DAVID BLOOM

20

Sedimentology (1977) **24**, 107–131

Distinctive thin-bedded turbidite facies and related depositional environments in the Eocene Hecho Group (South-central Pyrenees, Spain)

EMILIANO MUTTI

Istituto di Geologia dell' Università di Torino,
Palazzo Carignano, 10123 *Torino, Italy*

ABSTRACT

The vertical and lateral stratigraphic relations of facies and facies associations, palaeocurrent directions, and geometry and internal organization of associated thick-bedded and coarse-grained bodies of sandstone provide the framework for distinguishing five thin-bedded turbidite facies in the Eocene Hecho Group, south-central Pyrenees, Spain. Each facies is characterized by a number of primary features which are palaeoenvironmental indicators by themselves. These features and their palaeoenvironmental significance are summarized below.

(1) The impressive regularity and lateral persistence of bedding and depositional structures, combined with the association of thin hemipelagic intercalations are typical characteristics of the *basin plain* thin-bedded turbidites. Lateral variations in bed thickness, internal structures, grain size, sand : shale ratio, and amounts of hemipelagic intercalations are present in these sediments, but take place so gradually that they cannot generally be recognized at the scale of even very large exposures. The basin plain facies has a remarkable character of uniformity over great distances and considerable stratigraphic thicknesses.

(2) Thickening-upward and/or symmetric cycles with individual thicknesses ranging from a few metres to a few tens of metres are typical of *lobe-fringe* thin-bedded turbidites. The sediments that comprise the cycles contain small but recognizable variations in bed thickness and sand : shale ratio. The diagnostic cyclic pattern can be detected in relatively small exposures. It should be noted that in absence of coarse-grained and thick-bedded sandstone of the depositional lobes the above cyclic pattern is diagnostic of *fan-fringe* areas.

(3) An extremely irregular bedding pattern with lensing, wedging, and amalgamation of individual beds over very short distances, sharp rippled tops of many beds, and internal depositional structures indicative of mainly tractional processes without substantial fallout, are typical and exclusive characteristics of *channel-mouth* thin-bedded turbidites.

(4) Bundles of interbedded thin-bedded sandstone and mudstone as thick as a few metres that are separated in vertical sequences by mudstone units of roughly similar or greater thickness are typical of *interchannel* thin-bedded turbidites. The most diagnostic feature of this depositional environment is the presence of beds of sandstone filling broad shallow channels as probable crevasse-splays.

(5) Thin, thoroughly rippled sandstone beds with marked divergence of the bedding attitude characterize the *channel-margin* facies. The divergence or expansion in thickness, is consistently toward the channel axis. Small and shallow channels filled with thin-bedded deposits, interpreted here as crevasses cut into channel edges or levees during period of severe overbanking are also characteristic.

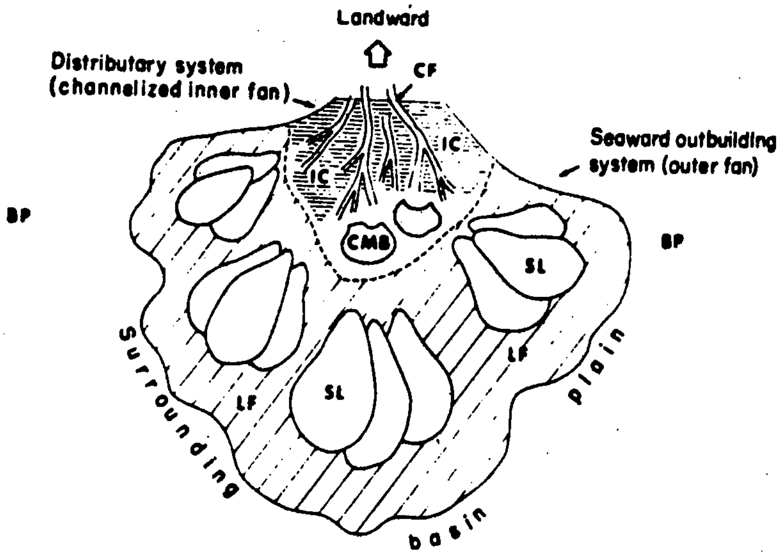


Fig. 2. Depositional model of the Hecho Group turbidite system as inferred from observed facies and facies association relationships. The model does not take into account the actual, elongate basin configuration and is not to scale. The distributary system depicted in the figure is highly diagrammatic and, as such, does not show the complex pattern of countless and relatively small channels observed in the Hecho Group deposits. Thin-bedded facies: IC inter-channel and levee; CMB Channel-mouth bar; LF Lobe fringe; BP Basin plain; Thick-bedded facies: CF Channel fill; CMB Channel-mouth bar; SL Outer fan sandstone lobe.

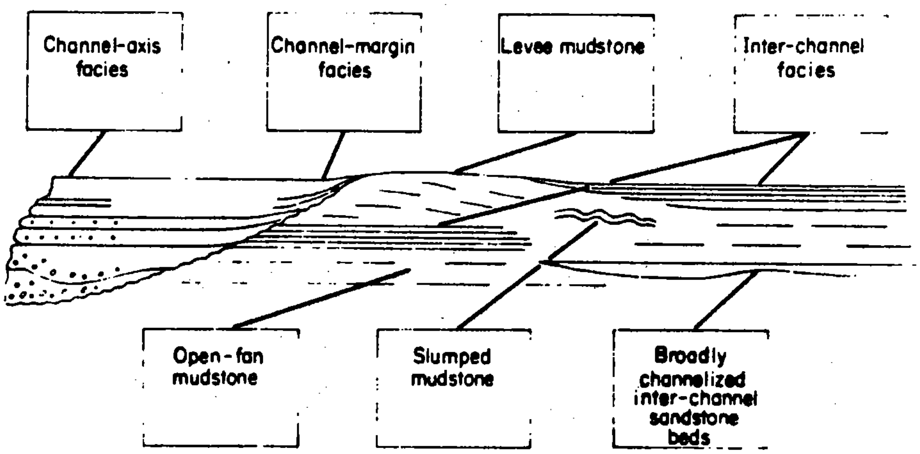


Fig. 3. Relationships and terminology of channel and interchannel turbidite facies as observed in the inner fan deposits of the Hecho Group System. Not to scale.

Table 1. Distinctive features of thin-bedded turbidite facies in the Eocene Hecho Group (south-central Pyrenees, Spain)

	Channel margin	Interchannel	Channel mouth	Lobe fringe	Basin plain
Definition	TBT developed at the margins of, but still within, channel-fill sequences	TBT occurring as bundles as thick as a few metres that are separated by open fan mudstone sequences of similar or greater thickness	TBT forming fringes of channel-mouth sandstone bars	TBT forming peripheral fringes of outer fan sandstone lobes	TBT forming thick and monotonous accretions in flat basin plain areas
Bedding pattern	Sandstone beds pinch out toward channel margins and are commonly bounded by wavy surfaces	Even and parallel bedding surfaces. Minor lensing and wedging	Very irregular because of ubiquitous lensing and wedging	Even and parallel bedding surfaces	Even and parallel bedding surfaces
Internal structures and Bouma sequences	T_{c-e} sequences are most common and may grade into thicker T_{b-e} and T_{a-e} units toward channel-axis	T_{d-e} and T_{c-e} with occasional T_{b-e} and very rare T_{a-e}	Small and large scale cross laminae. Bouma sequence not recognizable in most cases	T_{c-e} are most common	T_{c-e} are most common
Grain size	Fine sand	Mainly fine sand	Fine to very coarse sand	Mainly fine sand	Fine to very fine sand
Sand percentage	Typically very high. Mudstone partings uncommon	0·4 as an average	Highly variable both vertically and laterally	Ranges between 0·12 and 0·62	Typically less than 0·30
Hemipelagic intercalations	Absent	Not recognizable	Not recognizable	Occasionally present	Typically present
Facies types	D_1	D_1 and D_2	E and D_1	D_1 and D_2	D_2 and F
Other distinctive features	Occurrence of small crevasse channels	Occurrence of broad and shallow channels (crevasse-splays)	Downcurrent imbrication of numerous sandstone beds	Cyclic vertical variations of sandstone bed thickness and sand : shale ratio	Impressive regularity of bedding pattern both vertically and laterally
Associated coarse-grained and thick-bedded deposits	Channel-fill deposits	Channel-fill deposits	Channel-mouth bar deposits	Outer fan sandstone lobes	Thick-bedded and coarse-grained carbonate turbidites derived from tectonically unstable flanking platforms

TBT: Thin-bedded turbidites. Facies types after Mutti & Ricci Lucchi (1972, 1975)

The American Association of Petroleum Geologists Bulletin
V. 63, No. 12 (December 1979), P. 2164-2182, 7 Figs., 1 Table

KEN McMILLEN

Plate Tectonics and Sandstone Compositions[1]

WILLIAM R. DICKINSON[2] and CHRISTOPHER A. SUCZEK[3]

Abstract Detrital framework modes of sandstone suites from different kinds of basins are a function of provenance types governed by plate tectonics. Quartzose sands from continental cratons are widespread within interior basins, platform successions, miogeoclinal wedges, and opening ocean basins. Arkosic sands from uplifted basement blocks are present locally in rift troughs and in wrench basins related to transform ruptures. Volcaniclastic lithic sands and more complex volcano-plutonic sands derived from magmatic arcs are present in trenches, forearc basins, and marginal seas. Recycled orogenic sands, rich in quartz or chert plus other lithic fragments and derived from subduction complexes, collision orogens, and foreland uplifts, are present in closing ocean basins, diverse successor basins, and foreland basins. Triangular diagrams showing framework proportions of quartz, the two feldspars, polycrystalline quartzose lithics, and unstable lithics of volcanic and sedimentary parentage successfully distinguish the key provenance types. Relations between provenance and basin are important for hydrocarbon exploration because sand frameworks of contrasting detrital compositions respond differently to diagenesis, and thus display different trends of porosity reduction with depth of burial.

INTRODUCTION

Sandstone compositions are influenced by the character of the sedimentary provenance, the nature of the sedimentary processes within the depositional basin, and the kind of dispersal paths that link provenance to basin. The key relations between provenance and basin are governed by plate tectonics, which thus ultimately controls the distribution of different types of sandstones. Data for modern marine and terrestrial sands from known tectonic settings provide standards to evaluate the effect of tectonic setting on sandstone composition. By direct analogy with such modern sands and by inference for older sandstone suites, broad categories of sandstone can be correlated with specific types of source terranes and basins associated with diverse plate tectonic regimes. Crook (1974) and Schwab (1975) have shown previously that quartz-rich rocks are associated typically with passive continental margins, that quartz-poor rocks are mostly of volcanogenic derivation from magmatic island arcs, and that rocks of intermediate quartz content are associated mainly with active continental margins or other orogenic belts. Our conclusions here are extensions and amplifications of their views (see also Krynine, 1948).

FRAMEWORK MODES

As the character and amount of interstitial cement and matrix are largely a function of diagenesis, provenance studies focus on proportions of detrital framework grains (Dickinson, 1970). For comparative analysis of sandstone suites, varied framework modes must be cast in common terms that reflect key factors of sand genesis (Table 1). For this study, we recalculated all modal compositions as volumetric proportions of the following categories of grains (Graham et al, 1976): (1) stable quartzose grains, Q, including both monocrystalline quartz grains, Qm, and polycrystalline quartzose lithic fragments, Qp, which are chiefly chert grains; (2) monocrystalline feldspar grains, F, including plagioclase, P, and K-feldspar, K; and (3) unstable polycrystalline lithic fragments, L, of two kinds: (a) Lv, volcanic and metavolcanic types, and (b) Ls, sedimentary and metasedimentary types. The total lithic fragments, Lt, then equal the sum of unstable lithic fragments, L, plus stable quartzose lithic fragments, Qp. Extraneous constituents, such as heavy minerals and calcareous grains, are disregarded in this scheme.

---

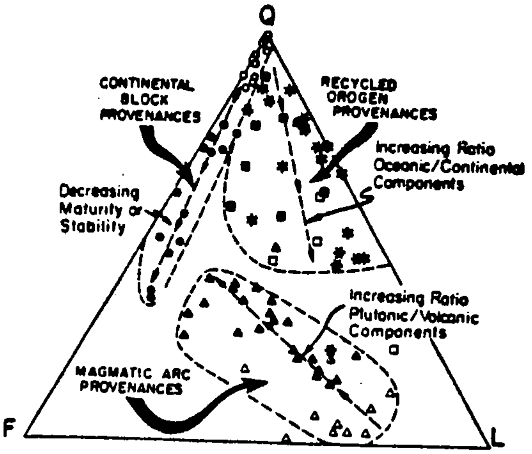
[1] Manuscript received, December 27, 1978; accepted, June 15, 1979.

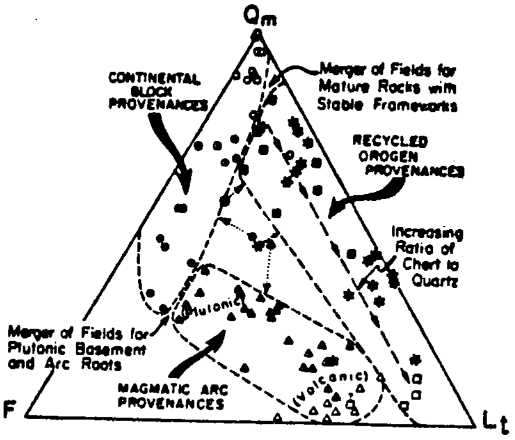
[2] Department of Geosciences, University of Arizona, Tucson, Arizona 85721.

[3] Geology Department, Western Washington University, Bellingham, Washington 98225.

Research was supported by the Earth Sciences Section, National Science Foundation, NSF Grant DES 75-14568 to Stanford University. We also thank John Decker for help with the calculations for Table 1.

Article Identification Number
0149-1423/79/B012-0003$03.00/0





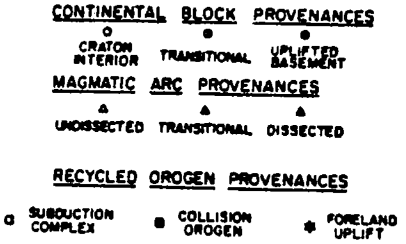


FIG. 1—Triangular *QFL* plot showing mean framework modes for selected sandstone suites derived from different types of provenances (data from Table 1): *Q* is total quartzose grains, including monocrystalline *Qm* and polycrystalline *Qp* varieties; *F* is total feldspar grains (all are monocrystalline); *L* is total unstable lithic fragments (all are polycrystalline).

