PART 5

MORPHOLOGY, GEOMETRY AND PALAEOCEANOGRAPHIC RECONSTRUCTIONS

CHAPTER 14

Contourite Drifts: Nature, Evolution and Controls

Jean-Claude Faugères *and* Dorrik A.V. Stow

Contents

14.1. Introduction 260
14.2. Drift Distribution and Characteristics 262
 14.2.1. Tectonic setting 262
 14.2.2. Water depth 262
 14.2.3. Drift size 262
 14.2.4. Drift shape 263
 14.2.5. Sediment type 263
 14.2.6. Bottom-current type 263
14.3. Growth History of the Blake Outer Ridge Drift System 264
 14.3.1. The first sedimentary unit 264
 14.3.2. The second unit 267
 14.3.3. The third unit 267
14.4. Factors Controlling Drift Location, Morphology and Depositional Pattern 268
 14.4.1. Bathymetric framework 268
 14.4.2. Current conditions 268
 14.4.3. Sediment supply 269
 14.4.4. Process interaction 269
 14.4.5. Sea level 269
 14.4.6. Climate change 270
 14.4.7. Tectonic setting and activity 271
 14.4.8. Time constraints 271
14.5. Contourite-Drift Types 271
 14.5.1. Sheeted drifts 272
 14.5.2. Mounded drifts 272
 14.5.3. Mixed drift systems 281
14.6. Discussion 283
 14.6.1. Spatial evolution of drifts 283
 14.6.2. Evolution of drifts in time 284
 14.6.3. Complex contourite systems 285
 14.6.4. Distinction from turbidite systems 285
 14.6.5. Buried contourite drifts in modern ocean successions 286
Acknowledgements 288

Developments in Sedimentology, Volume 60
ISSN 0070-4571, DOI: 10.1016/S0070-4571(08)00214-8

14.1. Introduction

Since the mid-1960s, following the pioneering work of Bruce Heezen and colleagues (Heezen et al., 1966; Schneider et al., 1967; Heezen and Hollister, 1971; Hollister and Heezen, 1972), the significance of bottom currents for sediment transport and deposition has been well documented. Such deep-water bottom currents, flowing in response to major thermohaline and wind-driven circulation, are known to construct large accumulations of sediments in the deep sea. These sediment bodies were first described from the North Atlantic Ocean (Figure 14.1),

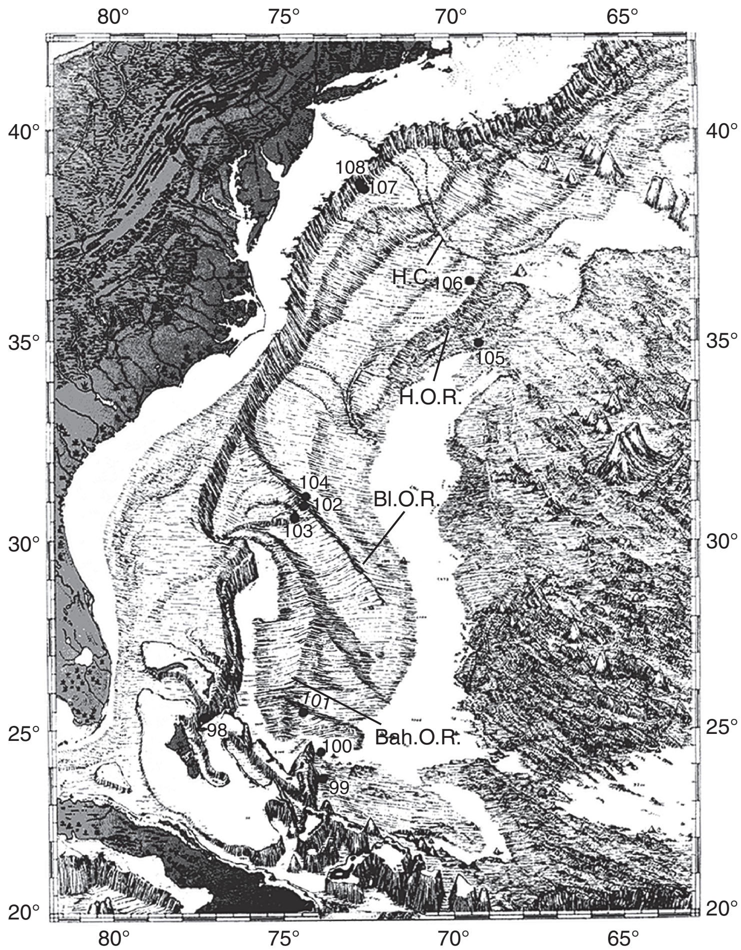

Figure 14.1 Physiography of a portion of the western North Atlantic (from Hollister et al., 1972), showing the shaping of the continental rise by deep geostrophic currents. Bl.O.R. = Blake Outer Ridge; Bah.O.R. = Bahamas Outer Ridge; H.O.R. = Hatteras Outer Ridge; H.C. = Hudson canyon. Numbers 100, 101, . . . refer to the location of DSDP Leg 11 drilling sites. A multicolour version of this figure is on the included CD-ROM.

and variously called "outer ridges" or "sediment drifts". They are now generally referred to as "contourite drifts" and are well-known throughout the world oceans, occurring everywhere from the abyssal floor, through deep continental margins, to mid-slope and even upper-slope settings (Figure 14.2). The term "shallow-water contourite drift" is preferred for those bodies constructed along the uppermost part of the continental slope and over the outer shelf edge. Contourite drifts are mainly composed of sediments deposited by contour currents (contourites), but may also contain associated deep-water facies, particularly hemipelagites, pelagites and glaciomarine sediments, and be variously intercalated with turbidites and debris-flow deposits.

In the past 40 years of research, a large number of drifts have been studied using a combination of seismic profiling, side-scan sonar, swath bathymetry, sea-floor photography, coring and drilling techniques. Some of the more recent syntheses of this work, particularly focusing on the nature and construction of contourite drifts, include publications by Stow and Faugères (1993, 1998), Stoker et al. (1998a), Faugères et al. (1999), Rebesco and Stow (2001), Stow et al. (2002f), Wynn and Stow (2002a), Rebesco (2005) and Viana and Rebesco (2007). These have demonstrated a wide variation in drift location, morphology, size, sediment patterns, construction mechanisms and their controls.

In this chapter, we briefly outline drift distribution and characteristics, consider the nature of drift development and the various controls that operate, and then

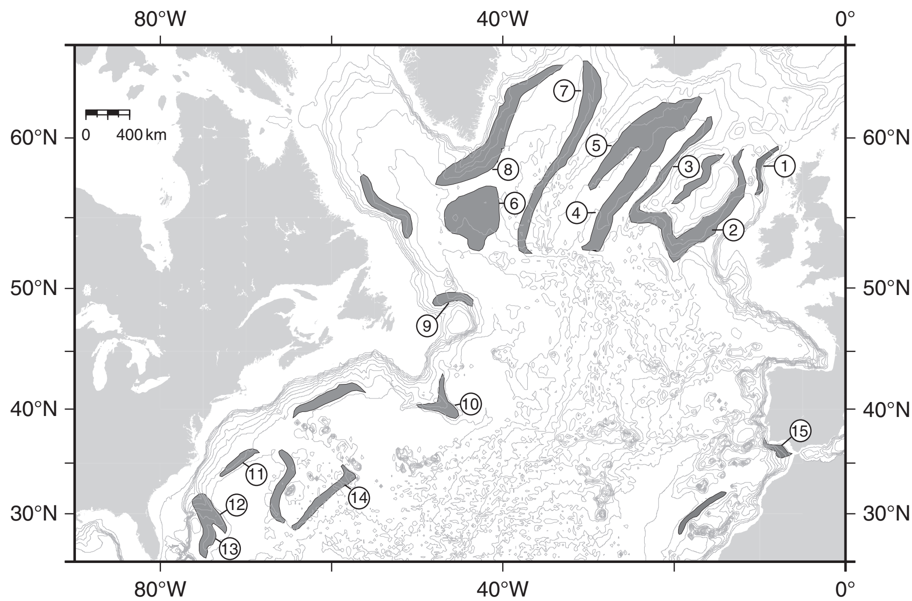

Figure 14.2 Contourite distribution and major giant contourite-drift locations in the North Atlantic Ocean (modified from Faugères et al., 1999; with permission from Elsevier). 1 = Hebrides drifts; 2 = Feni; 3 = Hatton; 4 = Gardar; 5 = Bjorn; 6 = Gloria; 7 = Snorri; 8 = Eirik; 9 = Sackville Spur; 10 = New Foundland; 11 = Hatteras; 12 = Blake; 13 = Bahama; 14 = Northern Bermuda; 15 = Faro.

summarise our current classification of drift types. Subsequent chapters will focus more specifically on contourite drifts from the abyssal regime (Hernández-Molina et al., 2008b), continental slopes (Hernández-Molina et al., 2008a), shallow water (Verdicchio and Trincardi, 2008a) and high latitudes (van Weering et al., 2008). A further chapter (Mulder et al., 2008) is devoted to mixed turbidite/contourite-drift systems.

AU1

14.2. Drift Distribution and Characteristics

Several attempts have been made over the years to classify contourite drifts (e.g. McCave and Tucholke, 1986; Faugères et al., 1993, 1999; Stow et al., 1996b, 2002d), although all run into the problem of just how best to sub-divide a continuous spectrum of deposit types (Rebe sco, 2005). Furthermore, any individual drift may evolve through time from one type to another – for example from a small patch drift, to a larger sheeted drift to an elongated mounded drift.

14.2.1. Tectonic setting

Contourite drifts are perhaps most common along the passive continental margins of the North Atlantic, Southwest Atlantic, Antarctic and southwest Indian Oceans. However, they also occur in mid-ocean settings (for instance, associated with the Mid-Atlantic Ridge, abyssal gaps or gateways and on abyssal plains), as well off active margins, such as the eastern New Zealand, southern Indonesian or Aleutian Margins and close to active margins, such as the northeastern Australian Margin.

14.2.2. Water depth

Although contourite drifts have been found at almost all depths in the oceans, there may be some differences in their origin, facies, or other features, related to the depth at which they occur. A threefold division has therefore been proposed (Viana et al., 1998a; Stow et al., 2002c) into deep-water (>2000 m), mid-water (300–2000 m) and shallow-water (<300 m) drift types. This is of little relevance for non-recent and fossil contourite drifts, for which the Palaeodepth is largely unknown (Rebesco, 2005).

14.2.3. Drift size

Contourite drifts can be as large in size as many sedimentary systems built by turbidity currents and related down-slope processes. Drift sizes range from small patch drifts (about 100 km^2), equivalent in size to isolated turbidite lobes or debris-flow masses on slopes, to giant elongated drifts (>100,000 km^2), which match many of the world's large muddy elongate fans. In some cases, with the Argentine Basin as an example, the contourite sheet deposits may cover an area of more than 1,000,000 km^2. Although they show a large morphological variability, the most easily recognised drifts have an elongated, mounded shape and variable dimensions, ranging up to the really giant drifts, tens to hundreds of kilometres long (up to 1000 km), 10 to more than 100 km wide, and with sediment thicknesses from some tens to 2000 m. These may show a relief up to 1500 m above the adjacent sea floor.

