

Read at the Annual Conference of the Ussher Society, January 1989

Gramscatho-Mylor facies relationships; Hayle, south Cornwall

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Shail, R.K. 1989. Gramscatho-Mylor facies relationships; Hayle, south Cornwall. *Proceedings of the Ussher Society*, 7, 125-130.



The Gramscatho Group and the Mylor Slate Formation are the two main lithostratigraphic groups that outcrop in south Cornwall. Their mutual relationship has been disputed for some time because of poor palaeontological control and the effects of polyphase deformation. A study of the lithofacies exposed around Hayle suggests a breakdown of the generally valid lithostratigraphy. A transitional zone occurs in which Gramscatho and Mylor lithofacies are seen to be contemporaneous and are interpreted as a rise-slope association. On the scale of south Cornwall, the Gramscatho Group comprises basinal and rise deposits whilst the Mylor Slate Formation comprises rise, slope and possibly outer shelf deposits.

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Introduction

Two major lithostratigraphic divisions outcrop in south Cornwall; the Gramscatho Group and the Mylor Slate Formation. Although it has long been recognised that this combined succession exhibits characteristics of a deep-water flysch sequence (Hendriks 1937), the relationships between some of the facies types and associations are still open to interpretation, and there is scope for refining the models already proposed (e.g. Wilson and Taylor 1976; Barnes and Andrews 1986; Holder and Leveridge 1986). In particular, the sedimentary environment of the Mylor Slate Formation is poorly understood (Goode and Taylor 1988) and its relationship to the Gramscatho Group needs to be reassessed.

The model described by Holder and Leveridge (1986) is largely based on south coast exposures and emphasises the presence of a series of thrust nappes containing deep-water fan deposits. The original sedimentary relationships between the Gramscatho Group and the Mylor Slate Formation are obscured as a consequence of this thrusting. In contrast, the parautochthonous north coast exposures, despite being modified by polyphase deformation, partially preserve these original relationships. This paper is based on a study of the facies types exposed on the north coast section around Hayle, and it addresses the possible significance of the Gramscatho-Mylor transition in south Cornwall.

Corry and Makower (1929) described the sandstones at Black Cliff in some detail but it was Smith (1966) who first ascribed a turbidite origin to most of the sandstone- and mudstone-rich lithologies between Hayle and Portreath. Wilson and Taylor (1976) suggested that the Mylor Slate Formation was older than the Gramscatho Group and the distal basinal equivalent of proximal debris flows exposed in Roseland and Meneage. The transition to the more proximal Gramscatho sequence was achieved by rapid uplift of a postulated southern source area. The authors interpreted the turbidite sandstones at Hayle as relatively distal whilst acknowledging they were coarser than relatively proximal turbidites further south. This apparent anomaly was tentatively explained in terms of a local unstable depositional slope in the Hayle area.

Structural and stratigraphic framework

Fig. 1 shows a simplified geology of south Cornwall. As a result of poor palaeontological control, the outcrop pattern was interpreted until quite recently in terms of the NE plunging "Truro Antiform". The Mylor Slate Formation was generally envisaged as being the older of the two successions and occupying the core of this fold, whilst the Gramscatho Group was exposed on the NW and SE limbs. However, the palynomorph data of Turner et al. (1979) suggested that

Mylor Slate Formation was in fact younger than the Gramscatho Group. This, together with offshore seismic reflection data and the re-interpretation of olistostromes at the southern Gramscatho-Mylor boundary as contemporaneous with thrusting lead to the concept of "The Carrick Nappe" (Leveridge et al. 1984). The outcrop pattern can now best be interpreted as a northern parautochthonous unit, in which Gramscatho Group youngs upwards into the Mylor Slate Formation, that has been over-riden by a series of NNW transported thrust nappes containing allochthonous Gramscatho Group. The Lizard Complex forms the highest onshore structural unit (Fig. 1).

