CHAPTER 9

THE NATURE OF CONTOURITE DEPOSITION

D.A.V. Stow[1], S. Hunter[1], D. Wilkinson[1] *and*
F.J. Hernández-Molina[2]
[1]*National Oceanography Centre, Southampton (NOCS), Waterfront Campus, Southampton, UK*
[2]*Facultad de Ciencias del Mar, Universidad de Vigo, Vigo, Spain*

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9.1. INTRODUCTION

Contourites are sediments that have been deposited by or significantly affected by bottom (contour) currents (Stow et al., 2002b; Rebesco, 2005; Stow and Faugères, 2008). They are a group of closely related, essentially deep-water facies, typically deposited below about 300 m water depth under the influence of semi-permanent current action, and are commonly referred to as *along-slope* deposits resulting from semi-continuous depositional processes. This distinguishes them from other deep-water facies that have been deposited either by episodic *down-slope* processes or events (turbidites, debrites, slides and hyperpycnites), or from continuous vertical settling – the so-called *background* processes (pelagites and hemipelagites).

Contourites are found covering large areas of the present-day sea floor beneath modern bottom-current systems, in some regions building up gigantic contourite mounds or drifts through semi-continuous deposition over a period of millions of years, often closely associated with and adjacent to regions of erosion (Rebesco and

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Stow, 2001; Faugères and Stow, 2008). This deposition represents a significant degree of sediment focussing compared with the much lower rates and thinner accumulation of normal background sediments. Contourites also occur closely interbedded with the other deep-water facies. They range from very fine-grained (mud and silt) to relatively coarse-grained (sand and gravel) deposits, and include siliciclastic, bioclastic, volcaniclastic and chemogenic compositional varieties.

Based on the large amount of information gleaned from modern contourite systems, it is possible to construct a fairly accurate picture of just how, where and when contourite deposition occurs. An associated picture emerges of when and where deposition gives way to non-deposition and erosion by bottom currents, and how long-term accumulation of contourites can result from the alternation of deposition and erosion in time and space. Following a brief overview of the bottom-current process, this chapter aims to review the depositional mechanisms of contourites at the large, intermediate and small scales. We therefore consider, in turn, the information that can be derived from drift construction and erosion, sea-floor bedform development, and the detail of sediment facies characteristics.

9.2. BOTTOM-CURRENT CHARACTERISTICS

Bottom (contour) currents are those currents that operate as part of either the normal thermohaline circulation or wind-driven circulation systems, and are generally semi-permanent features in the ocean basins, often long-lived through geological time. In general, therefore, they are acting continuously to affect the pattern of sedimentation in the areas where they occur. The principal characteristics of bottom currents that most affect contourite deposition have been derived from numerous sources (Nowell and Hollister, 1985; McCave et al., 1988; Gross and Nowell, 1990; Gross and Williams, 1991; Stow et al., 1996b) and can be summarised as follows (Figure 9.1).

1. They have a net flow along-slope, but can also flow up-slope, down-slope, around and over topographic obstacles or irregularities. The level within the water column at which maximum flow occurs is dependent on the density (determined by salinity, temperature, and suspended load) of the water mass involved, and the major effects on sedimentation are felt where this flow impinges on the sea floor.
2. They typically act as a broad sluggish movement of water (mean velocity $<10\,\mathrm{cm\,s^{-1}}$) over low gradient slopes and in ocean basins, as more constricted intermediate velocity flows (10–$30\,\mathrm{cm\,s^{-1}}$) over steeper slopes and around topographic obstacles, and as highly constricted high velocity flows ($>30\,\mathrm{cm\,s^{-1}}$) through narrow gateways, passages and over shallow sills. The lower velocity flows can only transport and deposit clay and fine silt-sized material, intermediate velocities can transport up to fine sand-sized material in suspension as well as move coarser sediment as bedload, whereas the higher velocity flows can affect still larger grain sizes.

