SURFACE MICROTEXTURES OF FRESHWATER HEAVY MINERAL GRAINS

by

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ABSTRACT

Scanning electron microscopy indicates that a wide variety of mechanical and chemical features are present on heavy mineral grains collected from the shore of Lake Michigan. Many microtextures common to these freshwater beach and back beach dune sands appear similar to those reported by others from marine environments (Setlow and Karpovich, 1972; Lin and others, 1974). Differences, particularly on garnet grains, may be the result of chemical conditions.

Detailed observations of the heavy mineral suite in a sedimentary deposit should supply useful information concerning depositional environments provenance and diagenetic history. Actually many problems remain because the relative importance of contributing factors such as relict original textures, composition, crystallography, depositional conditions, and diagenesis have not as yet been effectively separated. Additional complications in the present study area include possible mixing of material between environments and a complex source of supply of grains from glacial till.

Key words: Surface microtextures, Heavy minerals, S.E.M., Freshwater

INTRODUCTION

Early studies by Biederman (1962) Porter (1962), and Krinsley and Takashi (1962) described micromorphogenetic surface features of quartz sand grains as imparted by various sedimentary processes. The study of sediment grain surface features was continued by Krinsley and Donahue (1968), Krinsley and Margolis (1969), Fitzpatrick and Summerson (1971) and others. These studies sought to delineate significant textural features and to interpret their occurrence in terms of the sediment's provenance and depositional environment. Following the establishment of a basis for environmental discrimination, the technique has been applied in many studies of different types of deposits.

Studies of heavy mineral assemblages sought to interpret the provenance and deposition of clastic deposits based on the type, abundance, and distribution of component heavy minerals within a particular assemblage. The study of textural features of heavy mineral grains, as related to the distribution and significance of heavy mineral suites, was neglected.

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Recently, with the realization that all types of clastic grains in a sedimentary deposit may supply useful information, the two types of studies have been combined (Stieglitz, 1969a; Stieglitz and Rothwell, 1972). Quartz and heavy mineral grains from the marine environment along Florida's coast were studied and reported on by Setlow and Karpovich (1972). Merkle and Ferrell (1972) used a scanning electron microprobe to identify individual heavy mineral grains by textural and compositional criteria. Lin and others (1974), in an excellent study, documented the occurrence of surface microtextures of heavy minerals from the coast to Israel.

PURPOSE

This report seeks to document and illustrate different types of surface textures observed on several common kinds of heavy mineral grains from freshwater environments. Comparisons of these textures with textures reported previously by other workers from marine environments may lead to a fuller understanding of how textures are formed in each environment and an appreciation of which textures are truly distinctive of each.

Secondly, and possible most important, we wish to illustrate some of the problems remaining in the study of surface textures of heavy minerals and quartz grains as well, and problems with their application to environmental determinations. Schneider (1970) also addressed some aspects of this subject. However, it does not seem to be given enough consideration in most investigations.

Finally, we want to make suggestions of ways to overcome at least some of these problems as well as to point out possible additional applications for surface textural studies of heavy minerals.

METHODS

The sediment samples are of the heavy mineral assemblage from the beach and back-beach dunes along the Lake Michigan shore at Terry Andrae-Kohler State Park, Wisconsin (Fig. 1). Dubois (1972) reported magnetite, ilmenite, garnet, epidote, zircon, amphibole, and pyroxene as being common heavy constituents of the locale's sediment. These heavy minerals are concentrated by wave action in dark layers and lag pockets of beach sand. The area's energy system and sediment transport were subjects of a study by Turner (1972).

Between 900 and 1,000 individual grains were viewed under the JEOLCO/JSM-3 scanning electron microscope of the Surface Studies Laboratory at the University of Wisconsin-Milwaukee. Approximately 1/10 of that number were studied in some detail. Grains were hand picked under optical microscopes following initial electromagnetic separation of the bulk sand. Primary concerns of the study were restricted to those mineral types (1) most abundant in a size range from 1.5Ø (350μ) to 4.0Ø (62.5μ), (2) readily identifiable under plane- and polarized-light microscopes, and (3) easily selected by hand. In particular, grains of magnetite, amphibole, pyroxene, and garnet were studied in detail. Grains were analyzed with the attached Nuclear Diodes Micro analyzer as a further check on identification.

