EVALUATION OF THE EFFECTS OF OIL PRODUCTION PLATFORMS ON THE TURBIDITY OF LOUISIANA SHELF WATERS

by George M. Griffin

ABSTRACT

As part of the Offshore Ecology Investigation (OEI) of the Gulf Universities Research Consortium (GURC), water clarity and particulate matter in the South Timbalier OCS (Outer Continental Shelf) area offshore of central Louisiana were studied from 1972 to 1974, to determine whether or not long-term oil production and associated platforms have altered the natural turbidity of continental shelf waters.

Turbidity of surface waters varied seasonally from a mean of 0.8 mg/l in autumn 1972 to 5.3 mg/l following the Mississippi River flood of 1973. Mid-depth waters were the clearest, typically containing 0.15 mg/l. A turbid bottom-water layer persisted throughout the whole period; turbidity in this layer varied from 1.5 to > 10 mg/l. No differences in turbidity existed between the area of numerous production platforms and an undeveloped control area.

Clay minerals filtered from surface, mid-depth, and bottom-water layers are quantitatively similar to Mississippi River suspended sediment, and dissimilar to the cohesive surface of the shelf sediments. Therefore, the bottom turbid layer is not generated by erosion of the cohesive bottom muds, but by the settled residuum of Mississippi River suspended sediment.

The turbid layer of bottom-water is actively by-passing the shelf at present. A process model is outlined, indicating that the

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suspended river sediment settles from the turbid surface plume through the mid-depth water, into the turbid bottom layer. There it migrates laterally toward shore, in a series of resuspensive pulses, merges with a surf-generated littoral turbid layer, and ultimately is trapped by vegetation in the prograding Chenier Plain of southwestern Louisiana. Offshore production platforms have no detectable effect on this process or on the turbidity of the central Louisiana shelf waters.

INTRODUCTION

For more than 20 years, the central Louisiana shelf has been the site of intensive petroleum exploration and production, resulting in one of the highest densities of offshore structures in the world. The primary purpose of this particular study was to determine whether or not long-term offshore operations of that magnitude have affected the turbidity of the surrounding waters significantly enough to be considered an environmental impact. It was one of 23 separate projects, mostly biological in nature, run concurrently as part of the Offshore Ecological Investigation (OEI) of the Gulf Universities Research Consortium (GURC). Sampling was conducted simultaneously for all the projects, and a computerized data base was erected for storage, retrieval, and correlation of diverse geological, biological, and physical-oceanographic data. Wherever practical, platform areas were compared with an undeveloped control area that was deemed ecologically similar. Results from all studies are available on microfilm from GURC. As the OEI progressed, explanation of a turbid bottom-water layer discovered on the August 1972 cruise assumed particular importance. Much of this study was devoted to identifying the source of that layer and determining whether or not it is part of the natural ecosystem of the area.

Details of the sampling and analytical methods, as well as tabulations of all data, are in Griffin and Ripy (1974), available from GURC, and are not repeated here. The principal *in situ* tool for measuring turbidity was a Hydro Products Model 612 Transmissometer. Light transmittance readings (% transmittance/meter) from that instrument have been converted into suspended-sediment concentrations in mg/l using samples of Louisiana shelf mud to construct the conversion curve (figure 1). The conversion curve for the Louisiana shelf correlates well with a previously published curve from the California shelf (figure 2), and allows quantitative measurements of suspended particulate matter to less than the 1 part per million range.

Data were collected on eight cruises between August 1972 and January 1974, the times selected to observe seasonal changes. Seven of the cruises were in the South Timbalier area, and the eighth, for comparative purposes,

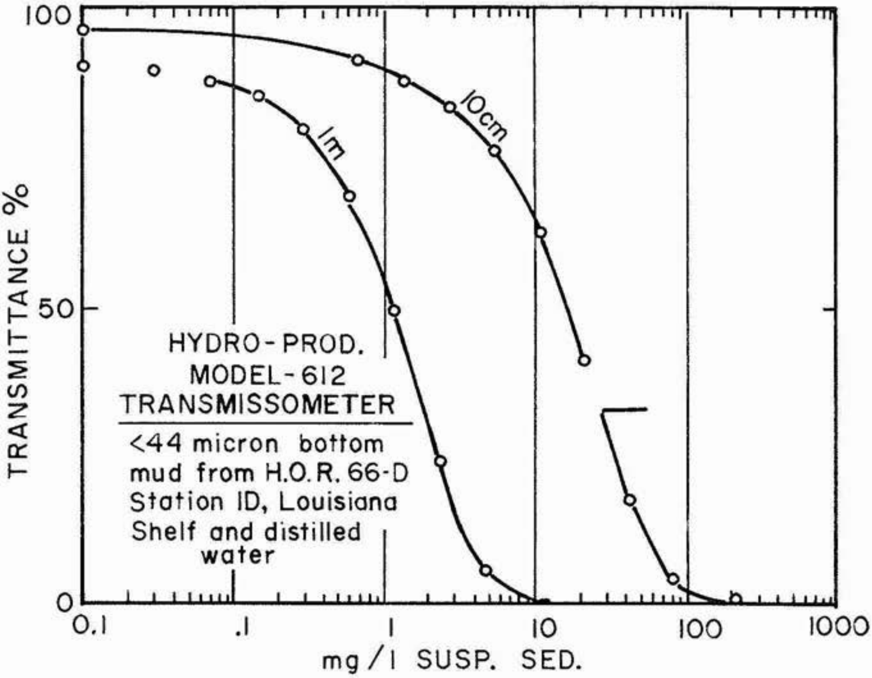

FIG. 1. TRANSMITTANCE VS. SUSPENDED SEDIMENT CONCENTRATION AS MEASURED IN A TEST TANK.

