4 Macduff, Dalradian Turbidite fan and glacial deposits

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Purpose

To demonstrate the sedimentology of the Macduff Slate Formation (Southern Highland Group, Dalradian) which display features typical of turbidite fan deposition, and to examine the Macduff Boulder Bed, which is interpreted as a glacial dropstone deposit. Locality 8 of this excursion is the starting point for Excursion 5 by Hudson (1987 guide book) which examines the Buchan type regional metamorphism of the area.

Access

The localities described occur in cliffs and on rocky foreshore at the east end of Macduff Shore 100 m east of the last of the old cottages facing the sea, and beside the fence surrounding the grassed-over site of Macduff rubbish tip, which is now used as a recreation area. Parking is available at this point, and also in Tarlair Bay (Figure 1). The area is covered by O.S. 1:50,000 sheet 29 and Geological Survey 1:63,360 sheet 96 (Banff).

Introduction

The Macduff Slates of the Southern Highland Group display the lowest metamorphic grade seen in the Dalradian in Buchan and are generally assumed to form the highest unit of the Dalradian in NE Scotland. They are best exposed on the coast from Banff to Gardenstown. East of the coastal Old Red Sandstone exposures of the Gamrie-Turriff Basin the Dalradian is increasingly metamorphosed and sedimentary features not so readily observed. To the west of Macduff the increase in metamorphic grade is described in Excursion 5 (Hudson 1987). Inland the Macduff Slates are thermally metamorphosed by the 'Newer Basic' intrusions and were folded and cleaved prior to the time of intrusion, which is dated at c. 470 +/– 9 Ma (TIMS zircon age) (Dempster et al. 2002).

Detailed accounts of the geological history of the area are given in Macdonald and Fettes (2007) and Trewin (ed) 2002. A poor microfossil assemblage was extracted from the Macduff Slates by Downie *et al.* (1971) which led them to suggest an age possibly as young as Llanvirn, and Molyneux (1998) considered that an acritarch from the slate could be early Ordovician. The Silurian graptolite *Monograptus priodon* in Hugh Miller's collection labelled from a locality within the Macduff Slates of the Gamrie area is wrongly localised (Trewin 1973). On stratigraphic evidence the Macduff Slates are possibly early Cambrian in age and may have been accumulating in a deep trough whilst the Durness Limestone was being deposited on shelf areas to the NW, but as indicated by Anderton (1985) it is still possible that the Macduff Slates are older than the Durness Limestone. However, Strachan et al. (2002) suggest an age of c 490–480 for the end of deposition of the Macduff Slates, hence placing them in the Ordovician. Such a young age is not consistent with the simple forms of trace fossils found in the Macduff Slates, hence my preference for an age no younger than early Cambrian (Trewin and Rollin 2002, Stoker et al. 1999).

With the exception of the Macduff Boulder Bed, the Macduff Slates are interpreted as the deposits of deep water turbidite fans of which simple models and bed types are shown in (Figure 2), (Figure 3), (Figure 4), (Figure 5). Sutton and Watson (1955) first recognised the deep water origin of the Macduff Slates and illustrated some of the characteristic structures.

Itinerary

Locality 1 [NJ 7120 6490]

On the shore to the west of the promontory there are good exposures with a variety of lithologies and sedimentary structures, best seen at the foot of the pebble beach where the rocks have been smoothed by wave action. Typical coarse greywackes (technically conglomerates) with abundant quartz and feldspar clasts of 5–8 mm size form beds that frequently include rip-up clasts of mudstone (Figure 6). Thinner beds are generally finer grained (medium to coarse sandstone) have erosive bases, and display grading and ripple lamination.

The rocks forming the promontory display a wide variety of sedimentary structures and bed types. The strata strike 020° and dip 80° east. The lowest strata exposed on the west of the promontory are thick-bedded coarse greywackes. Beds are 20–100 cm thick but become amalgamated into units of up to 3 m thickness. The greywackes are massive with little evidence of internal structures.

Towards the top of this coarse-grained unit the bed thickness decreases and normal grading is well developed in the greywackes. Internal structures are rare and confined to bed tops, and shale interbeds are thin and infrequent. A typical sequence at the top of the coarse, thick-bedded unit is shown in (Figure 5). The coarse-grained sequence probably forms part of a channel-fill sequence in an inner to mid-fan environment (Figure 2), (Figure 4).

Locality 2 [NJ 7122 6495]

The sequence at locality 1 is immediately followed by a finer-grained thin-bedded sequence which shows the development of graded beds up to 25 cm thick, many of which display the typical Bouma sequence of internal sedimentary structures characteristic of deposition from a decelerating turbidity current (Figs 3, 7). Suitably weathered cross-sections of beds show the structures in great detail and all types of sequence can be found, but the most frequent are thin beds showing base cut-out Bouma sequences (Figure 2) commencing with ripple- lamination and grading up through fine parallel-lamination to a graded mudstone top. A log of a typical sequence is shown in (Figure 5). Within this predominantly fine-grained sequence, coarse-grained material is present in a few prominent beds which show considerable lateral variation. The bed types comprise normal coarse-grained, thick, graded beds as previously noted, but one bed has almost symmetrical grading, a sharp top and base and dies out from 30 cm thickness in 15 metres laterally. Two other beds (Figure 5) show concentrations of abundant rip-up shale clasts, and in some places clasts exceed matrix in volume. The shale was torn up from the bed over which the current flowed, but the sediment-laden flow rapidly 'froze', so preserving the shale clasts before they fully disintegrated. Evidence of the erosive nature of the currents can be seen in examples of crosscutting relationships at bed bases where shale has been torn from the substrate. There are also beds that appear to have formed by coarse sand intruding and disrupting the original mudrocks. Some beds rich in shale clasts may have formed by liquefaction of sands containing interbedded muds, with consequent disruption and mixing of the partly consolidated mud interbeds.