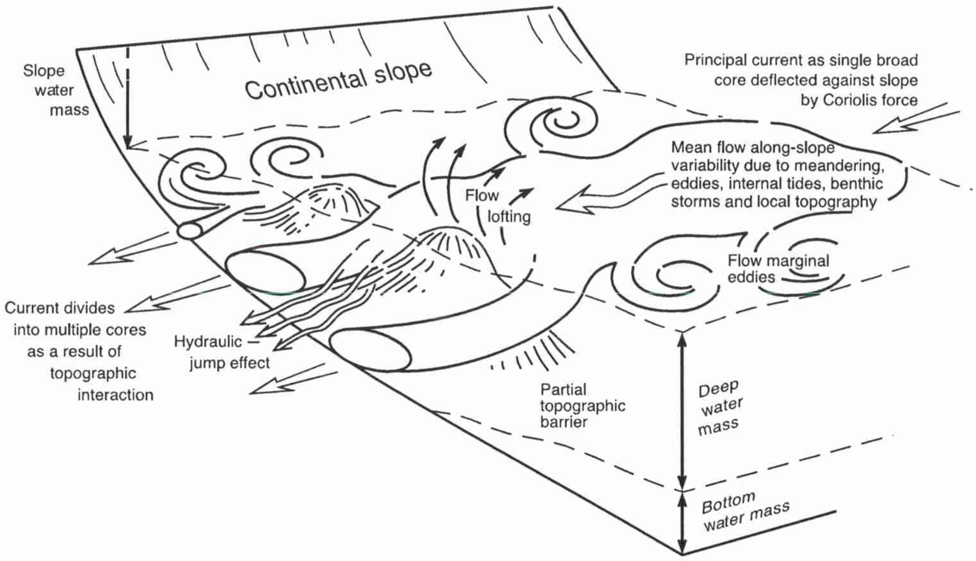


Figure 9.1 Bottom-current characteristics: a schematic summary of principal features. A multicolour version of this figure is on the enclosed CD-ROM.

3. Bottom currents are highly variable in location, direction and velocity over relatively short timescales (from hours to months). Velocity increase, decrease and flow reversal occur as a result of deep tidal effects (e.g. Shanmugam, 2008). Seasonal changes can result from variation in properties of the water masses generated in the source regions. The mean flow velocity decreases from the core to the margins of the current, where large eddies peel off and move at high angles or in a reverse direction to the main flow. The flow velocity is directly affected by changes in slope gradient and other topographic irregularities along its course; and also by current meandering and subdivision into two or more strands around obstacles. This kind of flow variability leads to many cycles of deposition, non-deposition and erosion during the course of contourite accumulation.
4. Eddy kinetic energy, sea-surface topographic variations and surface current instabilities can all be transmitted through the water column and so result in marked variation in kinetic energy at the sea floor. In places, this leads to an alternation of short (days to weeks) episodes of higher velocity benthic storms, and longer periods (weeks to months) of lower velocity. Benthic storms can result in further erosion and resuspension of large volumes of sediment, its incorporation into the bottom nepheloid layer (i.e. suspended sediment load) and transport downstream. Deposition occurs during the quieter low-velocity periods.
5. Bottom currents also show longer period variability (from decadal to millennial). Some of this can be directly related to climate and sea-level change, for example at the scale of Milankovitch cyclicity, which in turn influences the temperature–salinity

properties of the deep-water masses generated in the source regions as well as the volume of deepwater generated and, in some cases, the amount of water that escapes through oceanic gateways to feed thermohaline circulation. Controls on other period changes are less well understood at present, although their effects on cyclic deposition can be observed in the sediment record of contourites.

9.3. SEDIMENTATION RATES AND BUDGET

The average sedimentation rate of contourite deposits varies significantly depending on the location with respect to long-term nature and velocity of the bottom-current system and volume and source of sediment supply (McCave, 2008). Regions of long-term erosion and non-deposition will record zero rates of accumulation, whereas typical sedimentation rates on sheeted drifts range from 3 to 10 cm ka^{-1}, and on mounded drifts from 5–30 cm ka^{-1}. Rates as high as 65 cm ka^{-1} have been recorded on some drifts (Howe et al., 1994, 2002). These values compare with pelagic rates that are generally <2 cm ka^{-1} and hemipelagic rates of 5–15 cm ka^{-1} (Stow and Tabrez, 1998).

Sediment is transported within, and ultimately passes through, the bottom nepheloid layer on its way to form a contourite deposit. Although typical sediment concentrations are relatively low in nepheloid layers associated with bottom currents (0.01–0.1 ppm, or 0.02–0.2 mg l^{-1}) (McCave, 1981), they are episodically increased up to tenfold as a result of benthic storm erosion and resuspension. This increase presumably also applies to other temporal increases in sediment supply, e.g. from localised fine-grained turbidity current input.

