THE RELATION BETWEEN SIDESCAN-SONAR IMAGERY AND SEDIMENT PHYSICAL PROPERTIES: A COMPARISON OF TWO DEEP-SEA FAN SYSTEMS

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1. INTRODUCTION

The use of sidescan-sonar technology has expanded greatly in recent years in the marine geology community. Sidescan-sonar images, particularly if they are mosaicked together, provide a representation of large areas of the sea-floor, as opposed to information at a point, as is obtained from a core, or information along a track-line, as is obtained from a subbottom profile. Accordingly, the images serve somewhat the same role as that of an aerial photograph in subaerial geologic studies. One difficulty encountered in interpreting sidescan-sonar images, however, is an absence of a full understanding of the physical meaning of variations in acoustic backscatter intensity. There is a need for ground-truth studies to understand the causes of backscatter. We need to measure variations in physical and geometric properties of the sea-floor and compare them with variations in sidescan-sonar acoustic backscatter. We present in this paper comparative ground-truth studies of two deep-sea fan depositional lobes.

Conventional thinking about sidescan sonography [1] holds that some of the sea-floor characteristics that cause variations in backscatter intensity are: surface roughness, sediment composition, grazing angle, and topographic variability. The influence of each of these and the subbottom depth range over which sediment compositional variations are important will vary with the characteristics of the sidescan system used, particularly the frequency. To simplify a ground-truth study, the number of variables evaluated needs to be kept to a minimum. Accordingly, deep-sea fan systems are convenient locations for such studies because they tend to have nearly horizontal sea-floor surfaces. As a result, the topographic variability-bottom slope effect can be ignored. Also, deep-sea fan systems commonly include sandy deposits. Contrast between the physical character of these sandy deposits and that of surrounding muddy hemipelagic deposits is strong and provides an opportunity to evaluate the influence of sediment composition on backscatter intensity.

2. APPROACH

We conducted investigations of the distal depositional lobes of two major deep-sea fan systems, the Monterey fan in the eastern Pacific Ocean and the Mississippi fan in the Gulf of Mexico. In both cases we had available to us mosaics of long-range GLORIA [2] sidescan-sonar data [3, 4], which we used to identify juxtaposed high- and low-backscatter areas. For both fans, the region of highest backscatter was interpreted to be the most recent depositional lobe of the fan.

In the Mississippi fan study, the GLORIA mosaic was used as a reconnaissance tool to select an area (Fig. 1) for a higher resolution sidescan-sonar study using the SeaMARC IA system. Both sonar systems showed high backscatter areas interpreted as depositional lobes; the SeaMARC IA system, however, showed much greater detail in discerning a complex pattern of dendritic sublobes [5]. We used the SeaMARC IA mosaic as a basis for selecting piston and gravity coring locations (Fig. 2). We placed coring stations within the depositional lobes and beyond these lobes in basin-plain (hemipelagic) sediment. We consider 17 of these coring stations in the present paper. These cores (20-650 m long) are situated in the vicinity of three recently active sublobes [6] termed the 'young sublobe', the 'intermediate sublobe', and the 'old sublobe'.