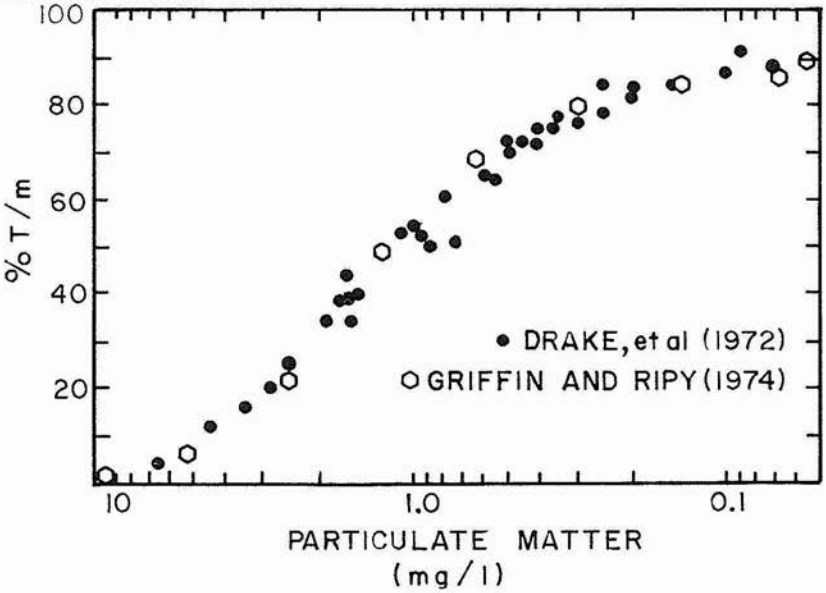

FIG. 2. COMPARISON OF TRANSMITTANCE VS. SUSPENDED SEDIMENT CONCENTRATION (• = California shelf, after Drake et al. 1972. ○ = Louisiana shelf, this study.).

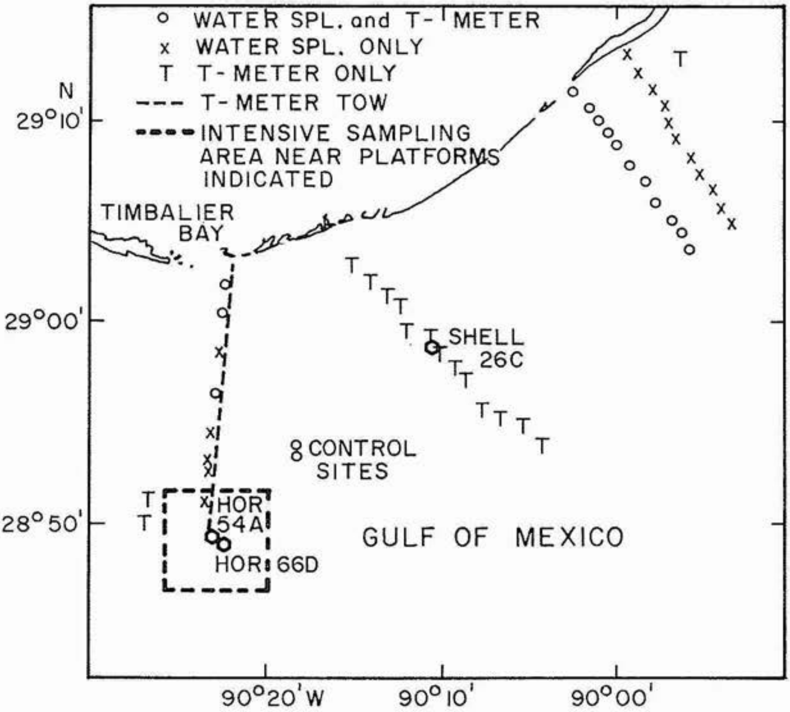

FIG. 3. STATION LOCATION MAP, SOUTH TIMBALIER OCS AREA, LOUISIANA.

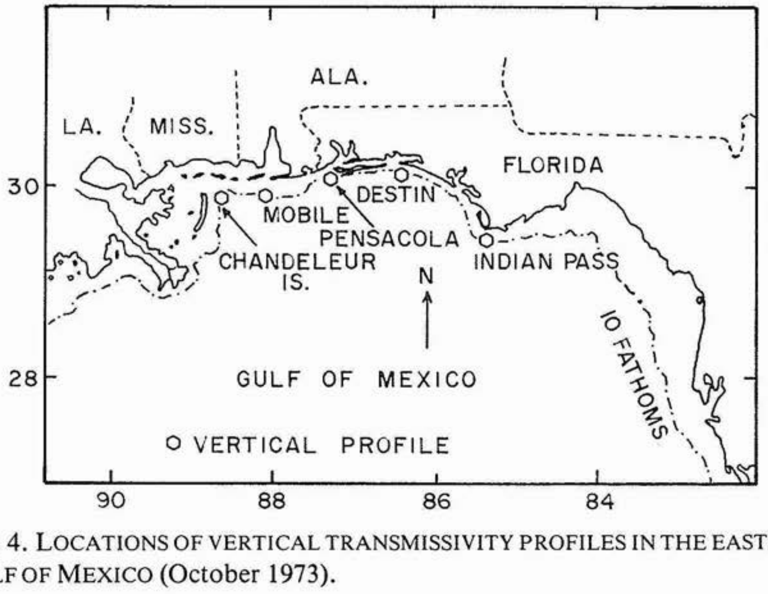

FIG. 4. LOCATIONS OF VERTICAL TRANSMISSIVITY PROFILES IN THE EASTERN GULF OF MEXICO (October 1973).

was east of the Mississippi Delta between Apalachicola, Florida, and the Chandeleur Islands. Stations are indicated on figures 3 and 4.

