset consists of ~0.30 m thick cross-cutting sets; poorly defined cross-bedding exhibiting signs of intense de-watering, i.e. flame structures and possible slump structures towards the southern (Right) section of outcrop; primary facies Ssd (Sd).

Interpretation

Outcrop 21.1: Palaeocurrent data relating to Outcrop 21.1 imply that the principal depositional palaeocurrent was towards the southwest (Fig. 4.4 Location 21). Variable coset and set thicknesses imply irregular channel depths and sediment input, likely facilitated by flood events with sediment migration and aggradation influenced by high and low-flow stages, respectively (Coleman, 1969; Bristow, 1987, 1993a; Ashworth *et al.,* 2011); the maximum set thickness of ~0.80 m (facies Sl-hpx <2.0 m) imply a maximum dune height and channel depth of ~2.90 m and ~8.65 m, respectively (cf. Reesink & Bridge, 2009; Leclair, 2011).

Initial two cosets relating to facies Sl-hss <1.0 m and Stsx <1.5 m, respectively, may represent: i. downstream-accretion of 3D mesoforms within a relatively shallow thalweg region of a low sinuosity channel influenced by high-flow stage which facilitated the formation of down-climbing dunes (cf. Bristow, 1988, 1993a; Ghinassi *et al.,* 2009; Miall, 2010b; Reesink *et al.,* 2014); ii. bar top vertical-accretion component of a channel bar, primarily due to dune stacking and relative shallow flow depth above the host bar (cf. Best *et al.*, 2003; Bridge & Lunt, 2006); or iii. migratory mid-channel bar bedform components; dune set components of such cosets likely formed within a multi-channelled fluvial system (cf. Reesink *et al.*, 2014) and such cosets may form individual consecutive small-scale unit bar components (cf. Sambrook Smith *et al.*, 2006;

Reesink & Bridge, 2009) of a much larger compound bar (cf. Allen, 1982; Bridge, 2003; Bridge & Lunt, 2006; Sambrook Smith *et al.*, 2006; Ashworth *et al.*, 2011). Facies Sl-hpx <2.0 m are predominantly constructed from repeated grain flow avalanche deposits (~0.02 m thick foresets; see Smith, 1972; Reesink & Bridge, 2007, 2009), such dune sets likely developed towards the channel thalweg/axis where large dunes tend to develop; the size of cross-bedding and relatively shallow inclined (≤04°) first-order bounding surface dip may correspond with downstream-accretion within a channel possessing high width to depth ratio (cf. Bristow, 1993a; Reesink & Bridge, 2009; Ashworth *et al.*, 2011; Reesink *et al.*, 2014). Such facies are also associated with downstream migration of: i. longitudinal bars (Ghinassi *et al.,* 2009); and ii. unit bars, although such bar heights coincide with dune heights (Ashworth *et al.*, 2011). Further, observed variable foreset azimuth-inclinations and angular foreset contacts are possibly related to bedforms that likely represent downstream migration and net aggradation of a transverse bar (2D macroforms), rather than a longitudinal or diagonal bar (cf. Smith, 1972; Hein & Walker, 1977; Collinson *et al.,* 2006); foreset variability is likely due to the lobate and asymmetrical morphology of a bar's tail and the angular foreset contacts are likely generated due to low fluid and low sediment discharge (cf. Smith, 1972; Hein & Walker, 1977; Collinson *et al.,* 2006; Bridge, 2003). Preservation of consecutive cross-laminated sets inevitably encompasses a measure of net deposition and subject to the inclination of their host bed most sets will climb at a similar angle (Leeder, 1982). Bedload deposition is related to flow stage i.e. fine and coarse-grained cross strata accumulate at low and high-flow stage, respectively (Reesink & Bridge, 2009 and references there in). Deposition of facies Sl-hpx <2.0 m would have contribute to channel fill and thereby reduce the overall channel depth and increase the flow rate over the bedform (cf. Reesink & Bridge, 2009).

Outcrop 21.2: Palaeocurrent data relating to Outcrop 21.2 imply variable southerly to westerly palaeocurrents, although the principal palaeocurrents were towards the west (Fig. 4.4 Location 21). Coset and set thicknesses imply variable channel depths and sediment input; a maximum set thickness of ~0.90 m (facies Sl-hpx <2.0 m) suggest a maximum dune height and channel depth of ~3.25 m and ~9.70 m, respectively (cf. Reesink & Bridge, 2009; Leclair, 2011).

Initial facies Stmx <1.5-3.0 m likely represents downstream migration and accretion of 3D mesoforms towards the thalweg/axis of a relatively broad/deep channel, as reflected by a dune height of ~1.80 m (cf. Reesink & Bridge, 2009; Ashworth *et al.*, 2011; Leclair, 2011; Reesink *et al.*, 2014). Such facies were probably generated by flood events with sediment migration and aggradation influenced by high and low-flow stages, respectively (Coleman, 1969; Bristow, 1987, 1993a; Ashworth *et al.,* 2011). Subsequent facies Sl-hss <1.0 m suggests migratory bedforms that likely developed within a relatively shallow channel (cf. Ashworth *et al.*, 2011), possibly on the surface of a larger sand flat (cf. Cant & Walker, 1976, 1978). Such bedforms are also associated with a series of distinct depositional episodes (cf. Collinson *et al.,* 2006) i.e. sets divided by first-order set boundaries which indicate repeated bedform migration probably as a train of dunes (dune stacking) which may have formed components of a channel bar top (cf. Bristow, 1993b; Best *et al.*, 2003; Bridge & Lunt, 2006; Mumpy *et al*., 2007; Miall, 2010b; Ashworth *et al.*, 2011). Shallow channel conditions also imply waning flow, aggradation and channel fill (cf. Cant & Walker, 1976; Ashworth *et al.*, 2011; Reesink *et al.*, 2014). Similarly, the sub-horizontal sets associated with facies Sl-hpx <2.0 m imply downstream migration and accretion of 2D mesoforms (cf. Coleman, 1969; Bristow, 1987, 1993a; Collinson *et al.*, 2006; Ashworth *et al.,* 2011), where deposition was influenced by an increase in channel depth likely facilitated by a flood event (high-flow stage) which enabled the formation of down-climbing dunes (cf. Bristow, 1988, 1993a; Reesink & Bridge, 2009; Ghinassi, 2011) and subsequent net sediment (dune) deposition during waning flow (low-flow stage) (cf. Coleman, 1969; Bristow, 1987, 1993a; Ashworth *et al.,* 2011). Further, such facies may also represent individual sub-horizontal set components of a larger host dune coset (cf. Haszeldine, 1983b), or small-scale downstream migrating unit bars (cf. Sambrook Smith *et al.*, 2006; Reesink & Bridge, 2009), which in turn likely form components of a much larger host compound bar (cf. Allen, 1982; Bridge, 2003; Bridge & Lunt, 2006; Sambrook Smith *et al.*, 2006; Ashworth *et al.*, 2011), although such component coset/unit bar heights coincide with dune heights (Ashworth *et al.*, 2011). Deposition of such dunes may have contributed to localised thalweg migration and alterations in flow direction (cf. Coleman, 1969; Bristow, 1987; Ashworth *et al.*, 2011) which may have influenced the subsequent southerly migration and deposition of facies Sl-hpx <2.0 m. The preservation of consecutive cross-laminated sets inevitably encompasses a measure of net deposition (Leeder, 1982), thereby contributing to channel fill deposition and reducing (locally) overall depth which likely influenced the deposition of facies Sl-hss <1.0 m. The ~0.05 m thick sets relating to facies Sl-hss <1.0 m imply flow conditions were sufficiently shallow to subdue dune formation and generate very low relief dunes (cf. Bristow, 1993a); preservation of low-angle dune morphology is facilitated by dune stoss and crest erosion, during high flow-stage, and deposition of eroded sediment in the dune's trough (Hendershot *et al.*, 2016). Low-angle bedforms may be attributed to the migration of low-amplitude (near horizontal) sand waves/dunes concomitant with the transitional zone between lower a and upper flow regimes and very shallow fluvial systems (cf. Smith, 1971; Todd, 1996); generally foreset gradients decline as a flow regime intensifies, vice versa (cf. Smith, 1972). Dune height also implies limited sediment input, likely influenced by high-flow stage which facilitated the formation of down-climbing dunes and downstream migration (cf. Bristow, 1988, 1993a; Reesink & Bridge, 2009; Ghinassi, 2011) and return to a westerly palaeocurrent. The shallow channel conditions (~0.50 m) relating to facies Sl-hss <1.0 m imply waning flow, aggradation of 2D or 3D mesoforms and channel fill (cf. Cant & Walker, 1976; Ashworth *et al.*, 2011; Reesink *et al.*, 2014). The subsequent deposition of facies Sl-hpx <2.0 m implies sediment deposition was influenced by a significant increase in channel depth, likely facilitated by a flood event (high-flow stage) and subsequent net sediment (dune) deposition during waning flow (low-flow stage) (cf. Coleman, 1969; Bristow, 1987, 1993a; Ashworth *et al.,* 2011). Such facies are also related to downstream migration of: i. longitudinal bars (Ghinassi *et al.,* 2009); and ii. unit bars, although such bar heights coincide with dune heights (Ashworth *et al.*, 2011).

Outcrop 21.3: Palaeocurrent data relating to Outcrop 21.3 imply variable southerly to westerly palaeocurrents (Fig. 4.4 Location 21). Coset and set thicknesses imply variable channel depths and sediment input; a maximum coset (dune) thickness of ~0.65 m (facies Stmx 1.5-3.0 m) suggests a maximum dune height and channel depth of ~2.35 m and ~7.00 m, respectively (cf. Reesink & Bridge, 2009; Leclair, 2011).

The relatively shallow channel conditions (0.50-1.00 m) relating to facies Sl-hhs <1.0 m indicate low-flow stage, aggradation of 3D mesoforms and channel fill (cf. Cant & Walker, 1976; Ashworth *et al.*, 2011; Reesink *et al.*, 2014). Similar bedforms are also associated with a series of distinct depositional episodes (cf. Collinson *et al.,* 2006) i.e. sets divided by first-order set boundaries which indicate repeated bedform migration probably as a train of dunes (dune stacking) which may have formed components of a channel bar top (cf. Bristow, 1993b; Best *et al.*, 2003; Bridge & Lunt, 2006; Mumpy *et al*., 2007; Miall, 2010b; Ashworth *et al.*, 2011); preservation of consecutive cross-laminated sets inevitably encompasses a measure of net deposition (Leeder, 1982). Such facies were likely deposited towards the thalweg region of the channel, rather than a host barform, as implied by the subsequent deposition of facies Stmx 1.5-3.0 m, which suggest sediment deposition was influenced by a significant increase in channel depth, likely facilitated by a flood event (high-flow stage) and subsequent net sediment (dune) deposition during waning flow (low-flow stage) (cf. Coleman, 1969; Bristow, 1987, 1993a; Ashworth *et al.,* 2011). Subsequent deposition of facies Sl-hhs <1.0 m imply a return to conditions concomitant with waning flow, aggradation of 3D mesoforms and channel fill, see above interpretations (cf. Cant & Walker, 1976; Ashworth *et al.*, 2011; Reesink *et al.*, 2014). Ensuing facies Sl-hpx <2.0 m imply sediment deposition was influenced by a further significant increase in channel depth, likely facilitated by a flood event (high-flow stage) and subsequent net sediment (dune) deposition in the form of repeated grain flow avalanche deposits (~0.02 m thick foresets; see Smith, 1972; Reesink & Bridge, 2007, 2009). Such mesoforms likely developed towards the channel thalweg/axis and the size of cross-bedding implies downstream-accretion within a relatively broad and deep channel (cf. Reesink & Bridge, 2009; Ashworth *et al.*, 2011; Reesink *et al.*, 2014) during waning flow (low-flow stage) (cf. Coleman, 1969; Bristow, 1987, 1993a; Ashworth *et al.,* 2011). Similarly, repeated deposition of facies Sl-hpx <2.0 m implies variable and reduced flow depth, likely influenced by flood events and a transferal from predominantly westerly to southerly palaeocurrents (Fig. 4.4 Location 21); deposition of relatively low-angle inclined (≤12°) first-order bounding surface dips likely correspond with downstream-accretion within a channel possessing relatively high width to depth ratio (cf. Bristow, 1993a; Reesink & Bridge, 2009; Ashworth *et al.*, 2011; Reesink *et al.*, 2014). Palaeocurrent transferal may represent fluvial readjustment due to flood initiated avulsion or lateral tilting facilitated by fault (syn-sedimentary tectonic) activity and/or subsidence along the North Craven Fault (cf. Kane *et al.*, 2010; Fidolini *et al.*, 2013). Dune heights (0.10-0.20) also imply reduced sediment input, likely influenced by high-flow stage which facilitated the formation of down-climbing dunes and downstream migration (cf. Bristow, 1988, 1993a; Reesink & Bridge, 2009; Ghinassi, 2011). Preservation of consecutive cross-laminated sets inevitably encompasses a measure of net deposition and subject to the inclination of their host bed most sets will climb at a similar angle (Leeder, 1982). Hence, the further deposition of facies Sl-hpx <2.0 m would have contributed to channel fill, thereby reducing the overall channel depth and increasing the flow rate over the bedform (cf. Reesink & Bridge, 2009). Subsequent deposition of facies Sl-hhs <1.0 m denotes a return to conditions concomitant with waning flow, aggradation of 3D mesoforms and channel fill, see above interpretations (cf. Cant & Walker, 1976; Ashworth *et al.*, 2011; Reesink *et al.*, 2014).

Outcrop 21.4: Palaeocurrent data relating to Outcrop 21.4 imply variable southerly to northerly palaeocurrents, although the principal palaeocurrents were towards the west (Fig. 4.4 Location 21). Coset and set thicknesses imply variable channel depths and sediment input; a maximum coset/bar thickness of ~1.30 m (facies Stsx <1.5 m) suggest a maximum unit bar height and channel depth of ~1.80 m and ~3.60 m, respectively (cf. Bristow, 1987; Bridge, 2003; Leclair, 2011; Reesink *et al*., 2014).

The pebble content (10-15%) and set thickness (~0.10 m) relating to facies Sl-hhs <1.0 m suggest influence of a relatively shallow flood event (high-flow stage) and subsequent net sediment deposition during waning flow (low-flow stage) (cf. Coleman, 1969; Bristow, 1987, 1993a; Ashworth *et al.,* 2011). Low-flow stage would have facilitated the aggradation of 3D mesoforms and channel fill (cf. Cant & Walker, 1976; Ashworth *et al.*, 2011; Reesink *et al.*, 2014). Similar bedforms are also associated with a series of distinct depositional episodes (cf. Collinson *et al.,* 2006) i.e. sets divided by first-order set boundaries which indicate repeated bedform migration probably as a train of dunes (dune stacking) which may have formed components of a channel bar top (cf. Bristow, 1993b; Best *et al.*, 2003; Bridge & Lunt, 2006; Mumpy *et al*., 2007; Miall, 2010b; Ashworth *et al.*, 2011); preservation of consecutive cross-laminated sets inevitably encompasses a measure of net deposition (Leeder, 1982). Facies Sl-hhs <1.0 m was probably deposited towards the channel thalweg region, rather than a host barform, as implied by the subsequent deposition of facies Spb >15% which likely represents a basal flood/scour deposit and high-flow stage (cf. Coleman, 1969; Bristow, 1987, 1993a; Ashworth *et al.*, 2011). Similarly, pebble deposits may also denote the location of a channels thalweg/axial region (cf. Fidolini *et al.*, 2013; Ghinassi *et al.*, 2014) where relatively larger bedforms develop (Reesink & Bridge, 2009; Ashworth *et al.*, 2011; Reesink *et al.*, 2014). Facies Spb >15% and Stsx <1.5 m possess increasing pebble content and set thickness, which denotes an increase in flow-stage and channel depth, respectively, likely influenced by flood events and north-westerly palaeocurrents. The scale of the ensuing coset (~1.30 m thick) relating to facies Stsx <1.5 m and change to a southerly palaeocurrent implies fluvial readjustment likely facilitated by a flood event and channel avulsion or fault (syn-sedimentary tectonic) activated lateral tilting and/or subsidence along the North Craven Fault (cf. Kane *et al.*, 2010; Fidolini *et al.*, 2013). Such activity likely facilitated the repeated downstream-accretion of 3D mesoforms influenced by high-flow stage and the formation of down-climbing dunes (cf. Bristow, 1988, 1993a; Reesink & Bridge, 2009; Ghinassi, 2011). The recurring downstream migration of such dunes probably formed a train of dune components associated with a discrete unit bar (3D mesoform, part of) (cf. Bridge & Lunt, 2006; Reesink & Bridge, 2009; Ashworth *et al.*, 2011); a set/coset thickness ≥1.00 m likely denotes unit bars, rather than dunes (cf. Bridge & Lunt, 2006). Similarly, Sambrook Smith *et al.* (2006) interpret sets >0.5 m, which possess inclined (i.e. ≤ angle-of-repose) cross-stratification, as a consequence of bar migration. Subsequent deposition of facies Sl-hhs <1.0 m denotes a return to conditions concomitant with waning flow, aggradation of 3D mesoforms and channel fill, see above interpretations (cf. Cant & Walker, 1976; Ashworth *et al.*, 2011; Reesink *et al.*, 2014) and fluvial readjustment with a return to deposition influenced by west to north-westerly palaeocurrent (Fig. 4.4 Location 21). The preserved coset thickness of ~1.20 m for facies Sl-hpx <2.0 m is similar to that of the ~1.30 m thick coset relating to facies Stsx <1.5 m described above, and correspondingly likely forms a discrete unit bar (cf. Bridge & Lunt, 2006; Ashworth *et al.*,2011), facilitated by a flood event and north-westerly palaeocurrent. The lag deposit (facies Ss-lp-lag) at the northern tail-end of the unit bar likely represents scouring (Miall, 2010b) or winnowing (cf. Collinson *et al.,* 2006) processes, which may be related to a channel surface; such lag deposits are known to denote channel thalweg/axial regions (Fidolini *et al.*, 2013; Ghinassi *et al.*, 2014). Further, tangential (or asymptotic) foresets associated with facies Sl-hpx <2.0 m were likely promoted by fairly frail separation eddies and a high rate of sediment deposition, from suspension, beyond the slipface of the dune's lee (cf. Leeder, 1982; Bristow, 1993a; Bridge, 2003). The overlying facies (Sl-hss <1.0 m) imply deposition influenced by high-flow stage which facilitated the formation of down-climbing dunes (cf. Bristow, 1988, 1993a; Reesink & Bridge, 2009; Ghinassi, 2011), see above interpretations. Together with the underlying facies (Sl-hpx <2.0 m), these mesoforms likely form components of small-scale downstream migrating unit bar (cf. Sambrook Smith *et al.*, 2006; Reesink & Bridge, 2009) components of a much larger host compound bar (cf. Allen, 1982; Bridge, 2003; Bridge & Lunt, 2006; Sambrook Smith *et al.*, 2006; Ashworth *et al.*, 2011). The sub-horizontal coset/unit bar contacts are likely third-order erosional surfaces (cf. Miall, 2010b; Ielpi *et al*., 2014), which denote a component of lateral coset (mesoform) accretion and growth of the host compound bar (macroform) through lateral and downstream-accretion (cf. Bridge & Lunt, 2006). Hence, Outcrop 21.4 likely represents the downstream migration and accretion of a compound bar and related unit bar components, although studies conducted by Skelly *et al.* (2003) and Ashworth *et al.* (2011) (and references there in) argue that the distinction between compound bar and adjacent channel fill core deposits, in sandy braided fluvial systems, is problematic.

Outcrop 21.5: Palaeocurrent data relating to Outcrop 21.5 imply variable south-westerly palaeocurrents (Fig. 4.4 Location 21). Coset and set thicknesses imply variable channel depths and sediment input; a maximum set/bar thickness of ~1.70 m (facies Sl-hpx <2.0 m) suggest a maximum unit bar height and channel depth of ~5.10 m and ~10.20 m, respectively (cf. Bristow, 1987; Bridge, 2003; Leclair, 2011; Reesink *et al*., 2014).

General interpretations relating to initial basal facies of Sl-hss <1.0 m are similar to those previously mentioned, see above interpretations. The subsequent deposition of facies Sl-hss-of <1.0 m implies an increase in net sediment input and channel depth, probably resulting from a flood event (high-flow stage) and the net deposition, through lateral-accretion, of 2D mesoforms during waning flow (low-flow stage) (cf. Coleman, 1969; Bristow, 1987, 1993a; Ashworth *et al.,* 2011). Further, topographic lows adjacent to bar margins may limit falling-stage currents that flow between bars (Collinson, 1970; cf. Reesink *et al*., 2014), thereby facilitating lateral-accretion by promoting deposition along bar margins (Collinson, 1970, 1996). The overlying facies (Sl-hss <1.0 m) denotes a return to conditions concomitant with high-flow stage which facilitated the formation of down-climbing dunes (cf. Bristow, 1988, 1993a; Ghinassi *et al.,* 2009; Miall, 2010b; Reesink *et al.,* 2014), see above interpretations. The lag deposit (facies Ss-lp-lag) at the base of facies Sl-hss <1.0 m likely represents scouring (Miall, 2010b) or winnowing (cf. Collinson *et al.,* 2006) processes, which may be related to a channel surface. Lag deposits are known to denote basal flood deposits and high-flow stage (cf. Coleman, 1969; Bristow, 1987, 1993a; Ashworth *et al*., 2011), along with channel thalweg/axial regions (Fidolini *et al*., 2013; Ghinassi *et al*., 2014) where relatively larger bedforms may develop (Reesink & Bridge, 2009; Ashworth *et al*., 2011; Reesink *et al*., 2014). Facies Sl-hpx <2.0 m implies sediment deposition was influenced by increasing channel depth, likely facilitated by a flood event (high-flow stage) and subsequent net sediment (dune) deposition during waning flow (low-flow stage) (cf. Coleman, 1969; Bristow, 1987, 1993a; Ashworth *et al.,* 2011). The ~0.15 m thick sets related to subsequent facies Sl-hhs <1.0 m and Spl/b imply flow conditions were sufficiently shallow to subdue dune formation and generate very low relief dunes (cf. Bristow, 1993a); preservation of low-angle dune morphology (~04° dip angles) is facilitated by dune stoss and crest erosion, during high flow-stage, and deposition of eroded sediment in the dune's trough (Hendershot *et al.*, 2016). Low-angle bedforms may be attributed to the migration of low-amplitude (near horizontal) sand waves, or low-relief dunes associated with parallel laminations, both are concomitant with the transitional zone between lower and upper flow regimes and very shallow fluvial systems (cf. Smith, 1971; Todd, 1996); generally foreset gradients decline as a flow regime intensifies, vice versa (cf. Smith, 1972). Facies Spl/b also denotes a relatively minor, localised, palaeocurrent transferal towards the south. Facies Sl-hpx <2.0 m implies sediment deposition was influenced by increasing channel depth likely facilitated by a further flood event (high-flow stage) and subsequent net sediment (dune) deposition during waning flow (low-flow stage) (cf. Coleman, 1969; Bristow, 1987, 1993a; Ashworth *et al.,* 2011). A subsequent major flood event is evidenced by the deposition of the overlying large-scale planar tabular cross-bedding (i.e. ~1.70 m thick set of facies Sl-hpx >2.0 m), which likely represents an alternate bar (2D macroform; McCabe, 1977; Collinson, 1996; Collinson *et al.*, 2006; Miall, 2010b) and increase in palaeo-discharge. The base of facies Sl-hpx >2.0 m forms an erosive contact with four of the preceding facies, all of which pinch out towards the west. McCabe (1977) interpreted alternate bars to have formed within distributary channels between 1.0 to 2.0 km wide and 30.0 to 40.0 m deep. Similarly, the scale of facies Sl-hpx >2.0 m suggests that the alternate bar probably formed in a relatively deep channel (cf. Reesink & Bridge, 2009; Ashworth et al., 2011; Reesink *et al.*, 2014); a set thickness ≥1.00 m likely denotes unit bars, rather than dunes (Bridge & Lunt, 2006). Similarly, Sambrook Smith *et al.* (2006) interpret sets >0.5 m, which possess inclined (i.e. ≤ angle-of-repose) cross-stratification, as a consequence of bar migration. A preserved set thickness of ~1.70 m suggests that the maximum barform thickness was ~5.10 m (cf. Leclair, 2011). Because bar heights may adjust between half and bankfull depth, the depth of host channel was probably between ~5.10 m and ~10.20 m, respectively (cf. Bristow, 1987; Bridge, 2003; Reesink *et al*., 2014). Such facies may also account for localised thalweg migration and alterations in flow direction, as evidenced by a minor transferal of palaeocurrent towards the south (Fig. 4.4 Location 21; cf. Coleman, 1969; Bristow, 1987; Ashworth *et al.*, 2011). The upper section of facies Sl-hpx >2.0 m appears affected by soft sediment deformation, as implied by an undulating contact and the subsequent deposition of facies Ssd. Soft sediment deformation (e.g. dish and flame structures) implies loss of grain stability (liquefaction) within unconsolidated water laden sediments, influenced by water saturation and event(s) that triggered de-watering processes, for example sudden overburden (rapid sediment deposition) post flood event and/or syn-sedimentary tectonic activity post deposition (cf. Barnhardt & Sherrod, 2006; Hubert-Ferrari *et al.*, 2017). Evidence to suggest that a sudden overburden of sediment was the triggering event is evident, due to the relative size of the overlying medium-scale sets subjected to soft sediment deformation (i.e. ~0.30 m thick sets of Stmx 1.5-3.0 m), although the effect of tectonic activity cannot be totally discounted. Further, the thickness of facies Ssd (~0.80 m) likely represents net sediment deposition during falling-flow stage (cf. Coleman, 1969; Bristow, 1987, 1993a; Ashworth *et al.,* 2011).

Overall, facies and palaeocurrents associated with Location 21 suggest that the location was influenced by a mixture of migrating channel dune and bar deposition. The variable thicknesses of individual sets and cosets evidence variable flow depths and sediment influx, likely facilitated by flood events (high-flow stage) and subsequent net sediment (dune/bar) deposition during waning flow (low-flow stage) (cf. Coleman, 1969; Bristow, 1987, 1993a; Ashworth *et al.,* 2011). Set thicknesses ≥1.00 m likely denotes unit bars, rather than dunes (Bridge & Lunt, 2006). Similarly, Sambrook Smith *et al.* (2006) interpret sets >0.5 m, which possess inclined (i.e. ≤ angle-of-repose) cross-stratification, as a consequence of bar migration. Correspondingly, distinct and recurring sets of down-climbing dunes (<1.0 m thick) likely influenced by high-flow stage (cf. Bristow, 1988, 1993a; Reesink & Bridge, 2009; Ghinassi, 2011) may also form small-scale unit bars (cf. Sambrook Smith *et al.*, 2006; Reesink & Bridge, 2009), although such bar heights coincide with dune heights (Ashworth *et al.*, 2011). Alternatively, distinct sub-horizontal sets of facies Sl-hss <1.0 m may form components of a larger host dune coset (cf. Haszeldine, 1983b). Palaeocurrent transferal may represent fluvial readjustment due to flood initiated avulsion or lateral tilting facilitated by fault (syn-sedimentary tectonic) activity and/or subsidence along the North Craven Fault (cf. Kane *et al.*, 2010; Fidolini *et al.*, 2013); soft sediment deformation is an indication of a post flood event and/or syn-sedimentary tectonic activity post deposition (cf. Collinson *et al.*, 2006). Further, palaeocurrent fluctuations may be correlated to the influence of a channel confluence, evidenced by the presence of an alternate bar which can develop in scour pools related to a channel confluence (McCabe, 1977; Collinson, 1996; Collinson *et al.*, 2006), such environments would account for the apparent limited areal extent of the observed bar (McCabe, 1977); confluences are also associated with anastomosing channels (McCabe, 1977). Potential scour locations include, downstream of mid-channel macroforms, upstream of large emergent bars and erosion against channel or island banks (Miall, 2010b and references there in). The depth of such scours may extend to six times the mean channel depth and may also develop avalanche aspects that facilitate lateral, oblique, or vertical infilling through avalanche deposits below mean channel depth, thereby promoting sediment preservation (Ashmore & Parker, 1983; Miall, 2010b and references there in). Hence, Outcrop 21.5 likely represents the downstream migration and accretion of dunes and bars conceivably influenced by channel scours, flood initiated avulsion or lateral tilting facilitated by fault (syn-sedimentary tectonic) activity and/or subsidence.

Table 4.22

Location, grid reference and associated literature	General description and lithology
22. Brimham Rocks (Facies Stlx >3.0 m) Outcrop 22.1: SE 20897 64929 Thompson, A. T. (1957) *The structure and stratigraphy of Nidderdale between Lofthouse and Dacre*. Unpublished, Doctoral thesis, Durham University. Available at Durham E-Theses Online: http://etheses.dur.ac.uk/722/. Reid, C. T. (1996) *The Alportian and Kinderscoutian (Namurian) of North Yorkshire: the sedimentary response to eustatic variation.* Unpublished Doctoral thesis, University of Keele.	A detailed description of Brimham Rocks is provided for in Chapter 3. Outcrop 22.1 is one of numerous various sized/shaped tors scattered throughout the Brimham Rocks estate and is included as it affords a good example of facies Stlx >3.0 m. Generally, all the outcrops are masked (in part) by soil, vegetation (e.g. lichen, moss and algae) and detritus associated with a moorland and woodland (in part) setting. Although several outcrops appear to have been displaced, the examined outcrop seems to be in- sitú and not affected by cambering; although it has been influenced by horizontal and vertical jointing, weathered and possesses a variable texture with relatively poor outcrop detail (e.g. foreset/sets), due to processes of weathering and erosion. Elevation of Outcrop 22.1 is ~270 m O.D.; main outcrop view is towards 095˚ (Fig. 4.4 Location 22). Outcrop 22.1: Coarse-grained to granular sandstone (variable) with 2-5% small to medium pebble content (variable), predominantly quartz grains; generally high sphericity; sub-angular to rounded; moderately to well sorted.

Identified sub-Facies, sedimentary structures and bounding surfaces of note

Outcrop 22.1 [~7.0 (H) x 9.0 (D) x 9.0 m (W)]: **1.** ~1.60 m thick coset of *Sl-hhs <1.0 m (Sh); likely small to medium-scale trough cross-bedding; coset consists of 0.15-0.20 m thick mainly horizontal sets; poorly defined sets and foresets; sharp, erosive and sub-horizontal contact with overlying set; **2.** *Stlx >3.0 m (St); large-scale trough cross-bedding >3.0 m trough width; ~1.35 m thick set (trough); coarser grain component delineates foreset boundaries – normal grading; sharp, erosive and predominantly horizontal contact with overlying coset; **3.** ~0.80 m thick coset of *Stmx 1.5-3.0 m (St); low to high-angle-inclined foresets forming low-amplitude medium-scale trough cross-bedding; coset consists of ~0.10 m thick cross-cutting low to high-angle sub-horizontal sets; poorly defined sets and foresets; coarser grain component delineates set boundaries – normal grading; sharp, erosive and predominantly horizontal contact with overlying coset; **4.** ~0.90 m thick coset of *Stsx <1.5 m (St); likely small-scale trough cross-bedding bedding <1.5 m trough width; coset consists of ~0.15 m thick mainly horizontal sets; poorly defined foresets; sharp (in part) horizontal contact with overlying set; **5.** *Sl-hpx <2.0 m (Sp); low to high-angle-inclined foresets forming large-scale planar cross-bedding; ~1.20 m thick horizontal set; coarser grain component delineates foreset boundaries (~0.01 m thick foresets) – normal grading; sharp sub-horizontal contact with overlying set; **6.** Spl/b (Sh); poorly defined planar low-angle laminations; ~0.20 m thick set; laminations pinch out towards the southern (Right) section of outcrop; sharp (in part) sub-horizontal contact with overlying set; **7.** *Sl-hpx <2.0 m (Sp); low to high-angle-inclined foresets forming medium to large-scale planar cross-bedding; ~0.70 m thick horizontal set, which narrows towards the southern (Right) section of outcrop; coarser grain component delineates foreset boundaries (~0.01 m thick foresets) – normal grading.

Interpretation

Palaeocurrent data relating to Outcrop 22.1 imply variable south-westerly to north-westerly palaeocurrents (Fig. 4.4 Location 22). Coset and set thicknesses imply variable channel depths and sediment input; a maximum set/bar thickness of ~1.35 m (facies Stlx >3.0 m) suggest a maximum unit bar height and channel depth of ~4.05 m and ~8.10 m, respectively (cf. Bristow, 1987; Bridge, 2003; Leclair, 2011; Reesink *et al*., 2014).

Initial facies of Sl-hhs <1.0 m may represent downstream migration and net accretion of 3D mesoforms within a relatively deep (~2.15 m deep; cf. Reesink & Bridge, 2009; Leclair, 2011) thalweg region of a low sinuosity channel (cf. Bristow, 1988, 1993a; Ghinassi *et al.,* 2009; Miall, 2010b; Reesink *et al.,* 2014), influenced by waning flow, net sediment aggradation and channel fill (cf. Cant & Walker, 1976; Ashworth *et al.*, 2011; Reesink *et al.*, 2014). Such facies may also indicate migratory bedforms that likely developed on the surface of a larger sand flat (cf. Cant & Walker, 1976, 1978) and/or they may represent the latter stages of a channel fill sequence (cf. Reesink *et al.*, 2014). Similarly, such bedforms are also associated with a series of distinct depositional episodes (cf. Collinson *et al.,* 2006) of assembled sets divided by first-order set boundaries which indicate repeated bedform migration probably as a train of dunes (dune stacking) which may have formed components of a channel bar top (cf. Bristow, 1993b; Best *et al.*, 2003; Bridge & Lunt, 2006; Mumpy *et al*., 2007; Miall, 2010b; Ashworth *et al.*, 2011). The preservation of consecutive cross-laminated sets inevitably encompasses a measure of net deposition (Leeder, 1982). Deposition of successive facies Stlx >3.0 m, Stmx 1.5-3.0 m and Stsx <1.5 m represent large, medium and small-scale trough cross-bedding, respectively. Such a sequence of facies imply an initial substantial increase in channel depth and net sediment input facilitated by a flood event with sediment migration (high-flow stage) and aggradation (low-flow stage) enabling the net deposition of 3D mesoforms during waning flow (Coleman, 1969; Bristow, 1987, 1993a; Ashworth *et al.,* 2011). The size of the initial cross-bedding (i.e. ~1.35 m thick set of Stlx >3.0 m) implies downstream migration and deposition of a unit bar (3D mesoform, part of; cf. Bridge & Lunt, 2006; Ashworth *et al.*, 2011); a set thickness ≥1.00 m likely denotes unit bars, rather than dunes (Bridge & Lunt, 2006). Similarly, Sambrook Smith *et al.* (2006) interpret sets >0.5 m, which possess inclined (i.e. ≤ angle-of-repose) cross-stratification, as a consequence of bar migration. Subsequent deposition of facies Stmx 1.5-3.0 m and Stsx <1.5 m likely represent a gradual decrease in channel depth and sediment input, influenced by continuing waning flow and channel fill (cf. Cant & Walker, 1976; Ashworth *et al.*, 2011; Reesink *et al.*, 2014). A further flood event likely facilitated the migration and subsequent deposition of predominantly planar cross-bedding (2D mesoforms), represented by a unit bar and ensuing dune (facies Sl-hpx <2.0 m, ~1.20 m and ~0.70 m thick sets, respectively (cf. Bridge & Lunt, 2006; Ashworth *et al.*, 2011, see above) and intervening interdune (facies Spl/b). Such interdunes are associated with waning flow conditions

(Collinson, 1996) (low-flow stage) whereby falling water levels, locally within interdune regions, likely increased the palaeocurrent velocity and thereby generate upper-stage (or lower-stage) plane-bed flow conditions which facilitated the deposition of planar interdune laminations (cf. Collinson, 1996; Carling *et al.*, 2000).

Overall the facies associated with Outcrop 22.1 likely represent downstream migration and channel fill sequence relating to the thalweg region of a relatively deep and wide channel, where relatively large bedforms had the potential to develop (Reesink & Bridge, 2009; Ashworth *et al.*, 2011; Reesink *et al.*, 2014) and migrate downstream.

