Kwartalnik Geologiczny, t. 24, nr 2, 1980 r., str. 217–232

UKD 552.517.4:549.514.51].08:539.24/.25:537.533.6:552.142/.143

David KRINSLEY

Scanning Electron Microscope Examination of Quartz Sandgrain Microtextures

The use of the scanning electron microscope in the examination of microtextural features on the surfaces of quartz sand grains is discussed. Differences in texture can be used to distinguish a number of different weathering or depositional environments. Thus it is possible to identify quartz sand grains emplaced in the following settings: weathered from granites, youthful rivers, subaqueous marine, aeolian and glacial. This technique can be used to reconstruct ancient depositional environments; sands as old as Lower Triassic have been successfully subjected to textural analysis.

Most aims of geological science involve the reconstruction of ancient environments. For instance, it is frequently possible to ascertain the temperature of an ancient ocean, to suggest the kinds of animals and plants that lived in that ocean, and the predator-prey relationships between them, the firmness and mineral composition of the ocean bottom, the water depth, etc. Thus an attempt is made to develop a detailed picture of the environment: every parameter available to the individual must be used.

As new instrumentation is developed, techniques become available that were not previously considered. For example, the determination of ancient water temperatures had to await the invention of the mass spectrometer.

Certain parameters present in sedimentary rocks have been used for environmental reconstruction. Size frequency analysis of sands has been employed to distinguish fossil environments such as dune, beach, river and so forth. Sedimentary structures are those larger features of sediments, that, in general are studied or seen best in outcrop rather than hand specimen or thin section and are either organic or inorganic in origin (F.J. Pettijohn, 1957, p. 100–132). The list of parameters is long, and it is necessary to use multiple criteria to document an environment successfully.

ELEKTRON MICROSCOPE METHODOLOGY

GENERAL

Recently, a new technique has been developed which permits environmental reconstruction to be made from individual grains of quartz sand (D.H. Krinsley, J. Doornkamp, 1973). Quartz sand grains (2 to 1/16 mm in diameter) are ubiquitous in sediments and thus the technique can be universally applied. The scanning electron microscope (SEM) is used in the emissive mode to examine the surface texture or roughness of individual quartz sand grains; this information is used to identify and distinguish grains that have been mechanically abraded in river, beach, continental shelf, dune and glacial environments. Post-depositional chemical action frequently modifies the grains, so that fossil examples must be carefully studied, but it is frequently possible to study both mechanical and chemical action in ancient sands. Certain subenvironments (and combinations thereof) such as hot and cold desert and coastal dune sands can be distinguished. Sand grains can frequently be found in silts and clays; some of the grains may have been affected during transport of the silt, while others were abraded in a previous depositional episode. It may thus be possible to obtain environmental information about both episodes.

Grains in the sand size and large silt range were collected from a number of different modern depositional environments; the textures noted on each group were distinctive enough to permit individual environments to be distinguished. These textures were then duplicated experimentally; the simulated textures were quite similar to those found in nature. Surface textures of quartz grains from known fossil environments were then compared to the modern and experimental features and were found to be similar, except for certain chemical features which could be ascribed to post-depositional alteration. These latter features were studied and partially duplicated in the laboratory. Finally the technique was used to identify unknown fossil environments with the proviso that as many other techniques as possible were to be used to confirm identification (D. Krinsley, J. Donahue, 1975).

TEXTURAL FEATURES

The types of features detected on quartz grain surfaces can be classified as mechanical or chemical features, or combinations of the two. The mechanisms producing these features are conchoidal fracture, cleavage (contrary to popular opinion, quartz does have cleavage or slip), and solution-precipitation. The abundances, intensities and spatial arrangement of the above three features can be used successfully to delimit a number of different depositional and weathering environments.

DEPOSITIONAL ENVIRONMENTS

Weathering and Youthful River Textures. Recently quartz grain textures from granites and their weathering residues were studied; also examined were grains from youthful rivers which presumably contained modified original granitic textures (C. Coch, D.H. Krinsley, 1976). There previously were a few published electron micrographs of original granitic textures (D.H. Krinsley, J. Doornkamp, 1973), but not enough information was available to be definitive.

Detailed examination was made of granite grus (weathering residue) and quartz from a single youthful stream draining the granite, both from the Black Hills of South Dakota (C. Coch, D.H. Krinsley, 1976; Fig. 1, A). Grus grains could generally be identified by microblock textures (see W.B. Whalley, D.H. Krinsley, 1974, for descriptions and photographs); a number of other minor features were present. As the granite quartz grains were carried downstream, the microblocks were progressively destroyed and their place taken by upturned plates (S.V. Margolis, D.H. Krinsley, 1971). The relative distance of transport could be determined by the ratio between microblocks and upturned plates.

Grain frosting as observed with the naked eye and the light microscope is a function of this ratio. Microblocks, being larger, permit light to pass through the grains without much scattering; thus clear grains are observed. Grains with upturned plates are small and their spacing approaches the wave length of visible light; thus the tiny ridges diffract or scatter visible light and a frosted appearance results (Pl. I, Fig. 1).