RESULTS

Seasonal variations in surface turbidity

The South Timbalier area lies 50-60 miles to the west, and in the lee, of the vast Mississippi Delta. This position produces considerable seasonal variations in surface-water turbidity that are correlatable with Mississippi River stages. High surface turbidities were noted especially during the summer of 1973, following a record Mississippi River flood (table 1, data for 7/73). At that time, a turbid plume spread through the area, and suspended sediment concentrations in the surface water reached an average of 5.3 mg/l in the immediate vicinity of Humble Oil and Refining Company (HOR) Platforms 54A and 66D, and 5.0 mg/l in the control area.

During lower river stages, surface concentrations declined to much lower values. In the summer and fall of 1972, only 0.8 to 1.2 mg/l were detected in the platform area, and 1.1 to 1.5 mg/l in the control area.

It is notable that the platform and control areas exhibited similar turbidity fluctuations; differences between the two areas were always less than 1 mg/l. On two cruises, the platform area was slightly more turbid, but on two other cruises, the control area was more turbid. None of these differences is considered significant.

On the whole, the surface water layer under non-flood conditions was clearer than might be expected off such a large river. The usual 1 to 2 mg/l range is, however, at least double the typical concentration level of water of the Florida Straits and other typical oceanic areas.

Turbidity of surface water adjacent to production platforms

Horizontal turbidity in the surface water within 6 km of HOR Platforms 54A and 66D was measured numerous times by towing the transmissometer along traverses radial to the platforms. Points extracted from the continuous chart record of September 18, 1972, are plotted on figure 5, which is representative of results from all tows. Turbidity on that day varied within a narrow range of 0.9 to 1.5 mg/l, with no effect from the platform at the center of the array.

A long traverse, from Platform 54A to near Grand Isle, was run on September 19, 1972 (figure 6). At the platform, the suspended-sediment concentration was only 0.8 mg/l, which is clear ocean water. The clear water continued shoreward for 13 km, after which the particulate content increased to 1.5 mg/l. Further shoreward, turbid plumes from Bayou Lafourche, Timbalier Bay, and Barataria Bay became evident, with a

TABLE 1. Suspended-Sediment Concentrations in Surface Water (<2m depth) Near H.O.R. Platforms 54A or 66D, and Comparisons with the Control Area. August 1972-January 1974. All Measurements with Hydro-Products Model 612 or 612A 1-m Transmissometer; Precision ± Percentage Points.

Optically-Measured Suspended Sediment Concentration (mg/l)

	Near Platforms						Control Area					
Cruise Dates	8/72	9/72	10/72	7/73	1/74	All Cruises	8/72	9/72	10/72	7/73	1/74	All Cruises
η	8	14	6	19	3	50	0	2	1	1	1	5
$\bar{x}$	1.2	1.0	0.8	5.3	2.8	2.7	-	1.1	1.5	5.0	2.3	2.2
$s \pm$	0.4	0.03	0.2	0.3	0.6	2.1	-	-	-	-	-	1.6
1 s range	0.8-1.6	1.0-1.1	0.6-1.0	5.0-5.6	2.2-3.4	0.6-4.8	-	-	-	-	-	0.6-3.8
max.	2.1	1.2	1.2	6.0	3.1	6.0	-	-	-	-	-	5.0
min.	0.9	1.0	0.7	5.0	2.1	0.7	-	-	-	-	-	1.0

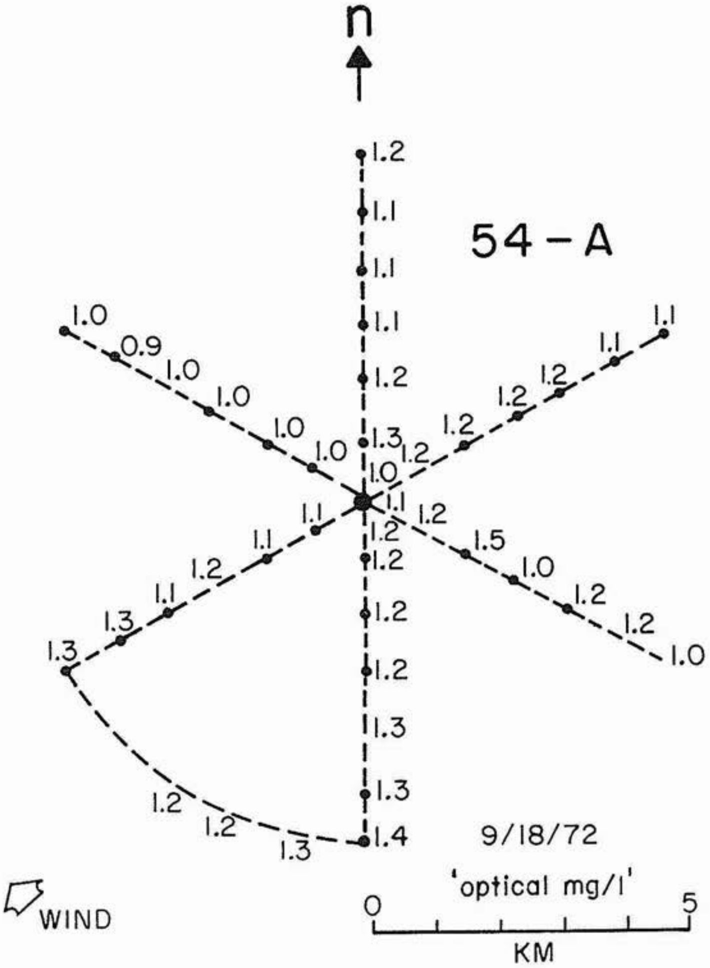

FIG. 5. SUSPENDED SEDIMENT CONCENTRATIONS (OPTICAL MG/L) IN SURFACE WATER (<0.3 M DEPTH). Derived from continuous recordings with an optical transmissometer, September 18, 1972. HOR Platform 54A was at the center of the pattern.

maximum of 17 mg/l reached 4.7 km off Barataria Pass in 6.1 m of water. The traverse terminated at that point.

