DISTAL AND PROXIMAL TURBIDITES AT NILSE HULLET, WESTERN SOUTH GEORGIA

By R. N. MORTIMORE

ABSTRACT. Twelve major turbidite units consisting of volcanic greywacke and totalling 525 m. in thickness were identified in measured sections at Nilse Hullet, South Georgia. Two turbidite lithofacies, one predominantly distal and the other proximal, occur in rhythms in the measured sections. Four of the major turbidite units, two distal and two proximal, were selected for more detailed study. The four characteristics used to differentiate the turbidite lithofacies were bed thickness, sand : mud ratio, general characteristics of decreasing proximality and proximality index. In the two major units with proximal characteristics, the average turbidite thickness is 2·3 m., sand : mud ratio is 4 : 1 and the proximality index is 91 per cent. This contrasts with the other two units which have a more distal nature, where the average turbidite thickness is 0·13 m., sand : mud ratio is 1 : 2·3 and proximality index is zero. Interspersed throughout the turbidite units are discrete flows of angular lithic tuff which superficially show no grain-size distribution and therefore were possibly deposited by autosuspension currents.

TRENDALL (1953, 1959) has summarized previous work on South Georgia and established the general geological relationships. He described two distinct groups of greywackes: the Cumberland Bay type which contains a high proportion of volcanic debris and tuff beds, and the Sandebugten type which contains a high proportion of quartzose debris and no tuffaceous beds.

The Cumberland Bay type of greywacke occupies the greater part of South Georgia (Fig. 1, inset) and is of Upper Jurassic–Lower Cretaceous age (Wilckens, 1947; Casey, 1961; Stone and Willey, 1973). This paper is concerned with the sedimentology of a small part of the rock exposure at Nilse Hullet on the south coast (Fig. 1, inset). Although the data presented here are limited, a larger area of exposure along the south coast was also investigated at reconnaissance level. The work was carried out in the 1973–74 summer season during the geological survey of this part of South Georgia.

A detailed petrological description of the greywacke is beyond the scope of this study but descriptions of the petrography of the Cumberland Bay type rocks from other localities can be found in Tyrrell (1915, 1930), Barth and Holmsen (1939), Trendall (1953, 1959), Skidmore (1972) and Stone (1975). Grain-size and grade have been assessed qualitatively for this paper.

Trendall (1953, 1959) identified most of the features of turbidites in the Cumberland Bay type of greywacke. During the past decade, refinements in the study of turbidite sedimentology provide a basis for detailed analysis of these sediments by measured section. Turbidites are divided into lithofacies (Blatt and others, 1972) which reflect the geometry of the sedimentary basin in which they were deposited; lithofacies have been identified in the Cumberland Bay type of greywacke using the Bouma divisions (Bouma, 1962).

High flow-regime divisions of Bouma's sequence (Allen, 1963; Walker, 1965) are shown to be the most variable both in occurrence and form. The individual Bouma divisions, by their presence or absence, form a regular pattern in the vertical section so that two major associations become apparent.

The first association consists of groups of beds with generally thick and variously graded "A" divisions. Lower flow-regime Bouma divisions may be present depending upon the degree of amalgamation. The second association consists of groups of thinly bedded units which start either with the "C" division or, more often, are bi-structured as A→E or DE turbidites. The nomenclature used here follows that of Bouma (1962), Walker and others (1965); A→E describes turbidites which grade from division A to division E without any intervening laminae; where intervening divisions occur they are written ABDE, etc.