Table 4.23

Location, grid reference and associated literature	General description and lithology
23. Eavestone Lake Outcrops 23.1: SE 22439 67948 23.2: SE 22700 67865 23.3: SE 22842 67968 Thompson, A. T. (1957) *The structure and stratigraphy of Nidderdale between Lofthouse and Dacre*. Unpublished, Doctoral thesis, Durham University. Available at Durham E-Theses Online: http://etheses.dur.ac.uk/722/.	Numerous various sized outcrops scattered throughout woodland setting adjacent to the northern and southern banks of Eavestone Lake. Outcrops are generally masked (in part) by soil, vegetation (e.g. lichen, moss and algae) and detritus associated with a woodland setting. Although several outcrops appear to have been disarticulated, displaced and/or inaccessible, the in-sitú examined outcrops are representative of the outcrops at the location and generally follow a line of intermittent fragmented outcrops moving from the southwest towards the northeast, along the northern bank of the lake. Generally, all the examined outcrops are jointed, horizontally and vertically, weathered and possess a variable texture with relatively poor outcrop detail (e.g. foreset/sets), due growth of moss, lichen and to the processes of weathering and erosion; the outcrops may have also been subjected to minor cambering. Elevation of Outcrops 20.1-20.3 is ~171, 171 and 187 m O.D, respectively; main outcrop views are towards ~080˚, 350˚ and 260˚, respectively (Fig. 4.4 Location 23). Outcrop 23.1: Medium-grained to granular sandstone with 2-5% small to medium pebble content (variable), predominantly quartz grains; generally low to high sphericity; sub-angular to rounded; poorly to very well sorted; Outcrop 23.2: Medium-grained to granular sandstone with 2-10% small to medium pebble content (variable), predominantly quartz grains; generally low to high sphericity; sub-angular to rounded; poorly to moderately sorted; Outcrop 23.3: Medium-grained to granular sandstone with 2-10% small to medium pebble content (variable), predominantly quartz grains; generally low to high sphericity; sub-angular to rounded; poorly to very well sorted.

Identified sub-Facies, sedimentary structures and bounding surfaces of note

Outcrop 23.1 [~11.0 (H) x 10.0 (D) x 36.0 m (W)]: **1.** *Sl-hpx <2.0 m (Sp); low to high-angle-inclined foresets forming large-scale planar cross-bedding; ~0.85 m thick horizontal set; coarser grain component delineates foreset boundaries (~0.02 m thick foresets) – normal grading; poorly defined sub-horizontal contact with overlying coset; **2.** ~0.70 m thick coset of *Sl-hhs <1.0 m (Sh); likely small-scale planar cross-bedding; coset consists of ~0.10 m thick mainly horizontal sets; poorly defined sets and foresets; poorly defined sub-horizontal contact with overlying coset; **3.** ~0.30 m thick coset of *Stsx <1.5 m (St); likely small-scale trough cross-bedding <1.5 m trough width; coset consists of ~0.15 m thick mainly horizontal sets; poorly defined foresets; poorly defined sub-horizontal contact with overlying coset; **4.** ~1.10 m thick coset of *Stmx 1.5-3.0 m (St); low to high-angle-inclined foresets forming medium-scale trough cross-bedding; coset consists of 0.25-0.35 m thick mainly horizontal sets; poorly defined sub-horizontal contact with overlying coset; **5.** ~0.30 m thick coset of *Stsx <1.5 m (St); likely small-scale trough cross-bedding <1.5 m trough width; coset consists of ~0.15 m thick mainly horizontal sets; poorly defined foresets; poorly defined sub-horizontal contact with overlying set; **6.** *Sl-hpx <2.0 m (Sp); low to high-angle-inclined foresets forming large-scale planar cross-bedding; ~1.30 m thick horizontal set; coarser grain component delineates foreset boundaries – normal grading; poorly defined (in part) horizontal contact with overlying coset and erosive (in part) contact with overlying set (channel base); **7.** 0-1.50 m thick coset of *Sl-hss <1.0 m (Sl); coset pinches out towards the centre of the outcrop when moving down from the northern section (right) of outcrop; cosets consists of ~0.10 m thick down-climbing and cross-cutting sub-horizontal sets; likely poorly defined low-amplitude trough cross-bedding <1.5 m trough width; sets delineated by coarser grain component and intermittent minor pebble lags; poorly defined foresets; sharp and erosive sub-horizontal contact with overlying set (channel base); **8.** *Sl-hpx <2.0 m (Sp); low to high-angle-inclined foresets forming large-scale planar cross-bedding; ~1.60 m thick set (deepest section of channel); coarser grain component delineates foreset boundaries – normal grading; evidence of reactivation surface; poorly defined (in part) horizontal contact with overlying coset; **9.** ~0.80 m thick coset of Stsx <1.5 m (St); likely small to medium-scale trough cross-bedding <1.5 m trough width; coset consists of ~0.20 m thick mainly horizontal sets; poorly defined foresets; poorly defined likely horizontal contact with overlying set; **10.** *Sl-hpx <2.0 m (Sp); low to high-angle-inclined foresets forming large-scale planar cross-bedding; ~1.30 m thick horizontal set; coarser grain component delineates foreset boundaries – normal grading; poorly defined likely horizontal contact with overlying coset; **11.** ~1.20 m thick fragmented coset of *Sl-hpx <2.0 m (Sp); low to high-angle-inclined foresets forming large-scale planar cross-bedding; coset consists of 0.10-0.20 m thick sub-horizontal cross-cutting sets; poorly defined foresets; sets delineated by coarser grain component and intermittent minor pebble lags;

Outcrop 23.2 [~4.5 (H) x 4.0 (D) x 6.0 m (W)]: **1.** ~1.90 m thick coset of *Sl-hpx <2.0 m (Sp); low to high-angle-inclined foresets forming medium to large-scale planar cross-bedding; coset consists of ~0.70, 0.50, 0.40 and 0.30 m thick tabular sets; slightly undulating horizontal contact between sets; coarser grain component and intermittent minor pebble lags delineate foreset boundaries (~0.02 m thick foresets) – normal grading; poorly defined slightly undulating horizontal contact with overlying coset; **2.** ~0.60 m thick coset of *Sl-hss <1.0 m (Sl); cosets consists of ~0.10 m thick down-climbing and cross-cutting sub-horizontal sets; likely poorly defined trough cross-bedding <1.5 m trough width; sets delineated by coarser grain component; poorly defined foresets; sharp sub-horizontal erosive contact with overlying set; **3.** Sl-hpx <2.0 m (Sp); low to high-angle-inclined foresets forming medium-scale planar cross-bedding; ~0.40 m thick horizontal set; poorly defined foreset boundaries; poorly defined slightly undulating horizontal contact with overlying set; **4.** *Sl-hpx <2.0 m (Sp); low to high-angle-inclined foresets forming large-scale planar cross-bedding; ~0.60 m thick horizontal set; coarser grain component delineates foreset boundaries (~0.02 m thick foresets) – normal grading; sharp horizontal contact with overlying coset; **5.** ~1.20 m thick coset of *Sl-hpx <2.0 m (Sp); low to high-angle-inclined foresets forming medium-scale planar cross-bedding; coset consists of ~0.40 m thick tabular sets; slightly undulating and poorly defined sub-horizontal contact between sets; coarser grain component and intermittent minor pebble lags delineate foreset boundaries (~0.02 m thick foresets) – normal grading;

Outcrop 23.3 [~5.0 (H) x 3.0 (D) x 40.0 m (W)]: **1.** ~0.80 m thick coset of Stsx <1.5 m (St); likely small to medium-scale trough cross-bedding <1.5 m trough width; coset consists of ~0.20 m thick mainly horizontal sets; poorly defined foresets; poorly defined undulating horizontal contact with overlying set; **2.** Sl-hpx <2.0 m (Sp); low to high-angle-inclined foresets forming large-scale planar cross-bedding; ~0.70 m thick horizontal set; coarser grain component delineates foreset boundaries – normal grading; poorly defined slightly undulating horizontal contact with overlying coset; **3.** ~0.70 m thick coset of Sl-hhs <1.0 m (Sh); likely small to medium-scale trough cross-bedding <1.5 m trough width; coset consists of 0.15-0.20 m thick horizontal sets; poorly defined sets and foresets; sharp horizontal contact with overlying coset; **4.** ~0.60 m thick coset of group of *Srsx 0.005-0.05 m (Sr); possible straight to sinuous-crested small-scale asymmetrical ripple cross-bedding, poorly defined; coset group consists of ~0.10 m thick horizontal cosets likely consisting of 0.01-0.02 m thick ripple heights (sets) and visible surface ripple wavelengths of ~0.30 m; ripple crestline's orientated southeast to northwest (e.g. 144°-324° and 154°-334°); poorly defined sets and foresets; sharp horizontal contact with overlying coset; **5.** ~1.10 m thick coset of Sl-hhs <1.0 m (Sh); likely small-scale trough cross-bedding <1.5 m trough width; coset consists of 0.10-0.15 m thick horizontal sets; coarser grain component and intermittent minor pebble lags towards base of sets – normal grading; poorly defined sets and foresets; sharp (in part) horizontal contact with overlying coset; **6.** ~0.35 m thick coset of Sl-hss <1.0 m (Sl); coset consists of ~0.10 m thick down-climbing and cross-cutting sub-horizontal sets; likely poorly defined trough cross-bedding <1.5 m trough width; coarser grain component and intermittent minor pebble lags towards base of sets – normal grading; poorly defined sets and foresets; poorly defined undulating horizontal contact with overlying coset; **7.** ~0.40 m thick coset of Stsx <1.5 m (St); likely small to medium-scale trough cross-bedding <1.5 m trough width; coset consists of ~0.20 m thick mainly horizontal sets; coarser grain component and intermittent minor pebble lags towards base of sets – normal grading; poorly defined sets and foresets.

Interpretation

Outcrop 23.1: Palaeocurrent data relating to Outcrop 23.1 imply variable westerly to south-westerly palaeocurrents (Fig. 4.4 Location 23). Coset and set thicknesses imply variable channel depths and sediment input; a maximum set/bar thickness of ~1.60 m (facies Sl-hpx <2.0 m) suggests a maximum unit bar height and channel depth of ~4.80 m and ~9.60 m, respectively (cf. Bristow, 1987; Bridge, 2003; Leclair, 2011; Reesink *et al*., 2014).

Initial facies of Sl-hpx <2.0 m are predominantly constructed from repeated grain flow avalanche deposits (~0.02 m thick foresets; see Smith, 1972; Reesink & Bridge, 2007, 2009) that likely represent downstream migration and accretion of 2D mesoforms, which developed towards the channel thalweg/axis; large dunes tend to develop towards deeper channel thalweg regions within relatively broad/deep channels, as reflected by a dune height of~3.10 m (cf. Reesink & Bridge, 2009; Ashworth *et al*., 2011; Leclair, 2011; Reesink *et al*., 2014). Such facies are also associated with the downstream migration of: i. longitudinal bars (Ghinassi *et al.,* 2009); and ii. unit bars, although such bar heights coincide with dune heights (Ashworth *et al*., 2011). Facies Sl-hhs <1.0 m may represent downstream migration and net accretion of 2D mesoforms within a relatively shallow (~1.10 m deep; cf. Reesink & Bridge, 2009; Leclair, 2011) thalweg region of a low sinuosity channel (cf. Bristow, 1988, 1993a; Ghinassi *et al.,* 2009; Miall, 2010b; Reesink *et al.,* 2014), influenced by waning flow, net sediment aggradation and channel fill (cf. Cant & Walker, 1976; Ashworth *et al*., 2011; Reesink *et al*., 2014). Such facies may also indicate migratory bedforms that likely developed on the surface of a larger sand flat (cf. Cant & Walker, 1976, 1978) and/or they may represent the latter stages of a channel fill sequence (cf. Reesink *et al*., 2014). Similarly, such bedforms are also associated with a series of distinct depositional episodes (cf. Collinson *et al.,* 2006) of assembled sets divided by first-order set boundaries which indicate repeated bedform migration probably as a train of dunes (dune stacking) which may have formed components of a channel bar top (cf. Bristow, 1993b; Best *et al*., 2003; Bridge & Lunt, 2006; Mumpy *et al*., 2007; Miall, 2010b; Ashworth *et al*., 2011). The preservation of consecutive cross-laminated sets inevitably encompasses a measure of net deposition (Leeder, 1982). Ensuing facies Stsx <1.5 m, Stmx 1.5-3.0 m and Stsx <1.5 m imply deposition of 3D mesoforms which likely relate to sediment migration influenced by a variable channel depth, facilitated by a flood event (high-flow stage) and subsequent net sediment deposition and aggradation of 3D mesoforms during waning flow (low-flow stage) (cf. Coleman, 1969; Bristow, 1987, 1993a; Ashworth *et al.,* 2011). Subsequent deposition of facies Sl-hpx <2.0 m implies substantial increase in channel depth and net sediment input, likely facilitated by a flood event with sediment migration and aggradation influenced by high and low-flow stages, respectively (Coleman, 1969; Bristow, 1987, 1993a; Ashworth *et al.,* 2011). The size of cross-bedding (~1.30 m) implies either downstream migration of a transverse bar (2D macroform, part of) (cf. Smith, 1972), or a unit bar component (2D mesoform, part of; cf. Bridge & Lunt, 2006; Ashworth *et al*., 2011); a set thickness ≥1.00 m likely denotes unit bars, rather than dunes (Bridge & Lunt, 2006). Similarly, Sambrook Smith *et al.* (2006) interpret sets >0.5 m, which possess inclined (i.e. ≤ angle-of-repose) cross-stratification, as a consequence of bar migration. Subsequent facies Sl-hss <1.0 m, with set thicknesses of ~0.10 m, is consistent with a relatively shallow host channel (~1.10 m deep; cf. Reesink & Bridge, 2009; Leclair, 2011). Although, if the coset relating to facies Sl-hss <1.0 m represents a small-scale unit bar (cf. Sambrook Smith *et al*., 2006; Reesink & Bridge, 2009), or dune coset (cf. Haszeldine, 1983b), the preserved coset thickness (~1.50 m) suggests that the maximum bedform thickness was ~1.75 m (cf. Leclair, 2011). Therefore, given that bar heights may adjust between half and bankfull depth, the depth of host channel may have been between 1.75 m and 3.50 m, respectively (cf. Bristow, 1987; Bridge, 2003; Reesink *et al*., 2014). Although, facies Sl-hss <1.0 m may represent: i. downstream-accretion of 3D mesoforms within a relatively shallow thalweg region of a low sinuosity channel, likely influenced by high-flow stage which facilitated the formation of down-climbing dunes (cf. Bristow, 1988, 1993a; Ghinassi *et al.,* 2009; Miall, 2010b; Reesink *et al.,* 2014); ii. bar top vertical-accretion component of a channel bar, primarily due to dune stacking and an initial relatively shallow flow depth above the host bar (cf. Best *et al*., 2003; Bridge & Lunt, 2006); or iii. a series of distinct depositional episodes (cf. Collinson *et al.,* 2006) of assembled sets divided by first-order set boundaries which indicate repeated downstream bedform migration, possibly as a train of dune components over the surface/crest or front/tail of a larger bar (macroform) (cf. Allen, 1982; Haszeldine, 1983b; Bristow, 1993b; Miall, 2010b; Ashworth *et al*., 2011), the coset of facies Sl-hss <1.0 m more likely represents a migratory mid-channel bedform that probably formed within a multi-channelled fluvial system (cf. Reesink *et al*., 2014), where the discrete sub-horizontal sets formed coset components of either an individual small-scale unit bar (cf. Sambrook Smith *et al*., 2006; Reesink & Bridge, 2009) or a distinct larger host dune (cf. Haszeldine, 1983b).

The subsequent erosive base of facies Sl-hpx <2.0 m likely forms a channel surface; the size of the cross-bedding (~1.60 m) suggests that channel formation, and associated palaeocurrent shift towards the northwest, were influenced by a flood event and the migration of a unit bar (cf. Bridge & Lunt, 2006; Ashworth *et al.*, 2011). The following facies of Stsx <1.5 m and Sl-hpx <2.0 m indicate a sustained period of variable flow, deposition of 3D and 2D mesoforms, respectively, and a maximum channel depth of ~7.80 m relating to the ~1.30 m thick set of facies Sl-hpx <2.0 m (cf. Reesink & Bridge, 2009; Leclair, 2011), see above for facies interpretations.

Overall the facies and palaeocurrents associated with Outcrop 23.1 imply that deposition was influenced by a mixture of westerly to south-westerly migrating channel dunes and small-unit bars (Fig. 4.4 Location 23). The variable thicknesses of individual sets and cosets evidence variable flow depths, sediment influx and downstream migration, likely facilitated by flood events (high-flow stage) and subsequent net sediment (bar or dune) deposition during waning flow (low-flow stage) (cf. Coleman, 1969; Bristow, 1987, 1993a; Ashworth *et al.,* 2011). Further, the shallow inclined (mainly ≤14°) second and fifth-order bounding surface dips, relating to facies Sl-hhs <1.0 m and Sl-hpx <2.0 m, respectively, may correspond to channels possessing high width to depth ratios (Bristow, 1993a).

Outcrop 23.2: Palaeocurrent data relating to Outcrop 23.2 imply a principally south-westerly palaeocurrent (Fig. 4.4 Location 23). Set thicknesses suggest variable channel depths and sediment input; a maximum set thickness of ~0.70 m (facies Sl-hpx <2.0 m) indicates a maximum dune height and channel depth of ~2.50 m and ~7.60 m, respectively (cf. Reesink & Bridge, 2009; Leclair, 2011).

The dominant facies associated with the outcrop is Sl-hpx <2.0 m, these facies are predominantly constructed from repeated grain flow avalanche deposits (~0.02 m thick foresets; see Smith, 1972; Reesink & Bridge, 2007, 2009) that may represent downstream migration and accretion of 2D mesoforms. Such mesoforms probably developed towards the channel thalweg/axis; large dunes tend to develop towards deeper channel thalweg regions within relatively broad/deep channels, as reflected by a dune height of~2.50 m (cf. Reesink & Bridge, 2009; Ashworth *et al.*, 2011; Leclair, 2011; Reesink *et al.*, 2014). Such facies are also associated with the downstream migration and net aggradation of: i. longitudinal bars (Ghinassi *et al.,* 2009); ii. unit bars (cf. Bridge & Lunt, 2006; Ashworth *et al.*, 2011), although such bar heights coincide with dune heights (Ashworth *et al.*, 2011); or iii. the observed angular foreset contacts suggest that the bedforms may represent transverse bars, generated as a result of low fluid and low sediment discharge (cf. Smith, 1972; Hein & Walker, 1977; Collinson *et al.,* 2006). The preservation of consecutive cross-laminated sets inevitably encompasses a measure of net deposition and subject to the inclination of their host bed most sets will climb at a similar angle (Leeder, 1982). Such primarily bedload deposition is also related to flow stage i.e. fine and coarse-grained cross strata accumulate at low and high-flow stage, respectively (Reesink & Bridge, 2009 and references there in); and the shallow inclined (≤12°) first and second-order bounding surface dips likely correspond to a channel possessing a high width to depth ratio (Bristow, 1993a).

Overall, Outcrop 23.2 may represent a sand flat remnant constructed from component unit bar deposits consisting of simple inclined (mainly <10°, but may be up to 35°) small to large-scale sets, which may show a vertical reduction in dune/set height correlated to a decrease in channel depth, the deposits may also display no significant vertical shift in grain size (cf. Bridge & Lunt, 2006). These traits are consistent with the facies associated with Outcrop 23.2, which likely represents two unit bar components of a host sand flat. The base and top of the initial unit bar is represented by facies Sl-hpx <2.0 m (~0.70 m thick set) and Sl-hss <1.0 m (~0.10 m thick sets), respectively, which is consistent with a gradual decrease in channel depth and available accommodation space for vertical dune accretion, there is also no obvious clear vertical grain size shift along the unit bar (cf. Bridge & Lunt, 2006). The upper unit bar consists of predominantly ~0.40 m thick sets of facies Sl-hpx <2.0 m. Comparable facies and palaeocurrents can be observed at an outcrop ~60.0 m due east (grid reference: SE 22758 67866, not featured) of Outcrop 23.2, which suggests a possible lateral relationship between both outcrops and a minimum of ~60.0 m lateral extent of the sand flat. Cant & Walker (1978) note that sand flats may extend downstream and laterally from 50–2000 m and 30-450 m, respectively, and up to 80% of a channel-belt's width (Sambrook Smith *et al.,* 2006).

Outcrop 23.3: Coset, set and foresets relating to Outcrop 23.3 are poorly defined, due to covering of moss, lichen and effect of weathering processes; therefore palaeocurrent data is limited, consisting of mainly east-west ripple trends (Fig. 4.4 Location 23), although the likely asymmetrical ripple morphology (facies Srsx 0.005-0.05 m) implies deposition was influenced by a westerly palaeocurrent and the shallow inclined (10°) second-order bounding surface dip associated with facies Sl-hhs <1.0 m likely corresponds to a channel possessing a high width to depth ratio (Bristow, 1993a). The blocky intermittent outcrop was examined moving from the left (southern section) towards the right (northern section) (Fig. 4.4 Location 23).

Initial facies of Stsx <1.5 m and Sl-hpx <2.0 m suggest in channel sediment migration and aggradation influenced by variable channel depths i.e. 1.30-2.15 m deep (facies Stsx <1.5 m; cf. Reesink & Bridge, 2009; Leclair, 2011) and 4.60-7.55 m deep (facies Sl-hpx <2.0 m; cf. Reesink & Bridge, 2009; Leclair, 2011); the migration and subsequent net deposition (aggradation) of 3D and 2D mesoforms, respectively, was likely facilitated by flood events (high-flow stage) and waning flow (low-flow stage), respectively (cf. Coleman, 1969; Bristow, 1987, 1993a; Ashworth *et al.,* 2011). Such facies probably formed towards the channel thalweg/axis, where larger bedforms generally develop (cf. Reesink & Bridge, 2009; Ashworth *et al.*, 2011; Reesink *et al.*, 2014). Facies Sl-hhs <1.0 m may represent downstream migration and accretion of 3D mesoforms within a relatively deep (~2.15 m deep; cf. Reesink & Bridge, 2009; Leclair, 2011) thalweg region of a low sinuosity channel (cf. Bristow, 1988, 1993a; Ghinassi *et al.,* 2009; Miall, 2010b; Reesink *et al.,* 2014), influenced by waning flow, net sediment aggradation and channel fill (cf. Cant & Walker, 1976; Ashworth *et al.*, 2011; Reesink *et al.*, 2014). Such facies may also indicate migratory bedforms that likely developed on the surface of a larger sand flat (cf. Cant & Walker, 1976, 1978) and/or they may represent the latter stages of a channel fill sequence (cf. Reesink *et al.*, 2014). Similarly, such bedforms are associated with a series of distinct depositional episodes (cf. Collinson *et al.,* 2006) of assembled sets divided by first-order set boundaries which indicate repeated bedform migration probably as a train of dunes (dune stacking) which may have formed components of a channel bar top (cf. Bristow, 1993b; Best *et al.*, 2003; Bridge & Lunt, 2006; Mumpy *et al*., 2007; Miall, 2010b; Ashworth *et al.*, 2011). Subsequent deposition of facies Srsx 0.005-0.05 m (ripple cross-stratification) is consistent with either upper channel fill (Bridge & Lunt, 2006; Ashworth *et al.,* 2011) or bar top

(Bristow, 1993b; Best *et al.*, 2003; Bridge & Lunt, 2006; Mumpy *et al*., 2007) deposition related to shallow channel flow conditions and low-flow stage deposition (Bridge & Lunt, 2006). The medium to coarse grain size of facies Srsx 0.005-0.05 m would have supported ripple formation (cf. Bridge & Lunt, 2006; Collinson *et al.,* 2006). Although not conclusive, due to the potential complex nature of ripple formation (Collinson *et al.,* 2006) and relatively poor outcrop detail, a ripple index of between 15-30 (cf. Lindholm, 1987; Collinson *et al*., 2006) suggests that the ripples were generated due to current, rather than wave, activity (Collinson *et al.,* 2006). The overlying facies denote an increase in grain size and textural change which indicate a significant adjustment in the palaeoflow strength and a general increase in channel depth, likely facilitated by flood events. Facies Sl-hhs <1.0 m likely represent net sediment aggradation, see above for further interpretations and the ensuing facies of Sl-hss <1.0 m and Stsx <1.5 m, respectively, represent net sediment migration. The development of the latter two facies was likely influenced by high-flow stage which facilitated the formation of down-climbing dunes (cf. Bristow, 1988, 1993a; Ghinassi *et al.,* 2009; Miall, 2010b; Reesink *et al.,* 2014), or mid-channel bedform migration, probably within a multi-channelled fluvial system (cf. Reesink *et al*., 2014), where the discrete sub-horizontal sets formed coset components of either an individual small-scale unit bar (cf. Sambrook Smith *et al.*, 2006; Reesink & Bridge, 2009), or a distinct larger host dune (cf. Haszeldine, 1983b).

Overall the facies associated with Outcrop 23.3 probably represents a channel fill sequence, rather than a migratory mid-channel bar; although mid-channel bars may also be interpreted as channel fill components, Skelly *et al.* (2003) and Ashworth *et al.* (2011) (and references there in) argue that the distinction between compound bar and adjacent channel fill core deposits, in sandy braided fluvial systems, is problematic. Further, Leeder (1982) argues that the preservation of consecutive cross-laminated sets inevitably encompasses a measure of net deposition, which inexorably necessitates that each individual foreset, set and coset deposit, for example, represent a contrasting scale of channel fill components.

Table 4.24

Location, grid reference and associated literature	General description and lithology
24. Plumpton Rocks Outcrop 24.1: SE 35581 53671 Thompson, A. T. (1957) *The structure and stratigraphy of Nidderdale between Lofthouse and Dacre*. Unpublished, Doctoral thesis, Durham University. Available at Durham E-Theses Online: http://etheses.dur.ac.uk/722/.	Numerous various sized outcrops scattered throughout woodland setting adjacent to the eastern bank of Plumpton Lake. The outcrops vary in size, possess a blocky and jointed (horizontally and vertically) appearance and display variable forms of cross-bedding e.g. planar and trough cross-bedding, which is masked (in part) by soil, vegetation (e.g. lichen, moss and algae) and detritus associated with a woodland setting. Although several outcrops appear to have been disarticulated and displaced, the in-sitú examined fragmented outcrop forms part of the lakes eastern bank and is representative of the outcrops at the location. Generally, the examined outcrop possess a variable texture with relatively poor outcrop detail (e.g. foreset/sets), due growth of moss, lichen and to the processes of weathering and erosion. Elevation of Outcrop 24.1 is ~50 m O.D; main outcrop view is towards ~092° (Fig. 4.4 Location 24). Outcrop 24.1: Coarse-grained to granular sandstone (variable) with 2-10% small to large pebble content (variable), predominantly quartz grains; generally low to high sphericity; sub-angular to rounded; poorly to well sorted.

Identified sub-Facies, sedimentary structures and bounding surfaces of note

Outcrop 24.1 [~14.0 (H) x 16.0 (D) x 33.0 m (W)]: **1.** ~0.70 m thick coset of *Sl-hss <1.0 m (Sl); likely small-scale trough cross-bedding; coset consists of 0.10-0.15 m thick sub-horizontal cross-cutting sets; poorly defined sets and foresets; poorly defined horizontal contact with overlying coset; **2.** ~0.90 m thick coset of *Sl-hhs <1.0 m (Sh); likely small to medium-scale planar cross-bedding; coset consists of 0.15-0.20 m thick mainly horizontal cross-cutting sets; poorly defined sets and foresets with coarser grain component delineating set/foreset boundaries (~0.02 m thick foresets) – normal grading; poorly defined horizontal contact with overlying coset; **3.** ~0.30 m thick coset of *Sl-hhs <1.0 m (Sh); likely small-scale trough cross-bedding; coset consists of 0.05-0.10 m thick mainly horizontal cross-cutting sets; poorly defined sets and foresets forming low-amplitude cross-bedding; sharp horizontal contact with overlying set; **4.** *Ss-lp-lag (Gh); small to large pebble lag deposit; variable lag thickness up to 0.04 m thick; sharp horizontal (in part) contact with overlying coset; possible channel scour or base; sharp horizontal contact with overlying coset; **5.** ~0.70 m thick coset of *Sl-hhs <1.0 m (Sh); likely low to high-angle-inclined foresets forming small-scale planar cross-bedding; coset consists of ~0.10 m thick mainly horizontal cross-cutting sets; poorly defined sets and tangential foresets; sharp horizontal contact with overlying set; **6.** *Sl-hpx <2.0 m (Sp); low to high-angle-inclined foresets forming medium-scale planar cross-bedding; ~0.60 m thick horizontal set; coarser grain component delineates 0.02-0.06 m thick foreset boundaries – normal grading; set pinches out towards the northern (Left) section of outcrop; sharp horizontal contact with overlying coset (in part); **7.** 0.30-0.40 m thick coset of Sl-hhs <1.0 m (Sh); likely small-scale trough cross-bedding; coset consists of 0.05-0.10 m thick mainly horizontal cross-cutting sets; poorly defined sets and foresets; sharp horizontal contact with overlying set; **8.** Ss-lp-lag (Gh); intermittent lag deposit, variable lag thickness up to 0.10 m thick; lag consists of 10-25% granules and small to medium pebbles; sharp horizontal contact with overlying coset; possible flat channel base; **9.** ~1.00 m thick coset of *Stmx 1.5-3.0 m (St); medium-scale trough cross-bedding 1.5–3.0 m trough width; 0.30-0.40 m thick cross-cutting sets; poorly defined sets and foresets; sharp convex-down contact with overlying coset; possible erosive incised channel base; **10.** ~2.30 m thick coset group of * Sl-hss-of <1.0 m (Sl); coset group consists of four sub-horizontal cross-cutting cosets (0.50-0.60 m) and 0.15–0.25 m thick sub-horizontal cross-cutting sets; likely small-scale oblique trough cross-bedding <1.5 m trough width; poorly defined cross-bedding; poorly defined (in part) horizontal contact with overlying coset; **11.** ~1.00 m thick coset of *Stmx 1.5-3.0 m (St); medium-scale trough cross-bedding 1.5–3.0 m trough width; ~0.30 m thick cross-cutting sets; poorly defined sets and foresets; poorly defined (in part) horizontal contact with overlying coset; **12.** ~2.00 m thick coset group of *Sl-hss <1.0 m (Sl); coset group consists of four sub-horizontal cross-cutting cosets (0.60-0.70 m) and 0.10–0.30 m thick down-climbing and cross-cutting sub-horizontal sets; likely a combination poorly defined small to medium-scale planar and trough cross-bedding; sets decrease in thickness moving up sequence; sharp horizontal contact with overlying coset (in part); **13.** ~1.80 m thick coset of *Sl-hpx <2.0 m (Sp); low to high-angle-inclined foresets forming medium-scale planar cross-bedding; 0.40-0.70 m thick down-climbing and cross-cutting sub-horizontal sets; sets decrease in thickness moving up sequence; sharp horizontal contact with overlying coset (in part); **14.** ~2.00 m thick coset group of *Sl-hss-of <1.0 m (Sl); coset group consists of two ~1.00 m thick sub-horizontal cross-cutting coset fragment; cosets consists of 0.10-0.20 m thick sub-horizontal cross-cutting sets, likely small-scale oblique trough cross-bedding <1.5 m trough width; sets increase in thickness moving up sequence; poorly defined cosets, sets and foresets.

Interpretation

Measurements obtained from jointing around centre of Outcrop 24.1 (i.e. lake side, moving to the rear and southern/right section, in part). Palaeocurrent data imply variable westerly and south-westerly migrating channel bedforms, below the concave-up channel base, whereas above the channel base deposition appears to have been influenced by south-westerly to south-easterly palaeocurrents (Fig. 4.4 Location 24). Irregular set and coset thicknesses suggest variable channel depths and sediment input; a maximum set thickness of ~0.60 m (facies Sl-hpx <2.0 m) indicates a maximum dune height and channel depth of ~2.20 m and ~6.50 m, respectively (cf. Reesink & Bridge, 2009; Leclair, 2011) and a cumulative coset thickness of ~1.80 m (facies Sl-hpx <2.0 m) indicates a maximum unit bar height and channel depth of ~2.80 m and ~5.70 m, respectively (cf. Reesink & Bridge, 2009; Leclair, 2011).

Initial basal facies Sl-hss <1.0 m suggest migratory bedforms that likely developed within a relatively shallow channel (cf. Ashworth *et al.*, 2011), possibly on the surface of a larger sand flat (cf. Cant & Walker, 1976, 1978). Alternatively, individual sub-horizontal sets of Sl-hss <1.0 m may form components of a larger host dune coset (cf. Haszeldine, 1983b), influenced by high-flow stage which facilitated the formation of down-climbing dunes (cf. Bristow, 1988, 1993a; Reesink &

Bridge, 2009; Ghinassi, 2011). Such cosets may represent migratory mid-channel bar bedform components (cf. Reesink & Bridge, 2009) that likely formed within a multi-channelled fluvial system (cf. Reesink *et al*., 2014) and/or small-scale downstream migrating unit bars (cf. Sambrook Smith *et al.*, 2006; Reesink & Bridge, 2009), which in turn likely form components of a much larger host compound bar (cf. Allen, 1982; Bridge, 2003; Bridge & Lunt, 2006; Sambrook Smith *et al.*, 2006; Ashworth *et al.*, 2011), although such component coset/unit bar heights coincide with dune heights (Ashworth *et al.*, 2011). Similar bedforms may also form a series of distinct depositional episodes (cf. Collinson *et al.,* 2006) i.e. sets divided by first-order set boundaries, indicating repeated bedform migration probably as a train of dunes (dune stacking) that may have formed components of a larger bar top (cf. Bristow, 1993b; Best *et al.*, 2003; Bridge & Lunt, 2006; Mumpy *et al*., 2007; Miall, 2010b; Ashworth *et al.*, 2011) and/or they may represent the latter stages of a channel fill sequence (cf. Reesink *et al.*, 2014). Subsequent deposition of facies Sl-hhs <1.0 m indicate an overall reduction in low-flow stage, aggradation of 2D and 3D mesoforms and channel fill (cf. Cant & Walker, 1976; Ashworth *et al.*, 2011; Reesink *et al.*, 2014). Such facies may also represent dune stacking similar to facies Sl-hss <1.0 m, see above interpretation. The preservation of consecutive cross-laminated sets inevitably encompasses a measure of net deposition (Leeder, 1982). The 0.05-0.10 m thick sets relating to facies Sl-hhs <1.0 m imply flow conditions were sufficiently shallow to subdue dune formation and generate very low relief dunes (cf. Bristow, 1993a); preservation of low-angle dune morphology is facilitated by dune stoss and crest erosion, during high flow-stage, and deposition of eroded sediment in the dune's trough (Hendershot *et al.*, 2016). Low-angle bedforms may be attributed to the migration of low-amplitude (near horizontal) sand waves/dunes concomitant with the transitional zone between lower and upper flow regimes and very shallow fluvial systems (cf. Smith, 1971; Todd, 1996); generally foreset gradients decline as a flow regime intensifies, vice versa (cf. Smith, 1972). Such facies were likely deposited towards the thalweg region of the channel, rather than a host barform, as implied by the ensuing deposition of facies Ss-lp-lag. Although lag deposits may represent scouring (Miall, 2010b) or winnowing (cf. Collinson *et al.,* 2006) processes, which may be related to channel surface's, such lag deposits are also known to denote channel thalweg/axial regions (Fidolini *et al.*, 2013; Ghinassi *et al.*, 2014). Further deposition of facies Sl-hhs <1.0 m imply a continuation of 2D mesoform aggradation and channel fill, as described above (cf. Cant & Walker, 1976; Ashworth *et al.*, 2011; Reesink *et al.*, 2014); the tangential (or asymptotic) foresets observed were likely promoted by fairly frail separation eddies and a high rate of sediment deposition, from suspension, beyond the slipface of a dune's lee (cf. Leeder, 1982; Bristow, 1993a; Bridge, 2003). Facies Sl-hpx <2.0 m and Sl-hhs <1.0 m indicate a substantial increase and subsequent reduction in channel depth and net sediment input, likely facilitated by a flood event with sediment migration and aggradation influenced by high and low-flow stages, respectively (Coleman, 1969; Bristow, 1987, 1993a; Ashworth *et al.,* 2011). Such flow stages also likely facilitated the deposition of ensuing facies Ss-lp-lag and Stmx 1.5-3.0 m towards the channel's thalweg/axial region (cf. Fidolini *et al.*, 2013; Ghinassi *et al.*, 2014), as described above; larger bedforms (e.g. Stmx 1.5-3.0 m) generally develop towards a channel's thalweg region (cf. Reesink & Bridge, 2009; Ashworth *et al.*, 2011; Reesink *et al.*, 2014). The flood events relating to the deposition of facies Sl-hpx <2.0 m and Stmx 1.5-3.0 m likely influenced the change in the palaeocurrent from a westerly to a more south-westerly direction. The relatively shallow inclined (<10°) first and fifth-order bounding surface dips (e.g. facies Sl-hhs <1.0 m and Ss-lp-lag, respectively) likely denote that the host channel was relatively broad and shallow. Such an interpretation corresponds with McCabe's (1977) observation that distributary channel dips were in the region of ≤10° and Bristow (1987, 1993a) arguing that bounding surfaces, with very low depositional dips, correspond to channels possessing high width to depth ratios. Further, Outcrop 24.1 is dominated by a coarse-grained to granular sandstone which coincides with Coleman's (1969) observation that rivers with significant quantities of coarse sediment are representative of broad, flat, island-obstructed fluvial systems, although the term bar-obstructed is more appropriate (sensu Bridge, 2003).