14.2.4. Drift shape

The most famous contourite drifts in the present-day oceans were first identified on the basis of their typical mounded morphology, and their elongation more or less parallel to the continental margin, and hence to the contour-current flow direction. However, a range of different shapes is now recognised, including less regular patches and sheets, as well as fan-shaped bodies downstream of deep-water gateways. In addition, it is clear that contourites also occur closely interbedded with other deep-water facies types, and do not necessarily form unique or distinctive sedimentary bodies.

14.2.5. Sediment type

Giant contourite drifts are predominantly formed of muddy and silty contourites, often as relatively thick and uniform successions, with less abundant sandy contourite horizons. Regarding their composition, they include siliciclastic, biogenic and volcaniclastic components, either mixed or alone, and may also contain ferromanganese horizons and nodules. They may be interbedded with pelagites, hemipelagites and fine-grained turbidites, and at high latitudes with glaciomarine hemipelagites and dropstones. Sandy contourites do not generally form whole drift systems, but are relatively restricted to more active bottom-current environments (contourite channels and gateways). The thin sandy horizons within muddy drift deposits correspond to episodes of higher current velocity.

Shallow-water contourite drifts, deposited on the outer-shelf/upper-slope (50–300 m water depth), typically have more reduced dimensions and may comprise coarser sediments (silty and sandy contourites) than those of the larger drifts. They are relatively closer to continental sources of sediment, and the currents involved in their construction may have a higher velocity.

14.2.6. Bottom-current type

In this chapter, we are principally concerned with drifts formed under the influence of bottom currents driven by the major thermohaline and wind-driven circulation systems. We also recognise, however, that a number of other bottom-current processes can deposit isolated contourite facies, often interbedded with other sediments, including upwelling and downwelling currents (Yoon and Chough, 1993; Seranne and Abeigne, 1999), up- and down-canyon currents (Stow et al., 1996b) and internal tides and waves (Rebesco, 2005). Sandy contourite sheets and patch drifts can be deposited in outer-shelf to upper-slope settings by a combination of related processes, collectively termed sea-floor polishing and spillover (Viana and Faugères, 1998; Stow and Mayall, 2000).

The classification of drifts followed in this chapter uses a combination of drift distribution and shape. First, however, we outline the growth and development of drifts using the well-known Blake Outer Ridge as an example.

14.3. Growth History of the Blake Outer Ridge Drift System

As contourite-drift deposition is mainly controlled by deep-water thermohaline circulation, drift initiation and growth history are closely related to global changes in the pattern of deep oceanic circulation. For many existing drifts in present-day ocean basins, drift development typically begins with – and overlies – a more or less flat, major erosional horizon, which is coeval and widespread throughout the basin. This hiatus corresponds to an important hydrological event involving the initiation of active bottom-water circulation in the basin. It is then overlain by contourite-drift deposits that begin to accumulate following some reduction in the vigorous circulation.

Following their initiation, the construction of most contourite drifts is semi-continuous over a very long time span, but is also typically marked by an alternation of intervals of deposition with intervals of erosion, dissolution or some other changes in the depositional regime. This periodicity reflects significant changes in circulation, which are, in turn, controlled by global climatic changes and polar ice-sheet development, often associated with plate-tectonic events (Kennett, 1982). Once contourite accumulation has ceased, following a last major change in bottom circulation, cessation for example, the drift is progressively covered by onlapping turbidites and/or by draping pelagite/hemipelagite deposits.

One of the first series of detailed studies of a major drift system was that of the Blake Outer Ridge (Figures 14.3 and 14.4) located along the eastern US Margin and associated with the Western Boundary Under Current (WBUC) (Ewing and Hollister, 1972; Shipboard Scientific Party, 1983; Mountain and Tucholke, 1985; Tucholke and Mountain, 1986; McMaster et al., 1989; Locker and Laine, 1992). This giant drift (about 600 km long, up to 100 km wide, between 1000 and 2500 m thick, and up to 1000 m relief) presents a mounded elongated morphology, as a prominent SE-trending extension of the continental rise, somewhat oblique to that of the continental margin. The drift overlies a major regional unconformity, A^u, which is marked by a widespread seismic reflector that corresponds approximatively to a zone of silicified sediments at depth within the margin succession. It has a complex origin but, as it is distributed along the whole of the American North Atlantic Margin and is associated with a large depositional hiatus, there is little doubt that it reflects widespread erosion by a newly initiated bottom-current system near the Eocene/Oligocene boundary.

14.3.1. The first sedimentary unit

The first sedimentary unit (Figure 14.4-1), Oligocene to Early–Middle Miocene in age, was deposited on the lower rise between Horizon A^u and a late Miocene

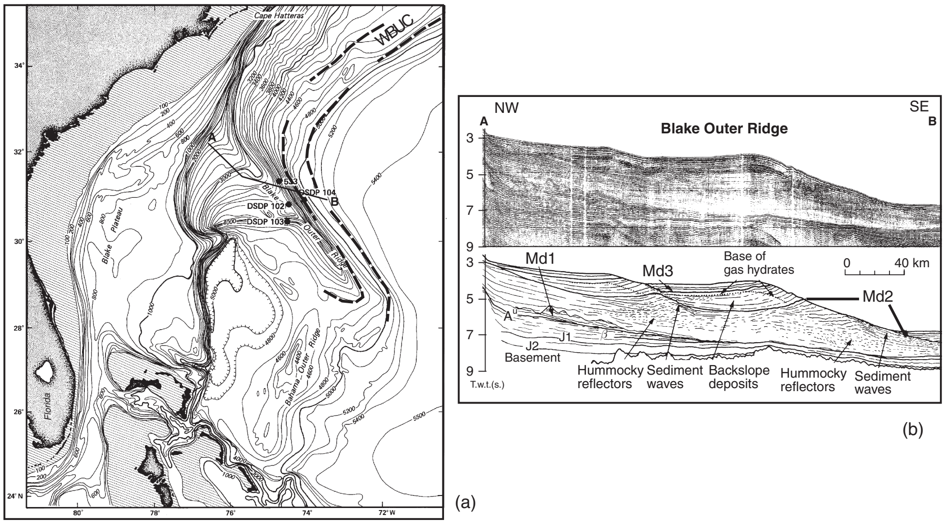

Figure 14.3 The Blake and Bahama Outer Ridges (SE US Margin). (a) Morphology of the contouritic drift (detached drifts) and localisation of seismic line (a, b) and DSDP drilling sites (102, 103, ...; modified from Shipboard Scientific Party, 1983). (b) Seismic line and interpretation showing three major discontinuities (Md1 = A^u; Md2 = "Merlin"; Md3 = "Blue") linked to global hydrological events (multi-channel seismic line, modified from Mountain and Tucholke, 1985).

unconformity ("Merlin" reflector), dated as about 12–10 Ma. The Merlin hiatus is related to a significant hydrological event that was synchronous with a sharp rise in sea level (Haq et al., 1987). The episode of drift growth between these horizons is characterized by a large sediment supply and predominant down-slope processes on the continental slope and upper rise. On the lower rise, along-slope processes were dominant. The contour currents were less intense than those that created horizon A^u, but still sufficiently strong to influence sedimentation on the rise. An active "Gulf Stream" (warm, wind-driven, surficial current) at this time led to marked erosion of the Blake Plateau on the adjacent upper continental slope (Pinet and Popenoe, 1989). Interaction of the deeper parts of this "Gulf Stream" with the underlying WBUC is believed to have been instrumental in causing contourite deposition and drift construction (Figure 14.4-5a and b).

The location of the "Gulf Stream" is believed to oscillate from NW to SE in response to eustatic sea-level changes. During the early Miocene sea-level low-stand, its shift towards a more southeasterly location would have been responsible for strong erosion of the Blake Plateau and for eastward deflection of the WBUC, leading to deposition of the Blake Outer Ridge drift with a trend oblique rather than parallel to the margin. Subsequently, during the latter part of the early and middle Miocene, the "Gulf Stream" veered back to a more northwesterly location as the sea level rose. At that time, it played no further significant role in drift sedimentation, which was instead wholly

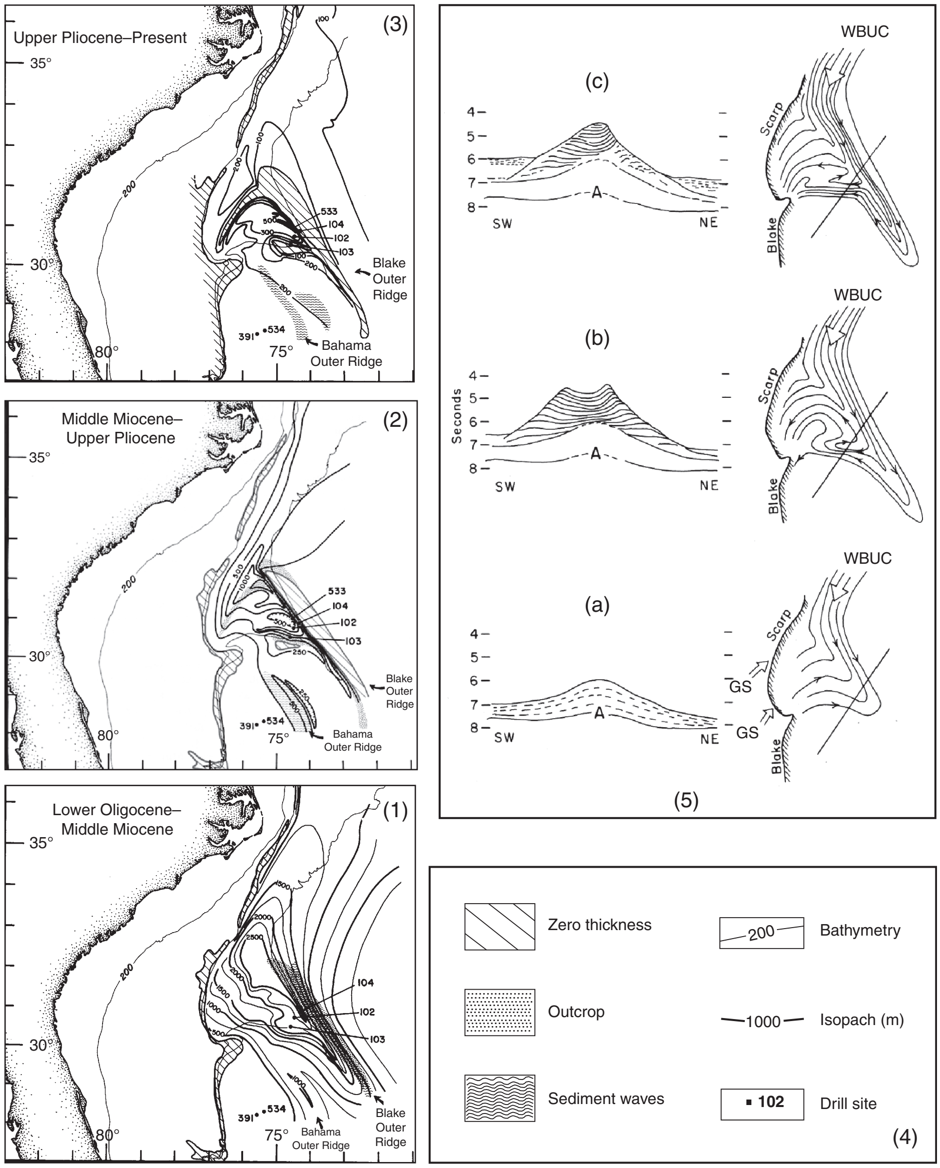

Figure 14.4 Interpretation of the Blake Outer Ridge growth. (1–3): Isopach maps showing the distribution and thickness variations (modified from Tucholke and Mountain, 1986). (1) = Lower Oligocene to Middle Miocene; (2) = Middle Miocene to Upper Pliocene; (3) = Upper Pliocene to Present). (4) = captions of the maps. (5) = hypothetical reconstruction of the ridge development above horizon A^u (from Ewing and Hollister, 1972). The initial Oligocene building (5a) is characterized by a surface (the "Gulf Stream": GS) and deep current interaction (Western Boundary Under Current: WBUC), predominant sediment aggradation with low southeastward deposit migration; (5b) corresponds to a time of predominant contour-current depositional processes, strong southeastward deposit migration, and initiation of a secondary drift with a westward migration, during the early Miocene. (5c) represents the last development of the ridge (Quaternary) characterised by contour-current-controlled erosion (northern flank of the ridge) and deposition (top and southwestern flank). A multicolour version of this figure is on the included CD-ROM.

controlled by the WBUC. However, the initial eastward deflection of the drift was more or less mirrored during the following stages of deposition, with only a gentle shift of the drift towards the southeast, as the deposits migrated into the deeper basin.

