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Risk Analysis

Final Technical Summary

Final Study Report

U.S. Department of the Interior
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Pacific OCS Region

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FINAL TECHNICAL SUMMARY

STUDY TITLE: The Transport and Fate of Drilling Muds

REPORT TITLE: Risk Analysis

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KEY WORDS: drilling muds; offshore oil; pollution; transport; fate; deep-water; shallow-water.

BACKGROUND: The disposal of drilling muds from offshore oil platforms is of concern because of the potential effects of pollution from these muds. Both drilling muds and fine-grained bottom sediments are similar in their general physical and chemical characteristics and can be studied by similar methods.

OBJECTIVES: To determine the transport and fate of drilling muds off the California coast.

DESCRIPTION: In order to investigate the transport and fate of drilling muds, a numerical model of this transport and fate has been developed. The model consists of a two-dimensional, vertically-integrated, time-dependent hydrodynamic and mass transport model coupled with a three-dimensional time-dependent model of the sediment bed and its properties. A deep-water environment and a shallow-water environment were studied. Calculations show that the non-linear effects of shear stresses on sediment resuspension dominate both regimes. Waves generated by large, low-probability storms result in burial of drilling muds deposited in deep water. By contrast, sediments deposited in shallow water are easily eroded by typical storm waves due to the higher bottom shear stress generated in this shallow-water environment.

STUDY RESULTS: For the deep water site, small storms were found to resuspend sediments from areas with minimal drilling mud deposition, and to subsequently deposit this material in deeper water where drilling muds are more likely to be found. Typical storms in shallow water generated bottom shear stresses large enough to erode significant quantities of drilling mud deposited in these environments. During large storms, the amount of sediment resuspended increases dramatically.

It must be noted that the extent of erosion is strongly dependent upon the choice of sediment bed properties. Due to a lack of available field data for these study regions, these results must be viewed as general descriptions of the transport and ultimate fate of drilling muds in marine environments. However, the non-linear relationship between resuspension/deposition and bottom shear stress leads to the conclusion that large storms account for the most significant quantities of sediment transport in both shallow and deep water environments.

SIGNIFICANT CONCLUSIONS: Determination of the ultimate fate of drilling muds discharged from offshore oil platforms requires a proper evaluation of the hydrodynamic character of the discharge region as well as an accurate calculation of suspended solids transport and sediment resuspension/deposition behavior. A numerical model possessing these characteristics has been employed to analyze the fate of drilling muds discharged from a platform sited in deep water at Platform Hidalgo on the California coast, and at a shallow water location at Eugene Isle in the northern Gulf of Mexico. Calculations for both sites reveal that large storms can resuspend drilling muds deposited in both deep and shallow water, although the influence of these storms in shallow water is considerably more pronounced.

FINAL STUDY REPORT

ABSTRACT

The disposal of drilling muds from offshore oil platforms is of concern because of the potential effects of pollution from these muds. A related problem is the concentration of pollutants from produced waters and other sources in bottom sediments. Fine-grained sediments (silts and clays) are especially important because of their great capacity for absorbing contaminants which are then transported with the sediments. Both drilling muds and fine-grained bottom sediments are similar in their general physical and chemical characteristics and can be studied by similar methods.

In order to investigate the transport and fate of drilling muds, a numerical model of this transport and fate has been developed. The model consists of a two-dimensional, vertically-integrated, time-dependent hydrodynamic and mass transport model coupled with a three- dimensional time-dependent model of the sediment bed and its properties. The sediment bed is assumed to be layered in the vertical direction. Properties of each layer depend on tune after deposition and the relative fraction of fine and coarse sediments. The number of layers and their thicknesses can be arbitrarily specified at the beginning of each calculation. Sediment settling speeds and resuspension parameters needed in the model were determined from laboratory and field tests.

A deep-water environment, represented by the Hidalgo Platform west of the Santa Barbara Channel, and a shallow-water environment, represented by Eugene Island in the Gulf of Mexico, was studied. Relevant hydrodynamic parameters modeled include current velocities, tidal incursions, and storm-generated wind waves.

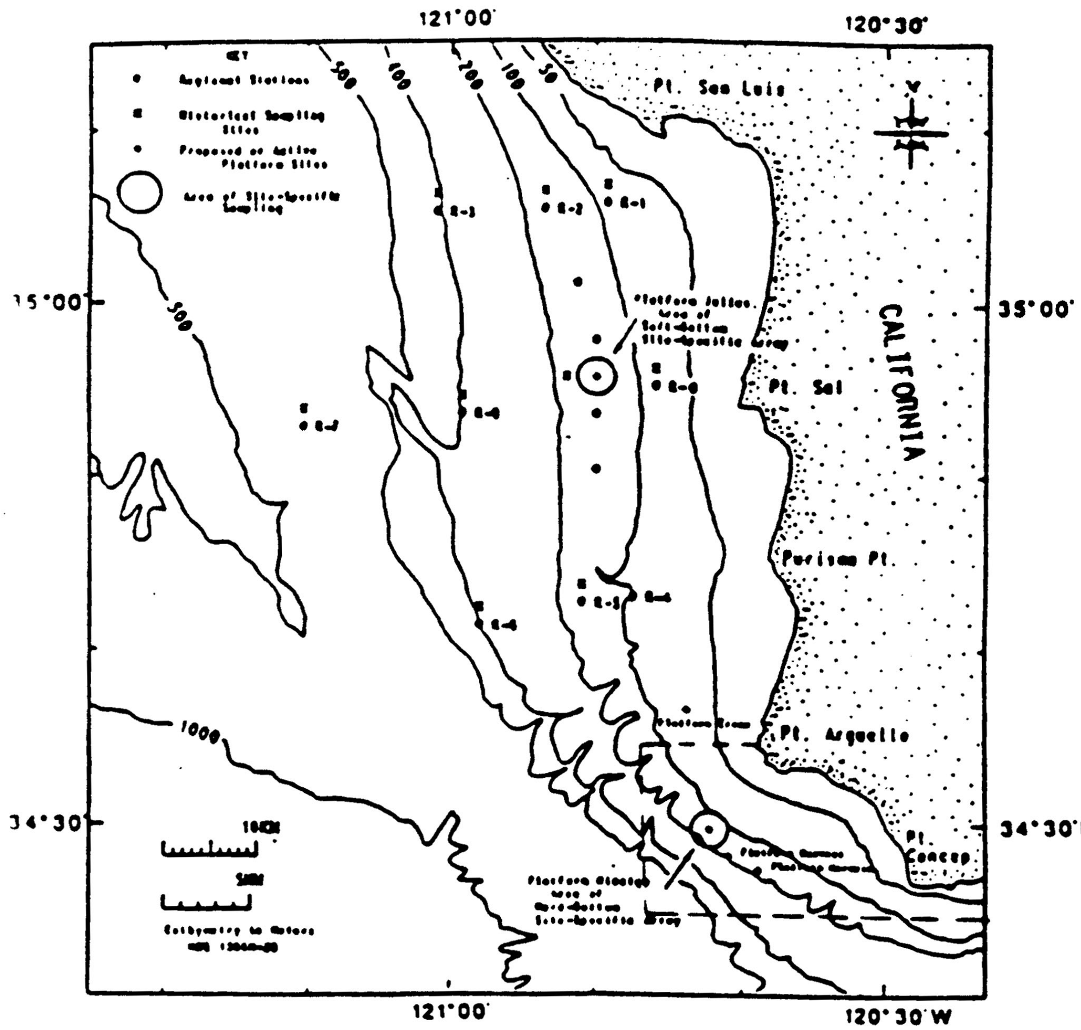
Calculations show that the non-linear effects of shear stresses on sediment resuspension dominate both regimes, with a few large storms causing almost all of the resuspension of bottom sediments. Waves generated by large, low-probability storms resuspend buried sediment layers that remain stationary during ordinary winter storms in the deep-water regime near Hidalgo. By contrast, sediments in the Gulf of Mexico are much more easily eroded by typical storm waves due to the higher bottom shear stress generated in this shallow-water environment.