Palaeontological control is still poor. Ages interpreted as syndepositional with the Gramscatho Group range from Eifelian (Sadler 1973) to Frasnian/?Famennian (Le Gall et al. 1985; Leveridge et al. in press). Knight and Wilkinson (1989) reported a mid-late Famennian miospore assemblage within "Mylortype" horizons south of Loe Bar. Hence, the Gramscatho Group appears generally older than the Famennian Mylor Slate Formation but the more recent work suggests it may be partially contemporaneous.

General characteristics of Gramscatho and Mylor lithofacies

In the absence of widespread palaeontological control, the Gramscatho Group and Mylor Slate Formation are

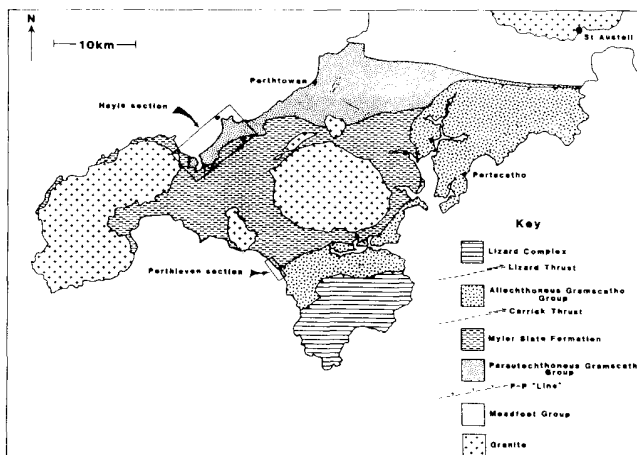


Figure 1. A simplified geological map of south Cornwall; modified after Holder and Leveridge (1986).

distinguished on the basis of their lithofacies associations. It is possible to define both "Gramscatho" and "Mylor" lithofacies as follows:

<i>Gramscatho lithofacies</i>	<i>Mylor lithofacies</i>
Sandstone turbidites	Fine-grained turbidites
Fine-grained turbidites	Sandstone turbidites
Hemipelagites	Hemipelagites
Limestone turbidites	Sedimentary breccias
Radiolarian turbidites	and debris flows
Proximal debris flows	Greenstones with intra-
Greenstones with MORB characteristics	plate tholeiite characteristics

The latter four categories of the Gramscatho lithofacies are found only within the allochthonous units (Fig. 1). It is obvious that the Gramscatho Group and Mylor Slate Formation share broadly similar lithofacies associations consistent with deposition in a deep-water basin. As a result, the distinction between the two lithostratigraphic groups on the basis of these associations is not always clear. However, the relative proportions of individual facies types within the above associations are usually characteristic. The Gramscatho association is relatively rich in sandstone lithologies, whereas the Mylor association is dominated by mud-rich types. Nevertheless, the original sedimentary contacts between the two successions are usually gradational rather than sharp, and substantial thicknesses of Mylor type lithofacies may occur within Gramscatho Group and *vice versa* (e.g. Hill and MacAlister 1906; Smith 1966). Despite these problems, the present lithostratigraphy appears to be generally valid as confirmed by available ages of the two sequences.

Two principal sections exist along which Gramscatho-Mylor relationships can be assessed; the Porthleven section and the Hayle section (Fig. 1). Throughout south Cornwall, the sedimentary sequences generally dip and young upwards to the SE; no evidence is available for large-scale inversion. Hence, the Mylor Slate Formation exposed along the Porthleven section is close to its upper tectonic boundary (described by Leveridge and Holder 1985), whilst that exposed in the Hayle section must be close to its lower contact with the generally older Gramscatho Group.

The Hayle section

The locations of outcrops described in this study are shown in Fig. 2. Palynomorphs retrieved just to the NE of the area yield Frasnian/Famennian ages (Leveridge *et al.* in press). The outcrops have been classified as either Gramscatho or Mylor lithofacies on the basis of the general characteristics previously outlined. However, no relative stratigraphic age relationships are implied.

A detailed description of the polyphase deformation seen throughout the section is beyond the scope of this paper, but reference will be made to structures that could have consequences for the facies interpretation. The scheme reported by Leveridge *et al.* (in press) appears to be valid and is adopted here.

