

Identification of ancient sandy contourites

J.P.B. Lovell, D.A.V. Stow

Grant Institute of Geology, University of Edinburgh
West Mains Road, Edinburgh EH9 3JW, Scotland

STRACT

Proposed criteria for the identification of ancient sandy contourites include occurrence (thin beds, reworked sandy turbidites, coarse lag), structure (bioturbated, no regular vertical sequence, orientation of cross-orientation perpendicular to regional downslope paleocurrents), grain size (silt or sand, little mud, low or negative skewness), fabric (grain orientation), and composition (downslope and along-slope provenance, concentrations of heavy minerals). A suggested three-stage approach to recognition of sandy contourites in the field involves work on a progressively increasing scale, with particular emphasis on paleocurrent data. The muds occur in deep-water settings in which disparate current directions may occur are summarized, and those in which sandy contourites may be formed and recognizably preserved are indicated. A broad definition of the term "contourite" is now possible because of the widespread documentation of contourites even in freshwater environments. Along-slope flow that is persistent in time and space is a requirement.

INTRODUCTION

In a recent review (Stow and Lovell, 1979), we discussed the recognition of contourites (Hollister and Heezen, 1972) in both modern and ancient sediments. We recognized two broad categories, siltstone and sandy contourites, which are significantly different end members of the contourite spectrum. The muds can be transported long distances and accumulate as thick sediment drifts. Where they have been drilled, the muddy contourites display a distinct hemipelagic character (Stow and Lovell, 1979). In contrast to the sands, on the other hand, they are introduced into an area of contour-current activity by other processes (for example, turbidity currents) and are either partly or completely reworked and transported only short distances. It is, therefore, crucial that the influence of contour currents on these sandy sediments be recognized and distinguished from the influence of the original depositional environment before the term "sandy contourites" can be applied convincingly. Since our review was published, an amount of ancient contourites in the Carian Flysch (Unrug, 1980) has raised the questions of identification and enclosure of sandy contourites dis-

cussed in an earlier paper (Unrug, 1977). The term contourite has also been applied to sediments in Lake Superior (Johnson and others, 1980), an extension of usage to freshwater deposits that we have previously been reluctant to accept (Stow and Lovell, 1979, p. 280), and an attempt has been made to identify contour-current activity in ancient sediments using trace-fossil evidence alone (Crimes and Crossley, 1980; compare Anketell and Lovell, 1976).

Our primary aim here is to set out criteria for the identification of ancient sandy contourites. We then provide a definition of the term "contourite" that we hope will prove generally acceptable. For the moment, we set aside the even more difficult problem of recognizing ancient muddy contourites, and we do not attempt again to review recent contourites.

CRITERIA FOR IDENTIFICATION OF ANCIENT SANDY CONTOURITES

The criteria set out in Table 1 result from extension and minor revision of our earlier suggestions (Stow and Lovell, 1979, Table V, p. 273). The limitations imposed by diagenesis, tectonism, and metamorphism on the use of the categories "grain-size," "fabric," and "composition" require little elaboration. The significance

SETTING	CURRENT DIRECTIONS	ANGLE OF DISPARITY	MODERN EXAMPLES
MEANDERING THALWEG IN CHANNEL		0-20°	NORTHWEST ATLANTIC MID-OCEAN CHANNEL
MEANDERING CHANNEL ON SLOPE		0-80°	HUDSON CHANNEL NORTHWEST ATLANTIC
CHANNEL OVERBANK FLOW		0-60°	MONTEREY FAN EAST PACIFIC
LATERAL AND AXIAL BASIN FILL		60-90°	ALEUTIAN TRENCH NORTH PACIFIC
CHANNEL MARGIN SLUMPS		30-90°	LAURENTIAN FAN NORTHWEST ATLANTIC
TRIBUTARIES DISTRIBUTARIES AND OVERLAPPING FAN LOBES		0-80°	LAURENTIAN FAN NORTHWEST ATLANTIC
COALESCING FANS		0-90°	NORTHWEST ATLANTIC MARGIN ?
HEAD vs. TAIL OF TURBIDITY CURRENT		? 0-60°	?
ABYSSAL PLAIN		0-90°	SOHM ABYSSAL PLAIN, MOST OTHERS