INTRODUCTION

The study of the transport and ultimate fate of drilling muds discharged from offshore oil platforms is of interest primarily due to the possibility of ecosystem sensitivity to drilling mud components. Similarly, pollutant concentrations due to the discharge of produced waters must be examined in light of their potentially negative impact on the marine environment. In order to gain insight into the transport processes of these effluents, it is necessary to accurately model the hydrodynamic and particle transport characteristics of the region in which the platform is located. Although drilling sites are highly variable in terms of geographical and bathymetric parameters, important conclusions can be drawn from the analysis of two extreme types of drilling environments. Specifically, the transport of drilling muds from a platform located in deep water will be compared to results obtained for a platform in shallow water.

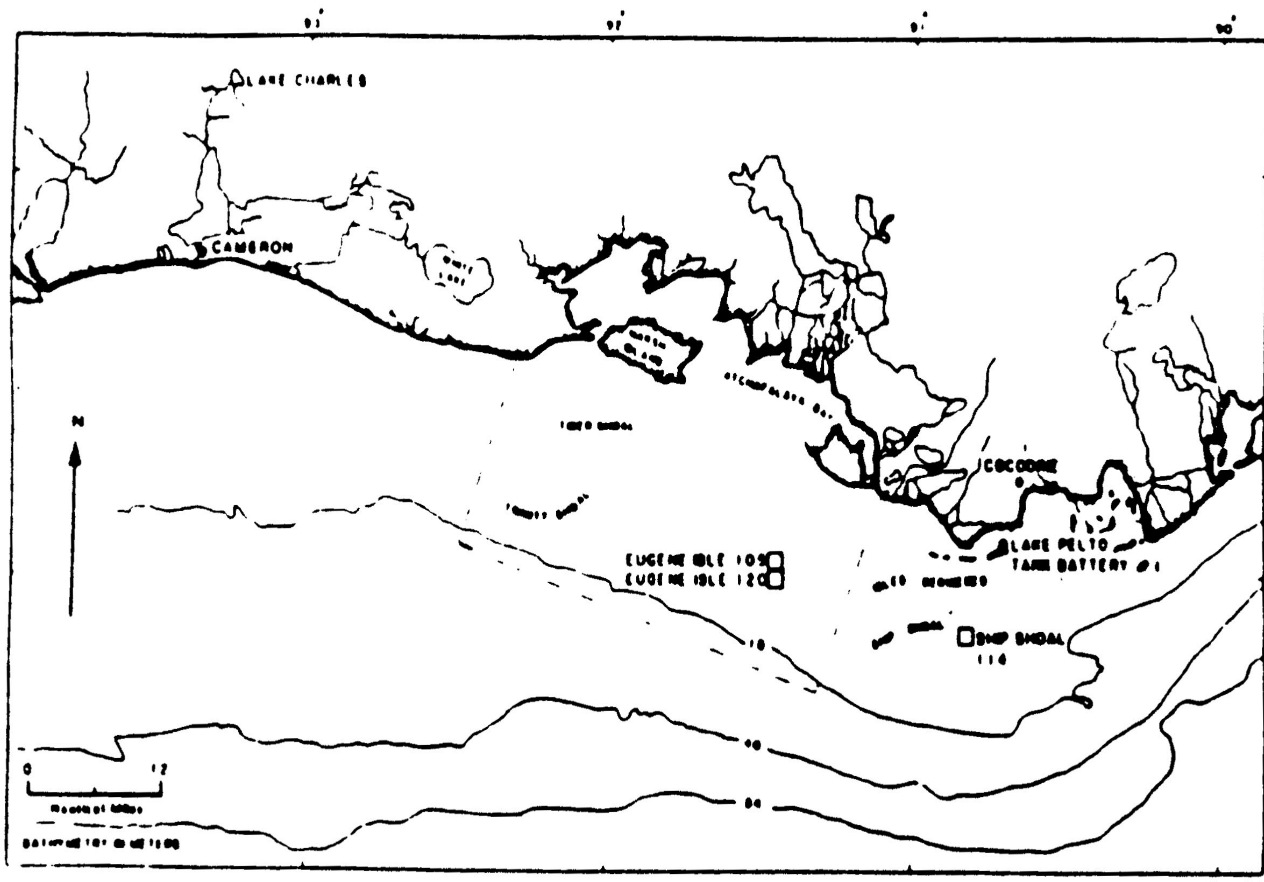
The deep water site selected, Platform Hidalgo, is located 10 km southwest of Point Arguello along the California Coast (Figure 1). This region has experienced minimal drilling and production activity. The platform itself is located in approximately 120 m water, with steep, irregular bathymetric contours dominating the topography. Currents along the California coast are highly variable in magnitude and direction, are complicated by strong diurnal and semi-diurnal tides, and are inherently three-dimensional. However, during major storms and hence high turbulence, the water column is well-mixed in the vertical. Because of this, significant insights into the transport of drilling muds can be obtained utilizing a two-dimensional, vertically integrated numerical model. This model and the approximations integral to the model will be discussed below.

