25. SOURCES OF SAND FOR THE MISSISSIPPI FAN[1]

Jim Mazzullo, Texas A&M University[2]

ABSTRACT

The shape characteristics of detrital quartz sand grains from the Mississippi Fan indicate that this submarine fan received sediment from both the Mississippi River and the rivers of the southeastern United States during the Pleistocene.

INTRODUCTION

The Mississippi Fan is a broad, thick arcuate accumulation of sediment that extends from the distal end of the Mississippi Delta into the northeastern corner of the Gulf of Mexico. The fan consists of seven discrete fan lobes, the youngest of which was drilled and cored during Leg 96 of the Deep Sea Drilling Project. The sediment of this fan lobe is composed of interbedded siliciclastic and some calcareous gravel, sand, and mud which was deposited in channel, levee, and overbank environments during the late Wisconsin low stand of sea level (introductory chapter, this volume).

During the late Wisconsin, the Mississippi Fan received siliciclastic sediment from the erosion of fluvial, deltaic, and littoral deposits on the present northeast Gulf of Mexico shelf and slope. Various investigators have recognized that there are two distinct sedimentary petrologic provinces for the late Quaternary siliciclastic sediment of the southern United States. The first is the Mississippi Province, which consists of relatively immature sediment derived from the continental interior of the United States and transported to the Gulf Basin by the Mississippi River. The second is the Eastern Gulf Province, which consists of highly mature sediment derived from the southern Appalachians and coastal plain and transported to the Gulf Basin by the numerous small rivers of the southeast United States (most notably the Apalachicola and Alabama Rivers; Hsü, 1960; Mazzullo and Bates, 1985).

The main conduit for the transport of Mississippi Province sediment to the fan would have been the Mississippi Canyon, which received sediment directly or indirectly from the Mississippi River during the low stand. The Mississippi Canyon was also a conduit for Eastern Gulf Province sediment, which was transported from the northeast Gulf of Mexico to the head of the Mississippi Canyon by fluvial and littoral systems (Fisk and McFarlane, 1955). In addition, because of its proximity to the Mississippi Fan, it can be speculated that De Soto Canyon, which drains the northeast Gulf of Mexico shelf and slope, was also a conduit for Eastern Gulf Province sediment.

In short, it can be hypothesized that the sediments of the Mississippi Fan are a mixture of both Mississippi and Eastern Gulf Province sediments. The purpose of this study was to determine the sources of sand for the Mississippi Fan and to test this hypothesis.

The sands of the two provinces have distinctive mineralogical and quartz-grain shape characteristics (van Andel and Poole, 1960; Hsü, 1960; Bates, 1984); thus, a comparison of these petrographic characteristics to those of the sands of the Mississippi Fan could be employed to achieve the stated goal. In this study, we employed quartz-grain shape analysis as the principal means of determining the sources of sand for the Mississippi Fan, as this technique is easily practiced upon the small samples usually dispensed by DSDP. We then complemented these data with a limited number of mineralogical analyses of representative samples.

TECHNIQUES

Grain shape and mineralogical analyses were conducted on the fine-sand fraction of each sample discussed in this study. This limitation on grain size is required in any source study to avoid variations in grain shape and mineralogy which may result solely from grain-size variation (Griffiths, 1967). Thus, the results of this study *in sensu stricto* refer only to this grain size, although cautious inferences could be made from these data about the sources of coarser or finer sand fractions.

Grain-shape measurement of the fine-sand fraction was also restricted to quartz grains, so as to avoid any shape variation caused by mineralogical variation (Griffiths, 1967). To prepare each sample for this analysis, the fine sand fraction was isolated by sieving and treated with 50% HCl and 19% HF to dissolve or etch nonquartzose detritus (Schultz, 1980). When necessary, samples were passed through a magnetic separator to remove any remaining nonquartzose detritus. A small split of each processed sample was then mounted in glycerine on a petrographic slide, and the edges of the maximum projection profiles of 200 fine quartz sand grains were digitized by an operator with the aid of an automated videodigitizer, ARTHUR II (Mazzullo and Kennedy, 1985).

From these raw edge-point data, the shape of each fine quartz sand grain was measured by a Fourier series in closed form (Ehrlich and Weinberg, 1970). Each grain's shape is represented by a series of terms, called "harmonics," each of the form

$$Rn \cos(n\theta - \phi n)$$

where Rn represents the "amplitude," or relative contribution, of the nth harmonic and the remainder concerns the phase angle of that harmonic. In our procedure, we routinely calculated amplitude values for Harmonics 2 through 24, for we have found through numerous tests that this number of harmonics is sufficient to measure precisely the shapes of most detrital quartz grains.