Subaqueous Marine Textures. Subaqueous features include rounded and smoothed grain edges; these tend to be found on littoral, shelf and turbidite sands. Grains between about 1000 and 1500 μm in diameter contain the best examples of these features; as smaller grains are examined, roundness and smoothing decrease, and on grains of less than about 300 μm, it may be difficult to find subaqueous features of any kind.

Characteristic mechanical V-shaped patterns and grooves are found on rounded and smoothed grain edges; the former generally have a density greater than 3 V's/μm^2. The V's appear to be a series of notches cut in upturned cleavage plates (parallel, thin, flat ridges, oriented at some angle to the grain surface) which are ubiquitous over many subaqueous abraded surfaces (D.H. Krinsley, J. Doornkamp, 1973). It is probable that the large V's represent single mechanical events with the smaller ones the result of irregular grinding of loose debris created by the original impact (Pl. I, Fig. 2). Fracture propagation of energy across crystallographic plates probably created the upturned cleavage plate topography. At high magnifications, rounded surfaces no longer appear smooth; cleavage plates and V-shaped patterns are generally ubiquitous on all abraded areas.

Straight or slightly curved grooves are observed scattered over subaqueous grain surfaces at the same magnifications which best show the mechanical V patterns; the grooves are never as numerous as the V's and frequently include satellite V's, the depressions forming one side of a given V. The grooves are depressed slightly below the surface and may be fairly straight, curve once or twice, or may even extend in ellipses with satellite V's along their lengths. They are not present on smaller grains (less than about 300 μm in diameter) perhaps because there is a decrease in imparted abrasion energy.

Although etch pits or V's formed by chemical etching may occur in any environment, they are most common in subaqueous situations and may be either syndepositional or diagenetic; the former is much more common. They tend to have very regular sides as compared to the somewhat irregular mechanical V's (Pl. II, Fig. 3). Etch pits are all oriented almost exactly the same and generally are located on either rhombohedral or prismatic quartz faces.

Depressions of varying size which contain evidence of solution and precipitation of silica occur irregularly scattered across subaqueous grain surfaces. Mechanical V's are not present within the depressions suggesting that the latter are protected from abrasion because of their location below the general grain level. Occasionally depressions are observed which contain conchoidal breakage patterns (probably representing a previous breakage cycle) indicating that they have not been acted upon chemically. However, these features contain precipitated, amorphous silica in more than 90% of the cases observed.

As subaqueous quartz sand grains of smaller and smaller size are examined, chemical solution and precipitation replace abrasion markings. Grains less than 300 μm in diameter almost never contain evidence of abrasion. Chemical action includes etching with the formation of etch pits as described above, formation of quartz crystal terminations on the surfaces of upturned plates (E. Pittman, 1973) and perhaps most numerous, irregular layers of precipitated silica covering most or all of a given grain with irregular solution markings scattered about the grain surface. The layers described may be very thin so that it is possible to see the underlying topography. On the other hand, precipitation may be so extensive that all topography is masked. The extent to which precipitation occurs is a function of a number of variables including time spent in the environment, surface characteristics (chemical and physical) of a given grain, the chemical environment of the surrounding water envelope, temperature and perhaps several others. Generally if abrasion does not occur on a given sand grain, in the subsequent environment solution and precipitation most certainly will.

Aeolian Textures. There appear to be four types of textural features that are characteristics of aeolian quartz grains from modern hot deserts.

"Upturned plates" (D.H. Krinsley, J. Doornkamp, 1973, Pls. 71, 84) commonly cover the surfaces of most grains greater than 400 to 500 μm in diameter. These plates appear as more or less parallel ridges ranging in length from about 0.5 to 10 μm and are the result of breakage along cleavage planes in the quartz lattice (Pl. II, Fig. 4, Pl. III, Fig. 6). Sand grains of this relatively large size generally travel as saltating or creeping bed load (R.A. Bagnold, 1941), experiencing a succession of high-velocity collisions. At the time of collision, the kinetic energy of each particle is at least partly converted into elastic energy in the grain. When typical aeolian velocities (R.A. Bagnold, 1941) are compared with grain velocities during aqueous transport, it becomes evident that the kinetic energy of a wind-moved particle (varying with the square of its velocity) must often be several hundred times greater than that of a particle moved by water. The results of these high-energy elastic collisions appear to be "abrasion fatigue" (K.J. Pascoe, 1961), and the upturned plates are thought to be resulting cleavage scarps. These plates are frequently modified in desert environments by solution and precipitation (F. Lucci, G. Casa, 1968; S.V. Margolis, D.H. Krinsley, 1971).

Equidimensional or elongate depressions (D.H. Krinsley, J. Doornkamp, 1973, Pl. 68), 20 to 250 μm in maximum dimension in size on smaller grains, are caused by the development of conchoidal fractures on the grain surface. They may result from direct, as opposed to glancing, impact between saltating or creeping grains.