Figure 1. Geographical map and computational region for Platform Hidalgo



Eugene Isle, an oil platform located approximately 20 km south of Atchafalaya Bay in the northern Gulf of Mexico, was selected for the shallow water site (Figure 2). The platform itself has been in production since 1981, with effluents in excess of 65,000 gallons/day (Neff, 1988) discharged to the surrounding waters. In many respects, Eugene Isle is typical of the thousands of platforms erected in this oil-rich region. Located in only 7 meters of water, depths do not exceed 13 m throughout the study region. The water column is well-mixed in terms of temperature and salinity, and currents flow westward, averaging 5 to 15 cm/s through most of the year (Murray, 1976). Additional hydrodynamic parameters to consider are tidal effects, which are weak in this region, and winter storms in which wind-driven waves become important. Because the water column is well-mixed, this site is an ideal candidate for the two-dimensional numerical model employed for the Platform Hidalgo site.

Figure 2. Geographical map and computational region for Eugene Isle



Contaminants in aquatic systems are frequently associated with fine-grained, cohesive sediments due to the capacity of these sediments for sorption of contaminants. While the precise nature of this association has yet to be adequately described, an accurate description of the transport of cohesive sediments has been developed by Gailani *et al* (1990). Since drilling muds frequently consist of bentonite and other fine-grained clay minerals, it may be assumed that the transport of these effluents can be adequately described by this model. Recent laboratory experiments (Huang, 1992) support this assumption, as the flocculation and resuspension relationships utilized in Gailani's model for fresh-water cohesive sediments are shown to apply to drilling mud behaviour as well.

The present study utilizes a two-dimensional, vertically integrated, time-dependent hydrodynamics model developed by Ziegler *et al* (1987). This model is coupled with a three-dimensional time-dependent model of the sediment bed and its properties. The sediment bed is assumed to be layered in the vertical direction. At the onset of a calculation, each layer is assigned an initial thickness, age, and critical shear stress. The critical shear stress is defined as the value of shear stress at which resuspension will be initiated. Resuspension will be discussed further in the next section. In addition, it is possible to specify the fraction of fine-grained (cohesive) material and the fraction of coarse-grained (sandy) material present in the sediment bed. It should be noted that flows and sediment bed parameters were selected such that a general description of the ultimate fate of drilling muds could be derived. Real-time simulations were not included in this study. The equations and necessary assumptions for the development of the numerical model are described in detail by Gailani (1991) and will not be repeated here. However, certain aspects of the model are critical to the understanding of the transport of drilling muds from these locations, and these aspects are discussed in the next section.

TRANSPORT EQUATIONS

Using the appropriate boundary conditions for currents and tidal activity, the model calculates current velocities in each region. However, wind wave generation represents a somewhat more challenging problem. Marine environments generally experience the effects of wind waves on a daily basis. Due to computer time and memory constraints, it is not presently possible to continuously model these systems. However, significant insights into the hydrodynamic character of these environments can be obtained by comparison of results obtained from a selection of wind wave events. For this purpose, values of significant wave heights and periods for the regions of interest were obtained from the National Oceanic and Atmospheric Administrion (National Climatic Data Center, 1990) sources. Buoys deployed near the drilling sites record on a regular basis both the significant wave height and dominant wave period. Data obtained for the period from 1979 through 1988 were analyzed to obtain appropriate values for these parameters. Linear wave theory was employed to obtain the maximum bottom orbital velocity for these wave events. Specifically,

$$u_{wbm} = \left(\frac{\pi H_s}{T_s}\right)(\sinh(kd))^{-1} \qquad (1)$$

where u_{wbm} is the maximum bottom orbital speed, k is the wave number, H_s is the significant wave height and d is the local water depth.

Having obtained the relevant fluid velocities, it is now necessary to calculate the appropriate bottom shear stress. Christoffersen and Jonsson (1985) derived friction factors for systems in which the bottom shear stress is due to the coupled effects of wind waves and current velocities. Utilizing a two-layer eddy viscosity model, they found that the total shear stress can be expressed as:

$$\tau_{bm} = \frac{1}{2} f_w \rho (u_{wbm})^2 m \qquad (2)$$

where τ_{bm} is the maximum bottom shear stress, f_w is the friction factor due to waves, ρ is the fluid density, and m is a factor determined from the relative magnitude and direction of the current and wave velocities.

Having derived the bottom shear stress, appropriate relationships between this stress and sediment behaviour must be applied. For these calculations, settling speeds and resuspension criterion must be available. Addressing resuspension first, the probability that material deposited to the sediment bed will remain in situ depends strongly upon the magnitude of the bottom shear stress. Experiments performed by Xu (1991), Tsai *et al* (1987), and MacIntyre *et al* (1990) have resulted in the following relationship:

$$\varepsilon = \frac{a_0}{t_d^2}(\tau - \tau_{cr})^n \qquad (3)$$

where ε is the maximum amount of sediment entrained per unit surface area (gm/cm^2), τ is the local shear stress ($dynes/cm^2$), τ_{cr} is the critical shear stress ($dynes/cm^2$) below which no resuspension occurs, t_d is the time since deposition (days), and a_0 and n are experimentally determined constants. Laboratory studies for fine-grained, cohesive sediments show that a_0 and n are approximately .008 and 3, respectively. The non-linear relationship between shear stress and resuspension will prove to be a determining factor for accurate calculation of sediment transport. In general, a shear stress of less than 1 $dynes/cm^2$ will produce negligible resuspension. The critical shear stress for the fine sands and clay sediments found in both study regions must be determined through field experiments. Since this information was not available for this study, it was assumed that measurable resuspension only occurs for shear stresses in excess of 1 $dynes/cm^2$. The validity of this assumption will be addressed in the discussion section.