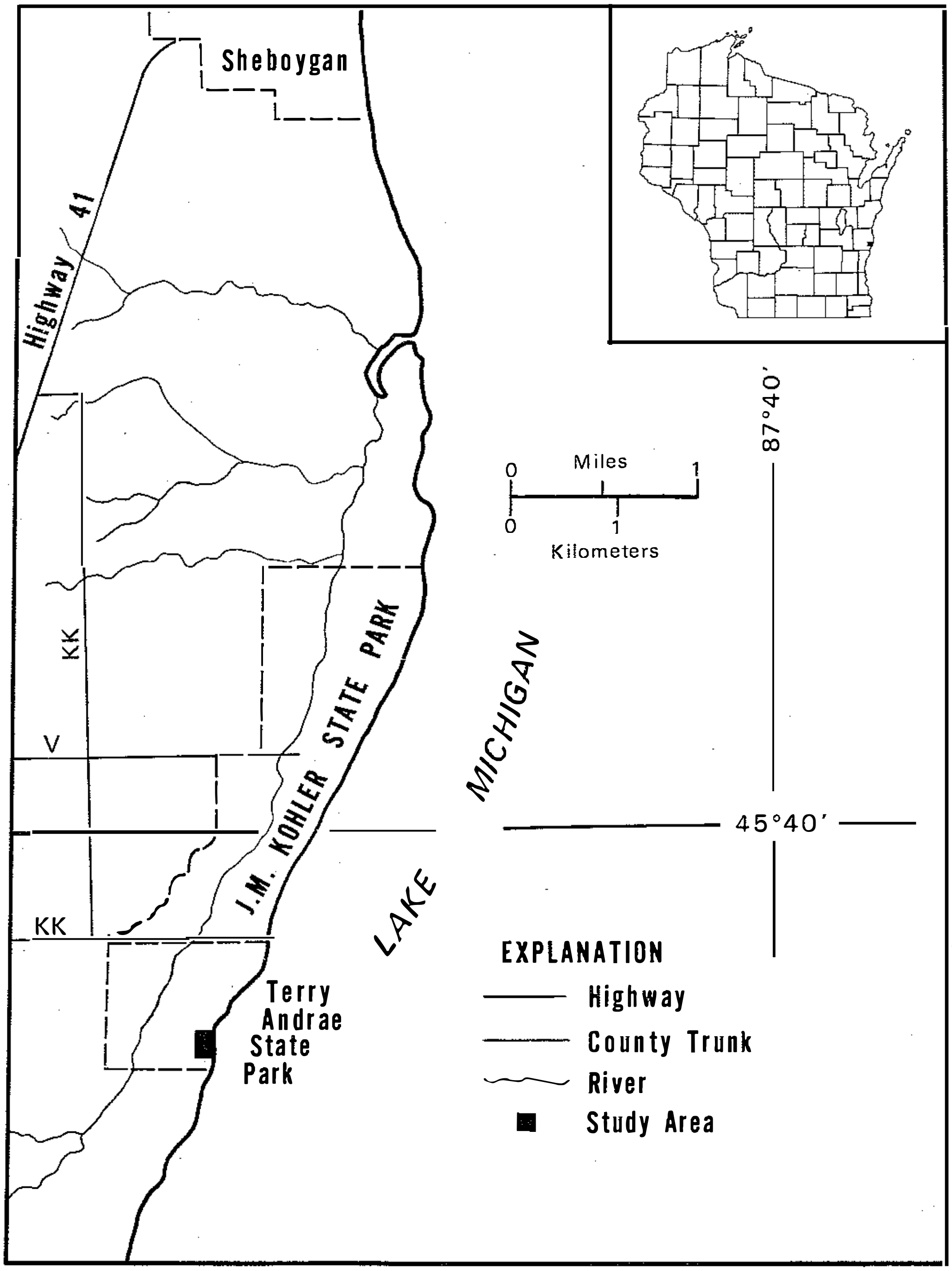

Figure 1. Generalized location map of the sample area. Modified from Turner (1972).

MICROTEXTURES

Our study was originally intended simply to sample several different, but adjacent, freshwater environments, catalog the textures observed, and determine which textures were characteristic or most abundant in each. As the work progressed it became apparent that separation of the various environments in this manner was not possible. We feel that there are a number of reasons why environmental distinctions are difficult to make. This section will describe the prominent textures displayed by several different kinds of heavy minerals. A discussion of the complicating factors will be reserved for a later section.