Sediment supply to the nepheloid layer (see also He et al., 2008) comes from a range of sources: (a) vertical flux from windblown particles, river suspension plumes, glaciomarine suspension and volcanic dust delivered to the sea surface; (b) vertical flux from sea surface primary productivity, including organic material, calcareous and siliceous bioclastic debris; (c) vertical to slow horizontal advection by a combination of hemipelagic processes, including suspension cascading; (d) direct downslope flux from low-density turbidity currents and hyperpycnal plumes; (e) intermittent downslope flux via spillover processes, including bioturbational and shelf-edge current resuspension and (f) erosion of the sea floor and resuspension by bottom currents immediately adjacent to and upstream from the site of deposition.

The relative importance of sediment flux from these different sources will vary considerably between drifts of different regions. As a schematic example, we can consider the total sediment budget for the Eirik Drift in the NW Atlantic off the southern tip of Greenland (Hunter et al., 2007a, b). Currently, the Eirik Drift measures some 300 km in length, has an average width of 70 km and is up to 0.7 km thick. The total flow of the Deepwater Boundary Current (DWBC) into the northern end of the drift is measured at approximately 6 Sv (6×10^6 m^3 s^{-1}). If the mean flow concentration (i.e. nepheloid layer) is 0.1 mg l^{-1}, then the mass sediment flux is around 600 kg s^{-1}, yielding an annual sediment flux of around 2×10^{10} kg (or 2×10^7 tonnes). We show the possible distribution of this flux between the different inputs in Figure 9.2.

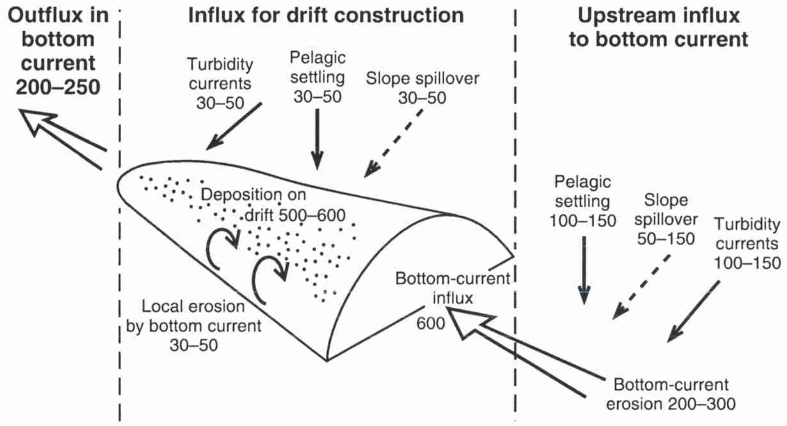


Figure 9.2 Estimated sediment flux from different inputs into the Deep Water Boundary Current that flows over and feeds sediment to the Eirik Drift. A multicolour version of this figure is on the enclosed CD-ROM. Arrows indicate sediment flux, not current position.

9.4. DRIFT DEPOSITION AND EROSION

At the large scale, contourite deposition is focused in contourite drifts, which range in scale from around 50 to $>10^6$ km^2, and in larger contourite depositional systems that comprise several related drifts and associated erosional elements (Faugères et al., 1993; Stow et al., 2002b; Rebesco, 2005). The larger drifts clearly demonstrate long-term continuity of deposition over several millions of years, which allows the accumulation of several hundreds of metres of contourite sediment. The associated erosional elements represent regions of marked erosion and/or non-deposition by bottom currents that may also persist for up to millions of years. In general, these areas display erosive winnowing of the sea floor and accumulation of coarser-grained (sand and gravel) contourites.

The principal types of contourite drift that have been identified include sheeted, mounded-elongate, channel-related, confined, infill and mixed systems (McCave and Tucholke, 1986; Faugères et al., 1993; Rebesco and Stow, 2001; Rebesco, 2005; Faugères and Stow, 2008). A fundamental difference exists between sheeted drifts that accumulate with very low relief over a broad area, and mounded drifts that develop an elevated relief of thicker accumulation over a narrower, elongate region. Both sheeted and mounded forms can occur as generally smaller deposits within channel settings (e.g. oceanic gateways), structurally confined basins, and as the infill of isolated topographic lows (e.g. slump scars). Mixed drift types are those that combine an element of both along-slope and down-slope deposition.