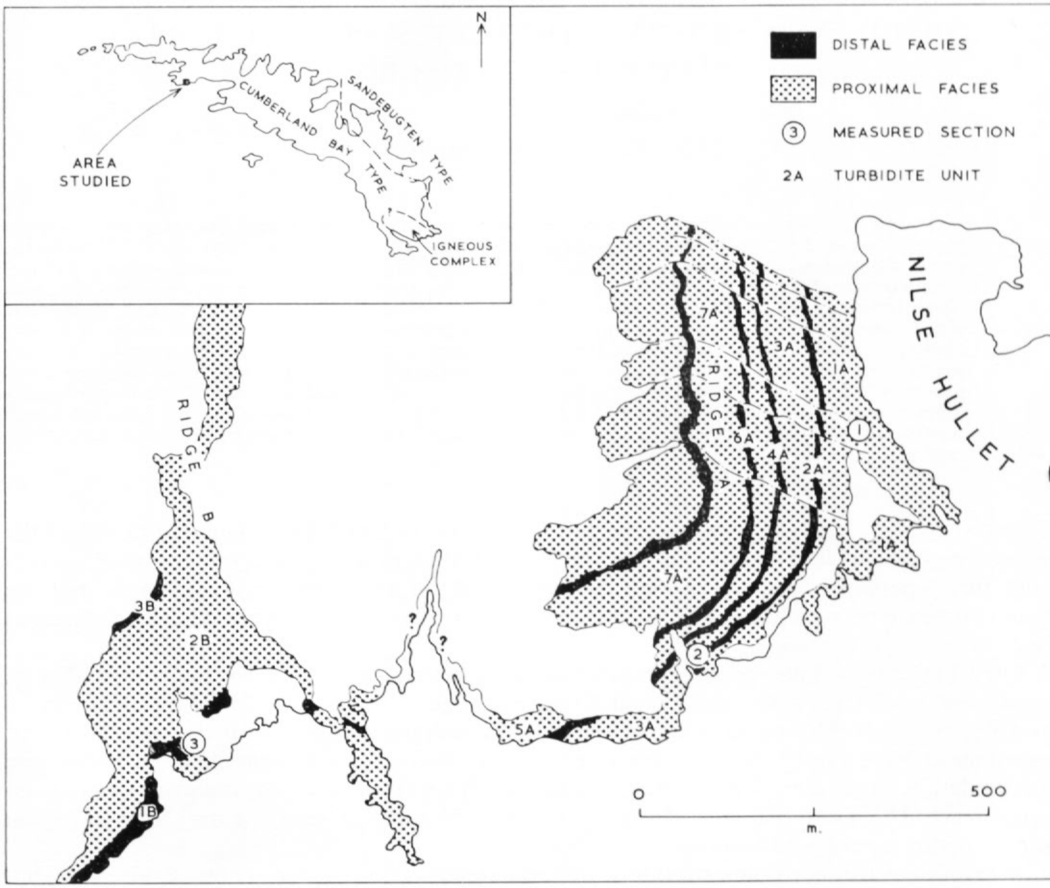

Fig. 1. Sketch map showing the distribution of distal and proximal turbidite units in the Nilse Hullet area, South Georgia. Detailed measurements were made on unit 1A at locality 1, units 2A and 3A at locality 2 and unit 1B at locality 3. The inset shows the location of the mapped area on South Georgia. (Based on a plane-table map at 1 : 10,000 by D. Habgood.)

Details of Measured Sections

Nilse Hullet is a sheltered cove formed where the sea has inundated an old cirque. Immediately west of Nilse Hullet there are two knife-edge ridges: the first forms the western wall of the cove; the second, 1·5 km. farther west, curves from the sea north-eastward to meet the first ridge and forms a second cirque (Fig. 1). The area of detailed study was confined to the western wall of Nilse Hullet cove, the summits of the two ridges and the narrow wave-cut platform linking the two cirques. The beds are gently folded about an almost horizontal east–west axis and weakly modified by a second set of folds trending north-north-west. An axial-planar slaty cleavage was strongly developed with the first set of folds and rodded iron pyrites defines a very fine lineation. These early structures have been modified by two crenulation cleavages, both of which locally give rise to intersection lineations on the first cleavage. Dip of the bedding is on average at 40° to the west, reflecting the combined effects of the deformations. A number of minor faults offset the bedding; the most prominent of these trend north-west and dip to the south-west (Fig. 1), and are in many places intruded by a suite of sandstone or "clastic" dykes.

Three sections were measured: the first at the entrance to Nilse Hullet cove where the cliffs are most accessible and the exposure freshest; the second in a steep prominent gully leading on to the first ridge from the wave-cut platform; and the third in a steep gully which is the only route out of the second cirque on to the second ridge and the open country to the west (locations on Fig. 1). Measurements were made to the nearest millimetre (the smallest discrete beds were often 1 mm. or less thick) on those slabs which provided the greatest vertical extent. Where a break occurred in the vertical sequence, the top bed was followed laterally until a second convenient slab was found. Where possible, any lateral variations were noted and three-dimensional structures studied. In this paper emphasis is placed on vertical variations in the succession as the nature of the terrain and the dip of the beds make lateral correlation unreliable.