On none of the traverses was there a detectable effect from the platforms. Such variations as were noted within several kilometers of the platforms were directly relatable to visible patches of plankton, the bubbles in tug boat wakes, and occasional surfacing of the transmissometer sensor.

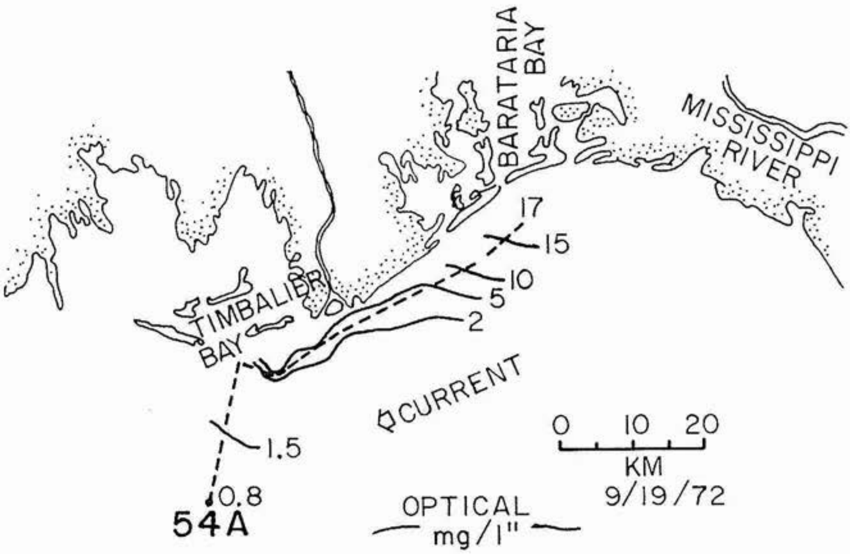

FIG. 6. SUSPENDED SEDIMENT CONCENTRATION (OPTICAL MG/L) IN SURFACE WATER (<0.3 M DEPTH) between HOR Platform 54A and the entrance to Barataria Bay. September 19, 1972.

Daily variations of approximately 1 mg/l were related to changes of current direction in the surface water. The greatest variations, on the order of 5 mg/l, were seasonal and attributable to the unusually large influx of Mississippi River floodwaters in the spring and summer of 1973.

Vertical Profiles of Turbidity

The central Louisiana shelf is characterized by a two- or three-layer stratified water column with a persistent turbid bottom-water layer. In detail, the profiles vary both daily and seasonally, but the turbid bottom-water layer was observed at 96% of the Louisiana stations regardless of season.

Diurnal variability

Figures 7 and 8 are profiles run on consecutive days at Platform 54A. Turbidity is plotted on the right-hand part of the figures as percentage of light transmission per meter of optical path length. In the discussion below, these values have been converted to mg/l by applying the working curve of

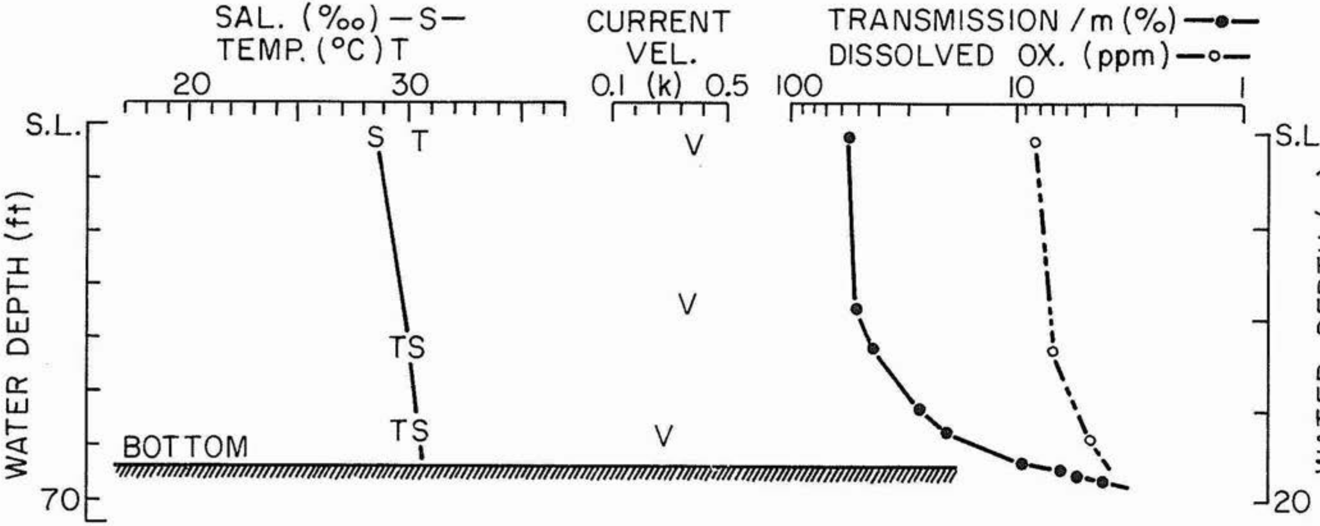

FIG. 7. TYPE 2 VERTICAL PROFILE OF TRANSMISSIVITY (% T/m) AND OTHER WATER MASS PARAMETERS. HOR Platform 54A. September 20, 1972.