The sediments are composed dominantly of silts and clays derived from an Appalachian source, as well as from a pelagic input rich in siliceous microfossils. The sedimentation rate was relatively high (19 cm ka^{-1}), as a result of turbid water flowing off the northern part of the Blake Plateau and feeding the southward flowing undercurrent. This succession was deposited by active contour currents, as underlined by active construction of the Blake drift and deposition of well developed sediment waves. During the early Miocene, part of the WBUC began to cut across the drift and to build a spur of sediment towards the west (Figure 14.4-5b).

14.3.2. The second unit

The second unit (Figure 14.4-2), late Miocene to late Pliocene in age, is bounded at the base by the Merlin unconformity, and at the top by a major late Pliocene unconformity ("Blue" reflector). This latter is believed to be related to an episode of bottom-current intensification following active glaciation in the Arctic region, which was in turn associated with the closing of the Central American gateway at Panama. Isopach maps of deposit thickness and seismo-facies both show strong evidence of contour-current deposition. The Blake drift experienced a sedimentation regime fairly similar to that of Unit 1 and continued to grow upwards and seaward with a sedimentation rate only slightly lower than during the previous period (14 cm ka^{-1}). However, contourite deposition was thicker on the southwestern flank of the drift (where the incipient spur developed further into a secondary E–W-oriented drift) than on the northeastern flank.

14.3.3. The third unit

The third unit (Figure 14.4-3), late Pliocene to Holocene, was deposited after the pulse of bottom-current erosion correlating with the "Blue" reflector. It forms a perched lens of sediment on the top of the ridge where the Pleistocene deposits had completely filled the trough between the crests of the main ridge and the secondary drift (Figure 14.4-5c). The sediments are dominantly silty clay, probably derived from enhanced glacial supply, and accumulated with a similar fairly high rate (14 cm ka^{-1} during the Pleistocene, at the very top of the drift). Sediment distribution still suggests a strong control by active contour currents. Along the southwestern flank, the deposits show patterns similar to those of the underlying succession. On the northeastern flank, sea-floor erosion linked to the "Blue" reflector has re-excavated the Merlin reflector, and the contour currents have remained strong enough to prevent significant sediment accumulation up to the present day.

14.4. Factors Controlling Drift Location, Morphology and Depositional Pattern

The example given above for the Blake Outer Ridge is only one of many, but does serve to show some of the key controls on drift development. Contourite drifts form in many different locations and water depths, and with different morphologies, sediment composition and depositional patterns. These large-scale features of drifts are controlled by a number of interrelated factors (Faugères et al., 1993; Rebesco, 2005), including (1) the bathymetric framework (water depth and morphological context), (2) the current conditions (velocity, variability, and Coriolis force), (3) the sediment supply (amount, type, source, input, variability), (4) interaction with other depositional processes (in time and space), (5) sea level and sea-level fluctuations, (6) climate and climate change, (7) tectonic setting and activity and (8) the length of time over which these various processes and controls have operated and varied. It is not a simple matter to disentangle these various controls as many clearly overlap and are interrelated. Neither is it always certain just what effect a particular control exerts. However, the following sections briefly review some of the above key controls and show some of the ways in which they may influence contourite drifts.

14.4.1. Bathymetric framework

To some extent, the water depth influences the size of the drift and the type of contourite deposits: at increasing depths, there is greater potential to develop larger drifts, and these are generally composed of finer-grained deposits. The removal of carbonate material below the carbonate compensation depth can also be significant. Bottom-current velocities in deep, flat basins are generally lower and less focused, so that deposits spread out as very large sheet drifts.

The morphological context plays a still more fundamental role. According to the slope gradient of the sea floor, the current velocity and confinement vary due to the Coriolis effect, which in turn affects the presence of erosional versus depositional processes and hence drift growth and sediment distribution. Variations of the trend of the margin strongly influence the flow pathway, flow separation and meandering, and hence the overall shape, position and number of individual drifts. Particular morphological contexts, such as slope terraces, channels, narrow oceanic gateways and confined basins, are responsible for specific drift morphologies and sediment distribution.

14.4.2. Current conditions

The velocity and intensity of the current is variable in time and space, as determined by a range of global factors and by the Coriolis force. The nature and distribution of currents thus determine (1) the type of contourite facies deposited, (2) the grain size of sediment transported, deposited or eroded over a drift system, (3) the amount of sediment carried, and the overall rate of accumulation and (4) the development of various depositional bedforms, erosional features, and seismic facies. Current variability creates cyclicity in sediment and seismic facies over different scales, and particularly intense current conditions lead to lack of deposition and/or erosion.

Hydrological events marked by drastic erosion may remove large volumes of sediment already deposited on the drift and form major discontinuities and sediment hiatuses. Long-term current conditions, together with other controls, ultimately determine what type of drift is deposited – sheet drifts tend to derive from slower, more spread-out currents, whereas elongated mounded drifts are formed under higher velocities. Short-term current changes, such as the benthic storms caused by high-energy disturbances (eddies), also have pronounced (but more local) control on contourite facies, deposition and erosion.

14.4.3. Sediment supply

The amount of sediment available partly controls the drift size, relief and deposit thickness. The source and input points (e.g. pirating of upstream turbidity currents, pelagic/hemipelagic contribution from the surface, erosion of contourite channels and transfer to drift) in part control the location of drift growth, and further determine drift form, development and composition.

The type of sediments (terrigenous, biogenic, volcaniclastic) influences the depositional bedforms and seismic facies, while variability in input affects contourite cyclicity (sequences) and facies. Sediment supply is, in turn, significantly affected by other variables such as tectonic activity, sea level and climate.

14.4.4. Process interaction

Contour currents rarely act alone in the marine environment, so that both the currents and their deposits will be affected by interaction with other processes. Sediment supply is significantly influenced by pelagic, hemipelagic, glaciomarine and turbidity-current input into the contour current. In some cases it may be that a drift origin at a particular location requires a specific sediment input from one or several other related processes, and certainly the rate and variability of drift growth is affected by such interaction. Interaction of one or more bottom currents or between different strands of the same current, and interaction with major surface-current systems, are all considered as significant controls in drift location, deposition and shape. Particularly close interaction with shallow-water processes, in the outer-shelf to upper-slope environment, leads to a variety of shallow-water drift types (Verdicchio and Trincardi, 2008a), whereas turbidity-current processes lead to the development of mixed drift systems (Mulder et al., 2008); high-latitude drifts have their own specific characteristics, in part related to interaction with glaciomarine processes (van Weering et al., 2008).

14.4.5. Sea level

Eustatic sea-level fluctuations also influence drift growth and morphology indirectly, as they partly control the nature and volume of sediment supply, the nature and generation of different water masses (surface and deep), and the oceanic circulation pattern (wind-driven and thermohaline). Sea-level fluctuations are closely linked also with global climatic fluctuations (see below). However, there are no unequivocal data that directly link the sea-level with rates of drift accumulation or destruction, and certainly not at a timescale approaching that of glacial/interglacial sea-level fluctuations. Detailed study of the complex contourite depositional system in the Gulf of Cadiz region, related to Mediterranean Outflow Water, reveals a complex relationship between sea level, climate and drift growth (Hernández-Molina et al., 2008a).

Whatever the relative intensity of bottom circulation, the influx of large volumes of continental sediment into the deep-sea – during a major sea-level lowstand – generally results in the masking of contourite sedimentation and hence dominance of down-slope deposits during that time span. Such a situation is particularly clear for the continental margin off the eastern USA (Tucholke and Mountain, 1986). Episodes of active bottom-current circulation (as during a global hydrological event) typically generate a widespread surface of erosion or non-deposition in drift systems. Therefore, significant accumulation on contourite drifts is favoured, on the one hand, by a moderate intensity of bottom currents and, on the other hand, by relatively low rates of sediment supply via turbidity currents or other mass flows. In such a case, contourite-drift development therefore does not fit neatly into highstand, lowstand or an intermediate position in sequence-stratigraphic models as proposed by some authors (Vail et al., 1977a, 1991; Posamentier et al., 1988; Haq, 1991).

14.4.6. Climate change

The lack of a good sequence-stratigraphic model incorporating sea-level change and contourite-drift development is closely linked with uncertainty in relating particular climatic conditions to the pattern and intensity of bottom circulation. For example, for bottom circulation linked to the North Atlantic Deep Water (NADW), the episodes of greatest intensity are found by some authors (Boyle and Keigwin, 1982, 1987; Duplessy et al., 1988; Lehman and Keigwin, 1992; Dowling and McCave, 1993; Howe et al., 1994) during the interglacials, but during the glacials by others (Robinson and McCave, 1994; Revel et al., 1995), or during deglaciation (Dowling and McCave, 1993). In fact, it appears that different water masses may behave differently during the same climatic episode. In the North Atlantic, there was an intensification of intermediate water and reduction of deep water during the Last Glacial Maximum, followed by a brief changeover and then a return to this pattern during the main deglaciation (Bond et al., 1992; McCave et al., 1995a).

The same pattern of intermediate- (Antarctic Intermediate Water) and deep-water circulation (NADW) was found for the Southwest Atlantic (Viana, 1998). We might therefore conclude that, at the scale of interglacial/glacial cycles or longer (i.e. 100,000–1,000,000 years) during the Neogene, the data from the drifts that have been studied best would appear to show a more or less random variation in drift growth related to climate and sea-level fluctuations.

14.4.7. Tectonic setting and activity

Many aspects of the overall tectonic framework act, directly or indirectly, as fundamental controls on drift development. The tectonic setting affects the slope gradient and morphology, the opening and closing of oceanic gateways, sediment supply (volume and input points), slope stability and, hence, more local sediment supply and generation of morphological features. Furthermore, neotectonic activity in a more local context can help produce physiographic obstacles to bottom-current flow as well as favoured pathways or contourite channels. This, in turn, affects the nature of the bottom-current system (one or multiple pathways, for example) and hence of the style and size of drift development. Such an interaction between neotectonics, morphology and contour currents has been clearly demonstrated for the complex contourite depositional system in the Gulf of Cadiz, (Hernández-Molina et al., 2006, 2008a; Llave et al., 2007, among others).