The major turbidite units are numbered from the base of each ridge and the ridges are lettered A and B. The thicknesses of the major units are as follows:

Turbidite unit	*Thickness* (m.)
5B	12
4B	96
3B	18
2B	105
1B	9
7A	58
6A	15
5A	63
4A	9
3A	41
2A	21
1A	80

General observation indicated the presence of major cycles in the succession but in the measured sections the boundaries of the major units were not always clear. In general, two types of boundary occur. In the first case the boundary is marked by the cessation of thinly bedded A→E turbidites and the influx of coarse thicker turbidites with a preponderance of high flow-regime divisions. In the second case the grain-size and the thickness of the beds may gradually increase or decrease. Boundaries in the second case have been chosen arbitrarily on field evidence, although Walker (1967) suggested the use of a "moving average scale".

The link between the succession of the major turbidite units on ridges A and B can be seen where the ridges join.

Turbidite unit 1A

Eighty-six individual turbidites were differentiated in 53·22 m., the remaining 30 m. being inaccessible. The mean thickness of individual turbidites is 0·5 m. with a maximum thickness of 2·67 m.; the great range in thickness of individual beds reflects the contrast between the lower and upper parts of this unit.

The lowest turbidites are thinly bedded (averaging 8 cm.) and fine-grained with a high proportion of silt and mud. Bedding is regular with no evidence of amalgamation. A bi-structured middle- and bottom-absent arrangement of the beds (AE, DE) is dominant. Mean thickness of D divisions is 5 cm., E divisions 4 cm. and rare C divisions range from 4 to 19 cm. The A divisions are not of the thickness (3–5 cm.) or the grain-size normally envisaged in the classic Bouma sequence, while grading from fine sand to silt to mud is imperceptible. In many cases, stringers of mud found towards the tops of the divisions mark the gradation into the D horizon.

There is a notable increase in turbidite thickness (up to 92 cm.) and bedding irregularity in the middle part of unit 1A, and complete Bouma sequences are not uncommon. A range of top-absent turbidites AA, ABA, ABCA, etc. suggests a degree of amalgamation borne out by the increase in abundance of mudflakes derived from E divisions (Fig. 2). A divisions range up to 67 cm. in thickness, B divisions 39 cm., D divisions 15 cm. and E divisions 12 cm. A pebble grade for material in the lower few centimetres of the A division is not uncommon. Thinly bedded turbidites still persist, interbedded with these coarser thicker units.

Fig. 2. Massive bedded amalgamated A–A proximal facies turbidites; east end of Sealers Beach, Bore, Jossac Bight. In the 3·5 m. of sandstone above the hammer two lines of mudflakes with prehnite haloes indicate successive amalgamations, producing a turbidite structure of A–A–ABDE. The hammer shaft is 50 cm. long.

In the upper part of unit 1A the thinly bedded turbidites are increasingly rare, A divisions reach 2 m., B divisions 1 m., C divisions 50 cm. and D divisions 5 cm. in thickness. Bedding between turbidites is increasingly irregular with erosive bases and amalgamation, and coarse flakes from E divisions are abundant.

Analyses of the Bouma divisions from this sequence are shown in Tables I and II. The most interesting development is the range of grading structures found in the A division. First, there is the almost imperceptible upward decrease in grain-size found in the 2–3 cm. thick A divisions of the thinly bedded units; the grading is usually normal but very occasionally it is reversed. Turbidites with this grading structure compare closely with the middle-absent A→E turbidites of Walker (1967). Secondly, the units become thicker and coarser-grained while the style of grading becomes increasingly irregular. In the middle units a bi-polar structure is common (Fig. 3), the coarse material being confined to a band in the centre of the division with finer material developed on either side. The upper units display a wide range of structure from normal, reverse and recurrent grading to non-graded beds.

Fig. 3. Close-up of proximal turbidites in the middle part of unit 1A of section 1, Nilse Hullet. The lower irregular contact of the middle turbidite (indicated by the pen which is 14 cm. long) shows the development of non-orientated flames and the usual prehnite halo. A bi-polar grading structure is shown in the A division of this turbidite and in the succeeding one. The structure of these turbidites is bi-polar A, laminated B and D, and a thin E division.