Mechanically produced features, etch features, overgrowth features, as well as some possible relict original textures were observed. The criteria for recognizing mechanical and chemical features have been presented in several papers (Margolis 1968; Margolis and Kennett 1971) and a useful summary is presented by Margolis and Krinsley (1974). In general, we have classified as mechanical features various kinds of pits and scratches often randomly distributed over the grain surface, and rather large blocky features with distinct outlines. Solution features observed include crystallographically oriented or controlled pits, rather deep tunnel-like pits and several extensive features where etching has accentuated apparent differences in composition or crystallographic orientation (Fig. 2D). In some instances solution has rounded edges or outlines of earlier features or somewhat subdued relief over large parts of grains. Overgrowths have produced crystallographically oriented positive features on some grains. Other types of both solution and overgrowth features have been recognized on quartz grains (Margolis and Krinsley, 1974). Possible relict original textures are suggested by clusters of relatively deep steep sided pits found on parts of some grains.

Although relatively little is known about the range of mechanical or chemical features to be expected on heavy mineral grains, even less is known about original textures of any type of grains.

Magnetite

Magnetite grains of the samples studied exhibited distinctive features which are characterized with a high degree of confidence. Commonly, the grains appear porous, almost spongelike (Fig. 2A); large relatively flat areas that may be relict crystal faces suggest octahedral crystals. The raised surfaces of breakage blocks (Fig. 2B) are more nearly planar than those of quartz grains. The sides of blocks exhibit steplike fracture patterns. Small shallow mechanically-produced pits are irregular in outline and are randomly distributed over the surface.

Surface textures interpreted as the result of chemical solution were not uniform on all grains viewed. Solution was extensive on most grains, as revealed by reduction of sharp mechanically produced features. Many grains exhibited a platy or furrowed appearance in some views (Fig. 2C). This same feature is apparently common on magnetite grains from the coast of Israel