The base of facies Sl-hss-of <1.0 m forms a curved concave-up (or convex-down) outline which represents an erosive channel incision into facies Stmx 1.5-3.0 m, thereby generating a fifth-order bounding surface (cf. Miall, 2010b). Such channels may form as a result of a hydraulic gradient during low-flow stage concentrating the flow towards the channel thalweg (cf. Bristow, 1987), analogous with the formation of a bar top chute channel (see Bristow, 1987; Bridge, 2003; Miall, 2010b). Similarly, the erosive channel outline may be related to initial diffluence (divergence) around a mid-channel bar of two first, second or third-order channels and subsequent (convergence) confluence which facilitated scouring ahead of the bar tail (cf. Bristow, 1987; Best *et al.*, 2003; Bridge, 2003). Conceivably, the erosive channel may represent either a constrained first-order channel (through reduced channel flow) or subordinate second or third-order channels (cf. Coleman, 1969; Bristow, 1987; Bridge, 2003; Miall, 2010b and references there in). Therefore, facies Sl-hss-of <1.0 m may represent lateral migration influenced by high-flow stage which facilitated the formation of down-climbing dunes (cf. Bristow, 1988, 1993a; Ghinassi *et al.,* 2009; Miall, 2010b; Reesink *et al.,* 2014), or mid-channel bedform migration, probably within a multi-channelled fluvial system (cf. Reesink *et al*., 2014), where the discrete sub-horizontal sets formed coset components of either an individual small-scale unit bar (cf. Sambrook Smith *et al.*, 2006; Reesink & Bridge, 2009), or a distinct larger host dune (cf. Haszeldine, 1983b). Sambrook Smith *et al.* (2006) observed unit bars migrating upstream and downstream of, and adjacent to, the flank of a mid-channel compound bar. Further, topographic lows adjacent to the channel's margins, during low-flow stage, may constrain falling-stage currents similar to topographic lows between channel bars (sensu Collinson, 1970; cf. Reesink *et al*., 2014), thereby facilitating lateral-accretion and deposition of facies Sl-hss-of <1.0 m along the channel margins, comparable to deposition along bar margins (sensu Collinson, 1970, 1996), whilst probably migrating towards the channel thalweg (cf. Best *et al.*, 2003). Further deposition of facies Stmx 1.5-3.0 m implies a return to channel flood conditions concomitant with a broad channel and westerly palaeocurrent. A further flood event and variation towards a south-easterly palaeocurrent is associated with the ensuing sub-horizontal sets of Sl-hss <1.0 m, which may form components of a larger host dune coset (cf. Haszeldine, 1983b), influenced by high-flow stage which facilitated the formation of down-climbing dunes (cf. Bristow, 1988, 1993a; Reesink & Bridge, 2009; Ghinassi, 2011). Such cosets may also represent migratory mid-channel bar bedform components (cf. Reesink & Bridge, 2009) that likely formed within a multi-channelled fluvial system (cf. Reesink *et al*., 2014) and/or small-scale downstream migrating unit bars (cf. Sambrook Smith *et al.*, 2006; Reesink & Bridge, 2009), which in turn may form components of a much larger host compound bar (cf. Allen, 1982; Bridge, 2003; Bridge & Lunt, 2006; Sambrook Smith *et al.*, 2006; Ashworth *et al.*, 2011), although such component coset/unit bar heights coincide with dune heights (Ashworth *et al.*, 2011). The subsequent deposition of facies Sl-hpx <2.0 m denotes a further flood event and palaeocurrent adjustment from a south-easterly to a westerly direction. The ~1.80 m thick coset relating to facies Sl-hpx <2.0 m likely represents the downstream migration of a unit bar (cf. Sambrook Smith *et al.*, 2006; Reesink & Bridge, 2009), which in turn may form a component of a much larger host compound bar (cf. Allen, 1982; Bridge, 2003; Bridge & Lunt, 2006; Sambrook Smith *et al.*, 2006; Ashworth *et al.*, 2011). The uppermost facies of facies Sl-hss-of <1.0 m represents a further palaeocurrent readjustment towards a southerly direction, likely related to the oblique migration of down-climbing dunes and increasing channel depth, as evidence by increasing set thicknesses towards the surface. Further, the variable palaeocurrent azimuths imply dune-scale bedforms may have migrated obliquely over, around and down a curved barform front/tail (cf. Haszeldine, 1983b). Individual sub-horizontal sets of Sl-hss-of <1.0 m may also form components of a larger host dune coset (cf. Haszeldine, 1983b), influenced by high-flow stage which facilitated the formation of down-climbing dunes (cf. Bristow, 1988, 1993a; Reesink & Bridge, 2009; Ghinassi, 2011). See above for further Sl-hss-of <1.0 m interpretations.

Overall, the initial facies associated with Outcrop 24.1, up to the concave-up channel base, probably represent channel fill deposits concomitant with a relatively broad channel influenced by a variable flow depth (≤6.50 m) and a predominantly westerly to south-westerly palaeocurrent. Although lag deposits may denote channel thalweg/axial regions (Fidolini *et al.*, 2013; Ghinassi *et al.*, 2014) and the base of compound bars (Ashworth *et al.*, 2011) for example, such deposits may also define a channel base and channel fill sequence (Ashworth *et al.*, 2011). Hence, the relatively horizontal lag deposit at the base of the initial Stmx 1.5-3.0 m deposit likely denotes a flat channel base. That said, the upper deposit of Stmx 1.5-3.0 m may form basal facies associated with a mid-channel bar (cf. Best *et al.*, 2003; Bridge & Lunt, 2006; Sambrook Smith *et al.*, 2006; Mumpy *et al*., 2007). The variable south-easterly to westerly palaeocurrents associated with the ensuing facies may denote the accretion of individual unit bars onto a host compound bar (macroform) through lateral and downstream-accretion (cf. Bridge & Lunt, 2006) whilst the main bar migrated downstream.

Table 4.25

Location, grid reference and associated literature	General description and lithology
25. High Wild Carr Farm (Old Crags) Outcrop 25.1: SE 17053 66178 Thompson, A. T. (1957) *The structure and stratigraphy of Nidderdale between Lofthouse and Dacre*. Unpublished, Doctoral thesis, Durham University. Available at Durham E-Theses Online: http://etheses.dur.ac.uk/722/. This study.	Situated within managed farmland adjacent a roadside, the examined outcrop forms an intermittent line of fragmented crags that run close to the ridgeline and down towards Mount Pleasant (grid reference: SE 17400 65824) and Blazefield Caravan Park, a former quarry site and council tip (grid reference: SE 17523 65625); the chain of fragmented outcrops extend in a north-westerly to south-easterly trend for ~870 m. The outcrops associated with Old Crags are of similar appearance, they possess a variable texture with relatively poor outcrop detail (e.g. foreset/sets), due to the processes of weathering, erosion and ground cover; they also share a comparable texture and facies sequence consistent with that of the Lower Brimham Grit. Although several outcrops have been displaced due to cambering, the examined in-sitú outcrop is representative of the outcrops associated with Old Crags. Elevation of Outcrop 25.1 is ~302 m O.D; main outcrop view is towards ~040˚ (Fig. 4.4 Location 25). Outcrop 25.1: Coarse to very coarse-grained sandstone with 2-5% small to medium pebble content (variable), predominantly quartz grains; generally low to high sphericity; sub-angular to rounded; moderately to well sorted.

Identified sub-Facies, sedimentary structures and bounding surfaces of note

Outcrop 25.1 [~2.6 (H) x 7.0 (D) x 6.4 m (W)]: **1.** ~0.60 m thick coset of *Sl-hpx <2.0 m (Sp); coset consists of at least two ~0.30 m thick tabular sets; low to high-angle-inclined ~0.05 m thick foresets forming medium-scale planar cross-bedding; sharp horizontal contact between sets and overlying coset; **2.** ~0.15 m thick coset of Stsx <1.5 m (St); coset consists of 0.05-0.10 m thick horizontal sets; likely small-scale trough cross-bedding <1.5 m trough width; poorly defined sets and foresets; sharp (in part) horizontal contact with overlying coset; **3.** ~0.95 m thick coset of *Sl-hpx <2.0 m (Sp); coset consists of two ~0.40 and 0.55 m thick tabular sets; low to high-angle-inclined foresets forming medium-scale planar cross-bedding; ~0.05 m thick poorly defined tangential foresets; sharp horizontal contact between sets; poorly defined (in part) erosive sub-horizontal contact with overlying coset (channel base); **4.** ~0.70 m thick coset of *Stmx 1.5-3.0 m (St); coset consists of ~0.15 m thick sub-horizontal sets; small to medium-scale trough cross-bedding with up to 1.5–3.0 m trough widths; poorly defined sets and foresets forming low-amplitude down-climbing cross-bedding; sharp (in part) erosive sub-horizontal contact with overlying set; **5.** *Sl-hpx <2.0 m (Sp); ~0.25 m thick horizontal set; low to high-angle-inclined foresets forming small to medium-scale planar cross-bedding.

Interpretation

Palaeocurrent data relating to Outcrop 25.1 imply that deposition was influenced by northerly palaeocurrents below the incised channel base and more north-westerly palaeocurrents above the channel base (Fig. 4.4 Location 25). Coset and set thicknesses suggest variable channel depths and sediment input; a maximum set thickness of ~0.55 m (facies Sl-hpx <2.0 m) indicates that the maximum dune height and channel depth was ~2.00 m and ~5.95 m, respectively (cf. Reesink & Bridge, 2009; Leclair, 2011).

Initial facies of Sl-hpx <2.0 m suggest in channel bedform migration and subsequent net deposition (aggradation) of 2D mesoforms likely facilitated by flood events (high-flow stage) and waning flow (low-flow stage), respectively (cf. Coleman, 1969; Bristow, 1987, 1993a; Ashworth *et al.,* 2011). Such facies probably formed towards the channel thalweg/axis where larger bedforms generally develop (cf. Reesink & Bridge, 2009; Ashworth *et al.*, 2011; Reesink *et al.*, 2014). The subsequent deposition of facies Stsx <1.5 m may represent: i. an overall reduction in channel depth which facilitated downstream and/or lateral-accretion of 3D mesoforms within a relatively shallow thalweg region of a low sinuosity channel (cf. Bristow, 1988, 1993a; Ghinassi *et al.,* 2009; Miall, 2010b; Reesink *et al.,* 2014); ii. a component of vertical-accretion along a sand flat surface (cf. Cant & Walker, 1976, 1978), primarily due to dune stacking and relatively shallow flow conditions above the host sand flat, similar to vertical-accretion related to bar tops (cf. Best *et al.*, 2003; Bridge & Lunt, 2006); iii. repeated bedform migration, probably as a train of dunes, over a larger bar surface (Miall, 2010b; cf. Ashworth *et al.*, 2011). Further flood events would have amplified the rivers flow and sediment load capacity, which probably facilitated the deposition of two additional sets of facies of Sl-hpx <2.0 m, see above for facies interpretation. The tangential (or asymptotic) foresets associated with facies Sl-hpx <2.0 m were likely promoted by fairly frail separation eddies and a high rate of sediment deposition, from suspension, beyond the slipface of the dune's lee (cf. Leeder, 1982; Bristow, 1993a; Bridge, 2003).

The base of facies Stmx 1.5-3.0 m forms a shallow (~6°) inclined erosive channel incision into facies Sl-hpx <2.0 m, thereby generating a fifth-order bounding surface (cf. Miall, 2010b). Such channels may form as a result of a hydraulic gradient during low-flow stage concentrating the flow towards the channel thalweg (cf. Bristow, 1987), analogous with the formation of a bar top chute channel (see Bristow, 1987; Bridge, 2003; Miall, 2010b). Similarly, the partial erosive channel outline may be related to a cut bank thalweg profile associated with a curved channel section (cf. Bridge, 2003). Conceivably, the erosive channel may represent either a constrained first-order channel (through reduced channel flow), subordinate second-order or third-order channels (cf. Coleman, 1969; Bristow, 1987; Bridge, 2003; Miall, 2010b and references there in). The deposition of relatively horizontal sets relating to facies Stmx 1.5-3.0 m likely represents downstream migration and accretion of 3D mesoforms that likely developed towards the thalweg/axis of a relatively broad and shallow channel (cf. Reesink & Bridge, 2009; Ashworth *et al.*, 2011; Reesink *et al.*, 2014), as suggested by the ~6° first and fifth-order set and channel inclines, respectively. Such an interpretation corresponds with McCabe's (1977) observation that distributary channel dips were in the region of ≤10° and Bristow (1987, 1993a) arguing that bounding surfaces, with very low depositional dips, correspond to channels possessing high width to depth ratios. The low-amplitude cross-bedding associated with facies Stmx 1.5-3.0 m was probably generated post flood, with sediment migration and aggradation influenced by high and low-flow stages, respectively (Coleman, 1969; Bristow, 1987, 1993a; Ashworth *et al.,* 2011). Preservation of low-angle dune morphology is facilitated by dune stoss and crest erosion, during high flow-stage, and deposition of eroded sediment in the dune's trough (Hendershot *et al.*, 2016). Low-angle bedforms are also attributed to the migration of low-amplitude (near horizontal) sand waves/dunes concomitant with the transitional zone between lower and upper flow regimes and very shallow fluvial systems (cf. Smith, 1971; Todd, 1996); generally foreset gradients decline as a flow regime intensifies, vice versa (cf. Smith, 1972). Such bedforms are also associated with a series of distinct depositional episodes (cf. Collinson *et al.,* 2006) of assembled sets divided by first-order set boundaries which indicate repeated bedform migration probably as a train of dunes (dune stacking) which may indicate waning flow, net sediment aggradation and channel fill (cf. Cant & Walker, 1976; Ashworth *et al.*, 2011; Reesink *et al.*, 2014), or migratory bedforms that likely developed on the surface of a larger sand flat (cf. Cant & Walker, 1976, 1978). The subsequent deposition of an additional set relating to facies Sl-hpx <2.0 m indicates an increase in channel depth/flow, probably influenced by a further flood event, see above for facies interpretations.

Overall, the relatively uniform north-westerly palaeocurrents associated with Outcrop 25.1 probably represent channel fill and sand flat deposits, rather than migratory mid-channel bars; although mid-channel bars may also be interpreted as channel fill components, Skelly *et al.* (2003) and Ashworth *et al.* (2011) (and references there in) argue that the distinction between compound bar and adjacent channel fill core deposits, in sandy braided fluvial systems, is problematic. Further, Leeder (1982) argues that the preservation of consecutive cross-laminated sets inevitably encompasses a measure of net deposition, which inexorably necessitates that each individual foreset, set and coset deposit, for example, represent a contrasting scale of channel fill components. Outcrop 25.1 is dominated by a coarse to very coarse-grained sandstone which coincides with Coleman's (1969) observation that rivers with significant quantities of coarse sediment are representative of broad, flat, island-obstructed fluvial systems, although the term bar-obstructed is more appropriate (sensu Bridge, 2003).

Table 4.26

Location, grid reference and associated literature	General description and lithology
26. Mount Pleasant (Oven Crags) Outcrop 26.1: SE 17400 65824 This study.	Situated within managed farmland the examined outcrop forms the lower Mount Pleasant section of the intermittent line of fragmented crags that run down from High Wild Carr Farm (grid reference: SE 17053 66178) towards Blazefield Caravan Park, a former quarry site and council tip (grid reference: SE 17523 65625); the chain of fragmented outcrops extends in a north-westerly to south-easterly trend for ~870 m. The outcrops associated with Oven Crags are of similar appearance, they possess a variable texture with relatively poor outcrop detail (e.g. foreset/sets), due to the processes of weathering, erosion and ground cover; they also share a comparable texture and facies sequence consistent with that of the Lower Brimham Grit. Although several outcrops have been displaced due to cambering, the examined in-sitú outcrop is representative of the outcrops associated with Oven Crags; the outcrop has an intermittent basal section which extends for ~70 m following a north-westerly (~290˚) to south-easterly (~110˚) trend. Elevation of Outcrop 26.1 is ~290 m O.D; main outcrop view is towards ~090˚ (Fig. 4.4 Location 26). Outcrop 26.1: Coarse to granular sandstone with 2-10% small to medium pebble content (variable), predominantly quartz grains; generally low to high sphericity; sub-angular to rounded; poor to moderately sorted.

Identified sub-Facies, sedimentary structures and bounding surfaces of note

Outcrop 26.1 [~7.0 (H) x 3.0 (D) x 70.0 m (W)]: **1.** ~1.60 m thick coset of *Sl-hpx <2.0 m (Sp); coset consists of four 0.30-0.40 m thick sub-horizontal sets; low to high-angle-inclined 0.02-0.03 m thick foresets forming poorly defined medium-scale planar cross-bedding; coarser grain component delineate foreset boundaries – normal grading; intermittent granule to medium pebble lag deposits delineate set boundaries; poorly defined (in part) sub-horizontal contact between sets and overlying coset; **2.** ~1.60 m thick coset group of *Stsx <1.5 m (St); two cosets ~0.70 and ~0.90 m thick, respectively; cosets consist of ~0.15 m thick sub-horizontal sets; likely low-amplitude small-scale trough cross-bedding <1.5 m trough width; poorly defined sets and foresets; intermittent granule to medium pebble lag deposits delineate set and coset boundaries; poorly defined (in part) undulating contact with overlying coset; **3.** ~0.50 m thick coset of *Stmx 1.5-3.0 m (St); poorly defined likely low-amplitude medium-scale cross-cutting trough cross-bedding 1.5–3.0 m trough width; 0.20-0.25 m thick sets; poorly defined (in part) undulating contact with overlying set; **4.** *Sl-hpx <2.0 m (Sp); low to high-angle-inclined 0.05 m thick foresets forming large-scale planar cross-bedding; ~1.10 m thick set with evidence of reactivation surface; coarser grain component delineate foreset boundaries – normal grading; sharp horizontal contact with overlying coset; **5.** 0.30-0.40 m thick coset of *Stsx <1.5 m (St); coset consist of ~0.05 m thick horizontal sets; likely low-amplitude small-scale trough cross-bedding <1.5 m trough width; poorly defined sets and foresets; sharp and poorly defined (in part) horizontal contact with overlying set; **6.** *Sl-hpx <2.0 m (Sp); low to high-angle-inclined foresets forming poorly defined small to medium-scale planar cross-bedding; ~0.30 m thick set; sharp and poorly defined (in part) horizontal contact with overlying set; **7.** *Stmx 1.5-3.0 m (St); poorly defined likely low-amplitude medium-scale cross-cutting trough cross-bedding 1.5–3.0 m trough width; 0. 50 m thick set; poorly defined set and foresets.

Interpretation

Although variable, the foreset palaeocurrent data relating to Outcrop 26.1 imply that deposition was mainly influenced by south-westerly palaeocurrents (Fig. 4.4 Location 26). Coset and set thicknesses suggest variable channel depths and sediment input; a maximum set thickness of ~1.10 m (facies Sl-hpx <2.0 m) indicates that the maximum bar height and channel depth was ~3.30 m and ~6.60 m, respectively (cf. Reesink & Bridge, 2009; Leclair, 2011).

The initial facies of Sl-hpx <2.0 m are predominantly constructed from repeated grain flow avalanche deposits (0.02-0.03 m thick foresets; see Smith, 1972; Reesink & Bridge, 2007, 2009) that likely represent downstream migration and accretion of 2D mesoforms. Such mesoforms probably developed towards the channel thalweg/axis; large dunes tend to develop towards deeper channel thalweg regions within relatively broad/deep channels, as reflected by a dune height of ~1.40 m (cf. Reesink & Bridge, 2009; Ashworth *et al.*, 2011; Leclair, 2011; Reesink *et al.*, 2014). Such facies are also associated with the downstream migration and net aggradation of: i. longitudinal bars (Ghinassi *et al.,* 2009); ii. unit bars (cf. Bridge & Lunt, 2006; Ashworth *et al.*, 2011), although such bar heights coincide with dune heights (Ashworth *et al.*, 2011); iii. the observed angular foreset contacts suggest that the bedforms may represent transverse bars, generated as a result of low fluid and low sediment discharge (cf. Smith, 1972; Hein & Walker, 1977; Collinson *et al.,* 2006); or iv. a sand flat sequence (cf. Cant & Walker, 1976, 1978). Such primarily bedload deposition is also related to flow stage i.e. fine and coarse-grained cross strata accumulate at low and high-flow stage, respectively (Reesink & Bridge, 2009 and references there in). The 14°-18° dip and 010° azimuth associated with the sets relating to facies of Sl-hpx <2.0 m may be attributed to syn-sedimentary tectonic subsidence along the North Craven Fault or sediment migration over a much slower moving host bedform (cf. Haszeldine, 1983a, 1983b; Collinson *et al.*, 2006). Conversely, deposition may have been related to bar top vertical and/or upstream-accretion associated with the bar head and/or mid-bar section of a mid-channel bar, primarily due to dune stacking (cf. Bristow, 1993a; Best *et al.*, 2003; Bridge & Lunt, 2006; Mumpy *et al*., 2007); also, preservation of consecutive cross-laminated sets inevitably encompasses a measure of net deposition and subject to the inclination of their host bed most sets will climb at a similar angle (Leeder, 1982). Further, field palaeocurrent data relating to facies Sl-hpx <2.0 m provide a foreset azimuth mean of 237°; when restoring the palaeocurrent set data (as noted above) to the horizontal provides a foreset azimuth mean of 215°, a shift towards the south by 22°. Hence, should syn-sedimentary tectonic subsidence be responsible for the set azimuth dips, the general palaeocurrent direction towards the southwest would not be significantly affected.

The subsequent deposition of facies Stsx <1.5 m may represent: i. bar top vertical and/or upstream-accretion of small-scale trough cross-bedding associated with the bar head and/or mid-bar section of a mid-channel bar, primarily due to dune stacking and relative shallow flow depth above the host bar (cf. Best *et al.*, 2003; Bridge & Lunt, 2006; Sambrook Smith *et al.*, 2006; Mumpy *et al*., 2007); ii. downstream and/or lateral-accretion of 3D mesoforms within a relatively shallow thalweg region of a low sinuosity channel (cf. Bristow, 1988, 1993a; Ghinassi *et al.,* 2009; Miall, 2010b; Reesink *et al.,* 2014); or iii. sand flat components relating to a channel fill sequence (cf. Cant & Walker, 1976, 1978). Stacked sets separated by first-order set boundaries indicate repeated bedform migration probably as a train of dunes over a larger bar surface (Miall, 2010b; cf. Ashworth *et al.*, 2011). Further, the subcritical set angles of facies Stsx <1.5 m imply that they may have migrated over a much slower moving host bedform (cf. Haszeldine, 1983a, 1983b; Collinson *et al.*, 2006); similarly, preservation of consecutive cross-laminated sets inevitably encompasses a measure of net deposition and subject to the inclination of their host bed most sets will climb at a similar angle (Leeder, 1982). Facies Stmx 1.5-3.0 m likely represent downstream migration and accretion of 3D mesoforms that may have developed towards the thalweg/axis of a relatively broad and deep channel (cf. Reesink & Bridge, 2009; Ashworth *et al.*, 2011; Reesink *et al.*, 2014). Such facies were probably generated by flood events with sediment migration and aggradation influenced by high and low-flow stages, respectively (Coleman, 1969; Bristow, 1987, 1993a; Ashworth *et al.,* 2011). A further increase in channel depth and flow likely resulted in palaeocurrent transferal towards the southeast and deposition of a ~1.10 m thick set of facies of Sl-hpx <2.0 m during falling-flow stage (cf. Coleman, 1969; Bristow, 1987, 1993a; Ashworth et al., 2011). Facies Sl-hpx <2.0 m is predominantly constructed from repeated grain flow avalanche deposits (~0.05 m thick foresets; see Smith, 1972; Reesink & Bridge, 2007, 2009) that likely represent downstream migration and accretion of a unit bar (3D mesoform) (cf. Bridge & Lunt, 2006; Ashworth et al., 2011); a set thickness ≥1.00 m likely denotes unit bars, rather than dunes (Bridge & Lunt, 2006). Similarly, Sambrook Smith *et al*. (2006) interpret sets >0.5 m, which possess inclined (i.e. ≤ angle-of-repose) cross-stratification, as a consequence of bar migration. The overlying succession is generally a repetition of the preceding three faces and consists of facies Stsx <1.5 m (~0.05 m thick sets), Sl-hpx <2.0 m (~0.30 m thick set) and Stmx 1.5-3.0 m (~0.50 m thick set). These facies denote an initial decrease and subsequent gradual increase in channel depth and flow (see above interpretations relating to facies Stsx <1.5 m, Sl-hpx <2.0 m and Stmx 1.5-3.0 m).

Overall, Outcrop 26.1 likely represents downstream-accretion and channel fill sequence consisting of individual unit bars and dunes, punctuated by flood events and a shifting fluvial channel, as indicated by an initial palaeocurrent transferal from a south-westerly direction towards the southeast, prior to migrating back to a westerly direction. An overall reduction in the observed palaeocurrent, coset and set azimuth dips from 18° (facies Sl-hpx <2.0 m) to 06° (facies Stsx <1.5 m) and 04° (facies Stmx 1.5-3.0 m), moving up the succession, suggests that the possible effect of any previous tectonic subsidence or upstream-accretion may have been mitigated by subsequent sediment deposition. The shallow inclined (≤10°) first and second-order bounding surface dips relating to facies Sl-hpx <2.0 m, Stsx <1.5 m, and Stmx 1.5-3.0 m, respectively, likely correspond to a channel possessing a high width to depth ratio (Bristow, 1993a). The preservation of low-angle dune morphology associated with facies Stsx <1.5 m and Stmx 1.5-3.0 m was likely facilitated by dune stoss and crest erosion, during high flow-stage, and deposition of eroded sediment in the dune's trough (Hendershot *et al.*, 2016). Low-angle bedforms may be attributed to the migration of low-amplitude (near horizontal) sand waves/dunes concomitant with the transitional zone between lower a and upper flow regimes and very shallow fluvial systems (cf. Smith, 1971; Todd, 1996); generally foreset gradients decline as a flow regime intensifies, vice versa (cf. Smith, 1972).

Table 4.27

Location, grid reference and associated literature	General description and lithology
27. Hindmes Wood Outcrop 27.1: SE 14955 64929 27.2: SE 14884 64963 Thompson, A. T. (1957) *The structure and stratigraphy of Nidderdale between Lofthouse and Dacre*. Unpublished, Doctoral thesis, Durham University. Available at Durham E-Theses Online: http://etheses.dur.ac.uk/722/.	Situated within managed woodland the examined fragmented and jointed outcrop is located near to a disused quarry located ~80 m towards the west. The rock within the quarry is consistent with that of the Libishaw Sandstone. The majority of the examined outcrop is obscured by ground cover, vegetation, moss and lichen consistent with a woodland setting. The outcrop possesses a variable texture with relatively poor outcrop detail (e.g. foresets and sets), due to the above-mentioned and the processes of weathering and erosion. Although the examined outcrop appears to be in-sitú, it may have been subjected to minor cambering. Outcrop measurements were obtained from the northern (left) section moving towards the central (right) section. Elevation of Outcrops 27.1 and 27.2 (Disused quarry) is ~182 m and ~192 m O.D, respectively; main outcrop views are towards ~076˚ (Outcrop 27.1) and ~116˚ (Outcrop 27.2) (Fig. 4.4 Location 27). Outcrop 27.1: Coarse-grained to granular sandstone with 2-5% small pebble content (variable), predominantly quartz grains; generally low to high sphericity; sub-angular to rounded; poorly to moderately sorted; Outcrop 27.2: Medium to coarse-grained sandstone; beige colouring; predominantly quartz grains; generally high sphericity; sub-rounded to rounded; well to very well sorted.

Identified sub-Facies, sedimentary structures and bounding surfaces of note

Outcrop 27.1 [~3.0 (H) x 7.5 (D) x 14.0 m (W)]: **1.** *Stlx >3.0 m (St); large-scale trough cross-bedding >3.0 m trough width; 0.40-0.50 m thick sets; coarsening up sequence from base – inverse grading; poorly defined low-amplitude troughs; sharp and poorly defined (in part) erosive sub-horizontal contact between sets and overlying coset; **2.** *Ssb (S-); ~0.70 m thick structureless bed with no obvious evidence of internal structures such as foresets; small to medium pebble lags delineate base of sets – normal grading; **3.** *Sl-hpx <2.0 m (Sp); low to high-angle-inclined foresets forming large-scale planar cross-bedding, poorly defined foresets;

Outcrop 27.2 [~4.0 (H) x 12.0 (D) x 12.0 m (W)]: **1.** Sub-horizontal beds dipping 26˚ with an azimuth of 084˚; the texture is consistent with that of the Libishaw Sandstone; no obvious cross-bedding visible; included as reference to the likely position of the North Craven Fault and the possible influence of cambering relating to Outcrop 27.1. Thompson (1957) describes the Libishaw Sandstone as a flaggy micaceous – medium grained – sub-greywacke to quartzitic sandstone, a description distinct from that of the Lower Brimham Grit, but not to dissimilar to that of the rocks associated with the disused quarry, Outcrop 27.2.

Interpretation

Outcrop 27.1: Given the proximity (~80.0 m) of the Libishaw Sandstone (Outcrop 27.2) to the Lower Brimham Grit (Outcrop 27.1), and the likely hood that both outcrops bestride the North Craven Fault, it is more than likely that both outcrops have been subjected to tectonic tilting, as indicated by the sub-horizontal Libishaw Sandstone beds. The position of Outcrop 27.1 and 27.2 suggest that are located to the south and north of the North Craven Fault, respectively. Initial palaeocurrent field data relating to Outcrop 27.1 imply that deposition was influenced by south-easterly palaeocurrents (Fig. 4.4 Location 27). After restoring the bedding to the horizontal (through stereographic projection relative to the 26˚ dip and 084˚ azimuth relating to the nearby sub-horizontal Libishaw Sandstone beds) the palaeocurrent trends shift 90 degrees westwards, suggesting that deposition was influenced by a more variable south to south-westerly palaeocurrent (Fig. 4.4 Location 27). Coset and set thicknesses suggest variable channel depths and sediment input; a maximum set thickness of ~0.60 m (facies Stlx >3.0 m) indicates that the maximum dune height and channel depth was ~2.20 m and ~6.50 m, respectively (cf. Reesink & Bridge, 2009; Leclair, 2011).

The general coarsening up sequence relating to the basal coset of facies Stlx >3.0 m implies prograding downstream migration of medium to large-scale 3D mesoforms, with successive dunes migrating over previous deposits. Such bedforms were likely influenced by high-flow stage which facilitated the formation of down-climbing dunes (cf. Bristow, 1988, 1993a; Reesink & Bridge, 2009; Ghinassi, 2011). The scale of the cross-bedding implies that they were deposited towards the thalweg/axis of a relatively broad and deep channel; large dunes tend to develop towards deeper channel thalweg regions within relatively broad/deep channels (cf. Reesink & Bridge, 2009; Ashworth *et al.*, 2011; Reesink *et al.*, 2014). Such facies were probably generated by flood events with sediment migration and aggradation influenced by high and low-flow stages, respectively (Coleman, 1969; Bristow, 1987, 1993a; Ashworth *et al.,* 2011). The preservation of consecutive cross-laminated sets inevitably encompasses a measure of net deposition and most sets will climb at a similar angle/dip to that of their host bed (Leeder, 1982). The subsequent deposition of facies Ssb, with no obvious internal structure (e.g. foreset detail), likely represents a relatively sudden decrease in channel flow capacity and rapid sediment deposition, influenced by a waning flow and channel fill (cf. Cant & Walker, 1976; Ashworth *et al.*, 2011; Reesink *et al.*, 2014). The small to medium pebble lags, which delineate the sets relating to facies Ssb, may represent scouring (Miall, 2010b) or winnowing (cf. Collinson *et al.,* 2006) processes with no obvious evidence of a fifth-order channel surface; lag deposits may also denote channel thalweg/axial regions (Fidolini *et al.*, 2013; Ghinassi *et al.*, 2014).

The overlying deposit of facies Sl-hpx <2.0 m implies an increase in channel depth and net sediment input, likely facilitated by a flood event with sediment migration and aggradation influenced by high and low-flow stages, respectively (Coleman, 1969; Bristow, 1987, 1993a; Ashworth *et al.,* 2011). The size of cross-bedding and relatively uniform foreset azimuths implies the downstream migration of a unit bar (2D mesoform), rather than a transverse bar (2D macroform) which possess variable foreset azimuths (cf. Smith, 1972); a set thickness ≥1.00 m likely denotes unit bars, rather than dunes (Bridge & Lunt, 2006). Similarly, Sambrook Smith *et al.* (2006) interpret sets >0.5 m, which possess inclined (i.e. ≤ angle-of-repose) cross-stratification, as a consequence of bar migration.

Overall the facies associated with Outcrop 27.1 likely represent downstream migration/accretion and channel fill sequence relating to the thalweg region of a relatively deep and wide channel, where relatively large bedforms had the potential to develop (Reesink & Bridge, 2009; Ashworth *et al.*, 2011; Reesink *et al.*, 2014) and migrate downstream. The apparent cambering and visible primary sedimentary detail (e.g. sets) indicate that the outcrop was subjected to post- rather than syn-sedimentary tectonic activity.

Table 4.28

Location, grid reference and associated literature	General description and lithology
28. Low Moor (Disused Quarry) Outcrop 28.1: SE 14570 63744 Thompson, A. T. (1957) *The structure and stratigraphy of Nidderdale between Lofthouse and Dacre*. Unpublished, Doctoral thesis, Durham University. Available at Durham E-Theses Online: http://etheses.dur.ac.uk/722/. Reid, C. T. (1996) *The Alportian and Kinderscoutian (Namurian) of North Yorkshire: the sedimentary response to eustatic variation.* Unpublished Doctoral thesis, University of Keele.	Situated within managed moorland the examined fragmented and jointed outcrop forms a circular disused quarry/tip located between Gillbeck Farm and Noonstone Farm. The majority of the examined outcrop is obscured by ground cover, vegetation, moss and lichen consistent with that of a disused quarry and moorland setting. The outcrop possesses a variable texture with relatively poor outcrop detail (e.g. foresets, sets and cosets), due to the above-mentioned and the processes of weathering and erosion. Evidence of coarse to granular sandstone in waste heaps adjacent to and within the quarry perimeter is present. Although the examined outcrop appears to be in-sitú, evidence of tectonic activity is visible. Outcrop measurements were obtained from an outcrop exposure in a hollow near to the central/eastern lower section (base) moving towards the central/northern lower section and upper eastern to southern sections (surface). Elevation of Outcrop 28.1 is ~270 m; main outcrop views are towards ~148˚ (overall view), ~210˚ (transverse, strike slip or wrench fault view) and ~348˚ (general view of northern, central and eastern sections) (Fig. 4.4 Location 28). Outcrop 28.1: Medium-grained to granular sandstone with ~2% small pebble content (variable) towards the upper section, predominantly quartz grains; generally low to high sphericity; sub-angular to rounded; moderately to very well sorted.