Bed thickness definitions, unless otherwise stated, are after Ingram (1954): thin beds, (1-10cm); medium beds, (10-30cm); thick beds, (30-100cm); and very thick beds, (> 100cm). The terms "sandstone-dominated turbidite" and "fine-grained turbidite" have been utilised both in the original characterisation of the lithofacies associations and in the description of the field relationships. They are explained as follows: "Sandstone-dominated turbidites" exhibit some combination of the regular vertical sequence of structural divisions (*Tahcde*) described by Bouma (1962) and comprise > 50% sand grade material. This is a simplification adopted for the sake of brevity in this paper; not all the turbidites can be adequately described in these terms, neither are they all sandstone-dominated. The

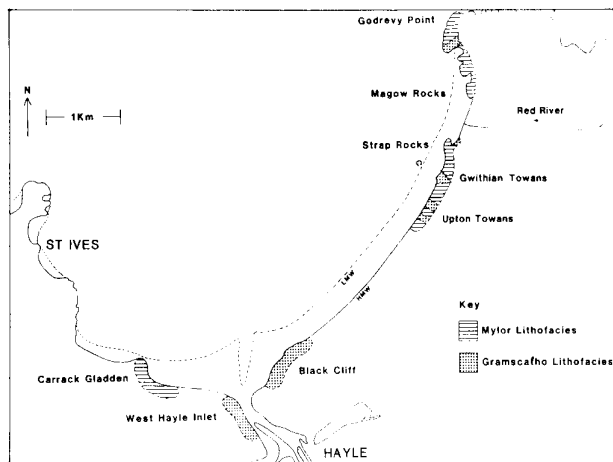


Figure 2. The Hayle section showing the location and lithofacies of outcrops described in this study.

range of facies types present is more fully accommodated in classes B and C of Pickering *et al.* (1986). "Fine-grained turbidites" comprise >50% silt and clay size material, but sand may be present towards the base. They occur as very thin to very thick beds. Silt turbidites may show structural divisions similar to those described in classical sandy turbidites and mud turbidite divisions have also been described (Stow and Piper 1984). "Structureless" is used as a field term when applied to mudstones and siltstones. The various facies types and their mutual relationships will now be described from west to east along the section.

Carrack Gladden: This locality is within the contact metamorphic aureole of the Land's End Granite. The Mylor lithofacies are variably spotted and the S5 cleavage is quite intense, locally transposing all earlier fabrics. Thin (1-2cm), well bedded, very fine sands are subordinate to dark-or silvery-grey mudstones and together are interpreted as the products of deposition from fine-grained turbidites and possibly hemipelagites. Elsewhere, bedding is often highly disrupted and elongate clasts of very fine sandstone are found within the mudstone matrix. Due to S5 transposition, it is not possible to assess the relationship of these clasts to S1, but they are thought to represent primary sedimentary breccias formed as a result of local slumping. Minor greenstone sills and rare thin- to medium-bedded sandstones are also present.

West Hayle Inlet/Black Cliff: Both these localities exhibit Gramscatho type lithofacies associations and can be considered together. Their sandstone-rich nature probably controlled the fold style, resulting in large wavelength F1 folds that were later disrupted by faulting along the line of the estuary.

At West Hayle Inlet, sandstone-rich facies predominate; S5 cleavage and contact metamorphic spotting are less intense. Thin-, medium- and thick-bedded sandstone-dominated turbidite units show variably developed scoured bases, amalgamation, normal grading, mudstone rip-up clasts, climbing ripple lamination, and are interbedded with fine-grained turbidites. Both types exhibit convolute bedding, loading and fluidisation structures. Local small slump folds are transected by S1.