Additional laboratory results are used in the model to obtain settling speeds of sediments. These are discussed in detail by Burban *et al* (1990), Gailani *et al* (1990) and Xu (1991). In general, these studies found that settling speeds of flocculating particles exhibit a non-linear dependence upon the suspended solids concentration and the fluid shear stress. Fine-grained cohesive sediments generally have settling speeds from 50 to 150 μm/s.

Having developed equations to accurately model sediment deposition and resuspension, it is now possible to perform numerical calculations of the flow field and sediment transport in the regions of interest.

NUMERICAL CALCULATIONS

Current velocities and directions at Platform Hidalgo are highly variable in the spatial and temporal domains (Minerals Management Service, 1990) and are further complicated by tides which may exceed 1 m in height. For this study, two general flow regimes were compared. In the first, a mean northwesterly flow of 10 cm/s was specified along the boundaries, and the results were compared to those for a southeasterly flow of the same magnitude. The maximum bottom shear stress for these flows was calculated as less than 1 $dynes/cm^2$ throughout the study region.

Calculations for drilling mud ejected at a rate of 7.5 kg/s over a 30 day period for either flow regime indicate that deposition is heaviest within 4 km of the platform (Figure 3). However, due to the water depth, these effluents were dispersed over a spatially wide area with a significant percentage convected out of the study region. Results for a mean southward flow of 10 cm/s and a 50 cm diurnal tide are shown in Figure 4. The influence of the tide was to transport drilling mud toward the near shore environment. In spite of the tidal effect, over 50 percent of the sediment deposited within the study region settled in water in excess of l00 m depth, and 80% settled in water more than 50 m deep. Calculations for a northward flow produced quantitatively similar results.

Figure 3. Drilling mud accumulation for a source at Platform Hidalgo. Discharge rate of 7.5 kg/s for 30 days. Contour interval is 0.0001 g/cm^2.

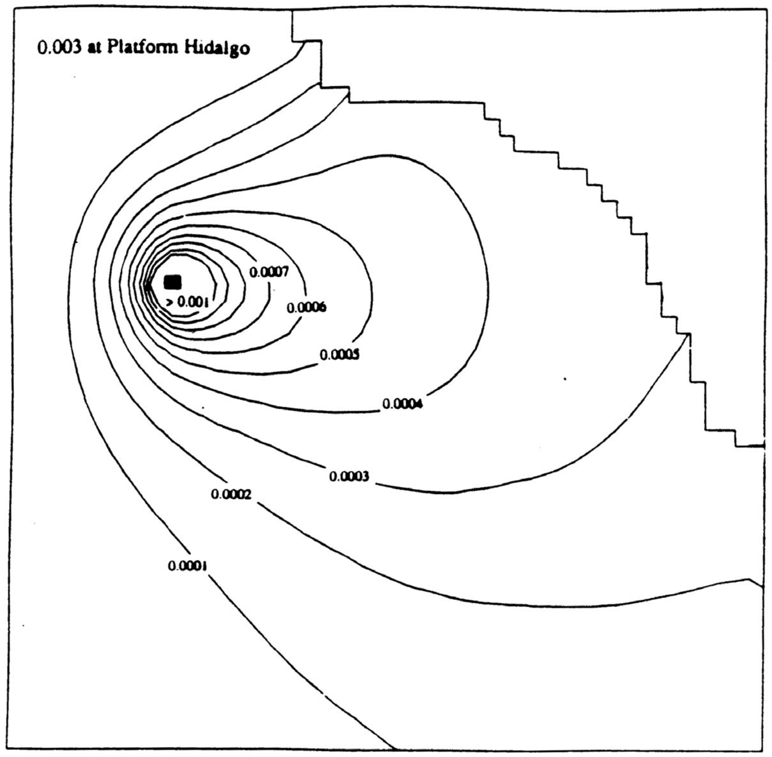
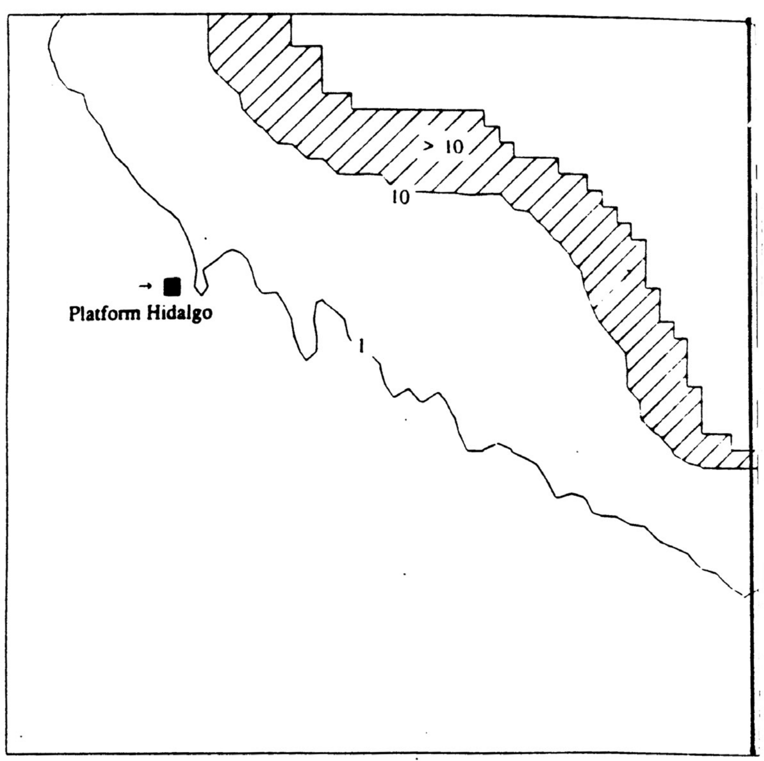


Figure 4. Bottom shear stress for H_s of 250 cm. Contour interval is 10 dynes/cm^2.