AU3

14.4.8. Time constraints

The length of time over which any of the above controls operates, and the periodicity of change or cycles in such controls obviously will affect drift nature, development and growth history distinctly. To construct drifts of significant thickness, size and with a mounded morphology, the contour-current processes involved must have remained semi-continuous in time and space (albeit possibly periodically interrupted by important erosive events) over several to tens of millions of years.

14.5. Contourite-Drift Types

The following classification of contourite drifts based on those of Faugères et al. (1999) and Stow et al. (2002c) uses a combination of drift distribution (i.e. location) and morphology, and also illustrates the drift development in the context of a particular hydrological background. We have refrained from dealing with additional drift types based largely on specific morphological and/or tectonic settings, as published by Rebesco and Stow (2001) and Rebesco (2005), as these make for greater complexity in classification and terminology but add little by way of fundamentally different genetic systems. Furthermore, we recognise that such classifications are never mutually exclusive, so that gradation and overlap between all types are the norm. At some still ill-defined point of morphology, a more or less flat drift with low mounded geometry (a "sheeted drift") will be called an "elongate mounded drift". There is a similar gradation between large (and quite long) "channel-related patch drifts" and "elongated mounded drifts", and between drifts dominated by contour-current deposition and those increasingly affected by other processes; therefore, we call them all "mixed drifts". Most drifts are either sheeted or mounded in overall morphology, but the mounded forms are further classified on the basis of their location with respect to other physiographic features.

14.5.1. Sheeted drifts

The overall geometry of contourite sheets or sheeted drifts differs only very subtly from turbidite sheets on basin plains or their cover of lower-slope and interchannel regions. They are characterised by a wide, mounded geometry, covering a large area with a fairly uniform thickness, showing a very slight decrease in thickness from the central region towards its margins. The internal seismofacies is typically one of low-amplitude, discontinuous reflectors or, in some parts, is more or less transparent. The depositional units that form the sheet have a fairly regular thickness over the whole area swept by the currents. They show a predominantly aggradational stacking pattern and no significant migration. They may comprise or be covered by large fields of sediment waves. The following three kinds of sheeted drift are identified: (1) abyssal sheets, which cover basin plains whose margins trap the bottom currents within a complex pattern of gyre-like circulation; (2) slope sheets, which are spread out across continental margins where a gentle gradient and smooth topography favour a wide non-focused current; and (3) channel-related patch sheets (see channel-related drifts below).

14.5.1.1. Abyssal sheeted drifts

Abyssal sheeted drifts (Figure 14.5) are the most impressive as they can cover large areas with deposits up to hundreds of metres thick. Examples include those of the South Brazilian Basin (Damuth, 1975; Damuth and Hayes, 1977; Mézerais et al., 1993), the Mozambique Basins (Kolla et al., 1980; Ben-Avraham et al., 1994), the Irminger Basin (Egloff and Johnson, 1975, 1978), the Argentine Basin (Flood and Shor, 1988) and the North Rockall Trough (Richards et al., 1987; Howe et al., 1994; Stoker, 1995, 1998b). These drifts may be capped by giant elongate bifurcated drifts like in the Irminger Basin (Gloria Drift) or the Argentine Basin (Zapiola Drift).

14.5.1.2. Slope sheeted drifts

Slope sheeted drifts (Figures 14.6 and 14.7) occur either near the foot of slopes where upwelling or downwelling bottom currents exist such as in the Gulf of Cadiz (Kenyon and Belderson, 1973; Faugères et al., 1985c; Nelson et al., 1993; Habgood et al., 2003), and the Faeroe–Shetland Channel (Howe et al., 2002), or plastered against the slope or rise, particularly where gentle relief and smooth topography favour a broad non-focused bottom current, such as on the Hebrides Margin (Howe et al., 1994; Stoker, 1998b; Stoker et al., 1998a), the Chatham rise (Wood and Davy, 1994) and the Brazilian Margin (Viana et al., 1998a).

14.5.2. Mounded drifts

These drifts are characterised by their distinctly mounded and more or less elongated geometry. Three kinds of sheeted drift are identified (Figure 14.8): (1) giant elongated drifts that are of spectacular dimensions and that are, because of their common elongation parallel or sub-parallel to contours, easily recognised as being of contourite origin, (2) channel-related drifts specifically related to deep channels, gateways or contourite moats and (3) confined drifts deposited in relatively small confining basin.

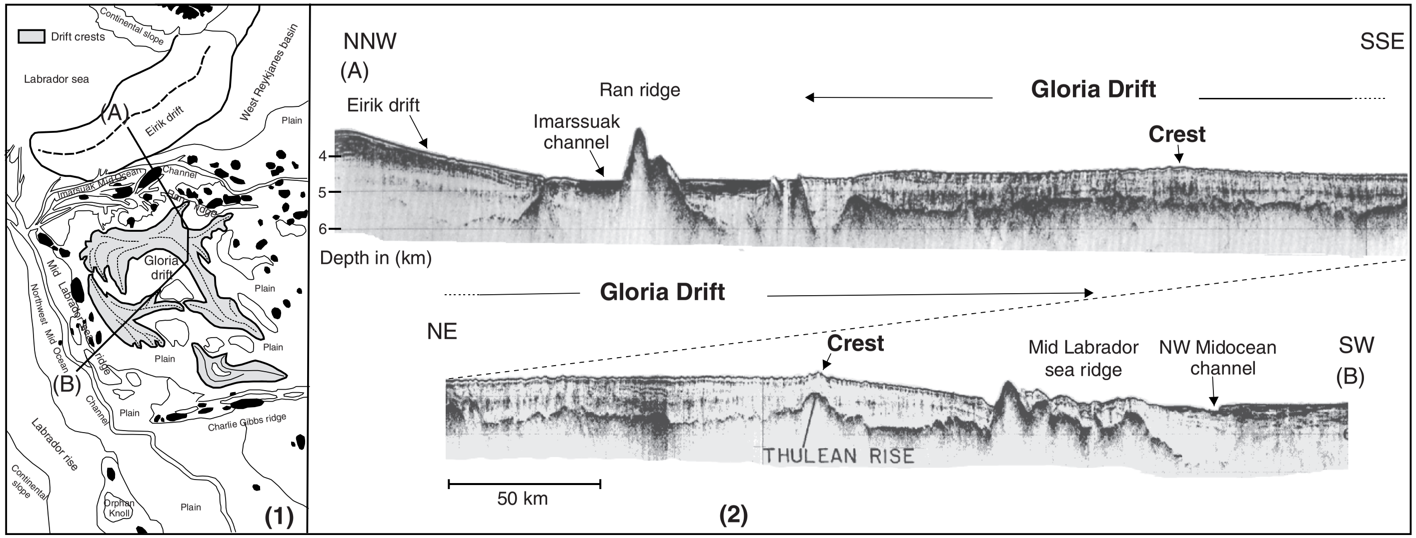

Figure 14.5 The abyssal Gloria sheeted drift (from Egloff and Johnson, 1975; with permission from the Canadian Research Council Press). (1) Morphological map. (2) Seismic line. A multicolour version of this figure is on the included CD-ROM.

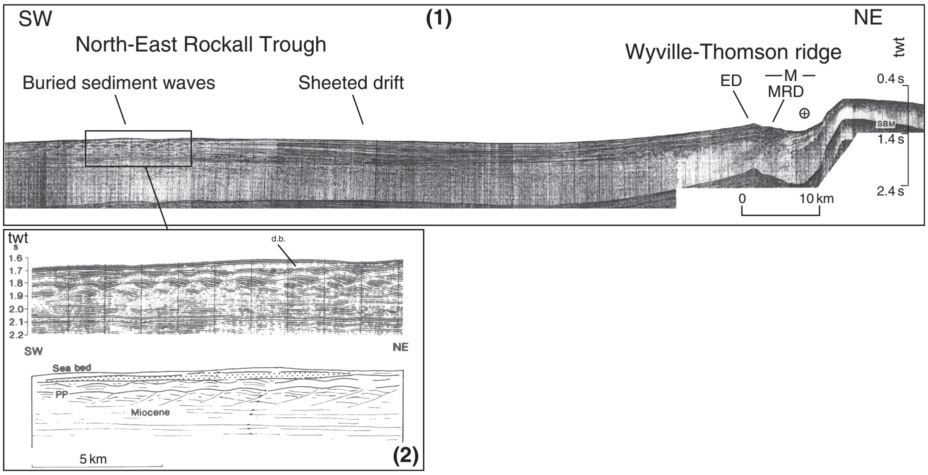

Figure 14.6 Slope sheeted drift in the Hebrides slope, adjacent to the Wyville-Thomson Ridge, Rockall Trough (single-channel air gun, from Stoker, 1998b, see also Howe et al., 1994; Stoker, 1995; Stoker et al., 1998a). (1) Seismic line showing a buried wavy sheeted drift overlain by a debris-flow package (d.b.) with transparent reflection (PP = base of Plio–Pleistocene), and a sheeted drift merging into a plastered/separated drift (ED = elongated low mounded relief) associated with moat-related drift (MRD). (2) Detail of the buried sediment wave field.

14.5.2.1. Giant elongate drifts

Their dimensions are variable: from a few tens of kilometres to over 1000 km long, with length/width ratios from 2:1 to 10:1, and thicknesses of up to several hundreds of metres. Both the elongation direction and directions of progradation can vary with respect to the contours of the continental margin or basin, and are dependent on the interaction between the morphology (i.e. slope gradient and regularity of the sea floor), the current system and intensity, and the Coriolis force. Three principal types are recognised (McCave and Tucholke, 1986): plastered, separated and detached drifts.

14.5.2.2. Plastered drifts

Plastered drifts (Figures 14.8 and 14.9) are located along a gentle slope swept by fairly low-velocity currents. Deposition occurs on one side, both sides and/or directly below the current pathway, together with lateral migration of the drift axis. Examples include the Gardar and Bjorn Drifts in the North Atlantic, the Guadalquivir Drift in the Gulf of Cadiz and other drifts along the New Zealand Margin (e.g. McCave et al., 1980; McCave and Tucholke, 1986; Faugères et al., 1999; Laberg et al., 2001).