Identified sub-Facies, sedimentary structures and bounding surfaces of note

Outcrop 28.1 [~10.0 (H) x 34.0 (D) x 34.0 m (W)]: **1.** Central – eastern depression; ~1.50 m thick coset of *Stsx <1.5 m (St); small-scale trough cross-bedding <1.5 m trough width; coset consists of ~0.20 m thick and likely down-climbing cross-cutting sets; poorly defined sets and foresets; sharp (in part), likely horizontal contact with overlying coset; **2.** Central – eastern depression; ~0.04 m thick coset of *Srsx 0.005-0.05 m (Sr); likely poorly defined straight-crested small-scale asymmetrical ripple cross-bedding; horizontal sets consist of ~0.01 m thick ripple heights (sets) and surface ripple wavelengths of 0.10-0.15 m; ripple crestline's are generally orientated east – west (i.e. 90°-270°); likely horizontal, but undefined overlying boundary contact; **3.** North western section ;Sl-hpx <2.0 m (Sp); low to high-angle-inclined foresets forming large-scale planar cross-bedding; evidence of tangential foresets; ~1.10 m thick set; sharp (in part), likely horizontal contact with overlying coset; **4.** Northern, eastern and southern sections; ~8.00 m thick coset group of *Stsx <1.5 m (St); likely small-scale trough cross-bedding <1.5 m trough width; five variable 1.00-1.50 m thick horizontal to slightly sub-horizontal cross-cutting cosets; cosets consist of 0.10-0.25 m thick horizontal to slightly sub-horizontal cross-cutting sets; poorly defined foresets, sets and cosets; likely third-order contacts' between cosets.

Interpretation

Although variable, foreset and set palaeocurrent data relating to Outcrop 28.1 imply that deposition was mainly influenced by northerly and westerly palaeocurrents (Fig. 4.4 Location 28). A maximum set thickness of ~1.10 m (facies Sl-hpx <2.0 m) indicates that the maximum bar height and channel depth was ~3.30 m and ~6.60 m, respectively (cf. Reesink & Bridge, 2009; Leclair, 2011). Conversely, variable set thicknesses of between ~0.10 and ~0.25 m (facies Stsx <1.5 m) indicates that deposition may have been dominated by varying amounts of sediment transport and input, likely influenced by minor flood events and related variable channel depths of between ~0.65 m and ~2.70 m, respectively (cf. Leclair, 2011).

The basal facies of Stsx <1.5 m may represent downstream migration and accretion of 3D mesoforms within a relatively deep (~2.15 m deep; cf. Reesink & Bridge, 2009; Leclair, 2011) thalweg region of a low sinuosity channel (cf. Bristow, 1988, 1993a; Ghinassi *et al.,* 2009; Miall, 2010b; Reesink *et al.,* 2014), influenced by waning flow, net sediment aggradation and channel fill (cf. Cant & Walker, 1976; Ashworth *et al.*, 2011; Reesink *et al.*, 2014). Such facies may also indicate migratory bedforms that likely developed on the surface of a larger sand flat (cf. Cant & Walker, 1976, 1978) and/or they may represent the latter stages of a channel fill sequence (cf. Reesink *et al.*, 2014). Subsequent deposition of facies Srsx 0.005-0.05 m (ripple cross-stratification) is consistent with either upper channel fill (Bridge & Lunt, 2006; Ashworth *et al.,* 2011) or bar top (Bristow, 1993b; Best *et al.*, 2003; Bridge & Lunt, 2006; Mumpy *et al*., 2007) deposition related to shallow channel flow conditions and low-flow stage deposition (Bridge & Lunt, 2006). The medium to coarse grain size of facies Srsx 0.005-0.05 m would have supported ripple formation (cf. Bridge & Lunt, 2006; Collinson *et al.,* 2006). Although not conclusive, due to the potential complex nature of ripple formation (Collinson *et al.,* 2006) and relatively poor outcrop detail, a ripple index of between 10-15 (cf. Lindholm, 1987; Collinson *et al*., 2006) suggests that the ripples were generated due to current, rather than wave, activity (Collinson *et al.,* 2006).

Subsequent deposition of facies Sl-hpx <2.0 m suggests in channel sediment migration and ensuing net sediment deposition (aggradation) of 2D mesoforms, likely facilitated by a flood event (high-flow stage) and waning flow (low-flow stage), respectively (cf. Coleman, 1969; Bristow, 1987, 1993a; Ashworth *et al.,* 2011). A set thickness ≥1.00 m likely denotes a unit bar deposit, rather than dune deposits (Bridge & Lunt, 2006). Similarly, Sambrook Smith *et al*. (2006) interpret sets >0.5 m, which possess inclined (i.e. ≤ angle-of-repose) cross-stratification, as a consequence of bar migration. Such facies probably formed towards the channel thalweg/axis where larger bedforms generally develop (cf. Reesink & Bridge, 2009; Ashworth *et al.*, 2011; Reesink *et al.*, 2014) and may represent either a: i. longitudinal bar (Ghinassi *et al.,* 2009); ii. unit bar (cf. Bridge & Lunt, 2006; Ashworth et al., 2011); or transverse bar (cf. Smith, 1972). The tangential (or asymptotic) foresets relating to facies Sl-hpx <2.0 m were likely promoted by fairly frail separation eddies and a high rate of sediment deposition, from suspension, beyond the slipface of a dune's lee (cf. Leeder, 1982; Bristow, 1993a; Bridge, 2003). Hence, it is unlikely that facies Sl-hpx <2.0 m represent a transverse bar (2D macroform, part of) which are associated with angular foreset contacts generated due to low fluid and low sediment discharge (cf. Smith, 1972; Hein & Walker, 1977; Collinson *et al.,* 2006). Set thicknesses of 0.10-0.25 m relating to the coset group of facies Stsx <1.5 m suggest influence from a channel with variable flow depth facilitated by flood events (high-flow stage) and subsequent net sediment deposition during waning flow (low-flow stage) (cf. Coleman, 1969; Bristow, 1987, 1993a; Ashworth *et al.,* 2011). Low-flow stage would have facilitated the aggradation of 3D mesoforms and channel fill (cf. Cant & Walker, 1976; Ashworth *et al.*, 2011; Reesink *et al.*, 2014). Similarly, such bedforms are associated with a series of distinct depositional episodes (cf. Collinson *et al.,* 2006) of assembled sets divided by first-order set boundaries which indicate repeated bedform migration probably as a train of dunes (dune stacking) which may have formed components of a channel bar top (cf. Bristow, 1993b; Best *et al.*, 2003; Bridge & Lunt, 2006; Mumpy *et al*., 2007; Miall, 2010b; Ashworth *et al.*, 2011). The sub-horizontal second-order coset bounding surface contacts may represent third-order erosional surfaces (cf. Miall, 2010b; Ielpi *et al*., 2014). Such contacts may denote a component of lateral coset (mesoform) accretion and growth of a possible compound bar (macroform) through lateral and downstream-accretion (cf. Bridge & Lunt, 2006). That said, given the proximity of the transverse fault within the quarry, the relatively low angle coset azimuths (~04°) may be a consequence of tectonic activity. consistent

Overall the facies associated with Outcrop 28.1 probably represent an upper channel fill sand body sequence, rather than migratory mid-channel bar deposit; although mid-channel bars may also be interpreted as channel fill components, Skelly *et al.* (2003) and Ashworth *et al.* (2011) (and references there in) argue that the distinction between compound bar and adjacent channel fill core deposits, in sandy braided fluvial systems, is problematic. Further, Leeder (1982) argues that the preservation of consecutive cross-laminated sets inevitably encompasses a measure of net deposition, which inexorably necessitates that each individual foreset, set and coset deposit, for example, represent a contrasting scale of channel fill components. Although limited in number, the relatively shallow inclined (~04°) third-order bounding surface dips relating to the upper cosets of Stsx <1.5 m may denote a relatively broad and shallow host channel. Such an interpretation corresponds with McCabe's (1977) observation that distributary channel dips were in the region of ≤10° and Bristow (1987, 1993a) arguing that bounding surfaces, with very low depositional dips, correspond to channels possessing high width to depth ratios; and Outcrop 28.1 is dominated by a coarse-grained to granular sandstone which coincides with Coleman's (1969) observation that rivers with significant quantities of coarse sediment are representative of broad, flat, island-obstructed fluvial systems, although the term bar-obstructed is more appropriate (sensu Bridge, 2003).

Evidence of tectonic activity along the western flank of the quarry face, i.e. extensive horizontal/lateral striations (slickensides) running along the entire length of the vertical western quarry face and jointing analogous with flower structures, is consistent with that of a transverse, strike slip or wrench fault trending 130˚-310˚ (cf. Arthurton, 1983; Dooley & Schreurs, 2012; Chemenda *et al*., 2016; Marinin & Tveritinova, 2012; Bhakuni *et al*., 2017) (Fig. 4.4 Location 28). Evidence of a flower structure (part of) is visible adjacent to southwest and northwest sections of the transverse fault. Positive flower structures are indicative of horizontal stress orientated perpendicular to the basement fault (transpression) and are the product of transverse shortening/convergence; conversely, negative flower structures are indicative of horizontal stress orientated parallel to the basement fault (transtension) and are the product of transverse extension/divergence (Dooley & Schreurs, 2012). Although there appears to be no obvious evidence within the quarry to suggest whether or not the flower structure is either positive or negative, the 130˚-310˚ trending vertical transverse fault is orientated perpendicular to the North Craven Fault located ~500 m to the northwest (exact location of the North Craven Fault is unkown). Hence, The preservation and sharp detail of the apparent horizontal slickensides and visible primary sedimentary detail in adjacent deposits (e.g. foresets and sets) indicate that the outcrop may have been subjected to post- rather than syn-sedimentary tectonic convergence (transpression). Further, due to the tectonic activity, it is likely that the whole western (or, part of) section was juxtaposed against the eastern section, therefore, the sections of the quarry examined may not provide a true depositional sequence. For example, due to the fragmented and jointed nature of the quarry and poor sedimentary detail, it cannot be said with certainty that facies Sl-hpx <2.0 m forms part of the main sequence, which is dominated by facies Stsx <1.5 m.

Table 4.29

Location, grid reference and associated literature	General description and lithology
29. Knox Wood Outcrop 29.1: SE 19173 63871 Thompson, A. T. (1957) *The structure and stratigraphy of Nidderdale between Lofthouse and Dacre*. Unpublished, Doctoral thesis, Durham University. Available at Durham E-Theses Online: http://etheses.dur.ac.uk/722/.	Located within a woodland setting, the examined fragmented and jointed outcrop forms a line of crags situated along a steep hillside, below the summit ridgeline, which follows the southern limb of Knox Wood. The outcrop is obscured by ground cover, dense vegetation, moss, lichen and leaf litter/detritus consistent with that of a woodland setting. The outcrop possesses a variable texture with relatively poor outcrop detail (e.g. foresets, sets and cosets), due to the above-mentioned and the processes of weathering and erosion. Although the examined outcrop appears to be in-sitú, it may have been subjected to minor cambering; the upper section is very jointed and blocky and has been subjected to soft sediment deformation (Ssd). Outcrop measurements were obtained from the central lower section (base) moving towards the west and up sequence. Elevation of Outcrop 29.1 is ~145 m; main outcrop view is towards ~090˚ (Fig. 4.4 Location 29). Outcrop 29.1: Coarse-grained to granular sandstone with 2-5% small to medium pebble content (variable), predominantly quartz grains; generally low to high sphericity; sub-angular to rounded; poorly to very well sorted.

Identified sub-Facies, sedimentary structures and bounding surfaces of note

Outcrop 29.1 [~9.0 (H) x 10.0 (D) x 60.0 m (W)]: **1.** ~1.00 m thick coset of *Stsx <1.5 m (St); likely poorly defined small-scale trough cross-bedding <1.5 m trough width; coset consists of 0.25-0.30 m thick down-climbing cross-cutting sets; poorly defined sub-horizontal contact with overlying coset; **2.** ~1.00 m thick coset group of *Sl-hpx <2.0 m (Sp); two ~0.50 m thick sub-horizontal cross-cutting cosets, delineated by granules – normal grading; cosets consist of ~0.10 m thick sub-horizontal cross-cutting sets; likely poorly defined high-angle-inclined foresets i.e. planar cross-bedding; sharp sub-horizontal contact with overlying coset; **3.** ~0.60 m thick coset of *Sl-hpx <2.0 m (Sp); coset consists of two ~0.30 m thick sub-horizontal sets; poorly defined low to high-angle-inclined foresets; coarser grain component delineates foreset boundaries (~0.02 m thick foresets) – normal grading; medium-scale planar cross-bedding; poorly defined (in-part) sub-horizontal contact with overlying coset; **4.** ~1.00 m thick coset of *Sl-hss-of <1.0 m (Sl); likely small-scale oblique low-amplitude planar cross-bedding; coset consists of 0.10–0.15 m thick sub-horizontal cross-cutting sets; evidence of very minor Ssd; coarser grain component delineates foreset boundaries – normal grading; poorly defined (in-part) sub-horizontal contact with overlying coset; **5.** ~0.70 m thick coset group of *Sl-hss-of <1.0 m (Sl); two ~0.35 m thick sub-horizontal cosets; cosets consist of ~0.10 m thick sub-horizontal cross-cutting sets; likely small-scale oblique low-amplitude planar cross-bedding; coarser grain component delineates foreset boundaries – normal grading; sharp sub-horizontal contact with overlying set; **6.** *Sl-hpx <2.0 m (Sp); low-angle-inclined foresets forming medium to large-scale low-amplitude planar cross-bedding; ~0.56 m thick sub-horizontal set; coarser grain component delineates foreset boundaries – normal grading; evidence of reactivation surfaces; sharp sub-horizontal contact with overlying set; **7.** *Sl-hpx <2.0 m (Sp); low to high-angle-inclined foresets forming large-scale planar cross-bedding; ~0.90 m thick sub-horizontal set; coarser grain component delineates foreset boundaries – normal grading; sharp sub-horizontal contact with overlying set; **8.** Sl-hpx <2.0 m (Sp); low to high-angle-inclined foresets forming medium-scale planar cross-bedding; ~0.30 m thick sub-horizontal set; coarser grain component delineates foreset boundaries – normal grading; poorly defined horizontal and undulating contact with overlying coset; **9.** ~0.80 m thick coset of Sl-hhs <1.0 m (Sh); poorly defined low-angle-inclined foresets; ~0.10 m thick horizontal sets of low-amplitude small-scale (<1.5 m) trough cross-bedding, or planar cross-bedding; poorly defined (in-part) horizontal contact with overlying coset; **10.** ~1.50 m thick coset of *Ssd (Sd); small-scale planar or trough cross-bedding <1.5 m trough width; coset consists of 0.10-0.20 m thick slightly sub-horizontal sets; poorly defined set bounding surfaces and cross-bedding; intermittent evidence of intense de-watering i.e. dish and flame structures, primary facies Ssd; poorly defined (in-part) horizontal contact with overlying coset; **11.** ~0.80 m thick coset of *Stsx <1.5 m (St); likely poorly defined small-scale trough cross-bedding <1.5 m trough width; coset consists of ~0.20 m thick sets; poorly defined likely horizontal sets; evidence of increase in grain size and pebble content.

Interpretation

Palaeocurrent field data relating to Outcrop 29.1 imply that deposition was mainly influenced by north-westerly palaeocurrents, with limited north-easterly and south-easterly bedform migration (Fig. 4.4 Location 29). Although not conclusive, several set and foreset data appear to possess onlap relationships with their underlying coset boundary (i.e. sets and foresets orientated similar to host coset possessing higher dip angle), not previously observed, rather than the more consistent offlap/downlap relationships (i.e. sets and foresets orientated similar to host coset possessing lower dip angle, or orientated obliquely to host coset with either higher, or lower, dip angles) (Fig. 4.4 Location 29). Collectively, with the cosets and sets that appear to possess a northerly dip direction and 38° foreset dips, these observations suggest that the lower section of Outcrop 29.1 (up to, but not including, facies Sl-hhs <1.0 m) may have been influenced by syn-sedimentary tectonic activity along the North Craven Fault. Such activity may be reflected by the 16° dip and 016° azimuth associated with the basal sets relating to facies Stsx <1.5 m. Conversely, the predominantly horizontal overlying facies (e.g. Sl-hhs <1.0 m appear not to have been subjected to tectonic tilting. The affected bedding and palaeocurrent data was restored through stereographic projection, relative to the 16˚ dip and 016˚ azimuth relating to the basal facies of Stsx <1.5 m. Once restored, the palaeocurrent data trends adopt a more variable north-easterly to south-westerly pattern (Fig. 4.4 Location 29); the previously recorded onlap set and foreset data also adopt a more offlap relationship (e.g. facies Sl-hss-of <1.0 m) and the apparent northerly dip (e.g. facies Sl-hpx <2.0 m) is restored to the horizontal. The restored data appears more consistent with that of previous outcrops; hence, the restored data was adopted when interpreting Outcrop 29.1. A maximum set thickness of ~0.90 m (facies Sl-hpx <2.0 m) indicates that the maximum dune height and channel depth was

~3.25 m and ~9.70 m, respectively (cf. Leclair, 2011). Conversely, variable set thicknesses of between ~0.10 m and ~0.30 m indicates that deposition may have been dominated by varying amounts of sediment transport and input, likely influenced by minor flood events and related variable channel depths of between ~0.65 m and ~3.25 m, respectively (cf. Leclair, 2011). The initial coset relating to facies Stsx <1.5 m may represent: i. downstream-accretion of 3D mesoforms within a relatively deep thalweg region of a low sinuosity channel, likely influenced by high-flow stage which facilitated the formation of down-climbing dunes (cf. Bristow, 1988, 1993a; Ghinassi *et al.,* 2009; Miall, 2010b; Reesink *et al.,* 2014); or, ii. a series of distinct depositional episodes (cf. Collinson *et al.,* 2006) i.e. sets divided by first-order set boundaries which indicate repeated bedform migration probably as a train of dunes (dune stacking) which may have formed components of a channel bar top vertical-accretion (cf. Bristow, 1993b; Best *et al.*, 2003; Bridge & Lunt, 2006; Miall, 2010b; Mumpy *et al*., 2007; Ashworth *et al.*, 2011); or iii. collectively form components of a larger host dune coset (cf. Haszeldine, 1983b) towards the channel thalweg/axis, large mesoforms tend to develop towards deeper channel thalweg regions within relatively broad/deep channels, as reflected by a mesoform height of ~1.00 m (cf. Reesink & Bridge, 2009; Ashworth *et al.*, 2011; Leclair, 2011; Reesink *et al.*, 2014).

Individual sub-horizontal cosets and sets of facies of Sl-hpx <2.0 m are predominantly constructed from repeated grain flow avalanche deposits (~0.02 m thick foresets; see Smith, 1972; Reesink & Bridge, 2007, 2009) that likely represent downstream migration and accretion of 2D mesoforms, which may in turn form components of a larger host dune coset (cf. Haszeldine, 1983b), probably towards the channel thalweg/axis, large mesoforms tend to develop towards deeper channel thalweg regions within relatively broad/deep channels, as reflected by a mesoform height of ~0.80 m (cf. Reesink & Bridge, 2009; Ashworth *et al.*, 2011; Leclair, 2011; Reesink *et al.*, 2014). Such cosets may represent migratory mid-channel bar bedform components (cf. Reesink & Bridge, 2009) that likely formed within a multi-channelled fluvial system (cf. Reesink *et al*., 2014) and/or small-scale migrating unit bar components (cf. Sambrook Smith *et al.*, 2006; Reesink & Bridge, 2009), which in turn likely form components of a much larger host compound bar (cf. Allen, 1982; Bridge, 2003; Bridge & Lunt, 2006; Sambrook Smith *et al.*, 2006; Ashworth *et al.*, 2011). Sambrook Smith *et al.* (2006) interpret sets >0.5 m, which possess inclined (i.e. ≤ angle-of-repose) cross-stratification, as a consequence of bar migration, although such component coset/unit bar heights coincide with dune heights (Ashworth *et al.*, 2011). The sub-horizontal second-order coset/unit bar bounding surface contacts are likely third-order erosional surfaces (cf. Miall, 2010b; Ielpi *et al*., 2014) which may denote: i. a component of lateral coset (mesoform) accretion and growth of the host compound bar (macroform) through lateral and downstream-accretion (cf. Bridge & Lunt, 2006); or ii. dune-scale bedform migration obliquely over, around and down a curved barform front/tail (cf. Haszeldine, 1983b), influenced by high-flow stage which facilitated the formation of down-climbing dunes (cf. Bristow, 1988, 1993a; Reesink & Bridge, 2009; Ghinassi, 2011). The low-angle bounding surfaces and foresets (predominantly ≤10°) associated with the upper deposits of facies of Sl-hpx <2.0 m are likely attributed to bedform migration and net deposition within a relatively broad/deep channel (cf. Bristow, 1987, 1993a), as reflected by a set thickness of ~0.30 m and associated ~1.10 m dune thickness and ~3.25 m channel depth (cf. Leclair, 2011).

The subsequent deposition of facies Sl-hss-of <1.0 m implies net deposition, through lateral-accretion of 2D mesoforms during waning flow (low-flow stage) (cf. Coleman, 1969; Bristow, 1987, 1993a; Ashworth *et al.,* 2011), which likely formed components of a small-scale unit bar (cf. Sambrook Smith *et al.*, 2006; Reesink & Bridge, 2009). Such post flood events may have also influenced thalweg migration and alterations in flow direction, as indicated in the palaeocurrent data relating to facies Sl-hss-of <1.0 m. The variable palaeocurrent azimuths imply dune-scale bedforms may have migrated obliquely over, around and down a curved barform front/tail (cf. Haszeldine, 1983b). Individual sub-horizontal sets of Sl-hss-of <1.0 m may also form components of a larger host dune coset (cf. Haszeldine, 1983b), influenced by high-flow stage which facilitated the formation of down-climbing dunes (cf. Bristow, 1988, 1993a; Reesink & Bridge, 2009; Ghinassi, 2011). Further, topographic lows adjacent to bar margins may limit falling-stage currents that flow between bars (Collinson, 1970; cf. Reesink *et al*., 2014), thereby facilitating lateral-accretion by promoting deposition along bar margins (Collinson, 1970, 1996), which may account for the presence of facies Sl-hss-of <1.0 m. The low-angle bedforms (predominantly ≤10°) associated with the upper deposit of facies of Sl-hss-of <1.0 m may be attributed to the migration of low-amplitude (near horizontal) sand waves/dunes concomitant with the transitional zone between lower and upper flow regimes and very shallow fluvial systems (cf. Smith, 1971; Todd, 1996); generally foreset gradients decline as a flow regime intensifies, vice versa (cf. Smith, 1972).

The ensuing deposition of three individual sets of facies Sl-hpx <2.0 m implies a substantial increase in channel depth (up to ~9.80 m deep) and net sediment input (up to ~3.25 m high dunes), likely facilitated by several flood events with sediment migration and aggradation influenced by high and low-flow stages, respectively (Coleman, 1969; Bristow, 1987, 1993a; Ashworth *et al.,* 2011). The size of cross-bedding suggests downstream-accretion within a relatively broad and deep channel with dune migration near to channel thalweg/axis (cf. Reesink & Bridge, 2009; Ashworth *et al.*, 2011; Reesink *et al.*, 2014). Collectively, the relatively constant westerly palaeocurrents associated with facies Sl-hpx <2.0 m may be related to the downstream migration of longitudinal bars (cf. Ghinassi *et al.,* 2009), or unit bars (cf. Bridge & Lunt, 2006; Ashworth *et al.*, 2011), although such bar heights coincide with dune heights (Ashworth *et al.*, 2011). The noticeable horizontal contact between the uppermost facies of Sl-hpx <2.0 m and overlying facies of Sl-hhs <1.0 m suggests that the influence of any former tectonic activity had been mitigated by the deposition of facies Sl-hpx <2.0 m, as implied by the subsequent horizontal bedding. The deposition of facies Sl-hhs <1.0 m may represent downstream migration and net accretion of 3D, or 2D, mesoforms within a relatively shallow thalweg region of a low sinuosity channel (cf. Bristow, 1988, 1993a; Ghinassi *et al.,* 2009; Miall, 2010b; Reesink *et al.,* 2014), influenced by waning flow, net sediment aggradation and channel fill (cf. Cant & Walker, 1976; Ashworth *et al.*, 2011; Reesink *et al.*, 2014). Such facies may also indicate migratory bedforms that likely developed on the surface of a larger sand flat (cf. Cant & Walker, 1976, 1978) and/or they may represent the latter stages of a channel fill sequence (cf. Reesink *et al.*, 2014). Similarly, such bedforms are also associated with a series of distinct depositional episodes (cf. Collinson *et al.,* 2006) of assembled sets divided by first-order set boundaries which indicate repeated bedform migration probably as a train of dunes (dune stacking) which may have formed components of a channel bar top (cf. Bristow, 1993b; Best *et al.*, 2003; Bridge & Lunt, 2006; Mumpy *et al.*, 2007; Miall, 2010b; Ashworth *et al.*, 2011). Further, the low-angle bedforms associated with facies of Sl-hhs <1.0 m may be attributed to the migration of low-amplitude (near horizontal) sand waves/dunes, see above interpretations relating to facies Sl-hss-of <1.0 m.

Soft sediment deformation relating to facies Ssd (i.e. dish and flame structures) is evidence of loss of grain stability (liquefaction) within unconsolidated water laden sediments, probably facilitated by de-watering processes such as rapid deposition and/or sediment overburden post flood event and/or syn-sedimentary tectonic activity post deposition (cf. Barnhardt & Sherrod, 2006; Hubert-Ferrari *et al.*, 2017). The original facies affected by Ssd was likely a ~1.50 m thick coset of facies Sl-hss <1.0 m; the variable 0.10-0.20 m thick component sets likely developed within a relatively shallow channel (cf. Ashworth *et al.*, 2011), possibly on the surface of a larger sand flat (cf. Cant & Walker, 1976, 1978). Such bedforms are also associated with a series of distinct depositional episodes (cf. Collinson *et al.,* 2006) i.e. sets divided by first-order set boundaries which indicate repeated bedform migration probably as a train of dunes (dune stacking) which may have formed components of a channel bar top (cf. Bristow, 1993b; Best *et al.*, 2003; Bridge & Lunt, 2006; Miall, 2010b; Mumpy *et al*., 2007; Ashworth *et al.*, 2011). Evidence to suggest that a sudden overburden of sediment was the triggering event is not obvious, due to the relatively small-scale (~0.20 m) overlying sets and poor outcrop detail; therefore, although sudden overburden cannot be totally discounted, the effect of tectonic activity may have played a more significant role and may also account for the sudden switch from a westerly (e.g. facies Sl-hpx <2.0 m) to south-easterly palaeocurrent (facies Ssd), which is also evident in the overlying facies of Stsx <1.5 m, see above interpretations relating to facies Stsx <1.5 m.

Overall, Outcrop 29.1 may represent a remnant of a compound bar (3D macroform) that was likely influenced by tectonic activity. Such bars are constructed from component unit bar deposits consisting of simple inclined (mainly <10°, but may be up to 35°) small to large-scale sets, which may show a vertical reduction in dune/set height correlated to a decrease in channel depth, the deposits may also display no significant vertical shift in grain size (cf. Bridge & Lunt, 2006). These traits are consistent with the facies associated with Outcrop 29.1 which likely represents an amalgamation of several unit bar components. The variable coset, set and foreset palaeocurrent azimuths may also evidence the downstream migration and/or lateral-accretion of a compound bar; and the preservation of consecutive cross-laminated sets inevitably encompasses a measure of net deposition and subject to the inclination of their host bed most sets will climb at a similar angle (Leeder, 1982). Further, the shallow inclined (≤12°) bounding surface and/or foreset dips, evident in certain facies e.g. Stsx <1.5 m, Sl-hpx <2.0 m and Sl-hss-of <1.0 m, likely denote that the host channel was relatively broad and varied in depth. Such an interpretation corresponds with McCabe's (1977) observation that distributary channel dips were in the region of ≤10° and Bristow (1987, 1993a) arguing that bounding surfaces, with very low depositional dips, correspond to channels possessing high width to depth ratios. Further, the relatively coarse-grained to granular sandstone texture associated with Outcrop 29.1 coincides with Coleman's (1969) observation that rivers with significant quantities of coarse sediment are representative of broad, flat, island-obstructed fluvial systems, although the term bar-obstructed is more appropriate (sensu Bridge, 2003).

Table 4.30

Location, grid reference and associated literature	General description and lithology
30. Sigsworth Crags Outcrops 30.1: SE 14187 70139 30.2: SE 14303 69907 30.3: SE 14512 69808 30.4: SE 14570 69786 30.5: SE 14802 69814 Thompson, A. T. (1957) *The structure and stratigraphy of Nidderdale between Lofthouse and Dacre*. Unpublished, Doctoral thesis, Durham University. Available at Durham E-Theses Online: http://etheses.dur.ac.uk/722/.	Numerous various sized outcrops scattered along a crescent shaped ridgeline situated to the south of Sigsworth Moor. Outcrops are generally masked (in part) by soil and vegetation (e.g. lichen, moss and/or heather) associated with a moorland setting. Although several outcrops appear to have been disarticulated and/or subjected to cambering, the in-sitú examined outcrops generally follow a ~920.0 m long north-westerly to south-easterly crescent shaped line of intermittent and fragmented crags. The examined outcrops form the initial main section of a larger disjointed chain of outcrops extending from the northwest to the southeast for ~4.1 km; mainly following the topographic contours, varying from ~350 m down to ~320 m. Generally, all the examined outcrops are jointed both horizontally and vertically, weathered and possess a variable texture with relatively poor outcrop detail (e.g. foreset/sets), due to the processes of weathering and erosion. Outcrops examined are a representative example of the outcrops in the locality and were surveyed moving from the northwest towards the southeast. Elevation of Outcrops 30.1-30.5 is ~350, 355, 350, 344 and 341 m O.D, respectively; main outcrop views are towards ~100˚, 080˚, 040˚, 022˚ and 024˚, respectively (Fig. 4.4 Location 30). Outcrop 30.1: Coarse-grained to granular sandstone with ~5% small to medium pebble content (variable), predominantly quartz grains; generally low to high sphericity; sub-angular to rounded; moderately to poorly sorted; Outcrop 30.2: Coarse-grained to granular sandstone with 2-10% small to medium pebble content (variable), predominantly quartz grains; generally low to high sphericity; sub-angular to rounded; moderately to poorly sorted; Outcrop 30.3: Coarse-grained to granular sandstone with 2-10% small to medium pebble content (variable), predominantly quartz grains; generally low to high sphericity; sub-angular to rounded; poorly to very well sorted; Outcrop 30.4: Coarse-grained to granular sandstone with 2-5% small to medium pebble content (variable), predominantly quartz grains; generally low to high sphericity; sub-angular to rounded; poorly to very well sorted; Outcrop 30.5: Coarse-grained to granular sandstone with 2-5% small to medium pebble content (variable), predominantly quartz grains; generally low to high sphericity; sub-angular to rounded; poorly to very well sorted.

Identified sub-Facies, sedimentary structures and bounding surfaces of note

Outcrop 30.1 [~2.0 (H) x 4.0 (D) x 5.0 m (W)]: **1.** ~2.00 m thick coset of *Sl-hhs <1.0 m (Sh); coset consists of poorly defined very low-amplitude cross-bedding forming ~0.10 m thick cross-cutting horizontal sets of likely small-scale (<1.5 m) trough cross-bedding; sharp horizontal contact with overlying coset;

Outcrop 30.2 [~5.0 (H) x 6.0 (D) x 9.0 m (W)]: **1.** Sl-hpx <2.0 m (Sp); low to high-angle-inclined foresets forming medium to large-scale planar cross-bedding; ~0.70 m thick set; sharp horizontal contact with overlying coset; **2.** ~0.40 m thick coset of *Sl-hhs <1.0 m (Sh); coset consists of poorly defined low-amplitude cross-bedding forming 0.10-0.15 m thick horizontal sets of likely small-scale (<1.5 m) trough cross-bedding; coarser grain component delineates trough base – normal grading; poorly defined horizontal contact with overlying set; **3.** *Sl-hpx <2.0 m (Sp); low to high-angle-inclined foresets forming medium-scale planar cross-bedding; ~0.40 m thick horizontal set; coarser grain component delineates foreset boundaries – normal grading; foresets vary in thickness up to 0.08 m thick; sub-horizontal contact with overlying set; **4. ***Stsx <1.5 m (St); small to medium-scale cross-cutting trough cross-bedding <1.5 m trough width; ~0.25 m thick climbing trough set; poorly defined foresets up to 0.05 m thick; sub-horizontal poorly defined contact with overlying coset; **5.** ~0.90 m thick coset group of *Stsx <1.5 m (St); likely poorly defined low-amplitude small-scale trough cross-bedding <1.5 m trough width; three ~0.30 m thick sub-horizontal climbing cosets; intermittent lag deposit (Ss-lp-lag) along coset base; ~0.10 m thick sub-horizontal cross-cutting climbing sets; coarser grain component delineates trough base – normal grading; sharp horizontal contact with overlying coset; **6.** ~1.60 m thick coset of *Sl-hss <1.0 m (Sl); likely poorly defined low-amplitude small-scale trough cross-bedding <1.5 m trough width; coset consists of ~0.10 m thick down-climbing and cross-cutting sets; sharp horizontal contact with overlying coset; **7.** ~1.00 m thick coset of *Sl-hhs <1.0 m (Sh); coset consists of poorly defined low-amplitude cross-bedding forming 0.10-0.15 m thick horizontal sets of likely small-scale (<1.5 m) trough cross-bedding;

Outcrop 30.3 [~5.5 (H) x 9.0 (D) x 16.0 m (W)]: **1.** ~0.70 m thick coset of *Sl-hpx <2.0 m (Sp); coset consists of ~0.15 m thick sub-horizontal down-climbing sets; poorly defined low to high-angle-inclined foresets; medium to large-scale planar cross-bedding; poorly defined sub-horizontal contact with overlying coset; **2.** ~1.00 m thick coset of *Sl-hpx <2.0 m (Sp); coset consists of 0.15-0.20 m thick sub-horizontal down-climbing sets; poorly defined low to high-angle-inclined foresets; coarser grain component towards base of sets – normal grading; large-scale planar cross-bedding; poorly defined sub-horizontal contact with overlying set; **3. ***Stsx <1.5 m (St); poorly defined small to medium-scale trough cross-bedding <1.5 m trough width; ~0.20 m thick down-climbing set; sub-horizontal poorly defined contact with overlying coset; **4.** ~0.70 m thick coset of ***Sl-hpx <2.0 m (Sp); coset consists of ~0.10 m thick sub-horizontal down-climbing sets; poorly defined low to high-angle-inclined foresets; coarser grain component towards base of sets – normal grading; medium to large-scale planar cross-bedding; poorly defined sub-horizontal contact with overlying set; **5. ***Stsx <1.5 m (St); poorly defined small to medium-scale trough cross-bedding <1.5 m trough width; ~0.20 m thick down-climbing set; sub-horizontal poorly defined contact with overlying coset; **6.** ~0.60 m thick coset of *Sl-hss <1.0 m (Sl); likely poorly defined low-amplitude small-scale trough cross-bedding <1.5 m trough width; coset consists of 0.10-0.15 m thick down-climbing cross-cutting sets; poorly defined horizontal contact with overlying coset; **7.** ~0.30 m thick coset of *Sl-hss <1.0 m (Sl); likely poorly defined low-amplitude small-scale trough cross-bedding <1.5 m trough width; coset consists of ~0.10 m thick down-climbing cross-cutting sets; coarser grain component towards base of sets – normal grading; sharp and poorly defined (in part) horizontal contact with overlying coset; **8.** ~2.50 m thick coset group of *Sl-hhs <1.0 m (Sh); three horizontal cosets 0.80-0.90 m thick; cosets consist of poorly defined low-amplitude cross-bedding forming 0.10-0.15 m thick horizontal cross-cutting sets of likely small-scale (<1.5 m) trough cross-bedding;

Outcrop 30.4 [~3.0 (H) x 3.8 (D) x 8.0 m (W)]: **1.** ~0.60 m thick coset of Sl-hhs <1.0 m (Sh); likely poorly defined low-amplitude small-scale trough cross-bedding <1.5 m trough width; coset consists of 0.05-0.10 m thick horizontal sets; slightly undulating and poorly defined (in part) horizontal contact with overlying coset; **2.** ~0.50 m thick coset of *Stsx <1.5 m (St); likely poorly defined low-amplitude small-scale trough cross-bedding <1.5 m trough width; coset consists of 0.15-0.20 m thick cross-cutting sets; poorly defined sub-horizontal contact with overlying coset; **3.** ~0.20 m thick coset of *Stsx <1.5 m (St); likely poorly defined low-amplitude small-scale trough cross-bedding <1.5 m trough width; coset consists of 0.05-0.10 m thick cross-cutting sets; sharp sub-horizontal contact with overlying set; **4.** *Sl-hpx <2.0 m (Sp); low to high-angle-inclined foresets forming medium to large-scale planar cross-bedding; ~0.70 m thick set; sharp sub-horizontal contact with overlying coset; **5.** ~0.45 m thick coset of *Sl-hss <1.0 m (Sl); likely poorly defined low-amplitude small-scale trough cross-bedding <1.5 m trough width; coset consists of ~0.05 m thick down-climbing cross-cutting sets; coarser grain component towards base of sets – normal grading; erosive poorly defined sub-horizontal contact with overlying coset; **6.** ~0.60 m thick coset of *Sl-hss <1.0 m (Sl); likely poorly defined low-amplitude small-scale trough cross-bedding <1.5 m trough width; coset consists of 0.10-0.15 m thick down-climbing cross-cutting sets; coarser grain component towards base of sets – normal grading; poorly defined sub-horizontal contact with overlying coset; **7.** ~0.50 m thick coset of *Sl-hpx <2.0 m (Sp); likely poorly defined low-amplitude small-scale planar cross-bedding exhibiting tangential foresets; coset consists of ~0.10 m thick down-climbing cross-cutting sets; coarser grain component towards base of sets – normal grading;

Outcrop 30.5 [~6.5 (H) x 12.0 (D) x 13.0 m (W)]: **1.** ~1.10 m thick coset of *Stsx <1.5 m (St); likely poorly defined small-scale trough cross-bedding <1.5 m trough width; coset consists of 0.15-0.20 m thick cross-cutting sets; poorly defined undulating horizontal contact with overlying coset; **2.** ~2.50 m thick coset group of *Sl-hpx <2.0 m (Sp); low to high-angle-inclined foresets; six cross-cutting horizontal cosets varying in thickness from 0.30-0.40 m; cosets consist ~0.10 m thick sub-horizontal cross-cutting sets; coarser grain component towards base of sets – normal grading; poorly defined sets and tangential foresets likely forming poorly defined planar cross-bedding; poorly defined horizontal contact between cosets and overlying coset; **3.** ~0.30 m thick coset of *Sl-hhs <1.0 m (Sh); likely poorly defined low-amplitude small-scale trough cross-bedding <1.5 m trough width; coset consists of ~0.05 m thick horizontal cross-cutting sets; poorly defined horizontal contact with overlying coset; **4.** ~1.30 m thick coset group of *Sl-hss <1.0 m (Sl); likely poorly defined low-amplitude small-scale trough cross-bedding <1.5 m trough width; three (i.e. 0.30-0.70-0.40 m thick) horizontal cosets; cosets consist of 0.10-0.15 m thick sub-horizontal cross-cutting sets; coarser grain component towards base of sets – normal grading; poorly defined horizontal contact between cosets and overlying coset; **5.** ~1.00 m thick coset of *Stmx 1.5-3.0 m (St); medium-scale trough cross-bedding 1.5–3.0 m trough width; shallow trough profile; ~0.50 m thick cross-cutting sets (troughs) with poorly defined foresets.

