CHAPTER 13

CONTOURITE FACIES AND THE FACIES MODEL

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Contents

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13.1. INTRODUCTION

Tremendous advances have been made in just over 40 years since contourites were first recognised and described, and their global significance in the present-day oceans began to be unravelled. Today, we have an enormous body of data documenting the nature and characteristics of contourite facies, derived from modern sedimentary systems throughout the world. These are the primary data used to construct the standard contourite facies models, as embraced by most contourite workers. Much less consensus exists with regard to the recognition and interpretation of contourites from the ancient record.

In this chapter, we briefly review the historical context, and then describe in some detail the different contourite facies recognised, outline the contourite facies models and discuss the interpretation of contourite sequences. We further consider some hybrid contourite facies and summarise criteria for the distinction between contourites and associated facies in deep-water systems. The focus is very much on what we have learned from studying modern contourite systems. The problems and controversy surrounding the recognition of fossil contourites in the ancient record is covered by Hueneke and Stow (2008).

13.2. HISTORICAL CONTEXT

Much of the early pioneering work on contourites was carried out along the eastern continental margin of North America, and served to document the strong influence of the deep Western Boundary Undercurrent (WBUC) in shaping the lower slope and rise (Heezen and Hollister, 1964; Heezen et al., 1966; Schneider et al., 1967). As there are no distinctive, mounded, contourite drifts along much of this margin, the contourite facies are found closely intercalated with associated deep-water sediments mainly deposited by turbidity currents, pelagic and hemipelagic processes. This led to early problems with the distinction between these different deep-water facies, as illustrated in the contrasting contourite characteristics outlined by Hollister and Heezen (1972), compared with those of Stow (1979) from the same margin.

Resolution of these differences has been achieved through the study of contourites from many more drifts worldwide, and especially those of incontrovertible bottom-current construction (see summary in Stow and Lovell, 1979). Furthermore, the Nova Scotian continental rise was selected for the HEBBLE (High Energy Benthic Boundary Layer Experiment) programme of the early 1980s, which provided a long-term in situ record of sea-floor conditions, bottom-current flow and sediment characteristics directly under the path of the WBUC (Nowell and Hollister, 1985; McCave et al., 1988). Hollister (1993), and Stow and Faugères (1993) agreed that many of the features originally attributed to contourites (e.g. Hollister and Heezen, 1972) were, in fact, those of bottom-current-reworked turbidites and/or fine-grained turbidites.

As many more descriptions of modern contourites emerged in the literature, more reliable facies models were developed for both muddy and sandy contourites

(Stow and Lovell, 1979; Stow, 1982). Following a scientific cruise on the Faro Drift in the Gulf of Cadiz, linking good core recovery with bottom photographs and high-resolution seismic records, the separate facies models were combined into the now standard contourite sequence model (Faugères et al., 1984; Gonthier et al., 1984; Stow and Piper, 1984). This has been the basis for most subsequent contourite work, at least on modern systems, with documentation of partial sequences (e.g. Howe et al., 1994; Stoker et al., 1998a) and few further changes (Stow et al., 2002b; Stow, 2005). Some further refinement to the model is presented here, but we must also note that there continues to be some dissent, especially from Shanmugam (2000, 2006a) and Shanmugam et al. (1993a, 1995).

13.3. THE RANGE OF CONTOURITE FACIES

The most widely accepted definition of contourites is both simple and flexible (Stow et al., 2002b): “contourites are the sediments deposited by or significantly affected by the action of bottom currents”. As bottom currents are semi-permanent currents that act in deep water, they naturally interact with other processes, including turbidity currents, hyperpycnal flows, pelagic and hemipelagic settling. They incorporate fine-grained material from these processes, which they may transport for long distances before its ultimate deposition. They are also capable of winnowing and eroding the sea floor, and of preventing deposition, thereby causing hiatuses and/or hardgrounds in the sediment record.

A wide range of different facies fall within the spectrum of contourites now recognised in deep-water deposits, and the database used here in summarising the characteristics of these contourite facies is a very extensive one. We have drawn on data published in the following:

1. early work as synthesised in Stow and Lovell (1979), and collated by Nowell and Hollister (1985), and McCave et al. (1988);
2. collected works published in the 1990s by Stow and Faugères (1993, 1998), Gao et al. (1998), Mienert (1998), Stoker et al. (1998b), and Maldonado and Nelson (1999a);
3. most recent compilations by Rebesco and Stow (2001), Stow et al. (2002f), Wynn and Stow (2002a), and Viana and Rebesco (2007).

In addition to these sources, we draw from a big synthesis of contourite drifts cored during some 50 DSDP (Deep Sea Drilling Program) and ODP (Ocean Drilling Program) legs at over 100 deep-water sites (see Table 1 in Stow et al., 1998a), and have compiled data on contourites from a number of the more recent and scattered publications, which are documented in Appendix 1 of this chapter. This represents detailed information from more than 200 piston and gravity cores on some 30 different drifts.

The range of contourite facies now recognised and well documented include the facies groups listed in Table 13.1. A full description is given for each of the individual facies, with illustrations where possible, except for the volcaniclastic contourites. In most regions well supplied with volcaniclastic material, this simply

Table 13.1 Range of different contourite facies

- Siliciclastic contourites
  - Muddy, silty, sandy and gravel-rich variations
- Shale-clast/shale-chip contourites
  - All compositions possible
- Volcaniclastic contourites
  - Muddy, silty, sandy and gravel-rich variations
- Calcareous bioclastic contourites
  - Muddy, silty, sandy and gravel-rich variations, also known as calcilutite, calcisiltite, calcarenite and calcirudite contourites in fossil contourite systems
- Siliceous bioclastic contourites
  - Mainly sand grade recognised
- Chemogenic contourites (within mud or calcilutite)
  - Include manganiferous layers, nodules, pavements
- Other contourite-related facies
  - "Shallow-water" contourites, reworked turbidites

forms a component of either siliciclastic or bioclastic contourites. Where it is the dominant component, the facies are analogous with those of their siliciclastic equivalents. Contourite-related facies are discussed in the final section.

13.3.1. Muddy contourites

Muddy contourites (Figures 13.1 and 13.2) are homogeneous and they commonly appear as thick featureless units. They are poorly bedded, in some cases showing centimetre- to decimetre-scale banding marked by subtle colour changes, and also noted during core logging as slight compositional variations.

They are generally highly bioturbated, often with an indistinct mottled appearance, and may further show distinct burrows of varied (deep water) ichnofacies (see Wetzel and Stow, 2008). There may be rare primary lamination present (partly destroyed by bioturbation), diffuse and indistinct, in places marked by colour change and in places by irregular winnowed concentrations of coarser material.

They have a silty–clay grain size (typical range 5–11 μm) and poor sorting (typically 1.4–2 μm). The composition is dominantly siliciclastic, but commonly mixed with some biogenic fraction. The components are in part local, including a pelagic contribution, and in part far-travelled.

13.3.2. Silty contourites

Silty contourites (also referred to as mottled silty–muddy contourites) (Figures 13.1 and 13.2) are similar in many ways to the muddy contourites but have a larger silt-sized component and, therefore, greater potential for revealing some internal structure. They are often gradationally interbedded with both muddy and sandy contourite facies.

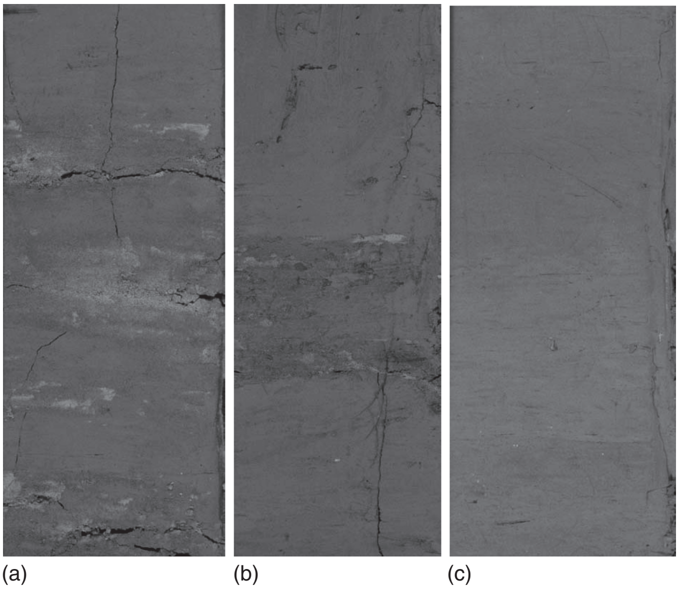

Figure 13.1 Muddy and silty contourite facies. Rockall Trough, NW UK Continental Slope. Core width 8 cm. (a) Silts and muds interlayered. (b) Mottled silt horizon within structureless muds. (c) Bioturbated muds with very indistinct lamination apparent in parts. A multicolour version of this figure is on the included CD-ROM.