In general, the nth harmonic amplitude represents the contribution of a circular shape with n evenly-spaced nodes to the observed shape

[1] Bouma, A. H., Coleman, J. M., Meyer, A. W., et al., *Init. Repts. DSDP*, 96: Washington (U.S. Govt. Printing Office).

[2] (Address) Department of Geology, Texas A&M University, College Station, TX 77843.

of the grain. The amplitudes of the lower-order harmonics (numbered 2 through 6) are measures of overall form, or gross shape, of grains, while the amplitudes of the higher-order harmonics (numbered 7 through 24) are measures of their overall angularity or roundness. The second harmonic amplitude, for example, measures the contribution to the observed shape of a binodal "figure eight," and is thus a measure of elongation (or sphericity, which is the absence of elongation); a grain with a relatively high second-harmonic amplitude value would be more elongate than one with a relatively low second-harmonic value. The tenth harmonic amplitude, on the other hand, measures the contribution of a decanodal (10-nodal) figure, and is thus a measure of grain roundness or angularity; a grain with a relatively high tenth harmonic amplitude value would be more angular than one with a relatively low tenth harmonic amplitude value.

To prepare samples for mineralogical analysis, the fine-sand fraction was again isolated by sieving, and then impregnated with epoxy resin, thin-sectioned, and stained to aid in the identification of feldspars. Compositional analyses were made using the Glagolev–Chayes method (Carver, 1971). In each slide, point-counting proceeded until 100 monocrystalline quartz grains were counted, and the data were tabulated in number percentages.

This brief description of these procedures illustrates the relative practicality of shape analysis over mineralogical analysis, and the reason why the former procedure was chosen as the principal method in this study. Most of the samples provided by DSDP are relatively small (5 to 10 cm^3) and poorly sorted. Thus, it was always possible to extract sufficient numbers of fine quartz sand grains from these samples for shape analysis, but with some exceptions not possible to extract sufficient volumes of fine sand for sample impregnation and thin-sectioning for mineralogical analysis.

PETROGRAPHY OF MISSISSIPPI AND EASTERN GULF PROVINCE SAND

The fine sands of the Mississippi and Eastern Gulf provinces differ markedly in their bulk mineralogy as well as their heavy mineralogy. Mississippi Province sands contain abundant monocrystalline quartz (mean = 64%, range = 56 to 69%), feldspar (mean = 10%, range = 0 to 12%) and sedimentary rock fragments (mean = 16%, range = 12 to 18%). Eastern Gulf Province sands, on the other hand, are extremely rich in quartz (mean = 93%, range = 82 to 99%) and are deficient in all other detrital species (Mazzullo and Bates, 1985; Hsü, 1960; Russell, 1937). The heavy mineral suites of these two provinces are also quite distinct: Mississippi Province sands are characterized by hornblende and pyroxene, whereas Eastern Gulf Province sands are characterized by kyanite and staurolite (van Andel and Poole, 1960).

A study by Mazzullo and Bates (1985) has shown that the shapes of quartz sand grains from these two provinces are also quite distinctive, especially in regard to their degree of sphericity. Using the second harmonic of the Fourier series in closed form (Ehrlich and Weinberg, 1970) to measure this characteristic of these grains, Mazzullo and Bates (1985) found that fine quartz sand grains from the Mississippi Province are usually quite spherical in form and are characterized by relatively low mean second-harmonic amplitude values, whereas those from the Eastern Gulf Province are usually more elongate and are characterized by relatively high mean second-harmonic amplitude values (Fig. 1).

Subsequent examination of these quartz grains with the scanning electron microscope showed that these differences in sphericity are the result of differences in the sources of sediment for the two provinces. Mississippi Province quartz sand grains (Fig. 2) are highly spherical and highly rounded, and their surfaces usually exhibit