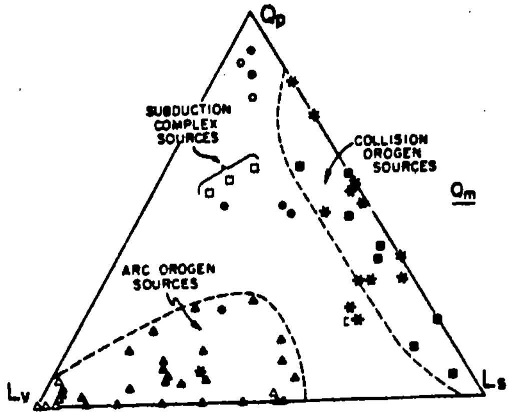
FIG. 2—Triangular *QmFLt* plot showing mean framework modes for selected sandstone suites derived from different types of provenances (data from Table 1): *Qm* is monocrystalline quartz grains; *F* is total feldspar grains (all are monocrystalline); *Lt* is total polycrystalline lithic fragments, including stable quartzose *Qp* as well as unstable *L* varieties.

To display the data, we use four complementary triangular diagrams (Figs. 1-4), each of which involves a different set of grain populations. The QFL and QmFLt plots (Figs. 1, 2) both show full grain populations, but with different emphasis: (a) where all quartzose grains are plotted together (QFL), the emphasis is on grain stability, and thus on weathering, provenance relief, and transport mechanism as well as source rock; (b) where all lithic fragments are plotted together (QmFLt), the emphasis is shifted toward the grain size of the source rocks, because finer grained rocks yield more lithic fragments in the sand-size range. The QpLvLs and QmPK plots (Figs. 3, 4) show only partial grain populations, but reveal the character of the polycrystalline and monocrystalline components of the framework, respectively. Each of the four plots serves to discriminate critically between certain pairs of provenance and basin types.

SANDSTONE POROSITY

The performance of sandstone reservoirs for hydrocarbons depends mainly upon the texture of the aggregate of framework grains, and not upon their composition. Moreover, the initial porosity of sand deposits is controlled primarily by the nature of the sedimentary processes active during dispersal and sedimentation. Thus, the mode and distance of transport and the local depositional environment influence initial porosity much more than does the nature of the provenance or the tectonic setting of the depositional basin. Consequently, detrital frameworks of widely varying composition can be deposited as aggregates having quite similar grain shapes, degrees of sorting, and initial porosities.

However, frameworks of contrasting compositions behave quite differently during diagenesis, and display various rates of porosity reduction



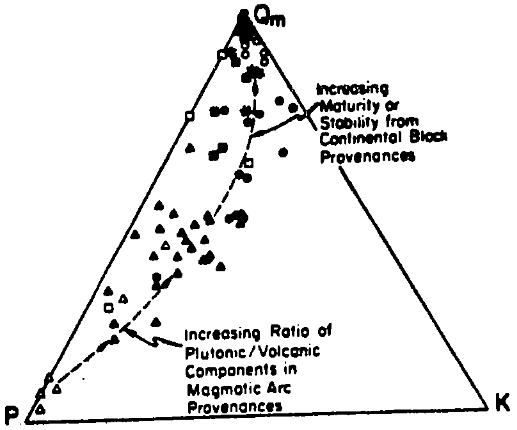


FIG. 3—Triangular *QpLvLs* plot showing mean proportions of polycrystalline lithic fragments for selected sandstone suites derived from different types of provenances (data from Table 1): *Qp* is polycrystalline quartzose grains, mainly chert; *Lv* is total volcanic-metavolcanic rock fragments; *Ls* is unstable sedimentary-metasedimentary rock fragments.

FIG. 4—Triangular *QmPK* plot showing mean proportions of monocrystalline mineral grains for selected sandstone suites derived from different provenances (data from Table 1): *Qm* is quartz grains; *P* is plagioclase feldspar grains; *K* is K-feldspar grains.

with depth of burial. Being chemically more reactive than quartz, feldspar grains and nonquartzose lithic fragments readily undergo mineralogic alteration and experience enhanced intrastratal solution at comparatively shallow depths. These effects tend to promote cementation or growth of authigenic matrix that inhibits retention of porosity during progressive burial. In addition, lithic fragments tend more readily to be deformed or crushed by increasing overburden. This effect accelerates the reduction of sandstone porosity by simple compaction as the depth of burial increases.

The diagenetic behavior of a particular sandstone during progressive burial is a specific response to a complex set of boundary conditions. For example, the nature of interbedded strata, the local geothermal gradient, the rate of burial, the chemistry of pore fluids, and the hydrodynamic setting of the stratigraphic horizon in question all exert influence on diagenetic processes. The evolution of sandstone porosity through time thus cannot be predicted for a given basin from a knowledge of framework composition alone.

Nevertheless, it is clear that striking contrasts in the rate of porosity reduction with depth of burial are typical for sandstones having generally quartzose, feldspathic, and lithic frameworks. For example, the rate of reduction in bulk porosity is substantially less than 5% net per kilometer of burial for quartzose sandstones of the Gulf Coast region, yet is about 5% net per kilometer of burial for arkosic (quartz-feldspar) sandstones in California (Zieglar and Spotts, 1978). In more lithic sandstones, the comparable figure is commonly well in excess of 5% net per kilometer of burial (Galloway, 1974). Although the exact constraints that control the progress of diagenesis vary in each example, the net integrated effect of prevalent diagenetic processes that pertain to porosity

from: SEDIMENTATION IN SUBMARINE
CANYONS, FANS, AND TRENCHES
(D.J. Stanley and G. Kelling, Eds.),
1978, Dowden, Hutchinson & Ross,
Stroudsburg, Pa., pp.377-388.

KEN McMILLEN

Chapter 25

Sedimentation in Submarine Canyons, Fans and Trenches: Appraisal and Augury

GILBERT KELLING
DANIEL JEAN STANLEY

Department of Geology
University of Keele
Staffordshire, England

Division of Sedimentology
Smithsonian Institution
Washington, D. C.

ABSTRACT

The study of sedimentation in ancient and modern submarine canyons, fans, and trenches is in a state of explosive growth. A review of the principal milestones in the development of this research and an evaluation of factors providing the impetus for the expansion of interest in this field suggest that there are a number of elements that have facilitated this evolution. These include (a) revived recognition of the intimate relationship between sedimentation and structure, brought about largely by the new global tectonics concept; (b) clarification and refinement of some existing terms and concepts that resulted from imprecise appreciation of deep marine environments and sequences; (c) development of conceptual models that systematize the description and interpretation of deep marine sediment sequences; and (d) recognition of the remarkable variety of those sediment processes that operate beyond the shelf edge. The uneven development in understanding aspects of this complex area of research results from disparities both in economic pressures and in the technological capacity to test prevailing hypotheses. Studies of ancient sequences have significantly contributed to our present understanding of outer margin sedimentation. A shift in emphasis to modern equivalents, including trench and arc margin basins, is anticipated and is likely to provide a more balanced and truly actualistic approach and to generate new concepts. These trends are exemplified by the current interest in developing a more sophisticated view of the transportation mechanisms for sands and muds, and in solving problems concerned with the occurrence of deepsea gravels.

INTRODUCTION

If, in retrospect, we can assign a date for the inception of concerted and organized research in the environments that are the concern of this volume, it probably should be placed somewhere between the early 1940s and late 1950s. That period witnessed the publication of an important series of detailed surveys of deeper marginal regions, most of which had a strongly morphological emphasis (Shepard and Emery 1941; Menard 1955; Heezen et al. 1959). The mid-1950s also was the period when, thanks primarily to the evangelistic efforts of Ph. H. Kuenen, the geological community began to realize that the thick piles of sand found in modern and ancient marine sequences were representative of deep sea environments (Heezen and Ewing 1952) equally as much as the dark muds and radiolarian oozes previously considered diagnostic of that sedimentary milieu.

During the intervening quarter-century, much has been learned concerning the processes and products that characterize this sector of the marine realm. Thanks to expanded research efforts, a more refined and flexible technology, and increased socioeconomic pressures, the past decade has seen a virtual quantum jump in our understanding of sedimentation in this area. Consequently a broad review of the state of our knowledge of sedimentation in submarine canyons, fans, and trenches – especially a review that includes both modern and ancient examples – appears both appropriate and opportune.

The collection of contributions gathered together in this volume is broadly representative, if not entirely comprehensive, of contemporary interests in this area of sedimentological research, and in this concluding chapter we attempt to assess the development, current status, and future growth of information and concepts relating to

KEN McMILLEN

The American Association of Petroleum Geologists Bulletin
V. 62, No. 9 (September 1978), P. 1584-1606, 22 Figs., 2 Tables

Petroleum Source Beds on Continental Slopes and Rises[1]

WALLACE G. DOW[2]

Abstract Continental slopes commonly are sites of high marine organic productivity and frequently contain reducing bottom conditions, quiet water, and intermediate sedimentation rates, all of which favor deposition of organic-rich sediments. These deposits typically have high percentages of aquatic organic matter with high petroleum yields as contrasted to relatively organic-lean shelf deposits which contain primarily low-yield terrestrial organic matter.

Conversion of organic matter in potential source beds to oil and gas requires a combination of temperature and time. These variables are controlled primarily by the geothermal gradient, the rate of burial, and the age of the source interval. Most divergent margins need between 2 and 4 km of overburden for oil generation and from 3 to 7 km for gas generation. Typically cooler and younger convergent margins and deltaic margins must have even greater burial depth to achieve the same results.

Continental margins, including present slopes and rises, can contain oil and gas source beds when minimum requirements of organic content, kerogen type, and thermal maturity are met. Migration and accumulation are most efficient, however, where reservoir sequences prograde over source beds in areas of structural complexity. Preservation of trapped petroleum requires effective seals and minimal structural readjustment after accumulation. All these conditions can be found on present slopes and rises, although they are not common, and must be considered as part of any economic evaluation of these largely untested deep-water realms.

INTRODUCTION

Continental slopes and rises are physiographic features of continental margins (Fig. 1), and there is no a priori reason why petroleum source beds should not exist there as they do on continental shelves. Deep sediments on slopes and rises have not been drilled and much of their geology, including reservoir and source potential, must be inferred. Recent data, especially from Deep Sea Drilling Project (DSDP) cores, have revealed certain features of slopes and rises which favor the preservation of organic matter in sediments. Some data defining the rate of maturation with depth also have been developed. Other aspects such as structural style and sediment thickness and approximate age can be postulated from regional geophysical profiles, especially when used in conjunction with DSDP core data. Analogy with relatively abundant data from test drilling on continental shelves is also useful, but present slopes and rises typically contain younger sediments than do shelves (Fig. 1), some of which may not have been deposited in deep-water environments. Some slopes and rises are underlain by older sediments that are not related to slope and rise sedimentation, and some of these might contain good petroleum source beds.

DEFINITION OF SOURCE BEDS

The question of what constitutes oil or gas source beds is still debated, and it is useful to define criteria for their recognition. In this paper, we apply the modern geochemical concept that petroleum and gas are formed from disseminated sedimentary organic matter (kerogen) by a series of predominantly first-order chemical reactions, the rates of which are dependent primarily on temperature and the duration of heating. The quantity and variety of petroleum generated are related to the concentration of organic matter in the source bed and the type of kerogen present. Whether petroleum-generating reactions have occurred is determined by the thermal maturity of the primary organic matter. Although geochemical criteria for the recognition of source beds are fairly well agreed on by most geochemists, factors governing expulsion and migration are less understood. Some favorable and unfavorable parameters can, however, be discussed.

Kerogen Concentration

Recent papers on kerogen (Dow, 1977b; Harwood, 1977) review criteria for the amount, type,

[1] Manuscript received, October 10, 1977; accepted, February 22, 1978. This paper will also appear in AAPG *Memoir* 29.

[2] Vice-president geochemistry, Robertson Research (U.S.) Inc., Houston, Texas 77060.

Sincere appreciation is expressed to Don Mathews, formerly of Superior Oil Co., for releasing the material on which the original version of this paper (Dow, 1977c) was based. Appreciation also is due Linda Samuels for her editorial assistance.

Article Identification Number
0149-1423/78/B009-0002$03.00/0

The American Association of Petroleum Geologists Bulletin
V. 63, No. 3 (March 1979), P. 286-300, 3 Figs., 5 Tables

Petroleum Prospects of the Deep Offshore[1]

H. D. HEDBERG,[2] J. D. MOODY,[3] and R. M. HEDBERG[3]

Abstract A rough general assessment of the possibilities of petroleum accumulations in deep ocean regions beyond the continental shelf has been undertaken, for convenience, under three major heads—the central ocean region, the continental margin region, and the small ocean basins region. The information used comes largely from marine geophysical surveys and from 417 holes of the Deep Sea Drilling Project.

Evaluation is based principally on thickness of sediments, organic carbon content, reservoir rocks, probability of accumulation traps, probable geologic history, and known occurrences of oil and gas. The distinction is made between environment-accordant sediments (formed under essentially the same geomorphic conditions as at their sites today) and environment-discordant sediments (formed under markedly different conditions).

The *central ocean region* is considered with respect to the sedimentary rock developments of each of its major geomorphic units. In general, the prospects for petroleum accumulations appear unfavorable because of thinness of sediments, low organic carbon content, scarcity of reservoirs, paucity of shows, and generally horizontal attitude militating against trapping conditions; however, there are some exceptional areas.

The *continental margin region* includes (1) marginal geosynclines, (2) outer-margin aprons, (3) marginal-plateau blocks, (4) marginal-trench fillings, (5) continent-related deep water fans, and (6) transmarginal ridges. The region as a whole has favorable aspects as regards thickness of sediments, source rocks, reservoirs, sealing rocks, petroleum shows, geologic history, and probability of traps.

In the *small ocean basins*, thick sedimentary sections, abundant terrestrial and marine organic matter, reducing bottom conditions, well-developed reservoirs, mobile tectonic environment, and commonly an abundance of evaporites and diapiric structures combine to give a very favorable rating, supported by prolific production from the borders of many of these basins.

With respect to production prospects, the deep offshore has obvious handicaps of unfavorable environment and costly operations, but where economic prospects are sufficiently good, the technological challenge can be met.