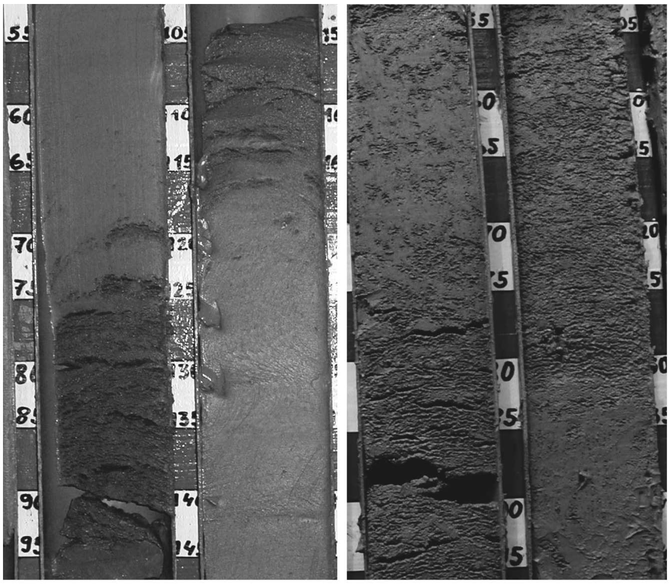

Figure 13.2 Silty and muddy contourite facies, showing homogeneous, bioturbated muds, mottled silts and indistinctly laminated silty mud facies. Gulf of Cadiz contourite depositional system. Core width 8 cm. A multicolour version of this figure is on the included CD-ROM.

They commonly show extensive bioturbational mottling as well as a range of more distinct burrows. There is some evidence of indistinct discontinuous lamination (partly destroyed by bioturbation), typically with sharp to irregular tops and bases of silty layers, together with thin lenses of coarser material. Rarely, remnants of thin cross-laminated beds are preserved.

They have a poorly sorted clayey–sandy silt size and a mixed siliciclastic/biogenic composition, as for muddy contourites. The range of grain sizes (3–11 μm) may be still greater than for muddy contourites, so that the sorting is in some cases very poor (>2 μm).

13.3.3. Sandy contourites

Sandy contourites (Figures 13.3–13.5) occur as both thin irregular layers and as much thicker units within the finer grained facies, and may display either distinct (abrupt) or gradational bed contacts. They are generally thoroughly bioturbated throughout, and may appear massive (structureless) at first viewing, or display a range of distinct burrows. In some cases, rare primary horizontal and cross-lamination is preserved (though partially destroyed by bioturbation), together with irregular erosional contacts and coarser concentrations or lags.

The mean grain size normally does not exceed fine sand (apart from coarser-grained horizons and lags), and sorting is mostly poor to moderate (0.8–2 μm), in

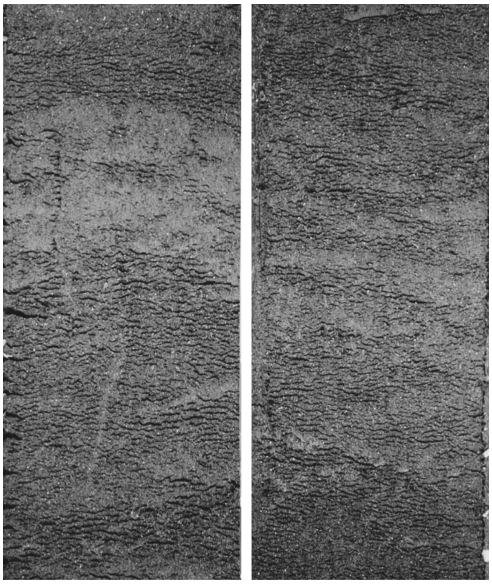

Figure 13.3 Bioturbated sandy contourite facies. These are poorly sorted, muddy sands, with some indication of indistinct parallel lamination. Brazilian Continental Slope (Campos Margin). Core width 5 cm (from Viana et al., 2002a; with permission from The Geological Society, London). A multicolour version of this figure is on the included CD-ROM.

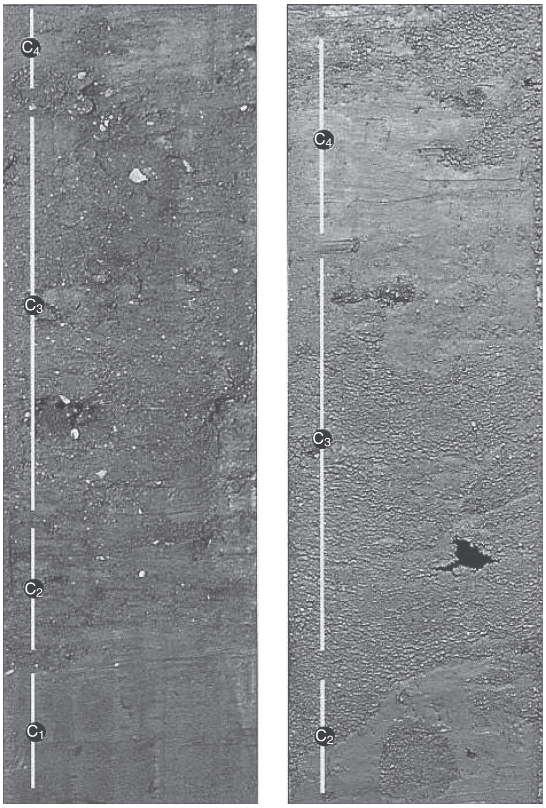

Figure 13.4 Muddy, silty and sandy contourite facies, showing part of standard C1 to C5 contourite facies sequence. From base to top: C1 mud, C2 mottled silty mud, C3 muddy sand, C4 mottled silty mud and C5 (this division not shown) mud. Note white bioclastic shell debris in parts of C3, bioturbation throughout, and partly disrupted discontinuous lamination with some sharp contacts. Faro Drift, Gulf of Cadiz contourite depositional system. Core width 8 cm (from Stow et al., 2002b; Stow 2005; with permission from The Geological Society, London). A multicolour version of this figure is on the included CD-ROM.

part due to bioturbational mixing. Both positive and negative grading may be present. A mixed siliciclastic–biogenic composition is typical, with evidence of abrasion, fragmented bioclasts and iron-oxide staining.

Laminated sandy contourites (Figure 13.5) are less common than their bioturbated counterparts and have been rarely documented, but do occur where high-energy (high-velocity) bottom currents are especially dominant and larger-scale bedforms (e.g. dunes) are evident on the sea floor. The few examples observed to date are thick to very thick-bedded and distinctly laminated. The lamination is relatively broad and diffuse, enhanced by slight colour variation, and parallel at the scale of the cores, although this may also be part of large-scale cross-bedding. Bioturbation is rare, but large sub-vertical burrows have been noted.

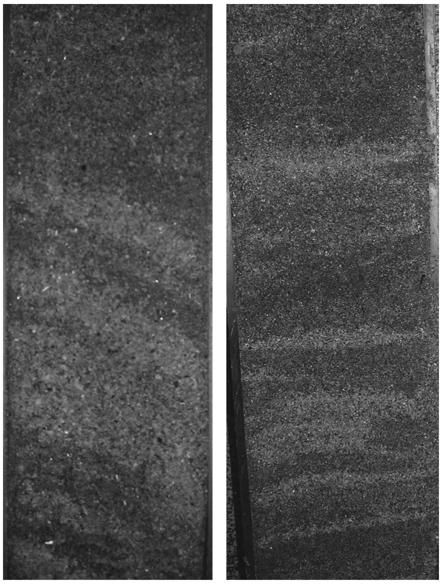

Figure 13.5 Laminated sandy contourite facies, showing parallel and inclined lamination as a result of sand wave migration. Gulf of Cadiz contourite depositional system, from sand sheet in proximal scour and ribbon sector. Core width 10 cm. A multicolour version of this figure is on the included CD-ROM.

The mean grain size is medium-grained sand, with moderately good sorting (0.5–0.7 μm). The sediment has a mixed siliciclastic/biogenic composition, with evidence of abrasion, fragmented bioclasts and iron-oxide staining.

13.3.4. Gravel-rich contourites and gravel-bearing contourites

Gravel-rich contourites and gravel-bearing contourites (Figure 13.6) are common in drifts at high latitudes as a result of input from ice-rafted material. Under relatively low-velocity currents, the gravel and coarse sandy material from ice rafting remains as a passive input into muddy, silty or sandy contourite deposits and is not subsequently reworked to any great extent by bottom currents. This facies is often indistinguishable from glaciomarine hemipelagites. Concentration of the coarser fraction occurs under higher-velocity currents and more extensive winnowing, yielding irregular layers and lenses of poorly to very poorly sorted (1 to >2 μm), sandy gravel-lag. Similar coarse-grained concentrations and gravel pavements are locally developed in response to high-velocity bottom-current activity in shallow straits, narrow contourite moats and passageways.

13.3.5. Shale-clast or shale-chip layers

Shale-clast or shale-chip layers (Figures 13.7c and 13.8b) can be developed in both muddy and sandy contourite facies, but have been recognised to date from relatively few locations only. They result from substrate erosion by strong bottom

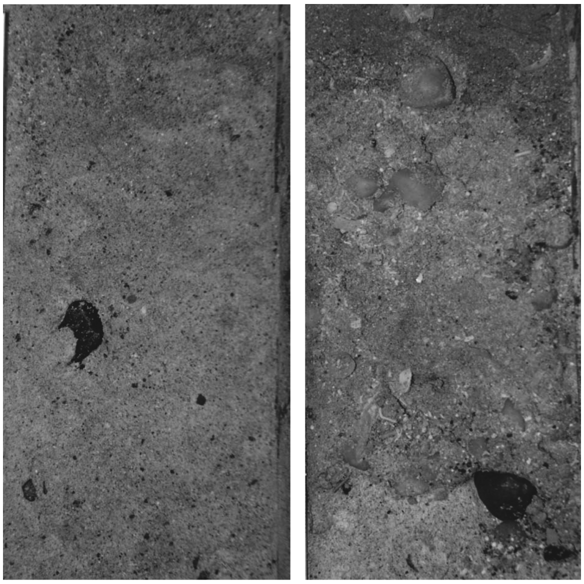

Figure 13.6 Pebbly sand and gravel-lag contourite facies – structureless with irregular concentration of coarse-grained clasts. Faeroe–Shetland Channel (gateway), NW UK continental margin. Core width 10 cm (from Akhurst et al., 2002; with permission from The Geological Society, London). A multicolour version of this figure is on the included CD-ROM.

currents (and perhaps during benthic-storm events), under conditions where erosion has reached a firmer substrate and, in some cases, burrowing on the non-deposition surface has helped break up the semi-firm mud. The shale clasts are generally millimetric in size, and occur with long axes sub-parallel to bedding and, presumably, also sub-parallel to the current direction.