Interpretation

Outcrop 30.1: Palaeocurrent data relating to Outcrop 30.1 imply that the principal depositional palaeocurrent was towards the west (Fig. 4.4 Location 30). The predominant set thicknesses for Sl-hhs <1.0 m (i.e. ~0.10 m) imply that sediment input was limited and the maximum dune height and channel depth was ~0.35 m and ~1.10 m, respectively (cf. Reesink & Bridge, 2009; Leclair, 2011). Facies Sl-hhs <1.0 m may represent downstream migration and net accretion of 3D mesoforms within a relatively shallow thalweg region of a low sinuosity channel (cf. Bristow, 1988, 1993a; Ghinassi *et al.,* 2009; Miall, 2010b; Reesink *et al.,* 2014), influenced by waning flow, net sediment aggradation and channel fill (cf. Cant & Walker, 1976; Ashworth *et al.*, 2011; Reesink *et al.*, 2014). Such facies may also indicate migratory bedforms that likely developed on the surface of a larger sand flat (cf. Cant & Walker, 1976, 1978) and/or they may represent the latter stages of a channel fill sequence (cf. Reesink *et al.*, 2014). Similarly, such bedforms are also associated with a series of distinct depositional episodes (cf. Collinson *et al.,* 2006) of assembled sets divided by first-order set boundaries which indicate repeated bedform migration probably as a train of dunes (dune stacking) which may have formed surface components of an underlying bar, for example (cf. Bristow, 1993b; Best *et al.*, 2003; Bridge & Lunt, 2006; Miall, 2010b; Ashworth *et al.*, 2011). The low-amplitude dunes imply that flow conditions were sufficiently shallow (≤1.10 m deep; cf. Reesink & Bridge, 2009; Leclair, 2011) to subdue dune formation and generate low relief dunes (cf. Bristow, 1993a); preservation of low-angle dune morphology is facilitated by dune stoss and crest erosion, during high flow-stage, and deposition of eroded sediment in the dune's trough (Hendershot *et al.*, 2016). Further, the preservation of consecutive cross-laminated sets inevitably encompasses a measure of net deposition and most sets will climb at a similar angle/dip to that of their host bed (cf. Leeder, 1982); the lateral extent (~90.00 m) of the intermittent outcrop associated with facies Sl-hhs <1.0 m implies that the bedform, and therefore the host channel, were likely >90.0 m wide; similarly, modern day compound bars may extend several 100's of meters, both downstream and laterally (cf. Bristow, 1993a; Best *et al*., 2003; Bridge & Lunt, 2006).

Outcrop 30.2: Set and foreset palaeocurrent data relating to Outcrop 30.2 imply that the principal depositional palaeocurrent was towards the southwest-west, with limited south-easterly bedform migration (Fig. 4.4 Location 30). A maximum set thickness of ~0.70 m (facies Sl-hpx <2.0 m) indicates that the maximum dune height and channel depth was ~2.50 m and ~7.60 m, respectively (cf. Leclair, 2011) and a cumulative coset thickness of ~1.60 m (facies Sl-hss <1.0 m) indicates a likely maximum unit bar height and channel depth of ~1.90 m and ~3.70 m, respectively (cf. Reesink & Bridge, 2009; Leclair, 2011). Conversely, variable set thicknesses of between ~0.10 m and ~0.40 m indicates that deposition may have been dominated by varying amounts of sediment transport and input, likely influenced by flood events and related irregular channel depths of between ~0.65 m and ~4.30 m, respectively (cf. Leclair, 2011). The uppermost ~0.15 m thick sets relating to facies Sl-hhs <1.0 m imply that sediment input was limited and the maximum dune height and channel depth was ~0.55 m and ~1.60 m, respectively (cf. Reesink & Bridge, 2009; Leclair, 2011).

The initial facies of Sl-hpx <2.0 m and Sl-hhs <1.0 m may represent the transition zone between the lower and upper sections of a channel bar, respectively, as the height of dune-scale stratification generally decreases upwards through a bar sequence, reflecting the decrease in flow depth associated with bar stoss and top regions (cf. Best *et al.*, 2003; Bridge & Lunt, 2006). The subsequent deposit of facies Sl-hpx <2.0 m may represent dune migration over a unit bar (Bridge & Lunt, 2006) and the overlying deposits of facies of Stsx <1.5 m likely form a distinct series of depositional episodes (cf. Collinson *et al.,* 2006) of assembled sets divided by first-order set boundaries which indicate repeated bedform migration probably as a train of dunes (dune stacking) (cf. Bristow, 1993b; Best *et al.*, 2003; Bridge & Lunt, 2006; Miall, 2010b; Ashworth *et al.*, 2011). Such sets may for components of larger host dune cosets (cf. Haszeldine, 1983b) and their subcritical set and coset bounding surface angles imply that they migrated over a much slower migrating host bedform (cf. Haszeldine, 1983a, 1983b; Collinson *et al.*, 2006). Similarly, deposition may have been related to bar top vertical and/or upstream-accretion associated with the bar head and/or mid-bar section of a mid-channel bar, primarily due to dune stacking (cf. Bristow, 1993a; Best *et al.*, 2003; Bridge & Lunt, 2006; Mumpy *et al*., 2007); the relative increase in pebble content may also relate to bar top deposition (cf. Best *et al.*, 2003). The sub-horizontal second-order coset bounding surface contacts are likely third-order erosional surfaces (cf. Miall, 2010b; Ielpi *et al*., 2014) delineated by intermittent lag deposits, which likely represent scouring (Miall, 2010b). Such contacts may also denote a component of lateral coset (mesoform) accretion and growth of the host compound bar (macroform) through lateral and downstream-accretion (cf. Bridge & Lunt, 2006). Sambrook Smith *et al.* (2006) observed unit bars migrating upstream of, downstream of and adjacent to, the flank of a mid-channel compound bar. The low-angle bedforms (~6°) associated with facies Stsx <1.5 m may be attributed to the migration of low-amplitude (near horizontal) sand waves/dunes concomitant with the transitional zone between lower and upper flow regimes and very shallow fluvial systems (cf. Smith, 1971; Todd, 1996); generally foreset gradients decline as a flow regime intensifies, vice versa (cf. Smith, 1972). The overlying ~1.60 m thick deposit of facies Sl-hss <1.0 m may represent: i. bar top vertical-accretion component of a channel bar, primarily due to dune stacking and relative shallow flow depth above the host bar (cf. Best *et al.*, 2003; Bridge & Lunt, 2006), influenced by high-flow stage which facilitated the formation of down-climbing dunes (cf. Bristow, 1988, 1993a; Ghinassi *et al.,* 2009; Miall, 2010b; Reesink *et al.,* 2014); ii. recurring downstream migration of 3D mesoforms, probably as a train of dunes over the crest or front/tail of a migrating channel bar (macroform) (cf. Allen, 1982; Haszeldine, 1983b; Miall, 2010b; Ashworth *et al.*, 2011); iii. individual sub-horizontal set components of a larger host dune coset (cf. Haszeldine, 1983b), which in turn likely forms a component of a much larger host compound bar (cf. Allen, 1982; Bridge, 2003; Bridge & Lunt, 2006; Sambrook Smith *et al.*, 2006; Ashworth *et al.*, 2011). The low-angle bedforms (≤6°) associated with facies Sl-hss <1.0 m may be attributed to the migration of low-amplitude (near horizontal) sand waves/dunes, see above interpretations relating to facies Stsx <1.5 m. The subsequent deposition of facies Sl-hhs <1.0 m may represent downstream migration and net accretion of 3D mesoforms within a relatively shallow thalweg region of a low sinuosity channel (cf. Bristow, 1988, 1993a; Ghinassi *et al.,* 2009; Miall, 2010b; Reesink *et al.,* 2014), influenced by waning flow, net sediment aggradation and channel fill (cf. Cant & Walker, 1976; Ashworth *et al.*, 2011; Reesink *et al.*, 2014). Such facies may also indicate migratory bedforms that likely developed on the surface of a larger sand flat (cf. Cant & Walker, 1976, 1978) and/or they may represent the latter stages of a channel fill sequence (cf. Reesink *et al.*, 2014). Similarly, such bedforms are also associated with a series of distinct depositional episodes (cf. Collinson *et al.,* 2006) of assembled sets divided by first-order set boundaries which indicate repeated bedform migration probably as a train of dunes (dune stacking) which may have formed components of a channel bar top (cf. Bristow, 1993b; Best *et al.*, 2003; Bridge & Lunt, 2006; Mumpy *et al*., 2007; Miall, 2010b; Ashworth *et al.*, 2011).

Overall, Outcrop 30.2 likely represents a compound bar (3D macroform) remnant encompassing the amalgamation of several component unit bars and/or dunes (cf. Allen, 1982; Bridge, 2003; Bridge & Lunt, 2006; Sambrook Smith *et al.*, 2006; Ashworth *et al.*, 2011). Evidence of such amalgamation may be reflected in the alternating palaeocurrents relating to the following facies. The initial coset deposit of Stsx <1.5 m was influenced by a westerly palaeocurrent, whilst the overlying three Stsx <1.5 m cosets were influenced by south-easterly palaeocurrents. The subsequent deposit of facies Sl-hss <1.0 m is represented by a return to a westerly palaeocurrent, prior to the ensuing deposit of facies Sl-hhs <1.0 m marking a return to a south-easterly palaeocurrent. Such palaeocurrent oscillations and related channel bar formation may be correlated to the influence of a channel confluence, which are also associated with anastomosing channels (McCabe, 1977). Although this study does not examine the morphology or hydrodynamics of confluence zones in any detail, there are numerous studies which examine a variety of channel bar and confluence interactions, for example: i. the formation alternate bars, McCabe, 1977 and Collinson, 1996; ii. deposition related to confluence scours, Ashmore & Parker, 1983, Miall, 2010b and references there in; iii. morphology and sedimentology, Petts & Thomas (1987); iv. mid-channel bar confluences, Szupiany *et al.*, 2009; v. flow and sediment dynamics, Leite Ribeiro *et al.*, 2012; and vi. hydromorphodynamics, Guillén-Ludeña *et al.*, 2016. That said, the alternating palaeocurrent may also be attributed to mesoform deposition within a multi-channelled fluvial system (cf. Reesink *et al*., 2014) and their localised effect on thalweg migration (cf. Coleman, 1969; Bristow, 1987; Ashworth *et al.*, 2011). The relatively small-scale mesoforms, and associated shallow channel conditions, towards the upper section of the outcrop evidence dune-scale stratification generally decreasing upwards through a bar sequence, reflecting a decrease in flow depth associated with bar stoss and top regions (cf. Best *et al.*, 2003; Bridge & Lunt, 2006) and related net sediment deposition during waning flow (low-flow stage) (cf. Coleman, 1969; Bristow, 1987, 1993a; Ashworth *et al.,* 2011). Such conditions would have likely facilitated the aggradation of 3D mesoforms and channel fill (cf. Cant & Walker, 1976; Ashworth *et al.*, 2011; Reesink *et al.*, 2014). Similarly, preservation of consecutive cross-laminated sets inevitably encompasses a measure of net deposition (Leeder, 1982), thereby reducing flow depth over the bar top which in turn would increase flow velocity and sediment transport (cf. Reesink & Bridge, 2009); generally foreset gradients decline as a flow regime intensifies, vice versa (cf. Smith, 1972).

Outcrop 30.3: Data relating to Outcrop 30.3 imply that the depositional palaeocurrent was relatively heterogeneous, varying from a northerly trend towards the base, an alternating northerly and westerly trend towards the central section and south-easterly tend towards the top of the sequence (Fig. 4.4 Location 30). A maximum cumulative coset thickness of ~1.00 m (facies Sl-hpx <2.0 m) indicates that the maximum dune or unit bar height and channel depth may have been ~1.50 m and ~3.00 m, respectively (cf. Leclair, 2011). Conversely, variable set thicknesses of between ~0.10 m and ~0.20 m, throughout the sequence, indicates that deposition may have been dominated by varying amounts of sediment transport and input, likely influenced by minor flood events and related variable channel depths of between ~0.65 m and ~2.15 m, respectively (cf. Leclair, 2011). The uppermost 0.10-0.15 m thick sets relating to the coset of facies Sl-hhs <1.0 m imply that sediment input was relatively limited and variable with a maximum dune height and channel depth of ~0.55 m and ~1.60 m, respectively (cf. Reesink & Bridge, 2009; Leclair, 2011).

Individual sub-horizontal cosets and sets of facies of Sl-hpx <2.0 m likely represent downstream migration and accretion of 2D mesoforms, which may in turn form components of a larger host dune cosets (cf. Haszeldine, 1983b), probably towards the channel thalweg/axis, large mesoforms tend to develop towards deeper channel thalweg regions within relatively broad/deep channels, as reflected by the likely mesoform heights and maximum channel depths of between 0.70-1.00 m and 2.20-3.00 m, respectively (cf. Leclair, 2011; cf. Reesink & Bridge, 2009; Ashworth *et al.*, 2011; Reesink *et al.*, 2014). Such cosets may represent migratory mid-channel bar bedform components (cf. Reesink & Bridge, 2009) that likely formed within a multi-channelled fluvial system (cf. Reesink *et al*., 2014) and/or medium-scale migrating unit bar components (cf. Reesink & Bridge, 2009), which in turn likely form components of a much larger host compound bar (cf. Allen, 1982; Bridge, 2003; Bridge & Lunt, 2006; although such component coset/unit bar heights coincide with dune heights (Ashworth *et al.*, 2011). The migration of the initial mesoform may have slowed or stopped and thereby acted as a nucleus for the amalgamation of a mid-channel bar (cf. Best *et al.*, 2003). Evidence of such deposits may be extrapolated from the sub-horizontal second-order mesoform bounding surface contacts which may denote: i. third-order erosional surfaces (cf. Miall, 2010b; Ielpi *et al*., 2014); ii. lateral mesoform accretion and growth of the host compound bar (macroform) through lateral and downstream-accretion (cf. Bridge & Lunt, 2006); and iii. the subcritical set angles imply migration over a much slower moving host bedform (cf. Haszeldine, 1983a, 1983b; Collinson *et al.*, 2006), likely influenced by high-flow stage which facilitated the formation of subcritical-climbing dunes (cf. Bristow, 1988, 1993a; Reesink & Bridge, 2009; Ghinassi, 2011). Similarly, preservation of consecutive cross-laminated sets inevitably encompasses a measure of net deposition and subject to the inclination of their host bed most sets will climb at a similar angle (Leeder, 1982). Unit bars may consist of simple inclined (mainly <10°, but may be up to 35°) small to large-scale sets, which may show a vertical reduction in dune/set height correlated to a decrease in channel depth, the deposits may also display no significant vertical shift in grain size (cf. Bridge & Lunt, 2006). These traits are consistent with the facies sequence associated with the basal and mid-section of Outcrop 30.3 (i.e. repeated sequence of facies Sl-hpx <2.0 m and overlying Stsx <1.5 m), which likely represent two unit bar components of a host compound bar, which may have also initially taken the form of a sand flat that facilitated the deposition of subsequent facies such as Sl-hhs <1.0 m, for example (cf. Cant & Walker, 1976, 1978). A general increase in pebble content from the lower to the upper unit bar implies downstream migration and progradation, with the ensuing unit bar migrating over previous deposits. The variable palaeocurrents related to the above facies may have been influenced by a multi-channelled fluvial system (cf. Reesink *et al*., 2014) and associated localised thalweg migration and alterations in flow direction, likely facilitated by flood events and ensuing net sediment (mesoform) deposition during falling-flow stage (cf. Coleman, 1969; Bristow, 1987; Ashworth *et al.*, 2011). The subsequent cosets relating to facies Sl-hss <1.0 m likely represent migratory mid-channel bedforms that probably formed within a multi-channelled fluvial system (cf. Reesink *et al*., 2014), where the discrete sub-horizontal sets formed coset components of either an individual small-scale unit bar (cf. Sambrook Smith *et al.*, 2006; Reesink & Bridge, 2009) or a distinct larger host dune (cf. Haszeldine, 1983b). Such cosets were probably influenced by high-flow stage which facilitated the formation of down-climbing dunes (cf. Bristow, 1988, 1993a; Ghinassi *et al.,* 2009; Miall, 2010b; Reesink *et al.,* 2014) and net sediment deposition during waning flow (low-flow stage) (cf. Coleman, 1969; Bristow, 1987, 1993a; Ashworth *et al.,* 2011), which likely facilitated the observed palaeocurrent variations. The subsequent deposition of facies Sl-hhs <1.0 m may represent downstream migration and net accretion of 3D mesoforms, see above interpretation relating to facies Sl-hhs <1.0 m (Outcrop 30.2). The relatively small-scale mesoforms, and associated shallow channel conditions, towards the upper section of the outcrop evidence dune-scale stratification generally decreasing upwards through a bar sequence, reflecting a decrease in flow depth associated with bar stoss and top regions (cf. Best *et al.*, 2003; Bridge & Lunt, 2006) and related net sediment deposition during waning flow (low-flow stage) (cf. Coleman, 1969; Bristow, 1987, 1993a; Ashworth *et al.,* 2011). Such conditions would have likely facilitated the aggradation of 3D mesoforms and channel fill (cf. Cant & Walker, 1976; Ashworth *et al.*, 2011; Reesink *et al.*, 2014). The preservation of consecutive cross-laminated sets inevitably encompasses a measure of net deposition (Leeder, 1982), thereby reducing flow depth over the bar top which in turn would increase flow velocity and sediment transport (cf. Reesink & Bridge, 2009). Such conditions would subdue dune formation and generate low relief dunes (cf. Bristow, 1993a), exhibited by the relatively low-angle bedforms (~10°) of facies Sl-hhs <1.0 m; generally foreset gradients decline as a flow regime intensifies, vice versa (cf. Smith, 1972).

The overall interpretation relating to Outcrop 30.3 is similar to that of Outcrop 30.2 above, although the initial dominance of facies Sl-hpx <2.0 m may have also facilitated the formation of a sand flat and is consistent with the subsequent deposition of facies similar to that of Sl-hss <1.0 m and Sl-hhs <1.0 m, for example (cf. Cant & Walker, 1976, 1978).

Outcrop 30.4: Palaeocurrent data relating to Outcrop 30.4 imply that the depositional palaeocurrent was relatively heterogeneous, varying from a westerly to an easterly trend towards the lower section and south-easterly tend towards the upper section (Fig. 4.4 Location 30). A maximum set thickness of ~0.70 m (facies Sl-hpx <2.0 m) indicates that the maximum dune height and channel depth was ~2.50 m and ~7.60 m, respectively (cf. Leclair, 2011) and a cumulative coset thickness of ~0.60 m (facies Sl-hss <1.0 m) indicates that the maximum dune or unit bar height and channel depth may have been ~1.00 m and ~2.00 m, respectively (cf. Leclair, 2011). Conversely, variable set thicknesses of between ~0.05 m and ~0.20 m, throughout the sequence, indicates that deposition may have been dominated by irregular amounts of sediment transport and input, likely influenced by minor flood events and related variable channel depths of between ~0.35 m and ~2.15 m, respectively (cf. Leclair, 2011).

Deposition of facies Sl-hhs <1.0 m may represent downstream migration and net accretion of 3D mesoforms within a relatively shallow thalweg region of a low sinuosity channel (cf. Bristow, 1988, 1993a; Ghinassi *et al.,* 2009; Miall, 2010b; Reesink *et al.,* 2014), influenced by waning flow, net sediment aggradation and channel fill (cf. Cant & Walker, 1976; Ashworth *et al.*, 2011; Reesink *et al.*, 2014). Such facies may also indicate migratory bedforms that likely developed on the surface of a larger sand flat (cf. Cant & Walker, 1976, 1978) and/or they may represent the latter stages of a channel fill sequence (cf. Reesink *et al.*, 2014). Similarly, such bedforms are also associated with a series of distinct depositional episodes (cf. Collinson *et al.,* 2006) of assembled sets divided by first-order set boundaries which indicate repeated bedform migration probably as a train of dunes (dune stacking) which may have formed components of a channel bar top (cf. Bristow, 1993b; Best *et al.*, 2003; Bridge & Lunt, 2006; Mumpy *et al*., 2007; Miall, 2010b; Ashworth *et al.*, 2011). Further, facies Sl-hhs <1.0 m may be attributed to the migration of low-amplitude (near horizontal) sand waves/dunes concomitant with the transitional zone between lower and upper flow regimes and very shallow fluvial systems (cf. Smith, 1971; Todd, 1996); generally foreset gradients decline as a flow regime intensifies, vice versa (cf. Smith, 1972). Similar to facies Sl-hhs <1.0 m, the overlying cosets relating to facies Stsx <1.5 m may represent downstream migration and net accretion of 3D mesoforms within a relatively shallow thalweg region of a low sinuosity channel (cf. Bristow, 1988, 1993a; Ghinassi *et al.,* 2009; Miall, 2010b; Reesink *et al.,* 2014), see above interpretation. Evidence of an initial increase and ensuing decrease in channel depth and sediment input is represent by two distinct series of 0.15-0.20 m and 0.05-0.10 m thick sets correlated with a westerly and easterly palaeocurrent, respectively. Further, the limited number of sets relating to facies Stsx <1.5 m may represent a reduction in repeated bedform migration (i.e. dune stacking), see above interpretation relating to dune stacking and low-amplitude bedforms. The subsequent deposit of facies Sl-hpx <2.0 m implies a substantial increase in channel depth, net sediment input and readjustment to a north-westerly palaeocurrent, likely facilitated by a flood event with sediment migration and aggradation influenced by high and low-flow stages, respectively (Coleman, 1969; Bristow, 1987, 1993a; Ashworth *et al.,* 2011). Although the size of cross-bedding (~0.70 m thick set) and relatively uniform foreset azimuths implies downstream migration of a medium to large-scale dune (2D mesoform), such bedforms are also related to migration of small-scale unit bars (cf. Sambrook Smith *et al.*, 2006; Reesink & Bridge, 2009; Ashworth *et al.*, 2011). For example, Sambrook Smith *et al.* (2006) interpret sets >0.5 m, which possess inclined (i.e. ≤ angle-of-repose) cross-stratification, as a consequence of bar migration. The sub-horizontal contact and orientation relating to the overlying cosets of facies Sl-hss <1.0 m (~140°) and underlying facies Sl-hpx <2.0 m (~330°) imply a substantial reduction in channel depth, which likely resulted in facies Sl-hpx <2.0 m stalling and thereby allowing facies Sl-hss <1.0 m to migrate up the lee side of facies Sl-hpx <2.0 m. Facies Sl-hss <1.0 m likely formed individual migratory bedforms that developed into sub-horizontal set components of a larger host dune coset (cf. Haszeldine, 1983b), influenced by high-flow stage which facilitated the formation of down-climbing dunes (cf. Bristow, 1988, 1993a; Reesink & Bridge, 2009; Ghinassi, 2011). The cosets may represent migratory mid-channel bar bedform components (cf. Reesink & Bridge, 2009) that likely formed within a multi-channelled fluvial system (cf. Reesink *et al*., 2014) and/or small-scale downstream migrating unit bars (cf. Sambrook Smith *et al.*, 2006; Reesink & Bridge, 2009), which in turn likely form components of a much larger host compound bar (cf. Allen, 1982; Bridge, 2003; Bridge & Lunt, 2006; Sambrook Smith *et al.*, 2006; Ashworth *et al.*, 2011), although such component coset/unit bar heights coincide with dune heights (Ashworth *et al.*, 2011). These bedforms may also form a series of distinct depositional episodes (cf. Collinson *et al.,* 2006) i.e. sets divided by first-order set boundaries, see above interpretation relating to 'dune stacking'; such bedforms may also represent sediment migration over a bar front/tail (cf. Allen, 1982; Haszeldine, 1983b; Bristow, 1993b; Miall, 2010b; Ashworth *et al.*, 2011), and possibly contributed to the latter stages of a channel fill sequence (cf. Reesink *et al.*, 2014). Further, a study conducted by Woodward *et al.* (2003), cited by Sambrook Smith *et al.* (2006), suggest that the low-angle bedforms (mainly ≤10°) relating to Sl-hss <1.0 m resemble bounding surface dips exposed in a cut-face interpreted as the lee of a mid-channel bar. Similarly, the ~0.10 m thick sets of the subsequent coset (facies Sl-hpx <2.0 m) likely represent downstream migration and accretion of 2D mesoforms, which probably form components of a larger host dune cosets (cf. Haszeldine, 1983b), see above interpretation relating to facies Sl-hss <1.0 m. The tangential (or asymptotic) foresets associated with facies Sl-hpx <2.0 m were likely promoted by fairly frail separation eddies and a high rate of sediment deposition, from suspension, beyond the slipface of the dune's lee (cf. Leeder, 1982; Bristow, 1993a; Bridge, 2003). The subcritical contact with the underlying facies (Sl-hss <1.0 m) implies migration over a much slower moving host bedform (cf. Haszeldine, 1983a, 1983b; Collinson *et al.*, 2006), likely influenced by high-flow stage which facilitated the formation of subcritical-climbing dunes (cf. Bristow, 1988, 1993a; Reesink & Bridge, 2009; Ghinassi, 2011).

The overall interpretation relating to Outcrop 30.4 suggests that deposition was related to the downstream migration of individual mesoforms that likely formed within a multi-channelled fluvial system (cf. Reesink *et al*., 2014) and/or small-scale downstream migrating unit bars (cf. Sambrook Smith *et al.*, 2006; Reesink & Bridge, 2009). The relatively shallow inclined (mainly ≤10°) first-order bounding surface dips relating to facies Stsx <1.5 m and Sl-hss <1.0 m, for example, imply that the host channel was relatively broad and shallow. Such an interpretation corresponds with McCabe's (1977) observation that distributary channel dips were in the region of ≤10° and Bristow (1987, 1993a) arguing that bounding surfaces, with very low depositional dips, correspond to channels possessing high width to depth ratios. Further, Outcrop 30.4 is dominated by a coarse-grained to granular sandstone which coincides with Coleman's (1969) observation that rivers with significant quantities of coarse sediment are representative of broad, flat, island-obstructed fluvial systems, although the term bar-obstructed is more appropriate (sensu Bridge, 2003).

Outcrop 30.5: Outcrop 30.5 appears to have been subjected to minor cambering towards the south, in comparison to a relatively smaller adjacent parallel outcrop which seems to possess horizontal bedding. The affected bedding and palaeocurrent data was restored through stereographic projection, relative to the 10˚ dip and 167˚ azimuth inferred from the inclination relating to the mid-upper sequence facies of Sl-hhs <1.0 m, in comparison to the same facies associated with the adjacent horizontal outcrop. The restored palaeocurrent data imply that deposition was mainly influenced by southerly palaeocurrents, with limited south-westerly and easterly bedform migration (Fig. 4.4 Location 30). Although the restored palaeocurrent data is marginally more variable than the original field data (Fig. 4.4 Location 30), the restored cross-bedding appears more consistent with that of the adjacent outcrop; hence, the restored data was adopted when interpreting Outcrop 30.5. A maximum set thickness of ~0.50 m (facies Stmx 1.5-3.0 m) indicates that the maximum dune height and channel depth was ~1.80 m and ~5.40 m, respectively (cf. Leclair, 2011) and a cumulative coset thickness of ~0.70 m (facies Sl-hss <1.0 m) indicates a likely dune or bar height and channel depth of ~1.10 m and ~2.20 m, respectively (cf. Reesink & Bridge, 2009; Leclair, 2011). Conversely, variable set thickness of between ~0.05m and ~0.20 m indicates that deposition may have been dominated by varying amounts of sediment transport and input, likely influenced by minor flood events and related fluctuating channel depths of between ~0.35 m and ~2.15 m, respectively (cf. Leclair, 2011).

Deposition of initial facies Stsx <1.5 m likely represent the downstream migration and net accretion of 3D mesoforms within a relatively shallow-medium thalweg region of a low sinuosity channel (cf. Bristow, 1988, 1993a; Ghinassi *et al.,* 2009; Miall, 2010b; Reesink *et al.,* 2014), influenced by waning flow, net sediment aggradation and channel fill (cf. Cant & Walker, 1976; Ashworth *et al.*, 2011; Reesink *et al.*, 2014). Such facies may also indicate migratory bedforms that likely developed on the surface of a larger sand flat (cf. Cant & Walker, 1976, 1978). Alternatively, such bedforms are also associated with a series of distinct depositional episodes (cf. Collinson *et al.,* 2006) of assembled sets divided by first-order set boundaries which indicate repeated bedform migration probably as a train of dunes (dune stacking) which may have formed components of a channel bar top (cf. Bristow, 1993b; Best *et al.*, 2003; Bridge & Lunt, 2006; Mumpy *et al*., 2007; Miall, 2010b; Ashworth *et al.*, 2011). The subsequent coset group of facies Sl-hpx <2.0 m likely represent repeated downstream migration of medium-scale bedforms, comparable to the deposition of the underlying facies of Stsx <1.5 m. Individual sub-horizontal sets of Sl-hpx <2.0 m likely form components of a larger host dune coset (cf. Haszeldine, 1983b), influenced by high-flow stage which facilitated the formation of down-climbing dunes (cf. Bristow, 1988, 1993a; Reesink & Bridge, 2009; Ghinassi, 2011). Such cosets may represent migratory mid-channel bar bedform components (cf. Reesink & Bridge, 2009) that likely formed within a multi-channelled fluvial system (cf. Reesink *et al*., 2014) and/or medium-scale migrating unit bars (cf. Sambrook Smith *et al.*,2006; Reesink & Bridge, 2009), which in turn may form components of a much larger host compound bar (cf. Allen, 1982; Bridge, 2003; Bridge & Lunt, 2006; Sambrook Smith *et al.*, 2006; Ashworth *et al.*, 2011), although such component coset/unit bar heights coincide with dune heights (Ashworth *et al.*, 2011). The horizontal second-order dune coset or unit bar bounding surface contacts are likely third-order erosional surfaces (cf. Miall, 2010b; Ielpi *et al*., 2014); similarly, lateral coset cross-cutting implies possible amalgamation and growth of a host compound bar (macroform) through lateral-accretion (cf. Bridge & Lunt, 2006), as the bedforms migrate downstream, which may have also initially taken the form of a sand flat that facilitated the deposition of subsequent facies such as Sl-hhs <1.0 m (cf. Cant & Walker, 1976, 1978). The relatively small-scale mesoforms and shallow channel conditions associated with the overlying facies of Sl-hhs <1.0 m, may evidence dune-scale stratification decreasing upwards through a bar sequence, reflecting a decrease in flow depth associated with bar stoss and top regions (cf. Best *et al.*, 2003; Bridge & Lunt, 2006) and related net sediment deposition during waning flow (low-flow stage) (cf. Coleman, 1969; Bristow, 1987, 1993a; Ashworth *et al.,* 2011). Such conditions would have likely facilitated the aggradation of 3D mesoforms and channel fill (cf. Cant & Walker, 1976; Ashworth *et al.*, 2011; Reesink *et al.*, 2014). The preservation of consecutive cross-laminated sets inevitably encompasses a measure of net deposition (Leeder, 1982), thereby reducing flow depth over the bar top which in turn would increase flow velocity and sediment transport (cf. Reesink & Bridge, 2009). Such conditions would subdue dune formation and generate low relief dunes (cf. Bristow, 1993a), exhibited by the relatively low-angle bedforms (<10°) of facies Sl-hhs <1.0 m; generally foreset gradients decline as a flow regime intensifies, vice versa (cf. Smith, 1972). The subsequent coset group relating to facies Sl-hss <1.0 m likely represent an increase in channel depth which facilitated the migration of discrete sub-horizontal set components of a larger host dune coset (cf. Haszeldine, 1983b), comparable to above interpretation relating to facies Sl-hpx <2.0 m. A subsequent flood event likely facilitated the deposition of facies Stmx 1.5-3.0 m, with sediment migration and aggradation influenced by high and low-flow stages, respectively (Coleman, 1969; Bristow, 1987, 1993a; Ashworth *et al.,* 2011). Facies Stmx <1.5-3.0 m likely represents downstream migration and accretion of 3D mesoforms towards the channel thalweg/axis of a relatively broad and deep channel where large dunes tend to develop (cf. Reesink & Bridge, 2009; Ashworth *et al.*, 2011; Reesink *et al.*, 2014).