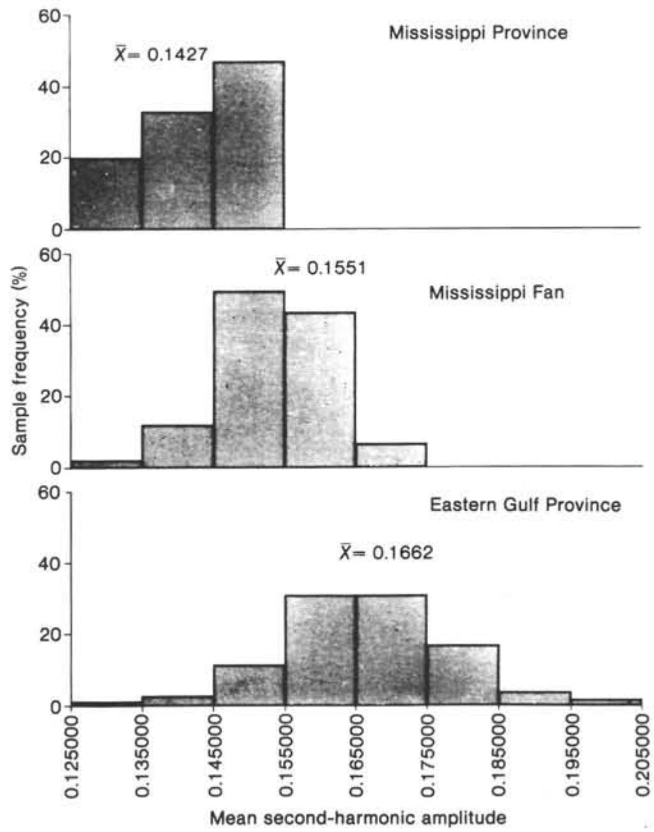

Figure 1. Mean second-harmonic amplitude values for samples from the Mississippi and Eastern Gulf provinces and the Mississippi Fan. Sample frequency is expressed in percentage of sample, in order to normalize the graphs. Data from Mississippi and Eastern Gulf provinces is from Mazzullo and Bates (1985).

textures formed by silica dissolution (Fig. 2A) and, more rarely, small incipient overgrowths (Fig. 2B). These characteristics indicate that the sands of this province were largely derived from unconsolidated sediment sources such as the Tertiary and Quaternary sediments of the southern coastal plain (Mazzullo et al., 1984) or the poorly-consolidated lower Paleozoic sandstones of the upper Mississippi Valley (e.g., the St. Peter Sandstone, a generally unconsolidated, well-rounded sand which forms the banks of the Mississippi River and its tributaries in southern Minnesota; Mazzullo and Ehrlich, 1983). Quartz grains with large, well-formed euhedral overgrowths, or with fractures and other breakage features, are very rare in the sands of this province, indicating that there is relatively little sediment contribution to this province from consolidated sedimentary rock sources (such as those of the Appalachian and Rocky mountains) or from glacial sources, respectively.

The Eastern Gulf Province sediments also contain abundant amounts of these highly spherical and rounded quartz grains, reflecting sediment contribution from the southeastern U.S. coastal plain strata (Mazzullo et al., 1984). However, these coastal plain sand grains are significantly diluted by more elongate and angular grains (Fig. 3) which give the sands of this province their distinctive grain shape characteristics. Most of the latter grains exhibit large euhedral overgrowths, suggesting their