There are large, almost untouched areas of deep offshore, sufficiently prospective to justify exploratory drilling, that urgently need evaluation. The United States alone has more than 1.5 million sq mi (3.9 million sq km) of combined shelf and deep-water offshore over which it can rightfully claim jurisdiction, of which only about 2% has ever been leased for development.

INTRODUCTION

It has long been recognized that the world's most favorable hunting grounds for petroleum lie adjacent to the margins of its continents and islands, past and present. There, great thicknesses of organic-rich sediment have accumulated, and both sedimentation and tectonics have favored the development of reservoir rocks along with the structural and stratigraphic traps necessary to commercial accumulations of hydrocarbons.

As the more obvious petroleum prospects[4] on land were identified and tested, attention began to turn increasingly to the offshore. It was recognized that the vast shallow-water areas of the submerged continental shelves of the world must have had much of the same geologic history as the emergent coastal plains. Following beginnings in such sheltered offshore areas as Lake Maracaibo, intensive exploration of the submerged continental shelf began in the 1940s. Today, more than 18% of the world's daily oil production comes from the offshore shelves. Of new fields to attain "giant" status in the last 5 years, 20% are totally offshore and another 22% are partly offshore (Klemme, 1977a, 1977b).

This paper looks into the future, beyond the land areas, beyond the shallow waters of the submerged continental shelf, to a third domain—the deep-water ocean regions. This third domain is looked at today much as the submerged continental shelf was viewed 30 years ago.

---

[1] Read before the Association at Research Symposium I: Petroleum Potential of Slopes, Rises, and Plateaus, at Washington, D.C., June 14, 1977. Manuscript received, September 12, 1977; revised and accepted, November 10, 1978.

[2] 118 Library Place, Princeton, New Jersey 08540.

[3] International Oil & Gas Corp., New York, N.Y. 10022.

Article Identification Number
0149-1423/79/B003-0001$03.00/0

[4] In this paper, the writers' usage of certain common evaluative words and expressions is as follows.

Prospects = chances; chances of being (e.g., "petroleum prospects" = chances of there being petroleum).

Prospective = meriting, deserving, or worthy of exploration or prospecting (e.g., "prospective petroleum areas" = areas worthy of exploration for petroleum).

Prospectiveness = merit or worth for prospecting

Potential (adj.) = having the capacity and/or a strong possibility of being or becoming (e.g., "potential source rock" = a rock having the capacity for and strong possibility of becoming a source rock).

re, Phys.

ry deep-
vince of
on Z-23:
p.
Spanien:
14-822.
lpersien:
03-813.
rungsart
skischen

ep-ocean
151-2169.
ogeogra-
in in the
Meded.,

tigraphie
oa. NW-
thys-Ge-
Kl., Abh..

58. Newly
G Bull., v.

McMillen

The American Association of Petroleum Geologists Bulletin
V. 62. No. 11 (November 1978). P. 2243-[illegible], 23 Figs

Sedimentation and Trapping Mechanism in Upper Miocene Stevens and Older Turbidite Fans of Southeastern San Joaquin Valley, California[1]

BRUCE A. MACPHERSON[2]

Abstract Most of the stratigraphic oil production in the southern San Joaquin Valley comes from the sandstones of the upper Miocene turbidites. Updip, time-equivalent rocks of the shallow-marine environment are second in productivity. Third in importance are the deep-marine, fractured, siliceous shales deposited beyond distal margins of the fan complex. Many underexplored areas remain in the San Joaquin Valley despite many years of field development and wildcat drilling.

The Miocene of the Bakersfield arch is representative of the classic arcuate type of turbidite deposits characteristic of modern submarine fans. Further paleogradient of the fans has been accentuated and not reversed through geologic time; stratigraphic oil fields are numerous. As in most California deep-marine troughs, the turbidite facies most easily reached by the drill, and in which most of the oil reserves have been developed, are in the mobile zone of basin-margin wedging. Two additional trapping aspects related primarily to depositional stratigraphy within the midfan facies are (1) intrabasin contemporaneous faults (analogous to Gulf Coast growth faults) resulting in expanded section and reverse drag on the downthrown block, and (2) compaction anticlines formed by post-sedimentary accommodation over submarine channel sands resulting in structural inversion with depth.

South of the Bakersfield arch is an earlier (pre-late Mohnian) turbidite basin, virtually unexplored and referred to informally as the "Maricopa subbasin," where drilling depths to potential Miocene pays range from 12,000 to 20,000 ft (3,600 to 6,000 m). Basic stratigraphic relations recognized in the Bakersfield arch may be applied in the subbasin to develop new hydrocarbon reserves.

INTRODUCTION

The Stevens sandstones have been the target of continued oil exploration for more than 40 years. Thus far, more than 450 million bbl of high-gravity crude has been proved with slightly more than 400 million bbl having been produced by 1973. These reserves are derived from only 15 fields on the Bakersfield arch. If the Stevens oil fields on the west side of the San Joaquin Valley (outside the scope of this study; Fig. 1) are included, the quoted reserves readily could be doubled for this most prolific pay.

Although the Bakersfield arch now might be considered a mature area of exploration, surprisingly few papers exist pertaining to Stevens stratigraphy. Yet the arch province, with its dense well control and numerous stratigraphic and structural traps, serves as an excellent pilot area for understanding the trapping mechanisms of the Stevens for future exploration for this zone as well as for pre-Stevens turbidite sands in underexplored areas of the San Joaquin basin. All of the anatomical parts of fossil turbidites are preserved here and are available for study to those with access to the data. All depositional environments have been found to be productive, each with its unique trapping mechanisms for hydrocarbon accumulation.

In this study, the "Stevens sandstone" is an all-inclusive term encompassing more than 4,000 ft (1,200 m) of interbedded deep-marine sandstone and shale originating as two major coalescing submarine fans issuing from two source areas at the eastern end of the Bakersfield arch, one at Rosedale Ranch field and the other at Fruitvale field (Fig. 2). Each fan complex is named by the writer, Rosedale fan and Fruitvale fan after its respective source.

Four discrete depositional cycles are recognized and informally named. In ascending order they are: "Rosedale," "Coulter," "Gosford," and "Bellevue."

The Stevens is of late Mohnian age but, herein, the early Mohnian Rosedale Sandstone of Martin (1963) also is included in the Stevens group (Fig.

---

[1] Manuscript received, May 9, 1977; accepted, March 20, 1978.

[2] Continental Oil Co., Oklahoma City, Oklahoma 73112.

The writer is indebted to Continental Oil Co. for permission to publish this report. Special acknowledgment is due Richard Louie, formerly of Continental Oil Co., for his assistance in computer analysis of turbidite-sand wedging; R. Skalecke and Paul Hagood for preparation of the illustrations; and Sandra Medland for typing and editing the manuscript.

The writer thanks AAPG Pacific Section for permission to publish this modification of his earlier paper (MacPherson, 1977).

Article Identification Number
0149-1423/78/B011-0004$03.00 0

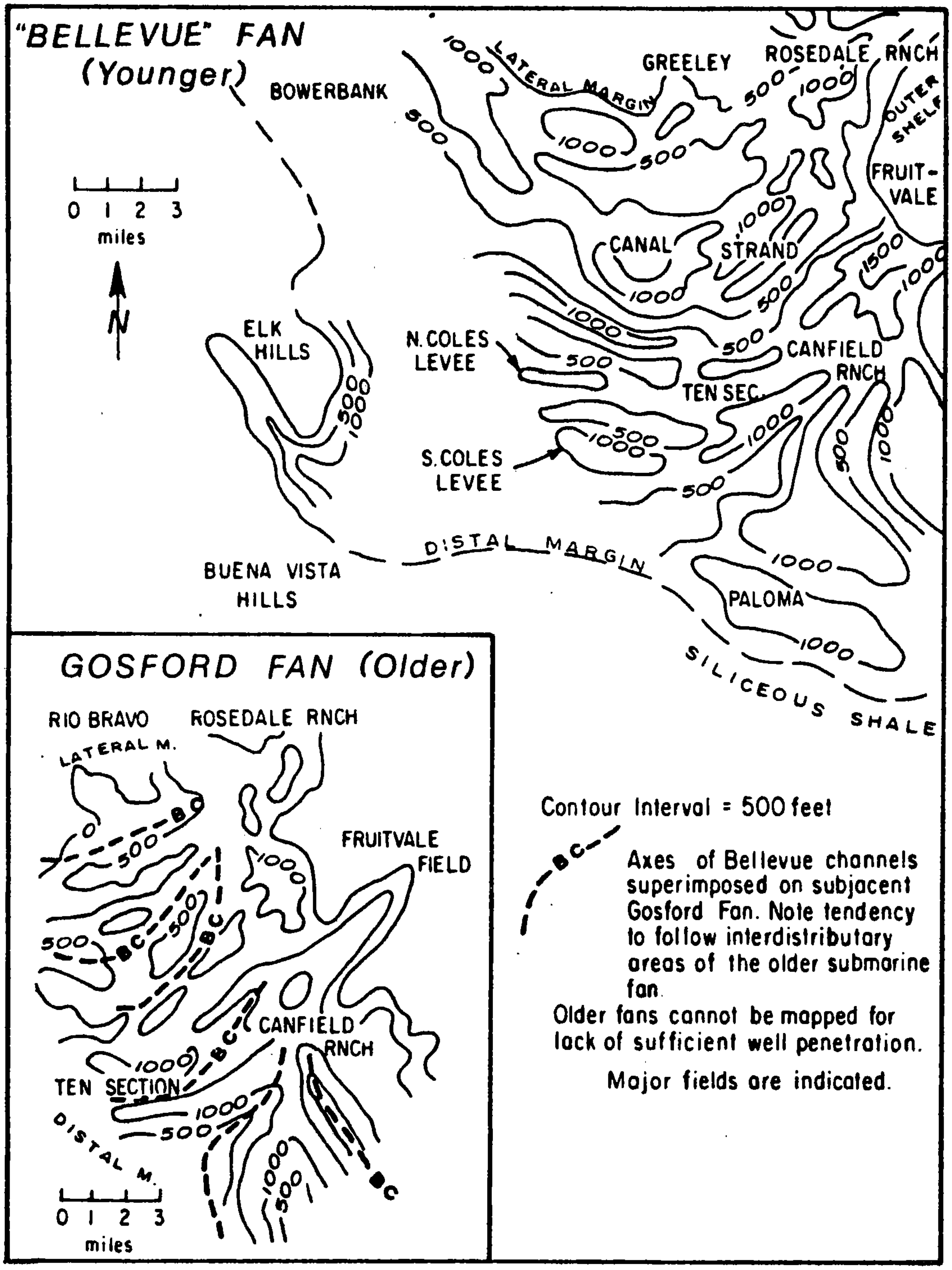


FIG. 6—Isopachs of Bellevue and Gosford turbidite fans on Bakersfield arch.

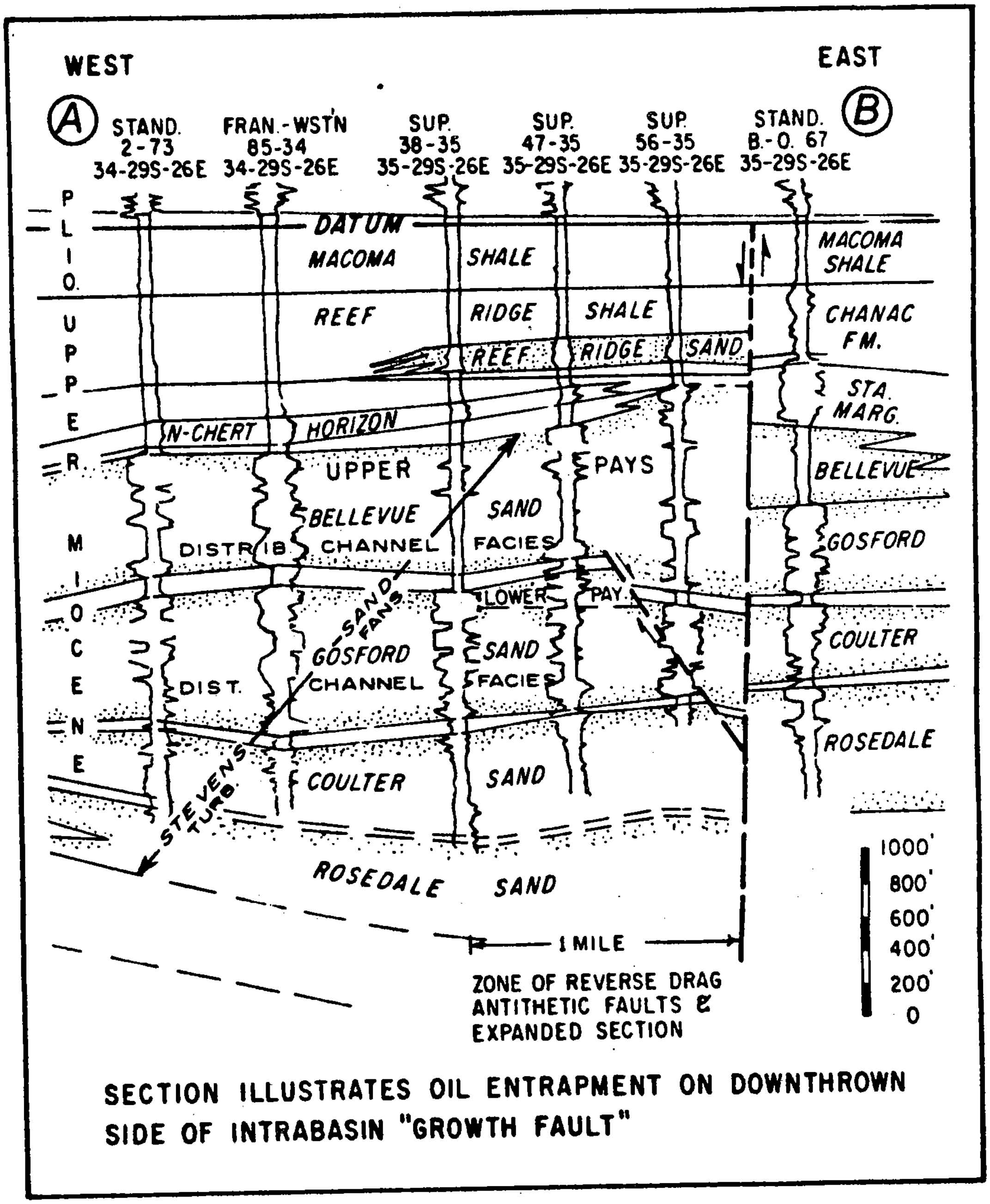
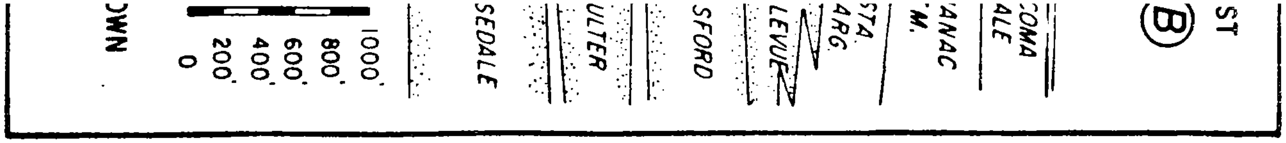


FIG. 10—Stratigraphic section across Bellevue field. See Figure 9 for location.