Sole structures are seldom well exposed and there is only one example of well-defined groove casts in the succession. These were found on the underbelly of a cliff in the uppermost units at locality 1 (Fig. 1) and are aligned north-north-east. Flame structures and current-ripple marks are generally the only indicators of current direction.

Turbidite unit 2A

This unit is 21 m. thick but only 12·4 m. were sufficiently clearly exposed for detailed analysis. 92 turbidites were identified having an average thickness of 0·16 m. and a maximum thickness of 1·7 m. Bottom-absent turbidites are dominant, 45 per cent are the bi-structured DE and 16 per cent are CDE turbidites (Fig. 4). The maximum and minimum thicknesses of the sand-silt fraction in the bi-structured beds are 7 cm. and 0·1 cm., respectively, with an average of 3·5 cm.

Two types of grading are apparent in the bi-structured turbidites: the sand fraction either grades into the E division without any intervening laminae, or very fine discontinuous mud laminae occur in the upper few millimetres before the E division commences. Structures of the first type resemble the grading in A→E turbidites (Walker, 1967) but those of the second type are more accurately described as A→DE or DE turbidites.

TABLE I. AVERAGE THICKNESS OF BOUMA DIVISIONS IN THE MAJOR UNITS

Major unit	*Bouma division*	*Average thickness* (cm.)
	E	3·8
	D	3·8
1B	C	5·5
	B	12·7
	A	19·8
	E	4·3
	D	12·1
3A	C	35·4
	B	52·0
	A	92·7
	E	3·6
	D	3·9
2A	C	6·1
	B	21·6
	A	33·2
	E	4·9
	D	6·1
1A	C	11·8
	B	26·1
	A	54·1

Sole structures are absent, while the loading of sand in mud occurs as ball-and-pillow structures rather than as flames. Current-ripple laminae are the only directional current structures but these are not now accepted as reliable for palaeocurrent analysis.

The transition from the upper part of unit 1A to the base of unit 2A is sharp, and it is marked by the sudden cessation of massive turbidites.

Turbidite unit 3A

Although this unit is 41 m. thick, there are only 23 turbidites in it, with an average thickness of 2·3 m. and maximum thickness of 4·2 m. Ideal ABCDE members comprise 48 per cent of the unit and 26 per cent consist of top-absent AB turbidites. The first turbidite is relatively thin (A, 0·12 m.; B, 0·22 m.) and top-absent. It is followed by more thickly bedded units (e.g. A, 240 cm.; B, 105 cm.) which are welded together or amalgamated. The first of these begins with a marked conglomerate at the base of the A division. An upward decline in amalgamation and grain-size of the A division is combined with an increase in the number of ideal ABCDE turbidites, the last one of which has A, 255 cm.; B, 110 cm.; C, 21 cm.; D, 7 cm. and E, 5 cm. Grading throughout beds in unit 3A is generally normal. The lower and upper contacts of unit 3A with 2A and 4A are sharp and marked by changes in successive beds.

Turbidite unit 1B

Unit 1B is composed of 75 turbidites in the 9 m. exposed above the water line, with an average thickness of 0·11 m. and a maximum thickness of 1·27 m. The turbidites are mainly bottom- or middle-absent, 50 per cent DE and 16 per cent CDE. A further 11 per cent were directly identified as A→E but a later study of the hand specimens suggested that many turbidites identified in the field as DE may be A→E. However, this does not affect interpretation.

The types of grading and general features of unit 1B are directly comparable with those of unit 2A.

TABLE II. PERCENTAGE OF EACH TURBIDITE TYPE IN THE MAJOR UNITS

Major unit	*Turbidite type*	*Percentage*	*Total number of turbidites*
	ABCDE	2	
	ABCD	2	
	AB	1	
	ACDE	1	
	ACD	1	
1B	A→E	14	78
	CDE	16	
	DE	52	
	D	2	
	E	9	
	Tuff	0	
	ABCDE	50	
	AB	28	
3A	ABE	10	23
	ABC	4	
	ABCD	4	
	A→E	4	
	Tuff	0	
	ABCDE	6	
	CDE	21	
	CD	2	
2A	CE	1	92
	DE	49	
	D	6	
	E	8	
	Tuff	7	
	ABCDE	15	
	A	4	
	AB	3	
	ABCE	2	
	ABDE	4	
	ABE	8	
	ADE	3	
	AD	2	
1A	A→E	3	86
	BCDE	1	
	BDE	4	
	BD	1	
	BE	1	
	CDE	3	
	DE	20	
	D	14	
	Tuff	12	