The principal erosional elements, as defined by Hernández-Molina et al. (2008b), include erosional terraces, abrasive surfaces, contourite channels, contourite moats, marginal valleys and furrows. These also divide into two fundamental genetic types: planar and linear erosive features. Erosional terraces and abrasive surfaces are both of broad planar extent, the former occurring under maximum current velocity with erosion and the latter under the influence of strong currents with non-deposition and erosional scouring, as well as deposition of sand sheets and sand/gravel ribbons. The linear features include larger contourite channels and smaller elongate furrows, as well as channels related to slope drifts (contourite moats), and those caused by erosion around a topographic obstacle such as a seamount (marginal valleys).

These different types of depositional and erosional contourite system are controlled largely by a combination of factors: the nature and style of bottom-current flow (e.g. tabular versus multicore flow of Hernández-Molina et al., 2008b); the slope gradient and other topographic features; and the sediment supply. The information they yield on the nature of contourite deposition is briefly reviewed below and illustrated in Hernández-Molina et al. (2008b; their Figure 19.17), with particular reference to slope contourite systems.

Sheeted drifts typically represent relatively slow rates of deposition of fine-grained contourites over a large area of sea floor (slope plastered drifts and abyssal sheet drifts). The flow is mostly simple and tabular, broad and regionally stable, although it may also include strands of more intense flow and giant eddy circulation. Contourite deposition appears to take place directly from suspension more or less evenly across the whole flow width. There is probably a complete gradation in depositional style between sheeted drifts (with very low mounded geometry) and thinner sheets (or beds) of contourites closely interbedded with other deepwater facies (hemipelagites, turbidites, etc). Contourite sand sheets are a depositional/erosional body linked with more localised zones of higher energy flow, as found in erosive terraces and abrasive surfaces below very active bottom currents. Erosion, winnowing and deposition as bedload alternate continuously.

Mounded drifts represent relatively enhanced rates of deposition of fine-to-medium-grained contourites, commonly focused into slope-parallel, elongate sediment bodies over moderate to large areas of sea floor. The flow may be either simple (as above) or part of multiple current pathways (multicore flow), and tends to be markedly intensified at drift margins, in some cases causing narrow erosional zones: contourite channels, moats and marginal valleys. Slower flow and large eddies dominate over the drift itself and lead to enhanced deposition and hence to gradual build up of the drift mound. It remains somewhat unclear on which side of the current core drift build-up is most likely to occur, and whether or not this is primarily a result of Coriolis deflection. There are a number of apparently contrasting examples in the literature, so that we consider it more likely that drift deposition is focused in-between different strands of a multicore flow pattern, whereas erosion, non-deposition and coarse-grained contourite facies occur directly beneath the high velocity cores. Over time, and in response to sea level, climate or other forcing factors, the flow pattern varies both spatially and in intensity, so that individual drifts build up by differential aggradation, progradation and erosion (Hernández-Molina et al., 2006c; Llave et al., 2001, 2006).

Channel-related drifts are those associated with deepwater channels, passageways or gateways through which bottom circulation is constrained, which leads to an increase in flow intensity and velocity. Where channels are broad, they are typified by multicore flow pathways that may result from topographic interaction and channel margin effects. Smaller channels by contrast may show simple flow, although flow meandering and edge effects are also common. The channel region is characterised by erosion, non-deposition and coarse-grained contourite facies, together with deposition of finer-grained contourites in localised patch drifts (either mounded or sheet-form). The channel exit region experiences flow broadening and deceleration, together with re-combination of distinct current strands. Deposition occurs as a sheet-like contourite-fan, typically with downflow decrease in contourite grain size (Faugères et al., 1998, 2002b: Massé et al., 1998).

Confined drifts are among the lesser known systems which, to some extent, appear similar to the broad channel systems (above). They are probably affected by multicore flow pathways and typified by zones of both erosion and deposition. Data from the Sicilian gateway in the central Mediterranean have suggested an interesting aspect of flow behaviour and contourite deposition (Reeder et al., 2002). There are a number of confined basins through which the Levantine Sea bottom water flows and in one of these the nature of sediments and high rate of sedimentation suggest that a process of bottom-current flow lofting has occurred. The result is one of a mixed contourite/hemipelagite sheet-like deposit.

Infill drifts are even less known and mixed systems are extremely variable. For both these types, which are not discussed here, additional information may be found in Faugères and Stow (2008).