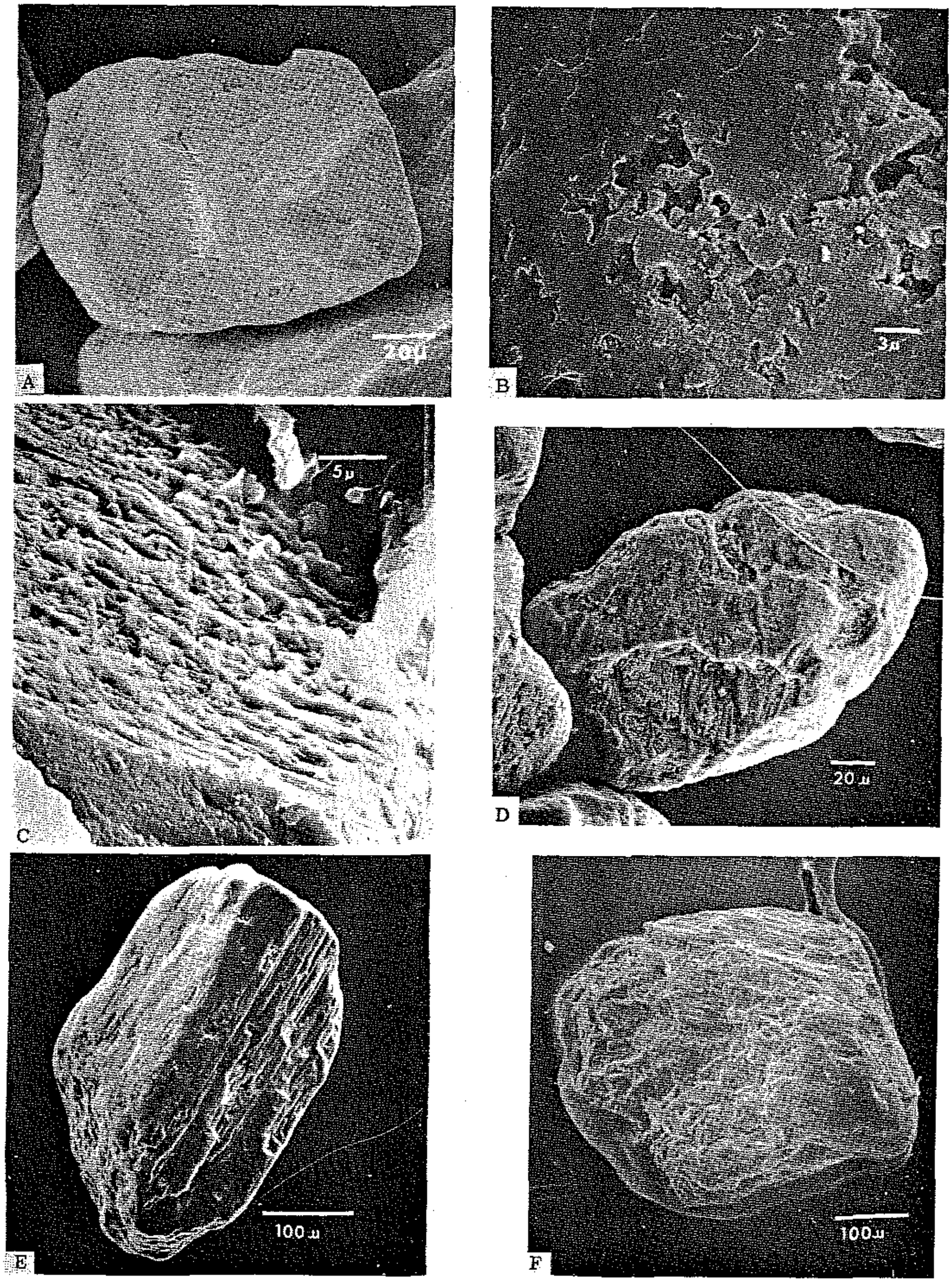

Figure 2. A: Porous appearing magnetite grain. B: Higher magnification of the magnetite surface texture. Note relatively flat breakage block surface and lack of V-shaped pits. C: Platy, step-like pattern exhibited by many magnetite grains. Approximately perpendicular view to that shown in B. D: Blocky, lattice-like solution pattern of magnetite. E: Amphibole grain. Note well developed cleavage parallel to grain elongation. F: Pyroxene grain. Note cleavage well developed but not as extensive as on grain in E.

(Lin and others, 1974). A small number of magnetite grains exhibited a striking blocky pattern. A similar pattern of solution-modified texture (Fig. 2D) was reproduced by etching laboratory-crushed magnetite with H_2SO_4.

Many magnetite grains exhibit clusters of steep sided deep pits on some raised surfaces (Fig. 2B). Scheider (1970, Figs. 2 & 3) illustrated the surface of a weathered but untrasported quartz grain and suggested that some textures observed on sedimentary grains may be relict features of this type. Pits such as those in Fig. 2B seem best interpreted as relicts on the higher flat parts of grains because these surfaces probably represent part of the original outline of the grain whereas lower areas develop by the removal of blocks of material; particularly during glacial transport. In addition, we feel that other original textures in addition to grain boundary indentations such as crystal or gas bubble inclusions may be more common than generally believed.

Amphibole and Pyroxene

The similar properties of amphibole and pyroxene observed in hand specimen or thin section carry over into the micromorphologic surface character of the grains (Figs. 1E & 1F). Numerous species of each group are reported from Lake Michigan beach sands and add to the problem of deriving a specific group of identifying features. For example, hornblend has a wide range of composition which produces a variety of physical properties (Berry and Mason, 1959). How that range or the differences within a pyroxene series such as the enstatite-hypersthene series influence surface textures is not known.

Surface textures on amphibole-pyroxene grains from the freshwater environment observed during this study appear similar to those described by Setlow and Karpovich (1972) from the marine environment. Cleavage of pyroxene grains, although well developed, is in many cases not continuously parallel with grain elongation. At high magnification (5000X), individual cleavage traces seem to show greater linear continuity and are closer together than on amphibole (Figs. 3A and 3B). Although many cleavage surfaces appeared fresh, chemical alteration of grains of either the pyroxene or the amphibole group appeared significant. In some instances, the cleavage faces have apparently been smoothed and the relief subdued (Fig. 3C). Some grains (Fig. 3A) presented a splintered appearance with sharp angles and reentrants. In other cases, small blocks have been removed (Fig. 3D) and the control of crystallinity is evident but the initiating cause, whether chemical or mechanical, is not clear.

Garnet

The garnet group exhibits development of surface textures, which reflect the influence of compositional differences. Imbricate wedge markings are common on both light-colored and dark-amber garnets (Figs. 4A and 4B). Well-developed symmetrical features apparently identical to those illustrated by Setlow and Karpovich (1972) are also exhibited. These crystallographically controlled features may have either positive or negative relief (Fig. 4A and