ANALYSIS OF BED THICKNESS AND BOUMA DIVISIONS

Turbidite structure at Nilse Hullet, whether ideal, top-absent, middle-absent or bottom-absent, follows changes in bed thickness and grain-size. These parameters can be used in the field to identify major groups of turbidites. The nature of the grading in the A division is also closely associated with bed thickness and grain-size, Using these parameters, the similarity between unit 3A and the middle and upper turbidites of unit 1A and also between units 2A and 1B is clear. Unit 1A was not subdivided because the degree of exposure of the lowest turbidites did not permit a precise dividing line to be drawn. The cycles in the succession defined by these parameters are emphasized by an analysis of the sand : mud ratio.

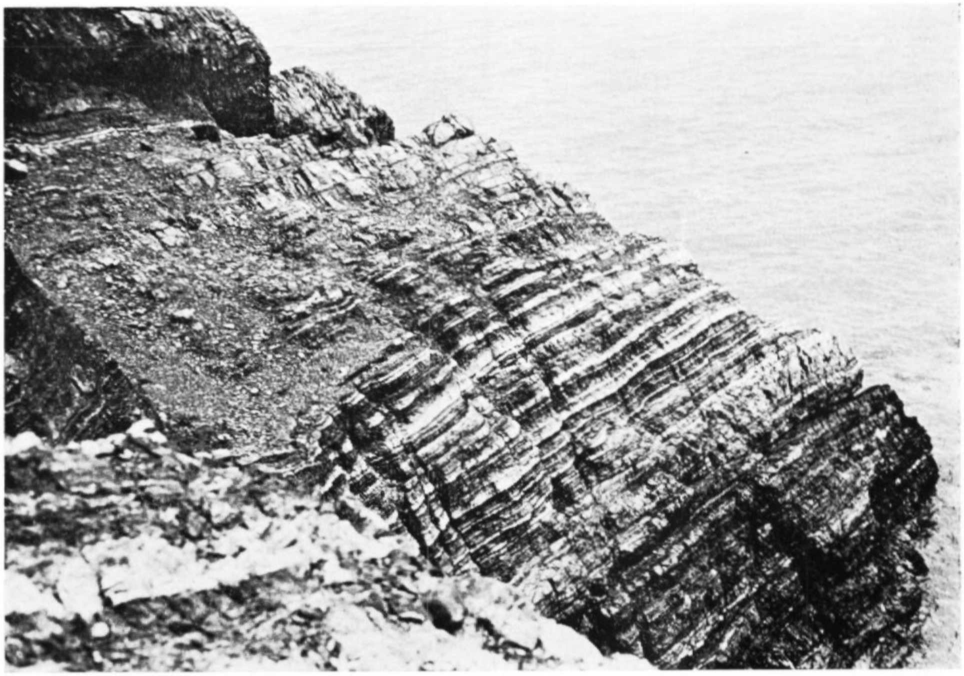

Fig. 4. Thin-bedded CDE and A→E distal turbidites above the proximal turbidites shown in Fig. 2; Bore, Jossac Bight. The black muds of the E divisions contrast sharply with the sands and silts of the A, C and D divisions (E divisions range from 4 to 10 cm. in thickness).

Major unit	*Thickness of sand : mud*	*Number of beds sand : mud*	*Number of beds A : E*
1B	1·2 : 1	1 : 2·3	1 : 10
3A	6 : 1	4 : 1	1 : 0·7
2A	1·5 : 1	1 : 2·3	1 : 16
1A	11 : 1	1·5 : 1	1 : 1·5

The most positive indication of the difference between major units is shown by the relative abundance of A and E divisions.

Palaeocurrent Analysis

The most reliable indicators of current directions in turbidites are sole structures but these are rare in the Cumberland Bay type volcanic greywackes and they were only found in unit 1A at Nilse Hullet. The groove casts are aligned north–south. Other palaeocurrent data collected from "flame" structures and current-ripple marks have been discounted.