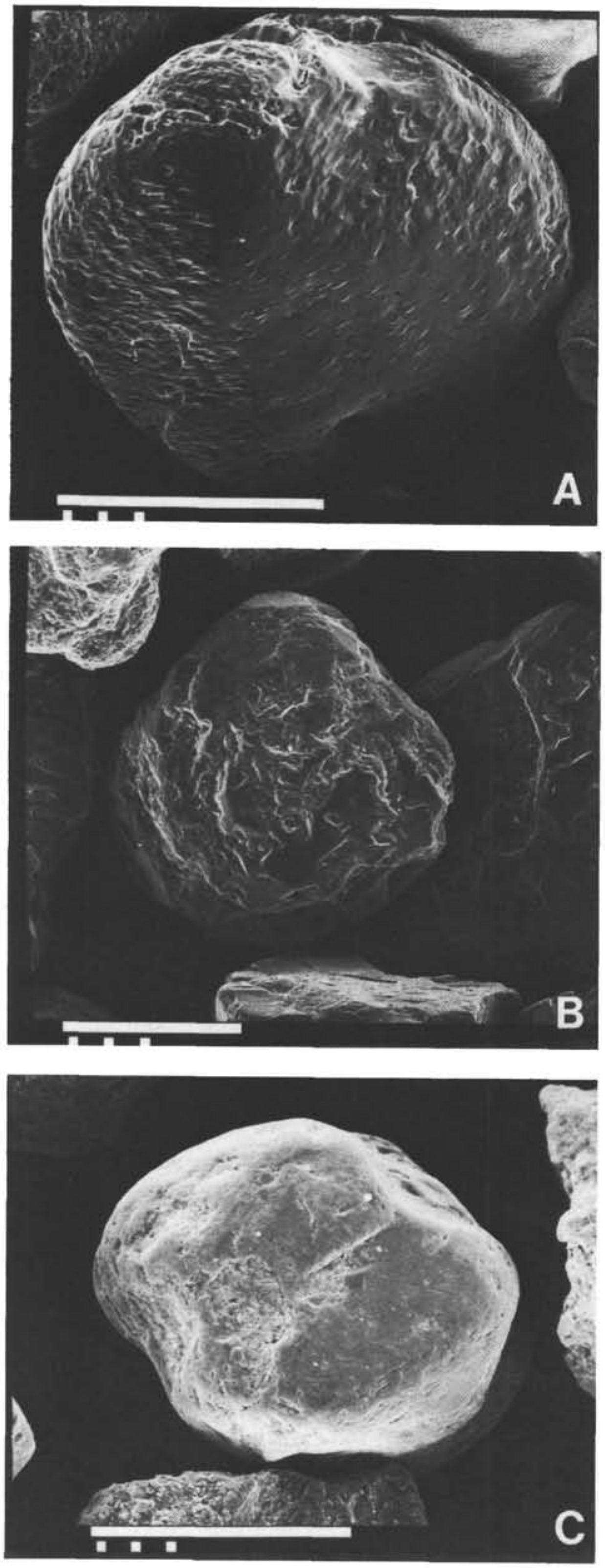

Figure 2. Spherical, rounded fine quartz sand grains from the Mississippi Province. A. Quartz grain with oriented v's (dissolution features) and smooth precipitation faces. B. Quartz grain with small euhedral overgrowths. C. Quartz grain with worn, possibly abraded surface. Scale bar = 100 μm.

derivation from the Paleozoic sandstones of the southern Appalachians. Others have highly irregular outlines and morphologies similar to quartz grains derived from crystalline rock sources (Magenheimer, 1985) and are thought to represent a sediment contribution from the Precambrian and Paleozoic granites of the southern Appalachians.

SOURCES OF SAND FOR THE MISSISSIPPI FAN

The shapes of 200 fine quartz sand grains from each of 89 sand-rich samples from Sites 615, 616, 621, 623, and 624 drilled on the Mississippi Fan (introductory chapter, this volume) were measured with the Fourier series using the techniques described above, and the mean second-harmonic amplitude value for each sample was calculated. These data are summarized in Figures 1 and 4.

It is clear from the studies of Fisk and McFarlane (1955) and others that the Mississippi River directly or indirectly supplied Mississippi Province sediment to the Mississippi Fan during the Pleistocene. If the Mississippi River had been the only ultimate source of siliciclastic sand for the Mississippi Fan, it would be expected that sands from the fan would have the same characteristics as those from the shelf deposits of the Mississippi River. As illustrated in Figure 1, however, the mean amplitude values for the Mississippi Fan samples are generally higher than those for the Mississippi Province, indicating that the spherical sand grains of the Mississippi Province were diluted by elongate grains.

The morphologies of fine quartz sand grains from Mississippi Fan samples were examined with the scanning electron microscope and the light microscope to determine the origins of the grain-shape types found in the fan sediments. Two distinct types of quartz grains were found: spherical, well-rounded quartz grains similar to those found in both Mississippi and Eastern Gulf Province shelf sands (Fig. 5A) and elongate, angular quartz grains derived from crystalline rock and lithified sedimentary rocks (Fig. 5B, C). Once again, fractured sand grains (Fig. 5D) are very uncommon in the fan sand, comprising between 1 and 2% of the sand grains of the fan (based upon visual estimations and point counts of nine fan samples).

Elongate, angular crystalline and sedimentary quartz grains are not common in the modern fluvial–deltaic deposits of the Mississippi River, although it is possible that such grains were transported from distal sources (such as the Canadian Shield) into the drainage basin of the Pleistocene Mississippi River by glacial processes. This possibility is readily dismissed, however, because fractured quartz grains, which are typical of glacial deposits (Mazzullo et al., 1984), are relatively rare in the fan.

If the ancestral Mississippi River is dismissed as a source of these elongate and angular grains, then it is logical to conclude that their source is the Southern Appalachian Mountains and that the sands of the Mississippi Fan are a mixture of sands from the Eastern Gulf and Mississippi provinces.