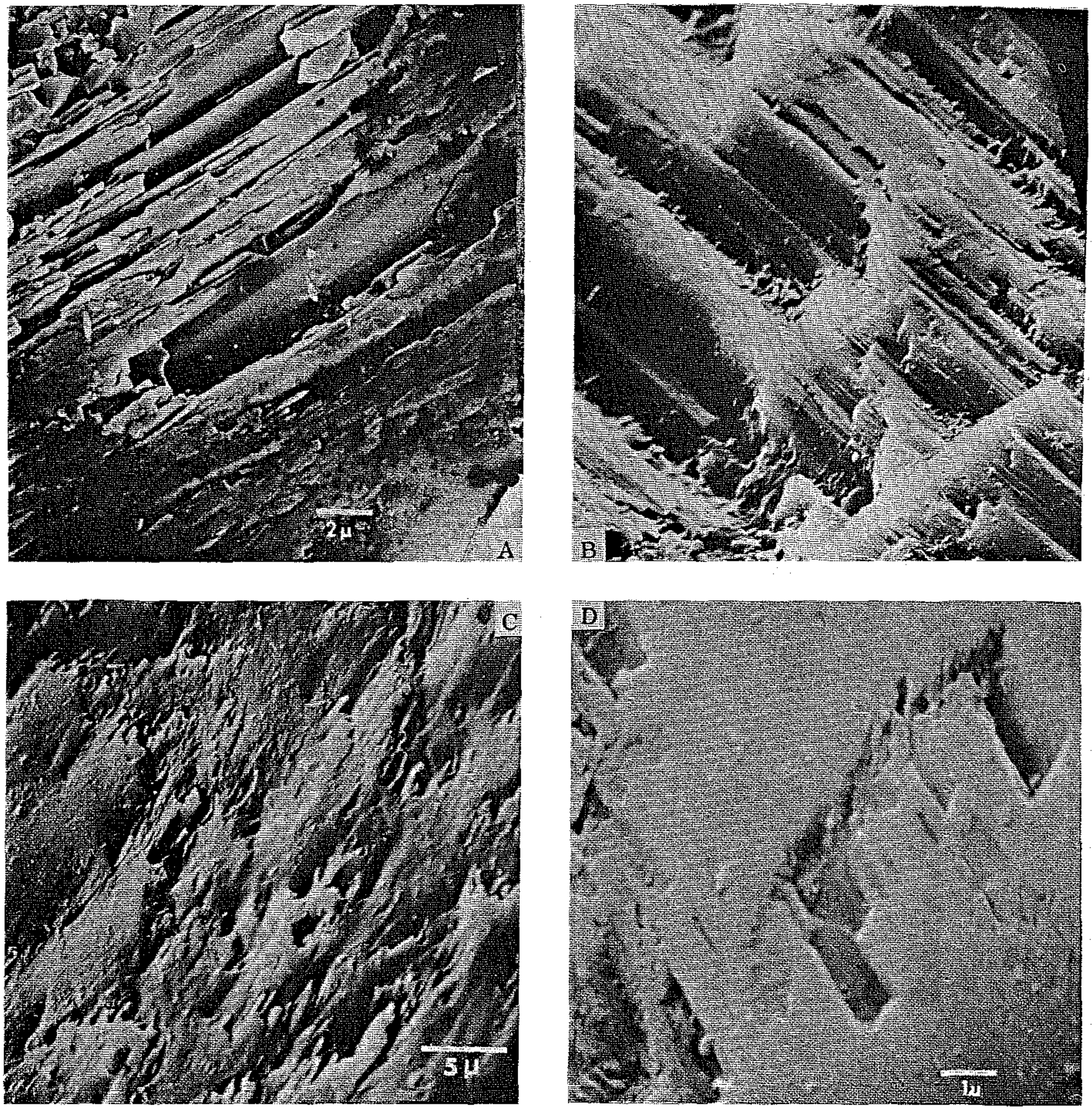

Figure 3. A: Higher magnification of amphibole cleavage faces. Note sharp edges and lack of smaller scale features. B: Higher magnification of pyroxene cleavage faces. C: Amphibole cleavage faces smoothed and subdued by solution. D: Small cleavage controlled features on an amphibole cleavage face.