14.5.2.3. Separated drifts

Separated drifts (Figures 14.8, 14.10a, 14.11, 14.12) are elongated parallel to the slope and can occur at any depth, particularly associated with steeper parts of the slope where the contour current is restricted due to Coriolis force. The elongated body is separated from the adjacent margin by a distinct contourite moat along which the principal flow is focused. Erosion and non-deposition are dominant near

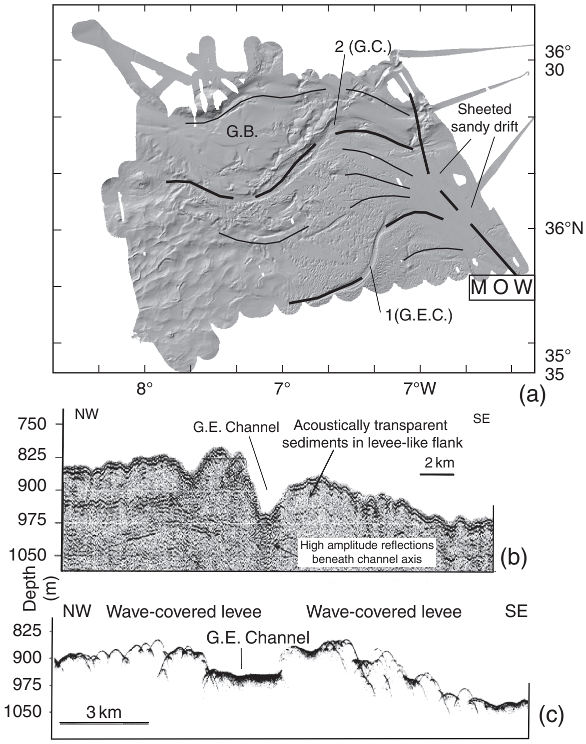

Figure 14.7 Contourite drift and bottom-current channel in the slope of the Gulf of Cadiz. (a) High-resolution bathymetric map (acquired with a SIMRAD EM300 multi-beam echo sounder) showing a sandy slope sheeted drift swept by the Mediterranean Outflow Water (M.O.W.) and channels that funnel the downflowing M.O.W (see Mulder et al., 2003b). 1 = "free-standing" bottom-current channel (G.E.C. = Gil Eanes Channel: Habgood et al., 2003); 2 = channel controlled by tectonic structures (G.C. = Guadalquivir Channel; G.B. = Guadalquivir Bank). (b) Single-channel air-gun seismic section. (c) 3.5 kHz profiles across the Gil Eanes Channel, showing contouritic lateral levees built by the M.O.W. downcurrent funnelled in the channel (from Habgood et al., 2003).

the current axis, while deposition occurs laterally, where the velocity decreases (to the left of the current on the northern hemisphere, and to the right on the southern hemisphere). The location of drifts with respect to the current axis can, however, be variously affected by other factors, including interacting currents and topographic obstacles. Such drifts show an up-slope lateral migration marked by oblique or sigmoidal reflector patterns in seismic lines.

The steep slope along which the drift is deposited may have various origins. In the case of giant elongate drifts, the relief of the continental margin is inherited from its long tectonic and sedimentary history. Locally, steep slopes may result, however, from fault activity or erosional scars associated with major slides or slumps (Figure 14.13). These can lead to the deposition of smaller elongate drifts, which have been termed "fault-controlled drifts" and "infill drifts", respectively (Rebesco and Stow, 2001; Rebesco, 2005).

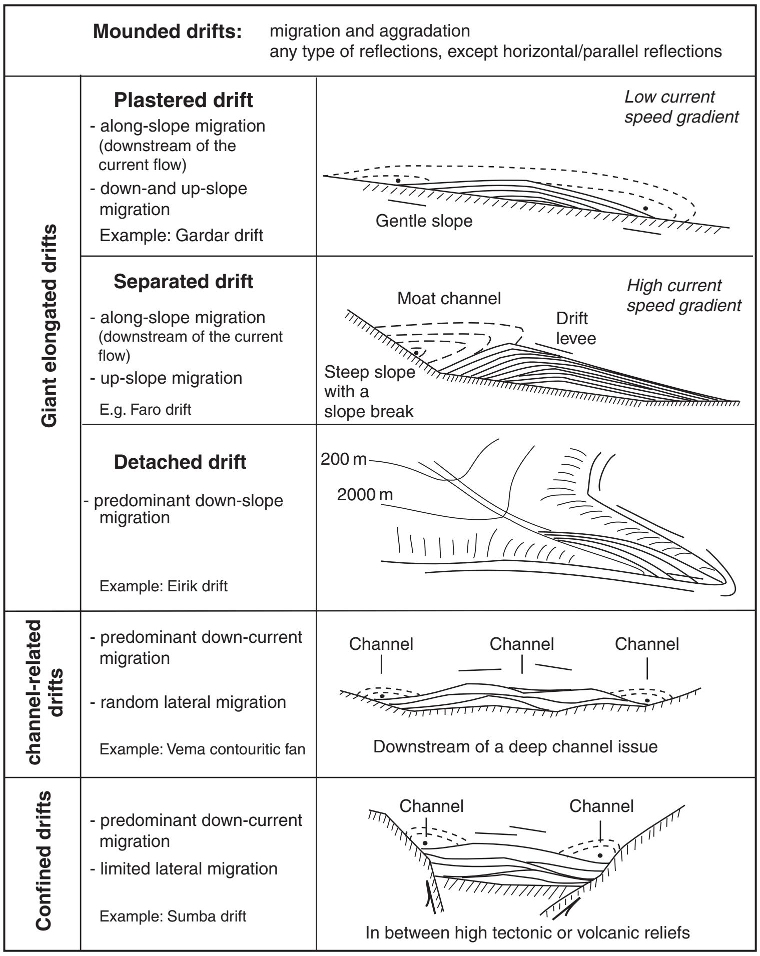

Figure 14.8 Summary of the different types of mounded contourite drift (see McCave and Tucholke, 1986; Faugères et al., 1993, 1999; Stow et al., 2002d), showing the drift general geometry and trend of migration–aggradation as well as inferred bottom-current pathways.

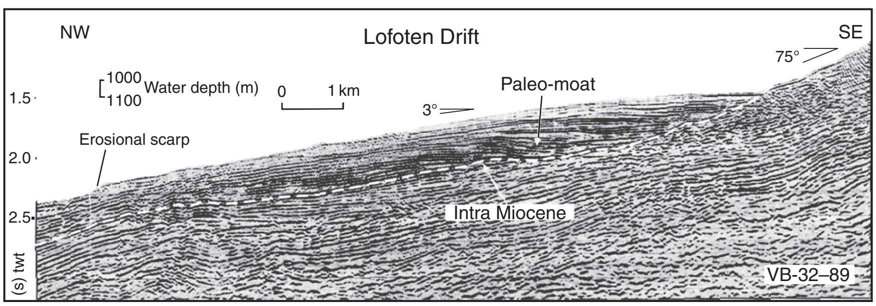

Figure 14.9 The Lofoten drift in the northern Norwegian Sea, a plastered contourite drift (from Laberg et al., 2001; with permission from Springer).

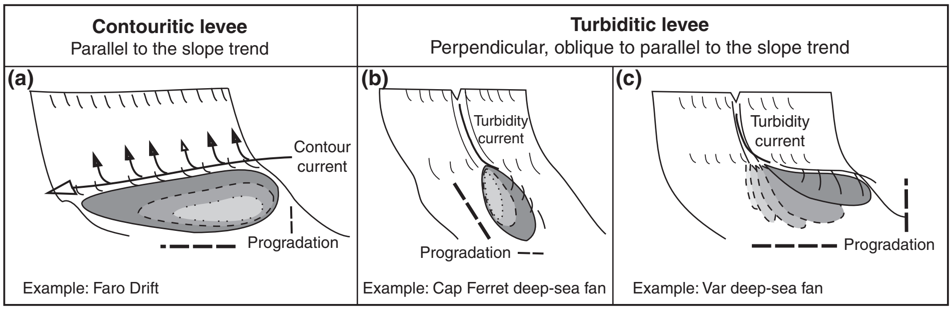

Figure 14.10 The relationship between the directions of contouritic and turbiditic levees and the direction of the margin along which the drifts are developed (from Faugères et al., 1999); black dashed arrow indicates deposit migration. (a) Usual trend for a contouritic drift. (b) Usual trend for a turbiditic levee. (c): Possible variations in direction during the growth of turbiditic levees.

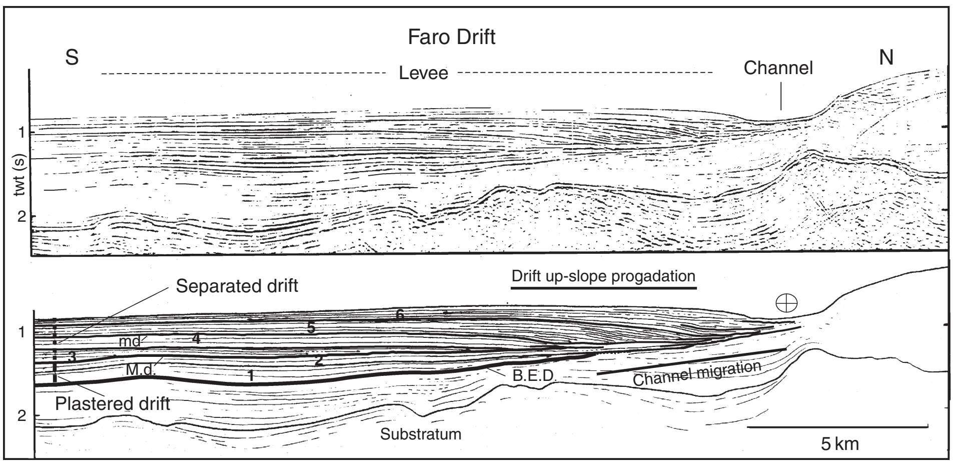

Figure 14.11 The Faro Drift in the Gulf of Cadiz, a separated contourite drift: multi-channel seismic line and interpretation (modified from Faugères et al., 1985a). Note that the contourite sediments are deposited first as a plastered drift (units 1 and 2) and then as a separated drift (units 3–6). The separated drift consists of a "channel–levee" couplet and is characterised by an up-slope direction of progradation. BED = basal erosive discontinuity of the drift; M.d. = major discontinuity between the plastered drift and the overlying separated drift; md = discontinuity bounding the major seismic units.

14.5.2.4. Detached drifts

Detached drifts (Figures 14.1, 14.3, 14.4, 14.8, 14.14a, b) typically present an elongation that deviates at a larger or smaller angle from the adjacent slope against which it first began to form. Such a drift development can result from a change in the margin's trend (Eirik Drift: Arthur et al., 1989; Hunter et al., 2007b), or from the interaction between surface and bottom currents (Cape Hatteras, Gulf Stream and Blake-Bahama Drifts: Tucholke and Laine, 1982; McCave and Tucholke, 1986).

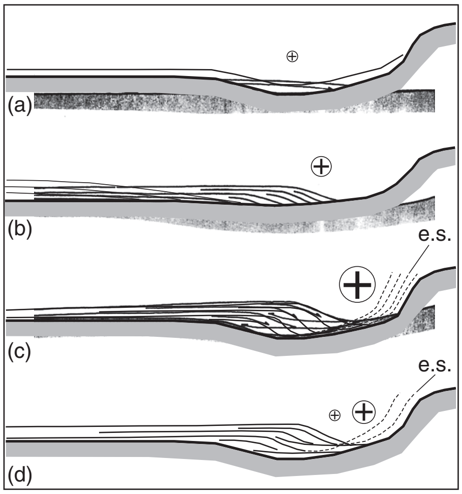

Figure 14.12 The Faro drift (Gulf of Cadiz). Interpretation of the separated drift deposit geometry and sedimentary processes according to the modifications of the sea-floor morphology and variations of the bottom-current velocity (modified from Faugères et al., 1985a). (a) Low-velocity current irrespective of the sea-floor morphology: draping deposit. (b) Medium to high current velocity on a flat or slightly dipping sea floor, with a fairly large gradient in the flow velocity (Coriolis Force): mostly deposition with gently downlapping reflectors; the mounded-drift relief is not well developed (cf. unit 3, Figure 14.11). (c) The mounded-drift relief is well developed and the currents tend to have a higher velocity, as they are funnelled in the channel; if the currents have a high velocity, oblique to sigmoid deposits prograde on the left (southern) flank of the channel, and erosion is prevailing on the channel bottom and the right (northern) flank (e.s. = erosional surface), due to the sharp current-velocity gradient (cf. unit 5, Figure 14.11). (d) Morphological pattern similar to the previous case, but unstable currents with alternating low- and high-velocity currents: the channel is partly filled by alternating downlapping and onlapping deposits, and the up-slope migration of the drift channel slows down compared to the previous case (e.s. = erosional surface; cf. unit 6, Figure 14.11).