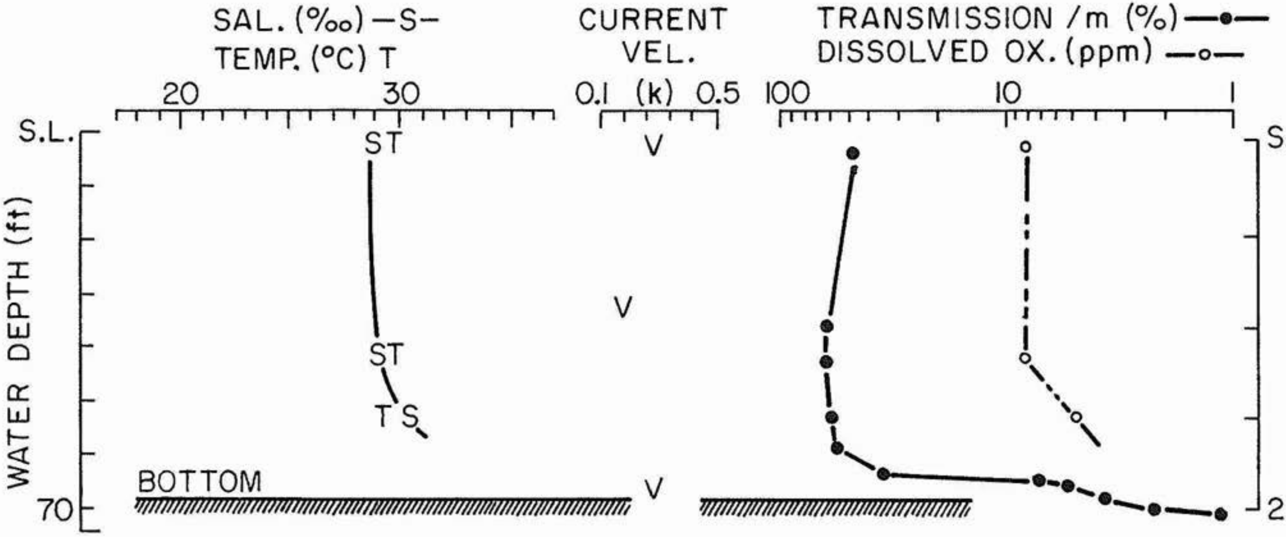

FIG. 8. TYPE 3 VERTICAL PROFILE OF TRANSMISSIVITY (% T/m) AND OTHER WATER MASS PARAMETERS. HOR Platform 54A. September 21, 1972.

figure 1. Approximately 60% of the Louisiana shelf profiles are of the types shown on figures 7 and 8.

On the September 20, 1972, profile (figure 7), turbidity increased exponentially with depth as particulate concentration increased from approximately 1 mg/l in the surface water to 6.4 mg/l in the turbid bottom water. The September 21, 1972, profile (figure 8) differs slightly in that a clearer mid-depth layer was present. On this day, the surface suspended-sediment concentration was near 1.2 mg/l, the mid-depth layer was near 0.7 mg/l, and the turbid layer contained as much as 10 to 15 mg/l.

The slightly differing profiles of September 20 and 21 correlated with a shift in current direction. On September 20, the weak (<0.5 k) current generally moved toward the north-northeast at all depths; on September 21, it moved toward the west-northwest at the surface and bottom, but toward the north in the mid-depth layer. Wind was less than 3 knots on both days.

Seasonal variability

Longer term, seasonal effects are illustrated by figure 9, taken at Platform 54A on July 9, 1973. A low-salinity, turbid surface layer is present, with a particulate concentration of 5 to 7 mg/l. This represents the turbid plume from the record Mississippi River flood of that year. It was approximately 20 feet thick at Platform 54A. Beneath the surface turbid layer, the mid-depth water was remarkably clear, with approximately 0.3 mg/l suspended matter, and a full marine salinity of 36 parts per thousand dissolved solids. Near the bottom, the turbid layer contained only 1.8 mg/l suspended sediment at this station. Surface water was moving toward the south at 0.55 knots, whereas the mid-depth water moved toward the east-northeast at 0.25 to 0.48 knots, and the

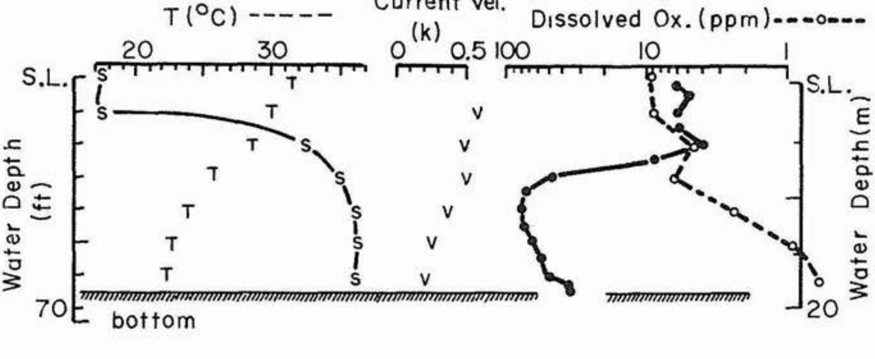

FIG. 9. TYPE 4 VERTICAL PROFILE OF TRANSMISSIVITY (% T/m) AND OTHER WATER MASS PARAMETERS. HOR Platform 54A. July 9, 1973.

bottom layer also moved east-northeast at 0.2 knots. Profiles similar to figure 9 were observed at 30% of the stations on the Louisiana shelf, all of them following the 1973 Mississippi River flood.