Below the major bed with rip-up clasts is a development of thin-bedded facies with rippled fine-grained sandstone forming thin wavy beds with pale sandy ripple lenticles set in mudstone. The ripple tops are frequently sharp and appear to have been formed by reworking of fine sand by clear water currents rather than sediment-laden density currents. The ripples indicate a consistent transport direction, and they may have been formed by contour currents flowing along the basin slope. The emplacement of the overlying coarse bed has caused slight disruption of this facies giving small sandstone filled dykes. The beds exposed are typical of deep water turbidite fan deposits and the individual bed sequence types can be assigned to a number of situations on a simple fan model (Table 1) and (Figure 2).

After examining the turbidites and associated sediments at localities 1 and 2 it is advisable to return to the parking area and follow the landward side of the fence eastwards until a gap can be found to scramble under or over the fence. Recent erosion has made it dangerous to attempt access from locality 1 to 2 on the seaward side of the fence. The dip of the strata decreases to the east until a synclinal axis is reached which strikes N-S and plunges gently north. Descend to the flat rock platform known as The Sclates (Figure 8) in the synclinal axis of the fold which exposes the Macduff Boulder Bed at locality 3.

Locality 3 Macduff Boulder Bed [NJ 7137 6492]

The Macduff Boulder Bed at this locality is at least 11 m thick but neither the top nor base are seen due to minor faulting. The majority of the deposit consists of dark coloured bedded mudstone or fine-grained sandstone with occasional pale coloured ripple lenticles giving evidence that bottom currents sorted and winnowed the sediment on the sea bed. Scattered throughout the deposit are particles of various rock types from sand to boulder size (Figure 9). The largest boulder is exposed in the landward face of a shore reef near the synclinal axis (Figure 10). This boulder is anorthositic in composition but others comprise a variety of rock types including granite, adamellite, quartz porphyry, gneiss, limestone and quartzite. The boulders and pebbles range from angular to well-rounded. The scattered boulders, pebbles and coarse sand are of different rock types to those found in the normal deep water sediments of the Macduff Slates.

The currents responsible for the sedimentary structures in the beds could not have transported the coarse material of the Boulder Bed. The most probable explanation for the presence of the boulders is that they were dropped from floating ice into the deep water environment (Sutton and Watson 1954). Some of the large clasts are clearly impressed into the underlying sediments, but compaction features have masked this relationship in most cases. The angular and rounded clasts were derived from glacial sediments frozen into icebergs derived from a glaciated area. The rounded pebbles were obviously water transported prior to incorporation in the floating ice and could have been derived from a river or beach environment.

A small area on the top of a reef near the sea contains the highest exposed part of the Boulder Bed. A greater concentration of pebbles (mainly limestone) within a calcareous matrix gives this patch of outcrop a different appearance but it can be traced laterally into 'normal' Boulder Bed. Hambrey and Waddams (1981) considered that this outcrop represented the top of the Upper Dalradian sequence in the area. This cannot be proven due to the local faulting present, and structural profiles and metamorphic patterns of the coast section as a whole render this highly improbable. They also likened this small outcrop to a lodgement till, deposited by grounded ice. This is also unlikely in view of the deep water nature of the rest of the sequence, and it seems more likely that this was a patch of stones dropped frozen together from floating ice, for which there are numerous Quaternary analogues. Sutton and Watson (1954) speculated on the source of the pebbles, and although some resemble lithologies found in the Moine or lower in the Dalradian, no definite derivations can be deduced. The source is certainly different from that supplying the turbidites.

On the flat surface on the synclinal axis a series of rounded troughs separated by sharper ridges are exposed oriented N–S (Figure 11). This structure is confined to one bedding surface in the bed below that containing the large boulder. This feature is a sedimentary structure similar to convolute lamination and was possibly caused by shock waves causing partial liquefaction and disruption of the soft sediment shortly after deposition. The structure does not seem to resemble 'slump folds' as suggested by Hambrey and Waddams (1981).

A prominent inclined bedding surface close the rough path that descends to the small bay to the west of the Sclates is covered in slickensides formed due to bedding-plane slip during folding (Figure 12). The slickensides are formed in quartz, and the direction of relative slip between the beds can be easily determined by running your hand over the surface.

On the wave smoothed west wall of the small bay to the east, the details of the ripple- lamination and bedding within the Boulder Bed can be examined and scattered pebbles found throughout the deposit. A fault intervenes in the gully at this point and (seen only at low tide) the rocks exposed in the bay are generally fine-grained, with ripple-lamination in thin beds. No dropped-in pebbles have been found in these rocks. This interpretation differs from that of Hambrey and Waddams (1981) who continue the dropstone bearing deposit into the bay and do not recognise a faulted margin.

A similar glacial dropstone facies, up to 22 m thick is exposed 4 km to the east of Macduff in a bay east of the Head of Garness [NJ 747 648] which could be visited to extend this excursion. Despite careful logging it cannot be proven that the two exposures represent the same unit but the possibility remains that they are at the same stratigraphic level and represent a single short period when floating ice entered this area.