14.5.2.5. Channel-related drifts

Channel-related drifts are specifically related to narrow conduits (deep channels, gateways or contourite moats) where the bottom circulation is constrained and flow velocities consequently markedly increased. Examples include, among others, the Faeroe–Shetland Channel (Bulat and Long, 2001), the Florida Strait (Denny et al., 1994), the Kane Gap (Mienert, 1986) and the Vema Channel (Mézerais et al., 1993) drifts in the Atlantic Ocean; the Amirante Passage drift in the Indian Ocean; the Samoan Passage and the Sand Dune Valley drifts in the Pacific Ocean (Lonsdale and Malfait, 1974; Lonsdale, 1981; Johnson et al., 1983). Significant erosion and scouring commonly occur on the channel floor and flanks. Irregular discontinuous sediment bodies may, however, be deposited both within the channel and at the down-current exit of the channel.

14.5.2.6. Axial and lateral channel-patch drifts

These are typically small (a few tens of square kilometres in surface area, 10–150 m thick) contourite accumulations preserved on channel floors and flanks. They

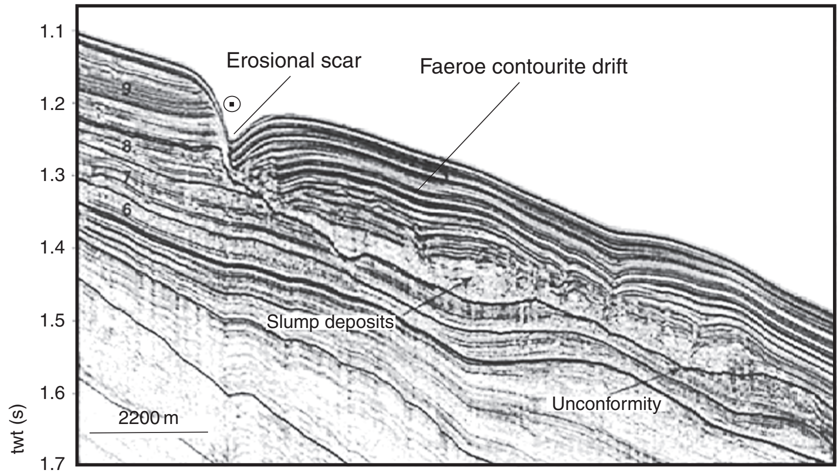

Figure 14.13 The Faeroe separated drift on the southern margin of the Norwegian Sea (from Nielsen and van Weering, 1998; Nielsen et al., 1998c, with permission from The Geological Society, London). The current-scoured channel and associated contourite levee are typical of a separated contourite drift. The location of the channel coincides with an earlier slump scar, the basal unconformity has been formed by mass movements, and the contourite deposits are overlying slump deposits.

may have either a gently mounded or sheeted form capped by wavy bedforms (Figure 14.15), and be either irregular in shape or elongated in the direction of flow. They can be reflector-free or with a chaotic seismic facies very similar to debris-flow lobes and masses, but more commonly show good parallel to sub-parallel seismic reflectors.

14.5.2.7. Contourite fans

Contourite fans (Figure 14.8; see also Faugères et al., 2002b) are typically much larger fan-shaped deposits deposited downstream of the channel exit. A good example is the Vema contourite fan, in the South Brazil Basin (Mézerais et al., 1993; Faugères et al., 2002). This drift is up to 100 km or more in width and radius, and 300 m in thickness. It is composed of an aggradation of flat irregular lenticular depositional units of limited extent, which are sedimentary relicts, bounded by major erosional surfaces. There is little clear or consistent evidence of migration, although the topmost unit normally shows down-flow progradation. As such it is similar to some small- and medium-sized turbidite fans, and may even contain distinct channel–overbank units. Their relative thin character, in combination with laterally extensive erosional discontinuities, can help distinguish them from purely turbiditic systems (Faugères et al., 1998).

14.5.2.8. Confined drifts

This drift type (Figures 14.8 and 14.16) is characterised by a mounded geometry elongated parallel to the axis of a relatively small confining basin or passage where

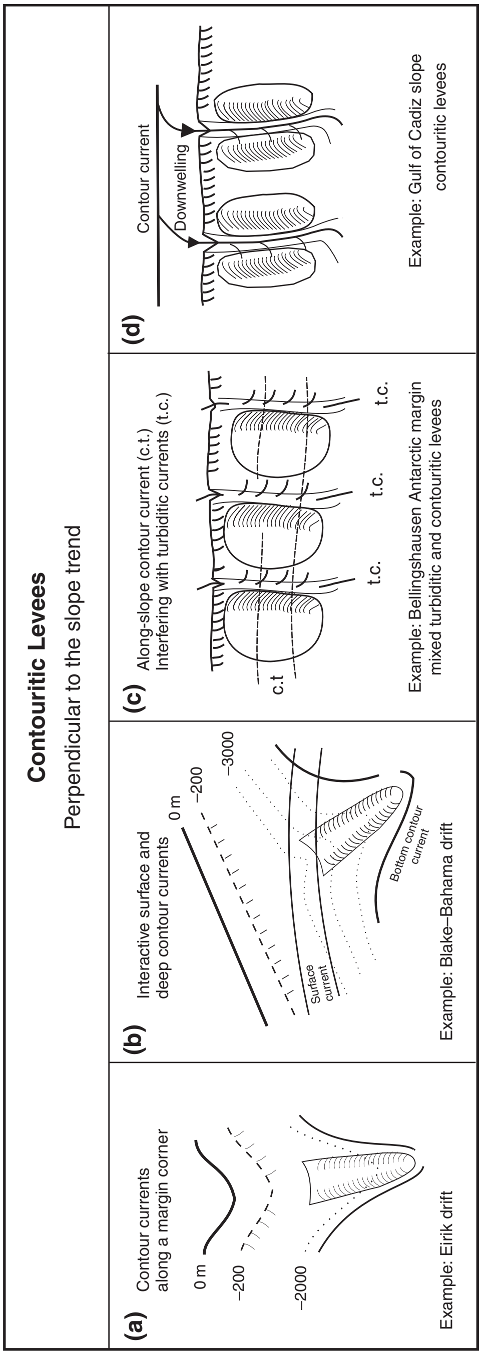

Figure 14.14 Various scenarios for contouritic levees perpendicular to the slope direction (modified from Faugères et al., 1999).

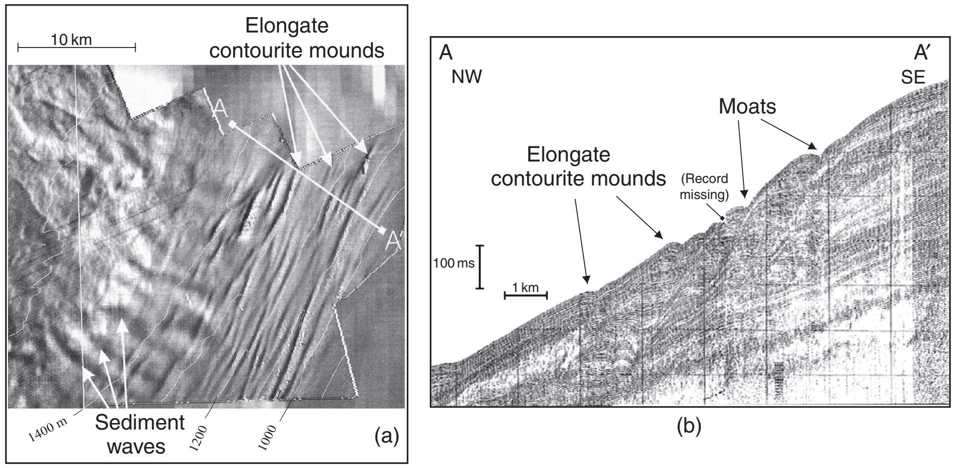

Figure 14.15 The Faroe–Shetland Channel (Bulat and Long, 2001; with permission from Springer). (a) Image performed from a 3-D seismic data set showing the lower part of the eastern flank and the bottom of the channel (1000–1500 m water depth). Note the current bedforms interpreted as elongate contourite mounds and sediment waves, and the interference pattern between these bedforms oriented NE–SW and NW–SE, respectively. (b) Seismic line crossing the elongate mounds: these bedforms have been interpreted as built by an along-slope northeastward flowing current (profile location in a). A multicolour version of this figure is on the included CD-ROM.

fairly slow contour currents are flowing. They have been described with distinct contourite moats along both flanks, suggesting that flow is confined on both margins, or perhaps develops into some kind of circulatory pattern within the basin. Relatively few examples are currently known of such drifts, typically within morphotectonically active areas, such as the northern Corsica Basin (Roveri, 2002) and Sicilian gateway (Reeder et al., 2002) in the Mediterranean Sea, the Louisville Drift in the deep part of the eastern New Zealand Margin (Carter and McCave, 1994), the Sumba Drift in the Sumba forearc basin of the Indonesian arc system (Reed et al., 1987), the Meiji Drift in the Aleutian Trench (Scholl et al., 1977) and an unnamed drift in the Falkland Trough (Cunningham and Barker, 1996; Cunningham et al., 2002). Apart from their topographic confinement, the gross seismic character appears similar to elongate-mounded drifts. They may show a complex stacking of convex-upward lenticular depositional units, partly in relation to active basin subsidence.

14.5.3. Mixed drift systems

Mixed drift systems are those that involve the significant interaction of along-slope contour currents with other depositional processes in the building of the drift body. AU5 As mentioned above (Section 4), sediment supply to contour currents is variously influenced by pelagic, hemipelagic, glaciomarine and turbidity-current input. Where pelagic/hemipelagic input is particularly significant, the drift system will