THE TURBID BOTTOM LAYER

Ecological significance

Upon discovery of the turbid bottom-water layer on the August, 1972, cruise, its potential ecological significance was quickly realized by several of the OEI project leaders. Biological stresses due to reduced light penetration through the bottom water were reported by Humm (1973) to be related to the lack of bottom-dwelling algae except on platform legs above the layer. George and Thomas (1973) found the depth of fouling organisms, such as barnacles, on platform legs to be limited by the average thickness of the turbid layer. Other biotic stresses and limitations were related to the very unstable nature of the sediment/turbid water-layer interface and to the sub-normal dissolved oxygen content of the layer. Although not all of these biological effects could be considered necessarily harmful to the environment, it was apparent that the turbid layer is an important governing factor in the ecology of the Louisiana shelf and that if it were caused by the platforms, it might be considered as an adverse environmental effect. Therefore, considerable effort was made to define various attributes of the layer including its thickness, distribution, concentration, dissolved oxygen content, and seasonality. Many of these features are summarized in table 2; other features are listed in Griffin and Ripy (1974).

Source of clastic particles in the turbid layer

Because the turbid layer is composed largely of suspended minerals, it was possible to collect filtrates from it and to use quantitive clay mineralogy as a natural tracer. In table 3, analysis of suspensates from the surface, mid-depth, and bottom turbid layers near Platforms 54A and 66D are compared with cohesive bottom sediments from the same area. Suspended sediment samples from the lower Mississippi River are included for comparison.

It is evident from the table that particulate matter in the turbid bottom layer, as well as in the surface and mid-depth waters near the platforms, is similar to the Mississippi River suspended sediment. On the contrary, cohesive bottom muds near the platforms differ mineralogically from the suspended sediment. This finding indicates that the inorganic particles in the turbid layer originate from the modern Mississippi River and are not generated by reworking of the surface of the Lafourche subdelta, which forms the cohesive shelf bottom in this area.

TABLE 2. Summary of Characteristics of the Bottom Turbid Layer within 5.5 km of H.O.R. Platforms 54A and 66D and within 2-m of the Seafloor.

	n	Mean	Std.Dev.	1-s Range	Max.	Min.
Transmissivity (% T/m)	38	12.7	±14.0	0-26.7	53	0
Attenuation Coefficient (a/m)	38	>2.69	>±1.27	<1.4->3.96	>4.61	0.63
Concentration ("optical mg/l")	38	>5.0	>2.9	<2.1->7.9	>9.8	0.8
Concentration (filtered, mg/l)	10	6.0	3.9	2.1- 9.9	11.8	2.4
Dissolved Oxygen (% saturation)	95	61.4	±32.9	28.5-94.3	130	<1
Thickness (m)	44	6.2	±1.9	4.3- 8.1	10.1	1.5

TABLE 3. Clay mineralogy of suspended sediment samples from near Platforms 54A and 66D, cohesive bottom sediments from the same areas, and Mississippi River suspended sediments.

	Percent of the Clay Mineral Suite (±5%)				Number of
	montmorillonite	illite	kaolinite	chlorite	Samples
Group A - Near Platforms 54A and 66D.					
Surface water	33	42	11	14	7
Mid-depth water	29	47	7	20	4
Turbid bottom water	33	42	10	16	22
Group B - Control area.					
Turbid bottom water	31	43	9	16	1
Group C - Mississippi R. at Avondale					
Suspended sediment	33	34	13	21	4
Group D - Cohesive bottom sediments from near Platforms 54A & 66D	58	21	8	11	12

TABLE 4. Ratios of Bottom/Surface Suspended Sediment Concentrations, Based on Best Approximations, including Optical and Filtering Data of Various Types

Type of Water Body	Bottom/Surface Concentrations
A. Open Shelf	1-3X
B. Shelf, Near Po Delta	10-15X
B. Shelf, Near Mississippi Delta	10-54X
C. Delta Distributaries	5-30X
D. Estuaries	2-89X
E. Fjords	3X
F. Tidal Straits	3X
G. Non-Estuarine Bays	2-4X
H. Tidal Flat	2X
I. Hypersaline Lagoon	33-400X

Worldwide distribution of turbid layers

Particular attention was also given to a thorough search of the literature to establish whether such layers were common to similar geographic areas elsewhere in the world, especially to provide a comparison between areas with and without petroleum-production facilities. The complete compilation, including data on suspended sediment concentrations and proposed mechanisms of formation, can be found in Griffin and Ripy (1974). Table 4 of this report is a short summary indicating the range of environments represented, and comparing surface and bottom-water concentrations of suspended sediment.

It was apparent from this review that turbid bottom-water layers are far from rare. Some of the areas listed are off urbanized coasts, others are off largely uninhabited areas; however, the California shelf described by Moore (1972) is the only other one in which petroleum production is at all intensive. All of the more than 35 writers attributed the turbid bottom water to natural mechanisms, especially resuspension of fine particles by tidal currents or waves; biologic reworking was cited occasionally as a method for resuspending cohesive muds.

Comparison with the Eastern Gulf of Mexico Shelf

During October 1973, vertical profiles were run and suspended sediments collected from the bottom-water layer at four sites on the N.W. Florida, Alabama, and Mississippi shelf (figure 4). At all of these sites, the water was very clear and was well mixed throughout the water column. No evidence of a turbid layer or any other form of stratification was found. Particulate contents in 60-80 feet of water off Mobile Bay, Alabama, and Destin, Florida, were uniformly much less than 0.1 mg/l, and approached the limit of measurement with the one-meter transmissometer. Filtrates from eight samples of the near-bottom water average 20% montmorillonite, 53% illite, 9% kaolinite, and 16% chlorite. Thus, they differ from the turbid-layer samples of the Louisiana shelf and from the Mississippi River.

TURBID LAYER TRANSPORT ON THE LOUISIANA COAST

As a result of the results and reasoning given above, the bottom turbid layer on the central Louisiana shelf is attributed primarily to influx from the modern Mississippi River, rather than to erosion of the partly consolidated, cohesive bottom sediments of the study area. Artificial additions from the offshore petroleum industry were not detected; they are either absent, quantitatively insignificant, or of the same composition as modern Mississippi River mud.