Locality 4 [NJ 7145 6485]

The excursion continues with further examples of turbidite fan deposits. Cross the small bay and ascend the path up the grassy slope into the western end of Berrymuir Quarry. The rocks described for this locality in the 1987 guide (Trewin 1987) are no longer exposed due to 'landscaping' of the quarry when the Wastewater Treatment Works was built. A section in very thick-bedded (to 5 m) coarse-grained greywackes in which individual beds are mostly amalgamated was formerly exposed. In environmental terms this thick-bedded facies probably represents the fill of large channels on the mid to inner fan area (Figure 2), (Figure 4). The associated fine-grained rocks with ripples represent fine-grained deposition on channel levees and in areas between the channels which were by-passed by the strong currents. Similar deposits can be examined at localities 6 and 7 (see below).

(Table 1) Environmental interpretations of bed sequence types in the Macduff Slates.

Bed sequence type
Thick-bedded (up to 5 m) generally massive, amalgamated beds, grading rare, occasional shale clasts, very few shale interbeds. Indistinct parallel- lamination and disruption structures present (Localites . 1, 4, 6).
Thick 20–100 cm beds with well developed grading, parallel- and ripple- lamination in top few cm of beds, thin shale interbeds but many beds amalgamated. Form thinning and fining-up sequences (Loc. 1).
Thin-bedded facies. Beds 5–25 cm thick with well-developed Bouma sequences with frequent base cut-out beds (Localites 2, 7).
Isolated ripples in mudstone with sharp-topped ripples due to reworking of fine sand, thin Bouma sequence beds also present and reworked. Coarse beds with shale clasts are intercalated in the fine-grained facies (Figure 3) and Localites. 2, 7).
Interpretation
Major channel sands of inner turbidite fan. Deposited by debris flow, liquefied flow, and high density turbidity currents. (Facies A-B, (Figure 2)).
Channel sands of mid to inner fan, deposited by high density turbidity currents. (Facies B)
Overbank facies from levéed channels when associated with coarse beds, or outer fan, deposition by weak turbidity currents. (Facies D)
Overbank (levee) deposits from channels and deposits in inter-channel areas. Deposited by turbidity currents and by reworking of sand by bottom currents. Coarse material from overflows and bursts from main channels. (Facies E).

Locality 5 [NJ 7164 6485]

The quarry face near the two white concrete silos displays similar sequences of greywacke turbidites to those already described. The strata generally strike close to 020° and are cut by several steeply inclined faults or shear planes which tend to fault out the axes of the folds. Anticlinal and synclinal axes can be observed with anticlinal axes trending around 020° and plunging north at 10° Landscaping has obscured some of the structures on the quarry face but they can be examined in the adjacent sea cliffs. On the beach north of the blue building in the treatment works a sharp anticlinal axis is easily examined (Figure 13), and a synclinal axis is preserved a few metres to the west. Follow the outside of the wire fence around to the road and continue into Tarlair Bay.

Locality 6 [NJ 7182 6475]

The cliffs at the western side of Tarlair Bay are composed of typical thick bedded, coarse- grained turbidites showing similar features to those at locality 1. Thick amalgamated beds with mud clasts are well exposed, and a rare instance of cross-bedding is seen. These are likely to be major channel deposits of a turbidite fan. The bay is cut in predominantly fine- grained units which can be examined at low tide on the rocky intertidal platform.

Locality 7 [NJ 7185 6430]

An isolated 2 metre-thick bed of coarse greywacke crosses the shore and rests on mudstone beds, and thin ripple-laminated beds. For some 50 cm below the base of the coarse bed the fine-grained lithologies have been strongly folded with the axial planes of the folds parallel to bedding. This folding appears to have taken place due to shear in the soft sediment at the time of emplacement of the coarse bed. Between this bed and the promontory within the bay which contains the natural arch known as the Needle's Eye, there are good exposures of the ripple-laminated lithology previously described at locality 2, and tentatively assigned to contour currents. There are also massive mudstones in which lamination is frequently indistinct and in places is clearly folded. It is possible that these mudstones were emplaced by slumping and represent 'Facies F**'** of (Figure 2).

Locality 8 [NJ 7190 6465]

After crossing a synclinal axis, the coarser grained turbidites seen at locality 6 again appear though now younging westwards. Some beds are underlain by distorted strata as described above at locality 7.

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Figures

(Figure 1) Locality map of Macduff area.

(Figure 2) Diagram of a simple fan model to illustrate common bed types found in turbidite fans, and sedimentary structures characteristic of each bed type. Bed sequences found in different areas of the fan are also illustrated. The distribution of facies associations A-G (Simplified from Mutti and Ricci Lucchi 1972) is illustrated on the fan model and the bed types normally associated with each facies are indicated. Brief diagnoses of each facies type are given below. Facies A. Coarse-grained debris flows and ?grain flows, occasionally conglomeratic. Normal, reverse and ungraded thick beds. Channel and scour features common, beds composite. Facies B. High density turbidite beds and fluidised flow beds. Usually medium- to coarse- grained and pebbly. Occur in amalgamated sequences lacking mud interbeds, commonly characteristic of channels in inner to mid-fan. Facies C. Laterally extensive turbidites with Bouma sequences. Beds 0.25–2.5 m thick characteristic of mid-fan lobes with increase in high density turbidite beds into channel mouth. Mud interbeds increase away from channel mouth. Facies D. Base cut-out Bouma sequences with dominant mud interbeds. Characteristic of outer fan, but also occur as overbank deposits between channels. Facies E. Thin sand and mud interbeds with frequent flaser bedding, associated with thin, massive beds and graded beds including base cut-out Bouma sequences. Strong gravity and traction currents occasionally sweep inter-channel areas. Facies F. Slump bedded material concentrated along base of slope and at channel margins in inner fan. Facies G. Pelagic and hemipelagic material deposited from suspension and possibly modified by traction currents, coarsest in inner fan and finest and most abundant at outer fan fringe.