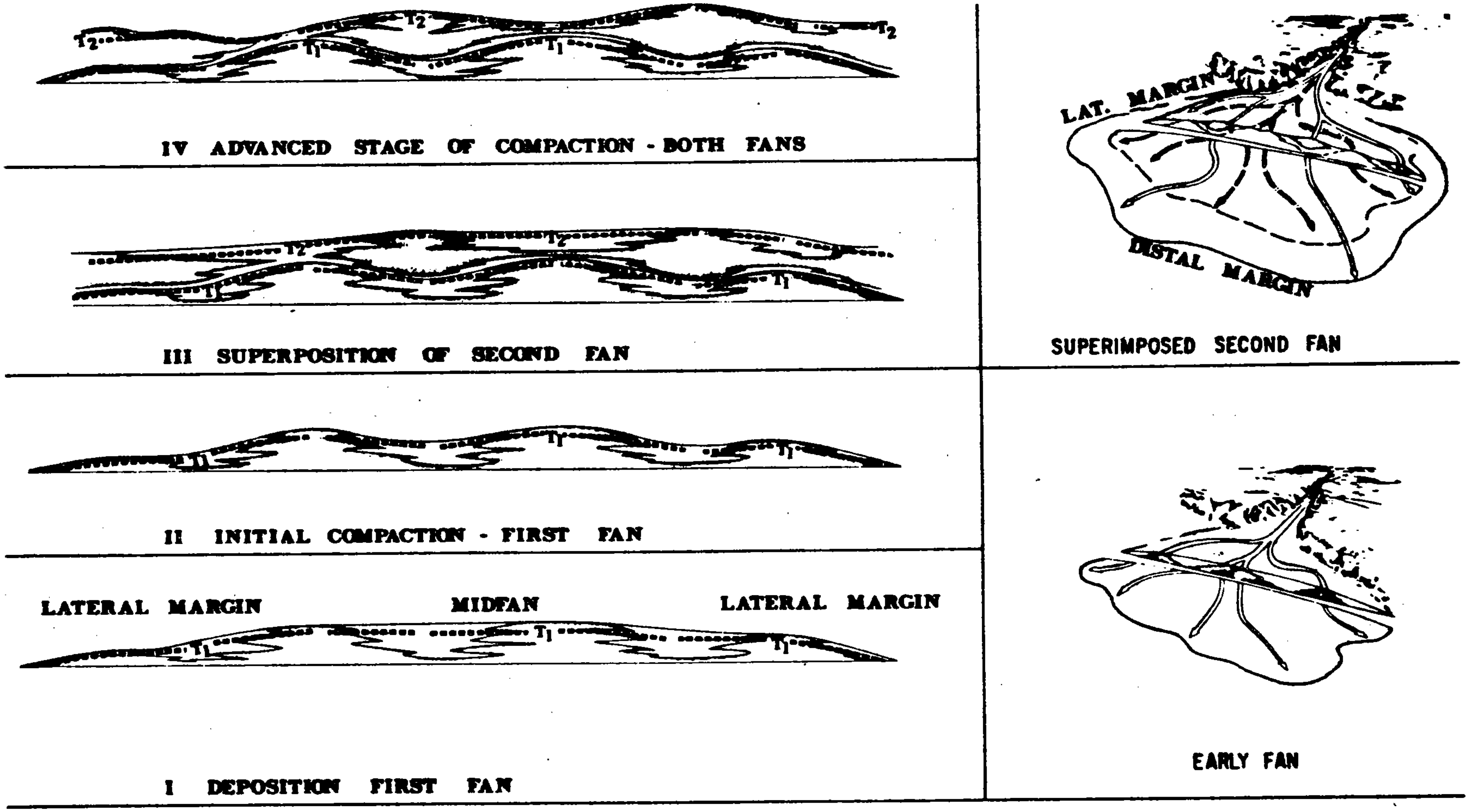


FIG. 11—Hypothetical reconstruction of depositional model for two Stevens turbidites illustrating sedimentary accommodation and alternate stacking with vertical offset of distributary channels on Bakersfield arch, Kern County, California. T_1, T_2 are time lines represented by thin shale zones.

With our best regards
Orr

The American Association of Petroleum Geologists Bulletin
V. 64, No. 6 (June 1980), P. 841-856, 10 Figs., 3 Tables

Comparison of Sand-Layer Geometry on Flat Floors of 10 Modern Depositional Basins[1]

ORRIN H. PILKEY,[2] STANLEY D. LOCKER,[3] and WILLIAM J. CLEARY[4]

Abstract A comparative study of 10 deep turbidite basins indicates that sand-layer thickness, frequency, and continuity can be related to their basin geometries, tectonics, and source areas. This study is based on piston-core data from the flat floors of four oceanic-crust abyssal plains (Sohm, Hatteras, Blake-Bahama, and Silver), two Bahama-Plateau reentrant basins (Columbus basin and Tongue of the Ocean), three subduction zone–island arc basins (Hispaniola-Caicos, Navidad, and St. Croix basins), and one continental-borderland basin (Santa Monica basin).

With increasing tectonic activity, sand layers on flat basin floors tend to be thinner and more frequent. Except in elongated narrow basins such as Navidad, source-area size is directly related to proximal sand-layer thickness. Continuity of individual sand layers is a function of drainage-basin size and depositional-basin shape. For example, on the Hatteras Abyssal Plain long-distance continuity (up to 500 km) of individual sand layers is achieved because most of the turbidites are large and are introduced only at the north "upstream" end. In the small horseshoe-shaped Columbus basin, sand-layer continuity is limited because flows are small and are introduced from three sides. In most basins, sands thin and the percentage of sand layers in the sediment column decreases away from source areas. However, in basins that are small relative to the typical turbidity-current size (e.g., Hispaniola-Caicos basin), the differences between basin-edge and basin-center sand layers are slight.

INTRODUCTION

Through early studies of deep ocean-basin sediments, marine sedimentologists gained insight into the frequency and thickness of sand layers to be expected in various environments (e.g., Ericson et al, 1961). However, available cores were far too widely spaced to indicate layer shape and continuity. More precise information was available from the study of ancient sediments.

In the last decade, closely spaced piston coring began in various deep-water sedimentary environments. Models of submarine fans and various associated sand bodies are particularly well understood both from the study of recent sediments (e.g., Normark, 1970; Nelson and Kulm, 1973; Nelson and Nilsen, 1974; Ricci-Lucchi, 1975; Wilde et al, 1978) and ancient counterparts (e.g., Mutti et al, 1978; Walker, 1978). At the same time, the development of sand-layer correlation techniques in modern basins (e.g., Conolly and Ewing, 1967; Bornhold and Pilkey, 1971; Sieglie et al, 1976) have provided a basis for estimating the continuity of individual sand bodies. Studies of flat floors are less numerous than studies of fan-rise systems. Studies of modern basin floors include those of Gorsline and Emery (1959), van Andel and Komar (1969), Horn et al (1971), Bennetts and Pilkey (1976), and Piper (1978).

The present study is concerned with the geometry of turbiditic sand layers underlying 10 deep, flat, basin floors, nine in the western North Atlantic Ocean basin and one California borderland basin. The purpose of the study is to relate basin geometry and basin source-area characteristics to the characteristics of sand layers produced under conditions prevailing during late Pleistocene-early Holocene time. By restricting the study to flat basin floors, the greatly complicating factor of topographic control of sedimentation is removed and basin-wide continuity of individual sand layers can be estimated.

STUDY AREAS

Figure 1 shows the locations of the various basins under investigation, and Table 1 summarizes basin characteristics. Outline maps of individual basins with piston-core locations are shown in Figure 2. Only the flat floors of these basins were studied. Sand layers from outer-fan depositional lobes and continental rises where topographic control of deposition may be significant were not

---

[1] Manuscript received, March 22, 1979; accepted, November 6, 1979.

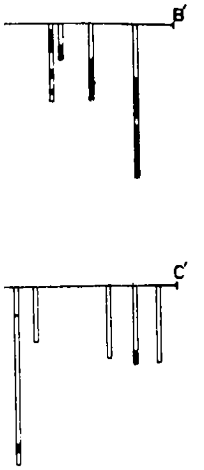
[2] Department of Geology and Marine Laboratory, Duke University, Durham, North Carolina 27708.

[3] U.S. Geological Survey, Woods Hole, Massachusetts 02543.

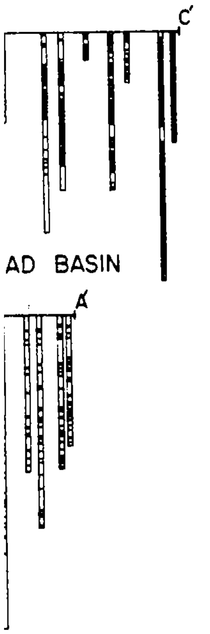
[4] Program in Marine Science, University of North Carolina at Wilmington, Wilmington, North Carolina 28401.

Wolfgang Schlager originally suggested this study to the senior author. We thank the National Science Foundation for support of various basin investigations that constitute this summary investigation and for support of Research Vessel *Eastward* from which most of the data were collected. Most of the data analysis was carried out while the senior author was on leave from Duke University with the U.S. Geological Survey, Marine Geology Branch, Woods Hole, Massachusetts. We thank the survey for its support of this endeavor. Douglas Glaeser and Jay Van Tassell read the manuscript and made substantive helpful suggestions.

Article Identification Number
0149-1423/80/B006-0002$03.00/0



basis of diagrammatic
sequences are mud.



on cores (Fig. 2). Dark

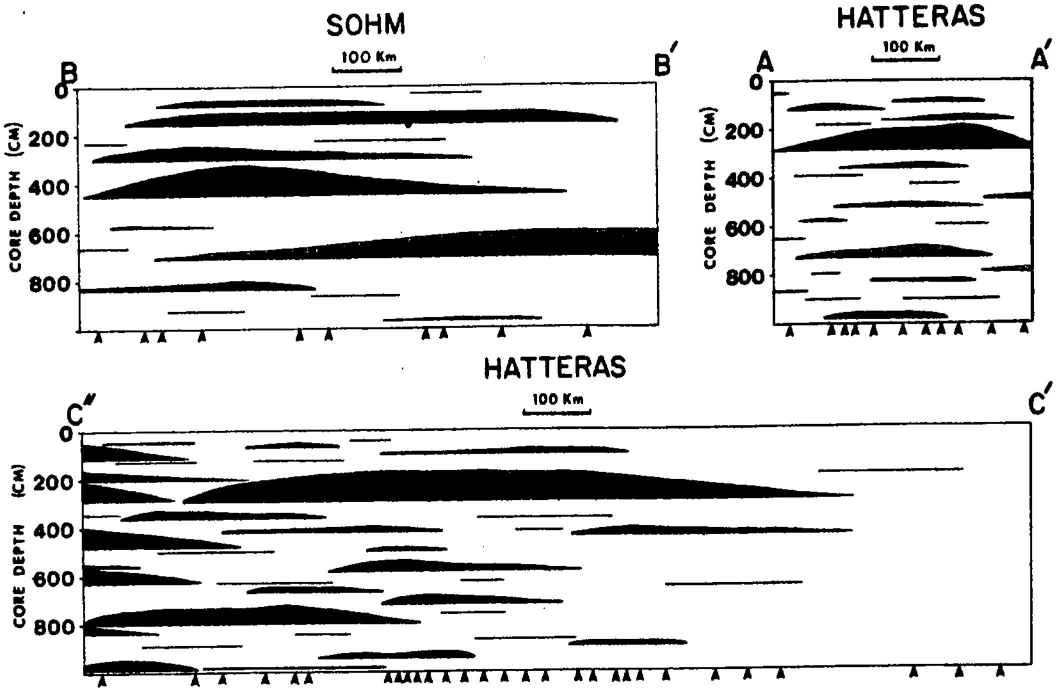


FIG. 5–Diagrammatic illustrations of sand-layer geometry of Sohm and Hatteras Abyssal Plains. Sand layers are represented by dark bands. Although sand layers are turbiditic, they should not be confused with complete turbidites, as turbiditic lutites are not included. Lines of section and sample locations are shown on Figure 2, raw sand-layer data in Figure 3. Arrows designate core locations.

summarized in Table 2. Techniques of sand layer correlation were reviewed by Bennetts and Pilkey (1976). A visual estimate of sand-layer continuity in the various basins can be gained from Figures 5 through 9. The maximum observed linear extent of any single sand layer in the basins is 500 km. This is the Black Shell turbidite of the Hatteras Abyssal Plain (Elmore et al, unpub. rept.).

On the Hispaniola-Caicos Abyssal Plain and in Navidad basin, sand-layer continuity is relatively small in terms of absolute distances, but in both basins some flows cover the entire available flat floor. Perhaps 50% of the sand layers in the 35-km long Navidad basin cover the entire flat floor (Sieglie et al, 1976). About 20% of the sand layers of Hispaniola-Caicos basin floor cover the entire area (Bennetts and Pilkey, 1976; Ditty et al, 1977). In contrast, the massive sand body 500 km long with a minimum volume of 100 cu km from the Hatteras Abyssal Plain covers only 60% of the floor of the depositional basin (Elmore et al, unpub. rept.).