Smooth surfaces occur on smaller grains (90 to 400 μm diameter); they are caused by precipitation (B. Waugh, 1970) and solution of silica and are unaffected to any great extent by abrasion (D.H. Krinsley, J. Doornkamp, 1973). Grains of this size are more normally carried in suspension (R.A. Bagnold, 1941, Chap. 1) rather than by creep or saltation and are therefore unlikely to collide. When collisions occur, development of features caused by abrasion fatigue are less common (K.J. Pascoe, 1961).

Arcuate, circular or polygonal fractures (F. Lucci, G. Casa, 1968, Pls. XCIII through XCV; D.H. Krinsley, J. Doornkamp, 1973, Pl. 82), are most commonly found on smaller (90 to 150 μm diameter) grains. These features may be the result of physical or chemical weathering, possibly including the crystallization of salts. Although weathering action might be expected to occur at times of rest on grains of all sizes, the textural evidence for it would be removed by abrasion of the larger saltating or creeping grains.

Aeolian sand grains from coastal and periglacial environments have been examined (S.V. Margolis, D.H. Krinsley, 1971), and significant variations in the occurrences of the above four features have been noted. These generalizations are based on examination of 20 samples from each environment (some of which are listed in S.V. Margolis, D.H. Krinsley, 1971); about 25 grains were studied in each sample.

Coastal aeolian sand grains contain upturned plates, but only on small patches of any grain surface. In contrast, hot desert grains show plates over most of their surfaces. Equidimensional or elongate depressions occur very occasionally on coastal aeolian grains but are almost always present on hot desert sand grains larger than 500 μm in diameter. Smooth surfaces and arcuate, circular or polygonal cracks on smaller grains are found frequently on hot desert sand but are very rarely found on coastal aeolian sand (Pl. II, Fig. 5).

Periglacial aeolian sand also contains upturned plates, but only in small patches on grain surfaces. Equidimensional or elongate depressions occur with greater frequency on periglacial sand than on coastal aeolian grains, but their frequency is less than on hot desert sand grains. Smooth surfaces on smaller grains and arcuate, circular or polygonal cracks are seldom found on periglacial aeolian sand.

Glacial Textures. W.B. Whalley, D.H. Krinsley (1974) have described the types of textures on quartz grains from glacial environments. It appears that many of the typical fracture patterns described previously in the literature such as arc steps, parallel and subparallel steps and arc shaped steps or grooves (D.H. Krinsley, J. Donahue, 1968; D.H. Krinsley, S.V. Margolis, 1969) probably originated either in the parent rock or when quartz grains were removed from that rock by weathering. In the case of "wet-base" glaciers, grinding in an environment where a thin layer of water surrounds the grains probably produces microblock and upturned plate textures. "Dry-base" glaciers may produce the various conchoidal patterns, as arc shaped steps, parallel and subparallel steps and are steps indicated above. No surface textures described so far reliably characterize any particular glacial subenvironment. The general variability of the grain surfaces from all glacial positions makes it impossible to determine the exact depositional environment. On the other hand, this great variability (in terms of type and size of feature) is generally characteristic of glacial deposits (Pl. III, Fig. 7). In particular, the variation in the amount of precipitation on grain surfaces and the degree to which small debris become attached or cemented is fairly definitive. Thus although glacial subenvironments cannot as yet by characterized by surface textures, the glacial environment can.

EXAMPLES

The first example concerns a sand deposit of Lower Triassic age from Budleigh Salterton, Devonshire, England; it was collected 60 cm above the top of the Budleigh Salterton Pebble Beds in a sea cliff exposure just west of the town, in the base of the Otter Sandstone Formation (M.R. Henson, 1970). A recent stratigraphic review (J. Pattison and others, 1973) suggested that the Pebble Beds and the Otter Sandstone Formation are Scythian and Anisian (early Middle Triassic), which would indicate an age of between 210 and 225 m.y. (W.B. Harland and others, 1964).

The sample consists of largely uncemented, brownish-yellow sand with well-rounded grains ranging in diameter from 0.8 to 0.09 mm. Thirty grains from each of three size ranges (>500 μm, 250 to 500 μm, and <250 μm diam.) were examined with the scanning electron microscope. Whole grains as well as magnified sections of typical features were photographed. The surfaces were compared with modern surface textures of quartz grains from the hot deserts of Libya, Arabia, Australia, and New Mexico and California (U.S.A.).

All of the characteristic eolian features above were found in the Triassic sample in the same proportions and on grains of the same diameters as in the modern hot-desert samples. The distribution of features typical of coastal or periglacial dune areas is absent.

Because diagenesis evens out surfaces on the various size grades, the quartz grain surfaces of the Triassic sample could not have been affected to any great degree by postdepositional processes. This unusual occurrence of ancient transport textures, unmodified by diagenesis, requires some special explanation that I cannot offer at the moment.