At Black Cliff on the NE side of the Hayle estuary, similar facies associations are very well exposed. The SW part of the Black Cliff outcrop comprises predominantly vertical or steeply dipping overturned beds that are consistent with being on the inverted limb of a large NNW facing F1 fold. Approximately 180m equivalent vertical thickness of Gramscatho lithofacies which exhibit relatively well preserved sedimentary structures are exposed. A detailed log of the lower 60m is presented in Fig. 3. Sandstone-dominated turbidites account for approximately 80% of the section. Bed thickness is highly variable, ranging

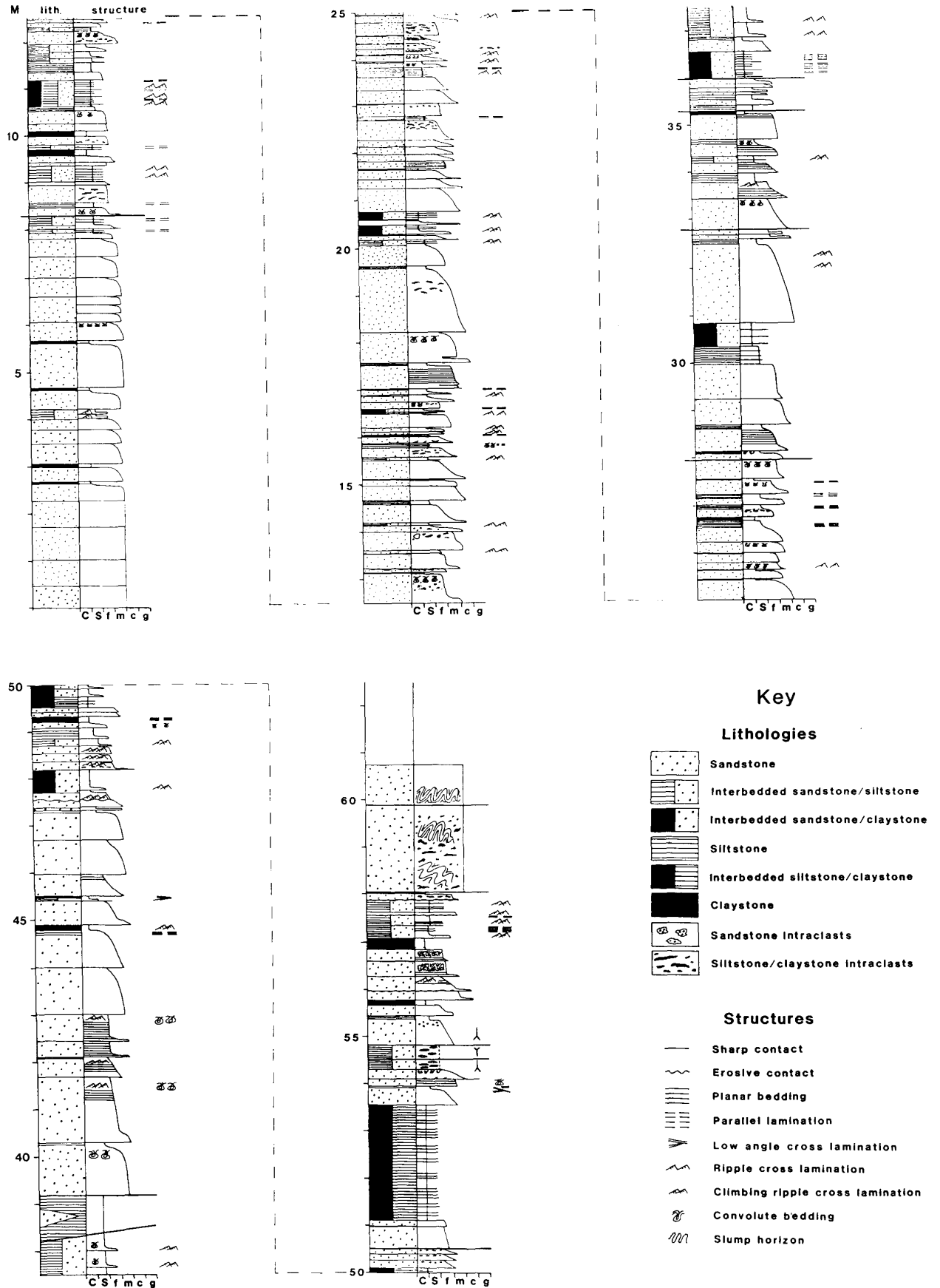


Figure 3. Logged sequence from SW Black Cliff, Hayle.