13.3.6. Volcaniclastic contourites

These are generally identical to the siliclastic facies described above, except that their composition is dominated by volcaniclastic material. They are not, therefore, described separately.

13.3.7. Calcareous muddy and silty contourites

Calcareous muddy and silty contourites (Figures 13.7a, b and 13.8c), together with calcareous sandy contourites with which they are commonly interbedded, commonly occur in regions of dominant biogenic input, including open-ocean sites, beneath areas of upwelling, and down-current from a source of biogenic/bioclastic material (such as a carbonate shelf or bioherm). In most cases, bedding is indistinct, but may be enhanced by cyclic variations in composition and/or grain size.

Primary sedimentary structures are poorly developed or absent, in part due to thorough bioturbation as in siliciclastic contourites, but some parallel to sub-parallel

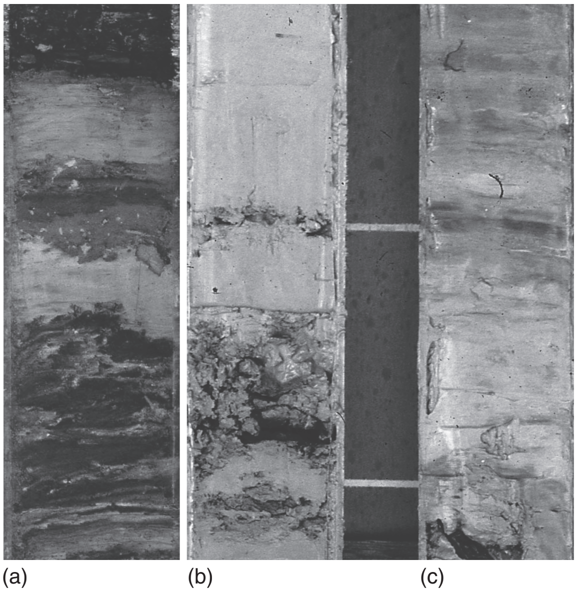

Figure 13.7 Bioclastic, chemogenic and mud-chip contourite facies. Vema Channel and Contourite Fan, Brazilian Basin. Core width 7 cm. (a) Lower part of thick manganiferous crust at top of section (current sea floor) overlying calcareous marl contourites (yellowish) and further interbedded black manganiferous deposits. (b) Sharp contact (erosive bottom-current event) between brownish-yellow calcareous marl contourites, with thin manganiferous horizons, and greenish muddy contourites. (c) Muddy contourites (as in b) with thin micro-brecciated horizons of mud-chip contourites (from Faugères et al., 2002a; with permission from The Geological Society, London). A multicolour version of this figure is on the included CD-ROM.

indistinct primary lamination may be preserved. The mean grain size is most commonly silty clay to clayey (and/or sandy) silt, poorly sorted (grain-size parameters as for muddy contourites) and in some cases with a distinct sand-sized fraction representing coarser pelagic biogenic particles that have not been too fragmented during transport.

The composition is typically pelagic to hemipelagic, including nannofossils and foraminifers as dominant elements, but in some cases the deposits may be largely composed of reworked shallow-water carbonate debris from off-shelf or off-reef supply. There is a variable admixture of siliciclastic or volcaniclastic material.

13.3.8. Calcareous sandy contourites

Calcareous sandy contourites are the calcareous equivalent of sandy contourites, typically occurring in successions with both calcareous silty and muddy contourites. Contacts between these different facies may be either gradational, yielding indistinct bedding, or much sharper due to the erosive action of relatively strong bottom currents, thereby yielding more distinct bedding. In thinner beds, primary sedimentary structures may be largely obscured due to strong bioturbation, but

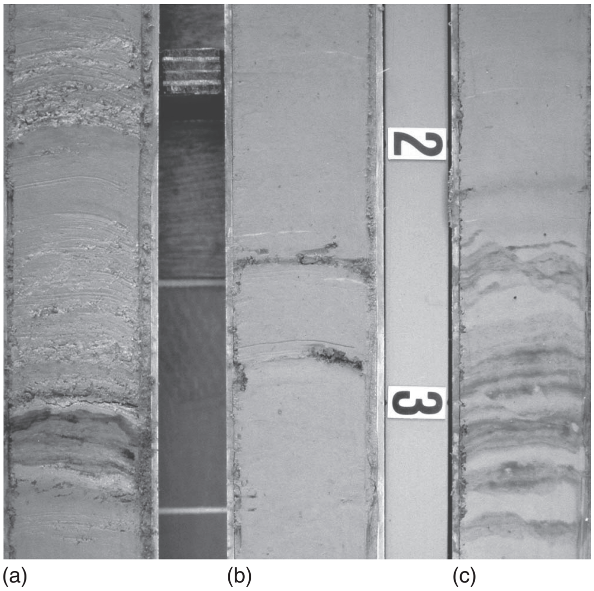

Figure 13.8 Bioclastic, chemogenic and muddy contourite facies.Columbia fan–drift system, Brazilian Basin. Core width 7 cm. (a) Yellow and black manganiferous contourites, with dark manganiferous crust (centre) and diatomaceous contourite mud (near top). (b) Greenish muddy contourite with thin disrupted layers (near centre) of shale-chip contourites. (c) Yellow and black manganiferous/calcareous contourites with irregular lamination and marbling structure. (from Faugères et al., 2002b; with permission from The Geological Society, London). A multicolour version of this figure is on the included CD-ROM.

thin-bedded cross-laminated foraminiferal contourites are also known. Thicker beds may preserve more structures, although lenticularity, non-depositional surfaces, hardgrounds and burrowing also appear common in this facies.

The mean grain size is sand, and both poorly sorted and well-sorted examples are known. These coarse-grained biogenic particles may be derived from pelagic, benthic, off-shelf and off-reef sources, and may have a variable admixture of siliciclastic, volcaniclastic and siliceous biogenic material. The bioclasts are often fragmented and iron-stained as a result of transport and oxidation.

13.3.9. Calcareous gravel-lag contourites

Calcareous gravel-lag contourites, including those comprising calcilutite microclasts or chips derived from erosion of the substrate, and are not well known from the modern record. They have been inferred and described from ancient contourite successions (see Hüneke and Stow, 2008).

13.3.10. Siliceous bioclastic contourites

Siliceous bioclastic contourites (Figures 13.8a) of mud, silt or sand grade are also rarely described from modern systems. Both muddy (siliciclastic) and calcareous (bioclastic) contourites may be relatively rich in diatomaceous and radiolarian material, particularly at higher latitudes, but are rarely dominated by siliceous bioclastic material. Cross-laminated radiolarian-rich contourite sands are known only from ancient contourite successions.

13.3.11. Chemogenic contourites

Chemogenic contourites (Figures 13.7a, b and 13.8a, c) are those in which chemical precipitation directly from sea water occurs in association with contourite deposition and/or erosion and hiatus surfaces.

13.3.11.1. Manganiferous contourites

Manganiferous contourites are those in which manganiferous or ferro-manganiferous horizons are common. This metal enrichment may occur as very fine dispersed particles, as a coating on individual particles of the background sediment, as fine encrusted horizons or laminae, or as micronodules. These features have been observed in both muddy/silty and calcilutite/calcisiltite ancient contourites from several drifts, and can also occur in association with non-deposition surfaces, hardgrounds and hiatuses. Bioturbation and burrowing are particularly evident in such cases, forming a tiered ichnofacies assemblage in the sediment below the non-deposition surface. Extensive areas of sea-floor with larger ferro-manganese nodules and pavements are well known, but the role of bottom currents in their formation is still controversial.

13.3.11.2. Chemogenic gravel-lag contourites

Where deep-water chemoherms (chemical–biogenic precipitates) of metal–carbonate chimneys, mounds and encrustations occur in the path of bottom currents, the sea floor, particularly in contourite channels, is seen to be strewn with the fallen and/or eroded debris of chemoherm material. In places, this has clearly been winnowed and aligned into chemogenic gravel-lag contourites. However, the role of bottom currents in the original growth and development of such chemoherms is unknown.

13.3.12. Other contourite-related facies

Other contourite-related facies, including modified hemipelagites, reworked turbidites and "shallow-water contourites" are considered in the "Discussion" section below.