(Figure 3) The Bouma sequence a-e of structures characteristic of deposition by turbidity currents.

(Figure 4) Diagram to show general cross-sectional form of a turbidite fan channel with leveés. An earlier channel fill A has been cut into by later channel B. Turbidity currents overtop the levees as shown, but most coarse sediment is transported within the channel. Channels can be 10's of metres to over 1 km wide and relief on large channels can be over 200 m above the channel floor. The vertical exaggeration is about 10 to 1.

(Figure 5) Log of turbidite sequences at localities 1 and 2 and interpreted depositional positions on a turbidite fan model.

(Figure 6) Rip-up clasts of shale within coarse-grained greywacke. Locality 1.

(Figure 7) Graded turbidite bed displaying Bouma sequence of sedimentary structures. Locality 2.

(Figure 8) View from the cliff-top of the synclinal fold axis at The Sclates. Locality 3.

(Figure 9) Cut and etched surface of specimen from the Macduff Boulder Bed showing sedimentary lamination and a variety of clasts ranging from angular to rounded that were dropped into the deposit from floating ice.

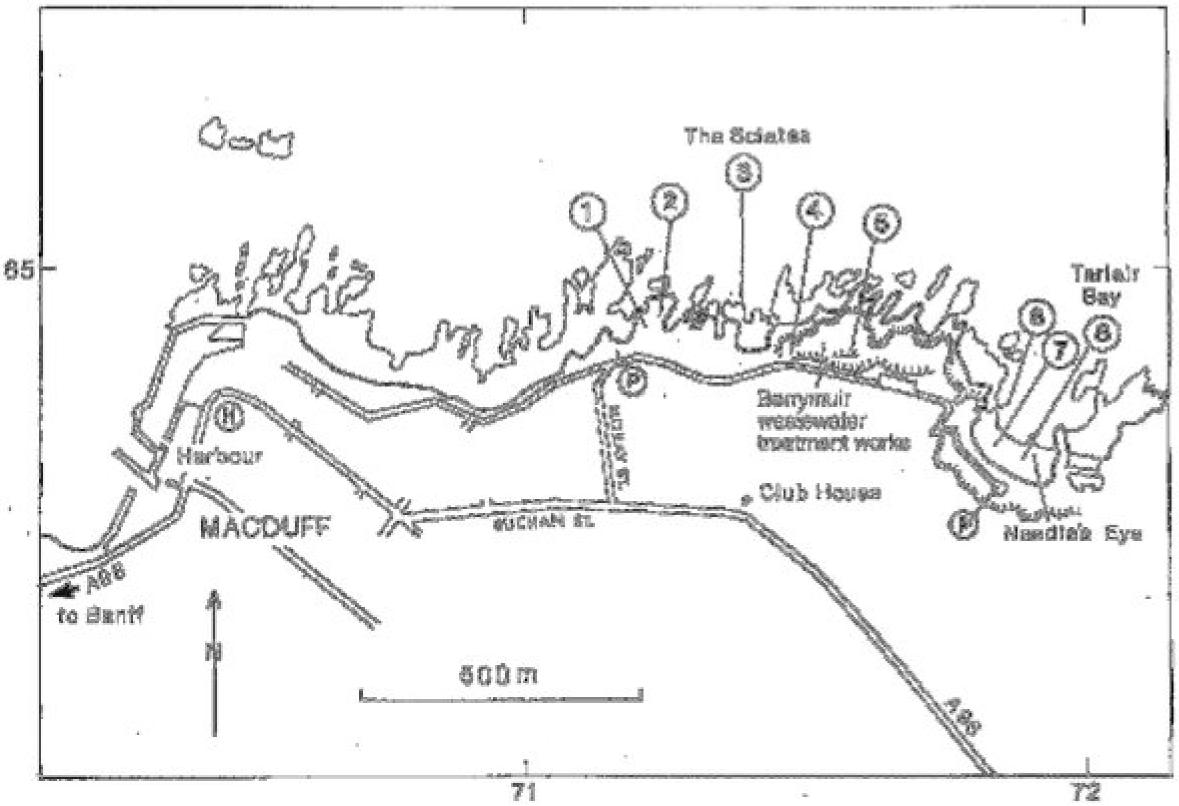
(Figure 10) The large dropstone boulder of anorthositic composition within the Macduff Boulder Bed at The Sclates. Locality 3.

(Figure 11) Internal soft-sediment deformation features with rounded synclines and sharp anticlines within a bed at The Sclates. Locality 3.

(Figure 12) Slickensides in quartz on a bedding plane. Locality 3.

(Figure 13) Anticlinal fold axis plunging to the north on beach. Locality 5.

(Table 1) Environmental interpretations of bed sequence types in the Macduff Slates.