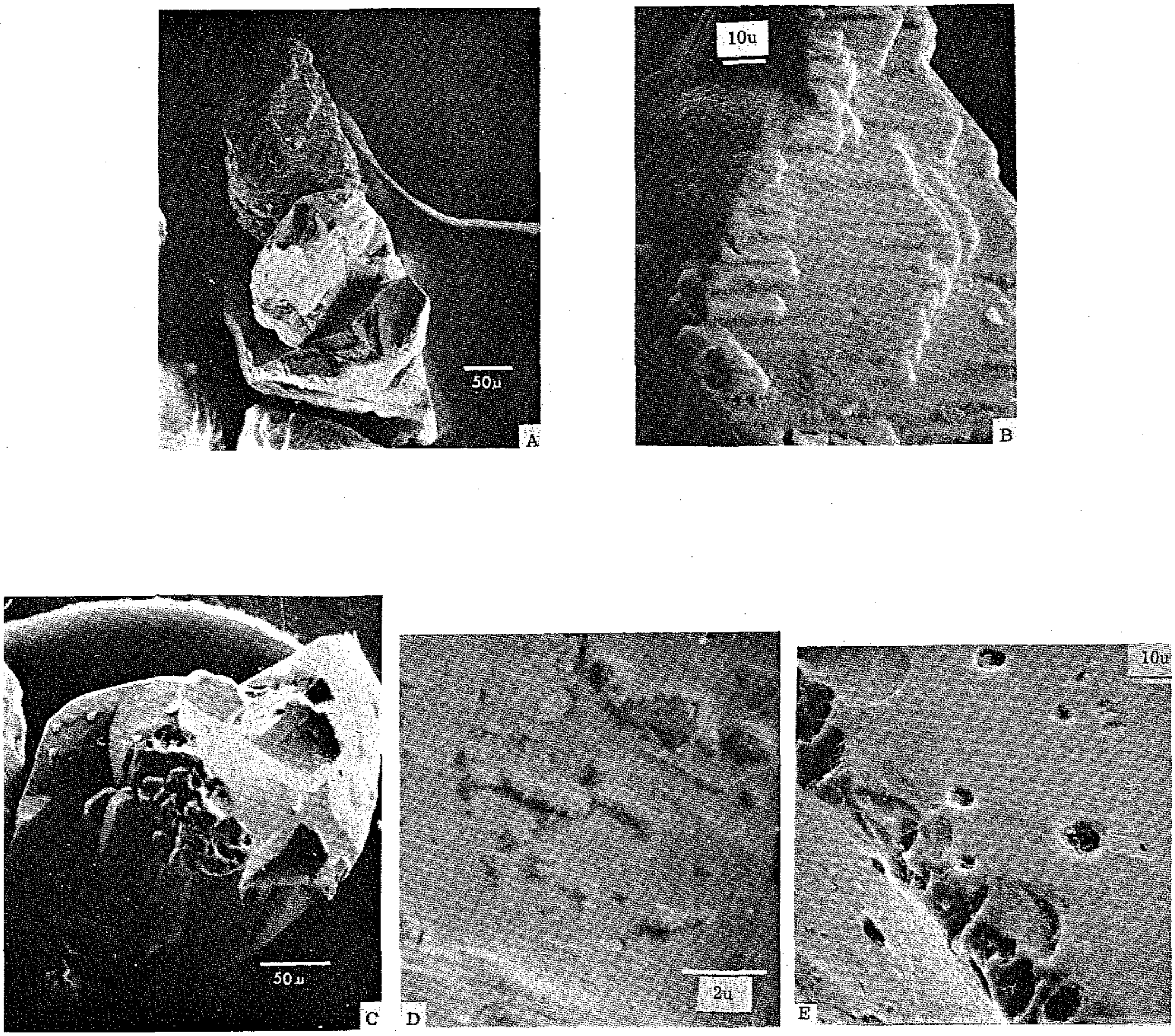

Figure 4. A: Garnet grains. Top grain covered by imbricate wedge markings. Middle grain has a well formed octahedral etch feature. B: Higher magnification of the imbricate wedge markings shown in A. C: Garnet grain modified by solution in the central part with octahedral shaped depressions on the upper right. D: Garnet grain with shallow, flat-bottomed pits and rectangular and tetrahedral shaped pits modified by solution. E: Deeper rounded pits on a garnet grain. Note also the crescent shaped mechanical features on the upper right and along the grain edge.

4C). It has been suggested that both wedge markings and the faceted features are formed by overgrowths on the grains (Simpson, 1976).

Setlow and Karpovich (1972, Fig. 4B), illustrate grains covered with "Mounds"; these grains appear similar to grains described by Stieglitz (1969b) as having a somewhat spalled appearance, although the Florida coastal examples do not seem to be as badly corroded. These grains possibly result from modification of imbricate wedge markings originally formed on rounded grain surfaces.

Parts of many grain surfaces are pockmarked by subround pits. These pits appear to be of two types when viewed closely. One type is flat bottomed and shallow and may result from solution modification of earlier mechanically formed features (Fig. 4D). Pits of the second type (Fig. 4E) are relatively deep, in some instances tunnel-like, as reported previously (Stieglitz, 1969b), and apparently result from grain solution or solution modification of relict inclusions.

Another common feature on garnet surfaces are small rectangular-to tetrahedral-shaped pits formed by impact. Removal of the small chips on impact seems to be influenced by crystallography, because a subparallel orientation of elongation can be seen. The orientation may differ from surface to surface. These features may be enlarged by solution in directions controlled by crystallography and may join to produce a somewhat anastomosing texture (Fig. 4D).