Tuffaceous Beds

Tuffaceous beds are an important element in the succession and Tyrrell (1930, p. 45) and Trendall (1953, p. 15) referred to the Cumberland Bay rocks as the "shale tuff series" or "tuff series". Tuff occurs as discrete beds in the Nilse Hullet sections, varying from 0·01 to 1·00 m. in thickness. The ratio of tuff beds to turbidites in unit 1A is 1 : 10 and in unit 2A it is 1 : 16, while there are no tuff beds in unit 3A. Rolled tuff horizons in the turbidites are not uncommon; this structure appears in the B division. With a hand lens, most of the tuffs are seen to be composed of angular fragments and Tyrrell (1930) described Radiolaria from similar beds. Most of the tuffs show no grain-size distribution and were probably deposited by auto-suspension currents.

Siltstones and Mudstones

Unusual thicknesses of mud (50 cm.) are intercalated with the turbidites. These are generally black and structureless, and are associated with a lighter-coloured mud showing micro-laminae of silt. Parkash and Middleton (1970) suggested that mud particles flocculate in the distal regions of turbidity current flows and that the density of the particles prevents normal graded fall-out which results in generally structureless muds. Thus, unusual thicknesses of muds probably represent the final distal depositions of a turbidity current. Oceanic currents have been regarded by many authors as the main transporting agent in turbidite basins and the depositor of the distal facies. However, the "E" divisions of the turbidites in the Nilse Hullet sections are remarkable for their lack of depositional structures and signs of re-working, other than those produced by an ensuing, thick coarse turbidite or by bioturbation. However, examples of re-working were found at Larvik (Fig. 5).

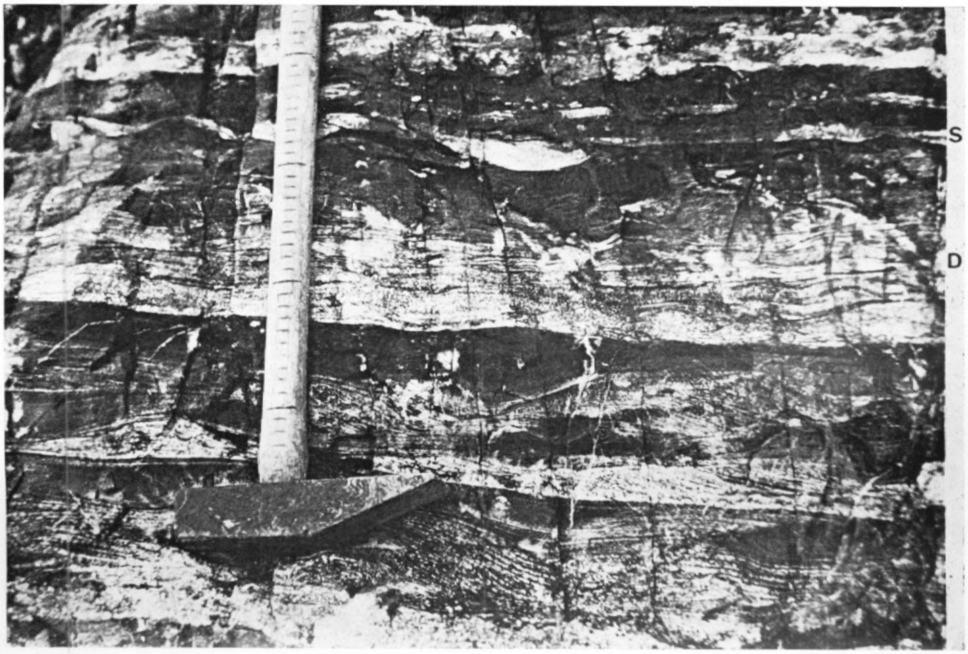

Fig. 5. Re-worked turbidites at Larvik showing sandy, silty and muddy laminae and mud drapes (D). Minor scours (S) are evident in some of the E divisions. The hammer shaft is graduated in centimetres.

Interpretation

There are several generally accepted characteristics of decreasing proximality in turbidites (Walker, 1967; Lovell, 1969; McCabe and Waugh, 1973) and these are shown for each major unit in Table III. These characteristics, together with bed thicknesses, grade of material and the sand : mud ratio, suggest that units 1A and 3A are more proximal than units 2A and 1B.

Walker's (1967) proximality index, P_1, has been criticized recently (McCabe and Waugh, 1973) but when applied to the Cumberland Bay type volcanic greywackes it gives results consistent with the other evidence of proximality.