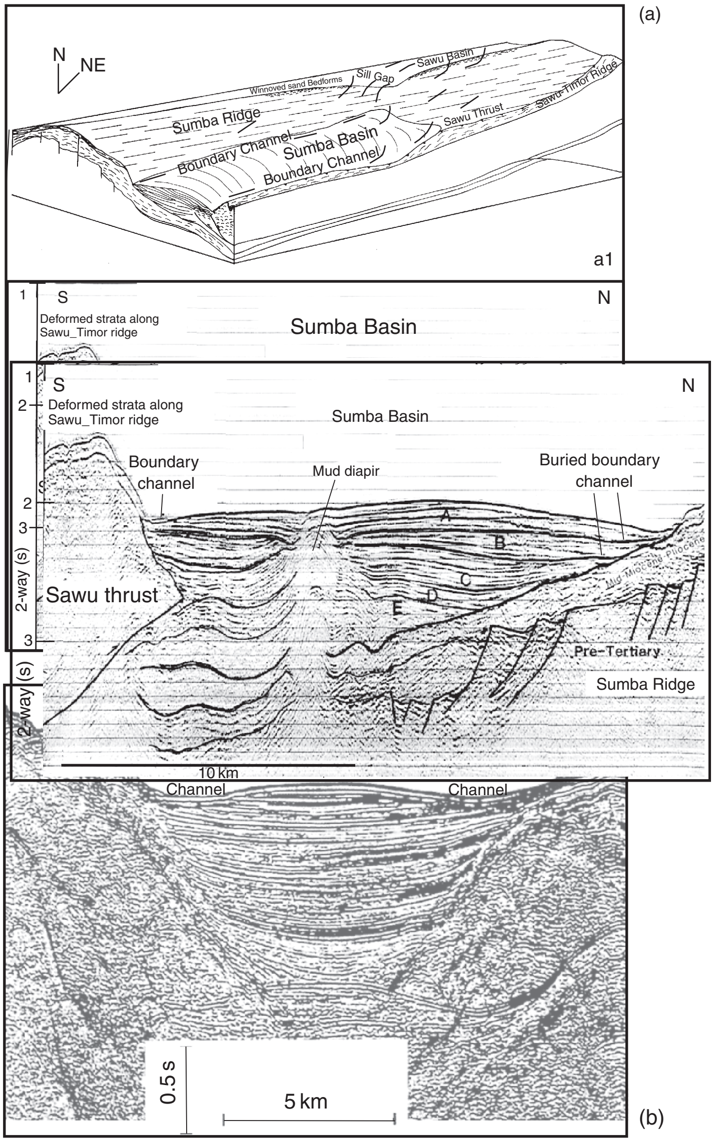

Figure 14.16 Confined drifts. (a) In a forearc basin (Sumba drift, modified from Reed et al., 1987). a1 = schematic diagram showing the morpho-structural and oceanic circulation background of the drift; a2 = water-gun seismic profile crossing the drift. (b) In a large gateway (Sicily Gateway, from Reeder et al., 2002; with permission of The Geological Society, London).

tend to be less pronounced morphologically – many of the sheeted drifts are probably of this type, although they are not generally termed "mixed drifts" because of the inherent difficulty in distinguishing between the processes involved. Particularly close interaction with shallow-water processes, in the outer-shelf to upper-slope environment, leads to a variety of shallow-water drifts or mixed drifts

(Viana et al., 1998a, 2002a; Verdicchio and Trincardi, 2008a). Interaction with glaciomarine processes at high latitudes may be clear from the sediment facies (scattered and winnowed ice-rafted debris), but does not generally produce distinct mixed drift types (see Van Weering et al., 2008). However, where glaciomarine input has been instrumental in triggering significant down-slope sediment movement, the resulting mixed drift systems are characterised by both down-slope and along-slope processes, and hence the normal contourite-drift morphologies and development may be markedly modified. Such down-slope/along-slope mixed drifts have been described from a number of locations, including the high-latitude Antarctic Margin (a.o. Rebesco et al., 1996, 1997, 2002, 2007), the middle-latitude NW European Margin (Armishaw et al., 1998, 2000; Stow et al., 2002b), the middle US Atlantic Margin, east off Cape Hatteras (a.o. Tucholke and Mountain, 1986; McMaster et al., 1989; Locker and Laine, 1992), the eastern New Zealand Margin (Carter and McCave, 1994, 2002; Shipboard Scientific Party, 1999a; Carter et al., 2004) and the low-latitude east Brazilian Margin (Massé et al., 1998; Faugères et al., 2002b). The variable characteristics of these drifts are outlined at more length in Mulder et al. (2008).

14.6. Discussion

Although the classification system outlined above neatly categorizes different drift types, it is important to emphasize again that the distinctive morphologies described are simply type members within a continuous spectrum. Looking at the drift morphology and overall deposit geometry, a high spatial and temporal variability can be found at the scale of the same drift. This results primarily from the depositional background and controlling factors (which change through time), and secondly from the influence of the drift relief, which is constantly growing and evolving in shape, thereby inducing changes in current flow and associated sedimentary processes during drift building.

14.6.1. Spatial evolution of drifts

Spatial morphological variations are exemplified by the Feni drift along the western and southern margins of the Rockall Trough (Figure 14.17). Bathymetric data (Kidd and Hill, 1986) show that this sediment body is initiated as a slope-plastered sheeted drift at its northern location. Further south, the drift evolves into a separated, elongated mounded drift, then becomes a plastered sheeted type again and, finally, just before the northwestern bend in drift trend, there is a complex section including formation of a secondary crest between the moat and the main drift to the east. These changes are believed to be due to variations in the slope gradient and to the fact that several superimposed contour currents are involved in the sediment deposition (Dickson and Kidd, 1986; Stoker et al., 1998a). Similar morphological drift variations are also observed along the Hebrides slope in the northern Rockall Trough (Stoker, 1998b).

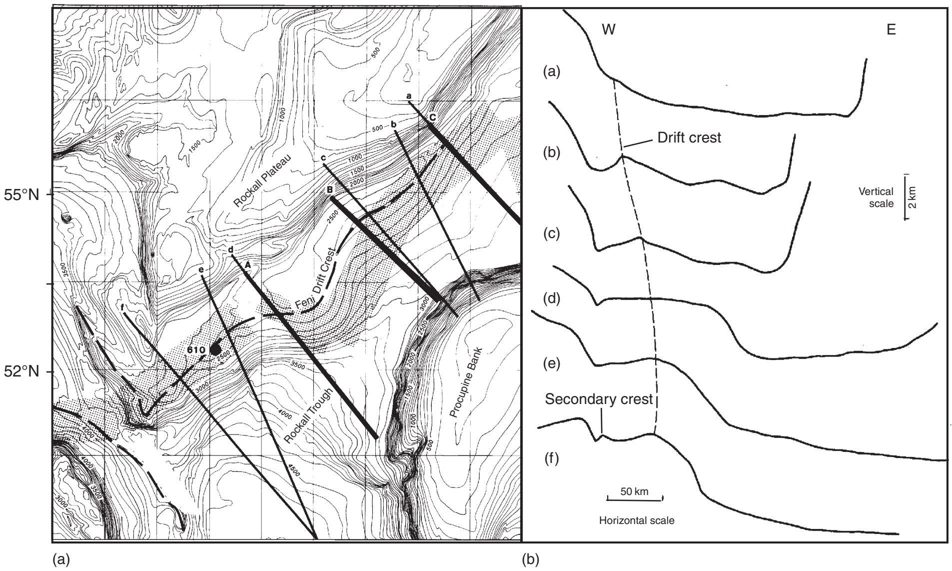

Figure 14.17 The Feni drift (modified from Kidd and Hill, 1986). (a) Bathymetric map of the eastern margin of the Rockall Plateau and Feni drift and location of the bathymetric cross-sections [a–f] seismic lines (A, B, C) and DSDP site 610. (b) Bathymetric cross-sections showing the morphological evolution of the drift with profiles typical of plastered sheeted or plastered drift (sections a, e) and separated drift (sections b–d).

14.6.2. Evolution of drifts in time

Drift evolution at a geological timescale and the complexity of the evolution controls may be illustrated by the Faro Drift (Faugères et al., 1984; 1985a) along the northern margin of the Gulf of Cadiz (Figures 14.11, 14.12). This drift is of medium size (50 km long, 10–25 km wide) and was constructed during the Pliocene–Quaternary on a large plateau located at the foot of a steeply faulted upper slope. Its development began following the opening of the Gibraltar, an important oceanographic event recorded along the whole margin by a major erosional surface on which lies the Faro Drift. The first stage of contourite deposition involved deposition of a sheeted drift (units 1 and 2; Figure 14.11) onlapping the continental slope. The second stage involved upward growth into a low-relief slope-plastered drift (units 3 and 4; Figures 14.11 and 14.12b) with gently downlapping reflections, up-slope migration and the beginning of moat development (non-deposition). The third stage involved its evolution into an elongated mounded and separated drift (units 5 and 6; Figures 14.11, 14.12c) with a deep moat. The drift thus became a prominent high-relief feature with sigmoidal to oblique reflectors, strongly downlapping onto the erosive moat floor. The whole system shows migration up-slope (and partly along-slope,) and significant erosion into the foot of the slope. Such drift evolution may be explained in part by increase of the contour-current velocity as the drift relief increased.

14.6.3. Complex contourite systems

Still more marked variations in time and space are noted in the Gulf of Cadiz region, where a complex contourite depositional system has been evolving for the past 5 million years since the opening of the Gibraltar Strait at the end of the Miocene. This system is now very well known following studies over the past 25 years; many of these have been summarised (Nelson et al., 1999; Llave et al., 2001, 2007; Stow et al., 2002b; Hernández-Molina et al., 2003, 2006). Both large-scale depositional (drift) and erosional features occur in relation to a strong mid-depth bottom current that shows a general decrease in intensity from east to west along the margin, but which also divides into a number of flow strands in response to the morphotectonic framework. Depositional features include sedimentary wave fields, sedimentary lobes, mixed drifts, elongated mounded drifts (plastered and separated drifts) and sheeted drifts, whereas the principal erosive features are contourite channels, furrows, marginal valleys and moats. The range of interacting controls that have led to this complex development over the whole margin are summarised in Hernández-Molina et al. (2008a).

A similar complex contourite system with various types of drifts deposited at different water depth is present along the continental slope of the South Brazilian Basin, where it results from complex interaction of hydrological and morphological factors (Duarte and Viana, 2007; Figure 14.18).

14.6.4. Distinction from turbidite systems

Contourite drifts perpendicular to the margin may also depend on down-slope and along-slope current interaction or downwelling bottom-current activity (Figures 14.14c, d). In the last case, bottom currents could be wholly responsible for the erosion of down-slope channels and, along the channel, the deposition of lateral "contourite levees". These may be true contourite drifts, as proposed for the Chattam Rise off NE New Zealand (Barnes, 1992, 1994) and in the Gulf of Cadiz (Faugères et al., 1985c), where they have been called "free-standing" bottom-current channels and associated levees by Habgood et al. (2003) (Figures 14.7 and 14.14d). However, this now seems less viable than a mixed turbidite/contourite system (Mulder et al., 2008).