The overall interpretation relating to Outcrop 30.5 is similar to that of Outcrop 30.4 above, although the dominance of the ~2.50 m thick coset group of facies Sl-hpx <2.0 m may have also facilitated the formation of a sand flat and is consistent with the subsequent deposition of facies similar to that of Sl-hhs <1.0 m and Sl-hss <1.0 m, for example (cf. Cant & Walker, 1976, 1978).

Table 4.31

Location, grid reference and associated literature	General description and lithology
31. Cow Close Crag Outcrops 31.1: SE 15293 68942 31.2: SE 15386 68770 31.3: SE 15471 68664 31.4: SE 15646 68617 Thompson, A. T. (1957) *The structure and stratigraphy of Nidderdale between Lofthouse and Dacre*. Unpublished, Doctoral thesis, Durham University. Available at Durham E-Theses Online: http://etheses.dur.ac.uk/722/.	Numerous various sized outcrops scattered along a ridgeline situated to the southwest of Howson Ridge. Outcrops are generally masked (in part) by soil and vegetation (e.g. lichen, moss and/or heather) associated with a moorland setting. Although several outcrops appear to have been disarticulated and/or subjected to cambering, the in-sitú examined outcrops generally follow a ~600.0 m long north-westerly to south-easterly line of intermittent and fragmented crags. The examined outcrops form the second main section of a larger disjointed chain of outcrops extending from the northwest to the southeast for ~4.1 km; mainly following the topographic contours, varying from ~350 m down to ~320 m. Generally, all the examined outcrops are jointed both horizontally and vertically, weathered and possess a variable texture with relatively poor outcrop detail (e.g. foreset/sets), due to the processes of weathering and erosion. Outcrops examined are a representative example of the outcrops in the locality and were surveyed moving from the northwest towards the southeast. Elevation of Outcrops 31.1-31.4 is ~336, 336, 336 and 332 m O.D, respectively; main outcrop views are towards ~080˚, 140˚, 006˚ and 018˚, respectively (Fig. 4.4 Location 31). Outcrop 31.1: Coarse-grained to granular sandstone, predominantly quartz grains; generally high sphericity; sub-angular to rounded; moderately to well sorted; Outcrop 31.2: Coarse-grained to granular sandstone with 2-25% small to medium pebble content (variable), predominantly quartz grains; generally low to high sphericity; sub-angular to rounded; poorly to well sorted; Outcrop 31.3: Coarse-grained to granular sandstone with 2-25% small to medium pebble content (variable), predominantly quartz grains; generally low to high sphericity; sub-angular to rounded; poorly to well sorted; Outcrop 31.4: Coarse to very coarse-grained sandstone, predominantly quartz grains; generally low to high sphericity; sub-angular to rounded; well to very sorted.

Identified sub-Facies, sedimentary structures and bounding surfaces of note

Outcrop 31.1 [~3.5 (H) x 23.0 (D) x 23.0 m (W)]: **1.** ~3.00 m thick coset group of *Sl-hhs <1.0 m (Sh); likely poorly defined low-amplitude small-scale trough cross-bedding <1.5 m trough width; three ~1.00 m thick horizontal cosets; cosets consist of 0.05-0.15 m thick horizontal cross-cutting sets;

Outcrop 31.2 [~4.0 (H) x 10.0 (D) x 42.0 m (W)]: **1.** ~1.20 m thick coset group of Sl-hhs <1.0 m (Sh); likely very poorly defined small-scale trough cross-bedding <1.5 m trough width; two ~0.60 m thick horizontal cosets; cosets consist of ~0.15 m thick horizontal cross-cutting sets; sharp erosive horizontal contact with overlying coset; **2.** ~0.80 m coset of *Stmx 1.5-3.0 m (St); medium-scale cross-cutting trough cross-bedding 1.5–3.0 m trough width; variable set thickness from 0.35–0.50 m; poorly defined, likely horizontal and (in part) sub-horizontal contact with overlying coset; **3.** ~0.60 m thick coset of *Sl-hss <1.0 m (Sl); likely small-scale trough cross- bedding <1.5 m trough width; coset consists of 0.05–0.10 m thick sub-horizontal cross-cutting sets; poorly defined low-amplitude cross-bedding; poorly defined horizontal contact with overlying set; **4.** Spb >15% (Gt/p); likely pebble rich poorly defined horizontal planar cross-bedding; ~0.30 m thick set pinches out part way along section; sharp horizontal contact with overlying coset; **5.** ~1.00 m thick coset group of *Sl-hhs <1.0 m (Sh); likely poorly defined small-scale low-amplitude trough cross-bedding <1.5 m trough width; two (i.e. ~0.35 m and 0.65 m thick) horizontal cosets; cosets consist of ~0.10 m thick horizontal cross-cutting sets; sharp horizontal contact with between cosets;

Outcrop 31.3 [~3.0 (H) x 3.0 (D) x 9.0 m (W)]: **1.** ~0.93 m thick coset group of *Stsx <1.5 m (St); three cosets ~0.40, 0.30 and ~0.23 m thick; cosets consist of ~0.20, 0.15 and 0.10 m thick horizontal sets, respectively; likely low-amplitude small-scale trough cross-bedding <1.5 m trough width; poorly defined foresets and cross-cutting sets; pebbles concentrated towards base of sets (troughs) – normal grading; generally poorly defined (in part) contact between cosets and overlying set; **2.** *Sl-hpx <2.0 m (Sp); low to high-angle-inclined foresets forming medium to large-scale planar cross-bedding; ~0.60 m thick horizontal set; coarser grain component towards base of foresets – normal grading; foresets vary in thickness up to 0.02 m thick; poorly defined horizontal contact with overlying coset; **3.** ~0.65 m thick coset group of *Sl-hss <1.0 m (Sl); likely poorly defined low-amplitude small-scale trough cross-bedding <1.5 m trough width; two ~0.30 and 0.35 m thick horizontal cosets; cosets consist of mainly ~0.05 m thick sub-horizontal cross-cutting sets; poorly defined (in part) likely sharp erosive horizontal undulating contact between cosets and overlying coset; **4.** ~0.70 m thick coset of *Spb >15% (Gt/p); likely pebble rich poorly defined low-amplitude small-scale trough cross-bedding <1.5 m trough width; coset consists of ~0.10 m thick horizontal cross-cutting sets; poorly defined horizontal contact with overlying coset; **5.** ~0.60 m thick coset of *Sl-hhs <1.0 m (Sh); likely poorly defined small-scale trough cross-bedding <1.5 m trough width; cosets consist of ~0.10 m thick horizontal cross-cutting sets;

Outcrop 31.4 [~3.2 (H) x 11.0 (D) x 17.0 m (W)]: **1.** ~3.20 m thick coset group of *Sl-hss <1.0 m (Sl); likely poorly defined low-amplitude small-scale trough cross-bedding <1.5 m trough width; three (~2.00, 1.00 and 1.20 m) thick sub-horizontal cross-cutting cosets; cosets consist of 0.10-0.15, 0.05 and 0.10 m, respectively, thick sub-horizontal cross-cutting sets; poorly defined, erosive (in part) sub-horizontal contact between cosets.

Interpretation

Outcrop 31.1: Although limited, palaeocurrent data relating to Outcrop 31.1 imply that the principal depositional palaeocurrent was towards the south (Fig. 4.4 Location 31). Variable set thicknesses of between ~0.05 m and ~0.15 m, throughout the sequence, indicates that deposition may have been dominated by irregular amounts of sediment transport and input, likely influenced by minor flood events and related fluctuating channel depths of between ~0.35 m and ~1.60 m, respectively (cf. Leclair, 2011) and maximum dune heights of 0.20 m and 0.55 m, respectively (cf. Reesink & Bridge, 2009; Leclair, 2011).

Facies Sl-hhs <1.0 m may represent downstream migration and net accretion of 3D mesoforms within a relatively shallow thalweg region of a low sinuosity channel (cf. Bristow, 1988, 1993a; Ghinassi *et al.,* 2009; Miall, 2010b; Reesink *et al.,* 2014), influenced by waning flow, net sediment aggradation and channel fill (cf. Cant & Walker, 1976; Ashworth *et al.*, 2011; Reesink *et al.*, 2014). Such facies may also indicate migratory bedforms that likely developed on the surface of a larger sand flat (cf. Cant & Walker, 1976, 1978) and/or they may represent the latter stages of a channel fill sequence (cf. Reesink *et al.*, 2014). Similarly, such bedforms are also associated with a series of distinct depositional episodes (cf. Collinson *et al.,* 2006) of assembled sets divided by first-order set boundaries which indicate repeated bedform migration probably as a train of dunes (dune stacking) which may have formed surface components of an underlying bar, for example (cf. Bristow, 1993b; Best *et al.*, 2003; Bridge & Lunt, 2006; Miall, 2010b; Ashworth *et al.*, 2011). The low-amplitude dunes imply that flow conditions were sufficiently shallow (≤1.60 m deep; cf. Reesink & Bridge, 2009; Leclair, 2011) to subdue dune formation and generate low relief dunes (cf. Bristow, 1993a); preservation of low-angle dune morphology is facilitated by dune stoss and crest erosion, during high flow-stage, and deposition of eroded sediment in the dune's trough (Hendershot *et al.*, 2016). Further, the preservation of consecutive cross-laminated sets inevitably encompasses a measure of net deposition and most sets will climb at a similar angle/dip to that of their host bed (Leeder, 1982). Comparable facies and palaeocurrents can be observed at an outcrop ~130.0 m towards the southeast (grid reference: SE 153388 68828, not featured) of Outcrop 31.1, which suggests a possible downstream and lateral relationship between both outcrops and a minimum of ~130.0 m downstream, and ~45.0 m lateral, extent of the bedform. Further, modern day compound bars may extend several 100's of meters, both downstream and laterally (cf. Bristow, 1993a; Best *et al*., 2003; Bridge & Lunt, 2006) and Cant & Walker (1978) note that sand flats may extend downstream and laterally from 50–2000 m and 30-450 m, respectively, and up to 80% of a channel-belt's width (Sambrook Smith *et al.,* 2006).

Outcrop 31.2: Although limited, set and foreset palaeocurrent data relating to Outcrop 31.2 imply that the principal depositional palaeocurrent was towards the southeast, with minor bedform migration towards the southwest (Fig. 4.4 Location 31). A maximum set thickness of ~0.50 m (facies Stmx 1.5-3.0 m) indicates that the maximum dune height and channel depth was ~1.80 m and ~5.40 m, respectively (cf. Leclair, 2011) and a cumulative coset thickness of ~0.60 m (facies Sl-hss <1.0 m) indicates that the maximum dune or unit bar height and channel depth may have been ~0.85 m and ~1.70 m, respectively (cf. Leclair, 2011). Conversely, variable set thicknesses of between ~0.05 m and ~0.15 m, throughout the sequence, indicates that deposition may have been dominated by irregular amounts of sediment transport and input, likely influenced by minor flood events and related variable channel depths of between ~0.35 m and ~1.60 m, respectively (cf. Leclair, 2011).

Basal facies relating to Sl-hhs <1.0 m may represent downstream migration and net accretion of 3D mesoforms within a relatively shallow thalweg region of a low sinuosity channel (cf. Bristow, 1988, 1993a; Ghinassi *et al.,* 2009; Miall, 2010b; Reesink *et al.,* 2014), influenced by waning flow, net sediment aggradation and channel fill (cf. Cant & Walker, 1976; Ashworth *et al.*, 2011; Reesink *et al.*, 2014), see above for further interpretations relating to facies Sl-hhs <1.0 m. A subsequent flood event likely facilitated the deposition of facies Stmx 1.5-3.0 m, with sediment migration and aggradation influenced by high and low-flow stages, respectively (Coleman, 1969; Bristow, 1987, 1993a; Ashworth *et al.,* 2011). Such facies likely represent downstream migration and accretion of 3D mesoforms towards the channel thalweg/axis of a relatively broad and deep channel where large dunes tend to develop (cf. Reesink & Bridge, 2009; Ashworth *et al.*, 2011; Reesink *et al.*, 2014). The overlying facies of Sl-hss <1.0 m suggest migratory bedforms that likely developed within a relatively shallow channel (cf. Ashworth *et al.*, 2011), possibly on the surface of a larger sand flat (cf. Cant & Walker, 1976, 1978). Alternatively, individual sub-horizontal sets of Sl-hss <1.0 m may form components of a larger host dune coset (cf. Haszeldine, 1983b), influenced by high-flow stage which facilitated the formation of down-climbing dunes (cf. Bristow, 1988, 1993a; Reesink & Bridge, 2009; Ghinassi, 2011). Such cosets may represent migratory mid-channel bar bedform components (cf. Reesink & Bridge, 2009) that likely formed within a multi-channelled fluvial system (cf. Reesink *et al*., 2014) and/or small-scale downstream migrating unit bars (cf. Sambrook Smith *et al.*, 2006; Reesink & Bridge, 2009), which in turn likely form components of a much larger host compound bar (cf. Allen, 1982; Bridge, 2003; Bridge & Lunt, 2006; Sambrook Smith *et al.*, 2006; Ashworth *et al.*, 2011), although such component coset/unit bar heights coincide with dune heights (Ashworth *et al.*, 2011). Similar bedforms may also form a series of distinct depositional episodes (cf. Collinson *et al.,* 2006) i.e. sets divided by first-order set boundaries, indicating repeated bedform migration probably as a train of dunes (dune stacking) that may have formed components of a larger bar top (cf. Bristow, 1993b; Best *et al.*, 2003; Bridge & Lunt, 2006; Mumpy *et al*., 2007; Miall, 2010b; Ashworth *et al.*, 2011) and the latter stages of a channel fill sequence (cf. Reesink *et al.*, 2014). The 0.05-0.10 m thick sets relating to facies Sl-hss <1.0 m imply flow conditions were sufficiently shallow to subdue dune formation and generate very low relief dunes (cf. Bristow, 1993a), see above interpretation relating to low-amplitude dunes (facies Sl-hhs <1.0 m). Although chute channels are generated as a result of falling-stage flow (drawdown) and bar top incision, due to overflow from the main channel as the flow rate subsided (cf. Bristow, 1987, 1993; Ashworth *et al.*, 2011), they could subsequently act as conduits to facilitate the subsequent deposition of facies Spb >15% in the form of basal flood/scour deposit during high-flow stage (cf. Coleman, 1969; Bristow, 1987, 1993a; Ashworth *et al.*, 2011). Such pebble deposits may also denote the location of a channels thalweg/axial region (cf. Fidolini *et al.*, 2013; Ghinassi *et al.*, 2014) where relatively larger bedforms develop (Reesink & Bridge, 2009; Ashworth *et al.*, 2011; Reesink *et al.*, 2014). The ensuing facies relating to Sl-hhs <1.0 m likely represent a return to downstream migration and net accretion of 3D mesoforms within a relatively shallow thalweg region of a low sinuosity channel (cf. Bristow, 1988, 1993a; Ghinassi *et al.,* 2009; Miall, 2010b; Reesink *et al.,* 2014), influenced by waning flow, net sediment aggradation and channel fill (cf. Cant & Walker, 1976; Ashworth *et al.*, 2011; Reesink *et al.*, 2014), see above for further interpretations relating to facies Sl-hhs <1.0 m.

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Although Skelly *et al.* (2003) and Ashworth *et al.* (2011) (and references there in) argue that the distinction between compound bar and adjacent channel fill core deposits, in sandy braided fluvial systems, is problematic, Outcrop 31.2 likely represents downstream migration and channel fill sequence with deposition of small to medium-scale dune components facilitated by flood events, evidenced by variable channel depths and scour deposit which may delineate the channels thalweg/axis. Further, the mainly shallow inclined first-order bounding surface dips (facies Sl-hss <1.0 m) may correspond to channels possessing a relatively high width to depth ratios (Bristow, 1993a).

Outcrop 31.3: Data relating to Outcrop 31.3 imply that the depositional palaeocurrent gradually switched from a mainly westerly direction (basal facies) to a southerly direction (upper facies) (Fig. 4.4 Location 31). A maximum set thickness of ~0.60 m (facies Sl-hpx <2.0 m) indicates that the maximum dune height and channel depth was ~2.15 m and ~6.50 m, respectively (cf. Leclair, 2011) and a cumulative coset thickness of ~0.35 m (facies Sl-hss <1.0 m) imply a potential maximum dune height and channel depth of ~0.60 m and ~1.20 m, respectively (cf. Leclair, 2011). Conversely, individual set thickness of ~0.10 m, relating to the uppermost facies (i.e. Spb >15% and Sl-hhs <1.0 m) indicate that deposition was likely dominated by regular sediment transport and input, probably influenced by minor flood events and related maximum channel depth of ~1.10 m (cf. Leclair, 2011).

Decreasing set thicknesses from ~0.20 m to ~0.10 m relating to the base and top, respectively, of facies Stsx <1.5 m suggest that deposition had been influenced by a channel with diminishing flow depth (i.e. ~2.15 to ~1.10 m), likely facilitated by weakening flood events (high-flow stage) and associated net sediment deposition during waning flow (low-flow stage) (cf. Coleman, 1969; Bristow, 1987, 1993a; Ashworth *et al.,* 2011). Low-flow stage would have facilitated the aggradation of 3D mesoforms and channel fill (cf. Cant & Walker, 1976; Ashworth *et al.*, 2011; Reesink *et al.*, 2014). Such bedforms may be associated with a series of distinct depositional episodes (cf. Collinson *et al.,* 2006) of assembled sets divided by first-order set boundaries that indicate repeated bedform migration, probably as a train of dunes (dune stacking) which may have formed components of a channel bar top (cf. Bristow, 1993b; Best *et al.*, 2003; Bridge & Lunt, 2006; Mumpy *et al*., 2007; Miall, 2010b; Ashworth *et al.*, 2011) or larger sand flat (cf. Cant & Walker, 1976, 1978). The general coarsening up sequence relating to the basal coset also implies prograding downstream migration of 3D mesoforms. Facies Sl-hpx <2.0 m are predominantly constructed from repeated grain flow avalanche deposits (~0.02 m thick foresets; see Smith, 1972; Reesink & Bridge, 2007, 2009). The size of cross-bedding implies downstream-accretion of 2D mesoforms within a relatively broad and deep channel near to the channel thalweg/axis where large dunes tend to develop (cf. Reesink & Bridge, 2009; Ashworth et al., 2011; Reesink et al., 2014). Such facies are also associated with downstream migration of longitudinal bars (Ghinassi *et al.,* 2009), or unit bars, although such bar heights coincide with dune heights (Ashworth *et al.*, 2011). Further, the relatively uniform foreset azimuth-inclinations may relate to bedforms that likely represent downstream migration and net aggradation of longitudinal or diagonal bars, rather than a transverse bars, which possess variable foreset azimuth-inclinations and more angular foreset contacts than those observed (cf. Smith, 1972; Hein & Walker, 1977; Collinson *et al.,* 2006). The overlying facies of Sl-hss <1.0 m suggest migratory bedforms that likely developed within a relatively shallow channel (cf. Ashworth *et al.*, 2011), possibly on the surface of a larger sand flat (cf. Cant & Walker, 1976, 1978). Alternatively, individual sub-horizontal sets of Sl-hss <1.0 m may form components of a larger host dune coset (cf. Haszeldine, 1983b), influenced by high-flow stage which facilitated the formation of down-climbing dunes (cf. Bristow, 1988, 1993a; Reesink & Bridge, 2009; Ghinassi, 2011) and adjustment in palaeocurrent from a westerly to south-westerly flow, see above (Outcrop 31.2 and 31.2) for further interpretations relating to facies Sl-hss <1.0 m and associated low-amplitude mesoforms. The ensuing facies (Spb >15%) likely represent repeated basal flood/scour deposits during high-flow stage (cf. Coleman, 1969; Bristow, 1987, 1993a; Ashworth *et al.*, 2011) and adjustment in palaeocurrent towards the south-east. Such pebble deposits may also denote the location of a channels thalweg/axial region (cf. Fidolini *et al.*, 2013; Ghinassi *et al.*, 2014) where relatively larger bedforms develop (Reesink & Bridge, 2009; Ashworth *et al.*, 2011; Reesink *et al.*, 2014), as evidenced by the previous deposition of facies Sl-hpx <2.0 m. The ensuing facies (Sl-hhs <1.0 m) likely represent continued downstream migration and net accretion of 3D mesoforms within a relatively shallow thalweg region of a low sinuosity channel (cf. Bristow, 1988, 1993a; Ghinassi *et al.,* 2009; Miall, 2010b; Reesink *et al.,* 2014), influenced by waning flow, net sediment aggradation, channel fill (cf. Cant & Walker, 1976; Ashworth *et al.*, 2011; Reesink *et al.*, 2014) and a further adjustment in palaeocurrent towards the south, see above (Outcrop 31.1) for further interpretations relating to facies Sl-hhs <1.0 m.

The overall interpretation relating to Outcrop 31.3 suggests that deposition was likely associated with the downstream migration of individual mesoforms that likely formed within a multi-channelled fluvial system (cf. Reesink *et al*., 2014) and/or downstream migration of unit bars (cf. Sambrook Smith *et al.*, 2006; Reesink & Bridge, 2009). The relatively horizontal set and coset contacts imply that the host channel was relatively broad. Such an interpretation corresponds with McCabe's (1977) observation that distributary channel dips were in the region of ≤10° and Bristow (1987, 1993a) arguing that bounding surfaces, with very low depositional dips, correspond to channels possessing high width to depth ratios. Further, Outcrop 31.3 is dominated by a coarse-grained to granular sandstone which coincides with Coleman's (1969) observation that rivers with significant quantities of coarse sediment are representative of broad, flat, island-obstructed fluvial systems, although the term bar-obstructed is more appropriate (sensu Bridge, 2003). Such fluvial systems may influence thalweg migration and alterations in flow direction, probably facilitated by a flood event and sediment deposition (e.g. facies Sl-hpx <2.0 m) during falling-flow stage, as indicated by the westerly to southerly adjustment in palaeocurrent (cf. Coleman, 1969; Bristow, 1987; Ashworth *et al.*, 2011).

Outcrop 31.4: Palaeocurrent data relating to Outcrop 31.4 imply that the principal depositional palaeocurrent was towards the south-southwest (Fig. 4.4 Location 31). A cumulative coset thickness of ~2.00 m (facies Sl-hss <1.0 m) imply a potential maximum bar height and channel depth of ~2.40 m and ~4.80 m, respectively (cf. Leclair, 2011). Conversely, individual set thicknesses of between ~0.05 m and ~0.15 m indicate that deposition may have been influenced by minor flood events and related variable channel depths of between ~0.35 m and ~1.60 m, respectively (cf. Leclair, 2011) and maximum dune heights of 0.20 m and 0.55 m, respectively (cf. Reesink & Bridge, 2009; Leclair, 2011).

The coset group of facies Sl-hss <1.0 m likely formed individual migratory bedforms that developed into sub-horizontal set components of larger host dune cosets (cf. Haszeldine, 1983b), influenced by high-flow stage which facilitated the formation of down-climbing dunes (cf. Bristow, 1988, 1993a; Reesink & Bridge, 2009; Ghinassi, 2011). The cosets may represent migratory mid-channel bar bedform components (cf. Reesink & Bridge, 2009) that likely formed within a multi-channelled fluvial system (cf. Reesink *et al*., 2014) and/or small to large-scale downstream migrating unit bars (cf. Sambrook Smith *et al.*, 2006; Reesink & Bridge, 2009), which in turn likely form components of a much larger host compound bar (cf. Allen, 1982; Bridge, 2003; Bridge & Lunt, 2006; Sambrook Smith *et al.*, 2006; Ashworth *et al.*, 2011). These bedforms may form a series of distinct depositional episodes (cf. Collinson *et al.,* 2006) i.e. sets divided by first-order set boundaries, indicating repeated bedform migration probably as a train of dunes (dune stacking) that may have formed components of a larger bar top (cf. Bristow, 1993b; Best *et al.*, 2003; Bridge & Lunt, 2006; Mumpy *et al*., 2007; Miall, 2010b; Ashworth *et al.*, 2011), and/or likely migrated over the bar front/tail (cf. Allen, 1982; Haszeldine, 1983b; Bristow, 1993b; Miall, 2010b; Ashworth *et al.*, 2011), and possibly contributed to the latter stages of a channel fill sequence (cf. Reesink *et al.*, 2014). Further, such facies may also indicate migratory bedforms that likely developed on the surface of a larger sand flat (cf. Cant & Walker, 1976, 1978) and/or they may represent the latter stages of a channel fill sequence (cf. Reesink *et al.*, 2014).Further, a study conducted by Woodward *et al.* (2003), cited by Sambrook Smith *et al.* (2006), suggest that the low-angle bedforms (mainly ≤10°) relating to Sl-hss <1.0 m resemble bounding surface dips exposed in a cut-face interpreted as the lee of a mid-channel bar. The low-amplitude dunes imply that flow conditions were sufficiently shallow (≤1.60 m deep; cf. Reesink & Bridge, 2009; Leclair, 2011) to subdue dune formation and generate low relief dunes (cf. Bristow, 1993a); preservation of low-angle dune morphology is facilitated by dune stoss and crest erosion, during high flow-stage, and deposition of eroded sediment in the dune's trough (Hendershot *et al.*, 2016). The preservation of consecutive cross-laminated sets inevitably encompasses a measure of net deposition and most sets will climb at a similar angle/dip to that of their host bed (cf. Leeder, 1982).

The overall interpretation relating to Outcrop 31.4 suggests that deposition was likely associated with the downstream migration of individual mesoforms that likely formed within a multi-channelled fluvial system (cf. Reesink *et al*., 2014) and/or downstream migration of unit bars (cf. Sambrook Smith *et al.*, 2006; Reesink & Bridge, 2009). The relatively low angle mesoforms (mainly ≤10° first-order set bounding surfaces) and sub-horizontal coset contacts imply that the host channel was relatively broad. Such an interpretation corresponds with McCabe's (1977) observation that distributary channel dips were in the region of ≤10° and Bristow (1987, 1993a) arguing that bounding surfaces, with very low depositional dips, correspond to channels possessing high width to depth ratios. Further, Outcrop 31.4 is dominated by a coarse to very coarse-grained sandstone which coincides with Coleman's (1969) observation that rivers with significant quantities of coarse sediment are representative of broad, flat, island-obstructed fluvial systems, although the term bar-obstructed is more appropriate (sensu Bridge, 2003).

Table 4.32

Location, grid reference and associated literature	General description and lithology
32. Yeadon Crag Outcrops 32.1: SE 15765 68338 32.2: SE 15809 68240 32.3: SE 15880 68107 Thompson, A. T. (1957) *The structure and stratigraphy of Nidderdale between Lofthouse and Dacre*. Unpublished, Doctoral thesis, Durham University. Available at Durham E-Theses Online: http://etheses.dur.ac.uk/722/. This study.	Numerous various sized outcrops scattered along a ridgeline situated to the southeast of Cow Close Crag. Outcrops are generally masked (in part) by soil and vegetation (e.g. lichen, moss and/or heather) associated with a moorland setting. Although several outcrops appear to have been disarticulated and/or subjected to cambering, the in-sitú examined outcrops generally follow a ~400.0 m long north-northwest to south-southeast line of intermittent and fragmented crags. The examined outcrops form the third main section of a larger disjointed chain of outcrops extending from the northwest to the southeast for ~4.1 km; mainly following the topographic contours, varying from ~350 m down to ~320 m. Generally, all the examined outcrops are jointed both horizontally and vertically, weathered and possess a variable texture with relatively poor outcrop detail (e.g. foreset/sets), due to the processes of weathering and erosion. Outcrops examined are a representative example of the outcrops in the locality and were surveyed moving from the northwest towards the southeast. Elevation of Outcrops 32.1-32.3 is ~330, 334 and 340 m O.D, respectively; main outcrop views are towards ~096˚, 140˚, 006˚ and 018˚, respectively (Fig. 4.4 Location 32). Outcrop 32.1: Medium-grained to granular sandstone with 0-15% small to large pebble content (variable), predominantly quartz grains; generally low to high sphericity; sub-angular to rounded; poorly to very well sorted; Outcrop 32.2: Coarse-grained to granular sandstone with 0-5% small to medium pebble content (variable), predominantly quartz grains; generally low to high sphericity; sub-angular to rounded; poorly to well sorted; Outcrop 32.3: Coarse-grained to granular sandstone with 0-10% small to large pebble content (variable), predominantly quartz grains; generally low to high sphericity; sub-angular to rounded; poorly to well sorted.

Identified sub-Facies, sedimentary structures and bounding surfaces of note

Outcrop 32.1 [~5.5 (H) x 5.0 (D) x 10.0 m (W)]: **1.** ~0.70 m thick coset of Sl-hhs <1.0 m (Sh); likely very poorly defined low-amplitude small-scale trough cross-bedding <1.5 m trough width; coset consists of ~0.10 m thick horizontal sets; slightly undulating (in part), sharp and slightly sub-horizontal contact with overlying set; **2.** *Sl-hpx <2.0 m (Sp); low to high-angle-inclined foresets forming medium to large-scale planar cross-bedding; poorly defined foresets; ~0.70 m thick set with evidence of reactivation surfaces; sharp and sub-horizontal erosive contact with overlying coset; **3.** ~0.60 m thick coset of *Sl-hss <1.0 m (Sl); likely very poorly defined low-amplitude small-scale trough cross-bedding <1.5 m trough width; coset consists of ~0.10 m thick sub-horizontal (down-climbing) cross-cutting sets; poorly defined horizontal and undulating contact with overlying set; **4. ***Stsx <1.5 m (St); small to medium-scale low-amplitude trough cross-bedding <1.5 m trough width; ~0.20 m thick set; poorly defined set/foresets; set pinches out towards the left/northern section of outcrop; erosive sub-horizontal contact with overlying coset; **5.** ~0.40 m thick coset of *Sl-hss <1.0 m (Sl); likely very poorly defined low-amplitude small-scale trough cross-bedding <1.5 m trough width; coset consists of 0.05-0.10 m thick sub-horizontal (down-climbing) cross-cutting sets; sharp horizontal contact with overlying set (**6.** Stsx <1.5 m) and coset (**7.** Sl-hss <1.0 m); **6. ***Stsx <1.5 m (St); small to medium-scale low-amplitude trough cross-bedding <1.5 m trough width; ~0.30 m thick trough set; poorly defined set/foresets; set pinches out towards the right/central section of outcrop; sharp (in part) sub-horizontal and erosive poorly defined truncated contact with overlying coset; **7.** ~0.40 m thick coset of *Sl-hss <1.0 m (Sl); likely very poorly defined low-amplitude small-scale trough cross-bedding <1.5 m trough width; coset consists of 0.05-0.10 m thick sub-horizontal (down-climbing) cross-cutting sets; sub-horizontal poorly defined contact with overlying coset; **8.** ~0.90 m thick coset of *Sl-hss-of <1.0 m (Sl); likely low-amplitude small-scale oblique trough cross-bedding <1.5 m trough width; coset consists of ~0.10 m thick sub-horizontal (down-climbing) cross-cutting sets; poorly defined sub-horizontal contact with overlying set; **9.** *Sl-hpx <2.0 m (Sp); low-angle-inclined foresets forming small-scale planar cross-bedding; ~0.20 m thick set with poorly defined foresets; poorly defined sub-horizontal contact with overlying coset; **10.** ~1.00 m thick coset of *Sl-hss-of <1.0 m (Sl); likely low-amplitude small-scale oblique trough cross-bedding <1.5 m trough width; coset consists of 0.10-0.15 m thick sub-horizontal (down-climbing) cross-cutting sets;

Outcrop 32.2 [~3.0 (H) x 2.0 (D) x 12.0 m (W)]: **1.** ~0.60 m thick coset of *Sl-hss <1.0 m (Sl); poorly defined small-scale trough cross-bedding <1.5 m trough width; coset consists of ~0.10 m thick sub-horizontal (down-climbing) cross-cutting sets; intermittent small pebble lag deposit and poorly defined horizontal contact with overlying coset; **2.** ~1.00 m thick coset group of *Sl-hss <1.0 m (Sl); poorly defined small-scale trough cross-bedding <1.5 m trough width; three cross-cutting cosets varying in thickness from 0.30-0.40 m; cosets consist of 0.10–0.15 m thick sub-horizontal (down-climbing) cross-cutting sets; poorly defined sub-horizontal erosive contact between cosets and sharp horizontal contact with overlying coset; **3.** ~0.90 m thick coset of *Sl-hpx <2.0 m (Sp); likely small-scale planar cross-bedding exhibiting tangential foresets; coset consist of 0.10–0.15 m thick sub-horizontal (down-climbing) sets; poorly defined cross-bedding exhibiting signs of soft sediment deformation (Ssd), centre-left section; evidence of lateral and downstream coset amalgamation; poorly defined horizontal contact with overlying coset; **4.** ~0.50 m thick coset of ***Stsx <1.5 m (St); small to medium-scale trough cross-bedding <1.5 m trough width; ~0.20 m thick cross-cutting sets; poorly defined sets/foresets; incomplete outcrop section;

Outcrop 32.3 [~6.0 (H) x 3.0 (D) x 12.0 m (W)]: **1.** ~0.90 m thick coset of *Sl-hhs <1.0 m (Sh); poorly defined small-scale trough cross-bedding <1.5 m trough width; coset consists of 0.10-0.15 m thick horizontal sets; sub-horizontal, erosive and poorly defined contact with overlying set; **2.** *Sl-hpx <2.0 m (Sp); low to high-angle-inclined foresets forming poorly defined medium-scale planar cross-bedding; ~0.50 m thick set with evidence of possible reactivation surface; sub-horizontal, erosive and poorly defined contact with overlying coset; **3.** ~1.50 m thick coset of *Stmx 1.5-3.0 m (St); medium-scale trough cross-bedding 1.5–3.0 m trough width; coset consist of poorly defined 0.30–0.35 m thick cross-cutting sets; intermittent minor granule to medium pebble lag towards base of troughs/sets – normal grading; sub-horizontal, erosive and poorly defined contact with overlying coset; **4.** ~2.00 m thick coset of *Sl-hpx <2.0 m (Sp); low to high-angle-inclined foresets forming medium-scale planar cross-bedding; coset consist of 0.40–0.50 m thick horizontal cross-cutting sets; poorly defined cross-bedding exhibiting signs of soft sediment deformation (Ssd), upper centre-right section; coarser grain component delineates foreset boundaries (~0.02 m thick foresets) – normal grading; sharp horizontal contact with overlying coset; **5.** ~0.20 m thick coset of *Sl-hhs <1.0 m (Sh); poorly defined low-amplitude small-scale trough cross-bedding <1.5 m trough width; coset consists of ~0.10 m thick horizontal sets; sharp horizontal contact with overlying set; **6.** *Sl-hpx <2.0 m (Sp); low to high-angle-inclined foresets forming medium to large-scale planar cross-bedding; ~0.80 m thick set with poorly defined cross-bedding exhibiting tangential foresets; coarser grain component delineates foreset boundaries (~0.02 m thick foresets) – normal grading.

Interpretation

Outcrop 32.1: Data relating to Outcrop 32.1 imply that the depositional palaeocurrent was relatively heterogeneous, varying from an easterly to northerly trend towards the base, an alternating westerly and southerly trend towards the central section and south to south-easterly trend towards the top of the sequence (Fig. 4.4 Location 32). A maximum cumulative coset thickness of ~1.00 m (facies Sl-hss-of <1.0 m) indicates that the maximum dune or unit bar height and channel depth may have been ~1.40 m and ~2.80 m, respectively (cf. Leclair, 2011). Conversely, variable set thicknesses of between ~0.05 m and ~0.30 m, throughout the sequence, indicates that deposition may have been dominated by varying amounts of sediment transport and input, likely influenced by flood events and related variable channel depths of between ~0.35 m and ~3.25 m, respectively (cf. Leclair, 2011). A maximum set thickness of ~0.70 m (facies Sl-hpx <2.0 m) indicates that the maximum dune height and channel depth was ~2.50 m and ~7.55 m, respectively (cf. Leclair, 2011).