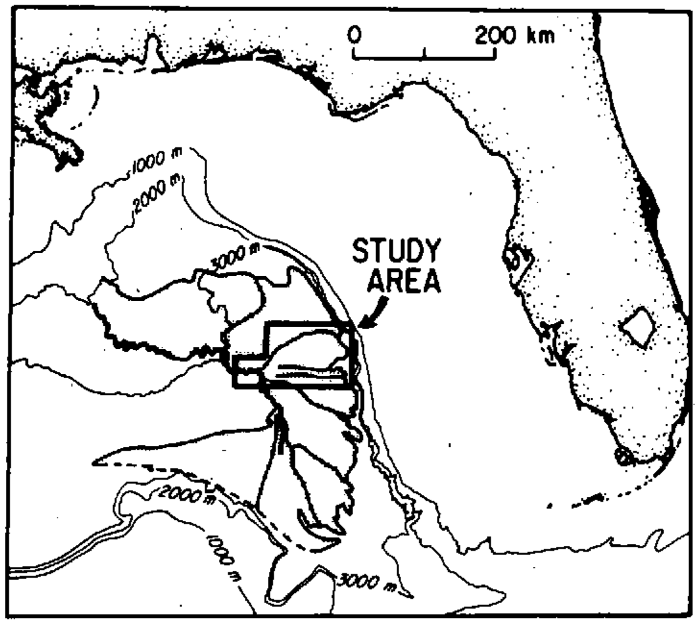

Figure 1-Location map-Mississippi fan study area

In the Monterey fan study area (Fig. 3), the GLORIA mosaic shows an area of generally high backscatter corresponding to the area interpreted to be the most recent depositional lobe [7]. Within this high backscatter area, however, we discerned a curious digitate low backscatter area (Fig. 4), which is termed the 'fingers' area [7]. We performed a detailed study over the 'fingers' area and the surrounding high backscatter area using bottom photography, high-resolution subbottom profiling, and piston and box coring. A later cruise surveyed the 'fingers' area using TOBI, a 30-kHz deep-towed sidescan sonar [8]. Properties of fourteen box cores (20-60 cm long) are included in this paper.

We measured downcore variations in density (calculated from water content assuming 100% saturation) and compressional-wave sound velocity for all cores taken in both fan systems. Compressional-wave sound velocity results from Mississippi fan cores are not yet available, and velocities presented here were estimated from density values using Hamilton's [9] correlation for continental terraces. Acoustic impedance is the product of density and sound velocity.

3. RESULTS

3.1 Mississippi Fan

Cores near the edges of distal lobes of Mississippi Fan show a clear association between the occurrence of sediment with a relatively high-acoustic impedance and high backscatter on the SeaMARC IA mosaic. Cores from the high-backscatter areas have sandy turbidites or chaotic silt beds [6] (suggestive of debris flow deposits) buried under 9 to 230 cm of hemipelagic mud. The muds overlying the sands or chaotic silts have similar properties to those present in the surrounding basin plain (Table 1) and could not cause the backscatter patterns. Accordingly, the subsurface sands and chaotic silts almost certainly produce the high backscatter. Such a relation between sand presence and high acoustic backscatter is in keeping with conventional thinking [1], although it suggests that the 30-kHz signal of Sea MARC IA penetrates at least 2.3 m into the sediment.

The sediment from the low-backscatter areas beyond the acoustically defined lobes and sublobes is characteristically a nearly uniform hemipelagic gray clay with occasional thin silt laminae for the uppermost 4-6 m that was cored. The hemipelagic sediment displays low backscatter on the sidescan mosaic. For a quantitative comparison, we averaged the downcore acoustic-impedance measurements (taken at a 2 to 10 cm spacing) for each core in the hemipelagic acoustic facies. Values of the 'DN' (digital number, a relative measure of the intensity of backscatter), were obtained over an 11x11 pixel grid (representing a 137x137 m