This discovery emphasizes the value of investigations of surface texture in environmental reconstruction by demonstrating that under certain conditions, early Mesozoic sand grain surfaces may have escaped diagenesis, at least as far as the resolution of the scanning electron microscope can determine.

Marine sediments contain a predominance of fine sand and coarse silt-sized particles and the lack of SEM studies on these fine-grained sediments has been unfortunate. However, as a result of work on selected Cretaceous and Tertiary samples from Leg 39 Deep Sea Drilling Project (DSDP) in the South Atlantic (D.H. Krinsley, F. McCoy, 1977), the use of silts and fine sands has proven to be a significant tool in deciphering environmental characteristics from finer-grained deep-sea deposits. It has been found that many of these samples contain silt-sized quartz particles with mechanical surface textures. They represent broken fragments of larger sand-sized grains and it is possible using the broken fragments to reconstruct their abrasional history. About 80% of the very fine sand-silt grains (75 μm to 150 μm approximately) were composite; they contained a surface or surfaces with mechanical features, either aeolian or subaqueous, and additional surfaces which indicated that these smaller grains had been portions of larger quartz sand grains. Thus two distinct surfaces were detected on each of the fragments, one with mechanical abrasion or chemical precipitation and/or solution representing texturing activity on the continent or shelf and a later, fresh breakage surface representing a final episode in which the grain broke into several parts. These broken fragments were emplaced in the deep sea by subaqueous processes but preserve characteristic markings of processes that occurred on land or on the shelf prior to transport into the deeper marine environment. In many cases it was even possible to reconstruct the original diameter of the grain by measuring the curvature of the unbroken portion of the fragment. In all samples, the final breakage event was indicated by conchoidal fractures containing little or no evidence of diagenetic alteration and it is interesting that within the magnification range used in SEM (20,000 ×), little or no quartz diagenesis occurred during an extreme time range of as much as 80,000,000 years in some cases.

Discovery of these fragmented grains thus makes it feasible to use finer-grained deep sea sediments for SEM environmental analysis and to provide information on continental and shelf environments. An exciting new application of SEM methods appears to be available, one that would have wide applicability.

Department of Geology
Arizona State University
Tempe, Arizona 85281 USA
Received: 14.II.1979

REFERENCES

BAGNOLD R.A. (1941) – The Physics of Blown Sand and Desert Dunes. Methuen and Co., Ltd. London.

COCH C., KRINSLEY D.H. (1976) – Surface Textures of Quartz Sand Grains from Coolidge Creek, South Dakota (Abstract). Program, Northeast-Southeast Annual Meeting, Geol. Soc. Amer., p. 152–153. Arlington, Virginia.

HARLAND W.B., SMITH A.G., WILCOCK B. (1964) – The Phanerozoic Time Scale. Geol. Soc. London. London.

HENSON M.R. (1970) – The Triassic Rocks of South Devon. Ussher Soc. Prov., **2**, p. 172–177, nr 3.

KRINSLEY D.H., DONAHUE J. (1968) – Environmental Interpretation of Sand Grain Surface Textures by Electron Microscopy. Bull. Geol. Soc. Amer., **79**, p. 743–748.

KRINSLEY D., DONAHUE J. (1975) – Scanning Electron Microscope Study of Quartz Grains in the Emissive and Cathodoluminescent Modes. In: Microstructural Science, ed. by P.M. French, R.J. Gray, J.R. McCall, **3**, p. 567–580.

KRINSLEY D.H., DOORNKAMP J. (1973) – Atlas of Quartz Sand Surface Textures. Cambridge University Press, England.

KRINSLEY D.H., MARGOLIS S.V. (1969) – A Study of Quartz Sand Grain Surface Textures with the Scanning Electron Microscope. New York Academy of Science Transactions, Series II, **31**, p. 457–477.

KRINSLEY D.H., McCOY F. (1977) – Significance and Origin of Surface Textures on Broken Sand Grains in Deep-sea Sediments. Sedimentology, **24**, p. 857–862.

LUCCI F., CASA G. (1968) – Surface Texture of Desert Quartz Grains. A New Attempt to Explain the Origin of Desert Frosting. Gior. di Geologia, Series 2, **36**, p. 761–776.

MARGOLIS S.V., KRINSLEY D.H. (1971) – Submicroscopic Frosting on Eolian and Subaqueous Sand Grains. Bull. Geol. Soc. Amer., **82**, p. 3395–3406.

PASCOE K.J. (1961) – An Introduction to the Properties of Engineering Materials. Blackie and Son Ltd., London, Glasgow.

PATTISON J., SMITH D.B., WARRINGTON G. (1973) – A Review of Late Permian and Early Triassic Biostratigraphy in the British Isles. In: The Permian and Triassic Systems and their Mutual Boundary, ed. by J. Logan, L.V. Hills. Canadian Soc. Petrol. Geol. Spec. Pub., **2**, p. 220–260.

PETTIJOHN F.J. (1957) – Sedimentary Rocks. Harper and Bros. New York.

PITTMAN E. (1973) – Diagenesis of Quartz in Sandstone as Revealed by Scanning Electron Microscopy. Jour. Sediment. Petrol., **42**, p. 507–519.