Facies Sl-hhs <1.0 m may represent downstream migration and net accretion of 3D mesoforms within a relatively shallow thalweg region of a low sinuosity channel (cf. Bristow, 1988, 1993a; Ghinassi *et al.,* 2009; Miall, 2010b; Reesink *et al.,* 2014), influenced by waning flow, net sediment aggradation and channel fill (cf. Cant & Walker, 1976; Ashworth *et al.*, 2011; Reesink *et al.*, 2014). Such facies may also indicate migratory bedforms that likely developed on the surface of a larger sand flat (cf. Cant & Walker, 1976, 1978) and/or they may represent the latter stages of a channel fill sequence (cf. Reesink *et al.*, 2014). Similarly, such bedforms are also associated with a series of distinct depositional episodes (cf. Collinson *et al.,* 2006) of assembled sets divided by first-order set boundaries which indicate repeated bedform migration probably as a train of dunes (dune stacking) which may have formed surface components of an underlying bar, for example (cf. Bristow, 1993b; Best *et al.*, 2003; Bridge & Lunt, 2006; Miall, 2010b; Ashworth *et al.*, 2011). The low-amplitude dunes imply that flow conditions were sufficiently shallow (≤1.60 m deep; cf. Reesink & Bridge, 2009; Leclair, 2011) to subdue dune formation and generate low relief dunes (cf. Bristow, 1993a); preservation of low-angle dune morphology is facilitated by dune stoss and crest erosion, during high flow-stage, and deposition of eroded sediment in the dune's trough (Hendershot *et al.*, 2016). Further, the preservation of consecutive cross-laminated sets inevitably encompasses a measure of net deposition (Leeder, 1982). A subsequent flood event likely facilitated the deposition of facies Sl-hpx <2.0 m, with sediment migration and aggradation influenced by high and low-flow stages, respectively (Coleman, 1969; Bristow, 1987, 1993a; Ashworth *et al.,* 2011). Such facies likely represent downstream migration and accretion of 2D mesoforms towards the channel thalweg/axis of a relatively broad and deep channel where large dunes tend to develop (cf. Reesink & Bridge, 2009; Ashworth *et al.*, 2011; Reesink *et al.*, 2014). The overlying facies of Sl-hss <1.0 m suggest migratory bedforms that likely developed within a relatively shallow channel (cf. Ashworth *et al.*, 2011), possibly on the surface of a larger sand flat (cf. Cant & Walker, 1976, 1978). Alternatively, individual sub-horizontal sets of Sl-hss <1.0 m may form components of a larger host dune coset (cf. Haszeldine, 1983b), influenced by high-flow stage which facilitated the formation of down-climbing dunes (cf. Bristow, 1988, 1993a; Reesink & Bridge, 2009; Ghinassi, 2011). Such cosets may represent migratory mid-channel bar bedform components (cf. Reesink & Bridge, 2009) that likely formed within a multi-channelled fluvial system (cf. Reesink *et al*., 2014) and/or small-scale downstream migrating unit bars (cf. Sambrook Smith *et al.*, 2006; Reesink & Bridge, 2009), which in turn likely form components of a much larger host compound bar (cf. Allen, 1982; Bridge, 2003; Bridge & Lunt, 2006; Sambrook Smith *et al.*, 2006; Ashworth *et al.*, 2011), although such component coset/unit bar heights coincide with dune heights (Ashworth *et al.*, 2011). Similar bedforms may also form a series of distinct depositional episodes (cf. Collinson *et al.,* 2006) i.e. sets divided by first-order set boundaries, indicating repeated bedform migration probably as a train of dunes (dune stacking) that may have formed components of a larger bar top (cf. Bristow, 1993b; Best *et al.*, 2003; Bridge & Lunt, 2006; Mumpy *et al*., 2007; Miall, 2010b; Ashworth *et al.*, 2011) and the latter stages of a channel fill sequence (cf. Reesink *et al.*, 2014). The above facies display an initial easterly and subsequent adjustment to a northerly palaeocurrent trend, conversely, the overlying facies (Stsx <1.5 m and Sl-hss <1.0 m) display alternating palaeocurrent trends from an initial westerly to subsequent southerly trend, before adjusting to a south-westerly flow. The component facies are probably related to the downstream migration of: i. individual dunes (facies Stsx <1.5 m); and ii. individual sub-horizontal sets (facies Sl-hss <1.0 m) which generated a cumulative host dune coset (cf. Haszeldine, 1983b) of 3D mesoforms, within a relatively shallow-medium thalweg region of a low sinuosity channel (cf. Bristow, 1988, 1993a; Ghinassi *et al.,* 2009; Miall, 2010b; Reesink *et al.,* 2014). Such facies were likely facilitated by variable flood events with sediment migration and aggradation influenced by high and low-flow stages, respectively (Coleman, 1969; Bristow, 1987, 1993a; Ashworth *et al.,* 2011) and may also indicate migratory bedforms that likely developed on the surface of a larger sand flat (cf. Cant & Walker, 1976, 1978), with high-flow stage facilitating the formation of down-climbing dunes (cf. Bristow, 1988, 1993a; Reesink & Bridge, 2009; Ghinassi, 2011). The subsequent deposition of facies Sl-hss-of <1.0 m denote a return to a southerly and south-easterly palaeocurrent and increase in net sediment input and channel depth, probably resulting from flood events (high-flow stage) with net deposition and lateral-accretion of individual sub-horizontal sets, which likely generated a cumulative host dune cosets (cf. Haszeldine, 1983b), during waning flow (low-flow stage) (cf. Coleman, 1969; Bristow, 1987, 1993a; Ashworth *et al.,* 2011). Such facies may be generated due to topographic lows adjacent to bar margins limiting falling-stage currents that flow between bars (Collinson, 1970; cf. Reesink *et al*., 2014) and thereby facilitate lateral-accretion by promoting deposition along bar margins (Collinson, 1970, 1996). Similarly, deposition may have been influenced by lateral-accretion and/or dune-scale bedform migration obliquely over, around and down a curved barform front/tail (cf. Haszeldine, 1983b). The intervening facies of Sl-hpx <2.0 m likely represents the downstream migration of an individual dune, as a result of an increase in sediment input and flow strength likely facilitated by a flood event with sediment migration and aggradation influenced by high and low-flow stages, respectively (Coleman, 1969; Bristow, 1987, 1993a; Ashworth *et al.,* 2011).

The overall interpretation relating to Outcrop 32.1 suggests that deposition was probably to some degree associated with the downstream, and lateral, migration of: i. individual mesoforms which likely developed within a multi-channelled fluvial system (cf. Reesink *et al*., 2014); ii. unit bars (cf. Sambrook Smith *et al.*, 2006; Reesink & Bridge, 2009); and/or iii. individual sets forming dune cosets (cf. Haszeldine, 1983b), or bar cosets. Deposition of such bedforms likely produced a localised effect on thalweg migration (cf. Coleman, 1969; Bristow, 1987; Ashworth *et al.*, 2011). The observed palaeocurrent variability may also be correlated to the influence of a channel confluence, which are also associated with anastomosing channels (McCabe, 1977). Although this study does not examine the morphology or hydrodynamics of confluence zones in any detail, there are numerous studies which examine a variety of channel bar and confluence interactions, for example: i. the formation alternate bars, McCabe, 1977 and Collinson, 1996; ii. deposition related to confluence scours, Ashmore & Parker, 1983, Miall, 2010b and references there in; iii. morphology and sedimentology, Petts & Thomas (1987); iv. mid-channel bar confluences, Szupiany *et al.*, 2009; v. flow and sediment dynamics, Leite Ribeiro *et al.*, 2012; and vi. hydromorphodynamics, Guillén-Ludeña *et al.*, 2016. The relatively low angle (mainly ≤10°) first and second-order bounding surfaces imply that the host channel was relatively broad. Such an interpretation corresponds with McCabe's (1977) observation that distributary channel dips were in the region of ≤10° and Bristow (1987, 1993a) arguing that bounding surfaces, with very low depositional dips, correspond to channels possessing high width to depth ratios. Further, Outcrop 32.1 is dominated by a coarse-grained to granular sandstone which coincides with Coleman's (1969) observation that rivers with significant quantities of coarse sediment are representative of broad, flat, island-obstructed fluvial systems, although the term bar-obstructed is more appropriate (sensu Bridge, 2003); and the preservation of consecutive cross-laminated sets inevitably encompasses a measure of net deposition and most sets will climb at a similar angle/dip to that of their host bed (Leeder, 1982).

Outcrop 32.2: Data relating to Outcrop 32.2 imply that the depositional palaeocurrent was relatively heterogeneous, varying from a north-easterly trend at the base, a south-westerly trend towards the central section and south-easterly trend towards the top of the sequence (Fig. 4.4 Location 32). A maximum cumulative coset thickness of ~0.90 m (facies Sl-hpx <2.0 m) indicates that the maximum dune or unit bar height and channel depth may have been ~1.30 m and ~2.60 m, respectively (cf. Leclair, 2011). Conversely, variable set thicknesses of between ~0.10 m (base of sequence) and ~0.20 m (top of sequence), indicates that deposition may have been dominated by varying amounts of sediment transport and input, likely influenced by flood events and related variable channel depths of between ~0.65 m and ~2.15 m, respectively (cf. Leclair, 2011).

Although, the initial cosets relating to facies Sl-hss <1.0 m may represent: i. downstream-accretion of 3D mesoforms within a relatively shallow thalweg region of a low sinuosity channel, likely influenced by high-flow stage which facilitated the formation of down-climbing dunes (cf. Bristow, 1988, 1993a; Ghinassi *et al.,* 2009; Miall, 2010b; Reesink *et al.,* 2014); ii. bar top vertical-accretion component of a channel bar, primarily due to dune stacking and an initial relatively shallow flow depth above the host bar (cf. Best *et al.*, 2003; Bridge & Lunt, 2006); or iii. a series of distinct depositional episodes (cf. Collinson *et al.,* 2006) of assembled sets divided by first-order set boundaries which indicate repeated downstream bedform migration, possibly as a train of dune components over the surface/crest or front/tail of a larger bar (macroform) (cf. Allen, 1982; Haszeldine, 1983b; Bristow, 1993b; Miall, 2010b; Ashworth *et al.*, 2011), the cosets of facies Sl-hss <1.0 m more likely represent mid-channel migratory bedforms, possibly on the surface of a larger sand flat (cf. Cant & Walker, 1976, 1978), that probably formed within a multi-channelled fluvial system (cf. Reesink *et al*., 2014) which may account for the initial palaeocurrent adjustment from a north-easterly (Sl-hss <1.0 m) to south-westerly (Sl-hpx <2.0 m) flow. The discrete sub-horizontal sets likely formed coset components of either an individual small-scale unit bar (cf. Sambrook Smith *et al.*, 2006; Reesink & Bridge, 2009) or a distinct larger host dune coset (cf. Haszeldine, 1983b). Further, the sub-horizontal coset contacts likely represent third-order erosive surfaces associated with the repeated downstream-accretion and migration of individual bedforms. An average coset thickness of ~0.40 m implies that the host channel may have been between 0.80-1.60 m deep (cf. Reesink & Bridge, 2009; Leclair, 2011) which together with the relatively low first-order bounding surface dips of ~10°, implies that flow conditions were sufficiently shallow to subdue dune formation and thereby generate low relief dunes (cf. Bristow, 1993a); preservation of low-angle dune morphology is facilitated by dune stoss and crest erosion, during high flow-stage, and deposition of eroded sediment in the dune's trough (Hendershot *et al.*, 2016). Low-angle bedforms may be attributed to the migration of low-amplitude (near horizontal) sand waves/dunes, or low-relief dunes associated with parallel laminations, both are concomitant with the transitional zone between lower and upper flow regimes and very shallow fluvial systems (cf. Smith, 1971; Todd, 1996); generally foreset gradients decline as a flow regime intensifies, vice versa (cf. Smith, 1972). The relative shallow channel conditions also imply waning flow, aggradation of 3D mesoforms and channel fill (cf. Cant & Walker, 1976; Ashworth *et al.*, 2011; Reesink *et al.*, 2014). The subsequent deposition of facies Sl-hpx <2.0 m implies an increase in net sediment input and channel depth, probably resulting from a flood event (high-flow stage) and the net deposition of 2D mesoforms during waning flow (low-flow stage) (cf. Coleman, 1969; Bristow, 1987, 1993a; Ashworth *et al.,* 2011). Such flood events may have also influenced thalweg migration and alterations in flow direction, as indicated in the palaeocurrent adjustment towards the south-west (cf. Coleman, 1969; Bristow, 1987; Ashworth *et al.*, 2011). The relative bedform size (~0.90 m thick coset) suggests downstream-accretion within a broad and deep channel with dune migration near to the channel thalweg/axis where large dunes tend to develop (cf. Reesink & Bridge, 2009; Ashworth et al., 2011; Reesink et al., 2014). Similar to the above interpretations relating to facies Sl-hss <1.0 m, the discrete sub-horizontal sets relating to facies Sl-hpx <2.0 m likely form coset components of either an individual small-scale unit bar (cf. Sambrook Smith *et al.*, 2006; Reesink & Bridge, 2009) or a distinct larger host dune coset (cf. Haszeldine, 1983b). Further, a lateral adjustment in the palaeocurrent relating to facies Sl-hpx <2.0 m likely represents a reactivation surface and/or the lateral and downstream amalgamation of an adjacent bar/dune coset. And, evidence of minor soft sediment deformation implies localised loss of grain stability (liquefaction) within unconsolidated water laden sediments, probably facilitated by sudden overburden through rapid sediment deposition post flood and/or syn-sedimentary tectonic activity post deposition (cf. Barnhardt & Sherrod, 2006; Hubert-Ferrari *et al.*, 2017). The subsequent deposition of facies Stsx <1.5 m likely denotes an overall reduction in channel depth that facilitated the downstream or lateral-accretion of 3D mesoforms which may represent deposition: i. within a relatively shallower thalweg region of a low sinuosity channel (cf. Bristow, 1988, 1993a; Ghinassi *et al.,* 2009; Miall, 2010b; Reesink *et al.,* 2014); ii. related to bar top vertical-accretion of a mid-channel bar, primarily due to dune stacking and relatively shallower flow conditions above the host bar (cf. Best *et al.*, 2003; Bridge & Lunt, 2006; Miall, 2010b; cf. Ashworth *et al.*, 2011); or iii. along the surface of a larger sand flat (cf. Cant & Walker, 1976, 1978).

Similar to Outcrop 32.1, the overall interpretation relating to Outcrop 32.2 suggests that deposition was likely associated with downstream migration and accretion within a relatively broad and deep multi-channelled fluvial system, see above overall interpretation relating to Outcrop 32.1.

Outcrop 32.3: The sub-horizontal bedding relating to Outcrop 32.3 appears to be the result of minor cambering towards the east, in comparison to an adjacent parallel outcrop. The affected bedding and palaeocurrent data was restored through stereographic projection, relative to the 10˚ dip and 080˚ azimuth inferred from the coset and set inclination relating to the mid-upper sequence facies of Sl-hpx <2.0 m. The restored palaeocurrent data imply that deposition was mainly influenced by south-easterly palaeocurrents, with limited south-westerly and north-easterly bedform migration (Fig. 4.4 Location 32). Although the restored palaeocurrent data is marginally more variable than the original field data (Fig. 4.4 Location 32), the restored cross-bedding appears more consistent with that of the adjacent outcrop; hence, the restored data was adopted when interpreting Outcrop 32.3. A maximum set thickness of ~0.80 m (facies Sl-hpx <2.0 m) indicates that the maximum dune height and channel depth was ~2.90 m and ~8.65 m, respectively (cf. Leclair, 2011) and a cumulative coset thickness of ~2.00 m (facies Sl-hpx <2.0 m) indicates a likely bar height and channel depth of ~3.30 m and ~6.60 m, respectively (cf. Reesink & Bridge, 2009; Leclair, 2011). Conversely, variable set thicknesses of between ~0.10 m and ~0.50 m indicates that deposition may have been dominated by varying amounts of sediment transport and input, likely influenced by variable flood events and related fluctuating channel depths of between ~0.65 m and ~5.40 m, respectively (cf. Leclair, 2011).

The basal facies of Sl-hhs <1.0 m may represent downstream migration and net accretion of 3D mesoforms within a relatively shallow thalweg region of a low sinuosity channel (cf. Bristow, 1988, 1993a; Ghinassi *et al.,* 2009; Miall, 2010b; Reesink *et al.,* 2014), influenced by waning flow, net sediment aggradation and channel fill (cf. Cant & Walker, 1976; Ashworth *et al.*, 2011; Reesink *et al.*, 2014), see above (Outcrop 32.1) for further interpretations relating to facies Sl-hhs <1.0 m. The subsequent deposition of facies Sl-hpx <2.0 m implies a substantial increase in channel depth and net sediment input, likely facilitated by a flood event with sediment migration and aggradation influenced by high and low-flow stages, respectively (Coleman, 1969; Bristow, 1987, 1993a; Ashworth *et al.,* 2011). The size of cross-bedding suggests downstream-accretion within a relatively broad and deep channel with dune migration near to channel thalweg/axis (cf. Reesink & Bridge, 2009; Ashworth *et al.*, 2011; Reesink *et al.*, 2014). Repeated deposition of ensuing facies Stmx <1.5-3.0 m probably denotes repeated downstream migration and accretion of 3D mesoforms towards the thalweg/axis of a relatively broad/deep channel, as implied by the fairly coarse grain and granular texture, pebble content and size of cross-bedding (cf. Reesink & Bridge, 2009; Ashworth *et al.*, 2011; Reesink *et al.*, 2014). Such facies were probably generated by flood events with sediment migration and aggradation influenced by high and low-flow stages, respectively (Coleman, 1969; Bristow, 1987, 1993a; Ashworth *et al.,* 2011). The intermittent lag deposits (Ss-lp-lag) likely represents scouring (Miall, 2010b) or winnowing (cf. Collinson *et al.,* 2006) processes with no obvious evidence of a fifth-order channel surface; similarly, lag deposits may denote the location of channel thalweg/axial region (Fidolini et al., 2013; Ghinassi et al., 2014). The overlying facies of Sl-hpx <2.0 m consists of repeated grain flow avalanche deposits (~0.02 m thick foresets; see Smith, 1972; Reesink & Bridge, 2007, 2009) that represent downstream migration and accretion of 2D mesoforms, probably towards a relatively broad/deep channel thalweg region where large dunes tend to develop (cf. Reesink & Bridge, 2009; Ashworth *et al.*, 2011; Reesink *et al.*, 2014). Further, the horizontal first and second-order bounding surfaces probably correspond to a channel possessing a high width to depth ratio (Bristow, 1993a). The sets likely relate to a series of distinct depositional episodes (cf. Collinson *et al.,* 2006) of assembled sets divided by first-order set boundaries, indicating repeated bedform migration probably as a train of dunes (dune stacking) which may form components of a larger bar (macroform) top (cf. Bristow, 1993b; Best *et al.*, 2003; Bridge & Lunt, 2006; Miall, 2010b; Ashworth *et al.*, 2011), or together with facies Stmx <1.5-3.0 m, may represent in channel deposition and overlying sand flat components, respectively (cf. Cant & Walker, 1976, 1978). Such mesoforms are also associated with the downstream migration and net aggradation of: i. longitudinal bars (Ghinassi *et al.,* 2009); ii. unit bars (cf. Bridge & Lunt, 2006; Ashworth *et al.*, 2011), although such bar heights coincide with dune heights (Ashworth *et al.*, 2011); or iii. the observed angular foreset contacts suggest that the bedforms may represent transverse bars, generated as a result of low fluid and low sediment discharge (cf. Smith, 1972; Hein & Walker, 1977; Collinson *et al.,* 2006). The preservation of consecutive cross-laminated sets inevitably encompasses a measure of net deposition (Leeder, 1982), influenced by a variable channel depth facilitated by related flood events (high-flow stage) and subsequent net sediment deposition during waning flow (low-flow stage) (cf. Coleman, 1969; Bristow, 1987, 1993a; Ashworth *et al.,* 2011). Such sediment aggradation inevitably encompasses a measure of channel fill and a reduction in overall channel depth (cf. Cant & Walker, 1976; Ashworth *et al.*, 2011; Reesink *et al.*, 2014), thereby increasing the flow rate over the bedform (cf. Reesink & Bridge, 2009), which in turn would have facilitated the deposition of facies Sl-hhs <1.0 m. The ~0.10 m thick sets relating to facies Sl-hhs <1.0 m implies flow conditions were sufficiently shallow to subdue dune formation and generate low relief dunes (cf. Bristow, 1993a);

preservation of low-angle dune morphology is facilitated by dune stoss and crest erosion, during high flow-stage, and deposition of eroded sediment in the dune's trough (Hendershot *et al.*, 2016). Low-angle bedforms may be attributed to the migration of low-amplitude (near horizontal) sand waves/dunes, or low-relief dunes associated with parallel laminations, both are concomitant with the transitional zone between lower and upper flow regimes and shallow fluvial systems (cf. Smith, 1971; Todd, 1996); generally foreset gradients decline as a flow regime intensifies, vice versa (cf. Smith, 1972). The relative shallow channel conditions also imply waning flow, aggradation of 3D mesoforms and channel fill (cf. Cant & Walker, 1976; Ashworth *et al.*, 2011; Reesink *et al.*, 2014). A further substantial flood event and return to deeper channel conditions (~8.65 m deep) is evidenced by the overlying facies of Sl-hpx <2.0 m, see above for further interpretations relating to facies Sl-hpx <2.0 m.

Although the cosets relating to facies Stmx <1.5-3.0 m and Sl-hpx <2.0 m may have facilitated the formation of a sand flat (cf. Cant & Walker, 1976, 1978), the overall interpretation relating to Outcrop 32.3 suggests that deposition was likely associated with downstream migration and accretion within a relatively broad and deep multi-channelled fluvial system, see above overall interpretation relating to Outcrop 32.1. Further, unit bars may consist of simple inclined (mainly <10°, but may be up to 35°) small to large-scale sets, which may show a vertical reduction in dune/set height correlated to a decrease in channel depth, the deposits may also display no significant vertical shift in grain size (cf. Bridge & Lunt, 2006). These traits are consistent with the coset relating to facies Sl-hpx <2.0 m (0.40-0.50 m thick sets) and overlying facies of Sl-hhs <1.0 m (~0.10 m thick sets). The base and top of the possible unit bar sequence is consistent with a decrease in channel depth and thereby available accommodation space for vertical dune accretion, there is also no obvious clear vertical grain size shift along the unit bar (cf. Bridge & Lunt, 2006).

Table 4.33

Location, grid reference and associated literature	General description and lithology
33. High Bishopside Outcrops 33.1: SE 15790 67713 33.2: SE 15797 67611 33.3: SE 15846 67483 33.4: SE 15916 67391 Thompson, A. T. (1957) *The structure and stratigraphy of Nidderdale between Lofthouse and Dacre*. Unpublished, Doctoral thesis, Durham University. Available at Durham E-Theses Online: http://etheses.dur.ac.uk/722/.	Various sized outcrops running along and up the western flank of High Bishopside. Outcrops are generally masked (in part) by soil and vegetation (e.g. lichen, moss and/or heather) associated with a moorland setting. Although several outcrops appear to have been disarticulated and/or subjected to cambering, the in-sitú examined outcrops generally follow a ~460.0 m long north-south line of intermittent and fragmented crags. The examined outcrops form the fourth main section of a larger disjointed chain of outcrops extending from the northwest to the southeast for ~4.1 km; mainly following the topographic contours, varying from ~350 m down to ~320 m. Generally, all the examined outcrops are jointed both horizontally and vertically, weathered and possess a variable texture with relatively poor outcrop detail (e.g. foreset/sets), due to the processes of weathering and erosion. Outcrops examined are a representative example of the outcrops in the locality and were surveyed moving from the north towards the south. Elevation of Outcrops 33.1-33.4 is ~320, 332, 348 and 350 m O.D, respectively; main outcrop views are towards ~090˚, 100˚, 094˚ and 358˚, respectively (Fig. 4.4 Location 33). Outcrop 33.1: Coarse-grained to granular sandstone with 2-15% small to large pebble content (variable), predominantly quartz grains; generally low to high sphericity; sub-angular to rounded; poorly to well sorted; Outcrop 33.2: Coarse-grained to granular sandstone with 0-5% small to medium pebble content (variable), predominantly quartz grains; generally low to high sphericity; sub-angular to rounded; poorly to well sorted; Outcrop 33.3: Coarse-grained to granular sandstone with 0-10% small to medium pebble content (variable), predominantly quartz grains; generally low to high sphericity; sub-angular to rounded; poorly to moderately sorted; Outcrop 33.4: Coarse-grained to granular sandstone with 2-5% small to medium pebble content (variable), predominantly quartz grains; generally low to high sphericity; sub-angular to rounded; poorly to moderately sorted.

Identified sub-Facies, sedimentary structures and bounding surfaces of note

Outcrop 33.1 [~4.5 (H) x 4.0 (D) x 20.0 m (W)]: **1.** ~1.20 m thick coset of *Sl-hpx <2.0 m (Sp); low-angle-inclined foresets forming poorly defined medium-scale planar cross-bedding; coset consist of 0.35–0.40 m thick erosive cross-cutting sets; likely sharp (in part) and poorly defined horizontal contact with overlying set; **2.** *Sl-hpx <2.0 m (Sp); low to high-angle-inclined foresets forming poorly defined medium-scale planar cross-bedding; ~0.60 m thick set pinching out towards the southern right/central section of outcrop; coarser grain component delineates foreset boundaries – normal grading; likely poorly defined horizontal/undulating contact with overlying coset, evidence of intermittent small-medium pebble lag; **3.** ~0.80 m thick coset of *****Stsx <1.5 m (St); poorly defined small to medium-scale trough cross-bedding <1.5 m trough width; coset consist of ~0.15 m thick down-climbing and cross-cutting sets; coarser grain component delineates trough boundaries – normal grading; likely sharp (in part) and poorly defined horizontal contact with overlying set; **4.** *Sl-hpx <2.0 m (Sp); low to high-angle-inclined foresets forming poorly defined medium-scale planar cross-bedding; ~0.60 m thick set; likely sharp (in part) and poorly defined horizontal contact with overlying coset; **5.** ~0.90 m thick coset of *Sl-hpx <2.0 m (Sp); low to high-angle-inclined foresets forming poorly defined small to medium-scale planar cross-bedding; coset consist of 0.15–0.30 m thick relatively horizontal cross-cutting sets, evidence of possible reactivation surfaces; sharp erosive sub-horizontal contact with overlying coset, possible channel base; **6.** ~1.20 m thick coset of *****Stsx <1.5 m (St); poorly defined small to medium-scale trough cross-bedding <1.5 m trough width; coset consist of 0.10-0.20 m thick generally horizontal cross-cutting sets; likely sharp (in part) and poorly defined horizontal contact with overlying set; **7.** *Sl-hpx <2.0 m (Sp); low to high-angle-inclined foresets forming poorly defined medium-scale planar cross-bedding; ~0.55 m thick set; ~0.03 m thick foresets; coarser grain component delineates foreset boundaries – normal grading; partial section;

Outcrop 33.2 [~5.0 (H) x 3.0 (D) x 22.0 m (W)]: **1.** ~0.95 m thick coset of *****Stsx <1.5 m (St); poorly defined small-scale trough cross-bedding <1.5 m trough width; coset consist of 0.10-0.15 m thick generally horizontal cross-cutting sets; likely poorly defined horizontal contact with overlying set; **2.** *****Stsx <1.5 m (St); small to medium-scale trough cross-bedding <1.5 m trough width; ~0.30 m thick set; poorly defined tangential (or asymptotic) foresets; likely poorly defined horizontal contact with overlying coset; **3.** ~0.70 m thick coset of *Sl-hss <1.0 m (Sl); poorly defined low-amplitude small-scale trough cross-bedding <1.5 m trough width; coset consists of 0.10-0.15 m thick sub-horizontal (down-climbing) cross-cutting sets; coarser grain component towards base of trough/set boundaries – normal grading; likely poorly defined and sharp (in part) slightly sub-horizontal contact with overlying set; **4.** *Sl-hpx <2.0 m (Sp); low to high-angle-inclined foresets forming poorly defined medium-scale planar cross-bedding; 0.15-0.50 m thick set thinning towards the northern (left) section of outcrop; coarser grain component delineates foreset boundaries – normal grading; ~0.05 m thick foresets; likely poorly defined and sharp (in part) horizontal contact with overlying coset; **5.** ~0.70 m thick coset of *Sl-hss <1.0 m (Sl); poorly defined low-amplitude small-scale trough cross-bedding <1.5 m trough width; coset consists of 0.10-0.15 m thick sub-horizontal (down-climbing) cross-cutting sets; coarser grain component towards base of trough/set boundaries – normal grading; likely poorly defined and sharp (in part) sub-horizontal erosive contact with overlying coset; **6.** ~0.80 m thick coset of *Sl-hpx <2.0 m (Sp); low to high-angle-inclined foresets forming poorly defined medium-scale planar cross-bedding; two ~0.40 m thick cross-cutting sets, likely lateral and downstream dune amalgamation; coarser grain component delineates foreset boundaries – normal grading; ~0.05 m thick tangential (or asymptotic) foresets; likely poorly defined horizontal contact with overlying coset; **7.** ~0.30 m thick coset of *Sl-hss <1.0 m (Sl); poorly defined low-amplitude small-scale trough cross-bedding <1.5 m trough width; coset consists of ~0.05 m thick sub-horizontal (down-climbing) cross-cutting sets; poorly defined and sharp (in part) erosive sub-horizontal contact with overlying coset (channel base); **8.** ~0.80 m thick coset of ***Stsx <1.5 m (St); poorly defined low-amplitude small-scale trough cross-bedding <1.5 m trough width; coset consist of 0.10-0.15 m thick generally horizontal cross-cutting sets; likely poorly defined horizontal contact with overlying coset; **9.** ~0.90 m thick coset of *Sl-hhs <1.0 m (Sh); poorly defined low-amplitude small-scale trough cross-bedding <1.5 m trough width; coset consists of ~0.05 m thick horizontal cross-cutting sets;

Outcrop 33.3 [~3.0 (H) x 3.0 (D) x 5.0 m (W)]: **1.** ~0.50 m thick coset of Sl-hhs <1.0 m (Sh); poorly defined low-amplitude small-scale trough cross-bedding <1.5 m trough width; coset consists of 0.05-0.08 m thick horizontal cross-cutting sets; poorly defined slightly sub-horizontal contact with overlying coset; **2.** ~0.50 m thick coset of *Sl-hss <1.0 m (Sl); poorly defined low-amplitude small-scale trough cross-bedding <1.5 m trough width; coset consists of 0.05-0.08 m thick sub-horizontal (down-climbing) cross-cutting sets; poorly defined likely sub-horizontal contact with overlying coset; **3.** ~0.50 m thick coset of Stsx <1.5 m (St); poorly defined small-scale trough cross-bedding <1.5 m trough width; coset consist of 0.10-0.15 m thick sub-horizontal (down-climbing) cross-cutting sets; sets pinch out laterally; sharp sub-horizontal erosive contact with overlying coset; **4.** ~0.40 m thick coset of *Stmx 1.5-3.0 m (St); medium-scale trough cross-bedding 1.5–3.0 m trough width; two ~0.25 m thick cross-cutting sets; intermittent minor granule to medium pebble lag towards base of troughs/sets – normal grading; sharp sub-horizontal contact with overlying coset; **5.** 0.40-0.50 m thick coset of *Sl-hss <1.0 m (Sl); poorly defined low-amplitude small-scale trough cross-bedding <1.5 m trough width; coset consists of ~0.10 m thick sub-horizontal (down-climbing) cross-cutting sets; poorly defined horizontal contact with overlying coset; **6.** ~0.90 m thick coset of *Sfp (Sf) evidence of fossilised plant remnants along base, within and along surface of coset; host facies likely poorly defined low-amplitude small-scale trough cross-bedding <1.5 m trough width; coset consists of 0.10-0.15 m thick slightly sub-horizontal cross-cutting sets;

Outcrop 33.4 [~1.0 (H) x 2.0 (D) x 5.0 m (W)]: **1.** ~0.90 m thick coset group of *Stsx <1.5 m (St); likely low-amplitude small-scale trough cross-bedding <1.5 m trough width; two cosets ~0.40 and ~0.50 m thick, respectively; cosets consist of ~0.10 m thick sub-horizontal (down-climbing) cross-cutting sets; poorly defined sets and foresets; sharp and poorly defined (in part) sub-horizontal contact between cosets.

Interpretation

Outcrop 33.1: The sub-horizontal bedding relating to Outcrop 33.1 appears to be the result of minor cambering towards the north, similar to that of other outcrops in the vicinity (e.g. Outcrop 33.2). The affected bedding and palaeocurrent data was restored through stereographic projection, relative to the 10˚ dip and 360˚ azimuth inferred from the coset inclinations relating to the mid sequence facies of Stsx <1.5 m and Sl-hpx <2.0 m. Although the depositional palaeocurrent appears relatively heterogeneous, varying from a north-westerly trend at the base to a south-easterly trend towards the top of the sequence, the restored palaeocurrent data imply that deposition was less heterogeneous with palaeocurrents concentrated more towards the west and southeast, with limited north-easterly bedform migration (Fig. 4.4 Location 33). The restored cross-bedding appears more consistent with that of lateral and/or downstream migrating bedforms; hence, the restored data was adopted when interpreting Outcrop 33.1. Variable set thicknesses of between ~0.10 m and ~0.60 m indicates that deposition may have been dominated by varying amounts of sediment transport and input, likely influenced by variable flood events and related fluctuating channel depths of between ~0.65 m and ~6.50 m, respectively (cf. Leclair, 2011).

A northwest-west palaeocurrent probably influenced the initial deposition of individual 2D mesoforms (facies Sl-hpx <2.0 m) towards the channel thalweg region of a relatively broad/deep channel where large dunes tend to develop, as reflected by a dune height and channel depth of~1.45 m and 4.30 m, respectively (cf. Reesink & Bridge, 2009; Ashworth *et al.*, 2011; Leclair, 2011; Reesink *et al.*, 2014). The very coarse to granular texture of the facies suggests that the primary bedload deposition was influenced by high flow stage, since fine and coarse-grained cross strata accumulate at low and high-flow stage, respectively (Reesink & Bridge, 2009 and references there in). Similarly, the observed relatively low angle cross-cutting cross-bedding suggests that deposition was influenced by high flow stage, given that foreset gradients decline as a flow regime intensifies, vice versa (cf. Smith, 1972). A subsequent flood event likely influenced thalweg migration and alteration in flow direction, evidenced by a palaeocurrent readjustment and further deposition of facies Sl-hpx <2.0 m towards the southwest (cf. Coleman, 1969; Bristow, 1987; Ashworth *et al.*, 2011). Such flood events would facilitate an increase in net sediment input and channel depth during high-flow stage and the net deposition of 2D mesoforms during waning flow (low-flow stage) (cf. Coleman, 1969; Bristow, 1987, 1993a; Ashworth *et al.,* 2011), expressed by a maximum dune height and channel depth of ~2.15 m and ~6.50 m, respectively (cf. Leclair, 2011). The initial deposition of facies Stsx <1.5 m likely represent a further flood event and the downstream-accretion of 3D mesoforms (i.e. ~1.20 m thick dune or bar) within a relatively deep thalweg region of a low sinuosity channel influenced by high-flow stage which facilitated the cumulative formation of down-climbing dunes (cf. Bristow, 1988, 1993a; Ghinassi *et al.,* 2009; Miall, 2010b; Reesink *et al.,* 2014). The component sub-horizontal sets may be related to: i. migratory mid-channel bar bedform components; dune set components of such cosets likely formed within a multi-channelled fluvial system (cf. Reesink *et al*., 2014); ii. individual consecutive small-scale unit bar components (cf. Sambrook Smith *et al.*, 2006; Reesink & Bridge, 2009) of a much larger compound bar (cf. Allen, 1982; Bridge, 2003; Bridge & Lunt, 2006; Sambrook Smith *et al.*, 2006; Ashworth *et al.*, 2011); or iii. individual sets which form components of a larger host dune coset (cf. Haszeldine, 1983b). The subsequent series of facies Sl-hpx <2.0 m likely represent repeated flood events and related downstream sediment migration and net deposition of 2D mesoforms, see above interpretation relating to facies Sl-hpx <2.0 m. Such repeated bedform deposition may be associated with the downstream migration and net aggradation of individual: i. longitudinal bars (Ghinassi *et al.,* 2009); ii. unit bars (cf. Bridge & Lunt, 2006; Sambrook Smith *et al.*, 2006; Ashworth *et al.*, 2011), although such bar heights coincide with dune heights (Ashworth *et al.*, 2011); iii. sand flat components (cf. Cant & Walker, 1976, 1978); or iv. the observed angular foreset contacts suggest that the bedforms may represent transverse bars, generated as a result of low fluid and low sediment discharge (cf. Smith, 1972; Hein & Walker, 1977; Collinson *et al.,* 2006). The sub-horizontal contact associated with the ensuing facies of Stsx <1.5 m likely forms an erosive low angle channel incision into facies Sl-hpx <2.0 m (cf. Miall, 2010b), thereby generating a fifth-order bounding surface (cf. Miall, 2010b). Such channels may form as a result of a hydraulic gradient during low-flow stage concentrating the flow towards the channel thalweg (cf. Bristow, 1987), analogous with the formation of a bar top chute channel (see Bristow, 1987; Bridge, 2003; Miall, 2010b). Conceivably, the erosive channel may represent either a constrained first-order channel (through reduced channel flow) or subordinate second or third-order channels (cf. Coleman, 1969; Bristow, 1987; Bridge, 2003; Miall, 2010b and references there in). Further, a flood event may have initially influenced thalweg migration and alteration in flow direction, evidenced by a palaeocurrent readjustment with the consequential channel scour facilitating deposition of facies Stsx <1.5 m towards the northwest (cf. Coleman, 1969; Bristow, 1987; Ashworth *et al.*, 2011). The final deposit relating to facies Sl-hpx <2.0 m is predominantly constructed from repeated grain flow avalanche deposits (~0.03 m thick foresets; see Smith, 1972; Reesink & Bridge, 2007, 2009) that probably represent downstream migration and accretion of 2D mesoforms. The size of cross-bedding (~0.55 m thick set) implies a further flood event and deposition of a ~2.00 m thick dune within a ~5.95 m deep channel (cf. Leclair, 2011), see above interpretation relating to facies Sl-hpx <2.0 m.

