Sand

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In retracing some of the "footprints in the sands of time," my mind goes back to a conversation some two years ago with my aunt, then eighty-four years young. She referred to "maple sand," a common "pest" to the maple-syrup makers in Vermont. The implication was that this "sand" had come up as sand from the soil through the circulatory system of the maple tree and then settled out in the boiling down of the sap. The resulting argument, as in so many cases, was based merely on lack of definition of terms. There *is* such a thing as maple sand, but it has *not* come up as sand from the soil. It's a fine, white, crystalline, rather impure calcium malate which, because of its relative insolubility (as compared with sugar) precipitates before the sugar in the syrup and sugar making. The solubility of calcium malate at 0°C. is 0.812 gm. per 100 cc. of water as compared with a solubility of sucrose, under the same conditions, of 179 gms. This relative difficulty of solution of the calcium malate as compared with sugar will explain the feeling of the maple-sugar maker that it is as insoluble as sand and the resultant naming of the material, "sand." Examination of two specimens of maple sand indicates a material much finer than what is usually called sand.

Table I. Grain Analyses of Two Specimens of Maple Sand[1] According to Modified Wentworth Classification. (Table II.)

	Coarse Sand ½ mm. plus	Fine Sand ½ mm.-1/16 mm.	Silt 1/16 mm.-1/256 mm.	Clay less than 1/256 mm.
a.	5.7%	8.5%	22.8%	62%
b.	3.5%	3.5%	45.5%	48%

Biologically the term sand is also applied to various kinds of material in the human body, such as brain, kidney, bladder, and prostate "sands." "Brain sand" is composed of irregular, agglutinated, yellowish or reddish grains found either in the pineal body or areas of toxoplasmic disease in the cortex.

Although pineal bodies do not consistently show brain sand, there is no positive evidence that its presence indicates a diseased condi-

[1] Specimen a, courtesy of the Vermont State Department of Agriculture; and, b, courtesy of Bradley St. John, Fairhaven, Vermont.

tion. In fact, when present, this pineal sand may perform a valuable function, if an x-ray photograph of the brain is necessary to determine the presence of a brain tumor. Such a brain tumor may not show up plainly on x-ray photographs, but, if present, it will frequently displace the pineal body from its normal median position. The pineal sand will photograph, thus showing the displaced position of the pineal body, and therefore indicating the side on which the brain tumor has developed. Kaufman (20, p. 1819) describes the pineal sand as mulberry-like reddish bodies composed of calcium carbonate with a layered albuminous material of unknown origin. Although it is not indicative of any specific disease, the amount of pineal sand frequently increases from about eight years.

Fig. 1. Photo Showing Human Pineal Body with a Section Removed from the Left Side, Exposing Pineal Sand. Courtesy of J. W. Papez, M.D. Photo, K. V. Palmer.

Brain sand in the cortex is positive evidence of various types of diseased condition in the brain—*tuberous sclerosis, toxoplasmosis,* possibly as *sclerotic* patches on the cerebral blood vessels.

The balancing mechanism of vertebrate animals contains *otoliths* (*otoconia* in the human body) frequently of the size of sand grains suspended in the inner ear. These bodies, either single or multiple granules (usually calcium carbonate) in a gelatinous mesh, are suspended in the endolymph in contact with the free ends of hairs projecting from the maculae, sensory areas of the utricle and saccule of the membranous labyrinth. Because of their size these granules frequently fall in the range of sand (Table II) and in the dog-fish shark *(Squalus acanthias* L.*)* actual grains of sand are used in this balancing mechanism. These grains are drawn down into the saccule through the endolymphatic duct. An examination of the grains from the balancing mechanism of one dog-fish,[2] which may or may not be typical, gives the following distribution of grain-sizes: between 28 and 297 microns, with the finer

[2] Obtained through the interest of Professor W. E. Martin.

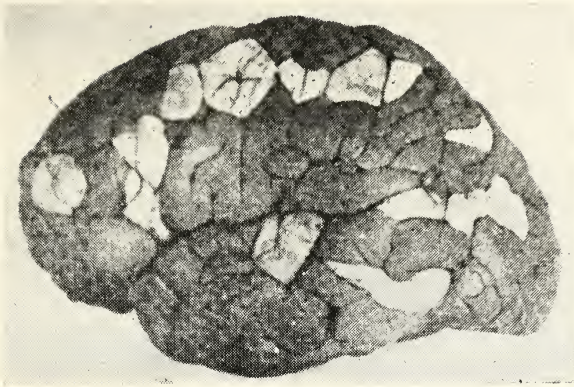

Fig. 2. Copy of "Lateral Surface of the Brain Showing the Distribution of Patches of Tuberous Sclerosis." (18, p. 234)

sizes the more abundant. In the Wentworth classification of clastic grains (Table II), 11/20 grains would be silt; 6/20, very fine sand; 3/20 fine sand.