from laminae (< 1cm) to very thickly bedded units. Amalgamation is quite common and may be undetected in some cases. Most beds appear to have planar non-erosive bases, although this may be a function of the limited length of alongstrike exposure (generally 5-10m) as scours up to 20cm deep are occasionally seen. Units are usually massive or additionally develop planar bedding, generally display normal grading and may be extremely rich in mud clasts (Fig. 4a). Climbing-ripple cross-lamination is quite widespread towards the tops of units and thin silts may or may not be present. Thinning and fining upwards sequences are partially developed and there is a fairly close correlation between bed thickness and maximum grainsize. Fine-grained turbidites usually occur in "packets" separating the more extensive sandstone-dominated units. They may exhibit thin (1-2cm) cross-laminated fine sandstone or siltstone bases that develop upwards into parallel-laminated siltstones. Both sandstone- and mudstone-dominated turbidites commonly show examples of loading, convolute bedding, fluidisation structures and local small slump horizons.

A lesser thickness of largely right-way-up strata that dips gently SE is exposed on the NE side of Black Cliff and corresponds to the complementary normal limb of the large F1 fold. It is separated from the limb to the SW by an intensely faulted hinge region. The facies types are very similar to those described above. However, thin-bedded, sharp based, well sorted, poorly graded fine sandstones showing mud-streaked cross-laminae and complex internal truncation surfaces are observed (Fig. 4b), as are rare swaley forms. Neither type is consistent with simple turbidite deposition. The muddy partings and internal truncation surfaces of the first example suggest possible reworking of an initial turbidite sand input by the migration of small sinuous-crested bedforms. The latter case is more equivocal; absence of three-dimensional control precludes certain identification of swaley or hummocky forms.

Thin sedimentary dykes are also seen. S3 cleavage is variably developed and can locally be seen axial-planar to SE verging and facing folds.

Upton Towans: There is a 2km break in exposure between the NE end of Black Cliff and the next available outcrop near Upton Towans at (SW 5734 4052). Fragments of green siltstone can be found in the intervening sand dunes. The first 120m of outcrop is very badly weathered and comprises very fine pale green sandstones and siltstones interlaminated with thinner black mudstones. No sedimentary structures are observed. At (SW 5741 4062) about 15m of subvertical thickly/very thickly bedded pale green weathered coarse sandstones are exposed within the siltstones. The beds are predominantly massive and exhibit delayed-grading into cross-laminated fine sands and thin green mudstone tops. Badly weathered pale-green siltstones with lesser medium-bedded fine sands and occasional black mudstones are exposed for a further 200m to (SW 5755 4081) where a landslipped cliff reveals another 60m of subvertical sandstone-dominated exposure. Thickly to very thickly bedded graded units similar to the previous location are again observed. They young to the NE into mud-dominated fine-grained turbidites.

The thick sandstones are classified as Gramscatho type lithofacies and interpreted as the deposition products of highdensity turbidity currents. The predominant mudstones are classified as Mylor type lithofacies and interpreted as finegrained (C)DE turbidites and hemipelagites. Due to the poor quality outcrop, structural control on this part of the section is not very good. The occurrence of subvertical beds up to 15m in height could be consistent with a continuation of the large-scale F1 folds seen at Black Cliff. However, the local development of minor SE verging and facing folds suggests that the D3 backthrust event may have disrupted these.