Columbus basin sand layers have low continuity in terms of absolute length and size relative to basin size (Fig. 8). Because of the small drainage area, Columbus basin flows are small relative to basin size; none reach the basin center. Continui-

Table 2. Estimated Maximum Sand-Layer Continuity from Six Basins*

Basin	Maximum Single Sand-Body Length (km)	Basin Floor Covered by Largest Single Sand-Body (%)
Hatteras	500	60
Silver	150	<50
Blake-Bahama	200(?)	100(?)
Columbus	25	15
Hispaniola-Caicos	110	100
Navidad	35	100

*Left-hand column affords measure of continuity along line of section. Right-hand column illustrates continuity relative to basin size. Blake-Bahama basin estimates are based on shipboard correlations unverified by laboratory studies.

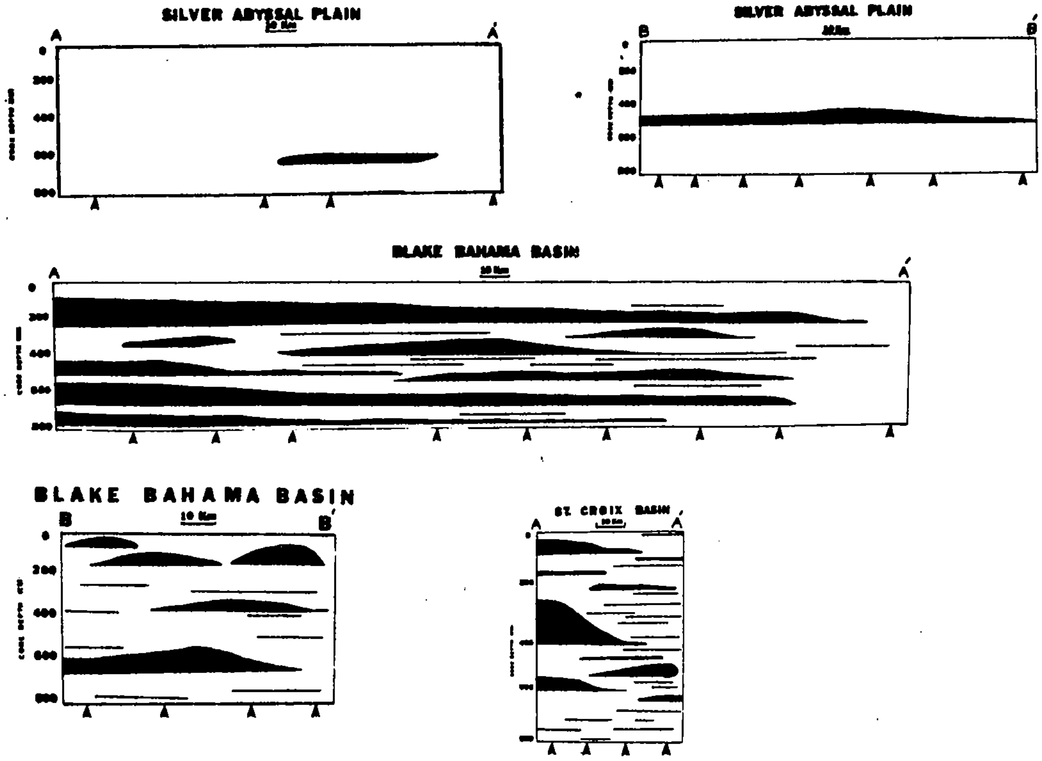


FIG. 6 – Diagrammatic illustrations of sand-layer geometry on Silver Abyssal Plain, Blake Bahama Abyssal Plain, and floor of St. Croix basin. Lines of section are shown in Figure 2. Arrows designate core locations.

ty of sand layers in Columbus basin is further reduced by turbidity currents entering the basin from three sides, causing a wide variety of orientations of the resulting tongue-shaped sand bodies. Thus along any line of section, the likelihood of tracing the complete linear extent of a sand body is low relative to what it would be if all Columbus basin flows came into the basin from a point source.

In summary, continuity of turbiditic sand layers on flat basin floors is related to the net effect of a combination of variables. Perhaps most important is the size of the source drainage area, hence maximum potential size of turbidites relative to basin-floor size. A more active tectonic setting might be expected to reduce sand-layer continuity by preventing sediment buildup. Location of basin entry points is an important factor, that is, point sources (Hatteras Abyssal Plain) versus multiple sources (Columbus basin). Other factors involved must include the amount of mud in turbidity currents, source-area climate, and relief.

SAND-LAYER THICKNESS

Table 3 clearly shows that the biggest basins have the thickest sand layers. There appears to be some correlation between thickness and basin drainage-area size (Tables 1, 3).

Range of sand-layer thickness reveals another big difference between the large abyssal plains and the other basin floors. There is a general correlation between sand-layer thickness range and drainage-basin size. In the Hatteras and Sohm Abyssal Plains (Fig. 5) there are essentially no very thin (<5 cm) sand layers. In most of the remaining basins the minimum layer thicknesses are 1 to 3 cm. Whether such thin layers in the Hatteras and Sohm Abyssal Plains are never deposited or are deposited and then eroded by the next large flow is not known. At the south end of the Hatteras Abyssal Plain numerous thin silt layers have been observed.

In most of the basins sand-layer thickness dramatically decreases away from sources of turbidi-

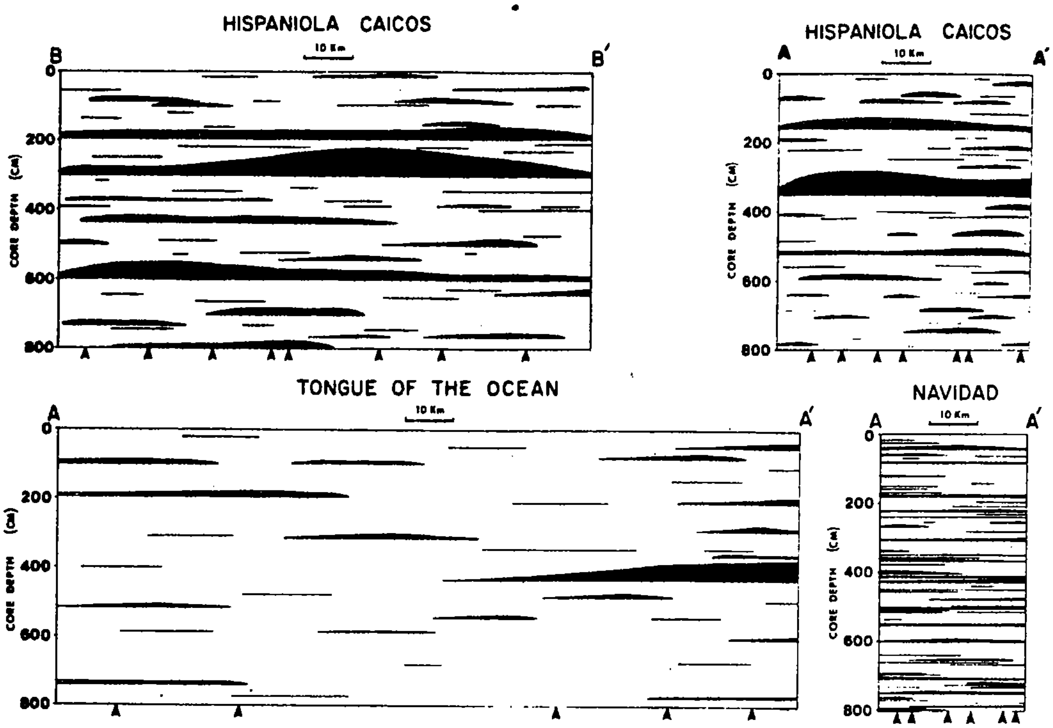


FIG. 7–Diagrammatic illustrations of sand-layer geometry on Hispaniola-Caicos Abyssal Plain and in Navidad and Tongue of the Ocean basin floors. Lines of section are shown in Figure 2. Raw sand-layer data for some sections are shown in Figure 4. Arrows designate core locations.

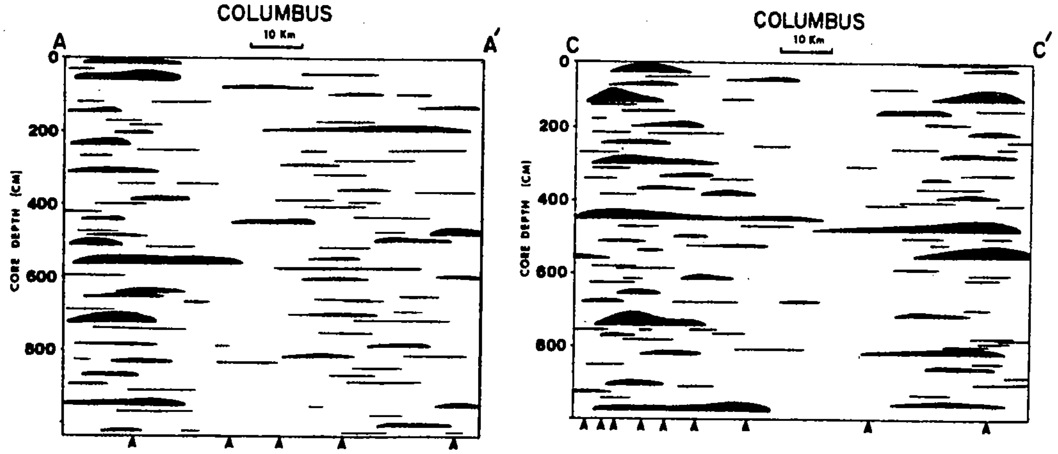
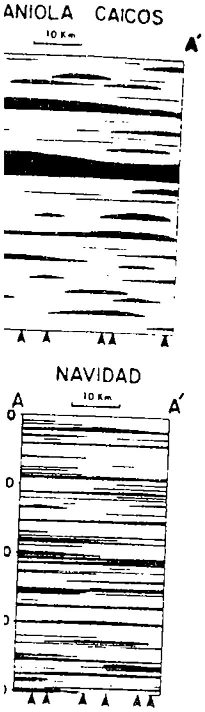
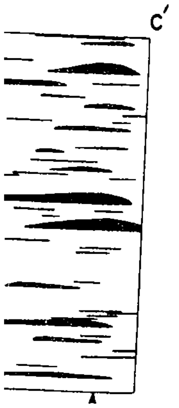


FIG. 8—Diagrammatic sand-layer geometry on Columbus basin floor. Lines of section are shown in Figure 2. Arrows designate core locations.



in and in Navidad
data for some sec-



wn in Figure 2.

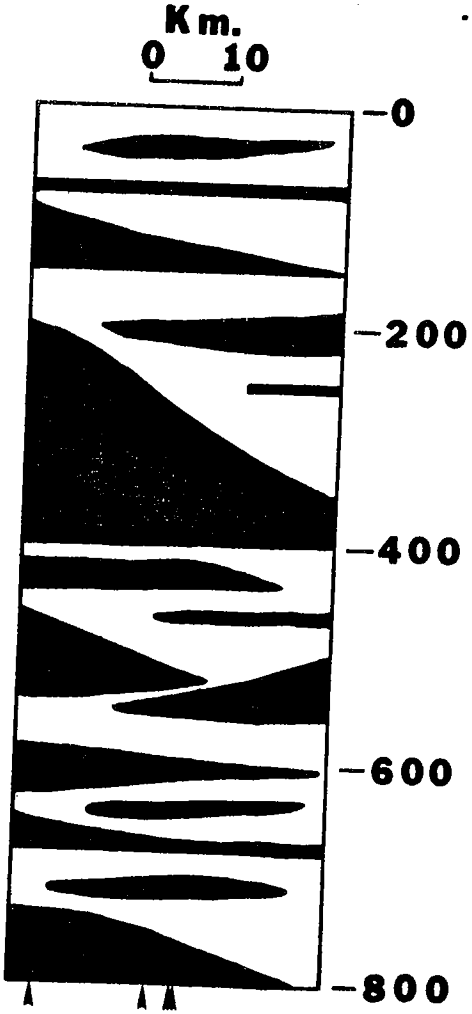


FIG. 9—Diagrammatic sand-layer geometry on Santa Monica basin floor. Line of section is shown in Figure 4. Arrows designate core locations. Vertical scale is in centimeters.

quency parts of the diagram (Fig. 10) relative to the more active subduction zone, continental-borderland basin floors. With similar consistency the quiescent basin floors plot highest along the vertical sand-layer thickness scale. Thus, in general, with increasing tectonic activity, sand-layer thickness decreases and sand-layer frequency increases.

SAND-LAYER CHARACTER IN INDIVIDUAL BASINS

Sohm and Hatteras Abyssal Plains

These abyssal plains are very large (Figs. 1, 2) and are among the major depositional basins in the present oceans. Both abyssal plains have large drainage areas capable of producing sediment accumulations sufficient for very large turbidity currents. Considerably more data are available from the Hatteras Abyssal Plain than from the Sohm. Sand-layer data in both of these basins (Fig. 5) are particularly affected by the problem of sand penetration by piston cores; mean proximal thicknesses are probably greater than those given in Table 3.

The average thickness of sand layers along the basin margin is greater in the Sohm Abyssal Plain than in any of the other basins studied. Correlation of sand layers was not attempted by Horn et al (1971). The fact that a sand layer 290 cm thick is present in the southernmost core of transect BB′ (Figs. 2, 5) is certain indication of long-distance continuity of a single sand layer. This southernmost core is 1,000 km from the nearest basin-entry point for turbidity currents which further suggests that the flow represented by the 290-cm thick sand layer is of tremendous volume.

The Sohm Abyssal Plain has formed by lateral infilling from two sides. The Hatteras Abyssal Plain in contrast has resulted from longitudinal infilling from the north (Cleary et al, 1977). Sand-layer continuity is high but the largest observed single sand layer covers only 60% of the flat basin floor. Sand-layer frequency varies greatly from north to south on the Hatteras Abyssal Plain (Fig. 5). Cores from the extremities of the plain near the Hudson Canyon mouth at the Sohm Gap have a lithologic sequence of nearly 100% sand layers. In contrast, no sand layers are present on the southern one-fourth of the plain.

For reasons that are not clear, thin sand layers, less than 5 cm thick, are uncommon on both major abyssal-plain floors.

Silver Abyssal Plain

This abyssal plain has a very large drainage area relative to basin-floor area because large flows from the Hatteras Abyssal Plain may spill over into the Silver Abyssal Plain (Fig. 1). Such flows, however, have long since lost their sand content, so the only sources of sand are the small carbonate banks such as Silver Bank on the west. Thus, sand-layer frequency is low because the major source of sediment is supplying only mud. The single sand body observed in piston cores (Fig. 6) in this basin is a large one by carbonate-bank source standards; hence continuity is high.