Kidney and bladder sand may be found in the kidneys, pelvis, urinary bladder, gall bladder, urethra and prepuce. The bodies range in size from very fine sand up to a diameter of several inches. The most common components according to Kaufmann (20, p. 1410) are: (a) uric acid or urates. The urate stones are the most common, moderately hard, with a soft granular or nodular surface, yellowish brown or reddish brown color, laminated structure; (b) calcium oxalate. These stones are small, warty, colorless or stained with hematin. They may be composed of alternate layers of calcium oxalate and urates; (c) calcium or ammonium magnesium phosphate. These are formed in alkaline urine.

Fig. 3. Copy of Section of the Cerebellum Showing Small Cavities Encrusted with Calcium Carbonate. (Nissl's Stain, Low Power.) (18, p. 241)

Prostate sand. Cross-sections of prostates of older men contain almost constant yellow, brown or black granules from the size of grains of snuff to that of a pea or larger. On examination of the prostate gland they may be felt through the rectum. (20, p. 1520)

Geologically, sand may be defined as fragmental rock material intermediate in size of grain between gravel and silt. The British classification as proposed by Boswell (1918) (27a, p. 108) differs from the American geologic practice as proposed by Wentworth. (50, p. 507)

Table II. Wentworth Classification of Clastic Particles on the Basis of Grain Size.

Boulder	256 mm. plus
Cobble	256-64 mm.
Pebble	64-4 mm.
Granule	4-2 mm.
Very coarse sand grain	2-1 mm.
Coarse sand grain	1-½ mm.
Medium sand grain	½-¼ mm.
Fine sand grain	¼-⅛ mm.
Very fine sand grain	⅛-1/16 mm.
Silt Particle	1/16-1/256 mm.
Clay particle	less than 1/256 mm.

In this classification, then, all sedimentary grains 1/16-2 mm. are in the sand range. In the opinion of the writer the Wentworth classification is a backward step as compared with the British in that it is based so largely on common fractions instead of decimals, the fundamental basis of the metric system.

In addition to the British and American geological classifications, The International Society of Soil Scientists have their own classification which with slight modification is shown in Table III.

Table III. Classification of Soil Grain Sizes as Adopted by the Int. Soc. of Soil Scientists. (40, p. 12)

Coarse sand grain	2.0 -0.2 mm.
Fine sand grain	0.2 -0.02 mm.
Silt	0.02-0.002 mm.
Clay	less than 0.002 mm.

Relation of Grain Size to Origin

A recent paper by Keller (22, p. 215) reports that a study of 700 samples from Pacific coast dunes and beaches, 370 samples from inland dunes as far east as Dunes Park, Indiana, and 272 samples of the St. Peter sandstone in Missouri, the Tensleep and Wyopo sandstones in Wyoming and the Navajo sandstone in Utah gave the following results: Beach sands are approximately four times as coarse as corresponding dune sands. The inland dunes seem to be more variable in coarseness than the dunes near the beaches. Comparison of the St. Peter, which has been frequently considered of eolian origin, with the beach and dune sands indicates definitely that the St. Peter had a beach origin.

Composition of Sands

Although commonly sand is thought of as being composed of quartz, it is considered technically as being of no single composition, but as being of a definite range of grain size as determined by the specific method of classification used. In general, it has been assumed that the number of minerals in a sand or sandstone decreases with distance from the source. Shaler reported (43) that "an unusually pure beach sand is found at West Palm Beach, on the Atlantic Coast of Florida (probably Palm Beach, E. R. S.), nearly everything but quartz being eliminated." Russell (41, p. 1347), however, in his study of samples of Mississippi River bottom sediments from Cairo to the Gulf concludes that the selective destruction of the "less resistant" minerals (either chemically or physically) has been generally overestimated. The hypothesis, that the presence of "less resistant" minerals in a sand indicates a nearby source, has no factual basis. "The absence of the 'less resistant' minerals in sediments should be attributed largely to solution and alteration either in the source rocks or after deposition rather than to destruction during transport."

The following is a list of sixty-eight minerals, with comments, found in various sands. There is no hard and fast boundary in the discussions of the minerals in this list between sand and gravel.

Actinolite is uncommon in desert sands studied by White. (52, p. 745) According to Condit (8, p. 154) the amphiboles are more common in Ohio glacial sands than in older sands and sandstones.

Albite. Where a sand is the result of deposition after rapid disintegration of granular, acid, igneous rocks, it frequently contains abundant, only slightly weathered, acid feldspars such as orthoclase, microcline, and albite. Such a sand or resulting sandstone is called arkose. Essential conditions, it is generally believed, are: (a) granitic terrane, (b) rapid disintegration and (c) quick deposition. As noted above, Russell discounts entirely the significance of any ordinary concept of quick deposition. (41, p. 1347) Twenhofel states (47, p. 229) that rapid disintegration is favored by aridity, high altitude, or high latitude. White, on the other hand, (52, p. 747) concludes: "It may be of interest to note that none of the (desert) sands studied was appreciably arkosic, a fact that would seem at complete odds with any conjectural notion of the mineralogy of sands of desert origin." Barton (2, p. 439), in his very complete study of arkose, states that it may be formed under less rigorous conditions—usually in deposits of smaller size, in which the feldspar is less fresh, showing the beginning of the decomposition process. The common argillaceous odor of arkose may be due to such predepositional decomposition or to decomposition after deposition as arkose. (E.R.S.) Albite (var. moonstone) has been found in the bed of Williams Creek, Indianapolis, Ind. (49)

Allanite is reported by Russell to be fairly common in all samples from Cairo to the Gulf, although always less than 1% of the heavy minerals. He considers that the infrequency of mention of allanite in detrital sediments is due to lack of recognition rather than to its absence. (41, p. 1328)

Anatase. In one sample of desert sand.