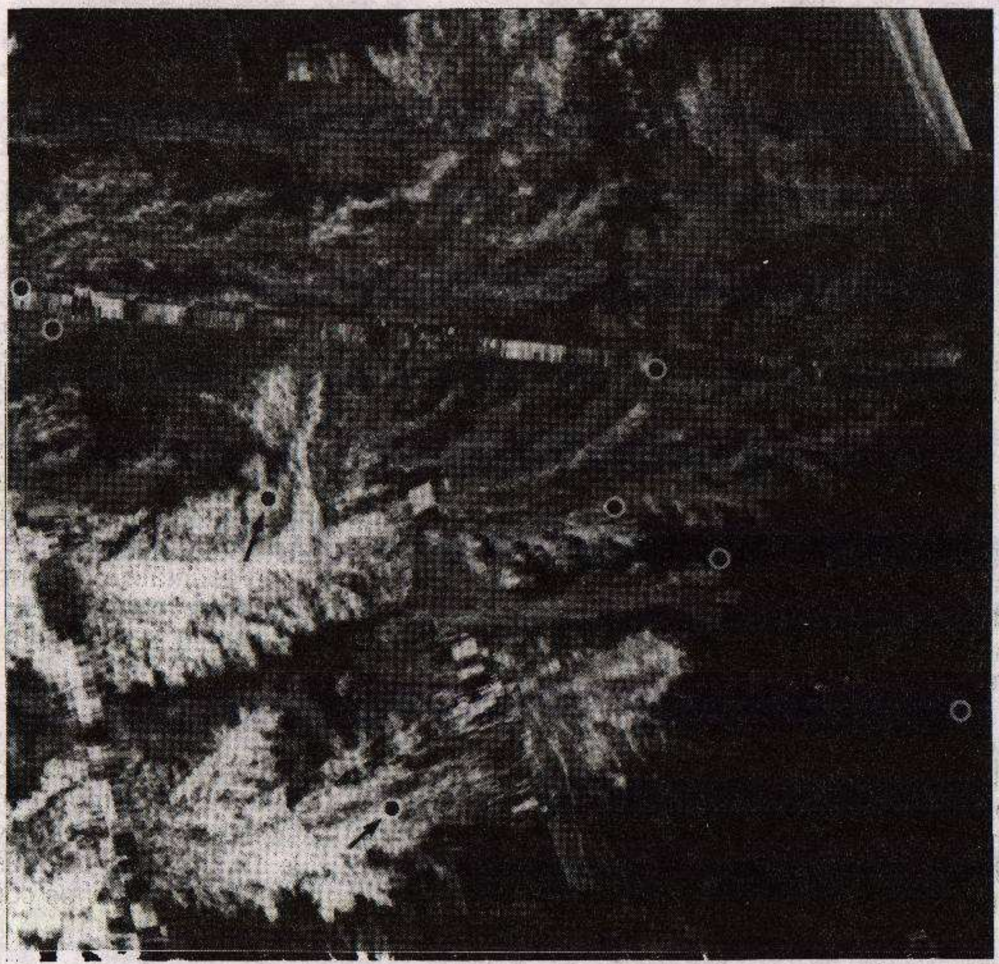

Figure 2-SeaMARC IA imagery of part of the intermediate sublobe of the Mississippi fan study area. Locations of some of the cores considered in the present study are shown by dots. The image represents a 10.3 by 9.8 km area.

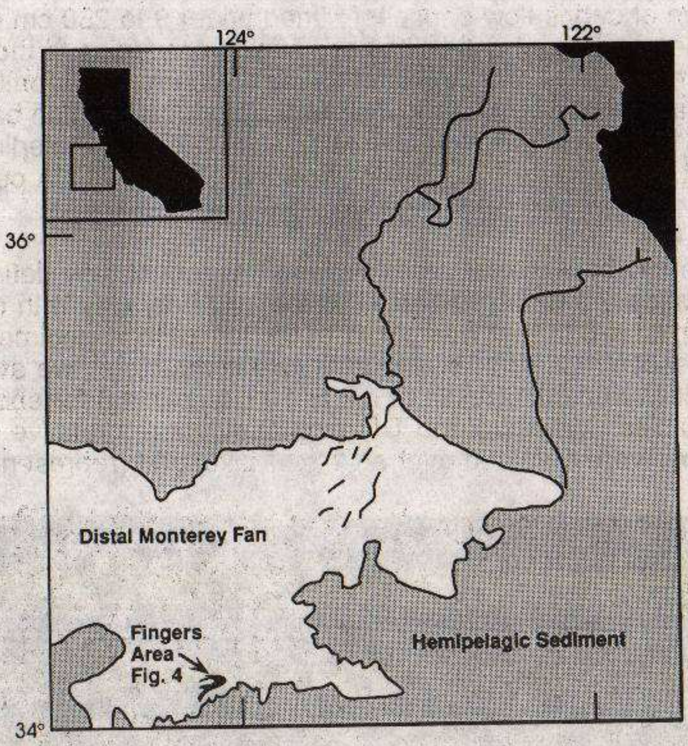

Figure 3-Location map-Monterey fan study area

area) surrounding the location of each core and averaged to obtain a representative value for each location. The mean of the five mean 'DN' values for the cores considered was taken to represent the hemipelagic acoustic facies (Fig. 5a).

The sandy turbidite-chaotic silt facies ('sediment below first facies interface') has a higher mean acoustic impedance than the overlying hemipelagic mud (3.28 vs. 2.25 g/scx10^5, Table 1). For the 'young sublobe', the corresponding value of 'DN' is also much higher than the value for the surrounding hemipelagic gray clay (Fig. 5a). Proceeding from the 'young sublobe,' through the 'intermediate sublobe' to the 'old sublobe', the mean 'DN' value representative of coring stations considered within each acoustic facies decreases almost linearly with the mean thickness of overlying hemipelagic mud (Fig. 5b). Such a decrease most likely results from sound attenuation in the hemipelagic mud.

3.2 Monterey Fan

Virtually all of the cores from the low-backscatter 'fingers' area of Monterey fan showed a similar lithology: approximately 10 cm of muddy sediment overlying a thick (44 cm or more) unit of graded sand. The sand has density and sound velocity characteristics that are remarkably similar to those of sandy turbidites from the Mississippi fan (Table 1). The only obvious difference between the Monterey and Mississippi sands is that the Monterey sands contain less mud (16% mud vs 48% mud for the Mississippi sands).