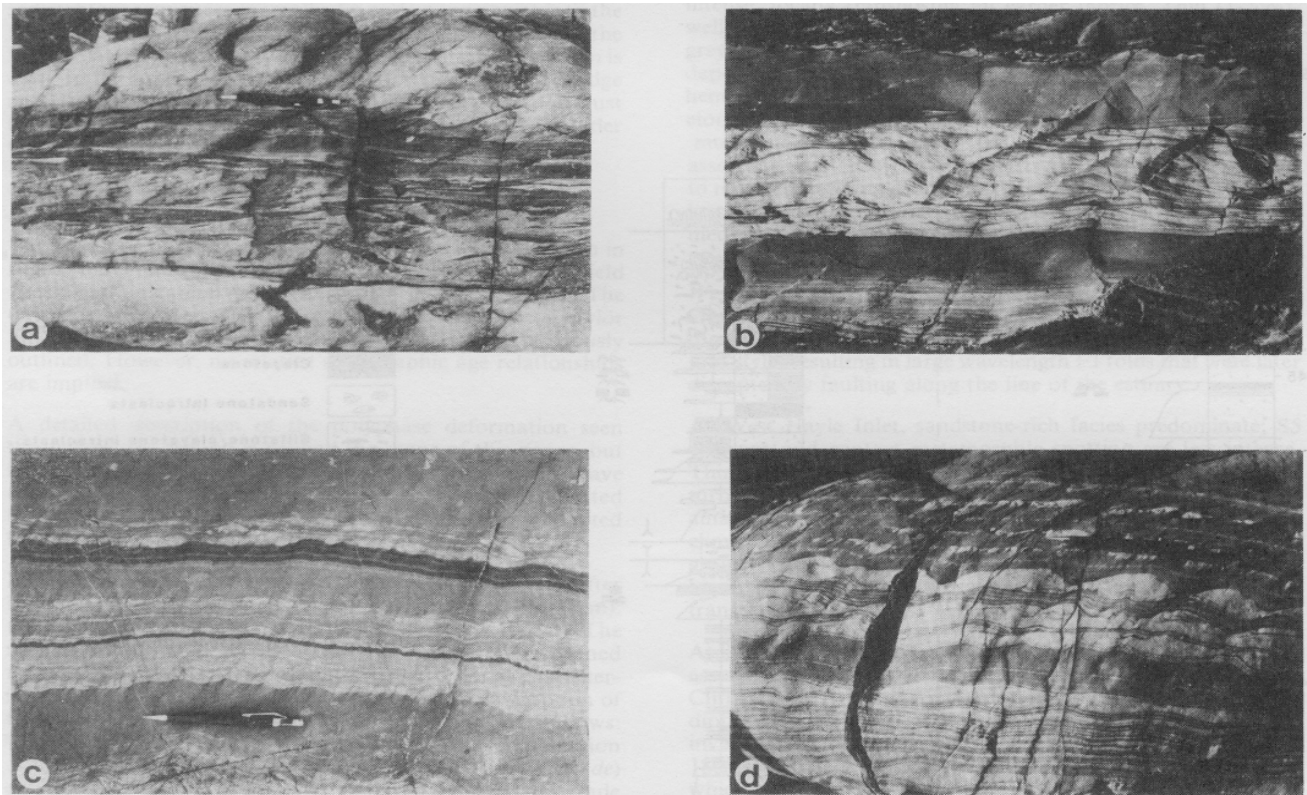


Figure 4. a) Slurred top to turbidite unit at SW Black Cliff, containing abundant elongate black mudstones clasts. Pencil rests on base of succeeding unit. b) Thin, poorly graded, mud-streaked fine sandstone showing internal truncation surfaces, possibly due to reworking. NE Black Cliff. c) Finegrained (C)DE turbidites showing slight convolution, Gwithian Towans. d) Reworked channel-margin turbidites, Peter's Point (SW 5772 4117).

Gwithian Towans: The quality of outcrop substantially improves and examples of the Mylor lithofacies association are well developed. These include fine grained (C)DE turbidites with locally developed 1-5cm thick fine sandstone bases (Fig. 4c), finely interlaminated silts (DE turbidites and hemipelagites), structureless black mudstones (hemipelagites), and rare mudstone sedimentary breccias. Here, the silvery- to dark-grey colour of the facies types contrasts with the predominantly pale-green colour further to the SW, but is sometimes seen to weather pale-green along joint-planes. The total amount of sandstone is very small, although a series of amalgamated, poorly-graded, fine-grained muddy sandstones are seen at (SW 5768 4105). There is again widespread evidence of convolution, loading and minor slumping.

At Peter's Point (SW 5772 4117) Gramscatho-type lithofacies are downfaulted into Mylor-type lithofacies. A larger area of Gramscatho-lithofacies is also exposed at Ceres Rock (SW 5746 4138). Both these localities largely comprise medium- and similar features to those seen at Black Cliff.