Blake-Bahama Abyssal Plain

The drainage basin of this abyssal plain (Fig. 1) cannot be accurately calculated because of our

SUBMARINE FAN DEPOSITION OF THE WOODBINE-EAGLE FORD INTERVAL (UPPER CRETACEOUS), TYLER COUNTY, TEXAS

Charles T. Siemers[1]

ABSTRACT

Production of gas and some condensate from fine-grained fractured sandstone of the Upper Cretaceous Woodbine-Eagle Ford interval at depths of 10,800 to 11,350 ft in central northern Tyler County, Texas, has provided the impetus for a detailed paleoenvironmental analysis of the geology in that area. The productive area (Sugar Creek Field) is located a short distance south of the Sabine Uplift, which was an active positive area previous to, during, and following Woodbine-Eagle Ford deposition, and is slightly down-dip from the Lower Cretaecous continental shelf edge as delineated by the Angelina-Caldwell flexure and the Edwards reef trend. The Woodbine-Eagle Ford interval (between the Buda Limestone below and Austin Chalk above) is 150-200 ft thick in the Sugar Creek Field area, but thins to less than 50 ft thick above the Edwards reef buildup, and northward toward the Sabine Uplift where it is missing. Southward (down-dip), the interval thickens to greater than 1500 ft within a distance of 15 miles.

The Woodbine-Eagle Ford interval in this down-dip position is a mud-dominated clastic wedge. Cores from seven wells in the Sugar Creek Field area and two down-dip wells were examined in detail. Dark gray, organic-rich, silty shale with thinly laminated to ripple-bedded siltstone beds and small siderite nodules comprise most (40% to greater than 80%) of the Woodbine-Eagle Ford interval and contain a microfauna (foraminifera) indicative of outer shelf to upper slope water depth. The reservoir sandstones occur as complex, single to multi-story bodies 15-40 ft thick and are composed of fine- to very fine-grained quartz arenites. As viewed in polished core slabs, the sandstones are mostly "massive-appearing" (without discernible sedimentary structures). Beds are characterized by very sharp (non-gradational) basal contacts (sandstone/shale) with abundant drag marks, flute casts and other sole markings, and by abrupt upper contacts with shale.

X-ray radiography of core slabs has revealed a multitude of sedimentary structures in the otherwise "massive-appearing" sandstones. Massive to laminated and cross-stratified sandstone is dominant, but ripple-stratification, soft-sediment-deformation, and scour features are also present. Burrows and bioturbation are common, but confined only to the upper parts of sandstone beds, which may be separated by thin (1-2 inch) shale beds. These sedimentary features and their positions within well-defined sandstone genetic units indicate rapid deposition of sand by low- to high-concentration submarine density (turbidity) currents and associated tractive currents. Mud deposition and burrowing of the upper parts of sand beds occurred during quiet periods between the sand pulses. Highly deformed siltstone intervals often are present below the sandstone bodies and indicate rapid loading by sand deposition and/or slumping on unstable slopes. A conglomeratic submarine debris-flow deposit is also well-displayed in one core.

Subsurface correlation and mapping of the discontinuous, lenticular, sandstone bodies indicate that they are best delineated as a series of coalescing, dip-oriented lobes. Deposition appears most likely to have been as prograding submarine fan lobes, with sediment being channeled from up-dip delta and near-shore deposits across a narrow shelf and through shelf-edge breaks and then dumped down slope. These basin-filling deposits prograded seaward until the sediment source was cut off and subsequent deposition of the Austin Chalk occurred. Although a major erosional unconformity exists above the Woodbine to the north, no such unconformity can be documented above the down-dip Woodbine-Eagle Ford interval in Tyler County.

INTRODUCTION

The most prolific oil and gas stratigraphic interval in Northeast Texas has been the Upper Cretaceous Woodbine Group. Since the first Woodbine oil discovery at a depth of approximately 3100 ft at Mexia in October 1920, subsequent discovery at Boggy Creek in March 1927, and discovery of the giant East Texas Field in 1931, (Alexander, 1951), the Woodbine has been one of the most sought-after hydrocarbon-productive intervals in East Texas. Discovery and development of Woodbine production in the East Texas embayment area has been mostly at depths of 3,000-6,000 ft north of the Angelina-Caldwell monoclinal flexure (and Edwards "reef trend" which parallels approximately the Angelina-Caldwell flexure, Fig. 1). Discovery and development of Woodbine gas over the past few years in Polk and Tyler counties, south of the Angelina-Caldwell flexure, has been at depths of 10,000 to greater than 15,000 ft. These two areas can be referred to informally as the "up-dip" and "down-dip" areas of the Woodbine interval in East Texas. Since the Angelina-Caldwell flexure and Edwards reef trend are regarded as marking the seaward edge of the Late Cretaceous continental shelf and the beginning of the continental slope (Stehli *et al.*, 1972), the "up-dip" Woodbine represents deposition north of the shelf break and "down-dip" Woodbine represents deposition south of the shelf break.

The depositional systems of the up-dip Woodbine have been rather well documented over the past 20-30 years. Oliver (1971) combined consideration of previous Woodbine study with his examination of Woodbine outcrops in northeastern Texas and southeastern Oklahoma with study of subsurface wire-line logs, cuttings and cores in northeast Texas to present an up-to-date synthesis of the depositional systems of the up-dip Woodbine. He represents that system as one that changes progressively from a southwestward flowing, fluvial coastal plain deposition in the northeastern most part of Texas, to delta plain and to near-shore marine and shallow marine prodelta shelf deposition in a southward and southwestward direction (Oliver, 1971, fig. 3 and 11). The down-dip Woodbine is a different story. Deep (greater than 10,000 ft) drilling south of the Angelina-Caldwell flexure (and the Edwards reef trend) has encountered a Woodbine lithologic sequence and depositional system which is considerably different from that of the up-dip Woodbine. The character and

---

[1] Exploration and Production Research, Cities Service Company, Tulsa, Oklahoma

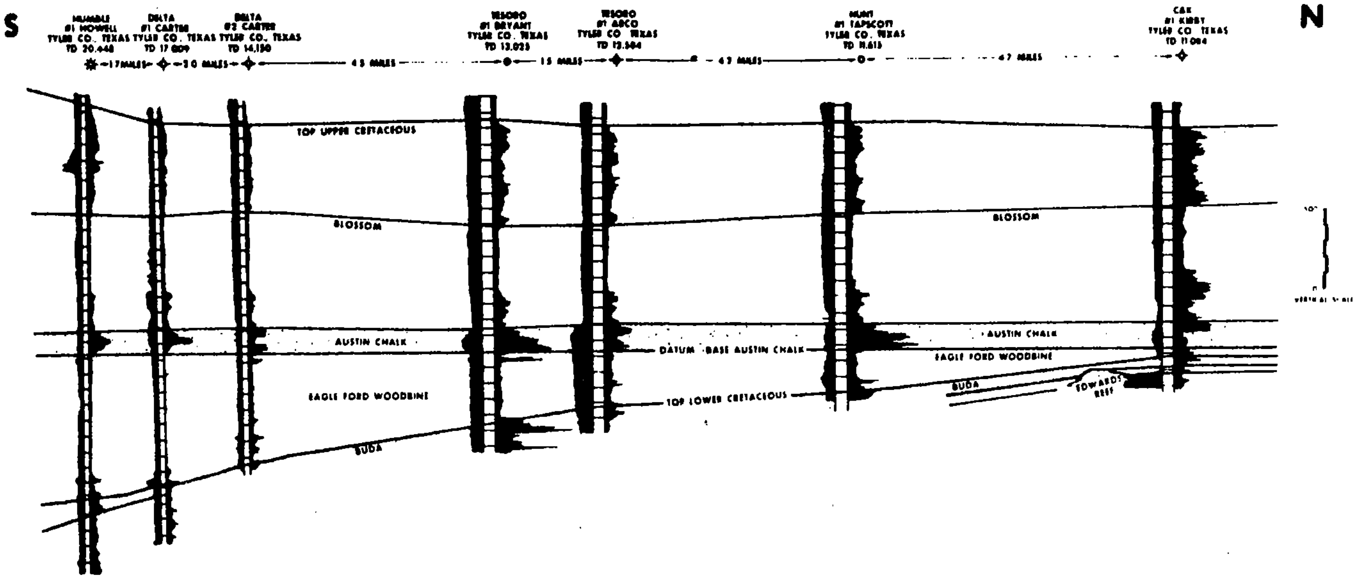


FIGURE 8 — North-south dip-section of Upper Cretaceous in Tyler County. Note the dramatic down-dip thickening of the mud-dominated Woodbine-Eagle Ford clastic wedge south of the Edwards reef trend. Position of cross-section is shown in Figure 5. Modified from working log section prepared by Kathy Barrie.

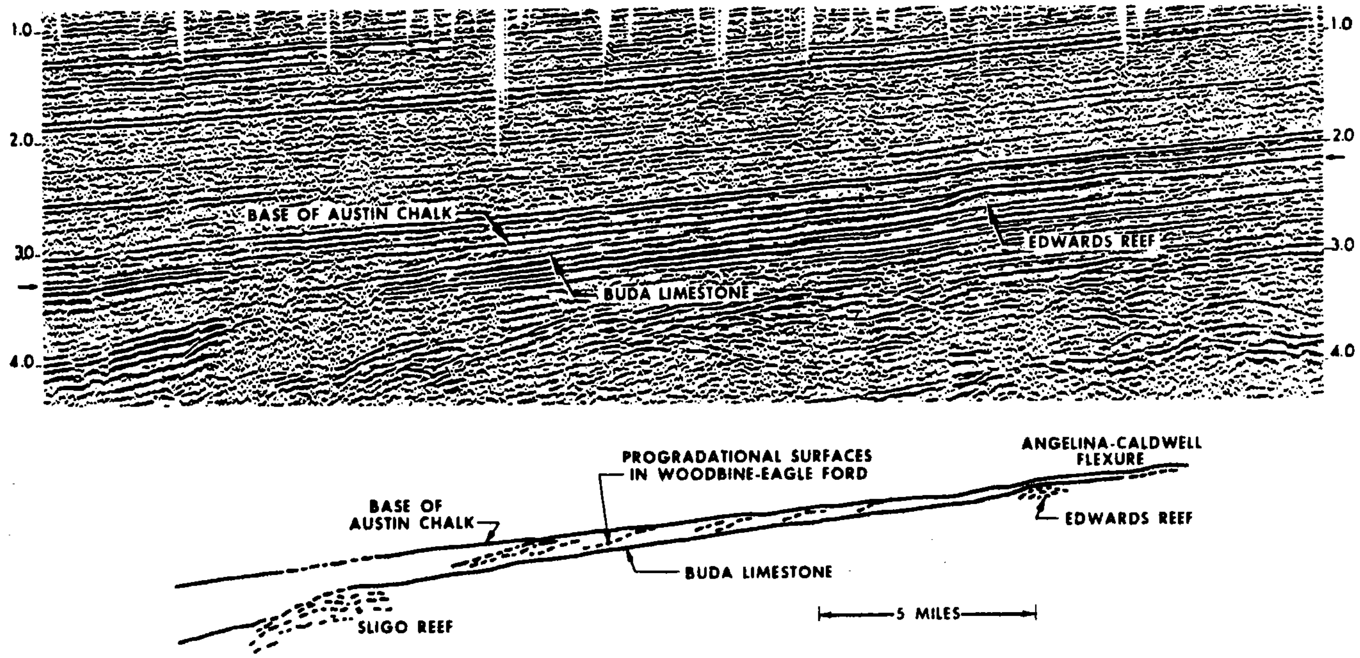


FIGURE 9 — Seismic section and sketch showing Woodbine-Eagle Ford down-dip clastic wedge in East Texas area. The positions of the Austin Chalk and Buda Limestone reflectors and the Edwards and Sligo reef build-ups are indicated. Also note the inclined reflectors within the mud-dominated Woodbine-Eagle Ford clastic wedge, indicating progradational surfaces. Modified from Sheriff (1976, fig. 10).

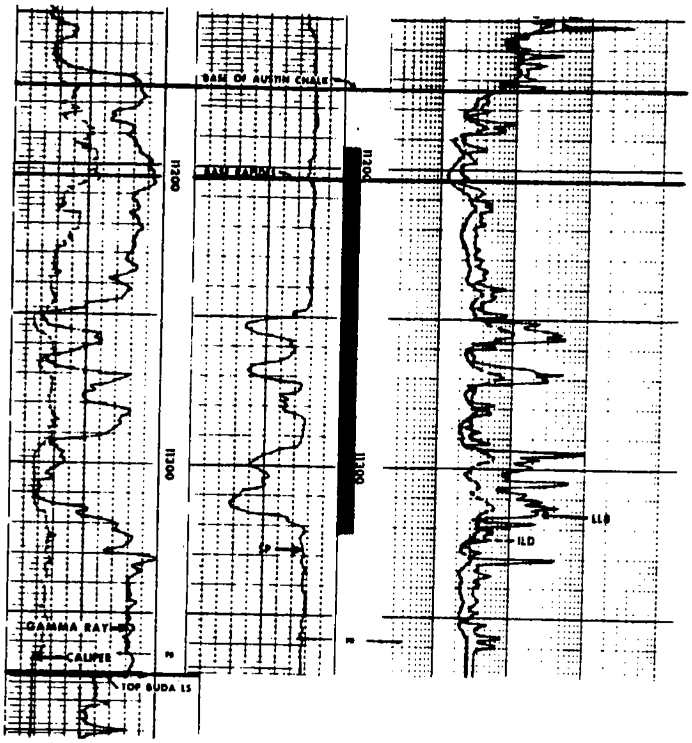


FIGURE 13 — Wire-line logs of the Woodbine-Eagle Ford interval, Cities Service, Sutton B-1 well, Tyler County. The cored interval is indicated by the black bar.