13.4. CONTOURITE FACIES MODEL AND THE CONTOURITE SEQUENCE

The facies models for both muddy and sandy contourites were originally based on data from many examples of contourites that had been cored from modern contour-current deposits up to the late 1970s (Stow and Lovell, 1979). Subsequent work demonstrated that these muddy and sandy facies, together with intervening silty contourites, commonly occur in composite sequences or partial sequences a few decimetres in thickness (typical range 0.2–3 m) (Faugères et al., 1984; Gonthier et al., 1984; Stow and Piper, 1984). It was also recognised that such facies sequences can be of siliciclastic, bioclastic, volcaniclastic or mixed composition. The ideal or complete sequence shows overall negative grading from muddy through silty to sandy contourites and then positive grading back through a silty to a muddy contourite facies (Figure 13.9). Well-defined sedimentary structures are generally absent, in part because they have been thoroughly destroyed by bioturbation. There may be an indistinct and discontinuous parallel lamination and lenses of coarser material. Primary structures, including rare cross-lamination, are more evident in the coarse silts and sands than in finer grained facies.

Since the first publication of the model, such sequences of grain size and facies variation have been widely recognized from many more drifts throughout the world, and they have also been used in the recognition and interpretation of ancient contourites (e.g. Stow et al., 1998a; Hüneke and Stow, 2008). In the same way as for the ideal turbidite sequences, partial sequences of different thickness are equally or more common than the full sequence. Following the turbidite analogy of notation for the Bouma turbidite sequences (see Stow, 2005), a shorthand

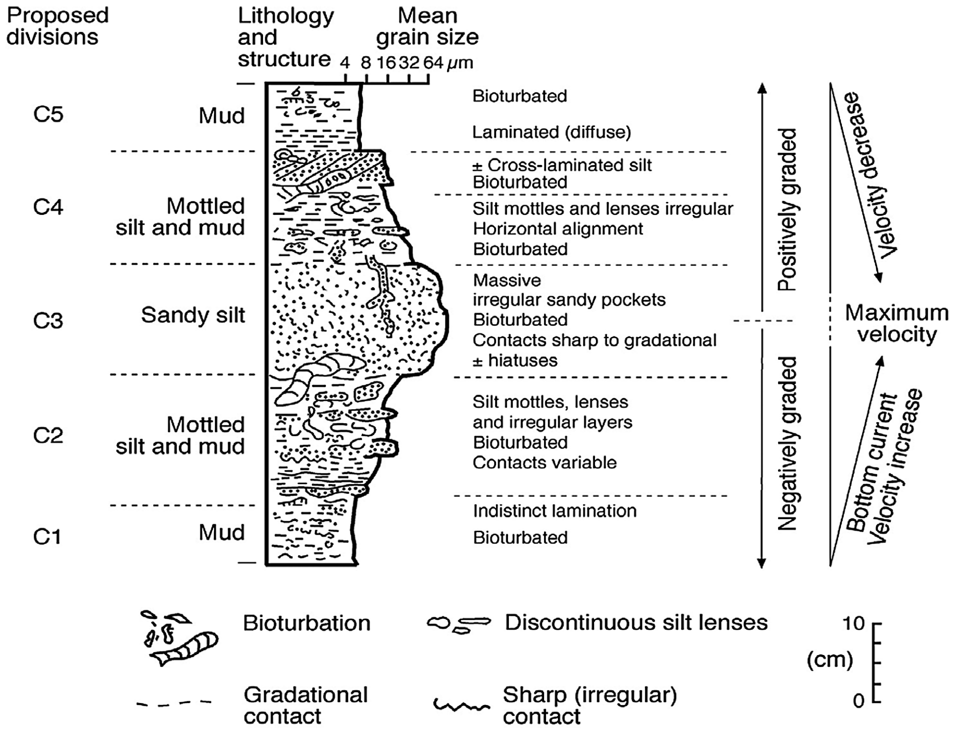

Figure 13.9 Composite contourite facies model showing grain-size variation through the standard mud–silt–sand contourite sequence, linked to variation in contour-current velocity (from Stow et al., 2002b; Stow, 2005; with permission from The Geological Society, London).

description of the contourite sequence using the notation C1–C5 has been introduced (Stow et al., 2002b). This lists the five principal divisions as follows:

C5 = upper muddy contourite division;
C4 = upper mottled silty contourite division;
C3 = middle sandy contourite division;
C2 = lower mottled silty contourite division;
C1 = lower muddy contourite division.

Thus a complete sequence *of any composition* is referred to as C1–5 (Figure 13.9). In a vertical succession of repeated sequences, there is a simple gradation from C5 of the underlying sequence to C1 of the overlying sequence. Separation of two superimposed sequences should be arbitrarily taken at the mid-point of the C5/C1 couplet.

We have constructed for this contribution a further refinement of the standard model that shows more clearly the variety of partial sequences and facies most commonly encountered in contourite successions (Figure 13.10). All these partial sequences have been recorded from modern contourite successions (see Appendix 1), in which the omission of certain divisions can commonly be related to an increase in bottom-current velocity resulting in a prolonged phase of erosion and/or non-deposition. Base-to-middle sequences reflect the abrupt truncation of the full sequence as a result of increased bottom-current velocity and subsequent

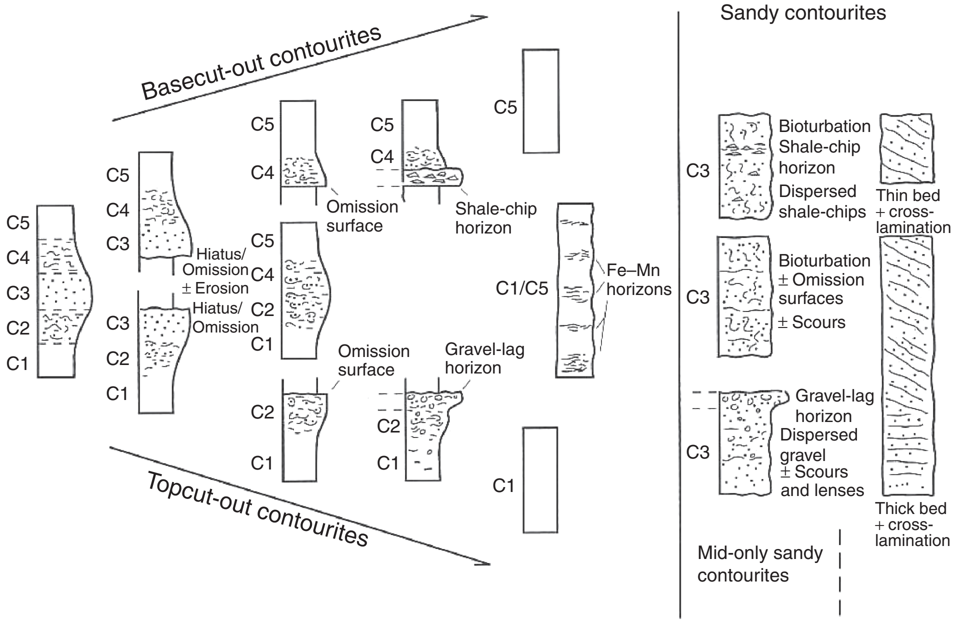

Figure 13.10 Variations on the standard contourite facies models showing the range of contourite facies, sequences and partial sequences commonly encountered in contourite successions.

non-deposition. Middle-to-top sequences reflect the gradual onset in deposition after a period of erosion. Partial sequences can also reflect velocity decrease downstream of a narrow gateway or channel, with middle-only sequences deposited proximally and top/base only sequences more distally. Base-only partial sequences are referred to as C1, C1–2 or C1–3, and top-only sequences as C3–5, C4–5 or C5, as appropriate. Rather than introducing a new division notation for the occurrence of other contourite facies within the sequence, it seems more sensible to highlight these departures from the standard sequence verbally. Base-only sequences that pass up into a gravel-lag and non-depositional surface are described as C1–3 *with a gravel top*. Likewise, top-only contourites are referred to as C3–5 with a sharp erosive base. Mid-only contourites can be referred to as C3 bioturbated, C3 laminated, or simply as bioturbated/laminated sandy contourites. Manganiferous horizons, non-deposition surfaces and hiatuses within contourite successions are all separately indicated.

13.4.1. Sequence origin and interpretation

The origin of the C1–5 sequence can be related to long-term fluctuations in the mean current velocity, and/or to variation in sediment supply. Stacked sequences and repeated partial sequences indicate cyclic variation in the forcing variables. A growing body of data now exists, based on the best biostratigraphic, oxygen-isotope and/or radiometric dating available in each case, to allow approximation of the mean time span of these cycles. This yields a periodicity of 5000–20,000 years for a variety of marginal drifts of terrigenous to mixed composition. In bioclastic successions, the cyclic facies pattern has a longer time (20,000–40,000 years) in the few examples from which we have good biostratigraphic dating, and is closely analogous to the Milankovitch cyclicity recognised in many pelagic and hemipelagic successions. It is therefore believed to be driven by the same mechanism of orbital forcing of climate that then affects changes in bottom-current velocity. Hüneke and Stow (2008) have estimated cycle periodicities for the few ancient successions of fossil contourites where dating has made such estimates possible. Their examples are all calcareous bioclastic in nature, the data suggesting cycles of between 20,000 and 200,000 years duration. These are therefore also possibly of Milankovitch origin.

As yet, physical oceanographers know insufficient about the medium and longer timescale (decadal to millennial) variations in bottom currents (see e.g. Bacon, 1998), so we are less able to interpret the 5000–20,000 cycles as a direct function of climate or current-related variation. The shorter (sub-annual) variations resulting from benthic storm events are likely to cause some of the specific features *within* the contourite sequence, such as sharp or erosional contacts, coarse-grained lenses and non-deposition surfaces. Subtle colour banding, ichnofacies changes and variation in certain proxy measurements (e.g. magnetic-susceptibility characteristics), appear to occur with a mean centennial-to-millennial periodicity. We can only speculate about links to, for instance, bottom-current changes due to eddy generation and cycling, or to periodic spillover of bottom water through oceanic gateways.