9.5. BOTTOM-CURRENT BEDFORMS

At a medium scale, the impact of bottom currents in shaping the deep sea floor over both depositional (drift) and erosional elements is well known (Hollister and Heezen, 1972; McCave and Tucholke, 1986; Masson et al., 2004). The sea floor is smoothed and/or sculpted into a wide variety of bedforms at a range of different scales that can provide important insights into both flow characteristics and depositional and erosional mechanisms of contourites. Surface lineation and ripples are ubiquitous at the centimetric scale, sand waves and dunes are common metric scale features, and mud furrows and sand ribbons occur with a spacing of tens of metres and lengths up to several kilometres.

In a recent paper, Stow et al. (in press) have synthesised a large amount of this data into a bedform/velocity matrix (Figure 9.3), from which one can derive information on flow direction, velocity, variability and continuity. The nature and distribution of bedforms also allows the following comments on various aspects of contourite deposition.

1. The widespread fine-grained contourites of many drifts, with smoothed sediment surfaces and/or surface lineation, represent deposition of silt and clay directly from suspension through a laminar boundary layer, which in places is subject to a series of sub-parallel, small-scale, helical flow vortices creating the linear sediment fabric.
2. The common presence of ripple bedforms at all scales on silt/sand substrates indicates that tractional movement of bedload at the base of flow is the normal

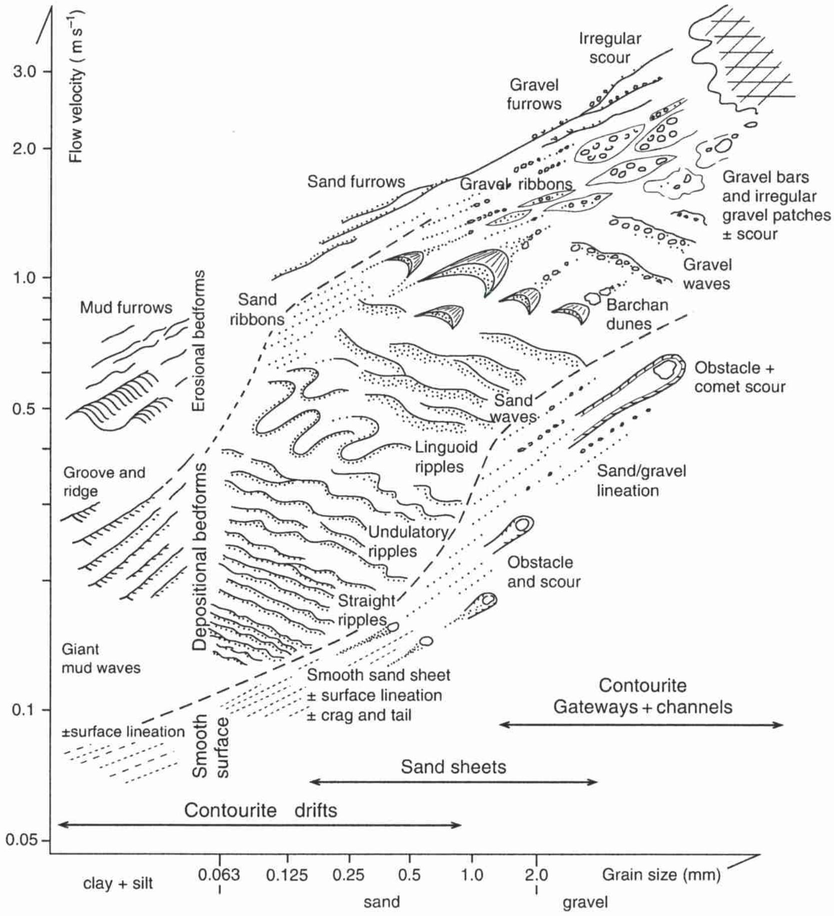


Figure 9.3 Bedform-velocity matrix: a schematic distribution of bedform types with respect to flow velocity and grain size (from Stow et al., in press; with permission from the Geological Society of America).

mode of transport and deposition of fine-to-medium-grained granular material in bottom currents.

3. In zones subjected to higher velocity currents, tractional movement of coarser materials is evidenced by sand waves, barchan dunes and, more rarely, gravel waves and bars. That these bedforms are often covered by smaller-scale ripples is evidence of bottom-current variability, probably over timescales of hours (tidal influence) to weeks (benthic storm effects). Periods of intense bedload transport therefore alternate with periods of lesser transport and deposition.
4. Some linear bedforms, known as furrows, are formed at relatively higher flow velocities in both mud and sand/gravel substrates. These represent mainly erosive conditions at the base of flow leading to sediment entrainment and transport. Groove and ridge structures (also known as longitudinal triangular

ripples (see also Martin-Chivelet et al., 2008) appear to be a smaller scale equivalent of mud furrows, formed at moderate flow velocities over fine substrates and involving both deposition and erosion.