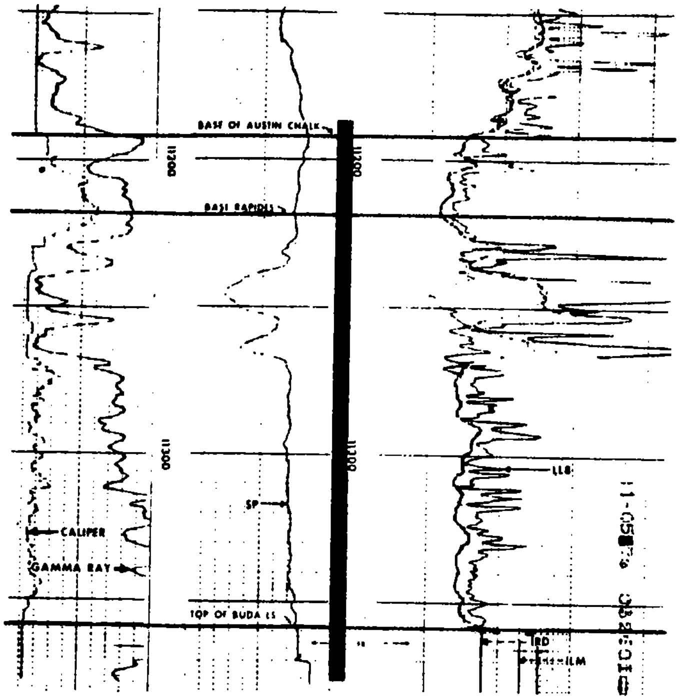


FIGURE 14 — Wire-line logs of the Woodbine-Eagle Ford interval, Cities Service, McHard A-1 well, Tyler County. The cored interval is indicated by the black bar.

cumulate and echinoids and soft-bodied organisms could thoroughly bioturbate the bottom. Such deposition eventually was interrupted by the increased influx of terrigenous mud now represented by the lower part of the Woodbine.

The character of the Buda/Woodbine contact already has been alluded to above. The contact is relatively sharp on wire-line logs (especially resistivity logs), but cores reveal a moderately distinct but transitional contact over a distance of about 2 feet to more than 5 feet. When the core and logs are compared, the Buda/Woodbine contact (as defined by the log) can be narrowed down to within a few inches in the core. Below that point, the lithology is medium-gray, dense, bioturbated limestone. For a few feet above the contact point, the lithology is a moderately fissile, dark-gray, calcareous shale with vaguely interbedded clayey limestone. The transitional nature of the contact is documented by the gradual increase of quartz silt toward the top of the Buda and the persistence of calcispheres well up into the lower shale of the Woodbine-Eagle Ford. Abundant calcispheres were observed at least 2 feet above the "contact" in the Cities Service, McHard A-1 well (Fig. 16D) and over 5 feet above the "contact" in the Cities Service, Long Bell No. 1 well. The significance of this contact will be re-emphasized later in the discussion of this report.

Woodbine-Eagle Ford Shale and Deformed Siltstone

As indicated above, and illustrated in Figures 11 and 12, the Woodbine-Eagle Ford interval consists of three main lithofacies: 1) silty shale of highly variable character, 2) highly contorted sandy and shaly siltstone, and 3) massive-appearing sandstone. The shales and deformed siltstone intervals are described and discussed in this section. A significant feature of the Woodbine-Eagle Ford lithofacies is that they appear not to have any major ordered occurrence. That is, sandstone does not occur only in the lower part of the interval, and shale and siltstone only in the upper part, or any other part, of the interval. Subtle lithologic relationships were observed however, in some of the cores examined, but it is difficult to determine if such relationships are normal. For example, shales in the Woodbine-Eagle Ford interval contain relatively few thin siltstone beds in the lower part and commonly are quite shelly in the upper part, and deformed siltstone intervals appear to most commonly underly thick sandstone units.

The shale of the Woodbine-Eagle Ford interval is generally medium to dark gray (N4-N3), silty non-calcareous and irregularly fissile (Fig. 15; interval B), but displays many variations. Detrital clay mineral composition is a mixture of illite and montmorillonite, with minor amounts of kaolinite and chlorite. Burrows are not evident mega-

FIGURE 12 — (Preceding page) Sketch of lithologic sequence of Woodbine-Eagle Ford interval (including lower part of Austin Chalk and upper part of Buda Limestone) observed in cores and dip-meter plot (5 inch to 10 ft scale Geo-Dip) from the Cities Service, McHard A-1 well, Tyler County. Sedimentary structures in sandstone units were observed with the aid of X-ray radiography. See Figure 11 for explanation of symbols.

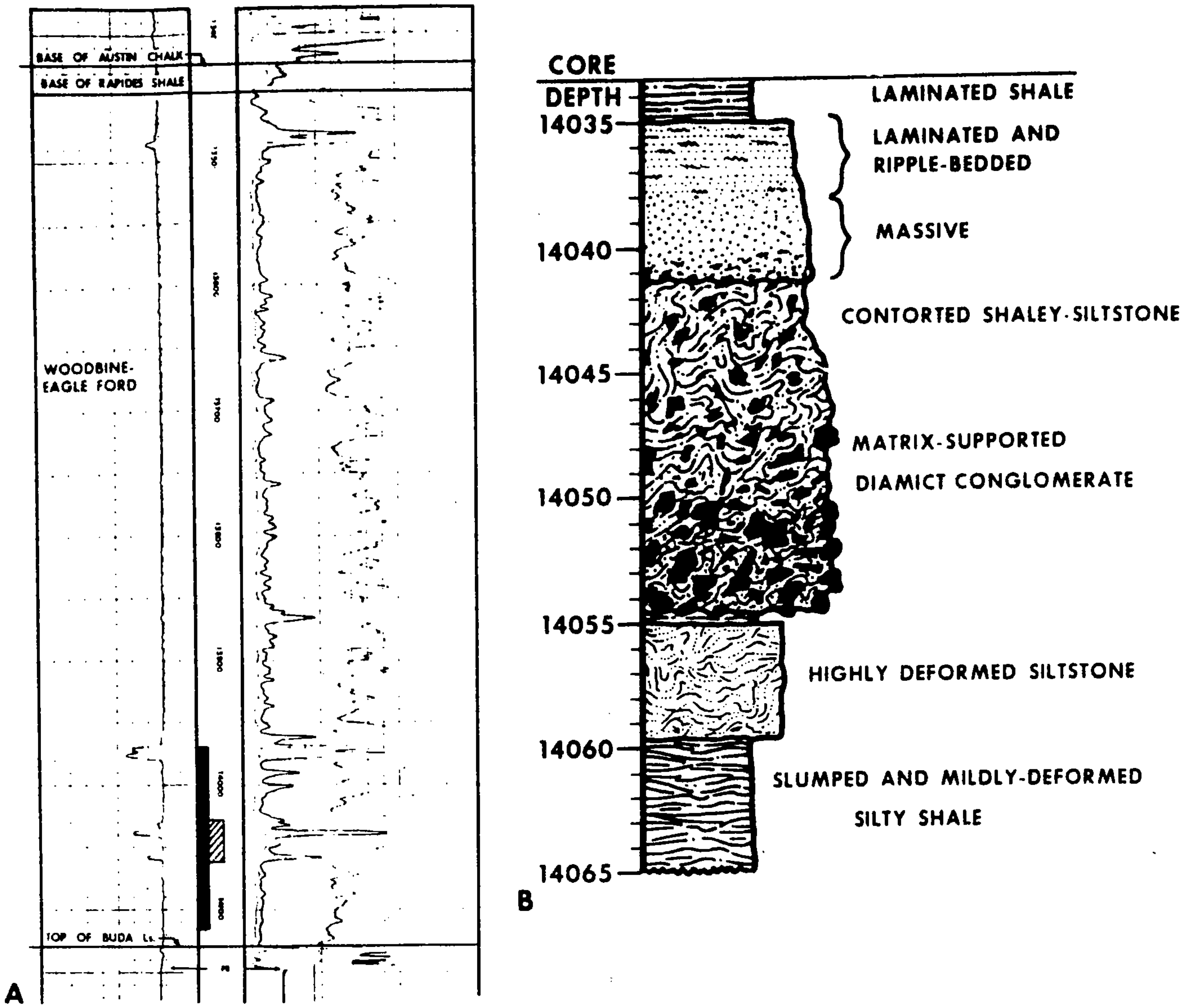


FIGURE 32 — Wire-line SP-Induction log of Delta, Carter No. 2 well and sketch of core interval containing diamict conglomerate and graded sandstone units. The entire core interval examined is indicated by the solid black bar on the log; the core interval illustrated in Figure 31 and by the sketch is indicated by the cross-ruled bar.

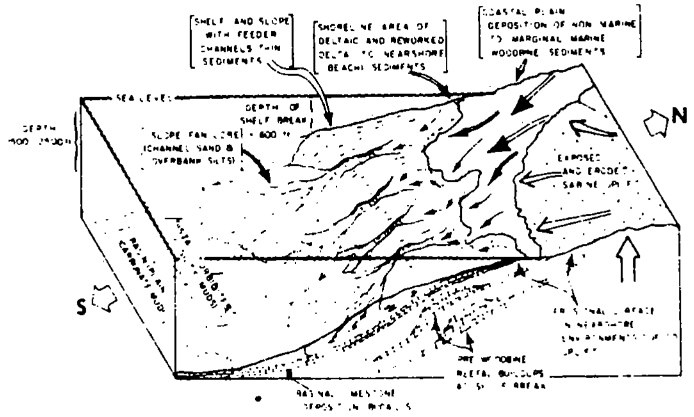


FIGURE 33 — Conceptual model for submarine-fan deposition of Woodbine-Eagle Ford, central-northern Tyler County, Texas.

OTC 3116

TURBIDITE FACIES AND DEEP-SEA FANS — WITH EXAMPLES FROM KODIAK ISLAND, ALASKA

by Arnold H. Bouma and Tor H. Nilsen, U.S. Geological Survey

This paper was presented at the 10th Annual OTC in Houston, Tex., May 8-11, 1978. The material is subject to correction by the author. Permission to copy is restricted to an abstract of not more than 300 words.

ABSTRACT

Deposition by turbidity currents and other types of sediment gravity flows in a continuum of subenvironments results in a variety of horizontal and vertical layer characteristics and turbidite facies associations. Lateral changes are typical of such deposits, commonly making correlation of outcrops or of drill sites impossible. Because a number of turbidite formations are known to be excellent hydrocarbon reservoirs, it is necessary to understand the complexity of such deposits in order to develop new areas, especially in outer shelf and upper slope regions.

Turbidite facies associations, layer characteristics, paleocurrent directions, and stratigraphic relationships can be determined in the field. With the help of models such as those of Bouma and of Mutti and Ricci Lucchi, facies associations can be reconstructed to their former environmental settings--submarine canyon, upper, middle and lower fan, basin plain. In some cases even the subenvironments, such as channels, levees, and interchannel areas can be recognized. Studies on modern fans are generally restricted to the collection of morphologic and sediment data, with little detailed stratigraphic information. The different approaches in fossil and recent turbidite research have resulted in certain discrepancies and differences in terminology. A summary and integration of knowledge on ancient and recent turbidites is presented through a review of the most pertinent literature; examples from fieldwork conducted on Kodiak Island, Alaska, are used to illustrate the main conclusions.

INTRODUCTION

Part of the world's onshore and offshore hydrocarbon production comes from turbidite sequences that have accumulated by different sediment transport processes in a variety of different subenvironments, yielding a corresponding variety of horizontal and vertical changes in layering and lithology. This, in turn, often makes facies interpretation difficult and correlation between outcrops or drill sites impossible. The widespread occurrence of turbidite deposits, however, together with their economic importance and scientific challenge, have inspired many interpretative and genetic studies.

Since the introduction of the concept of trubidity current deposits in the English literature by Kuenen and Migliorini (1950), it has gradually become apparent that the turbidites form part of a continum of deposits that have accumulated in many environments and by many processes. It has also become clear that we still lack an adequate understanding of turbidites. Major gaps exist between field observations made on outcrops and oceanographic observations from cores and seismic studies. Outcrop studies can provide stratigraphic information and descriptions of layering, sedimentary structures, lithologic sequences, and paleocurrent directions. These studies have resulted in the development of important concepts of turbidites such as the Bouma (1962) sequence and the facies and facies associations of Mutti and Ricci Lucchi (1972, 1975).

Marine studes have provided much data regarding the morphology and interrelations between deep-sea environmental settings and much detail regarding the sedimentological characteristics of the uppermost deposits, which are easily sampled. Experimental and theoretical approaches to turbidity current processes have contributed significantly to understanding the natural processes. Unfortunately, the different approaches to studying ancient and recent turbidites have resulted in certain discrepancies and differences in terminology. The purpose of this paper is to review and integrate the more important aspects of ancient and recent turbidite sequences, realizing that space is not sufficient for complete discussion and review of literature. In the final section we briefly describe the Upper Cretaceous and lower Tertiary turbidites on Kodiak Island, Alaska, to illustrate the various types of Bouma sequences and Mutti and Ricci Lucchi facies associations commonly present in turbidite deposits.

References and illustrations at end of paper

OTC 3117

ANATOMY OF AN EOCENE SUBMARINE CANYON-FAN SYSTEM, SOUTHERN CALIFORNIA BORDERLAND

by John M. Lohmar, Exxon Company, U.S.A., and
John E. Warme, Rice University

This paper was presented at the 10th Annual OTC in Houston, Tex., May 8-11, 1978. The material is subject to correction by the author. Permission to copy is restricted to an abstract of not more than 300 words.

ABSTRACT

Lower (?) to middle Eocene submarine canyon and associated inner fan deposits are well exposed along seacliffs and in outcrops immediately inland in northern San Diego County, California. Seven environments are interpreted from these basin-margin deposits. These subenvironments were recognized on the basis of bed forms, sedimentary structures, textures and paleobathymetrically significant microfaunas. The seven subenvironments are: (1.) canyon head-channeled upper slope, (2.) lower slope, (3.) inner fan channel, (4.) channel margin, (5.) inner fan, (6.) inner fan fringe and (7.) passive slope.

The canyon enclosed an anastomosing system of large channels which were repeatedly cut and filled with varying sediment types during most of middle Eocene time. Paleo-depths ranged from bathyal (600 to 6000 feet) in the canyon head to inner abyssal (greater than 6000 feet) on the lower slope. The facies relationships of these deepwater channel-fill deposits to adjacent shelf platform deposits indicate that this channel system redistributed large volumes of shelf- and river-transported sediment into deep basins offshore.