DISCUSSION

In contrast to the number of papers concerning quartz microtextures, studies of heavy mineral grains by the electron microscope are few. Until surface features of grains other than quartz are documented for a wide variety of environments and assemblages, unique characterizations of microtextures for a particular locale are of doubtful validity. Furthermore, the influence of many aspects of grain history cannot be effectively segregated until such documentation exists. Study of material from restricted environments or prepared under controlled laboratory conditions seems necessary to determine whether or not a suite of microtextures characteristic of specific environments exists, as appears to be the case with quartz grains. Recent studies (Setlow and Karpovich 1972, Lin and others 1974, Simpson 1976) have begun to answer some of the questions and establish a firmer base for interpretations.

Heavy minerals would seem to be ideally suited to adding another dimension to the study of clastic deposits. First, they have a range of hardness values, magnetite 5 $\frac{1}{2}$ - 6 $\frac{1}{2}$, pyroxenes and amphiboles about 6, epidote 7, garnet 7 - 7 $\frac{1}{2}$, zircon 7 $\frac{1}{2}$, and they should behave somewhat differently under different abrasion conditions. Second, because they vary in composition and crystallography, chemically induced microtextures may be imprinted on a grain during weathering, transportation, deposition, or diagenesis which will supply information on the chemical conditions at each of these times. Because of dissimilar responses to chemical conditions, it may be possible for one type of mineral grains to become etched while another develops overgrowths. If the stability fields for each mineral can be accurately determined experimentally, heavy minerals may supply a history of the chemical conditions experienced by a deposit.

In our study different microtextures were recognized but they did not seem to be specific enough to draw environmental interpretations. Surface features observed did not appear mutually exclusive for beach and back-beach dune samples. Textures observed, however, are useful in comparison to those reported from marine environments. For example, minerals such as amphibole and pyroxene exhibit cleavage on small-sized grains. This is apparently true of grains from both marine (Setlow and Karpovich, 1972) and nonmarine areas sampled in this study. However, some minerals, such as those in the garnet group and magnetite, seem to exhibit subtle differences of texture, perhaps as a result of petrogenesis, composition, crystallography, or the chemical conditions of the depositional environment. Hoblitt and Larson (1975) present striking evidence of etch features on magnetic minerals. The artificially etched grain illustrated in Figure 2D and others observed from our samples exhibit this type of selective solution. This may also explain the furrowed appearance of many magnetite grains in that possibly laminae of different crystal orientation or composition are preferentially removed. Subtle differences in the composition and crystallinity of magnetite from different sources (Fleischer, 1965) may influence the shape, size and/or abundance of features present. If this can be demonstrated for other minerals a tool may be available to determine the source of even very small particles. Comparison of the sand or silt grain with artificially etched samples from the supposed source rocks may provide supportive evidence.

In the region from which our samples were obtained other factors, in addition to composition and crystallographic differences, further complicate environmental determinations by heavy mineral grain surface microtextures. Foremost of these is that the sand in the area is derived from wave erosion of lake bluffs composed of till. The glacial deposits of the area contain material from a number of sources including crystalline and sedimentary rocks as well as previous glacial deposits of northern Wisconsin, Michigan and Canada. Therefore, the till contains a mixed assortment of fresh and recycled grains, some of which may have been transported long distances, while others may have been carried only a short distance by the ice. Another problem in the sample area is that local mixing of material among the shallow water, beach, and back-beach dune systems may occur seasonally or with irregular periodicity. Grains may move relatively short distances into another environment and retain features developed previously.

Although we did observe a great many individual grains, the observations are nevertheless limited when compared to the complexity of the source and depositional systems. Baker (1976), as well as other studies, have indicated a statistical approach may be required to evaluate the significance of surface microtextures. Many studies of quartz grain microtextures have similar drawbacks, resulting in some uncertainty as to the mutual exclusiveness of individual textures. The "glacial" appearing microtextures reported by Setlow and Karpovich (1972) from Gulf of Mexico beach sands is a case in point.