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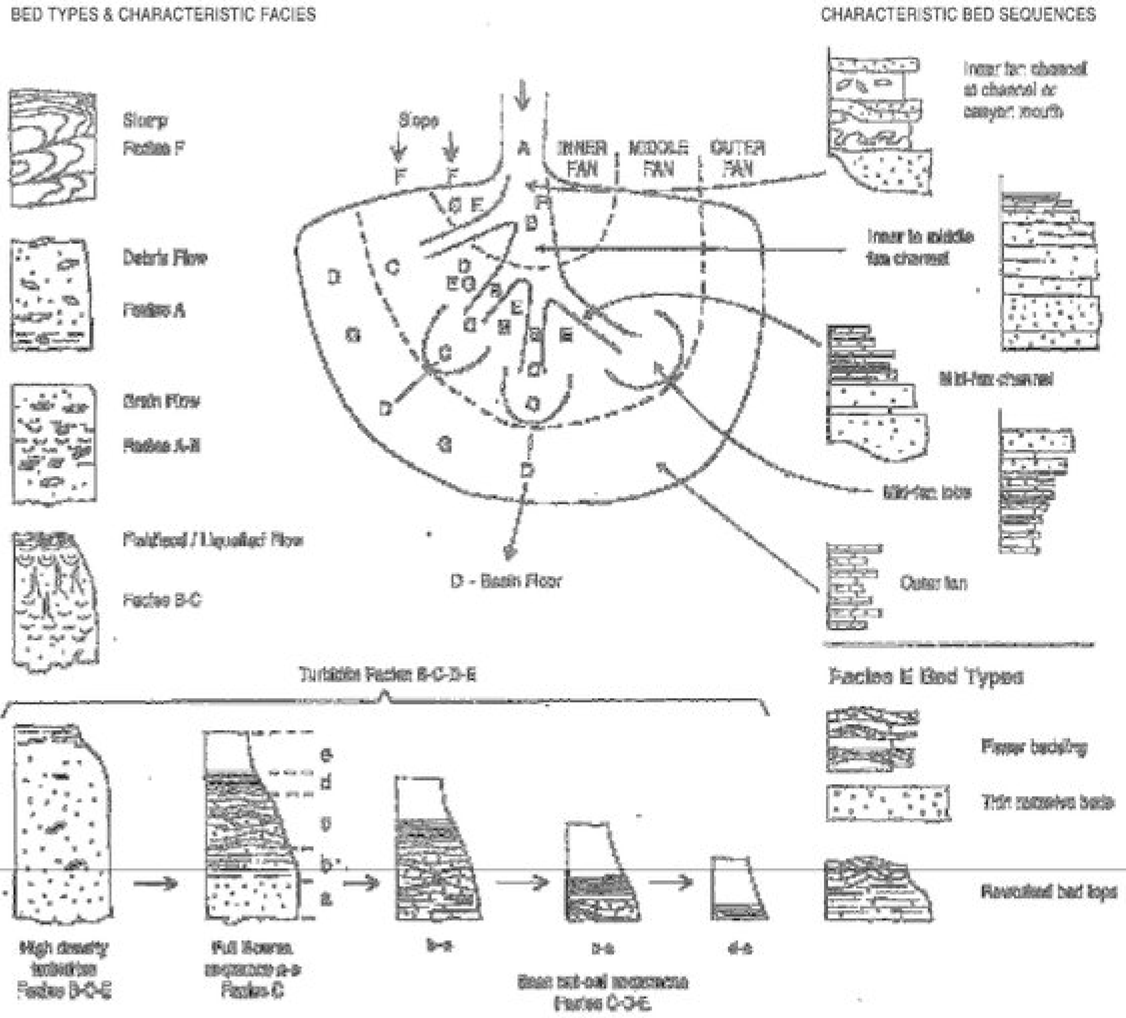
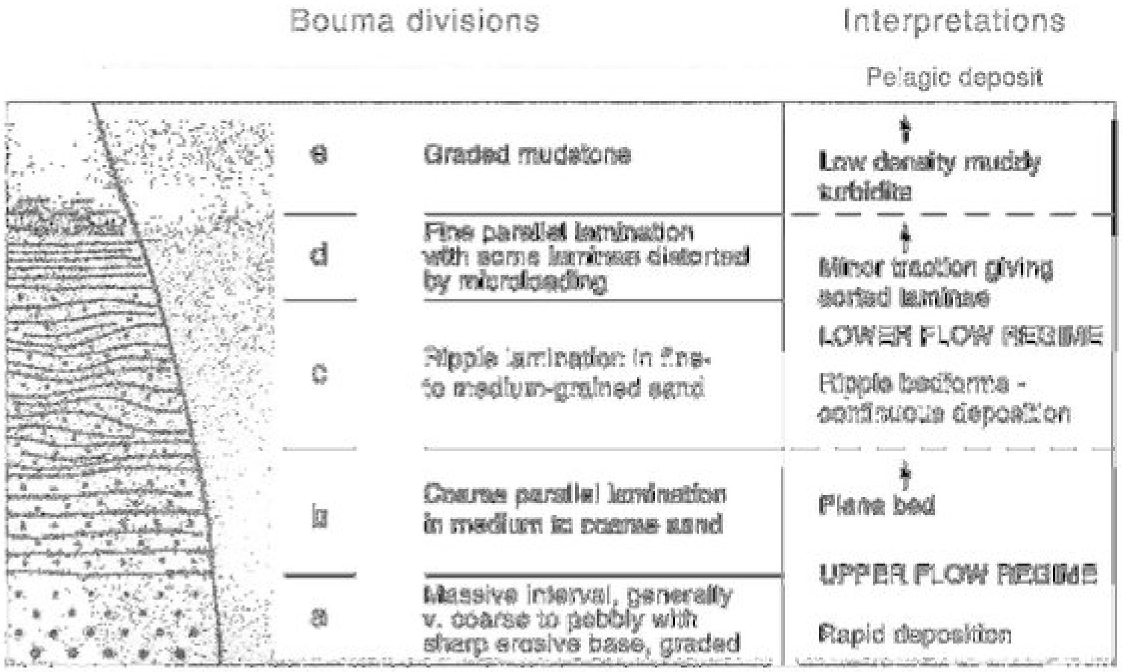
BED TYPES & FACIES DISTRIBUTION ON A SIMPLE FAN MODEL