To test this conclusion further, the mineralogies of the fine-sand fraction in fan samples with variable mean

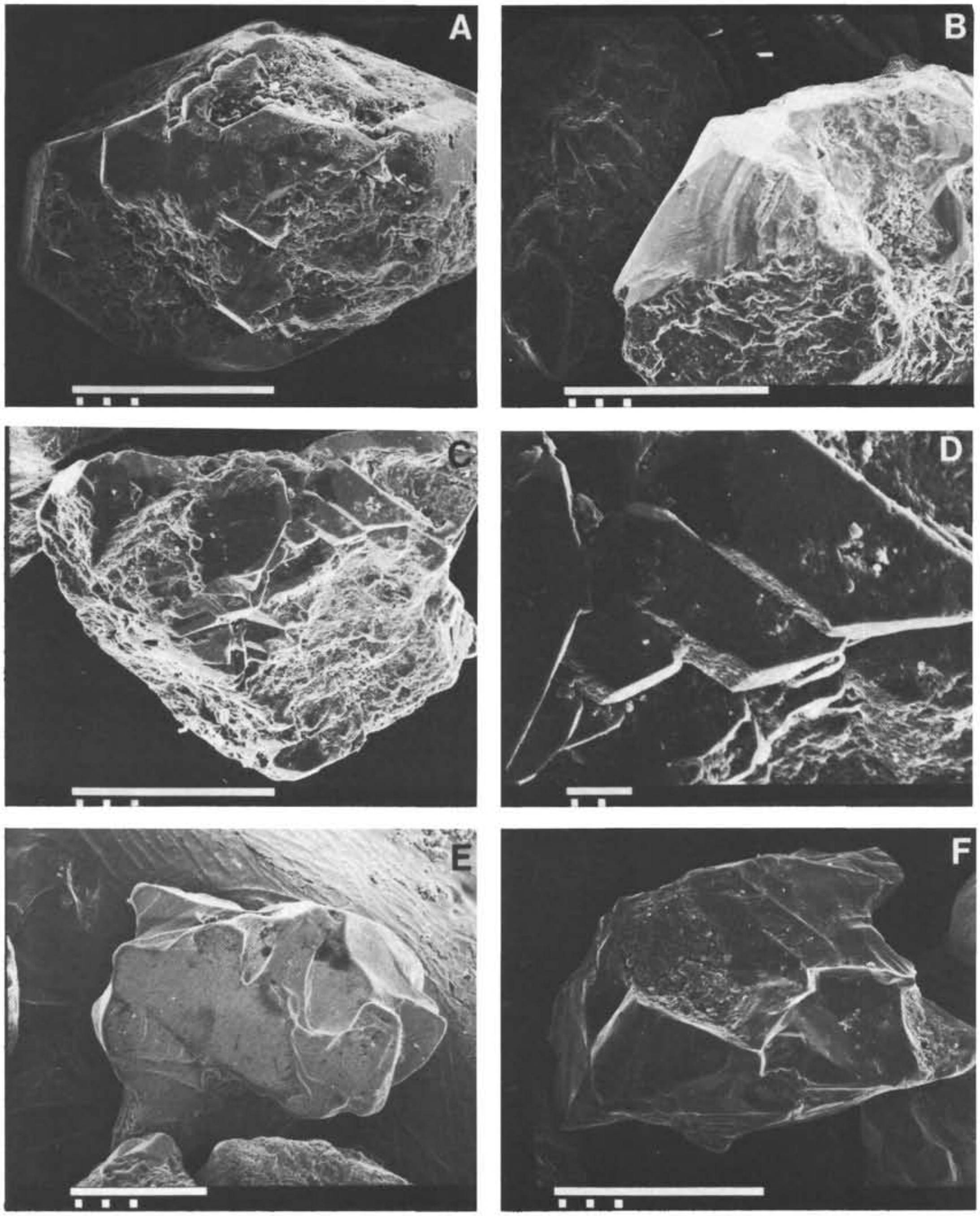

Figure 3. Elongate, angular fine quartz sand grains from the Eastern Gulf Province. A–D. Quartz grains with large euhedral overgrowths. E, F. Irregular and angular quartz grains with crystalline nodes and impression embayments, of probable crystalline-rock origin (Magenheimer, 1985). Scale bars with three dots are 100 μm; those with two dots are 10 μm.

second-harmonic amplitude values were examined using the technique described above. The results of this analysis are summarized in Figure 6, in which the mean second-harmonic amplitude values for the fan samples are plotted against their monocrystalline quartz content and the ratio of monocrystalline quartz to sedimentary rock fragments (SRF). These data show that as the mean second-harmonic amplitude value increases from the low values typical of Mississippi Province sands toward the high values typical of Eastern Gulf Province sands (Fig. 1), the mineralogies of the sands become progressively more enriched in quartz, the detrital species associated with the Eastern Gulf Province, and more deficient in the detrital species (SRF) common to the Mississippi Province. These results support the conclusion that the sands of the Mississippi Fan are indeed mixtures in various proportions of both Eastern Gulf and Mississippi Province sands.