The canyon-fan system was probably cut into the shelf edge, west of the present shoreline, during a low stand of sealevel in early Eocene time. A comparison of the canyon deposits with Tertiary eustatic cycles suggests that the canyon then eroded headward into drowned shelf platform deposits during a eustatic rise in sealevel in late early Eocene time, and filled with predominantly fine-grained deepwater deposits during a high stand of sealevel in middle Eocene time. Middle to outer neritic channel-fill deposits (paleo-depths 350 to 600 feet) were then deeply incised into this deepwater canyon fill during another low stand in the late middle Eocene. An understanding of the depositional patterns produced by these eustatic fluctuations in sealevel can greatly enhance the exploration of Tertiary basins in the Southern California Borderland.

References and illustrations at end of paper.

INTRODUCTION

Purpose and Scope

The Eocene rocks in the San Diego area form an eastward-thinning wedge of continental margin deposits that extends from Oceanside, California southward to the international border with Mexico. The strata include open marine, marginal marine and non-marine deposits that accumulated along the northwest-trending shoreline of the Eocene San Diego Embayment (Fig. 1) from early (?) to late Eocene time. In general, these terrigenous clastic rocks grade westward from fluvial and alluvial deposits resting directly on crystalline basement, into lagoonal, barrier bar and shallow shelf deposits, which in turn grade into outer continental shelf and slope deposits outcropping along the present shoreline. The purposes of this report are (1.) to describe the facies relationships and sedimentary environments of the outer shelf and slope (shelf margin) deposits, (2.) to interpret both the history and the pattern of shelf margin sedimentation in the San Diego area in Eocene time and (3.) in so doing, to comment on the nature and distribution of corresponding basinal deposits offshore which are likely targets for hydrocarbon exploration.

Seacliff outcrops in western San Diego County afford a unique opportunity for detailed stratigraphic analysis of shelf margin deposits. The present shoreline is oriented obliquely to the general basinward trend of the Eocene San Diego Embayment (Fig. 1). As a result, the seacliffs from Torrey Pines State Park southward to Scripps Institution of Oceanography are interpreted here as an oblique downslope section through the Eocene shelf margin (Fig. 2). The seacliffs are also oriented obliquely to the depositional strike of the embayment, thus exhibiting both lateral and vertical facies relationships. By examining these relationships, it has been possible to determine both the general pattern and the history of shelf margin sedimentation in Eocene time.

du bassin de
)asins of the Af-
ieol. Surveys, p.

e du bassin Ga-
African coasts:
p. 171-191.
y and continen-
ital drift to the
ess, v. 7, p. 451-

in the deep At-
p. 141-143.
the world's cli-

ship of igneous
)l. Mag., v. 110,

ıy: New York,

ntal margin of
)ntinental mar-
91-407.
fit of the south-
-144.
Le Bassin sec-
edimentary ba-
. African Geol.

ire-tertiaire du
African coasts:
. 80-94.
of the continen-
Palmas, *in* The
ital margin; 4,
Rept. 70/16, p.

sic deposits of
—comparison:

72, Cretaceous
ınd their bear-
ion, *in* Stratig-
t. Geol. Cong.,

The American Association of Petroleum Geologists Bulletin
V. 62, No. 2 (February 1978), P. 235-246, 9 Figs.

Stratigraphy and Structure of Chicontepec Turbidites, Southeastern Tampico-Misantla Basin, Mexico[1]

DANIEL A. BUSCH[2] and AMADO GOVELA S.[3]

Abstract The Tampico-Misantla basin was a deep-water embayment directly southwest of the Golden Lane oil pools in east-central Mexico. Most of the sedimentary rocks in the basin are Paleocene-Eocene turbidites derived from the Sierra Madre Oriental. The Paleocene was deeply eroded by submarine currents moving in a west-northwest direction. This erosion not only cut through all of the Paleocene but, also, through the entire underlying Cretaceous and Upper Jurassic section. During late Paleocene and early Eocene times, the deep-basin submarine canyon was filled with turbidites (Chicontepec). On the northeast side, along the southwest margin of the Golden Lane reef trend, the canyon had numerous submarine tributaries which brought admixtures of micritic and pelitic reef-derived clastic material that "contaminate" the turbidites of the canyon fill. Multiple individual beds and lenticular zones of sandstone beds within the canyon fill generally contain commercial hydrocarbon accumulations. The entire area of Chicontepec sandstone is considered to be prospective. Known oil accumulation is unrelated to the structural positions of the wells completed. There is a wide range of initial potential and cumulative potential in different wells. Areas of thickest net sandstone, therefore, offer the most attractive reservoir possibilities.

INTRODUCTION

The Tampico-Misantla basin was a deep-water embayment directly southwest of the Golden Lane oil pools (Fig. 1) in east-central Mexico. Hundreds of wells have been drilled in this area with Jurassic reservoirs being the prime targets. During this intensive drilling, oil and gas in commercial quantities were noted in the Chicontepec of the lower Tertiary and have been produced from a scattering of fields and isolated wells (Fig. 2). The reasons for these scattered hydrocarbon entrapments are not understood. Thus, the purposes of this investigation of the Chicontepec are to: (1) understand trapping mechanism(s) of known localizations of hydrocarbons; (2) determine the distribution and variations in thickness; (3) determine the depositional environment; (4) map the subcrop distribution of the subjacent formations; (5) map the structure; and (6) delineate prospective area(s) for hydrocarbon occurrences.

This study was conducted as a team effort involving subsurface stratigraphers, a geophysicist, and micropaleontologists. Only by integrating their respective disciplines was it possible to achieve the purposes outlined.

Perhaps the most basic part of the study involved the construction of nine stratigraphic profiles, five of which are indicated on Figure 2. The selection of a suitable stratigraphic reference datum proved quite troublesome. Widespread electric-log "markers" are nonexistent. Index fossils are not abundant and the sampled intervals are too great for precision in time-stratigraphic correlation. These problems were mitigated by combining electric-log character and micropaleontology and then selecting large enough contour intervals, for isopach and structural mapping, so errors in detailed correlation are of no consequence.

The construction of a structural map of the Chicontepec in areas of abundant well control, such as along the northeast margin of the study area, is no problem. However, in the southwestern half of the area, the well density is such that meaningful structural mapping is impossible. Normally, one would map a seismic reflection near or coincident with the top of the Chicontepec in this area, but there is no reliable seismic event in this part of the Tertiary. In fact, all seismic reflections within the Tertiary are of poor quality. To make a structure map of the southwestern half of the study area it was necessary to use a reflection at the top of the Cretaceous Mendez formation. Inasmuch as the Mendez was eroded away in the deeper parts of the Chicontepec channel system, it was necessary to extrapolate the structure of the Mendez in such areas.

A complete understanding of known Chicontepec oil and gas accumulation is a necessary prerequisite for delineating prospective areas.

---

[1] Manuscript received, March 31, 1977; accepted, July 7, 1977.

[2] Consulting Geologist, Tulsa, Oklahoma 74103.

[3] Geologist, Petroleos Mexicanos, Poza Rica, Mexico.

Grateful acknowledgment is made to Petroleos Mexicanos for permission to publish the results of this investigation.

Article Identification Number
0149-1423/78/B002-0005$3.00/0

The American Association of Petroleum Geologists Bulletin
V. 62, No. 6 (June 1978), P. 912-931, 12 Figs.

Fan Valleys, Channels, and Depositional Lobes on Modern Submarine Fans: Characters for Recognition of Sandy Turbidite Environments[1]

WILLIAM R. NORMARK[2]

Abstract The growth-pattern concept for modern submarine fans has been reviewed and broadened by additional data published or obtained in the last five years. The similarities in morphology, structure, and surficial-sedimentation patterns among modern fans from different geographic and geologic settings support a general growth-pattern model that can be applied to ancient turbidite deposits. Most submarine fans have three recognizable morphologic divisions that are related to distinct facies associations for sandy and coarser turbidites. (1) The large-leveed valley(s) of the upper fan produce wide (1 to 5 km) valley-floor deposits that are the coarsest on the fan and are deposited in meandering or braided, shallow channels within the general confines of the valley. These coarse deposits grade laterally into finer grained and more regularly bedded levee sands and silts. (2) The middle-fan region is recognized as a convex-upward depositional bulge on a radial profile and includes a depositional lobe or suprafan at the terminus of the leveed valley. The coarsening- and thickening-upward sequence of sandy turbidites on the upper suprafan are cut by numerous channels, channel remnants, and isolated depressions, whereas the lower suprafan is relatively free of such features. Suprafan channels are generally less than 1 km across and probably are filled by thinning- and fining-upward sequences. (3) The lower fan division is characteristically free of channel features (and coarse turbidites), is nearly flat-wing or ponded, and, therefore, is indistinguishable morphologically from basin-plain or abyssal-plain settings in many cases.

Basin shape and relief and the ultimate size of the fan appear less important than sediment-input parameters, such as the grain-size distribution and rate of sediment supply, in controlling development of the three morphologic divisions of the fan. Specifically, canyon-fed systems common along western North America tend to have a single-leveed valley terminating in a suprafan depositional lobe; some fans, such as the Monterey, have slightly more complex features where more than one canyon is involved in fan development. If the grain-size distribution is weighted toward the silt and clay fractions as in some delta-fed systems, the fans tend to have multiple-leveed valleys on the upper fan (although only one may be active at any given time), to have long valleys crossing much of the fan, and to lack (or have poorly developed) suprafan relief.

INTRODUCTION

Studies of modern marine turbidite sediments within the last 20 years resulted in a variety of depositional schemes or model submarine fans. Such models typically are derived from the overall surface morphology of a fan as determined by echo sounding, the gross structure of the turbidites determined through reflection-profiling techniques, and/or from the distribution and internal structures of the surficial sediments (Menard, 1955; Wilde, 1965; Shepard et al, 1969; Piper, 1970; Normark, 1970a; Haner, 1971; Nelson and Kulm, 1973; Damuth and Kumar, 1975). The lack of resolution with conventional echo-sounding and reflection-profiling techniques, the relatively shallow penetration of fan sediments by standard sampling techniques, and the large size of most submarine fans (compared to exposures of ancient turbidites) may tend to distort the perspective of the exploration geologist if he is not careful how he attempts to use modern fan models as predictive tools. As a further complication, the fluctuation of sea level related to the Pleistocene glacial cycles has had marked effects on the sediment supply for modern submarine fans (Normark and Piper, 1969, 1972; Carson, 1971; Nelson and Kulm, 1973; Damuth and Kumar, 1975). The result is that for some fans the present distribution of surficial sediment largely may be unrelated to (not in equilibrium with) the gross morphology and structure of the fan and, without knowing the depositional history of the fan, i.e. its growth pattern, any derived models may be misleading (Normark, 1970a, 1974). As a result, submarine-fan depositional models based on ancient examples (but tempered by observations from the modern environment) may have more practical applications as exploration tools at this time (Mutti and Ricci Lucchi, 1972; Walker and Mutti, 1973; Mutti, 1974; Nelson and Nilsen, 1974; Walker, this issue AAPG *Bull.*).

This review of modern submarine fans will follow the growth-pattern concept of Normark (1970a, 1974) with emphasis on the similarities between modern fans despite orders-of-magnitude differences in size. Congruity between features from modern fans and the general depositional model developed by Walker (this issue) also will be stressed. The review focuses on the

---

[1] Manuscript received, August 19, 1977; accepted, November 8, 1977.

[2] U.S. Geological Survey, Menlo Park, California 94025.

This manuscript is the outgrowth of a New Orleans Geological Society short course in 1976. I thank F. N. Spiess and the engineers of the deep-tow group at the Marine Physical Laboratory, as their instrumentation provided the key data used in my interpretations. Discussions with D. J. W. Piper, G. R. Hess, J. E. Damuth, E. Mutti, C. H. Nelson, R. G. Walker, A. H. Bouma, P. R. Carlson, and J. Yount helped in the formulation and adjustment of my interpretations; the manuscript was reviewed critically by P. R. Carlson and R. G. Walker.

from: SEDIMENTATION IN SUBMARINE
CANYONS, FANS, AND TRENCHES
(D.J.Stanley and G. Kelling, Eds.),
1978, Dowden, Hutchinson & Ross,
Stroudsburg, Pa., pp. 85-115.

With complts
DJS.

Chapter 8

Coarse Sediment Transport by Mass Flow and Turbidity Current Processes and Downslope Transformations in Annot Sandstone Canyon–Fan Valley Systems

DANIEL JEAN STANLEY

Division of Sedimentology
Smithsonian Institution
Washington, D.C.

HAROLD D. PALMER

Dames & Moore
Washington, D.C.

ROBERT F. DILL

West Indies Laboratory,
Fairleigh Dickinson University
St. Croix, U.S. Virgin Islands

ABSTRACT

A series of submarine canyon axis, canyon wall, tributary canyon and fan valley, and interchannel facies of the Upper Eocene Annot Formation are well exposed in the French Maritime Alps. The dispersion of outcrops along major paleoslope trends allows definition of downslope, coarse sediment, depositional patterns in both channelized and unconfined outer margin environments. The geometry, stratification characteristics, internal structures, and fabric of the major sediment types reflect a broad spectrum of gravity-induced transport processes. This evaluation of downslope transport focuses on the different coarse facies sequentially, from those in proximal environments (which comprise a reduced proportion of obvious turbidites) to those in more distal parts of the paleobasin (characterized by enhanced proportions of turbidites).

The major depositional type in confined Annot Basin canyon and fan channel systems is a thick, amalgamated, nongraded or poorly graded, low-matrix pebbly sandstone that generally does not display typical turbidite structures. Most such massive units are attributed to high concentration sediment gravity flows, and associated with these are deposits from slumping, rockfalls, sandfalls, and a plexus of mass flow processes whose origin is less well defined. Classic turbidites account for only a minor portion of canyon-fan channel fills. The lithofacies assemblages that change downslope suggest a possible modification of grain support mechanisms and evolution from one type of flow to another. A scheme that involves down-axis segregation of material during transport is proposed to explain the distinction between sediment types in confined settings and those in more open environments further in the basin. Massive, low-matrix sands were deposited as "quick" beds from high-concentration underflows primarily in canyon and fan channels, whereas graded sands and finer fractions settled more progressively from lower-density turbidity current flows that bypassed canyon mouths and overtopped fan channel levees. The facies assemblages record significant changes in transport processes in base-of-slope environments, primarily in front of canyon mouths and on proximal fan apices.

INTRODUCTION

As is readily acknowledged, sediment entrapment, confinement, and transport in the submarine canyon and fan