In addition, it is not easy to differentiate the relative importance of current velocity versus sediment supply in the development of contourite sequences, so that some of the cycling may be wholly due to supply variability that is not linked with bottom-current fluctuations. The most thorough approach to untangling this problem is to analyse variations in grain-size properties (including bulk-sediment mean size, sortable silt, carbonate-free mean size), and then to consider the co-variance or not of compositional attributes (e.g. terrigenous/biogenic ratios, benthic/planktonic ratios, percentage of coarse sand/gravel and shale chips, presence/absence of far-travelled components, clay/silt ratio), current indicators (e.g. scour surfaces, lamination, lag horizons, coarse-grained lenses, shale-chip concentrations) and bioturbation intensity coupled with ichnofacies types. These data need to be collated and compared for different sites over the same drift to distinguish regional from local effects, and to observe down-current trends (Stow et al., 2002b). Cycle irregularity is likely to result from interaction of sediment supply and current velocity.

13.5. LAMINATION VERSUS BIOTURBATION IN CONTOURITES

The great majority of contourites recovered from drift systems beneath extant contour currents are characterised by a notable absence of clear, distinct lamination and by the presence of common to abundant, pervasive bioturbation (see Appendix 1 of this chapter; see also Table 1 in Stow et al., 1998a). However, in some cases, they also exhibit an indistinct and discontinuous parallel lamination, partial grain alignment, sub-horizontal to irregular erosion surfaces, winnowed concentrations of thin layers and lenses of coarser material. These features are all reflected in the standard contourite model and sequence described above.

Intuitively, we might expect the sediments deposited by any bottom-current system to show lamination as a result of fluid-flow processes and depositional sorting mechanisms. At moderate and higher flow velocities, we observe bedforms (ripples, dunes, etc.) on the sea floor beneath bottom currents, and would therefore expect their deposits to show cross-lamination at different scales. Such cross-lamination is only rarely described from modern examples of these facies, however, and extensive bioturbation is generally dominant. It was this expectation of primary current lamination that led initially to a discussion about the diagnostic sedimentary structures in contourite facies. This disagreement still persists in the current literature, where well-laminated deposits are interpreted as contourites (see Hüneke and Stow, 2008; Martín-Chivelet, 2008; Shanmugam, 2008).

There may be several reasons for the lack of clear lamination in contourites:

- contourite accumulation rates are low and continuous, so that bioturbation is more than able to keep pace with deposition and so effectively destroys most primary lamination; indistinct lamination and other current-related features are all that remain;
- for thick, muddy contourite accumulations, the low to very low current velocities are insufficient to result in primary lamination;
- the very low sediment concentrations associated with most contour-current nepheloid layers are insufficient to permit the depositional sorting mechanism that develops silt/mud lamination in fine-grained turbidites.

There are, however, a number of notable exceptions in which lamination in present-day contourites has been described, and for which we have included new categories of contourite facies as described in the first part of this chapter (Figure 13.5). They are not as common as their bioturbated counterparts and are therefore best referred to as specific facies and/or depositional settings, as discussed below.

13.5.1. Laminated sandy contourites

Laminated sandy contourites (Viana et al., 1998a; Nelson et al., 1999; Habgood et al., 2003) include siliciclastic facies where high-velocity bottom currents are dominant and large-scale bedforms (e.g. dunes) are evident on the sea floor. The lamination is distinct, but can also be diffuse, and may be associated with bioturbation. They also include bioclastic sandy contourites (biogenic calcareous and siliceous), in which both parallel and cross-lamination have been observed. Preservation of primary lamination in both siliciclastic and bioclastic facies is probably due to the high current velocity and dearth of organic matter inhibiting extensive bioturbation.

13.5.2. Laminated muddy/silty contourites

The distinct parallel laminated facies in muddy contourites observed on the Baffin Sea slope (Yoon and Chough, 1993) are associated with continuous bioturbation, and can be clearly distinguished from interbedded turbidites and hemipelagites. They are interpreted to be related in part to down-slope flow of relatively high-concentration bottom currents following the generation of cold, dense waters near the surface, and in part to the preservation of lamination under harsh high-latitude conditions where bioturbation is insufficient to completely destroy primary structures. Distinctly laminated muds from the Baltic Sea (parallel lamination diffuse and abundant) have been interpreted as shallow-water contourites (Sivkov et al., 2002). If their interpretation and terminology is correct, the preservation of primary lamination can be related to relative lack of oxygen as well as to high rates of sediment input, both acting to suppress bioturbation. The laminated muddy facies presented in compilations by Stow (Stow, 1994; Stow et al., 1996b, 2002f) has always indicated that these are shallow-water contourites, but the better known examples are interpretations from the ancient record and must therefore remain more suspect.

13.5.3. Mixed turbidite/contourite systems

With respect to mixed turbidite/contourite systems (Rebesco et al., 1996, 1997, 2002; Pudsey, 2000; Escutia et al., 2002), much debate has centred around the interpretaion of thick elongate sediment accumulations (drifts) off the western Antarctic Peninsula, which have now also been recognised from the northern margin off Wilkes Land. Most researchers would now accept that these are turbidity-current supplied systems that have been variously pirated and reworked by contour currents. The clear, but somewhat irregular and discontinuous lamination, locally associated with bioturbation, is best interpreted as the result of a combined turbidity-current/contour-current process, although the nature of this process remains unresolved.

Laminated, barren sediments containing ice-rafted debris (IRD) layers are observed on much of the Antarctic margin and are interpreted as contourites although they are atypically not bioturbated (Lucchi et al., 2002). In this case, the presence of IRD layers within laminated sediments is an indication against the hypothesis of a turbiditic origin, as turbidity currents are too short-lived to incorporate distinct layers of IRD. This particular type of glacigenic contourite facies appears associated to glacial times only, and is interpreted to result from unusual, climate-related, environmental conditions of suppressed primary productivity and oxygen-poor deep waters (Lucchi and Rebesco, 2007).

13.6. CONTOURITE-RELATED FACIES

As is often stressed, contourites are not an easily recognised deep-water facies, nor is the process of deposition a simple one. It is important to recognise that bottom currents will influence to a greater or lesser extent other deep-water sediments – particularly pelagic, hemipelagic, turbiditic and glacigenic – both during and after deposition. Where the influence is marked and deposition occurs in a drift, the sediment is termed "contourite". Where the influence is less severe, such that features of the original deposit type remain dominant, the sediment is said to have been influenced by bottom currents.

Many pelagic and hemipelagic successions may have experienced some bottom-current influence, creating local winnowing of foraminiferal sands, regional variations in thickness or hiatuses. Reeder et al. (2002) interpreted the relatively high rates of hemipelagic accumulation in the Sicily Gateway as the result of bottom-current lofting and re-suspension of the bottom-current load into the overlying water column. This can be considered as an example of bottom-current-influenced hemipelagites. Marked thickness variations in mid-ocean pelagic successions, as noted by Dennielou (1997), might also be interpreted as weak bottom-current influence on an otherwise normal pelagite facies. Distinguishing features of contourites, hemipelagites, pelagites and other closely related facies have been discussed by Stow and Tabrez (1998). Part of the table from that work is reproduced here (Table 13.2).

The recognition and interpretation of bottom-current-reworked turbidites has been notoriously more difficult. Some good modern examples have been described from the Columbia Gateway in the SW Atlantic (Massé et al., 1998; Faugères et al., 2002a, b) and the Sicily Gateway in the Mediterranean (Reeder et al., 2002). Rather more ambiguous, however, are the thin, clean, cross-laminated sands originally described by Hollister and Heezen (1972) from the NE American margin, as these might also be interpreted as normal fine-grained turbidites (e.g. Stow, 1979). The features that we suggest best characterise reworked turbidites are summarised in Table 13.3, together with those of normal (depositional) contourites and sandy contourites. These differ from the criteria proposed subsequently by several workers that are based purely on ancient turbidite successions (e.g. Stanley, 1988; Mutti, 1992; Shanmugam et al., 1993a, 2000). However, we believe that criteria developed purely from known modern drift systems (as herein) are more reliable, because of the inherent uncertainties of interpretation when dealing with ancient series.