5. The lateral juxtaposition of bedform types occurs over a horizontal scale of metres, indicating the variability in velocity of strands of flow (or regions of flow) at this order of magnitude. There is also the larger-scale of variation over hundreds of metres from more dominantly erosive to mainly depositional. This can occur in an across-flow sense, from erosive marginal moat to central depositional drift, and in a down-flow sense, away from a gateway or channel exit.
6. The development of large fields of giant sediment waves and their persistence in time through the sedimentary record (thousands to a few million years), reflects the broad tabular flow and long-term stability of low-velocity bottom currents in their region of formation. Deposition of the fine clays and silts that make up these bedforms is almost certainly directly from suspension, under the influence of internal lee waves in a weakly stratified bottom current (Flood, 1988).

9.6. CONTOURITE FACIES AND FEATURES

At the scale of the sediment itself, a wide range of different contourite facies are now recognised (Stow et al., 1996b, 1998a, 2002b; Stow and Faugères, 2008). These range in grain size from fine muds, through silts and sands, to sand and gravel lag deposits, and are often poorly sorted mixtures of different grain-size fractions. In composition they are equally varied, including siliciclastic, bioclastic (calcareous, siliceous), volcaniclastic and chemogenic (manganiferous) varieties, commonly displaying a mixed composition. Their principal characteristics, as illustrated and tabulated in the above referenced papers (including Figures 13.9 and 13.10 in Stow and Faugères, 2008), give further important insights into the mechanism of contourite deposition.

9.6.1. Sedimentary structures

Based on the many observations of smoothed sediment, surface lineation and regular bedforms (ripples, dunes, etc.) on the sea floor beneath bottom currents (see above), we might expect contourite sediments to show extensive parallel lamination as a result of fluid flow processes and depositional sorting mechanisms, as well as cross-lamination at different scales as a result of bedload traction (Martin-Chivelet et al., 2008). However, most 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. In some cases, they appear completely homogeneous, whereas in other cases they show indistinct and discontinuous parallel lamination, partial grain alignment, sub-horizontal to irregular erosion surfaces, thin layers and lenses of coarser material. Cross-lamination is only rarely present in silts and fine sands, and slightly more common in medium to coarse-grained sands.

The presence of pervasive bioturbation rather than lamination might be explained by relatively low rates of contourite accumulation, so that bioturbation is able to keep pace with deposition and effectively destroy most primary lamination, leaving only remnants as indistinct lamination. Furthermore, for thick, muddy contourite accumulations, the low to very low current velocities and sediment concentrations are insufficient to result in primary lamination through the depositional sorting mechanism that develops silt/mud lamination in fine-grained turbidites, for example. The minor erosion/non-depositional surfaces as well as coarser lenses and layers within muddy contourites provide evidence of repeated and alternating phases of erosion, winnowing and deposition.

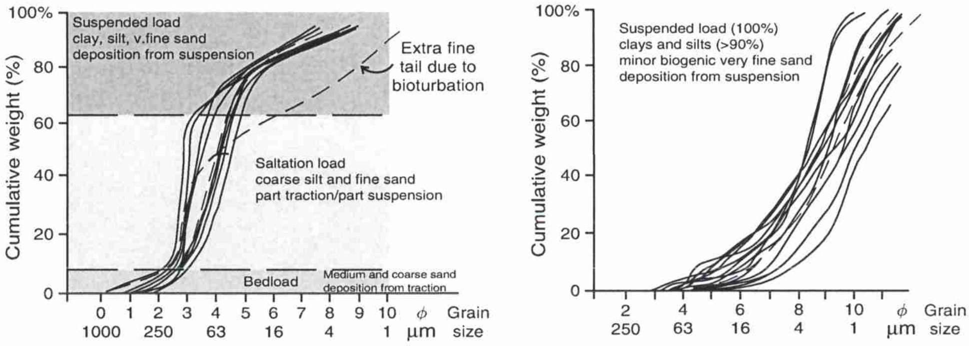
Laminated and cross-laminated sandy contourites are known from beneath higher-velocity bottom currents with large-scale bedforms (e.g. dunes) evident on the sea floor. The lamination is distinct, but can also be diffuse, and may be associated with bioturbation. The presence of such structures clearly indicates bedload tractional movement of granular sediments by the bottom current. Preservation of the primary lamination is probably due either to intermittently rapid sedimentation from high-velocity currents and/or dearth of organic matter inhibiting extensive bioturbation.