Figure 1. Turbidity-current scenarios.

of grain orientation in both modern and ancient turbidites and contourites is being actively reviewed (Ledbetter and Ellwood, 1980; Taira and Scholle, 1979), and our suggestions here are tentative. More work on the retention of primary grain orientation in tectonically deformed ancient

SETTING	CURRENT DIRECTIONS	ANGLE OF DISPARITY	MODERN EXAMPLES	RECOGNIZABLE IN ANCIENT SEQUENCES
TURBIDITE-CONTOURITE INTERBEDDING ON SLOPE-RISE (SEPARATE EVENTS)		60-90°	NOVA SCOTIAN SLOPE AND RISE, NORTHWEST ATLANTIC MARGIN	YES
TURBIDITY CURRENT/BOTTOM CURRENT INTERACTION		60-90°	AS ABOVE	YES
TURBIDITE-CONTOURITE INTERBEDDING AT FOOT OF SEAMOUNT OR ISLAND		0-90°	GILLISS SEAMOUNT, NORTHWEST ATLANTIC, ARCHIPELAGIC APRONS	POSSIBLY
BOTTOM CURRENT FLOW THROUGH RESTRICTED CHANNEL AND MARGINAL SLUMPING		30-90°	SAMOAN PASSAGE, AMIRANTE PASSAGE, WESTERN INDIAN OCEAN?	POSSIBLY
"CLEAR-WATER" CURRENTS IN CANYONS AND CHANNELS		0-180°	CALIFORNIAN AND EAST NORTH AMERICAN CANYONS	?
DEFLECTION OF LOW-VELOCITY TURBIDITY CURRENT BY BOTTOM CURRENT		20-90°	?	?
INTERNAL VARIABILITY OF TURBIDITY OR BOTTOM CURRENTS		0-180°?	WESTERN BOUNDARY UNDERCURRENT, NORTH ATLANTIC	REQUIRES FURTHER STUDY

Figure 2. Turbidity-current-bottom-current scenarios.

sandstones (for example, Scott, 1967) would be particularly helpful. Circular reasoning is a constant threat when one seeks to recognize contourites by their mode of occurrence, but we contend that careful use of the criteria listed under structure in Table 1, combined with the other evidence, can lead to identification of ancient sandy contourites (see, for example, Anketell and Lovell, 1976; Unrug, 1980).

Barusseau and Vanney (1978) and Barusseau (1979) have synthesized many useful data on the geologic and geodynamic effects of bottom currents. They emphasized that, at the present time, the main effect of bottom currents is to prevent deposition and, to a lesser extent, to erode sediment actively. In ancient rocks these effects will show up as paraconformities, unconformities, and condensed sequences. However, the characteristics they summarized, by which contourites can be recognized and distinguished from turbidites (Barusseau and Vanney, 1978, Table IV, p. 80; Barusseau, 1979, Table 2, p. 742), present the same difficulties as some of those originally proposed by Hollister and Heezen (1972). Their turbidite characteristics do not cover thin-bedded turbidites, and some of their contourite characteristics (for example, the number of beds per 10 m) could be misleading (see discussion by Stow, 1979).