A moderate winter storm in the vicinity of Platform Hidalgo generates a significant wave height of 250 cm. Due to the water depth at the platform, maximum bottom shear stresses for this event do not exceed 1 dynes/cm^2, except in the near shore region. As seen in Figure 5, shear stresses in excess of 10 dynes/cm^2 occur in areas less than 50 m depth. The sediment bed for this calculation was specified as containing four layers. Relevant parameters for this sediment bed are illustrated in Table 1. Note that all but the bottom two layers were initially empty. This permits accurate modeling of sediment dynamics during resuspension and deposition (Gailani *et al*, 1990). In addition to the parameters listed in Table 1, it was also assumed that the composition of the sediment varied from 100% coarse material for shallow water (<l0 m), to 100% fine-grained material in water over l00 m in depth. For these conditions, a maximum of 1 gm/cm^2 of sediment was resuspended in regions between 50 m and l00 m depth, with less than 0.1 gm/cm^2 in regions greater than 52 m depth. The amount of sediment resuspended in water more than l00 m deep was negligible. Significant net erosion (>10 gm/cm^2) was present only very near to shore, where depths are less than l0 m and accumulated drilling mud sediment is comparatively small. Calculations showed that, after the storm ended, material resuspended during the event settled primarily in water over 50 m deep. Deposition at Platform Hidalgo was 0.4 gm/cm^2 24 hours after waves subsided. Thus drilling muds deposited prior to the storm experienced minimal resuspension, and were subsequently buried by material transported from shallower areas. Statistically, a storm of this nature will occur at least 20 times annually in the Platform Hidalgo region. Note that the units of erosion and deposition are in mass per unit area. The actual thickness of these layers is dependent upon the water content of the sediment bed. While it is not theoretically possible to evaluate this quantity, a rough approximation is that the thickness is twice the amount of material eroded/deposited in gm/cm^2.

Figure 5. Bottom shear stress for H_s of 900 cm. Contour interval is 10 dynes/cm^2.

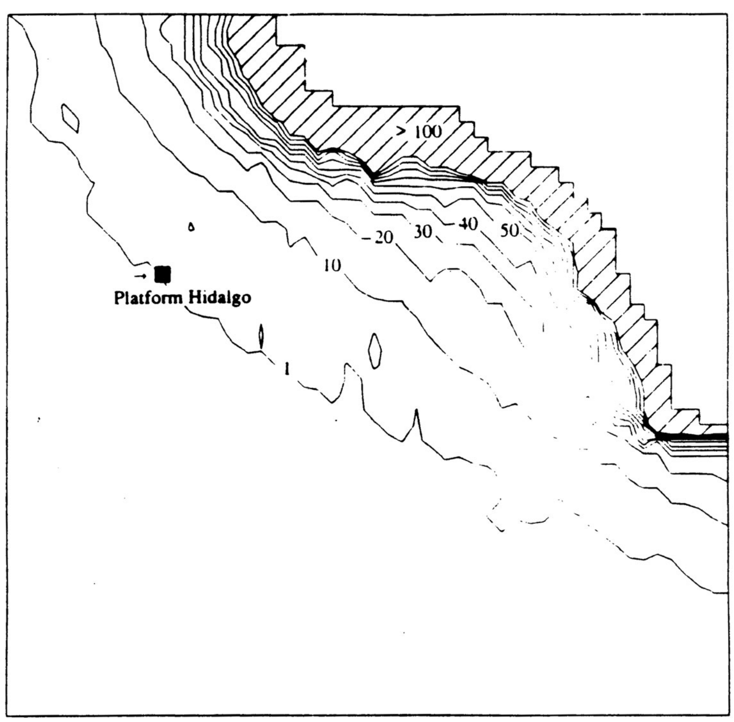
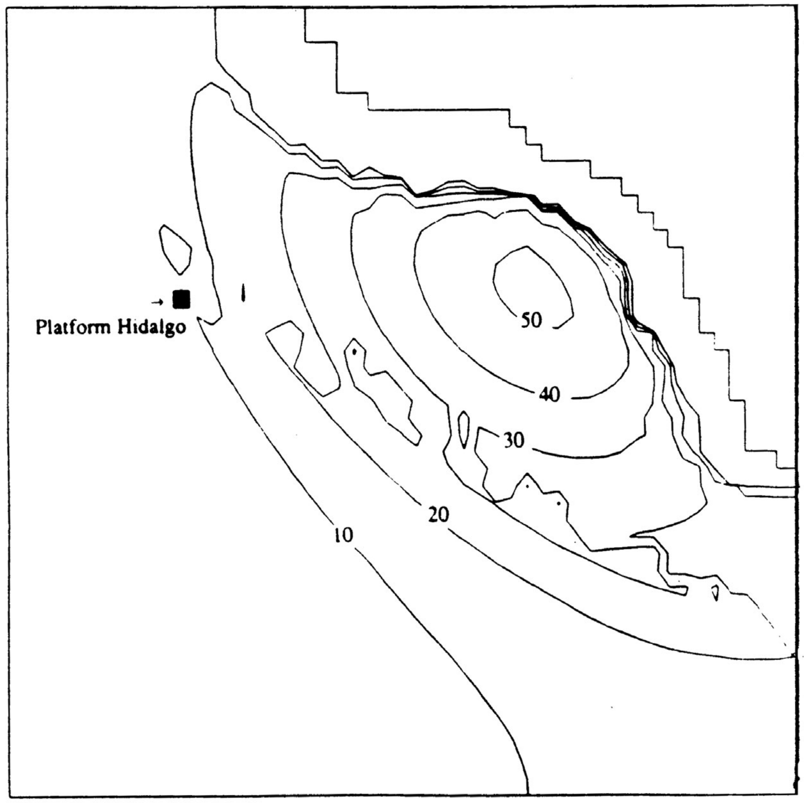


Table 1. Sediment Bed Parameters

Sediment Bed Particles			
Layer	Age (days)	Thickness (gm/cm^2)	Critical Shear Stress ($dynes/cm^2$)
1	0.25	0.0	1.0
2	0.50	0.0	1.0
3	1.00	1.0	1.0
4	7.00	100.0	10.0

According to NOAA buoy data, a storm exceeding 900 cm significant wave height sweeps the Point Arguello region once every ten years. Calculated bottom shear stresses for an event of this magnitude are shown in Figure 5. Clearly these shear stresses are sufficient to cause erosion of sediments deposited in l00 m of water or less, with a maximum bottom shear stress of just less than 1 $dynes/cm^2$ at Platform Hidalgo, and 10 $dynes/cm^2$ at a distance of 2 km east of the platform. The maximum value of bottom shear stress for this storm was calculated at 184 $dynes/cm^2$ in the near shore region. Assuming the same sediment bed as that used for the smaller storm, resuspension of up to 10 gm/cm^2 sediment was resuspended in water of 50m depth during the storm event. No sediment resuspension took place at Platform Hidalgo, since the shear stress was less than the critical value. Calculations show that in excess of 100 gm/cm^2 was resuspended in regions of less than 50 m depth during this huge storm. Since the upper layer was specified as quite thin, most of this represents material resuspended from a layer having a critical shear stress of 10 $dynes/cm^2$. Locations in deep water experienced resuspension of up to 2 gm/cm^2. Note that this is less than the accumulated deposition for several small storms. As the storm subsided, large quantities of suspended solids were transported with the prevailing currents. Deposition of these solids occurred primarily in deeper water, as illustrated in Figure 6. Net deposition at the platform was 10 gm/cm^2 24 hours after the storm ended. Drilling muds resident at the platform would thus be buried under approximately 20 cm of sediment after a huge storm.