9.6.2. Sedimentary texture and fabric

The dominant grain size of mud-rich contourite drift deposits is clayey silt and silty clay, generally ranging between 3 and 11Φ (125–0.5 μm). They commonly show poor sorting (1.4–2.5 Φ), bimodal or polymodal grain-size distribution, and may contain significant (up to 15%) sand-size material (>63 μm) (Figure 9.4). Grain alignment of silt and fine magnetic particles (using anisotropy of magnetic susceptibility measurements) shows flow-parallel trends. These characteristics are all commensurate with transport of a mixed-composition load within the bottom current and deposition directly from suspension. The finest material (<10 μm) is most likely carried in the form of larger aggregates, flocs and faecal pellets, which are then disaggregated during grain-size analysis. These are more or less hydrodynamically equivalent to the silt fraction between 10 and 63 μm, which is referred to as sortable silt and used as an indicator of flow velocity (McCave et al., 1995b; McCave, 2008).

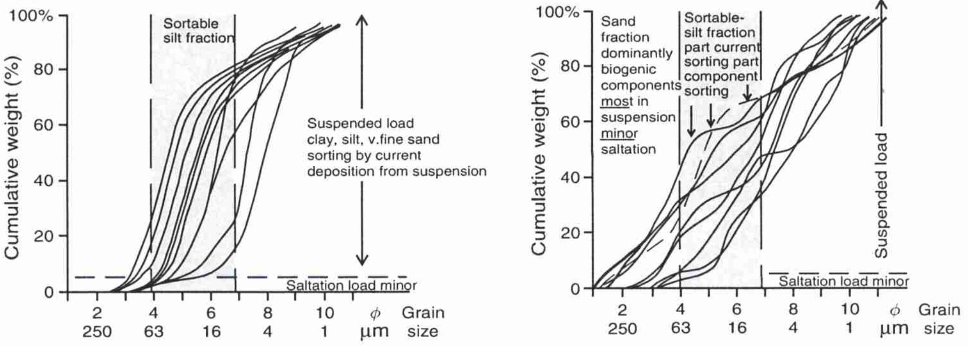
Sand-sized material in muddy contourites is typically made up of biogenic tests (calcareous or siliceous), which may either be hydrodynamically light and so be transported within the ambient current suspended load, or represent the direct fall of pelagic material through the current. At higher latitudes, ice-rafted debris is a common addition, which almost certainly represents glaciomarine hemipelagic fallout.

Sandy contourites are mostly fine to medium-grained, more rarely coarse-grained or with a gravel component. In many cases, they are only moderately to poorly sorted (0.8–2Φ), partly as a result of bioturbational mixing with mud grade material, whereas the laminated sands may be moderately well sorted (0.5–0.7Φ). There is little good fabric data available for this facies. Grain-size distribution spectra are more or less unimodal and, on cumulative frequency plots, commonly show a tripartite subdivision into a coarser-grained bedload fraction moved by



(a) Contourite sands

(c) Contourite muds



(b) Contourite silts

(d) Biogenic-rich contourites

Figure 9.4 Grain-size distribution and characteristics of a range of different contourite facies, plotted as smoothed cumulative frequency curves. (a) Sandy contourites, (b) silt and silt–mud contourites, (c) muddy contourites and (d) biogenic-rich contourites. A multicolour version of this figure is on the enclosed CD-ROM.

traction, an intermediate fraction moved as saltation load, and a finer-grained fraction transported wholly in suspension (Figure 9.4). Each fraction may show more than one compositional sub-population separated by hydraulic sorting during transport and deposition. Still coarser grained contourites (coarse sand and gravel-rich) are moved wholly and intermittently as bedload, whereas in gravel-bearing muddy contourites, the gravel clasts generally have an ice-rafted origin.