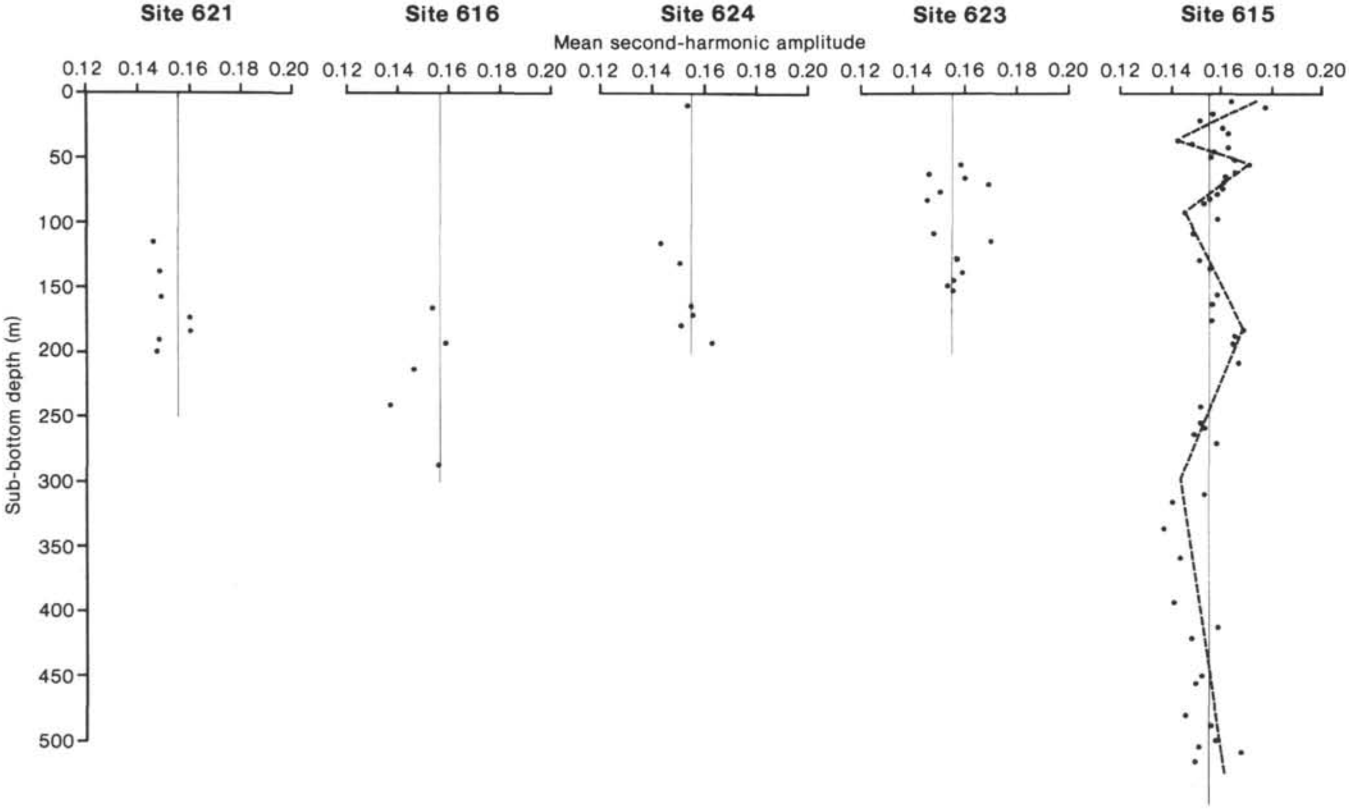

Figure 4. Vertical variations in mean second-harmonic amplitude values in five cores from the Mississippi Fan. Site 621 was drilled in the western part of the fan; the remaining sites were drilled on its eastern part. Sites 616 and 624 were drilled in overbank areas, and Sites 623 and 615 were drilled in levee and channel areas. See text for explanation of dashed line on Site 615 graph.

VERTICAL AND LATERAL VARIATIONS IN SOURCE

The mean second-harmonic amplitude value for each sample is plotted against its depth in its respective hole (Fig. 4). In this figure, the amplitude value of 0.155 is marked by a vertical line; this value is noted because, as shown in Figure 1, all of the Mississippi Province samples were characterized by mean amplitude values below 0.155, whereas 89% of the samples from the Eastern Gulf Province were characterized by mean amplitude values above this value. Thus, this value serves as an approximate dividing line between sand derived predominantly from the Mississippi Province (points to the left of the line) and sand derived predominantly from the Eastern Gulf Province (to the right).