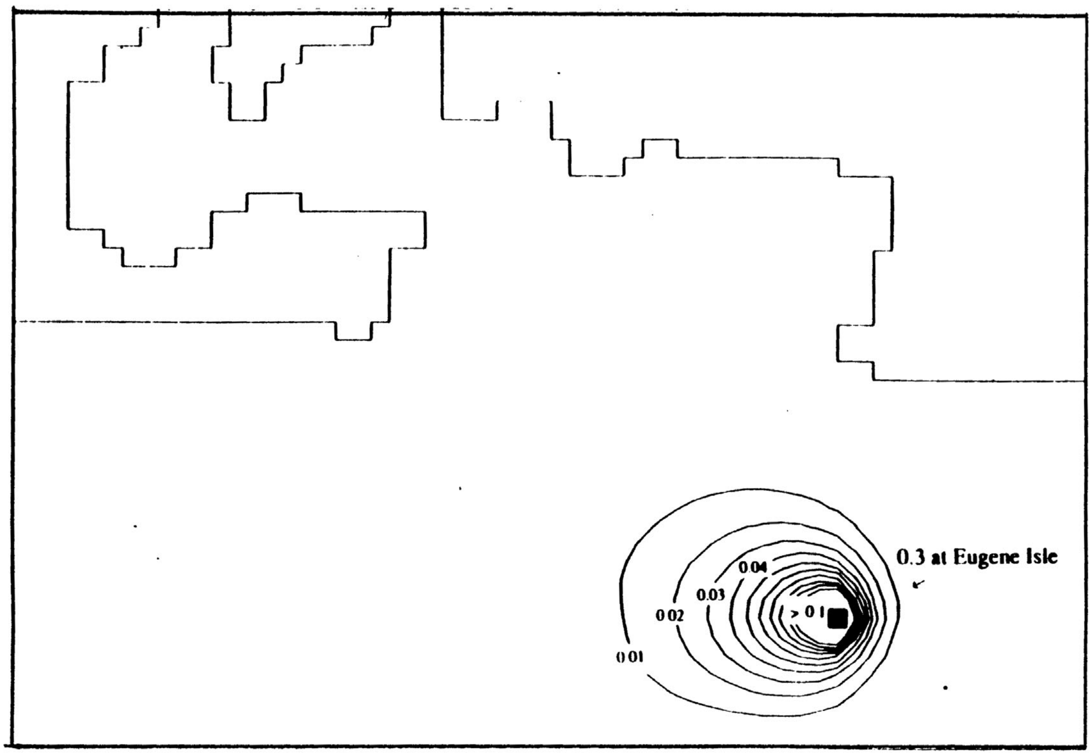
Figure 6. Sediment deposition ten days after subsidence of waves of 900 cm. Contour interval is 10 gm/cm^2.



For the Eugene Isle platform, a mean northwesterly flow of 10 cm/s was specified along the boundaries. This yielded current velocities of 8 cm/s in the vicinity of the platform. Imposition of a 50 cm daily tide did not produce appreciable change in the velocity profile at the platform; tidal influences were most pronounced within the Atchafalaya Bay region. Since this is not an area of interest for this particular study, these findings will not be addressed in detail. The maximum bottom shear stress resulting from these conditions was less than 1 $dynes/cm^2$ at the platform. As mentioned previously, shear stresses less than this critical value result in only negligible amounts of resuspension.

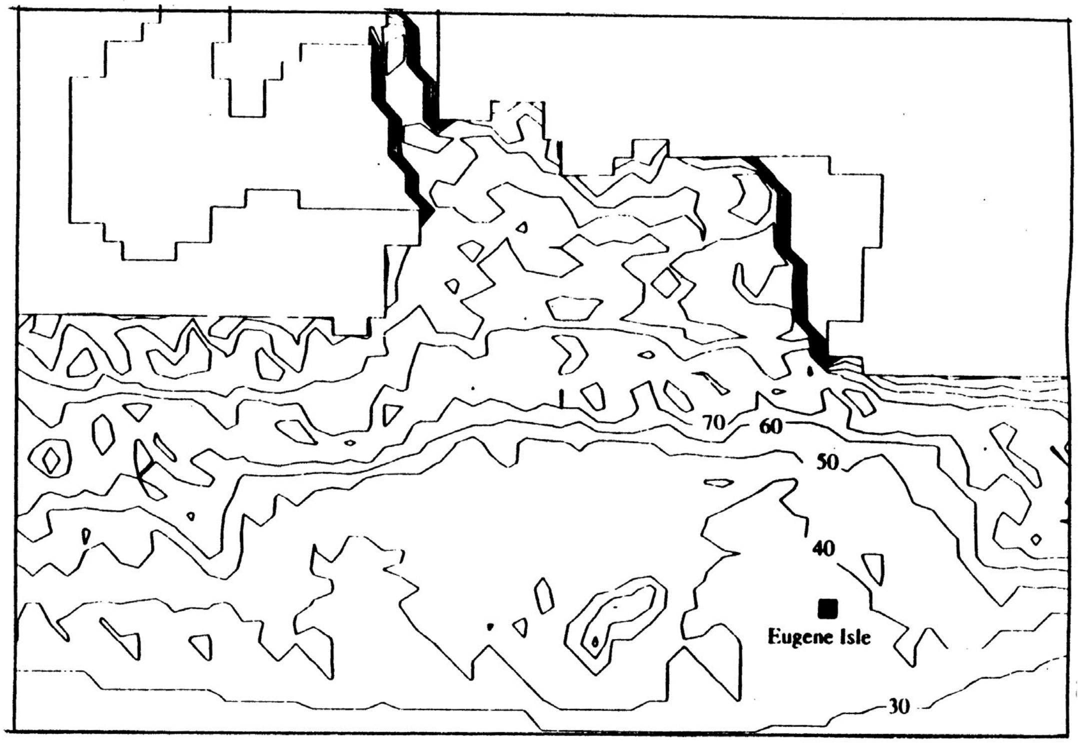
Calculated deposition for drilling mud discharged from the platform at a rate of 7.5 kg/s is shown in Figure 7. The shallowness of the water coupled with a low bottom shear stress resulted in heavy deposition of these sediments in the immediate vicinity of the platform.