AU3
AU4

Table 13.2 Diagnostic criteria for the recognition and distinction of various fine-grained deep-water facies

Turbidites (fine grained, thin bedded)	Turbidites–Unifites[a] (fine grained, very thick bedded)	Hermiturbites[b] (thick, bioturbated muds, with mixed characteristics)	Contourites (fine grained, depositional)	Hemipe-lagites	Pelagites (biogenic ooze)	Pelagites (abyssal red clay)
Bedding						
Usually well defined, continuous, thin bedded, regular	Usually well defined, regular, extensive; beds >1 m, and may exceed 25 m thick	Poorly defined bedding	Poorly defined and irregular, may be absent; irregular, variation of very thin to very thick beds	Poorly defined or moderate, regular, but may be absent; beds when present may be even bedded and medium thick	Poorly defined to absent	Poorly defined to absent
Structures						
Lamination lenticular and parallel, regular or indistinct; micro-cross-lamination, low-amplitude climbing ripples, fading ripples and convolute lamination common	*Structureless* or with very indistinct parallel lamination near base of bed	*Primary structures* absent, but may cap fine-grained laminated turbidites	*Lamination* in parts only, mainly irregular, wavy, indistinct or lenticular, cross-lamination only rarely present in silt or fine-sand layers; irregular mottling very common	*No* primary structures, but may develop fine fissile lamination where deposited under anoxic conditions	*No* primary structures	*No* primary structures

(*Continued*)

Table 13.2 (*Continued*)

Turbidites (fine grained, thin bedded)	Turbidites–Unifites[a] (fine grained, very thick bedded)	Hermiturbites[b] (thick, bioturbated muds, with mixed characteristics)	Contourites (fine grained, depositional)	Hemipe-lagites	Pelagites (biogenic ooze)	Pelagites (abyssal red clay)
Contacts usually sharp at bases and sharp or gradational at top of laminae; micro-scours, loading and injection structures	*Contacts* sharp at bases and sharp or gradational at top; little or no scouring evident	*Contacts* gradational and bioturbated	*Contacts* can be sharp or gradational at tops and bases of layers and laminae; often gradations between the two along same contact; often irregular, sometimes erosive	*Contacts* between beds always gradational and bioturbated	*Contacts* gradational and bioturbated	*Contacts* gradational and bioturbated
Bioturbation episodic, concentrated near tops of beds, often small scale, sometimes absent, rarely destroys all primary structures	*Bioturbation* in upper part of beds	*Bioturbation* continuous throughout bed; may be distinctive monospecific ichnofacies	*Bioturbation* continuous and intensive, throughout sequence; several tiers of burrows, types vary according to contourite facies; can markedly alter or destroy primary structure	*Bioturbation* continuous and intensive throughout sequence; several tiers of burrows, uniform ichnofacies; may become homogenized	*Bioturbation* continuous and intensive as for hemipelagites	*Bioturbation* continuous; may be less evident than in oozes and hemipelagites; mottling and homogenization common

Textures						
Grain size from fine to sand to clay grade	*Grain size* typically from silt to clay	*Grain size* very fine silt and clay	*Grain size* from sand to clay grade	*Grain size* from sand to clay grade, with >40% of terrigenous fraction being silt sized; locally coarser	*Grain size* from sand to clay grade	*Grain size*, clay and fine silt
Distribution and moderate to good *sorting* indicate current deposition; silt and mud laminae usually well separated; silts often positively skewed (fine tail)	*Sorting* moderate to poor	*Sorting* moderate to poor	*Sorting* usually poor to moderate but *distribution* does indicate current deposition; silt and mud often irregularly mottled; silts often have low positive or negative skew (i.e. both coarse and fine tails)	*Sorting* usually poor to moderate, but *distribution* does indicate current deposition; silt and mud often have low positive or negative skew (i.e. both coarse and fine tails)	*Sorting* poor to moderate, no current indications	*Sorting*, poor to moderate
Grading positive, often in regular graded-laminated units	*Grading* absent or very poor slight positive grading	*Grading* generally absent	*Grading* irregular, both positive and negative sequences	*No true grading*, but irregular grain-size fluctuation may be present	*No grading*	*No grading*
Fabric						
Grain alignment (silts) parallel to downslope currents	*Fabric* not studied; presumed similar to thin-bedded turbidites	*Fabric* not studied	*Grain alignment* (silts) may be parallel to along-slope currents; more often distributed by bioturbation	*No grain alignment*	*No grain alignment*	*No grain alignment*

(*Continued*)

Table 13.2 (*Continued*)

Turbidites (fine grained, thin bedded)	Turbidites–Unifites[a] (fine grained, very thick bedded)	Hermiturbites[b] (thick, bioturbated muds, with mixed characteristics)	Contourites (fine grained, depositional)	Hemipe-lagites	Pelagites (biogenic ooze)	Pelagites (abyssal red clay)
Mud fabric may show large particles clusters (flocs) with random orientation			*Mud fabric* may show small particle clusters, with horizontal orientation where not bioturbated	*Mud fabric* may show small particle clusters and isolated particles; bed parallel	*Fabric* with small clusters and isolated particles; bed parallel	*Fabric* with small clusters and isolated particles, bed parallel
Magnetic fabric (?) parallel to down-slope currents			*Magnetic fabric* (?) parallel to along-slope currents	*No magnetic fabric*	*No magnetic fabric*	*Random magnetic fabric*
Composition						
Allochthonous elements introduced into an area, so that turbidite composition often differs markedly from that of interbedded sediments	*Allochthonous composition*	Mainly *allochthonous* composition as for associated turbidites, plus admixture of hemipelagic input	*Uniform* composition at scale of drift or margin deposit; part may be far-travelled, but most derived locally from pelagic and turbidite input and bottom-current re-suspension	*Uniform* composition, local and far-travelled in surface currents, winds; varied inputs	*Uniform* composition derived from primary productivity in surface waters	*Uniform* composition

Nature can be terrigenous, biogenic, volcanigenic, or mixed, often containing shallow-water elements; may show compositional grading	Terrigenous, biogenous, volcanigenic or mixed; may show compositional grading		*Nature* usually a mixture of terrigenous and biogenic; can be >80% one or other, can also include volcanigenic, debris; reworked biogenic material common, often as broken and iron-stained debris; Fe–Mn rich in parts	*Nature* usually a mixture of terrigenous and biogenic (dominantly pelagic) elements, can include volcanigenic debris or glacio-marine input	*Nature*, calcareous, siliceous or mixed; with rare volcanigenic, terrigenous and cosmogenic input; Fe–Mn modules and crusts locally	*Terrigenous* and *volcaniclastic* clays and fine silts; wind-blown dust, cosmogenic input, microtektites, Fe–Mn nodules and crusts
Distribution						
Vertical sequence often a regular succession of positively graded beds, or graded-laminated units (2–20 cm thick); these can form part of thicker coarsening- or fining-upward sequences	Typically occur as isolated *megabeds*	Typically occur within distal turbidite basin-plain succession	*Vertical sequence* often an irregular succession of positively and/or negatively graded intervals (10–100 cm thick); large-scale sequences not yet clearly defined	*Vertical sequence* absent or as regular cycles of more or less biogenic-rich compositions	*Vertical sequence* absent or as regular cycles of more or less biogenic-rich compositions	No *vertical sequence*

(*Continued*)

Table 13.2 (*Continued*)

Turbidites (fine grained, thin bedded)	Turbidites–Unifites[a] (fine grained, very thick bedded)	Hermiturbites[b] (thick, bioturbated muds, with mixed characteristics)	Contourites (fine grained, depositional)	Hemipe-lagites	Pelagites (biogenic ooze)	Pelagites (abyssal red clay)
Sedimentation rates						
Horizontal trends of sedimentary features (e.g. bed thickness, grain size, composition) along turbidity current pathways, i.e. down-slope trends	*Horizontal trends* generally absent or very subtle	*Horizontal trends* absent	*Horizontal trends* of sedimentary features (e.g. grain size, composition) along bottom-current pathways (i.e. along-slope trends parallel to the margin or drift)	*Horizontal trends* not present or weakly developed over large area	*Horizontal trends* not present or weakly developed over large area	No *horizontal trends*
Current evidence (ripples, flute-casts, fabric) also shows down-slope trends			*Current evidence* (ripples, fabric), where preserved, also show along-slope trends	No *bottom-current evidence*	No *bottom-current evidence*	No *bottom-current evidence*
Episodic turbidite sedimentation, background sedimentation continuous, hiatuses uncommon except when associated with coarser-grained turbidites	*Episodic*, typically less frequent than thin-bedded turbidites	*Episodic* events but with very long settling periods (e.g. 0.5–1 a)	*Semi-continuous* sedimentation, with irregularly spaced, often prolonged hiatuses when bottom currents particularly strong	*Continuous* sedimentation, no hiatus	*Continuous* sedimentation, but may be very reduced in places	*Continuous* sedimentation

Rate very variable, 0 to 1000 cm ka^{-1}			*Rates* variable, low to moderate, <2 to 15 cm ka^{-1}	*Rates* relatively constant, commonly low, <10 cm ka^{-1}; may vary with carbonate cycles; locally may be moderate to very high (> 100 cm ka^{-1})	*Rates* very low, typically <1 cm ka^{-1}; very rarely up to 5 or 10 cm ka^{-1}	*Rates* extremely low, <<1 cm ka^{-1}; may be <0.1 cm ka^{-1}

Source: Modified from Stow and Tabrez (1998).

[a] Unifites (Stanley, 1981) are defined as thick, structureless muds of gravity flow origin that are the result of slow (hemipelagic) settling from detached turbidity currents in well-stratified basins.

[b] Hemiturbidtes (Stow and Wetzel, 1990) are defined as thick, bioturbated muds with partly turbiditic and partly hemipelagic characteristics. They are deposited from suspension clouds formed at the distal end of turbidity current pathways by a process of upward buoyancy.