The natural process sequence proposed for development of the turbid layer is as follows:

1. Turbid fresh-brackish water issues from the passes of the Mississippi Delta as a distinct surface plume, carrying approximately 40 to 500 mg/l suspended sediment (Coleman, Wright, and Suhayda 1972). The plume is most marked during floods, when it spreads west at least as far as the shelf south of Timbalier Bay; however, it is present to some extent during most river stages. The plume conforms generally to the hypopycnal plane-jet theory of Bates (1953), as modified by Coleman, Wright, and Suhayda (1972). Its remnants eventually result in the common salinity variations off western Louisiana noted by Geyer (1950), and the turbidity fluctuations noted by Scruton and Moore (1953) east of the delta, and by us to the west.
2. Because of the significant density differences between the brackish surface plume and the clearer mid-depth open-Gulf water, eddy diffusivity is limited, and the surface plume persists as a distinct water mass for tens of miles away from the delta. Slow erosion of the base of the turbid plume, by internal waves at the density interface, allows only small quantities of the suspended sediment to descend into the mid-depth layer at any point. The plume sediment is therefore dissipated slowly into the mid-depth water and diluted as the turbid surface plume drifts away from the delta with the prevailing current. Its initial movement is toward the west. This is a result of several factors: (1) the tide propagates from east to west and during the flood tide the plume is deflected strongly to the west (Coleman, Wright,

and Suhayda 1972); (2) the coreolis force tends to deflect the plume westward (Bates 1953); and (3) the net effective winds tend to produce a dominant westward flow of the surface layer along the Louisiana coast (Lipsey 1919; Scruton 1956).

The quantity of suspended material that settles through the mid-depth water at any one place is therefore small, and the relative clarity and low suspended-sediment concentration (0.1-1.0 mg/l) of the mid-depth layer is maintained. As I pointed out earlier, however, the clay mineralogy of the mid-depth water is quantitatively identical to the surface plume from which it evidently was derived.

3. The particles that pass downward into the mid-depth layer continue to settle slowly, and as that water mass migrates, they are distributed over a wider area. Eventually the sea floor is reached, and in the absence of any bottom motion, the particles would be sedimented. Bottom motion *does* normally occur, however, either through tidal action, stirring by long-period storm waves, upwelling of slope water, or the stirring action of fish, shrimp, and other near-bottom dwellers or benthos. Thus, the fine particles are not plated onto the sea floor permanently, but accumulate temporarily in a turbid near-bottom water layer that is subject to lateral migration and further distribution of the river-derived clay. Part of the suspended load of the turbid layer is undoubtedly temporarily sedimented onto the bottom during quiet times. Even after deposition, however, the initial high water-content of the freshly sedimented material inhibits columbic attraction between clay particles, which allows it to be easily resuspended by weak agitation. Thus, the tendency is for the sediment to form a bottom turbid-water layer that is similar in composition to its parent turbid-water layer from the Mississippi River, and which varies seasonally in sediment concentration, thickness, salinity, and temperature.[1]

   At times, the turbid bottom layer migrates laterally into areas in which the bottom waters are temporarily clear. If at those times the clear water is more dense, the turbid layer can override it, and the remnants of the original water mass then form a thin clear layer underlying the turbid layer. Such events are doubtless transitory but have been seen by divers (E. A. Shinn, personal communications 1973-74) and have been measured by me on three occasions.

4. From the current observations of Oetking (1973), we can predict some features of turbid layer movement across the Louisiana shelf, and the nature of the multiple resuspension process. These

data indicate a predominant migration of the bottom water toward the coast, often unrelated and sometimes contrary to surface or mid-depth movements. The average speed of the bottom current is only 0.21 knots (11 cm/sec), versus 0.7 knots (38 cm/sec) in the surface water. Bottom-water movement is affected by tidal motion, so that parcels of water describe elongated elliptical gyres, but the net result is shoreward movement.

Oetking (1973:8) states that in the summer regime, "Flooding occurs dominantly on the bottom, with ebb at mid-depth. . . ." The winter regime is less definite, with bottom water showing flood, ebb, and westerly influence (1973:9). Addition of flood tide movement to the net non-tidal flow tends to produce a pulsating bottom-water motion with a (tidal) period of 24 hours; this motion would tend to be most pronounced during the summer regime, when the floodtide reinforcement of the non-tidal flow is most pronounced. Thus, multiple resuspension of the freshly-sedimented, very hydrous, non-cohesive sediment particles from the turbid layer would tend to occur during the summer regime.

The dominant landward migration of the bottom turbid layer is important to note. The general case for landward migration of fine sediment has been presented for the Atlantic Coast by Meade (1972), and the data presented here indicate that it is also applicable to the Louisiana coast.

5. The stations occupied on the April 6, 1973, synoptic cruise allowed turbid-layer movement in the nearshore zone to be further defined (figure 10). Those stations suggest that the fine sediment transported landward in the turbid layer ultimately reached the inner shelf where it encountered a second "littoral turbid layer" of a different type. The littoral turbid layer occupied the entire 6-m water column at the most inshore station (2.8 km offshore). It protruded seaward under clearer surface waters as a relatively cool, low-salinity, turbid, *oxygen-saturated* wedge recognizable to about 14.8 km offshore. The clearer water at the 16.7 km juncture of the two turbid layers is not easily explained (figure 10), but seaward of 18.5 km, the shelf-generated "neritic turbid layer" is recognized by its warmer temperature, higher salinity, and lower oxygen content (<74% saturated). Presumably, the near-shore turbid materials in both the neritic and littoral layers tend to migrate westward as part of the littoral drift, and it is predicted that their distinctive characteristics are gradually blurred by diffusion near their juncture.