We stress again that only by using a

TABLE 1. IDENTIFICATION OF ANCIENT SANDY CONTOURITES

Main criteria	Detailed observations
Occurrence	(a) Thin beds in thick mudstone sequences that are identified on other grounds as relatively deep-water deposits (b) In turbidite sequences (especially as reworked tops of sandy turbidites) (c) Coarse lag in areas of nondeposition and erosion
Structure	(a) In many cases disturbed and bioturbated, irregular coarse layers with little primary structure (b) In other cases, horizontal- and cross-lamination resembling that in turbidites, but with no regular vertical structural sequence such as Bouma divisions of classical turbidite unit. Orientation of cross-lamination is predominantly unimodal, persistent through space and time, and perpendicular to regional downslope paleocurrents, especially turbidite sole marks. Current directions determined from sole marks and cross-laminations in the same turbidite unit are particularly significant (c) Beds may show reverse grading near their tops, and have sharp upper contacts
Grain size	(a) Silt or sand, rarely gravel (b) May contain little mud and be well sorted (c) Tendency to low or negative skewness (d) Any regional grain-size trends will be along paleoslope as well as downslope
Fabric	(a) Grain orientation along paleoslope, perpendicular to associated downslope turbidite grain orientation? (b) Grain orientation may be more polymodal or random than in (a) because of reworking of earlier deposits or postdepositional disturbance
Composition	(a) Related to both periodic downslope supply by turbidity currents and other processes (for example, Shepard and others, 1979), and to local supply of material along-slope by persistent regional bottom currents (b) Grains of higher specific gravity may be concentrated in laminations

TABLE 2. STAGES IN THE IDENTIFICATION OF ANCIENT SANDY CONTOURITES

Stage	Procedure
Small (exposure and laboratory)	Do beds have range of features shown in Table 1? In the case of possible mixed turbidite-contourite sequences, is there clear distinction between (downslope) turbidite paleocurrents and (along-slope) contourite paleocurrents? If these occur as separate beds, is there sufficient evidence to discount one of the various turbidite scenarios shown in Figure 1?
Medium (formation, region)	Do regional trends in occurrence (facies), paleocurrents, and texture confirm any indications of perpendicular paleocurrent directions found in stage 1? Do they fit one of the "contourite" patterns in Figure 2? Is there other evidence of possible existence of bottom currents? (unconformities, condensed sequences, and so forth)
Large (system, continent)	How do conclusions from stages 1 and 2 fit with what is known from other, independent, lines of evidence concerning main trends of past continental margins and oceanic circulation? (Clearly this stage does not apply to all categories of contourites as defined here)

Recognition of characteristics will correct identification of ancient contourites be. For example, although paleocurrent directions are especially important, we illustrate in Figures 1 and 2 the various deep-water settings in which disparate current directions may occur and suggest that it is only in the case of these that sandy contourites can be formed and recognizably preserved. In Table 2 we have applied the three-stage scheme presented in our previous work (Stow and Lovell, 1979, p. 279) to the field identification of sandy contourites. We hope that Table 2, used in conjunction with Table 1 and Figures 1 and 2, will enable further progress to be made in the identification of these rocks. The distinction between turbidites and contourites in some cases be made more easily in ancient sediments exposed on land, if it is possible to gather relatively clear the vital evidence of current flow. These results can then aid studies of ancient sediments. Winterer (1980, p. 173) has indicated the broad significance of this work: "The proper recognition of contourites deposited by deep thermohaline currents is not a trivial question, for it is one of the most fundamental aspects of oceanic circulation."

CONTOURITE DEFINITION AND NOMENCLATURE

For two reasons, we are reluctant to change the use of the term "tractionites" in the manner suggested by Unrug (1977, p. 365)—that is, as a broad category of contourites that includes contourites. First, Ricci Lucchi has pointed out (footnote in Unrug, 1977, p. 365), the term has been used previously in a different context.

Second, the distinction between deposition from "suspension" and deposition by "traction" is a fine one, even in laboratory experiments, let alone in work with ancient sediments. Given the problems involved in such work, how widely may the term "contourite" be applied? If one accepts the recent extension to lake sediments (Johnson and others, 1980), then a reasonable definition may prove to be as follows.

Contourite: a bed deposited or significantly reworked by a current that is persistent in time and space and flows along slope in relatively deep water (certainly below wave base). The water may be fresh or salt; the cause of the current is not necessarily critical to the application of the term.

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