(Figure 2) Diagram of a simple fan model to illustrate common bed types found in turbidite fans, and sedimentary structures characteristic of each bed type. Bed sequences found in different areas of the fan are also illustrated. The distribution of facies associations A-G (Simplified from Mutti and Ricci Lucchi 1972) is illustrated on the fan model and the bed types normally associated with each facies are indicated. Brief diagnoses of each facies type are given below. Facies A. Coarse-grained debris flows and ?grain flows, occasionally conglomeratic. Normal, reverse and ungraded thick beds. Channel and scour features common, beds composite. Facies B. High density turbidite beds and fluidised flow beds. Usually medium- to coarse- grained and pebbly. Occur in amalgamated sequences lacking mud interbeds, commonly characteristic of channels in inner to mid-fan. Facies C. Laterally extensive turbidites with Bouma sequences. Beds 0.25–2.5 m thick characteristic of mid-fan lobes with increase in high density turbidite beds into channel mouth. Mud interbeds increase away from channel mouth. Facies D. Base cut-out Bouma sequences with dominant mud interbeds. Characteristic of outer fan, but also occur as overbank deposits between channels. Facies E. Thin sand and mud interbeds with frequent flaser bedding, associated with thin, massive beds and graded beds including base cut-out Bouma sequences. Strong gravity and traction currents occasionally sweep inter-channel areas. Facies F. Slump bedded material concentrated along base of slope and at channel margins in inner fan. Facies G. Pelagic and hemipelagic material deposited from suspension and possibly modified by traction currents, coarsest in inner fan and finest and most abundant at outer fan fringe.



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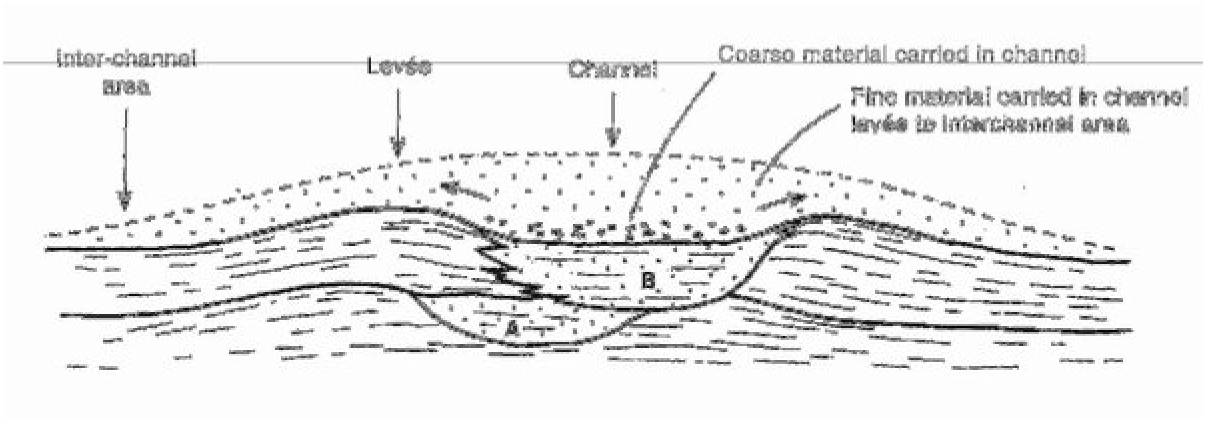