9.6.3. Contourite composition

As noted earlier, there is a wide range of different components in contourite sediments, which themselves yield some clues as to the nature of deposition. The most common components are shown in Figure 9.5, together with their typical range of grain size. Although some contourites have a more or less single uniform composition, such as mid-ocean drifts with >90% pelagic biogenic material and high-latitude drifts with >90% glaciomarine hemipelagic material, most contourites show a characteristically mixed composition. This indicates a range of sources and supply

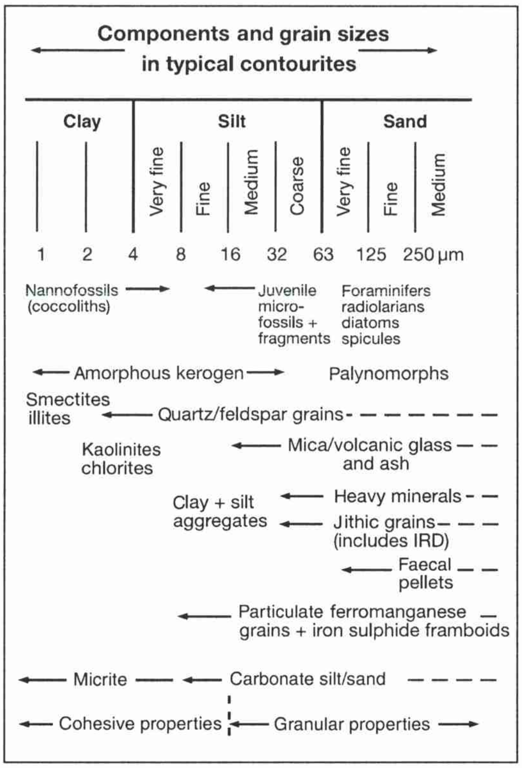


Figure 9.5 Common components of contourites and their typical grain-size range.

routes coupled with a depositional process (or processes) that tends to mix rather than segregate components (see also Figure 9.2). Certain processes and hence component inputs will dominate in different contourite settings. In most cases, the sand-sized fraction will show partial fragmentation, rounding and iron staining, which is all indicative of bottom-current transport as saltation load and bedload.

9.7. CONTOURITE CYCLICITY

Variation in contourite characteristics and hence in the nature of contourite deposition, appears to be the norm at all scales of observation, from the seismic cycles recognised by Llave et al. (2001, 2006) and Stow et al. (2002b), to sediment facies cycles depicted in the standard facies model for contourites (Stow and Faugères, 2008; Hüneke and Stow, 2008), and to the less regular alternation of coarser-grained lenses and layers with fine muddy contourites (see above). The origin of both the seismic cycles and the facies sequence can be related to long- and medium-term fluctuations in the mean current velocity, and/or to variation in sediment supply (Knutz et al., 2001, 2002a, b). Stacked sequences and repeated partial sequences indicate cyclic variation in the forcing variables, while cycle irregularity is likely to result from interaction of sediment supply and current velocity. The periodicity ranges from 1000 to 2000 years for some of the shorter period facies cycles to 100,000–200,000 years for some of the regular seismic cycles. At the smallest scale of observation, alternation of coarser- and finer-grained contourites in partial and rather indistinct layers and lenses is the result of multiple intermittent depositional, non-depositional and erosional phases (over a period of hours to weeks) within an overall continuous sedimentation regime.

9.8. SUMMARY

There is now a considerable body of evidence on the nature of contourite deposition, derived from direct observations of bottom currents, deep-sea nepheloid layers, contourite drifts, sea-floor bedforms and contourite sediment facies. The principal characteristics of that deposition reflect:

1. in part, the long-term stability of bottom-current systems, allowing for significant sediment focusing and large-scale drift accumulation coupled with zones of pronounced erosion and non-deposition;
2. in part, spatial and temporal variability in mean current velocity and/or sediment supply; semi-permanent bottom currents lead to semi-continuous deposition of contourites at rates some 10–20 times the normal background rate for pelagic accumulation;
3. sediment influx into the bottom current, which occurs via vertical settling of material from the surface, slow horizontal downslope advection, direct input from low-density turbidity currents and other down-slope spillover processes, and by direct bottom-current erosion;
4. drift deposition beneath simple tabular flow operating over broad regions of a gently sloping seafloor, and under more complex current systems (including multicore current strands), over steeper slopes and through narrow gateways and channels;
5. deposition, non-deposition and erosion, which occur repeatedly over both short and long timescales as a result of variation in bottom-current velocity, flow location and sediment influx;
6. for the coarser-grained to finer-grained facies, bedload traction, winnowing, re-suspension, sediment saltation and direct fallout from suspension;
7. mostly relatively slow and semi-continuous, intense post-depositional bioturbation, which is the norm for most contourites.

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