The Mylor-type lithofacies around Peter's Point are quite unusual. A series of 15-25cm thick mudstone-dominated units with complex fine sandstone bases are developed (Fig. 4d). A well-defined sequence occurs in 80% of examples: a sharp, locally scoured base is followed by several trains of rippleforms, each separated by a mudstone drape. The ripples have slightly asymmetric forms, average wavelengths of 5-10cm, amplitudes of 2cm and form-concordant internal cross-laminae that indicate a consistent direction of relative palaeocurrent flow both within and between separate units. Climbing ripple cross-lamination or associated forms are very rare. Above the rippled horizons there is a decrease in the sand:mud ratio; parallel-laminated mud-streaked sand and subsequently sand streaked muds give way to a silvery-grey mudstone. Loading and soft-sediment deformation are again widespread. These units are not consistent with deposition from a single waning flow and therefore do not represent simple *Tcde* divisions of fine-grained turbidites.

Strap Rocks: Beyond Peter's Point, the Mylor lithofacies continue NE for another 500m. They largely comprise thin to medium bedded fine-grained (C)DE turbidites and hemipelagites that show ubiquitous loading and fluidisation structures. Thickly-bedded, fine-grained DE turbidites are exposed around Strap Rocks. The last available outcrops are badly weathered medium to fine-grained massive sandstones that locally contain angular mudclasts. Along this section there is evidence for a D3 backthrust event. Two scales of structure are involved; large folds with a short-limb length of up to 10m, and smaller folds with short limb lengths of up to 0.3m both verge and usually face to the SSE. They are associated with a moderately NW dipping cleavage (S3) that can be seen to crenulate S2. The short limbs of the larger F3 folds are often subvertical and at (SW 5785 4143) clearly occur above a thrust fault. The smaller F3 folds are often developed close to such dislocations.

Magow Rocks to Godrevy Point: The outcrops to the north of the Red River comprise predominantly Mylor-type lithofacies. Fine-grained turbidites and hemipelagites are interbedded with rare thickly to very thickly bedded sandstone-dominated turbidites. These sandstones are massive and/or planar-bedded and exhibit amalgamation into "packets" 3-4m thick. To the north side of Godrevy Cove (SW 5800 4295), the outcrop comprises very thickly bedded, usually structureless, pale green-grey siltstones and fine sandstones interbedded with fine-grained turbidites. The true thickness of individual depositional events in the silts and sands is difficult to ascertain due to the lack of sedimentary structures, but units in excess of 10m thick are seen. In the cliffs above the platform exposure, the silts are structurally overlain by turbidites variably showing the full *Tabcde* Bouma sequence. Immediately north at (SW 5802 4313), an ENE-WSW trending normal fault with a 10m downthrow to the north exposes a further 80m of this

Gramscatho-type lithofacies. Medium to thickly bedded sandstone-dominated turbidites exhibit spectacular large-scale SE verging F3 folds. At their northern limit, NW verging folds developed in the turbidites are not expressed in the structureless pale green-grey silts below and their upper boundary may have acted as a local decollement during renewed NW directed thrusting.

Interpretation and discussion

There are substantial gaps in available outcrop along the Hayle section due to extensive areas of blown sand. This clearly restricts our knowledge of some of the boundaries between the different lithofacies units; they could be either sedimentary or tectonic. Although minor faulting is widespread, there is no direct evidence of major thrust or strike-slip faults with significant displacements. In the absence of good palaeontological control it seems reasonable to consider the Hayle section as a series of fault-bound sedimentary packets which, although disrupted, show a general coherence. The intimate association of the two main lithofacies in unfaulted parts of the section suggests that their juxtaposition in faulted and poorly exposed parts of the same section does not necessarily invalidate the overall facies interpretation. It seems probable that there is a close spatial and temporal relationship between the two associations as described below.