The variations in mean second-harmonic amplitude value through the longest and most heavily-sampled hole, taken at Site 615 (the southeasternmost site on the fan), reveal periodic changes in the predominant source of sand for the Mississippi Fan. These changes are characterized by gradual increases or decreases in mean second-harmonic amplitude values for successive samples, which is interpreted as representing gradual shifts in the major source of sand for the fan from the Mississippi Province to the Eastern Gulf Province (shown by dashed line in Fig. 4). This same pattern of alternating sources for the fan is also observed in the section drilled at Site 623, which is proximal to Site 615 on the eastern side of the fan.

There appears to be a significantly lesser contribution of Eastern Gulf Province sand to the sediments drilled at Sites 621, 616, and 624 (although it could be argued that there is an insufficient number of samples from these sections upon which to base such an observation). Of the 19 sands sampled in these holes, only 4 appear to have been derived in large part from the Eastern Gulf Province. This is in contrast to Sites 623 and 615, in which more than half of the sands were derived in large part from this province.

ACKNOWLEDGMENTS

This research was funded by a grant from Texaco Inc. The author wishes to thank Donald Sims, Deanne Prusak, and Pamela Leschak for their assistance in the preparation of this manuscript. This manuscript was reviewed by D. Krinsley and R. Ehrlich.

REFERENCES

Bates, C., 1984. Sources and distribution of fine quartz sand in the northeastern Gulf of Mexico [M. S. thesis]. Texas A&M University, College Station.

Carver, R. E., 1971. *Procedures in Sedimentary Petrology:* New York (Wiley Interscience).

Ehrlich, R., and Weinberg, B., 1970. An exact method for characterization of grain shape. *J. Sediment. Petrol.*, 40:205–212.

Fisk, H. N., and McFarlane, E., 1955. Late Quaternary deposits of the Mississippi River. *Geol. Soc. Am. Spec. Pap.*, 62:279–302.

Griffiths, J., 1967. *The Scientific Method in the Analysis of Sediments:* New York (McGraw-Hill, Inc.).

Hsü, K. J., 1960. Texture and mineralogy of the Recent sands of the Gulf Coast. *J. Sediment. Petrol.*, 30:380–403.

Magenheimer, S., 1985. The original morphological and compositional characteristics of fine sand derived from crystalline and sedimentary source rocks of Texas [M. S. thesis]. Texas A&M University, College Station.

Mazzullo, J., and Bates, C., 1985. Sources of Pleistocene and Holocene sand for the northeast Gulf of Mexico shelf. *Trans. Gulf Coast Assoc. Geol. Soc.*, 35:457–466.

Mazzullo, J., and Ehrlich, R., 1983. Grain shape variation in the St. Peter Sandstone: a record of eolian and fluvial sedimentation of an early Paleozoic cratonic sheet sand. *J. Sediment. Petrol.*, 53: 105–119.

Mazzullo, J., Ehrlich, R., and Hemming, M. A., 1984. Provenance and areal distribution of late Pleistocene and Holocene quartz sand on the southern New England continental shelf. *J. Sediment. Petrol.*, 54:1335–1348.

Mazzullo, J., and Kennedy, S., 1985. Automated mesurement of the nominal sectional diameters of individual sedimentary particles. *J. Sediment. Petrol.*, 55:593–595.

Russell, R. D., 1937. Mineral composition of Mississippi River sands. *Geol. Soc. Am. Bull.*, 48:1307–1348.

Schultz, D. J., 1980. The effects of hydrofluoric acid on quartz shape—Fourier grain shape analysis. *J. Sediment Petrol.*, 50:644–645.

van Andel, T. H., and Poole, D. M., 1960. Sources of recent sediments in the northern Gulf of Mexico. *J. Sediment. Petrol.*, 30: 910–922.