Confusion between elongate-mounded drifts and turbidite levees (Figure 14.10) can, therefore, occur on several counts: (1) both have a similar elongate mounded geometry, (2) drifts that are commonly elongated parallel to the slope, can be elongated down-slope as in the cases outlined above, (3) turbidite channel–levee systems – being usually elongated in down-slope direction (Figure 14.10b) – can, in part, be elongated along-slope (Figure 14.10c), where migration has been influenced by the Coriolis force or any morpho-tectonic control, as in the case of the Var levee (Migeon et al., 2000) and (4) true mixed turbidite/contourite levees exist (Figure 14.14c). Turbidite and contourite levees can, therefore, not always be distinguished on the basis of mounded geometry or elongation trend, except where the mounds are clearly isolated from down-slope supply, as in the case of separated drifts. Clearly, though, an along-slope orientation is typical of many contourite drifts and is an important pointer towards their interpretation. In addition, mounded contourite drifts commonly lie on a more or less flat, major erosion surface that corresponds to

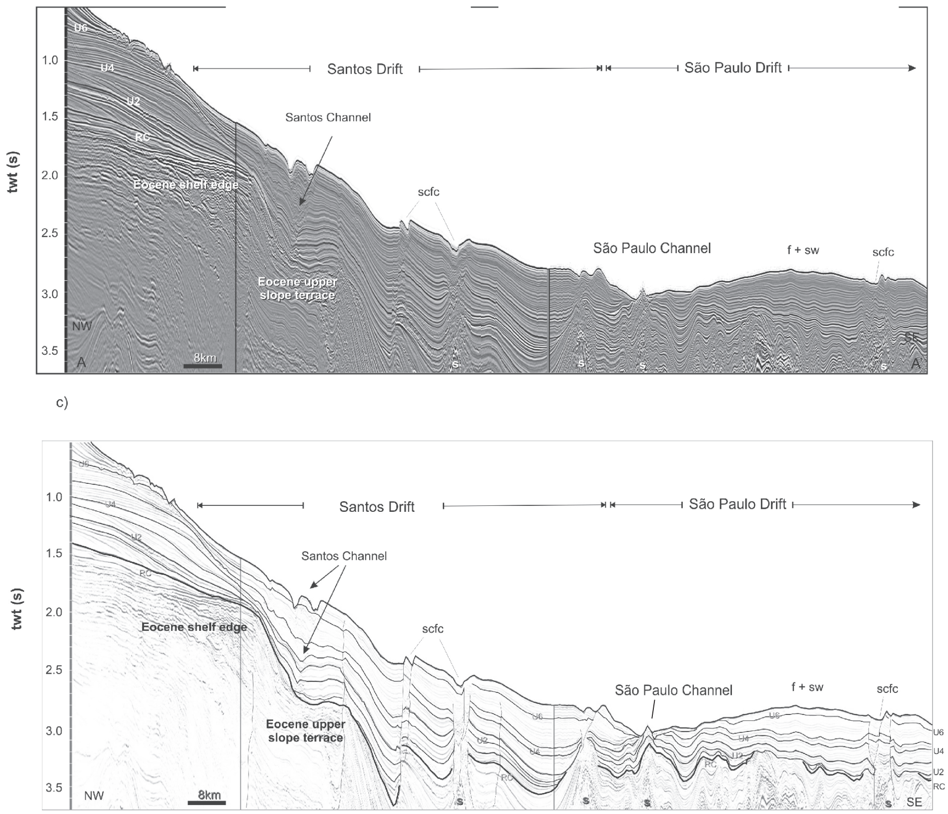

Figure 14.18 The Santos Basin (southern Brazilian continental slope; from Duarte and Viana, 2007, with permission from The Gological Society, London). Note the occurrence of two superimposed channel (moat) drift systems: (1) the Santos Channel–Drift system located on the upper slope and associated with a northward flowing current, and (2) the Sao Paulo Channel–Drift system on the lower slope (Sao Paulo Plateau, where salt diapirs are active) associated with a deeper, north-flowing current. f = furrows; sw = sediment waves; scfc = salt crestal fault channels; R = Rupelian unconformity; U2 = early Miocene unconformity; U4 = mid-late Miocene unconformity; U6 = Mio–Pliocene unconformity.

an important hydrological event associated with the initiation of active bottom-water circulation in the area. Such basal erosion surfaces overlain by contourite deposits are found in most of the drifts of the Atlantic and Pacific Oceans (Faugères et al., 1999). This is not normally the case for turbidite levees.

14.6.5. Buried contourite drifts in modern ocean successions

The different contourite-drift types that are well individualized on the bottom of the modern oceans have also been identified, with similar patterns, in sub-surface sediments, where they are buried by shelf to deep-sea deposits. Some examples (among many others) that come from various domains of the continental oceanic margins are as follows:

1. in the Neogene shelf sediment prism off the SE New Zealand Margin (Fulthorpe and Carter, 1991; Carter, 2007), shallow-water drifts (25 km long and 15 km wide) that mimic separated drifts (Figure 14.19);
2. in the northeastern Australian continental slope, the Marion separated drift (Figure 14.20a), built along a carbonate platform during the Pliocene–Early Quaternary (Shipboard Scientific Party, 1991), is covered by a recent sediment drape;
3. in the eastern US continental rise, the buried Chesapeak Drift and wave field (middle Miocene to early Pliocene) is overlain by the Pliocene-Quaternary deposits of the Norfolk-Washington fan (Mountain and Tucholke, 1985; Locker and Laine, 1992);
4. on the eastern New Zealand Margin (Figure 14.20b), the Chatham separated drift (Wood and Davy, 1994) was deposited during the Neogene and buried by recent onlapping sediments that could be associated to bottom currents of reduced activity and/or gravity currents, and the south moat filled up by probably gravity sediments (debris-flow and turbidite);

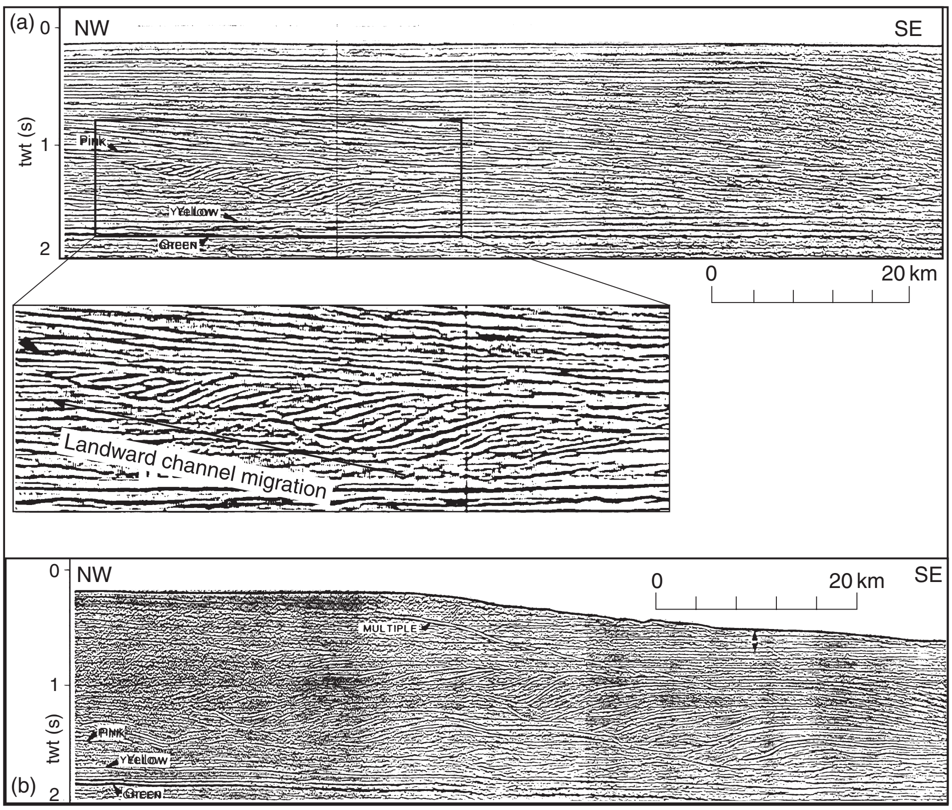

Figure 14.19 Buried shallow-water drifts in the Neogene shelf sediment prism of the SE New Zealand Margin (modified from Fulthorpe and Carter, 1991; with permission from the Geological Society of America; see also Carter, 2007). (a) Isolated shallow-water drift showing a clear northwestward migration. (b) Superimposed shallow-water drift showing a similar migration direction.

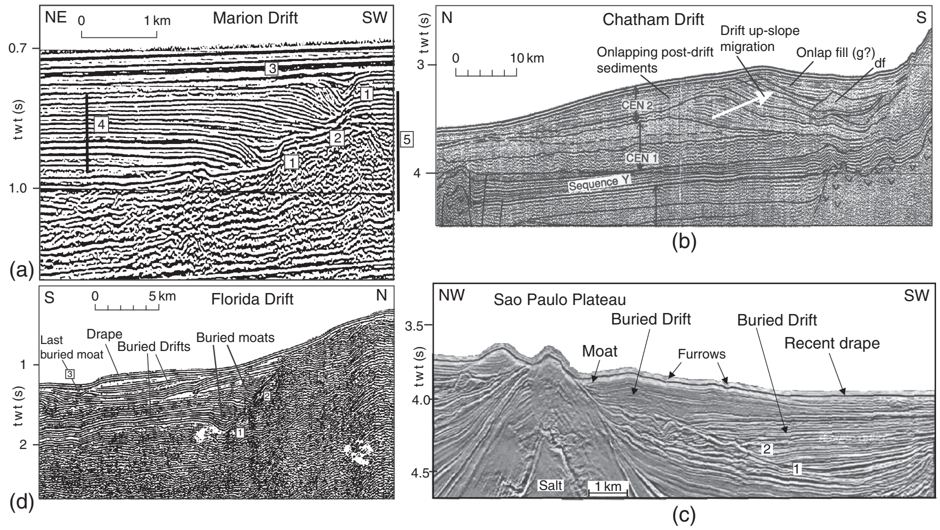

Figure 14.20 Buried drifts. (a) The Marion buried separated drift on the northeastern Australian Margin (modified from Shipboard Scientific Party, 1991); the drift (black arrow 4) was built along a carbonate platform (black arrow 5) by contour currents flowing northwestward. Note: (1) narrow and deep channels suggesting strong current activity; (2) is a large and shallow channel related to slow currents; (3) draping surficial deposits could be associated with a strong deceleration of the bottom currents as soon as the platform relief has been overflown. (b) Northeastern Chatham Drift on the eastern New Zealand Margin (air-gun seismic line; modified from Wood and Davy, 1994). Up-slope migrating drift buried by onlapping sediments possibily associated with bottom currents of reduced activity and/or gravity currents, and moat infill probably due to gravity processes (CEN1 and CEN2 = late Oligocene, Miocene to Recent successions; g? = possible gravity-flow deposits; d.f. = : debris-flow). (c) Sao Paulo Plateau buried drifts (modified from Viana, 2001; with permission from Springer). Note the two generations of buried drifts built along a diapiric relief and covered by a recent sediment drape (1 = erosional basal discontinuity; 2 = buried moat). (d) Florida Drift in the Florida Strait (modified from Denny et al., 1994). Note the up-slope migration of two superimposed buried moat–drift systems (1 to 2), the seaward shift of the most recent system (3 = last moat axis), following a change in the slope morphology (erosion), and the modern sediment drape.

5. in the Brazilian Basin (Sao Paulo Plateau), two generations of superimposed drifts that fill a depression between diapiric reliefs have been described by Viana (2001) (Figure 14.20c);
6. in the Florida Strait (Figure 14.20d), successive Neogene moat–drift systems are buried below modern sediments along the northern flank of the strait (Denny et al., 1994).

Acknowledgements

The authors thank E. Gonthier and A. Viana for valuable discussions and useful comments. They are also grateful to Thierry Mulder for his helpful critical review.

Chapter No: 14

Query No	Contents
AU1	In order to match with the reference list, we have changed the reference citation "Trincardi and Verdicchio, 2008a" to "Verdicchio and Trincardi, 2008a" here and elsewhere. Please check if this is OK.
AU2	Reference "Revel et al., 1995" has been cited in the text but not provided in the list. Please check.
AU3	Please specify the reference citation "Hernández-Molina et al., 2006" whether this "2006a or 2006b or 2006c".
AU4	Please specify the reference citation "Faugéres et al., 2002" whether this "2002a or 2002b or 2002c".
AU5	In the sentence "As mentioned above (Section 4)..., please specify the section number.
AU6	Please specify the reference citation "Hernández-Molina et al., 2006" whether this "2006a or 2006b or 2006c".
AU7	Please check the changes in the caption (change of (a–f) to [a–f]) and artwork (inclusion of parts 'a' and 'b') in Figure 14.17.