Figure 7. Drilling mud accumulation for a source at Eugene Isle. Discharge rate of 7.5 kg/s for 30 days. Contour interval is 0.01 gm/cm^2.



Vigorous storms in the Gulf of Mexico occur most frequently during the winter months. Currents during this season flow to the northwest. A storm of moderate intensity will result in a significant wave height of 150 cm; statistically, waves of this magnitude will be present at least 50 times per year. Calculations for this typical storm generate a bottom shear stress of 35 dynes/cm^2 at Eugene Isle and up to 83 dynes/cm^2 in the near shore regions (Figure 8). The sediment bed parameters for the Gulf of Mexico were the same as those employed for Platform Hidalgo, except that the bed was assumed to consist of 70% coarse-grained material throughout the study region. For these conditions, approximately 6 gm/cm^2 was resuspended at the platform during the storm. As the waves subsided, settling of these suspended solids, as well as those eroded from the near shore regions, took place. Twenty-four hours after the storm ended, total deposition at the platform of 8 gm/cm^2 was calculated, resulting in a net deposition of 2 gm/cm^2 at Eugene Isle. Areas of net erosion occurred only in the shallowest region near shore (>50 gm/cm^2).

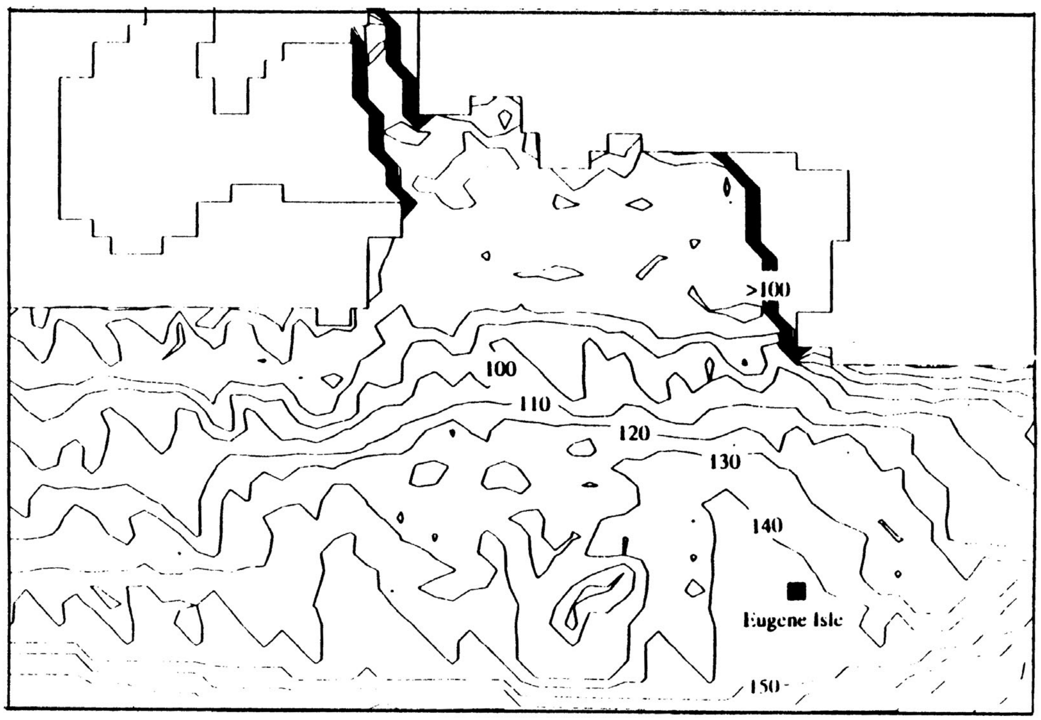
Figure 8. Bottom shear stress for H_s of 150 cm. Contour interval is 10 dynes/cm^2.



Drilling mud eroded near the platform during the storm was transported with the prevailing currents, settling out when the shear stress declined to less than 1 dynes/cm^2.

According to NOAA data, a storm event having a significant wave height of 850 cm will occur only once in a ten year period. For this very large storm event, bottom shear stresses exceed 150 dynes/cm^2 at the platform. The distribution of calculated bottom shear stresses for this event is shown in Figure 9. Extensive erosion of bottom sediments occurs during an event of this magnitude. Assuming a critical shear stress of 1 dynes/cm^2 for all layers, over 5 m of sediment will be resuspended at the platform. Since this is not a realistic occurrence, a five layer sediment bed was assumed with very high critical shear stresses of 10 dynes/cm^2 and 100 dynes/cm^2 and thicknesses of 100 gm/cm^2 and 1000 gm/cm^2 for the fourth and fifth layers of the sediment bed, respectively. All other parameters for the sediment bed were unchanged from the previous calculation. During the storm, the calculated erosion was 119 gm/cm^2 at the platform, decaying to a net erosion of 19 gm/cm^2 twenty-four hours after the storm ended. As for the smaller storm, resuspended material was transported by the currents.

Figure 9. Bottom shear stress for H_s of 850 cm. Contour interval is 10 dynes/cm^2.