Table III. Proximality indicators

Characteristics of decreasing proximality	Evidence	Inference	Evidence	Inference	Evidence	Inference	Evidence	Inference
	1B		**3A**		**2A**		**1A**	
1. Beds become thinner	Average thickness 0·11 m. Maximum thickness 1·27 m.	Distal	Average thickness 2·3 m. Maximum thickness 4·2 m.	Proximal	Average thickness 0·16 m. Maximum thickness 1·7 m.	Distal	Average thickness 0·5 m. Maximum thickness 2·67 m.	No lateral comparison but proximal in vertical section
2. Beds become finer-grained	Only 7 per cent of turbidites have coarse A sets	Distal	96 per cent of beds have well-developed A sets	Proximal	Only 5 per cent with A sets of medium sand	Distal	Upper units are coarse; size of source material unknown	Upper units proximal; lowest units distal
3. Amalgamation decreases	No amalgamation	Distal	At least 26 per cent amalgamation	Proximal	No amalgamation	Distal	Amalgamation increases upwards	Upwards progressively proximal
4. Reduction of mudflakes	No mudflakes	Distal	Abundant mud-flake-conglomerate	Proximal	No mudflake	Distal	Mudflakes increase upwards	Upwards progressively proximal
5. Scours, wash-outs and channels	None	Distal	Soles of units not exposed	—	None	Distal	Groove moulds in upper units	Upper units proximal
6. Sole marks to tool marks ratio decreases	No evidence	Distal	Not calculated	—	Not calculated	—	Not calculated	—
7. Beds better graded	Good grading in thin A→E beds	Distal	74 per cent well graded	Distal	Good grading in thin A→E units	Distal	Grading less regular in upper units	Upper units proximal
8. Upper part of turbidite grades into finer material rather than being sharp	Contact very gradual in thin A→E and DE beds	Distal	Grading in finer parts often sharp; only 4 per cent A→E units	Proximal	Contact very gradual in thin A→E units	Distal	Ideal sequences and sharp upward change common in upper units	Upper units proximal
9. Lamination and ripples more common	Low flow-regime laminae common	Distal	B set and D set laminations abundant	Distal	Low flow-regime laminae common	Distal	Better developed in middle and lower parts	Upwards progressively proximal
10. Mudstone layers between sandstones better developed	94 per cent of turbidites have mudstones	Distal	64 per cent of turbidites have E sets	Distal	85 per cent of turbidites have E sets	Distal	64 per cent of turbidites have E sets	Distal
11. Beds more regularly bedded	Bedding very regular	Distal	Bedding fairly regular	Medial	Bedding very regular	Distal	Bedding varies	—

Major unit	P_1
1B	zero
3A	91
2A	zero
1A	45

Thus the facies interpretation is that units 1A and 3A are proximal and units 2A and 1B are distal. On this evidence, the cycles in the succession are the result of the repetition of two turbidite lithofacies. The proximal facies at Nilse Hullet, displaying a wide variety of grading in the "A" division, was probably deposited by an immature turbidity current with a high velocity and strong erosive power (Walker, 1965). The ideal Bouma sequence is generally thought to result from deposition by mature turbidity currents, while the senile stage deposits the distal facies (Walker, 1965). Thus there is a down-current distribution of facies based on waning erosive and carrying power.

Discussion

Turbidite facies, as reported elsewhere, generally occur as major formations having the same characteristics throughout, for example, Bouma (1962) found that of the 1,061 units in the Tertiary Flysch Grès de Peïra-Cava 64 per cent were bottom-absent CDE turbidites; Walker (1965) found that of the 1,410 units in the Carboniferous Mam Tor sequence 51 per cent were middle-absent A→E turbidites and McCabe and Waugh (1973) found 60 per cent of the Silurian Austwick Formation to be ideal ABCDE turbidites.

The Nilse Hullet sections suggest that the Cumberland Bay type of volcanic greywacke is unusual in that at least two facies occur in regular alternation in short bursts throughout the vertical succession. Further work on palaeocurrent data may assist in finding an explanation for this phenomenon. Discrete tuff flows in the turbidites confirm Tyrrell's (1930) observations on rocks collected from the north coast, that volcanic activity was persistent throughout the deposition of these rocks. Scattered plant debris (Tyrrell, 1930; field observations by R. A. S. Clayton and R. N. Mortimore) and rare fragments of a shelly fauna (Stone and Willey, 1973) suggest that the source area for the turbidites was a shelf sea, while the bioturbation in the E divisions of the turbidites (generally in the form of *Chondrites*) is consistent with trough sedimentation (Seilacher, 1967).