WAUGH B. (1970) – Formation of Quartz Overgrowths in the Penrith Sandstone (Lower Permian) of Northwest England as Revealed by Scanning Electron Microscopy. Sedimentology, **14**, p. 309–320.

WHALLEY W.B., KRINSLEY D.H. (1974) – A Scanning Electron Microscope Study of Surface Textures of Quartz Grains from Glacial Environments. Sedimentology, **21**, p. 87–105.

David KRINSLEY

BADANIA MIKROSTRUKTUR ZIARN PIASKU KWARCOWEGO PRZY ZASTOSOWANIU ELEKTRONOWEGO MIKROSKOPU SKANNINGOWEGO

Streszczenie

Ziarna piasku kwarcowego badane za pośrednictwem elektronowego mikroskopu skanningowego ujawniają wiele cech mikrostrukturalnych, jakie mogą być wykorzystane w badaniach litologicznych osadów, dla określenia tak charakteru macierzystego źródła, jak również warunków transportu materiału. Ziarna te ulegały bowiem wpływom środowiska, które zaznaczyło się w specyficznych śladach zmian chemicznych i mechanicznych.

Na powierzchniach ziarn kwarcu obserwuje się ślady zmian mechanicznych lub chemicznych, albo też kombinacje obu wymienionych cech. Do pierwszych należą przełamy muszlowe i pęknięcia, do drugich formy trawień-wytrąceń. Ze względu na zróżnicowanie śladów powierzchni ziarn kwarcu można wyróżnić cztery główne rodzaje środowisk transportu, depozycji i wietrzenia.

Struktury powierzchni ziarn kwarcu z młodych rzek, transportujących materiał granitowy, odznaczają się na ogół mikroblokową strukturą. W miarę oddalania się od źródła materiału kwarc ulega spękaniu na coraz to mniejsze bloki i dzieli się na płytki.

Powierzchnie ziarn kwarcu pochodzącego ze środowiska morskiego są zaokrąglone i gładkie. Przy dużych powiększeniach stwierdza się, że powierzchnie są gęsto pokryte formami V-kształtnymi, będącymi śladami pojedynczych mechanicznych zderzeń z innymi ziarnami. Ponadto przy dużych powiększeniach widoczne są wyżłobienia powierzchni. W ziarnach o średnicy mniejszej niż 300 μm zmniejsza się stopniowo udział form V-kształtnych, a coraz większą rolę odgrywa proces chemicznych przeobrażeń kwarcu, polegający na trawieniu powierzchni lub wytrącaniu się na niej cienkich otoczek krzemionki. Procesy chemicznego trawienia kwarcu lub wytrącania się na jego powierzchni krzemionki wskazują na przeobrażenia chemiczne i warunki w jakich zachodziły te zmiany, a obfitość form rzeźby pochodzenia mechanicznego na energię ośrodka w jakim odbywały się transport i osadzanie materiału.

Wśród kwarcu pochodzenia eolicznego wyróżnia się cztery typy mikrostruktur charakterystycznych dla środowiska współczesnych gorących pustyń. „Zadziorowe powłoki" (ang. *upturned plates*) pokrywają większość ziarn kwarcu średnicy powyżej 400 – 500 μm i ułożone są w mniej lub bardziej równoległych pasmach odległych 0,5 – 10 μm. Formy te są wynikiem ogromnej ilości kolizji ziarnowych.

Wgłębienia koliste lub wydłużone są rezultatem rozwoju muszlowych przełamów. Tworzą się one pod wpływem uderzeń ziarn wleczonych i podrzucanych przez wiatr.

Gładkie powierzchnie są wynikiem wytrącania się krzemionki na małych ziarnach, mniej podatnych na odkształcenia mechaniczne.

Łukowate, koliste lub poligonalne formy spotykane są głównie na powierzchniach małych ziarn. Formy takie są rezultatem mechanicznego i chemicznego wietrzenia, zachodzącego przypuszczalnie przy współudziale soli.

Powierzchnie kwarcu pochodzenia glacjalnego odznaczają się ogromną różnorodnością mikrostruktur, co jest cechą danego środowiska. Różnorodność powyższa powoduje, że w chwili obecnej nie ma jeszcze opracowanych podstaw umożliwiających dokładną ocenę warunków środowiska i przeprowadzenia szczegółowego podziału. Zauważono natomiast istotne różnice między śladami na powierzchni kwarcu z ośrodka mokrego i suchego; w pierwszym dominuje budowa blokowa, a w drugim przełamy muszlowe.

Давид КРИНСЛЕЙ

ИЗУЧЕНИЕ МИКРОСТРУКТУРЫ ЗЁРЕН КВАРЦЕВОГО ПЕСКА С ПОМОЩЬЮ СКАННИНГОВОГО ЭЛЕКТРОННОГО МИКРОСКОПА

Резюме

Зёрна кварцевого песка, изучавшиеся под сканнинговым электронным микроскопом, отличаются многими микроструктурными особенностями, которые могут быть использованы при литологическом изучении пород, как для определения источника их происхождения, так и условий транспортировки материала. Эти зёрна испытывали воздействие окружающей среды, проявившееся в специфических изменениях химического и механического порядка.