The depositional lobe deposits that surround the 'fingers' area are varied and contain hemipelagic mud, mud and silt clasts, apparent debris-flow materials, and some sandy turbidites. The mean acoustic impedance of the sediment sampled with a box corer from these

Figure 4-GLORIA imagery-Monterey fan study area. Locations of cores considered in the present study are shown by dots

deposits was low (2.41 g/scx10^5) relative to that of the sand from the 'fingers' area (3.2 g/scx10^5). A surprising observation is that the sand-rich 'fingers' area appears dark (lower backscatter) against the relatively bright (higher backscatter) distal fan deposits on GLORIA imagery (Fig. 4). In addition, the 'fingers' did not show up at all on the high-resolution TOBI sidescan-sonar survey.

The abyssal hill hemipelagic sediment that lies beyond the distal fan deposits has a similar acoustic impedance (2.16 g/scx10^5) to that of the basin-plain sediment beyond the Mississippi sublobes. That this sediment also produces low acoustic backscatter in contrast with the neighboring deep-sea fan is in keeping with conventional wisdom.

Figure 6 shows these results quantitatively in the form of mean acoustic impedance vs 'DN' value (corrected for slant range but otherwise unprocessed) from the GLORIA mosaic (not directly comparable with the 'DN' values from the SeaMARC IA). The sandy sediment from the 'fingers' area has the highest acoustic impedance and the lowest amount of backscatter, even lower than that of the hemipelagic sediment that surrounds the fan.

Table 1. Average properties of cores from Monterey and Mississippi fan study areas

	Monterey Fan	Mississippi Fan
Acoustically defined 'fingers' area (Monterey) or lobe areas (Mississippi):		
Mud above first facies interface:		
Thickness (cm)	10	9 ("young sublobe'), 76 ('intermediate sublobe"), 230 ('old' sublobe')
Sound velocity (km/s)	1.55	1.54 (estimated)
Density (g/cc)	1.43	1.46
Acoustic impedance (g/scx10^5)	2.21	2.25
Sediment below first facies interface (sandy turbidites and chaotic silts):		
Mean thickness (cm)	>44	48 (range of 10-100)
Sound velocity (km/s)	1.74	1.72 (estimated)
Density (g/cc)	1.84	1.91
Acoustic impedance (g/scx10^5)	3.20	3.28
Mean % sand	84	52
High backscatter area surrounding 'fingers'; Monterey fan:		
Sound velocity (km/s)	1.59	
Density (g/cc)	1.52	
Acoustic impedance (g/scx10^5)	2.41	
Hemipelagic sediment beyond fan deposits:		
Sound velocity (km/s)	1.50	1.53 (estimated)
Density (g/cc)	1.44	1.40
Acoustic impedance (g/scx10^5)	2.16	2.14

4. DISCUSSION

Most of the results of this study agree with the conventional thinking that sandy sediment produces higher backscatter in comparison with muddy sediment. A puzzling result is the response of the 'fingers' area on Monterey fan, where a sandy deposit appears to produce lower backscatter than mud. The comparative results from the Mississippi fan reinforce the puzzling nature of the 'fingers': the sedimentology and physical properties of the Mississippi sublobe sands are almost identical to those of the 'fingers' sands but produce an opposite backscatter response.

One partial explanation for this paradox may lie in the geologic complexity of fan deposits that surround and underlie the sandy deposit of the 'fingers' area. The deposits are highly heterogeneous and likely contain internal inhomogeneities such as mud clasts that could serve as good volume scatterers of sound. Also, the properties shown in Table 1 were measured on box core samples that were only 20 to 60 cm long. Because the GLORIA system has a frequency of 6.5 kHz, sound probably penetrated deeper into the sea-floor and may have