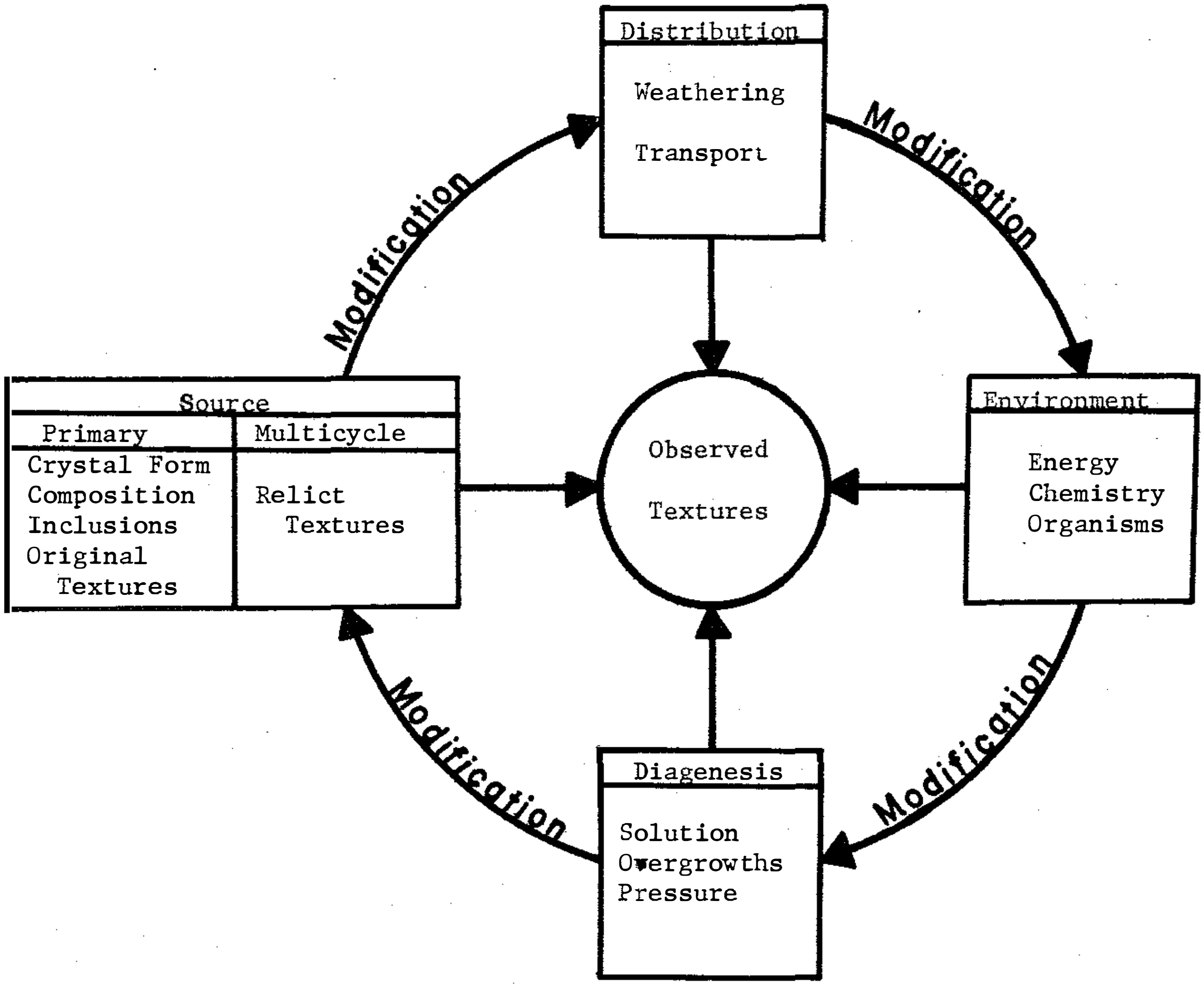

Figure 5. Factors affecting grain surface microtextures.

Figure 5 is a summary of the multiple factors which can affect the microtextures observed on a clastic grain. Basically they can be grouped into four categories: 1) features characteristic of a particular source, 2) features which may be imprinted onto the grain during weathering or transport prior to its arrival in the environment of deposition, 3) features developed in the depositional environment, and 4) features developed by diagenetic processes after deposition. The separation of the categories is somewhat arbitrary, particularly between distribution and deposition, but it does allow for a more complete concept of the total process. Features developed at any point in the history of a grain may be preserved and be observed when the grain is sampled. Correspondingly, some of the features developed may be obliterated or modified by a succeeding process. Microtextures developed during diagenesis can be observed in addition to or as modification of any of the preceeding categories of textures when the grain is from an ancient deposit. When the grain is recycled by subsequent erosion diagenetic microtextures may be modified by processes acting during distribution or deposition. Recently, Potter (1968) has shown that garnets may be significantly affected by intrastratal solution. Rahmani (1973) described intricate solution features on various kinds of heavy mineral grains from Cretaceous-Paleocene sandstones. Such multicycle source materials are probably common in nature.

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