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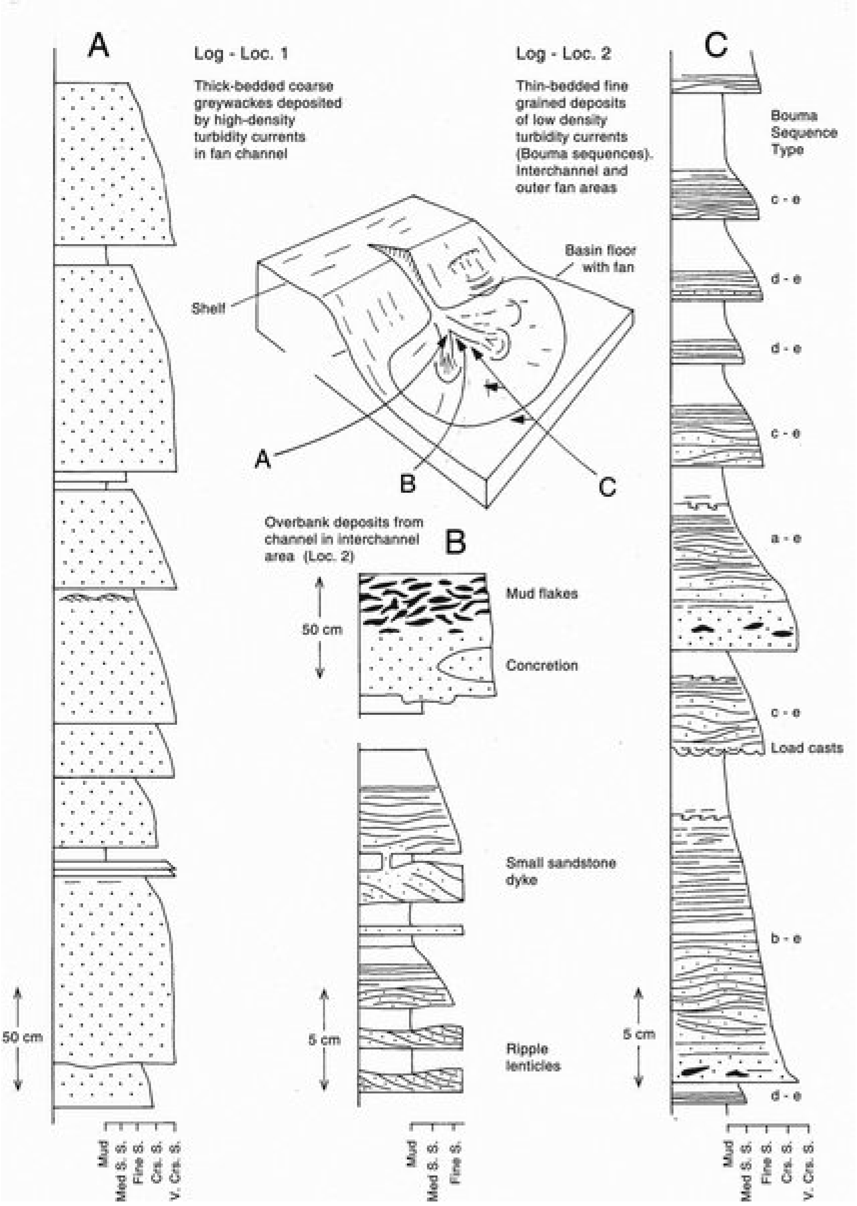
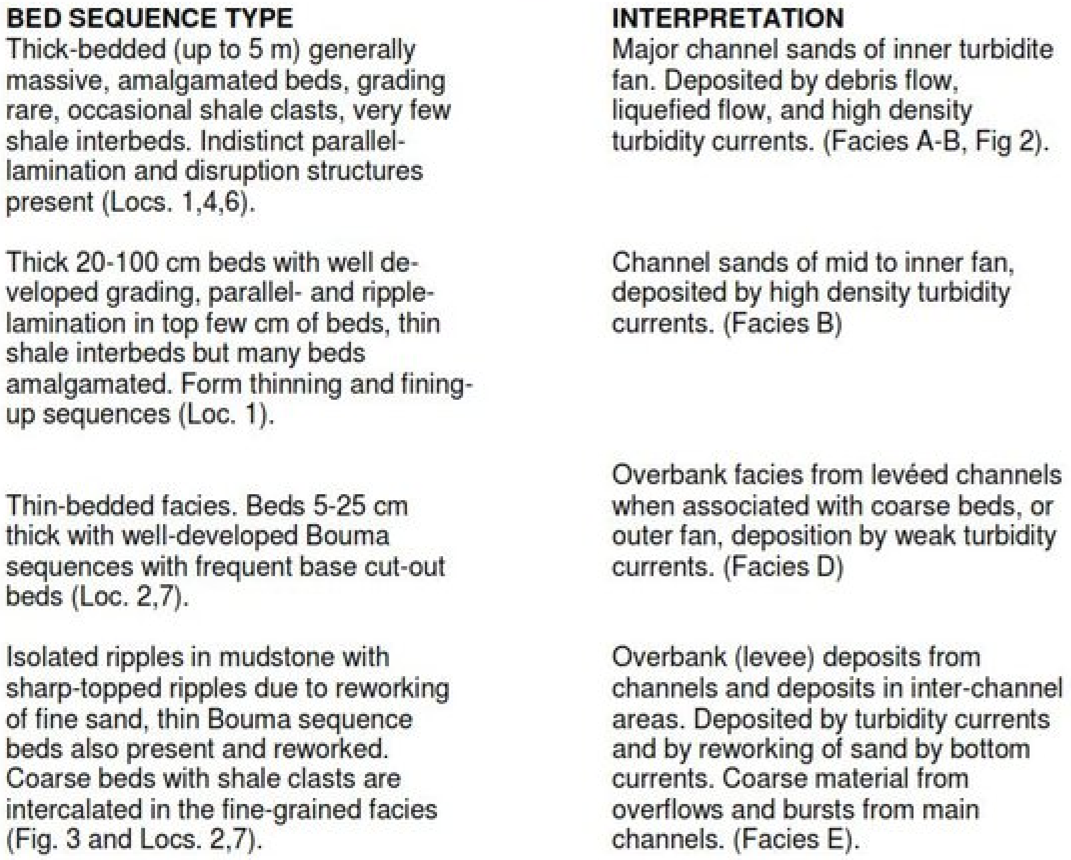


(Figure 5) Log of turbidite sequences at localities 1 and 2 and interpreted depositional positions on a turbidite fan model.

(Figure 6) Rip-up clasts of shale within coarse-grained greywacke. Locality 1.