Date of Initial Receipt: 12 March 1985
Date of Acceptance: 28 June 1985

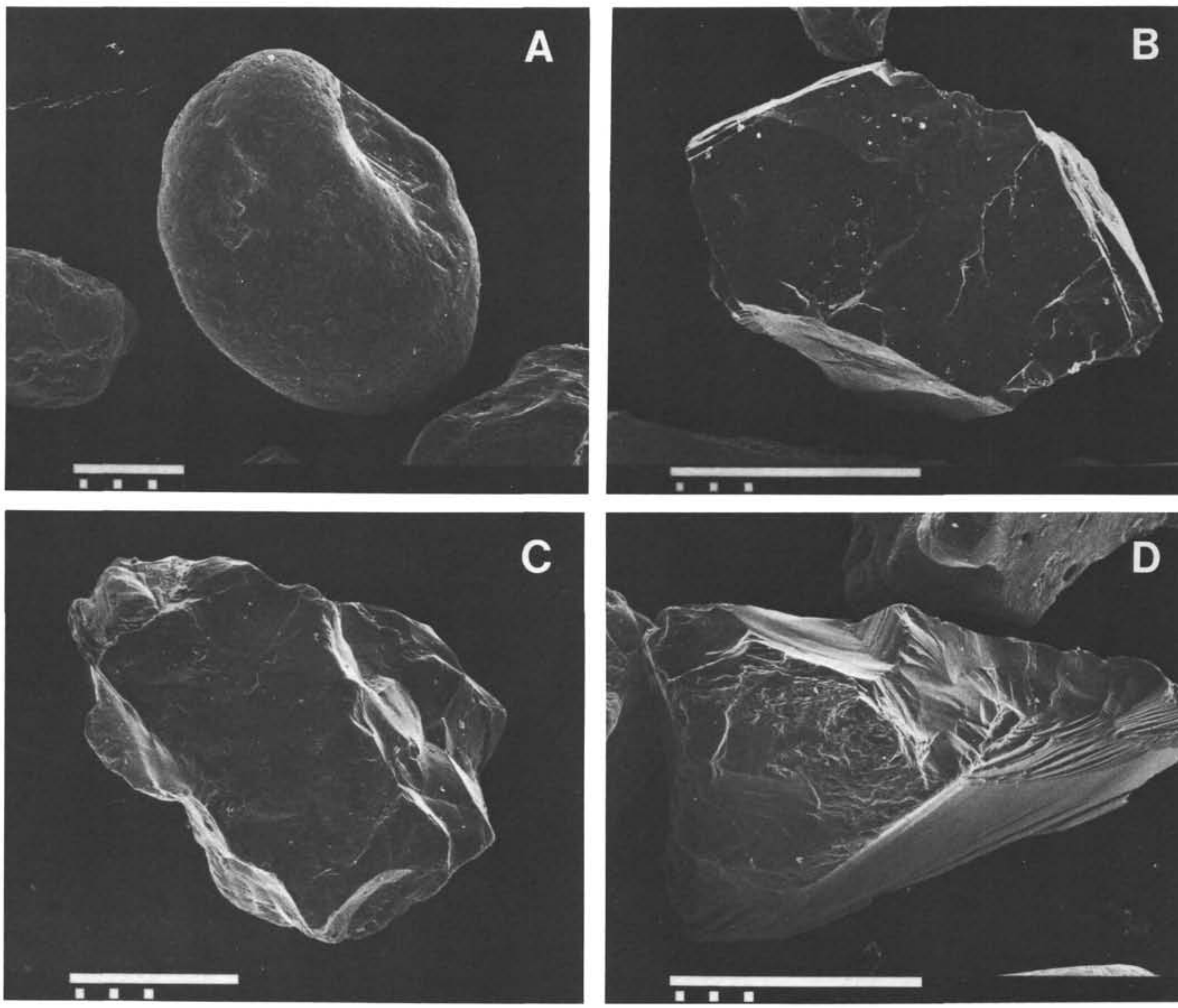

Figure 5. Fine quartz sand grains from the Mississippi Fan. The sands are mixtures of three types of grains: spherical and rounded grains (A) typical of both the Mississippi and Eastern Gulf Province, and elongate and angular grains (B and C) of sedimentary-rock and crystalline-rock origin respectively, typical of the Eastern Gulf Province. Fractured quartz grains of possible glacial origin (D) are very rare in the sands of the fan. Scale bar = 100 μm.

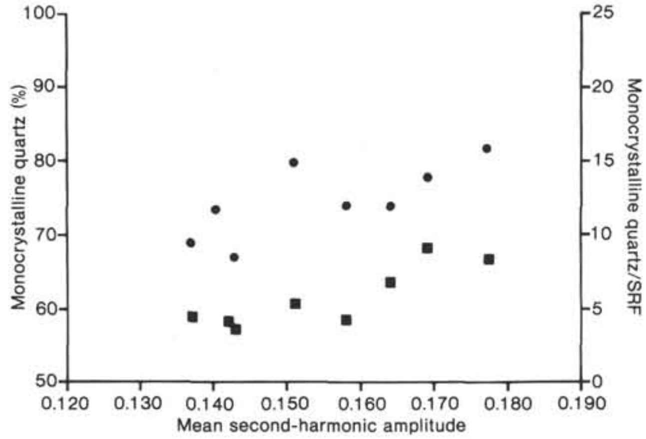

Figure 6. Variation in the mineralogy of the fine sand fraction from fan samples as a function of mean second-harmonic amplitude value. Monocrystalline quartz contents (●) and the ratio of monocrystalline quartz to sedimentary rock fragments (SRF) (■) are plotted. See text for discussion.