DISCUSSION OF RESULTS

Numerical calculations for the transport and fate of drilling muds have been performed for offshore oil platforms located in both shallow and deep water. Conditions examined included normal current and tidal phenomena, typical winter storms, and severe, low-probability storms. Results of these calculations coupled with experimental studies show that the amount of material resuspended is strongly dependent upon the magnitude of the bottom shear stress. To illustrate this point, consider a uniform bed located in the vicinity of Eugene Isle having a critical shear stress of 1 dynes/cm^2. A significant wave height of 150 cm in l0 m of water generates a bottom shear stress of 13 dynes/cm^2 and resuspension of 1.2 x 10^{-1} gm/cm^2. Increasing H_s by a factor of roughly 5 results in a non-linear increase in the bottom shear stress to approximately 200 dynes/cm^2 with a concomitant increase in the amount of sediment resuspended by a factor of 10^4. In deep water, the erosional influence is less severe due to decreased values of u_{wbm}. However, significant quantities of material will be transported from shallow regions, resulting in heavy deposition of near-shore sediments during large storms. To illustrate this point, consider that increasing H_s by a factor of 3.5 in the Platform Hidalgo region resulted in an increase in deposition by a factor of 50. If the sediment bed had been assumed uniform, the amount of deposition in deep water would have been significantly greater. Clearly, the relationship between sediment deposition and shear stresses is also highly non-linear.

In real physical systems, sediment beds are not uniform. If field data is not available, the properties of these beds must be approximated using a reasonable set of assumptions, and through numerical experimentation to evaluate the correspondence of calculations to probable physical outcomes. The sediment beds assumed for these calculations were developed utilizing the following: 1) laboratory experiments for river, lake, and oceanic sediments (Xu, 1990; Tsai *et al*, 1987; MacIntyre *et al*, 1990), 2) field data for continental shelf sediments (Larsen *et al*, 1980), 3) field data for study regions (Neff, 1988) and (MMS, 1990), and 4) numerical experimentation to determine reasonable sediment layering.

There are several factors which must be considered with regard to these assumptions, most significant of which is the dearth of laboratory studies for resuspension of buried marine sediments subjected to high shear stresses, and for drilling muds in marine environments. In particular, the empirical relationship utilized (Eqn 3) was derived for sediments under low (<15 dynes/cm^2) shear stress conditions. While current studies indicate that the general form of the relationship for resuspension versus shear stress is valid for a wide range of sediments, the problem of high shear stresses has yet to be resolved.

Yet another concern relates to the actual layering of the sediment bed and the assumed composition of this bed. Numerical experimentation is highly subjective, especially in studies such as this in which complete field data is unavailable. Values of the critical shear stress for the upper layers have been documented for the California continental shelf in the literature (Larsen *et al*, 1980; Drake, 1976; MMS .1990). Some studies have indicated that lower threshold values may apply (Miller *et al* 1977). Thus the assumption for the upper layers may be considered within the range of available data for Platform Hidalgo, and may even be too conservative. The assumption that the critical shear stress increases with depth is certainly reasonable from a physical standpoint, but exact values must be found from field studies. Similar studies were not available for the Gulf of Mexico. It was therefore necessary to assume that conditions were similar to those found along the California coast. Results for this region would be more satisfactory if parameters for Eqn 3 were available for sandy material.

The issues addressed in the preceding discussion must not obscure the fact that this study resulted in quantitative evaluation of the transport, deposition, and resuspension of drilling muds and marine sediments. While refinements to the process are needed, the non-linearity of the relationship between resuspension and shear stress represents a fundamental parameter in the accurate calculation of sediment transport. Integrating laboratory studies, field data, and numerical modeling, it has been found that large storms are responsible of disproportionately greater amounts of sediment and pollutant transport when compared to smaller storms.

CONCLUSION

Determination of the ultimate fate of drilling muds discharged from offshore oil platforms requires a proper evaluation of the hydrodynamic character of the discharge region as well as an accurate calculation of suspended solids transport and sediment resuspension/deposition behaviour. A numerical model possessing these characteristics has been employed to analyze the fate of drilling muds discharged from a platform sited in deep water at Platform Hidalgo on the California coast, and at a shallow water location at Eugene Isle in the northern Gulf of Mexico.

Calculations for both sites reveal that large storms can resuspend drilling muds deposited in both deep and shallow water, although the influence of these storms in shallow water is considerably more pronounced. For the deep water site, small storms were found to resuspend sediments from areas with minimal drilling mud deposition, and to subsequently deposit this material in deeper water where drilling muds are more likely to be found. Typical storms in shallow water generated bottom shear stresses large enough to erode significant quantities of drilling mud deposited in these environments. During large storms, the amount of sediment resuspended increases dramatically.

It must be noted that the extent of erosion is strongly dependent upon the choice of sediment bed properties. Due to lack of available field data for these study regions, these results must be viewed as general descriptions of the transport and ultimate fate of drilling muds in marine environments. However, the non-linear relationship between resuspension/deposition and bottom shear stress leads to the conclusion that large storms account for the most significant quantities of sediment transport in both shallow and deep water environments.

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The Department of the Interior Mission

As the Nation's principal conservation agency, the Department of the Interior has responsibility for most of our nationally owned public lands and natural resources. This includes fostering sound use of our land and water resources; protecting our fish, wildlife, and biological diversity; preserving the environmental and cultural values of our national parks and historical places; and providing for the enjoyment of life through outdoor recreation. The Department assesses our energy and mineral resources and works to ensure that their development is in the best interests of all our people by encouraging stewardship and citizen participation in their care. The Department also has a major responsibility for American Indian reservation communities and for people who live in island territories under U.S. administration.

The Minerals Management Service Mission

As a bureau of the Department of the Interior, the Minerals Management Service's (MMS) primary responsibilities are to manage the mineral resources located on the Nation's Outer Continental Shelf (OCS), collect revenue from the Federal OCS and onshore Federal and Indian lands, and distribute those revenues.

Moreover, in working to meet its responsibilities, the **Offshore Minerals Management Program** administers the OCS competitive leasing program and oversees the safe and environmentally sound exploration and production of our Nation's offshore natural gas, oil and other mineral resources. The MMS **Royalty Management Program** meets its responsibilities by ensuring the efficient, timely and accurate collection and disbursement of revenue from mineral leasing and production due to Indian tribes and allottees, States and the U.S. Treasury.

The MMS strives to fulfill its responsibilities through the general guiding principles of: (1) being responsive to the public's concerns and interests by maintaining a dialogue with all potentially affected parties and (2) carrying out its programs with an emphasis on working to enhance the quality of life for all Americans by lending MMS assistance and expertise to economic development and environmental protection.