TABLE 1



BED SEQUENCE TYPE	INTERPRETATION
Thick-bedded (up to 5 m) generally massive, amalgamated beds, grading rare, occasional shale clasts, very few shale interbeds. Indistinct parallel-lamination and disruption structures present (Locs. 1,4,6).	Major channel sands of inner turbidite fan. Deposited by debris flow, liquefied flow, and high density turbidity currents. (Facies A-B, Fig 2).
Thick 20-100 cm beds with well developed grading, parallel- and ripple-lamination in top few cm of beds, thin shale interbeds but many beds amalgamated. Form thinning and fining-up sequences (Loc. 1).	Channel sands of mid to inner fan, deposited by high density turbidity currents. (Facies B)
Thin-bedded facies. Beds 5-25 cm thick with well-developed Bouma sequences with frequent base cut-out beds (Loc. 2,7).	Overbank facies from levéed channels when associated with coarse beds, or outer fan, deposition by weak turbidity currents. (Facies D)
Isolated ripples in mudstone with sharp-topped ripples due to reworking of fine sand, thin Bouma sequence beds also present and reworked. Coarse beds with shale clasts are intercalated in the fine-grained facies (Fig. 3 and Locs. 2,7).	Overbank (levee) deposits from channels and deposits in inter-channel areas. Deposited by turbidity currents and by reworking of sand by bottom currents. Coarse material from overflows and bursts from main channels. (Facies E).

TABLE 1. Environmental interpretations of bed sequence types in the Macduff Slates.

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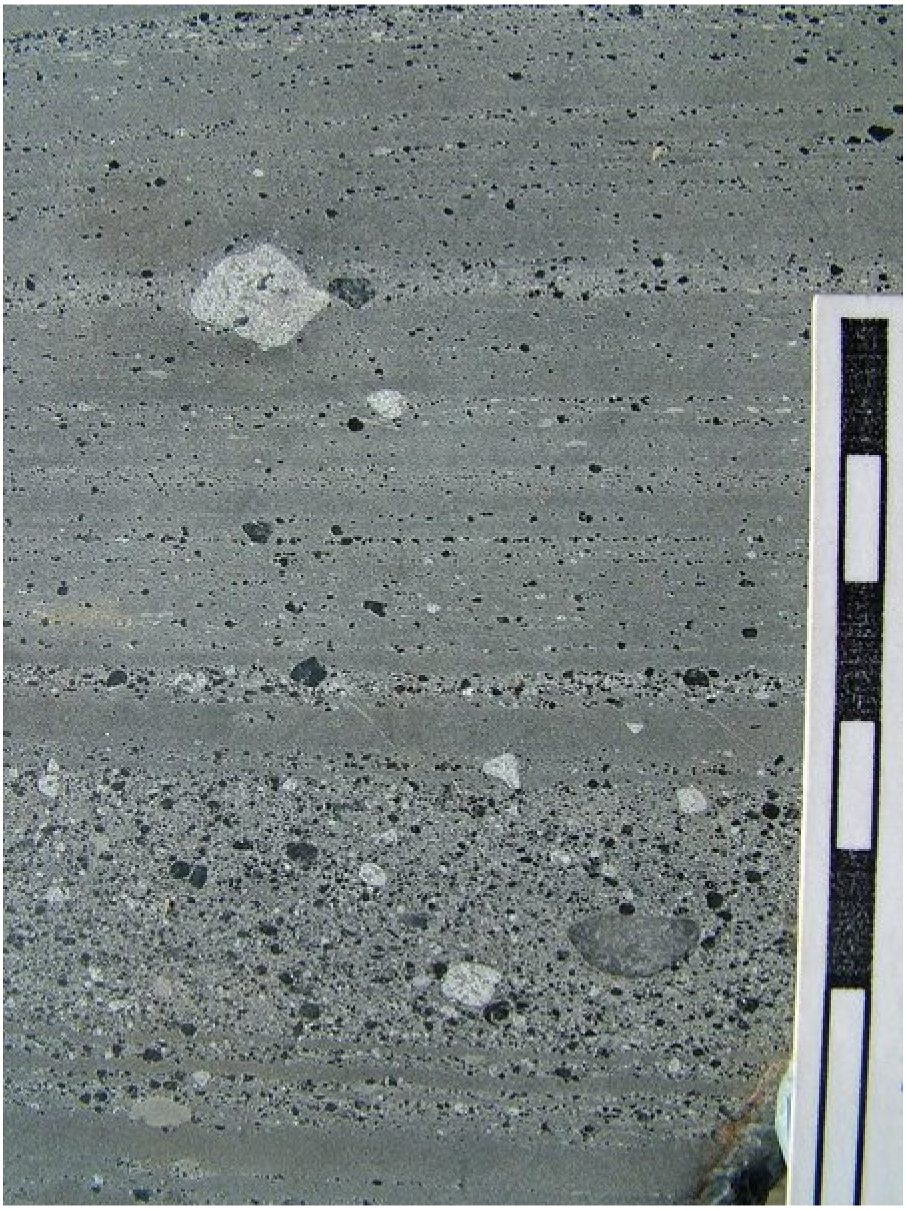
(Figure 8) View from the cliff-top of the synclinal fold axis at The Sclates. Locality 3.



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(Figure 12) Slickensides in quartz on a bedding plane. Locality 3.

(Figure 13) Anticlinal fold axis plunging to the north on beach. Locality 5.

(Figure 7) Graded turbidite bed displaying Bouma sequence of sedimentary structures. Locality 2.