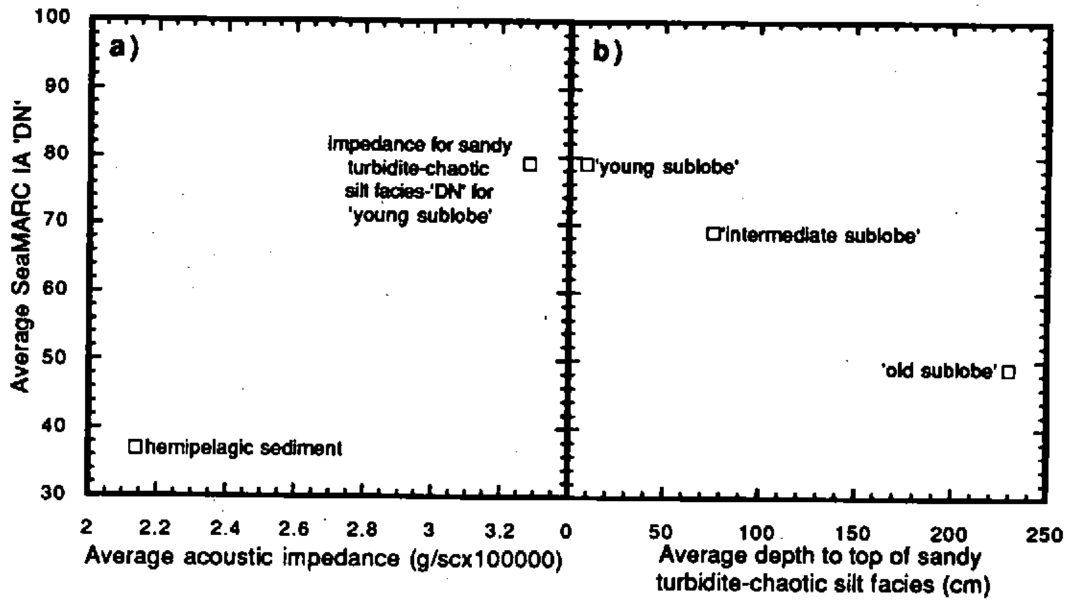

Figure 5-Sediment characteristics vs. 'DN'; Mississippi fan study area

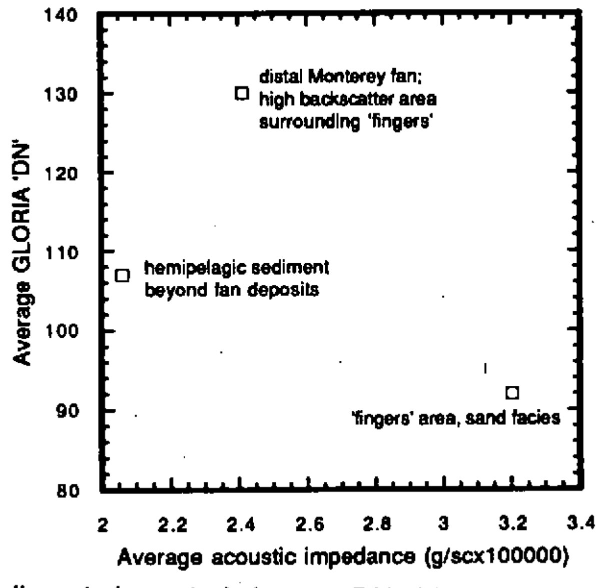

Figure 6-Sediment characteristics vs. 'DN'; Monterey fan study area

backscattered from more deeply buried sediment having a high acoustic impedance [7]. Finally, bottom photography showed large sonar targets (typically rocks) estimated to be larger than 20 cm and ranging up to 2 m or more. There was a slightly greater propensity for these objects to be found in association with the fan deposits away from the 'fingers'. Accordingly, the fan deposits may be much better scatterers of sound than suggested by the results of tests on box cores, and the very high backscatter ('DN' values in Fig. 6) from the fan deposits may be explained in this way. If so, a partial explanation for the dark appearance of the 'fingers' is contrast with the very high backscatter from the distal fan.

Contrast with an area of very high backscatter is not the full explanation for the darkness of the 'fingers', however. The GLORIA 'DN' values (corrected for slant range but otherwise unprocessed) show that the 'fingers' area produces even less backscatter than the hemipelagic sediment surrounding the distal fan (Fig. 6). Accordingly, this is a clear example of a sandy deposit producing less backscatter than a mud. Attributes that could cause such low backscatter are (1) a very smooth sand surface that would reflect most sound away from the ship rather than scatter it back and (2) significant sand thickness and coarseness that would attenuate sound passing into the sand and prevent backscattering from deeper reflectors or volume scatterers. We observed that the sand from the 'fingers' has a lower mud content and possibly is thicker than the sand from the Mississippi fan. Both of these factors could lead to greater attenuation. Possibly some quality of the Monterey fan 'fingers' sand also leads to a very smooth surface, but this quality has not been identified.

5. CONCLUSION

Sidescan-sonar is a valuable tool for mapping sediment facies variations in topographically simple environments. As a rule, coarser sediment produces greater acoustic backscatter but the rule is not universal. Unexplained acoustic interactions can lead in some cases to an inverse correlation between sediment grain size and backscatter. Clearly, those interpreting mosaics should be cautious in believing that coarser sediment textures necessarily result in higher backscatter. Physical sampling of sediment deposits is advised to confirm interpretations derived from sidescan-sonar imagery.

6. REFERENCES

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