На поверхности зёрен кварца наблюдаются следы механических и химических преобразований или следы сочетавшегося влияния обоих этих факторов. К первым относится раковистый излом и трещины, ко вторым — формы травления-осаждения. По разнообразию следов на поверхности кварцевых зёрен, можно представить четыре типа сред, в которых происходил перенос осадков, их осаждение на местах и выветривание.

Строение поверхности кварцевых зёрен из молодых рек, переносивших гранитный материал, отличаются микроблоковой структурой. По мере удаления от источника, кварц трескается на всё меньшие по размеру блоки и расслаивается на таблички.

Поверхность зёрен кварца из морской среды округлая и гладкая. При большом увеличении замечается, что поверхность густо покрыта V образными формами, являющимися следами отдельных механических столкновений с другими зёрнами. Кроме того, на поверхности можно заметить бороздки. В зёрнах диаметром менее 300 μm количество V образных форм уменьшается, а появляется всё больше и больше признаков химического преобразования кварца, путём травления поверхности или осаждения на ней тонких кремнистых оболочек. Процессы химического травления кварца или осаждения на его поверхности кремнезёма говорят о химическом преобразовании и условиях, в которых эти изменения происходили, а богатство форм рельефа механического происхождения, указывает на подвижность среды, в которой происходил перенос и осаждение материала.

В кварце эолового происхождения выделяется четыре типа микроструктур, характерных для условий современных горячих пустынь. „Шершавые оболочки" (*upturned plates*) покрывают большинство кварцевых зёрен диаметром свыше 400—500 μм и расположены более менее параллельными поясами на расстоянии 0,5—10 μм. Эти формы появились в результате многочисленных столкновений зёрен.

Кругообразные или удлиннённые углубления — последствия раковистых изломов. Они возникают при ударах зёрен, несомых и подбрасываемых ветром.

Гладкие поверхности образуются вследствие осаждения кремнезёма на малых зёрнах, менее подверженных механическому разрушению.

Дугообразные, кругообразные и полигональные формы наблюдаются главным образом на поверхности малых зёрен. Эти формы появились как результат механического и химического выветривания, вероятно при участии слои.

Поверхность кварца ледникового происхождения отличается многообразием микроструктур, что характерно для этой среды. Ввиду этого многообразия до сих пор не разработаны основы для детальной оценки свойств и детального расчленения. Отмечено существенное различие между следами на поверхности кварца, относящегося к водной и сухой среде; в первом случае преобладает блоковое строение, а во втором — раковистые изломы.

PLATE I

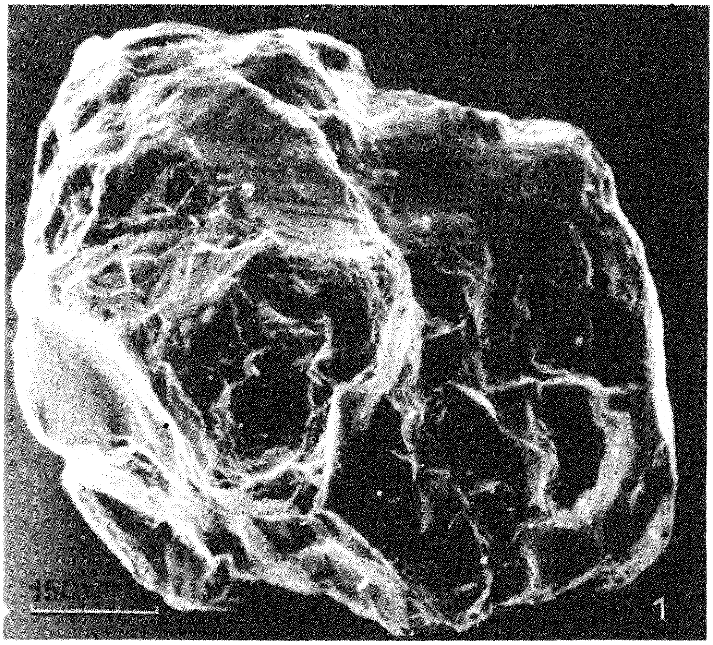
Fig. 1. Quartz sand grain from a river in Black Hills, South Dakota, draining granite terraine. Note microblocks with upturned plates on edges representing river erosion