Acknowledgements

The author is indebted to Drs. P. W. G. Tanner and B. Waugh (Department of Geology, University of Hull) for their painstaking advice and criticism, and to his colleagues, particularly Drs. R. A. S. Clayton, P. Stone and L. E. Willey, and T. H. Pettigrew, for stimulating discussions. My wife has spent many hours typing various drafts of the manuscript, and I am most grateful to her.

MS. received 1 August 1975

REFERENCES

Allen, J. R. L. 1963. Henry Clifton Sorby and the sedimentary structures of sands and sandstones in relation to flow conditions. *Geologie Mijnb.*, **42,** No. 7, 223–28.

Barth, T. F. W. *and* P. Holmsen. 1939. Rocks from the Antarctandes and the Southern Antilles. Being a description of rock samples collected by Olaf Holtedahl 1927–1928, and a discussion of their mode of origin. *Scient. Results Norw. Antarct. Exped.*, No. 18, 64 pp.

Blatt, H., Middleton, G. *and* R. Murray. 1972. *Origin of sedimentary rocks.* New Jersey, Prentice-Hall Incorporated.

Bouma, A. H. 1962. *Sedimentology of some flysch deposits: a graphic approach to facies interpretation.* Amsterdam and New York, Elsevier Publishing Company.

CASEY, R. 1961. A monograph of the Ammonoidea of the Lower Greensand. Part 2. *Palaeontogr. Soc.* [*Monogr.*], 45–118.

LOVELL, J. P. B. 1969. Tyee Formation: a study of proximality in turbidites. *J. sedim. Petrol.*, **39**, No. 3, 935–53.

MCCABE, P. J. *and* B. WAUGH. 1973. Wenlock and Ludlow sedimentation in the Austwick and Horton-in-Ribblesdale inlier, north west Yorkshire. *Proc. Yorks. geol. Soc.*, **39**, No. 21, 445–70.

PARKASH, B. *and* G. MIDDLETON. 1970. Downcurrent changes in sedimentary structures in Ordovician turbidite greywackes. *J. sedim. Petrol.*, **40**, No. 2, 572–90.

SEILACHER, A. 1967. Bathymetry of trace fossils. *Mar. Geol.*, **5**, Nos. 5–6, 413–28.

SKIDMORE, M. J. 1972. The geology of South Georgia: III. Prince Olav Harbour and Stromness Bay areas. *British Antarctic Survey Scientific Reports*, No. 73, 50 pp.

STONE, P. 1975. *The geology of the north-east coast of South Georgia*. Ph.D. thesis, University of Birmingham, 90 pp. [Unpublished.]

———. *and* L. E. WILLEY. 1973. Belemnite fragments from the Cumberland Bay type sediments of South Georgia. *British Antarctic Survey Bulletin*, No. 36, 129–31.

TRENDALL, A. F. 1953. The geology of South Georgia: I. *Falkland Islands Dependencies Survey Scientific Reports*, No. 7, 26 pp.

———. 1959. The geology of South Georgia: II. *Falkland Islands Dependencies Survey Scientific Reports*, No. 19, 48 pp.

TYRRELL, G. W. 1915. The petrology of South Georgia. *Trans. R. Soc. Edinb.*, **50**, Pt. 4, No. 25, 823–36.

———. 1930. The petrography and geology of South Georgia. (*In Report on the geological collections made during the voyage of the "Quest" on the Shackleton–Rowett Expedition to the South Atlantic and Weddell Sea in 1921–1922*. London, Trustees of the British Museum, 28–54.)

WALKER, R. G. 1965. The origin and significance of the internal sedimentary structures of turbidites. *Proc. Yorks. geol. Soc.*, **35**, Pt. 1, No. 1, 1–32.

———. 1967. Turbidite sedimentary structures and their relationship to proximal and distal environments. *J. sedim. Petrol.*, **37**, No. 1, 25–43.

WILCKENS, O. 1947. Paläontologische und geologische Ergebnisse der Reise von Kohl-Larsen (1928–29) nach Süd-Georgien. *Abh. senckenb. naturforsch. Ges.*, No. 474, 66 pp.