The overall interpretation relating to Outcrop 33.1 suggests that deposition was probably related to downstream migration and accretion associated with in channel deposition consisting of: i. individual mesoforms which likely developed within a multi-channelled fluvial system (cf. Reesink *et al.*, 2014); ii. unit bars (cf. Sambrook Smith *et al.*, 2006; Reesink & Bridge, 2009); and/or iii. individual sets forming dune cosets (cf. Haszeldine, 1983b). Deposition of such mesoforms may have also produced a localised effect on thalweg migration (cf. Coleman, 1969; Bristow, 1987; Ashworth *et al.*, 2011). Collectively the mesoforms may have taken the form of a sand flat, which in turn could have facilitated the generation of an erosive low angle channel incision into facies Sl-hpx <2.0 m (cf. Miall, 2010b), thereby generating a fifth-order bounding surface (cf. Miall, 2010b). The erosive channel may represent either a constrained first-order channel (through reduced channel flow) or subordinate second or third-order channels (cf. Coleman, 1969; Bristow, 1987; Bridge, 2003; Miall, 2010b and references there in). Equally, a flood event may have initially influenced thalweg migration and alteration in flow direction towards the northeast with the consequential channel scour facilitating deposition of facies Stsx <1.5 m (cf. Coleman, 1969; Bristow, 1987; Ashworth *et al.*, 2011). The relatively horizontal first and second-order bounding surfaces (i.e. facies contacts), low angle channel incision and variable size of cross-bedding imply that the host channel was comparatively broad and deep. Such an interpretation corresponds with McCabe's (1977) observation that distributary channel dips were in the region of ≤10° and Bristow (1987, 1993a) arguing that bounding surfaces, with very low depositional dips, correspond to channels possessing high width to depth ratios. Further, Outcrop 33.1 is dominated by a coarse-grained to granular sandstone which coincides with Coleman's (1969) observation that rivers with significant quantities of coarse sediment are representative of broad, flat, island-obstructed fluvial systems, although the term bar-obstructed is more appropriate (sensu Bridge, 2003); and the preservation of consecutive cross-laminated sets inevitably encompasses a measure of net deposition (Leeder, 1982).

Outcrop 33.2: The sub-horizontal bedding relating to Outcrop 33.2 appears to be the result of minor cambering towards the northeast, similar to that of other outcrops in the vicinity (e.g. Outcrop 33.1). The affected bedding and palaeocurrent data was restored through stereographic projection, relative to the 08˚ dip and 044˚ azimuth inferred from the coset and set inclinations relating to the mid to upper sequence of facies Sl-hpx <2.0 m and Sl-hss <1.0 m. Although the depositional palaeocurrent appears relatively heterogeneous moving up the sequence, the restored palaeocurrent data imply that deposition was less heterogeneous with palaeocurrents concentrated more towards the west and southeast; the very low angle (i.e. 01˚-03˚) restored set and coset bounding surfaces suggest that the host bedding was relatively horizontal (Fig. 4.4 Location 33). The restored cross-bedding appears more consistent with that of lateral and/or downstream migrating bedforms; hence, the restored data was adopted when interpreting Outcrop 33.2. Variable set thicknesses of between ~0.05 m and ~0.50 m indicates that deposition may have been dominated by varying amounts of sediment transport and input, likely influenced by variable flood events and related fluctuating channel depths of between ~0.55 m and ~5.40 m, respectively (cf. Leclair, 2011).

The basal coset of facies Stsx <1.5 m may represent downstream migration and accretion of 3D mesoforms within a low sinuosity channel (cf. Bristow, 1988, 1993a; Ghinassi *et al.,* 2009; Miall, 2010b; Reesink *et al.,* 2014). Set thicknesses of 0.10-0.15 m relating to facies Stsx <1.5 m suggest that deposition was influenced by a channel with variable flow depth (1.10-1.60 m deep; cf. Reesink & Bridge, 2009; Leclair, 2011), probably facilitated by flood events (high-flow stage) and subsequent net sediment deposition during waning flow (low-flow stage) (cf. Coleman, 1969; Bristow, 1987, 1993a; Ashworth *et al.,* 2011). Further, such facies may indicate migratory bedforms that likely developed on the surface of a larger sand flat (cf. Cant & Walker, 1976, 1978) and/or they may represent the latter stages of a channel fill sequence (cf. Reesink *et al.*, 2014). Low-flow stage would have also facilitated the aggradation of 3D mesoforms and channel fill (cf. Cant & Walker, 1976; Ashworth *et al.*, 2011; Reesink *et al.*, 2014). Similarly, such bedforms are associated with a series of distinct depositional episodes (cf. Collinson *et al.,* 2006) of assembled sets divided by first-order bounding surfaces which indicate repeated bedform migration probably as a train of dunes (dune stacking) that may have formed components of a channel bar top (cf. Bristow, 1993b; Best *et al.*, 2003; Bridge & Lunt, 2006; Mumpy *et al*., 2007; Miall, 2010b; Ashworth *et al.*, 2011). A further flood event would have amplified the rivers flow and sediment load capacity, which probably facilitated the downstream migration and subsequent deposition of an additional 0.30 m thick set of facies of Stsx <1.5 m. Such facies further indicate that deposition was towards the channel thalweg/axis where larger bedforms generally develop (cf. Reesink & Bridge, 2009; Ashworth *et al.*, 2011; Reesink *et al.*, 2014). The tangential (or asymptotic) foresets associated with facies Stsx <1.5 m were likely promoted by fairly frail separation eddies and a high rate of sediment deposition, from suspension, beyond the slipface of the dune's lee (cf. Leeder, 1982; Bristow, 1993a; Bridge, 2003). The subsequent deposition of facies of Sl-hss <1.0 m denotes an alteration in the palaeocurrent from a south-easterly to westerly flow. Although facies Sl-hss <1.0 m may represent: i. downstream-accretion of 3D mesoforms within a relatively shallow thalweg region of a low sinuosity channel, likely influenced by high-flow stage which facilitated the formation of down-climbing dunes (cf. Bristow, 1988, 1993a; Ghinassi *et al.,* 2009; Miall, 2010b; Reesink *et al.,* 2014); ii. bar top vertical-accretion component of a channel bar, primarily due to dune stacking and an initial relatively shallow flow depth above the host bar (cf. Best *et al.*, 2003; Bridge & Lunt, 2006); or iii. a series of distinct depositional episodes (cf. Collinson *et al.,* 2006) of assembled sets divided by first-order set boundaries which indicate repeated downstream bedform migration, possibly as a train of dune components over the surface/crest or front/tail of a larger bar (macroform) (cf. Allen, 1982; Haszeldine, 1983b; Bristow, 1993b; Miall, 2010b; Ashworth *et al.*, 2011), the coset of facies Sl-hss <1.0 m more likely represents a migratory mid-channel bedform that probably formed within a multi-channelled fluvial system (cf. Reesink *et al.*, 2014), where the discrete sub-horizontal sets formed coset components of either an individual small-scale unit bar (cf. Sambrook Smith *et al.*, 2006; Reesink & Bridge, 2009) or a distinct larger host dune (cf. Haszeldine, 1983b). The low-amplitude dunes imply that flow conditions were sufficiently shallow to subdue dune formation and generate low relief dunes (cf. Bristow, 1993a); preservation of low-angle dune morphology is facilitated by dune stoss and crest erosion, during high flow-stage, and deposition of eroded sediment in the dune's trough (Hendershot *et al.*, 2016). The slightly sub-horizontal contact with the overlying facies of Sl-hpx <2.0 m likely represents a third-order erosional bounding surface and minor south-westerly shift in palaeocurrent flow. Facies Sl-hpx <2.0 m is constructed from repeated grain flow avalanche deposits (~0.05 m thick foresets; see Smith, 1972; Reesink & Bridge, 2007, 2009) which likely relate to sediment migration influenced by increasing channel depth facilitated by a flood event (high-flow stage) and subsequent net sediment deposition and aggradation of 2D mesoforms during waning flow (low-flow stage) (cf. Coleman, 1969; Bristow, 1987, 1993a; Ashworth *et al.,* 2011). The size of cross-bedding (0.15-0.50 m thick set) suggests downstream-accretion within a relatively broad and 1.60-5.40 m deep channel with dune migration near to channel thalweg/axis (cf. Reesink & Bridge, 2009; Ashworth *et al.*, 2011; Reesink *et al.*, 2014). The related flood event may have also influenced thalweg migration and alterations in flow direction towards the southwest (cf. Coleman, 1969; Bristow, 1987; Ashworth *et al.*, 2011). The overlying succession is generally a repetition of the preceding two faces and consists of a 0.70 m thick coset facies Sl-hss <1.0 m, two 0.40 m thick sets of Sl-hpx <2.0 m and a 0.30 m thick coset of Sl-hss <1.0 m. These facies denote a gradual increase and subsequent decrease in the channels flow (~2.20 m to ~4.30 m to ~0.85 m deep channel, respectively) and sediment load capacity, influenced by waning flow and channel fill (cf. Cant & Walker, 1976; Ashworth *et al.*, 2011; Reesink *et al.*, 2014), see above interpretations relating to facies Sl-hss <1.0 m and Sl-hpx <2.0 m. Further, the two cross-cutting sets relating to facies Sl-hpx <2.0 m likely represent the lateral and downstream amalgamation of adjacent dunes, which would account for the 20° difference in palaeocurrent data between the dune sets. Such dune sets may also form components of a larger compound bar (cf. Allen, 1982; Bridge, 2003; Bridge & Lunt, 2006; Sambrook Smith *et al.*, 2006; Ashworth *et al.*, 2011), or which collectively, with the underlying facies (e.g. Sl-hpx <2.0 m), may have taken the form of a sand flat (cf. Cant & Walker, 1976, 1978). Equally, Leeder (1982) argues that the preservation of consecutive cross-laminated sets inevitably encompasses a measure of net deposition and the height of dune-scale stratification generally decreases upwards through a bar sequence, reflecting a decrease in flow depth associated with bar stoss and top regions (cf. Best *et al.*, 2003; Bridge & Lunt, 2006). Such deposition and decrease in dune-scale stratification is also likely to be evident in channel fill sequences; Skelly *et al.* (2003) and Ashworth *et al.* (2011) (and references there in) argue that there is no clear distinction between compound bar and adjacent channel fill core deposits, in sandy braided fluvial systems, a similar analogy may be drawn from outcrops with limited exposure. The sub-horizontal contact associated with the ensuing facies of Stsx <1.5 m likely forms an erosive low angle channel incision into facies Sl-hss <1.0 m and Sl-hpx <2.0 m (cf. Miall, 2010b), thereby generating a fifth-order bounding surface (cf. Miall, 2010b). Such channels may form as a result of a hydraulic gradient during low-flow stage concentrating the flow towards the channel thalweg (cf. Bristow, 1987), analogous with the formation of a bar top chute channel (see Bristow, 1987; Bridge, 2003; Miall, 2010b). Conceivably, the erosive channel may represent either a constrained first-order channel (through reduced channel flow) or subordinate second or third-order channels (cf. Coleman, 1969; Bristow, 1987; Bridge, 2003; Miall, 2010b and references there in). Further, a flood event may have initially influenced thalweg migration and alteration in flow direction, evidenced by a palaeocurrent readjustment with the consequential channel scour facilitating deposition of facies Stsx <1.5 m towards the south-southeast (cf. Coleman, 1969; Bristow, 1987; Ashworth *et al.*, 2011). A further palaeocurrent alteration towards the southeast is denoted by the overlying facies of Sl-hhs <1.0 m which likely represents the downstream migration and net accretion of 2D or 3D mesoforms within a relatively shallow thalweg region of a low sinuosity channel (cf. Bristow, 1988, 1993a; Ghinassi *et al.,* 2009; Miall, 2010b; Reesink *et al.,* 2014), influenced by waning flow, net sediment aggradation and channel fill (cf. Cant & Walker, 1976; Ashworth *et al.*, 2011; Reesink *et al.*, 2014)). Such facies may also be attributed to bedforms that developed on the surface of a larger sand flat (cf. Cant & Walker, 1976, 1978) and the migration of low-amplitude (near horizontal) sand waves/dunes concomitant with the transitional zone between lower and upper flow regimes and very shallow fluvial systems (cf. Smith, 1971; Todd, 1996); generally foreset gradients decline as a flow regime intensifies, vice versa (cf. Smith, 1972).

Similar to Outcrop 33.1, the overall interpretation relating to Outcrop 33.2 suggests that deposition was probably related to downstream migration and accretion associated with in channel deposition, see above overall interpretation relating to Outcrop 33.1.

Outcrop 33.3: Although limited, data relating to Outcrop 33.3 imply that the depositional palaeocurrent was generally towards the northeast (Fig. 4.4 Location 33), although possible minor cambering towards the north may have produced a 10˚ -15˚ bias in the palaeocurrent data towards the east. A maximum cumulative coset thickness of ~0.50 m (facies Sl-hss <1.0 m) indicates that the maximum dune or unit bar height and channel depth may have been ~0.75 m and ~1.50 m, respectively (cf. Leclair, 2011). Conversely, variable set thicknesses of between ~0.05 m (e.g. facies Sl-hhs <1.0 m) and ~0.25 m (facies Stmx 1.5-3.0 m), indicates that deposition may have been dominated by varying amounts of sediment transport and input, likely influenced by flood events and related variable channel depths of between ~0.55 m and ~2.70 m, respectively (cf. Leclair, 2011).

The initial facies of Sl-hhs <1.0 m may represent downstream migration and net accretion of 3D mesoforms within a relatively shallow thalweg region of a low sinuosity channel (cf. Bristow, 1988, 1993a; Ghinassi *et al.,* 2009; Miall, 2010b; Reesink *et al.,* 2014), influenced by waning flow, net sediment aggradation and channel fill (cf. Cant & Walker, 1976; Ashworth *et al.*, 2011; Reesink *et al.*, 2014). Such facies may also indicate migratory bedforms that likely developed on the surface of a larger sand flat (cf. Cant & Walker, 1976, 1978) and/or they may represent the latter stages of a channel fill sequence (cf. Reesink *et al.*, 2014). Similarly, such bedforms are also associated with a series of distinct depositional episodes (cf. Collinson *et al.,* 2006) of assembled sets divided by first-order set boundaries which indicate repeated bedform migration probably as a train of dunes (dune stacking) which may have formed surface components of an underlying bar, for example (cf. Bristow, 1993b; Best *et al.*, 2003; Bridge & Lunt, 2006; Miall, 2010b; Ashworth *et al.*, 2011). The low-amplitude dunes imply that flow conditions were sufficiently shallow (~0.85 m deep; cf. Reesink & Bridge, 2009; Leclair, 2011) to subdue dune formation and generate low relief dunes (cf. Bristow, 1993a); preservation of low-angle dune morphology is facilitated by dune stoss and crest erosion, during high flow-stage, and deposition of eroded sediment in the dune's trough (Hendershot *et al.*, 2016). Further, the preservation of consecutive cross-laminated sets inevitably encompasses a measure of net deposition (Leeder, 1982). The subsequent deposition of facies Sl-hss <1.0 m suggests migratory bedforms that likely developed within a relatively shallow channel (cf. Ashworth *et al.*, 2011), possibly on the surface of a larger sand flat (cf. Cant & Walker, 1976, 1978). Alternatively, the individual sub-horizontal sets may form components of a larger host dune coset (cf. Haszeldine, 1983b), influenced by high-flow stage which facilitated the formation of down-climbing dunes (cf. Bristow, 1988, 1993a; Reesink & Bridge, 2009; Ghinassi, 2011). Such cosets may represent migratory mid-channel bar bedform components (cf. Reesink & Bridge, 2009) that likely formed within a multi-channelled fluvial system (cf. Reesink *et al*., 2014) and/or small-scale downstream migrating unit bars (cf. Sambrook Smith *et al.*, 2006; Reesink & Bridge, 2009), which in turn likely form components of a much larger host compound bar (cf. Allen, 1982; Bridge, 2003; Bridge & Lunt, 2006; Sambrook Smith *et al.*, 2006; Ashworth *et al.*, 2011), although such component coset/unit bar heights coincide with dune heights (Ashworth *et al.*, 2011). Such bedforms may also form a series of distinct depositional episodes (cf. Collinson *et al.,* 2006) i.e. sets divided by first-order set boundaries, indicating repeated bedform migration probably as a train of dunes (dune stacking) that may have formed components of a larger bar top (cf. Bristow, 1993b; Best *et al.*, 2003; Bridge & Lunt, 2006; Miall, 2010b; Ashworth *et al.*, 2011) and the latter stages of a channel fill sequence (cf. Reesink *et al.*, 2014). The ensuing facies of Stsx <1.5 m and Stmx <1.5-3.0 m likely represent downstream migration and accretion of 3D mesoforms within a low sinuosity channel (cf. Bristow, 1988, 1993a; Ghinassi *et al.,* 2009; Miall, 2010b; Reesink *et al.,* 2014). A gradual increase in set thicknesses from 0.10 m (facies Stsx <1.5 m) to 0.25 m (facies Stmx <1.5-3.0 m) suggest a gradual increase in the channels flow and sediment load capacity, probably facilitated by flood events (high-flow stage) and subsequent net sediment deposition during waning flow (low-flow stage) (cf. Coleman, 1969; Bristow, 1987, 1993a; Ashworth *et al.,* 2011). The size of cross-bedding relating to facies Stmx <1.5-3.0 m implies downstream-accretion within a relatively broad and deep channel with dune migration near to the channel thalweg/axis; larger dunes tend to develop towards deeper channel thalweg regions within relatively broad/deep channels (cf. Reesink & Bridge, 2009; Ashworth et al., 2011; Reesink et al., 2014). The intermittent minor granule to medium pebble lags, which delineate the sets relating to facies Stmx <1.5-3.0 m, may represent scouring (Miall, 2010b) or winnowing (cf. Collinson *et al.,* 2006) processes with no obvious evidence of a fifth-order channel surface; lag deposits may also denote channel thalweg/axial regions (Fidolini *et al.*, 2013; Ghinassi *et al.*, 2014). A further deposit of facies Sl-hss <1.0 m denotes a return to shallower fluvial conditions decreasing the channels flow and sediment load capacity, influenced by waning flow and channel fill (cf. Cant & Walker, 1976; Ashworth *et al.*, 2011; Reesink *et al.*, 2014), see above interpretations relating to facies Sl-hss <1.0 m. The uppermost facies of Sfp likely represent the horizontal to slightly sub-horizontal migration and net accretion of 3D mesoforms within a relatively shallow thalweg region of a low sinuosity channel (cf. Bristow, 1988, 1993a; Ghinassi *et al.,* 2009; Miall, 2010b; Reesink *et al.,* 2014), influenced by waning flow, net sediment aggradation and channel fill (cf. Cant & Walker, 1976; Ashworth *et al.*, 2011; Reesink *et al.*, 2014), see above interpretations relating to facies Sl-hhs <1.0 m and Sl-hss <1.0 m. Evidence of channel fill is provided by various fossilised plant remnants throughout the facies which suggests that the fluvial channel was sufficiently shallow to entrap plant debris prior to being encased by subsequent sediment deposits which facilitated fossil preservation; if propagated locally the presence of vegetation would have promoted channel bank and/or channel bar stability.

The overall interpretation relating to Outcrop 33.3 suggests that deposition was probably related to downstream migration and accretion associated with the latter stages of a channel fill sequence. Palaeocurrent data suggests that the principal channel flow was towards the northeast, unlike previous outcrops (e.g. Outcrops 33.1 and 33.2) which were relatively more heterogeneous.

Outcrop 33.4: Although limited, data relating to Outcrop 33.4 imply that the depositional palaeocurrent was generally towards the northeast (Fig. 4.4 Location 33).

Deposition of facies Stsx <1.5 m likely represent the downstream migration and net accretion of 3D mesoforms within a relatively shallow thalweg region of a low sinuosity channel (cf. Bristow, 1988, 1993a; Ghinassi *et al.,* 2009; Miall, 2010b; Reesink *et al.,* 2014), influenced by waning flow, net sediment aggradation and channel fill (cf. Cant & Walker, 1976; Ashworth *et al.*, 2011; Reesink *et al.*, 2014). Such facies may also indicate migratory bedforms that likely developed on the surface of a larger sand flat (cf. Cant & Walker, 1976, 1978). Alternatively, such bedforms are also associated with a series of distinct depositional episodes (cf. Collinson *et al.,* 2006) of assembled sets divided by first-order set boundaries which indicate repeated bedform migration probably as a train of dunes (dune stacking) which may have formed components of a channel bar top (cf. Bristow, 1993b; Best *et al.*, 2003; Bridge & Lunt, 2006; Mumpy *et al*., 2007; Miall, 2010b; Ashworth *et al.*, 2011), or may have formed along the crest or front/tail of a migrating bar (macroform) (cf. Allen, 1982; Haszeldine, 1983b; Miall, 2010b; Ashworth *et al.*, 2011). A predominant dune height of ~0.36 m implies minor sediment input into a relatively shallow channel (~1.10 m deep) subjected to turbulent flow conditions, probably facilitated by flood events (high-flow stage) which facilitated dune migration and the formation of down-climbing dunes (cf. Bristow, 1988, 1993a; Reesink & Bridge, 2009; Ghinassi, 2011) and subsequent net sediment deposition during waning flow (low-flow stage) (cf. Coleman, 1969; Bristow, 1987, 1993a; Ashworth *et al.,* 2011). Low-flow stage would have also facilitated the aggradation of 3D mesoforms and channel fill (cf. Cant & Walker, 1976; Ashworth *et al.*, 2011; Reesink *et al.*, 2014). Collectively such mesoforms may form unit bars (cf. Sambrook Smith *et al.*, 2006; Reesink & Bridge, 2009), or components of a host dune coset (cf. Haszeldine, 1983b); a collective coset thickness of ~0.50 m equates to a maximum channel depth of ~1.50 m. Similarly, preservation of consecutive cross-laminated sets inevitably encompasses a measure of net deposition and subject to the inclination of their host bed most sets will climb at a similar angle (Leeder, 1982).

The overall interpretation relating to Outcrop 33.4 suggests that deposition was probably related to downstream migration and accretion associated with the latter stages of a channel fill sequence. Palaeocurrent data suggests that the principal channel flow was towards the northeast, similar to Outcrop 33.3.

Table 4.34

Location, grid reference and associated literature	General description and lithology
34. Knoxstone Crags (Fell Beck) Outcrops 34.1: SE 20070 65837 Thompson, A. T. (1957) *The structure and stratigraphy of Nidderdale between Lofthouse and Dacre*. Unpublished, Doctoral thesis, Durham University. Available at Durham E-Theses Online: http://etheses.dur.ac.uk/722/.	Various sized outcrops running from Knoxstone Crags along, and scattered down, the eastern flank of Fell Beck, in a south-westerly direction. Outcrops are generally masked (in part) by soil and vegetation (e.g. lichen, moss and/or detritus) associated with a woodland setting. Although several outcrops appear to have been disarticulated and/or migrated down the eastern flank of Fell Beck, the in-sitú examined outcrop is the largest of a number of small outcrops running along the ridge line. Generally, all the outcrops are jointed both horizontally and vertically, weathered and possess a variable texture with relatively poor outcrop detail (e.g. foreset/sets), due to the processes of weathering and erosion. Outcrop examined is a relatively small representative example of the outcrops in the locality. Elevation of Outcrop 34.1 is ~206 m O.D; main outcrop view is towards ~090˚ (Fig. 4.4 Location 34). Outcrop 34.1: Coarse-grained to granular sandstone with ~2% small to medium pebble content (variable), predominantly quartz grains; generally low to high sphericity; sub-angular to rounded; poorly to moderately sorted.

Identified sub-Facies, sedimentary structures and bounding surfaces of note

Outcrop 34.1 [~2.0 (H) x 3.0 (D) x 6.0 m (W)]: **1.** ~0.80 m thick coset of *Stsx <1.5 m (St); small-scale trough cross-bedding <1.5 m trough width; coset consist of 0.15-0.20 m thick cross-cutting sets; poorly defined low-amplitude cross-bedding towards upper section of coset; poorly defined, likely horizontal and undulating contact with overlying coset; **2.** ~0.40 m thick coset of *Stmx 1.5-3.0 m (St); medium-scale trough cross-bedding 1.5–3.0 m trough width; coset consist of ~0.20 m thick cross-cutting sets; poorly defined low-amplitude cross-bedding; sharp likely horizontal contact with overlying coset; **3.** ~0.60 m thick coset of *Sl-hpx <2.0 m (Sp); low to high-angle-inclined foresets forming small to medium-scale planar cross-bedding; two 0.25-0.35 m thick slightly sub-horizontal sets; poorly defined tangential foresets (in part).

Interpretation

Outcrop 34.1: The sub-horizontal bedding relating to Outcrop 34.1 appears to be the result of minor cambering towards the northwest. The affected bedding and palaeocurrent data was restored through stereographic projection, relative to the 16˚ dip and 322˚ azimuth inferred from the contact inclinations relating to the boundary between facies Stmx 1.5-3.0 m and Sl-hpx <2.0 m. Although the initial depositional palaeocurrent appears relatively constant towards the northwest, the restored palaeocurrent data suggests that the principal channel flow migrated from a north-westerly direction to a more westerly direction, as the bedform size and channel depth increased (Fig. 4.4 Location 34). The restored cross-bedding appears more consistent with that of lateral and/or downstream migrating bedforms; hence, the restored data was adopted when interpreting Outcrop 34.1.

Set thicknesses of 0.15-0.20 m relating to the basal coset of facies Stsx <1.5 m suggest influence from a channel with variable flow depth (1.60-2.15 m; cf. Leclair, 2011) facilitated by flood events (high-flow stage) and subsequent net sediment deposition during waning flow (low-flow stage) (cf. Coleman, 1969; Bristow, 1987, 1993a; Ashworth *et al.,* 2011). Low-flow stage would have also facilitated the aggradation of 3D mesoforms and channel fill (cf. Cant & Walker, 1976; Ashworth *et al.*, 2011; Reesink *et al.*, 2014). Similarly, such bedforms are associated with a series of distinct depositional episodes (cf. Collinson *et al.,* 2006) of assembled sets divided by first-order set boundaries which indicate repeated bedform migration probably as a train of dunes (dune stacking) which may have formed components of a channel bar top (cf. Bristow, 1993b; Best *et al.*, 2003; Bridge & Lunt, 2006; Mumpy *et al*., 2007; Miall, 2010b; Ashworth *et al.*, 2011). A subsequent flood event likely facilitated the deposition of facies Stmx 1.5-3.0 m, with sediment migration and aggradation influenced by high and low-flow stages, respectively (Coleman, 1969; Bristow, 1987, 1993a; Ashworth *et al.,* 2011). The subsequent coset of facies Sl-hpx <2.0 m likely represent downstream migration of a medium-scale bedform, where the individual sub-horizontal sets of Sl-hpx <2.0 m likely form components of a larger host dune coset (cf. Haszeldine, 1983b), influenced by high-flow stage which facilitated the formation of down-climbing dunes (cf. Bristow, 1988, 1993a; Reesink & Bridge, 2009; Ghinassi, 2011). Such cosets may also represent migratory mid-channel bar bedform components (cf. Reesink & Bridge, 2009) that likely formed within a multi-channelled fluvial system (cf. Reesink *et al*., 2014) and/or medium-scale migrating unit bars (cf. Sambrook Smith *et al.*,2006; Reesink & Bridge, 2009), which in turn may form components of a much larger host compound bar (cf. Allen, 1982; Bridge, 2003; Bridge & Lunt, 2006; Sambrook Smith *et al.*, 2006; Ashworth *et al.*, 2011), although such component coset/unit bar heights coincide with dune heights (Ashworth *et al.*, 2011). Taken individually, a set thickness of ~0.35 m equates to a maximum dune height and channel depth of ~1.25 m and ~3.80 m, respectively; collectively, the~0.60 m thick coset relating to facies Sl-hpx <2.0 m equates to a maximum dune/unit bar height and channel depth of ~1.50 m and ~3.00 m, respectively. The increasing size of cross-bedding moving up the outcrop sequence implies downstream-accretion within a relatively broad and increasingly deeper channel with dune migration near to the channel thalweg/axis; large dunes tend to develop towards deeper channel thalweg regions within relatively broad/deep channels (cf. Reesink & Bridge, 2009; Ashworth et al., 2011; Reesink et al., 2014).

Generally, the facies sequence associated with Outcrop 34.1 is probably related to the downstream migration and accretion of channel fill components. The relative increase in set thicknesses moving up the outcrop implies that the channel was progressively deeper moving up the sequence and the restored palaeocurrent data suggests that the principal channel flow migrated from a north-westerly direction to a more westerly direction, as the bedform size and channel depth increased. The preservation of consecutive cross-laminated sets inevitably encompasses a measure of net deposition (Leeder, 1982); thereby reducing flow depth over the component bedform which in turn would increase flow velocity and sediment transport (cf. Reesink & Bridge, 2009). Such conditions would subdue dune formation and generate low relief dunes (cf. Bristow, 1993a), as exhibited by the relatively low-angle bedforms (≤10°) associated with the host channel; generally foreset gradients decline as a flow regime intensifies, vice versa (cf. Smith, 1972). Further, preservation of low-angle bounding surfaces (e.g. facies Stsx <1.5 m and Stmx <1.5-3.0 m) correspond to channels possessing high width to depth ratios (Bristow, 1987, 1993a); similarly, Outcrop 34.1 is dominated by a coarse-grained to granular sandstone which coincides with Coleman's (1969) observation that rivers with significant quantities of coarse sediment are representative of broad, flat, island-obstructed fluvial systems, although the term bar-obstructed is more appropriate (sensu Bridge, 2003).

Location and Grid Reference	Associated Literature	Notes
35. Crag Hall SE 18030 55030	Wilson, A.A. (1977) The Namurian Rocks of the Fewston Area. *Transactions of the Leeds Geological Association*, 9, No. 1, 1-42.	Small stream flowing through a steep sided gully with dense vegetation along embankment. Stream bed appears to consist of a fine grained flaggy sandstone with similar poorly exposed <1.0 m thick blocks of fine grained sandstone observed along gully embankment, outcrops are likely related to the Libishaw Sandstone (see Wilson, 1977). Also outcropping along embankment are poorly exposed <1.0 m thick blocks of very coarse-grained to granular sandstone, likely related to the Lower Brimham Grit (see Wilson, 1977); insufficient detail for facies or palaeocurrent analysis.
36. Thrucross Quarry SE 15110 58470	Wilson, A.A. (1977) The Namurian Rocks of the Fewston Area. *Transactions of the Leeds Geological Association*, 9, No. 1, 1-42.	No obvious exposure and no evidence of quarry activity, appears that any former quarry at the locality was probably used for landfill. Local resident confirms that there were no quarries in the vicinity.
37. Lower Brimham Grit outlier SE 18500 55000	Wilson, A.A. (1977) The Namurian Rocks of the Fewston Area. *Transactions of the Leeds Geological Association*, 9, No. 1, 1-42.	Open pasture with no obvious outcrop exposure; grid reference referred to by Wilson (1977) probably relates to the general location of a Lower Brimham Grit outlier, or the grid reference may be incorrect.
38. Scarah Bank Disused Quarry SE 27715 62135	Thompson, A. T. (1957) *The structure and stratigraphy of Nidderdale between Lofthouse and Dacre*. Unpublished, Doctoral thesis, Durham University. Available at Durham E-Theses Online: http://etheses.dur.ac.uk/722/.	Small disused and partially filled quarry adjacent to Scarah Bank; quarry consists of very fragmented and disarticulated rock fragments; insufficient detail for facies or palaeocurrent analysis, primarily due to the effects of weathering and erosion.
40. Scarah Bank Disused Quarry SE 27300 62300	Thompson, A. T. (1957) – *As above.*	Small disused and partially filled quarry located in woodland near to Scarah Bank; quarry consists of very fragmented and disarticulated rock fragments; insufficient detail for facies or palaeocurrent analysis, primarily due to the effects of weathering and erosion.
41. Low Farm SE 23500 65000	Thompson, A. T. (1957) – *As above.*	Informed by local farmer that there were no obvious outcrops of note near to stream running across farmland; location not visited.
42. High Moor SE 22200 66550	Thompson, A. T. (1957) – *As above.*	Informed by local game keeper that there were no obvious outcrops of note on High Moor; location not visited.
43. Colber Beck SE 25000 64700	Thompson, A. T. (1957) – *As above.*	Informed by local farmer that the beck runs along the surface, with no obvious outcrops of note near to beck; location not visited.
44. Sawley Hall SE 25650 66800	Thompson, A. T. (1957) – *As above.*	Informed by groundsman that the grounds were the location of a borehole, with no obvious outcrops in the immediate locality; location not visited.
45. Calf Haugh Wood SE 24300 65800	Thompson, A. T. (1957) – *As above.*	Informed by local game keeper that the location was overgrown with Rhododendron shrubs and that access was restricted; location not visited.
46. Hebden Wood House Farm SE 24400 65400	Thompson, A. T. (1957) – *As above.*	Informed by local farmer that there were no obvious outcrops of note near to the locality; location not visited.
48. Volla Wood Farm SE 24730 64970	Thompson, A. T. (1957) – *As above.*	Location recorded as borehole site; location not visited.
49. Gill Moor Farm SE 24420 64290	Thompson, A. T. (1957) – *As above.*	Location recorded as borehole site; location not visited.
50. High Gill Moor Farm SE 23780 64900	Thompson, A. T. (1957) – *As above.*	Location recorded as borehole site; location not visited.
51. Klondyke Quarries SE 24300 65800	Thompson, A. T. (1957) – *As above.*	Quarries mainly filled in, Brimham Grit outcrops visible within adjoining woodland, access restricted due to vegetation. Outcrops extend eastwards from Quarry Hill (SE 22060 65770) to North Owl (SE 22830 65710), access to farmland not permitted, due to livestock.
52. Middle South Farm SE 22570 65060	Thompson, A. T. (1957) – *As above.*	Stream section not visited, access to farmland not permitted, due to livestock.