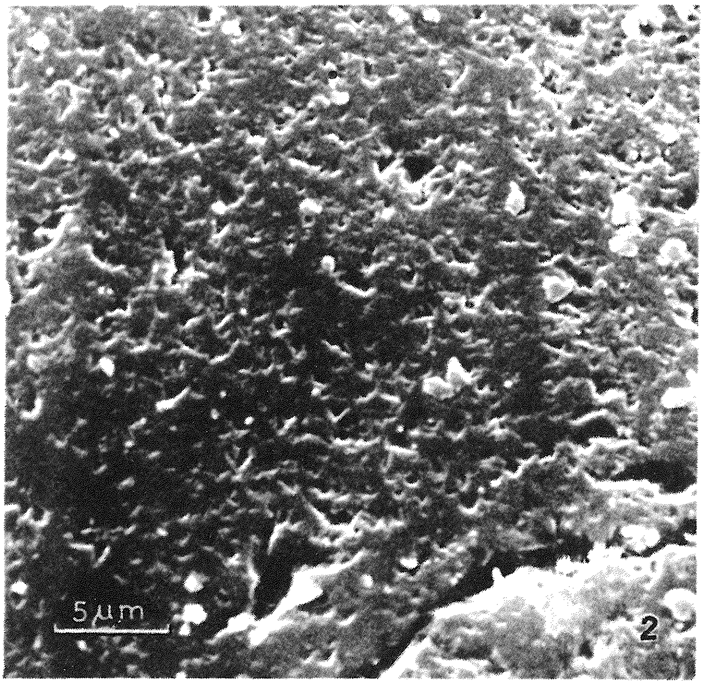
Ziarno piasku kwarcowego z rzeki w Black Hills w Południowej Dakocie, drenowanego obszaru granitowego. Zauważa się mikroblockność i „zadziorowe powłoki" na krawędziach, będące wynikiem erozji rzecznej

Fig. 2. Portion of a quartz sand grain from the South African continental shelf. Note mechanical V-shaped patterns and elongate patterns indicating subaqueous action

Fragment ziarna piasku kwarcowego z kontynentalnego szelfu Południowej Afryki. Widoczne są V-kształtne ślady i formy wydłużone, wskazujące na mechaniczną działalność podwodną

PLATE I





David KRINSLEY – Scanning Electron Microscope Examination of Quartz Sandgrain Microtextures

PLATE II

Fig. 3. Portion of a quartz sand grain which was artificially etched in sodium hydroxide solution. The en echelon V-shaped depressions are exactly like those observed on natural grains

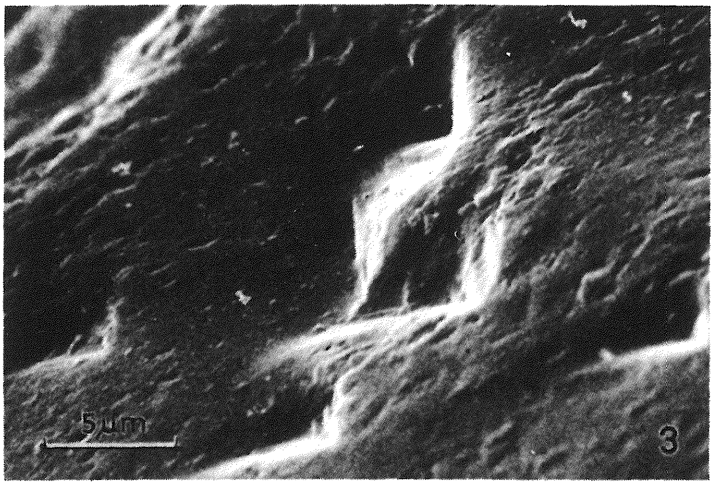
Fragment ziarna piasku kwarcowego sztucznie wytrawionego w NaOH. Stwierdza się podobieństwo figur V-kształtnych do naturalnych

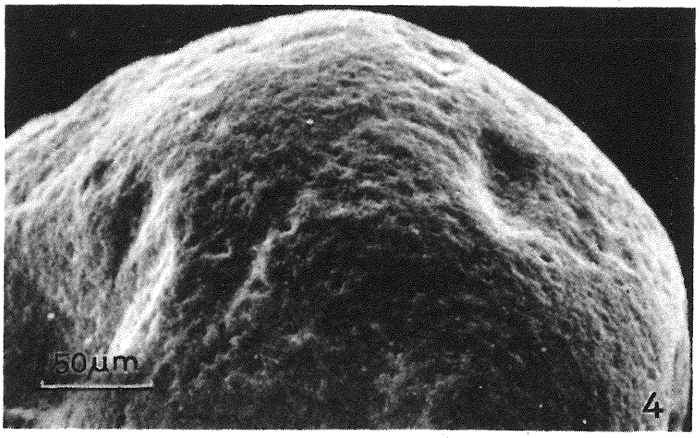
Fig. 4. Portion of an aeolian quartz sand grain from the Algodones Dune Field, California. Note upturned plates and equidimensional or elongate depressions on grain surface