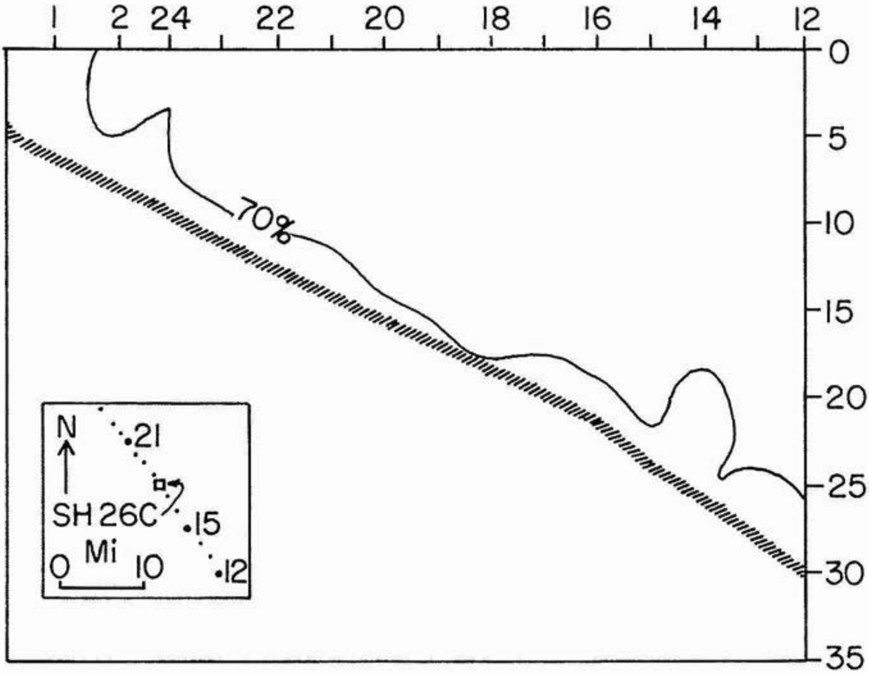

FIG. 10. CROSS-SECTION OF VERTICAL TRANSMISSIVITY (% T/10 cm) profiles along a transect passing close to Shell Platform 26C. April 6, 1973. A turbid layer is indicated between the seafloor and the 70% T/10 cm contour line. The seaward part of the turbid layer is believed to originate on the shelf, and the landward part is generated in the littoral zone. Note that a 10-cm path length was used on this cruise, as the 1-m instrument was being repaired.

6. The ultimate result of shoreward, then westward, littoral migration of the bottom turbid zone probably is an addition of fines to the western Louisiana coast (e.g., at Cameron, LA). There, much of the suspended material is ultimately trapped in the coastal marsh system, where it contributes to the progradation of the Chenier Plain mud flats, which is known to be occurring (Morgan, Nichols, and Wright 1958; Gould and McFarlan 1959; Gould and Morgan 1962). Besides documenting the significant trapping of clay during abnormally high tides, and the resulting formation of clay drapes overlying other coastal deposits, Morgan has subsequently found similar clay deposits

overlying Cheniers as old as 2000 years B.P. (personal communication 1974).

SUMMARY AND CONCLUSIONS

Louisiana shelf waters south of Timbalier Bay are characterized by a two- or three-layer water column with a persistent near-bottom turbid layer. The turbid bottom layer was detected at 96% of the vertical stations and at all seasons, although with large variations in thickness and concentration. The bottom turbid layer was absent from four stations on the Florida-Alabama shelf where the rate of clastic influx is much lower than on the Louisiana shelf. However, similar turbid layers are common to clastic depositional environments throughout the world, and the Louisiana shelf is quite normal in that respect.

The clay-mineral composition of the suspended sediment was identical in surface, mid-depth, and turbid bottom-water layers. It was also indistinguishable from Mississippi River suspended sediment. However, the suspended sediment differed significantly from the clay mineralogy of the cohesive, older bottom sediments of the study area. From this, I concluded that the suspended material in the turbid bottom layer and the water column as a whole is derived from the modern Mississippi River, without detectable additions from erosion of the older recent bottom sediments or from offshore petroleum operations.

A process model for turbid-layer transport of Mississippi River suspended sediment follows. The material originates in the surface turbid plume, settles slowly through the clear mid-depth water, and is distributed in accordance with net-westerly water movements that affect those upper two layers. Ultimately, through further settling, the particles enter a near-bottom zone where they accumulate as a nepheloid cloud of fine particles, here designated the *turbid layer*. The turbid water mass slowly migrates toward the coast via an often-interrupted multiple-resuspension process involving tidal gyres plus non-tidal movements. The shelf-bottom is by-passed by the fine sediment particles, which are neither permanently sedimented nor measurably augmented by erosion of the older, cohesive shelf sediments. Within 8 kilometers of the coast, the shelf turbid layer is joined by turbid water generated in the littoral zone. There, littoral drift carries the combined turbid water mass westward, where it can be trapped in the coastal marshes and mudflats of the prograding Chenier Plain of southwestern Louisiana.

Offshore production platforms of the type examined were found to have no detectable effect on the turbidity of the Louisiana shelf, or on the suspended sediment transport process described above. Turbidity parameters were identical in all respects adjacent to the platforms and in an ecologically similar, but undeveloped, control site.

NOTES

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1. In water deeper than approximately 100 m off the active Mississippi Delta, the massive, clayey nature of the accumulating bottom sediment suggests that resuspensive forces are too weak to winnow the fines effectively, and the massive pro-delta clay of Fisk et al. (1954) accumulates. However, at the 20-30 m depth of the OEI area, resuspension is evidently active, so that winnowing and further transport is occurring.

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