Sandstone-dominated lithofacies: The sand-rich nature, high erosive power (local scours and large mudclasts), high flow competence (medium-coarse sand), widespread amalgamation, reasonable correlation between bed thickness and maximum grain size, and thinning/fining upwards sequences together suggest that the succession at West Hayle Inlet/Black Cliff was deposited in a relatively proximal channel environment. The less extensive outcrops of the same lithofacies at Upton Towans, Gwithian Towans and Godrevy probably represent smaller channels as there always seems to be a fairly complete partitioning of sand grade material into the sand-dominated sections.

Mudstone-dominated lithofacies: These predominantly comprise the depositional products of low-density turbidity currents with a minor contribution from hemipelagites. Major depositional channels have largely by-passed this assemblage.

These two main lithofacies associations could individually occur in a range of deep-water environments. The mudstone-dominated (Mylor) association could represent basin plain, rise, slope or even outer shelf environments. The traditional interpretation of such deposits as "distal turbidites" is not always valid (e.g. Mutti 1977). The sandstone-dominated (Gramscatho) association at Hayle would typically be interpreted as a mid- to inner-fan sequence, but an elongate basin geometry seems likely and such fan models may be inappropriate (Walker 1984 and references therein). However, if we consider both associations as contemporaneous, a rise-slope interpretation seems likely, particularly in relation to the whole Gramscatho-Mylor sequence. The sedimentary breccias exposed at Carrack Gladden suggest proximity to a palaeoslope and the very thickly bedded siltstones observed to the north of Godrevy Cove are consistent with remobilised ponded slope deposits. The overall mudstone-rich facies association is similar to that interpreted by Pickering (1982) as an ancient continental slope deposit. The sandstone-rich facies association represents the infill of channels cut through these slope deposits in an analogous manner to that described by Dott and Bird (1979).

The unusual rippled sands developed at Peter's Point (Fig. 4d) resemble the "channel-margin facies" of Mutti (1977), but their internal mud-partings do not seem consistent with a single waning flow. The overall upwards decrease in the sand:mud ratio above an erosive base suggests periodic reworking of an initial minor turbidite sand input. The tail of the original

current and/or subsequent currents overflowing the channel could effect such reworking. A channel margin setting is favoured due to the restriction of this facies type around Peter's Point (as noted by Goode and Taylor 1988) where it is adjacent to a downfaulted block of the sandstone-dominated lithofacies. The thin sands at NE Black Cliff (Fig. 4b) have probably also been reworked in a similar way, but within the channel environment rather than at its margin. Brenchley (1985) ascribes a storm-induced turbidity current origin for deposits similar to those above with mudstone partings. Whilst such a mechanism cannot be discounted, those outlined above seem more likely and the probable absence of true swaley forms suggest sedimentation below storm wave base. No trace fossils were observed (as possible indicators of water depth) and the locally pyritic nature of the black hemipelagic mudstone suggests the basin was, at times, anoxic.

The Hayle section represents a zone along which the characteristic lithofacies associations of the Gramscatho Group and the Mylor Slate Formation are both observed. The two associations are interpreted as a contemporaneous rise-slope assemblage marking the transition from the predominantly basinal and rise environment of the Gramscatho Group to an inferred rise, slope and possibly outer shelf environment for the rest of the Mylor Slate Formation.

The transition described occurs relatively late in the development of the Gramscatho Basin and may have been achieved by the NNW migration of thrust nappes during basin closure (see Holder and Leveridge 1986). However, in the absence of palaeocurrent control, we must also consider a northern source region possible.

Conclusions

- 1) The sandstone-rich (Gramscatho) and mudstone-rich (Mylor) lithofacies associations exposed along the Hayle section are interpreted as a rise-slope assemblage.
- 2) The generally valid lithostratigraphy breaks down along the Hayle section as the two main lithofacies associations are contemporaneous.
- 3) On the scale of south Cornwall, the Gramscatho Group comprises basinal and rise deposits whilst the Mylor Slate Formation comprises rise, slope and possibly outer shelf deposits that cannot be considered distal relative to source.

Acknowledgements. I would like to thank Dr P.A. Floyd for general supervision during the tenure of a Keele Departmental Studentship, Prof. G. Kelling for helpful advice and discussion in the field and Richard Burgess for the photographs.

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