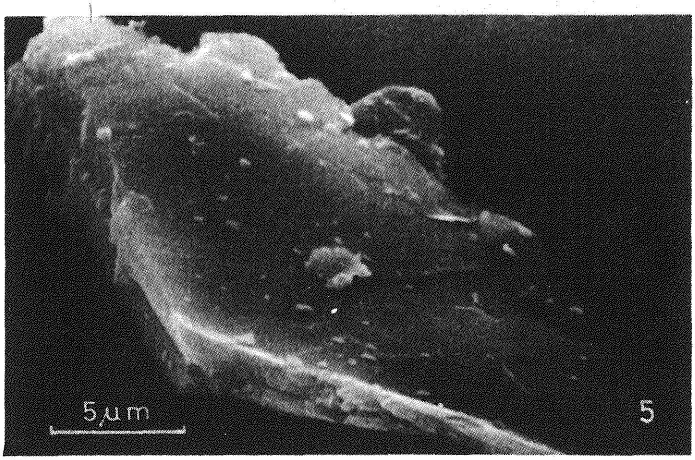
Fragment kwarcowego ziarna piasku eolicznego z wydm Algodones w Kalifornii. Widoczne są „zadziorowe powłoki" oraz centryczne i wydłużone wyżłobienia na powierzchni ziarna

Fig. 5. Large quartz silt grain from same location as Fig. 4. Note angularity and flatness (cleavage)

Duże ziarno mułu kwarcowego z wydm Algodones w Kalifornii. Na uwagę zasługuje kanciastość i płaskość (spękania)







David KRINSLEY – Scanning Electron Microscope Examination of Quartz Sandgrain Microtextures

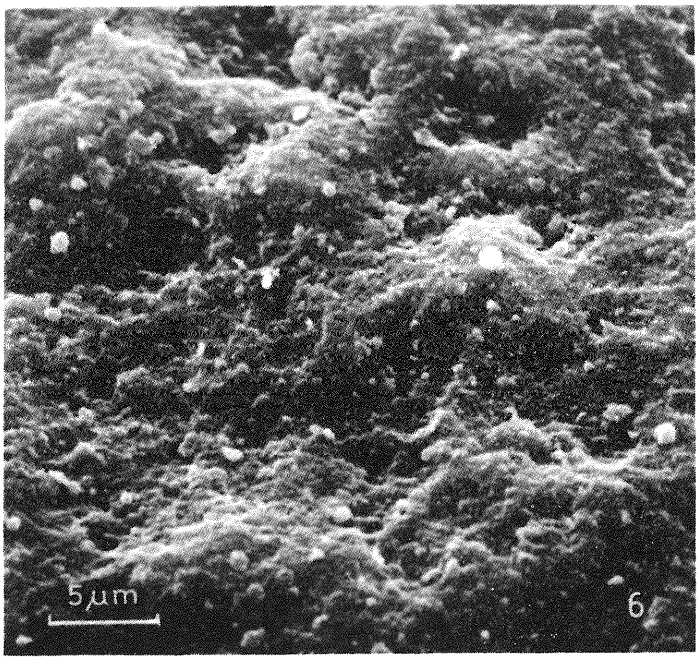
PLATE III

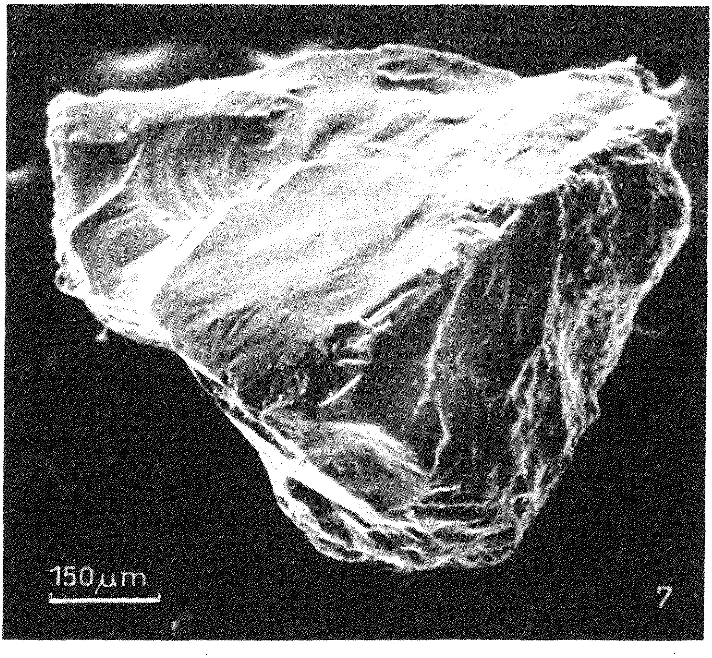
Fig. 6. Portion of an aeolian quartz sand grain from the same location as Fig. 4. Note the upturned plates which have been rounded by solution

Fragment kwarcowego ziarna piasku eolicznego z wydm Algodones w Kalifornii. Widoczne są „zadziorowe powłoki" wygładzone przez roztwory

Fig. 7. Quartz sand grain from a Norwegian Fjord. Note fresh conchoidal fractures and lack of precipitation

Ziarno piasku kwarcowego z fiordu norweskiego. Uwagę zwracają świeże przełamy muszlowe i brak form wytrąceń


5 µm
6


150 µm
7