Table 13.3 Distinguishing features of muddy contourites, sandy contourites and bottom-current-reworked turbidites

	Muddy contourites (terrigenous or biogenic)	Sandy contourites (terrigenous or biogenic)	Reworked turbidites (any composition)
Occurrence	Thick uniform sequences of fine-grained sediment in deep-water settings	Thin to medium beds in muddy contourite sequences, rarely thick/very thick units	In any normal turbidite setting where strong permanent bottom currents have been active
	Interbedded with turbidites and other resedimented facies on inferred continental margins	Reworked tops of sandy turbidites in interbedded sequences Coarse lag in deep-sea channels and straits	
Structure	Dominantly homogenous, bedding not sharply defined but cyclicity common	Generally bioturbated and burrowed throughout with little primary structure remaining	Lower divisions of turbidite may be preserved, with the upper divisions either removed completely or modified by reworking
	Bioturbational mottling generally common to dominant	Parallel and cross-lamination more rarely preserved (often with bioturbation)	Bioturbation/burrowing common through reworked top reverse grading and irregular lag concentrations
	Distinct burrows (typical deep-water assemblage) present in many places	No regular structural sequence as in turbidites	Bi-directional cross-lamination, may be clean micro-cross-laminated silts with bioturbation
	Coarse lag concentrations (especially biogenic) reflect composition of course fraction in mud	May show reverse grading near top, with sharp/erosive contacts common	Sharp erosive contacts may occur within turbidite sequence
	Primary silt/mud lamination – rare, but no regular sequence as in turbidites		
	Sharp and erosive contacts common in parts		

Table 13.3 (*Continued*)

	Muddy contourites (terrigenous or biogenic)	Sandy contourites (terrigenous or biogenic)	Reworked turbidites (any composition)
Texture	Dominantly silty mud Frequently high sand content (0–15%) of biogenic tests in clastic contourites Medium to poorly sorted, ungraded, no offshore textural trends May show marked textural difference from interbedded turbidite if transport distances are different	Silt to sand-sized, more rarely gravel May be relatively free of mud and well sorted in some cases Tendency to low or negative skewness values No offshore trends	Removed/non-deposition of fines Significant textural differences from underlying turbidite (e.g. cleaner, better sorted, reverse grading + lag, negative skewness)
Fabric	Mud-fabric – typically more parallel alignment of clays than for turbidites, but not well present in fossil contourites Primary silt laminae or coarse lag deposits show grain orientation parallel to the current (along-slope)	Indication of grain orientation parallel to bottom current (along-slope) or more randomised by bioturbation Other features (e.g. structures) also indicate along-slope flow, where preserved	Interbedded, reworked turbidite layers may show widely bimodal orientations or a more random palymodel fabric
Composition	Mixed contourites have combination of biogenic and terrigenous material (may be distinct from interbedded turbidites) Terrigenous material dominantly reflects nearby land/shelf source with some along-slope mixing and small amount of far travelled material (no down-slope trends)	Mixed biogenic/terrigenous composition, typical terrigenous composition dependent on local source Biogenic material from pelagic, benthic and re-sedimented sources, typically fragmented and iron-stained Organic carbon content very low	Composition entirely reflects that of turbidite, with part of fine fraction removed Long exposure and winnowing may lead to chemogenic precipitation (probably rare) Organic carbon content very low

(*Continued*)

Table 13.3 (*Continued*)

	Muddy contourites (terrigenous or biogenic)	Sandy contourites (terrigenous or biogenic)	Reworked turbidites (any composition)
Sequence	Typically arranged in decimetric cycles of grain-size and/or compositional variation with sandy contourites	Typically in decimetric cycles of grain-size and/or compositional variation with muddy contourites	Presents a typical turbidite sequence (i.e. top-absent or top reworked)
		See model (Figure 13.9) – partial sequences also common	Does not occur within standard cyclic contourite sequence

Source: Modified from Stow et al. (2002b).

Some of the sediments that have been described recently from mixed drift systems, such as those on the Antarctic Peninsula Margin (Rebesco et al., 2002) have been interpreted as the result of sediment supply from turbidity currents, followed by capture of the fine suspended cloud by active bottom currents. This material is then deposited at varying distances from the supply channel across the adjacent levees or mixed-drift bodies in a downcurrent direction. They show clear, but somewhat irregular lamination coupled with bioturbation where lamination is less pronounced. Bulk grain-size analysis shows a very poorly sorted silty clay grain size, although individual silty laminae are no doubt slightly coarser grained. A mixed turbidite/contourite facies type seems reasonable.

In our opinion, there is not yet enough evidence to fully characterise and interpret various facies described from shallow-water, upper-slope to outer-shelf settings (Viana and Faugères 1998; Roveri, 2002; Sivkov et al., 2002; Viana et al., 2002a, b). Viana et al. (1998a) have made an important advance in this direction by synthesising data on all bottom-current-controlled sands, from deep-water true contourite sands to shallow-water bottom-current-influenced sands. However, the so-called shallow-water contourite facies, of all compositions and grain sizes, still requires further work.

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APPENDIX 1

DETAILS OF CONTOURITE FACIES RECOVERED FROM MODERN DRIFT SYSTEMS USING CONVENTIONAL CORING TECHNIQUES AS PUBLISHED OVER THE PAST 15 YEARS

13A1.1. NW UK CONTINENTAL MARGIN

Bottom currents: North Atlantic Deep Water (NADW), NE Atlantic Water slope current (NEAW), Norwegian Sea Overflow Water (NSOW).

Drift system: complex drift system in NE Rockall Basin.

Contourite facies: muds, sandy muds, muddy sands, ± dispersed IRD; well bioturbated and mostly lacking primary structures, some indistinct lamination, rare cross-lamination, irregular winnowed concentrations of IRD; mixed composition, mainly siliciclastic, some bioclastic; distinct cyclicity, partial and complete sequences, 30–120 cm thick.

References: Howe et al. (1994, 2002); Stoker et al. (1998a); Morri (2004).

Drift system: Hebridean Slope, Barra mixed fan, Barra contourite sand sheet.

Contourite facies: muds, mottled silts, muddy and silty sands, ± dispersed IRD, and bottom-current-influenced glaciomarine sandy gravels; well bioturbated and mostly lacking primary structures, some indistinct lamination, irregular winnowed concentrations of IRD and relict IRD sandy gravels; mixed composition, mainly siliciclastic, some bioclastic; indistinct cyclicity in lower part (with masking by interbedded turbidites), partial base-only reversed-graded sequence common at surface, 20–400 cm thick.

References: Armishaw et al. (1998, 2000); Stow et al. (2002a); Knutz et al. (2001, 2002b).

Drift system: sheeted drift system in Faroe–Shetland Channel.

Contourite facies: muds, sandy muds, muddy sands ± dispersed IRD, thin micro-shale-clast horizons; well bioturbated and mostly lacking primary structures, some indistinct lamination, irregular winnowed concentrations of IRD; mixed composition, mainly siliciclastic, some bioclastic; distinct cyclicity, partial and complete sequences, 40–180 cm thick, good lateral correlation over 40–80 km.

References: Akhurst et al. (2002); Howe et al. (2002).

13A1.2. NORWEGIAN CONTINENTAL MARGIN

Bottom currents: Norwegian (slope) current, Arctic Intermediate Water (AIW).

Drift system: Lofoten Drift, mounded elongated separated drift.

Contourite facies: silty muds, sandy muds ± dispersed IRD; well to less well bioturbated, some parts lacking primary structures, others with indistinct to faint lamination, irregular winnowed concentrations of IRD, including some micro-shale clasts; mixed composition, mainly siliciclastic, some bioclastic; indistinct cyclicity, partial and complete sequences, 60–180 cm thick.

References: Laberg et al. (1999, 2002); Stoker et al. (1998a); Vorren et al. (1998).

Drift system: Barents Sea slope, sheet contourites intercalated with down-slope and hemipelagic deposits.

Contourite facies: silty muds, sandy muds ± dispersed IRD; well to less well bioturbated, pervasive through contourite facies, some parts lacking primary structures, most with indistinct to faint lamination (diffuse and discontinuous); mixed composition, mainly siliciclastic, some bioclastic. Note: diffuse laminated contourites interpreted as result of down-slope bottom currents from bottom-water formation near the surface.

References: Yoon et al. (1991); Yoon and Chough (1993).

13A1.3. GREENLAND CONTINENTAL MARGIN

Bottom currents: Norwegian Sea Overflow Water (NSOW).

Drift system: Eirik Drift, mounded elongated drift.

Contourite facies: muds, silty muds, sandy muds/silts ± dispersed IRD; well to less well bioturbated, rare indistinct lamination; mixed composition, mainly siliciclastic, some bioclastic; indistinct cyclicity, 10–200 cm thick, and smaller-scale colour banding in parts.

References: Hunter et al. (2007a, b).

13A1.4. GULF OF CADIZ, IBERIAN MARGIN

Bottom currents: Mediterranean Sea Overflow Water (MOW) divides into several slope current strands.

Drift system: erosive systems close to Gibraltar Gateway, leading to complex contourite depositional system, including Faro–Albufeira Drift.

Contourite facies: muds, mottled silts and sands in depositional system; sands, laminated sands and sandy gravel-lag contourites in erosive system; mainly well bioturbated, faint lamination in parts, silt/sand lenses; some thick-bedded sands, well laminated (diffuse laminae); mixed siliciclastic/bioclastic composition; distinct cyclicity, partial and complete sequences, 20–140 cm thick, good lateral correlation of 40–50 km over some parts.

References: Llave (2003); Nelson et al. (1999); Habgood et al. (2003); Stow et al. (1986, 2002b).

13A1.5. MEDITERRANEAN SEA

Bottom currents: Mediterranean Bottom Water (MBW), Levantine Sea Intermediate Water (LIW).

Drift system: Ceuta Drift, SW Alboran Sea.

Contourite facies: muds, silty clays and sandy muds; mainly homogeneous (well bioturbated), faint lamination in parts, thin concentrations of bioclastic material; mixed siliciclastic/bioclastic composition; indistinct cyclicity, partial and complete sequences, 20–100 cm thick.

References: Ercilla et al. (2002).

Drift system: Corsica Basin Margin, Corsica Channel drifts, N Tyrrhenian Sea.

Contourite facies: muds and silty muds; mainly homogeneous (well bioturbated), rare thin concentrations of bioclastic material; mixed siliciclastic–bioclastic composition; indistinct cyclicity, partial and complete sequences, 50–200 cm thick.

References: Roveri (2002).

13A1.6. EAST NORTH AMERICAN CONTINENTAL MARGIN

Bottom currents: WBUC, plus influence of deep Gulf Stream and Antarctic Bottom Water.

Drift system: HEBBLE area, Nova Scotian continental rise.

Contourite facies: muds, sandy muds, some IRD gravelly muds; well bioturbated to moderately bioturbated; mainly siliciclastic composition, but sand fraction mostly bioclastic material; near surficial sediment study only (sequences unclear), good photographic evidence of current bedforms; note: top reworked turbidites present.

References: McCave (1985b, 1988); McCave et al. (2002).

Drift system: Greater Antilles Outer Ridge.

Contourite facies: muds, silty clays and clayey silts; homogeneous and well bioturbated, thin irregular silty horizons; mainly siliciclastic composition, some bioclastic carbonate, silty horizons (minor sand) of bioclastic material, ash and Mn micronodules; no clear cyclicity, variation in sedimentation rates, plus hiatuses; distinct interbedded thin turbidites present.

References: Tucholke (2002).

13A1.7. EAST SOUTH AMERICAN CONTINENTAL MARGIN

Bottom currents: NADW current, Brazil Intermediate Current, Brazil Current, Southern Ocean Water, AABW.

Drift system: Campos middle-lower slope, Brazilian continental margin.

Contourite facies: muds, silty muds and sandy muds, muddy sands; mainly well bioturbated, rare faint lamination, rare partly preserved cross-lamination (though extensive current bedforms at surface); mainly siliciclastic composition, some bioclastic material; distinct cyclicity, partial and complete sequences, 20–110 cm thick.

References: Viana et al. (1998a, b, 2002a).

Drift system: Campos upper slope, Brazilian continental margin.

Contourite facies: fine- to coarse-grained sands (some pebbles), sandy muds and muddy silts; fine-grained facies mainly well bioturbated, rare faint lamination; sandy facies homogeneous to laminated (extensive current bedforms at surface); mainly siliciclastic composition, some bioclastic material; distinct but irregular cyclicity, overall coarsening to fining-upward sequence, top sands up to 10 m thick on upper slope.

References: Viana and Faugères (1998); Viana et al. (1998a, b, 2002a).

Drift system: Vema Channel contourite fan, Brazilian continental margin.

Contourite facies: muds and silty muds, with micro-shale-clast layers and manganiferous horizons; mainly homogeneous (well bioturbated), rare faint lamination and Mn lamination; dominant siliciclastic composition, plus manganiferous horizons; distinct cyclicity, mostly small-scale colour sequences, 5–20 cm thick.

References: Mézerais et al. (1993); Faugères et al. (1998, 2002a).

Drift system: Columbia mixed fan drift, Brazilian continental margin.

Contourite facies: contourite muds and silty muds, with manganiferous horizons, and interbedded turbidites; contourite facies homogeneous (well bioturbated), with Mn lamination and micronodules; dominant siliciclastic composition, plus manganiferous horizons; no cyclicity evident; turbidites occur both as thin laminated silt-to-mud units, and as top-truncated thin silt beds.

References: Massé et al. (1994, 1996, 1998); Faugères et al. (2002b).

13A1.8. EAST NEW ZEALAND CONTINENTAL MARGIN, SW PACIFIC

Bottom currents: SW Pacific Deep Western Boundary Current, and complex water-mass movement.

Drift system: Campbell Skin Drift, thin sheet drift over elongate mound/wedge overlying pelagic–hemipelagic succession.

Contourite facies: mixed biogenic sands, Mn-rich sands, interbedded with muds; well bioturbated, lacking primary structures; Mn nodule concentration and extensive reworking of older sediments; mixed terrigenous–biogenic composition, forams and Mn nodules/micro-nodules.

References: Carter and McCave (1997, 2002); McCave and Carter (1997).

Drift system: North Chatham Drift, plastered drift along the Chatham Margin.

Contourite facies: muddy sands and sandy muds (sandy biogenic oozes), interbedded with silty muds; well bioturbated, lacking primary structures; mixed terrigenous/biogenic composition, foram-rich sand component.

References: Carter and McCave (1997, 2002); McCave and Carter (1997).

Drift system: Hikurangai Fan–Drift, bottom-current deflected accumulation modified from major down-slope turbidite fan.

Contourite facies: surficial muds and silty muds, well bioturbated, lacking primary structures, overlying thick unit of distinct turbidite muds and silty muds interbedded with bioturbated units; dominantly terrigenous composition as drift lies near or below Carbonate Compensation Depth, some airfall volcaniclastic silts.

References: Carter and McCave (1997, 2002); McCave and Carter (1997).

13A1.9. ANTARCTIC CONTINENTAL MARGIN AND WEDDELL SEA

Bottom currents: Antarctic Circumpolar Current (AACC), AABW (Weddell Gyre).

Drift system: North Weddell Sea drifts, plastered and mounded drifts transitional to hemipelagic basin fill.

Contourite facies: silty muds, sandy muds, muddy sands ± dispersed IRD; well bioturbated, mainly lacking primary structures, others with indistinct to faint lamination, Mn lamination and irregular winnowed concentrations of IRD; mixed composition, mainly siliciclastic, some bioclastic; distinct glacial/interglacial cyclicity in texture and biogenic content, sequences 30–150 cm thick.

References: Pudsey (1992, 2002); Gilbert et al. (1998).

Drift system: South Weddell Sea mixed drift/turbidite system.

Contourite facies: complex mix of fine-grained silty muds and sandy muds ± dispersed IRD, fed by turbidity currents and reworked by bottom currents; mostly laminated (from original turbidite?), some bioturbated; mixed composition, mainly siliciclastic, some bioclastic; distinct glacial/interglacial cyclicity in texture and biogenic content, but sequences confused by turbidite input.

References: Weber et al. (1994); Melles et al. (1995); Diekmann and Kuhn (1999); Michels et al. (2002).

Drift system: Scotia Sea, plastered, detached and sheeted drift system.

Contourite facies: silty muds and muddy ooze ± dispersed IRD; mostly bioturbated, some with distinct colour lamination; alternating siliciclastic/bioclastic composition; distinct glacial/interglacial cyclicity in texture and biogenic content, sequences 0.5–2.4 m thick.

References: Howe and Pudsey (1999); Pudsey and Howe (1998, 2002).

Drift system: Falkland Trough, plastered and confined mounded drift system.

Contourite facies: silty muds, sandy muds, muddy sands and sands ± dispersed IRD; mostly bioturbated, with rare silty laminae; mixed composition, including siliciclastic muds with biogenics, bioclastic sands and glauconitic sands; distinct cyclicity in texture and composition, partial and complete sequences (including hiatuses) 15–110 cm thick.

References: Cunningham and Barker (1996); Cunningham et al. (2002).

Drift system: Western Falkland Trough, surficial sandy contourites.

Contourite facies: foraminiferal sands over sandy glauconite-rich contourites; foram sands are pale cream coloured, no visible burrows but homogenized by bioturbation; moderately well sorted, medium to fine grained; mixed composition of 60% biogenic material (forams, diatoms, radiolarians, nannofossils) and 40% terrigenous material.

Glauconite-rich sands, greenish black, heavily bioturbated, with rare lamination and thin horizons of dropstones; fine to very fine grained and well sorted; well rounded glauconite grains.

References: Howe et al. (1997).

Drift system: Antarctic Peninsula, mixed drift–turbidite system.

Contourite facies: fine-grained silty muds and sandy muds ± dispersed IRD, fed by turbidity-current overspill, hemipelagic plumes and reworked by bottom currents; some laminated (diffuse laminae), some bioturbated; mainly siliciclastic composition, rare bioclastic material; indistinct cyclicity between bioturbated and laminated, sequences 50–150 cm thick.

References: Camerlenghi et al. (1997); Pudsey and Camerlenghi (1998); Pudsey (2000); Rebesco et al. (1996, 1997, 2002).

Drift system: Wilkes Land continental margin, mixed drift–turbidite system.

Contourite facies: silty muds and sandy muds ± dispersed IRD, fed by turbidity-current overspill and reworked by bottom currents; some laminated (diffuse parallel laminae), some bioturbated; mainly siliciclastic composition, rare bioclastic material; cyclicity between bioturbated and laminated.

References: Escutia et al. (2002).

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AU1	Reference “Wetzel and Stow, 2008” has been cited in the text but not provided in the list. Please check.
AU2	They have a silty–clay grain size (typical range 5–11 *v*), the symbol “*v*” has been changed to “μm” throughout. Please check if it is OK.
AU3	Please specify the reference citation “Stanley, 1998” whether this 1998a or 1998b.
AU4	In order to match with the reference list, we have changed the reference citation “Mutti et al., 1992” to “Mutti, 1992”. Please check if this is OK.