Andalusite. Of 33 desert sands studied by White, (52, p. 745) four showed andalusite.

Apatite. About one-third of the desert sands studied by White (52, p. 745) showed apatite in greater or less abundance.

Augite. The pyroxenes and other ferro-magnesian silicates are uncommon in sands or sandstones unless they are the result of quick deposition of rapidly disintegrated, granular, basic igneous rocks. When cemented, such a rock is called graywacke. (47, p. 175) Because of the ease of decomposition of most of the basic minerals, graywacke is not as common as arkose.

Barite. White reports barite as rare in three of the 33 desert sands studied. (52, p. 745)

Biotite. Uncommon in desert sands. (52) Bleached and battered flakes are found in the Mansfield sandstone of Indiana. (12, p. 131)

Brookite is reported by Gault (12, pp. 131, 132, 133) as a persistent heavy mineral in the Mansfield sandstone. He concluded that it had developed *in situ* because of the perfection of the crystals and because they are sometimes found projecting from fragile specimens of leucoxene.

Calcite is probably the commonest mineral cementing sand grains into sandstone. It is also common (below the zone of weathering, E. R. S.) as comminuted fragments in glacial sand. (8) Many cases of marine sands of nearly pure $CaCO_3$ are reported. Such fragmental, calcareous sands are deposited in the "sand zone" especially off shores of a land of low relief. After deposition, the sand may be picked up by the wind and redeposited in calcareous dunes. There are such dunes on Bermuda composed of coral, mollusk and foram shells or fragments. In addition to the marine calcareous sands deposited off low-lying land areas, fragmental calcareous sands are deposited off shores composed predominantly of limestones. Cases of this type are found on the beaches of Anticosti Island and Gotland where over 90% of the sand grains are of limestone. Calcareous sands, of whatever origin, are characterized by the common features of other sands such as ripple marks and cross-bedding. (47, p. 250) It is probably true that some of the cross-bedding in the St. Genevieve limestone of Indiana, such as may be seen in the old quarries on the penal farm at Putnamville, is of sand-dune origin, although some as evidenced by the coarseness is of beach origin. (E. R. S.) White, (52, p. 744) as a result of his study of desert sand, states: "Calcite is, to be sure, not uncommon in sediments of subaqueous deposition, but in those of desert origin it is ubiquitous."

Cassiterite is the chief mineral of tin placer deposits.

Ceylonite was found in one sample of desert sand. (52, p. 745)

Chlorastrolite (49) found by Dr. Kelso while panning for gold in Brown County, Indiana, is believed to give very positive evidence of the direction of movement of the Illinois glacier—Isle Royale in Lake Superior to Brown County, Ind. Native copper and native silver found in the "gold counties" of Indiana give similar evidence, Keweenaw Peninsula origin. (49)

Chlorite, glauconite, greenalite, serpentine, and epidote are chiefly responsible for the green color of sandstone. Chlorite was found by White in three desert sands. It is a sporadic mineral in the Mansfield sandstone. (12, p. 132)

Chromite. One of the heavy minerals reported in sands and sandstones.

Clinozoisite was reported by White as rare in three desert sands.

Collophane is not commonly reported in clastic sediments. Martens (27) has pointed out the frequency of its occurrence. Russell (41, p. 1331) suggested that, since nearly all samples of lower Mississippi sediments showed collophane, its infrequency of mention may be due to its solubility in acids with which sediments are frequently treated before study.

Corundum. Wade (49) reports, not only chatoyant crystals of common corundum, but also ruby and sapphire of fine quality from the Indiana "gold counties."

Diallage is reported by Russell as being fairly common, but less than 1% of the heavy minerals, in Mississippi River sediments.

Diamond. Occasionally, when panning for gold, there are picked up here and there in the "gold counties," not only in Indiana, but also Ohio, Michigan, Illinois and Wisconsin, diamonds of excellent water up to more than five carats in size. There are records of at least eleven diamonds from Indiana alone. Hobbs has reported a 17ct. and a 23ct. diamond from Wisconsin. (49) These were brought down by the Pleistocene glacier from some as yet undiscovered diamond lodes in Canada. These are but a sample of the tremendous diamond production from placer deposits—streams, the ocean, winds —in South Africa, Belgian Congo, Gold Coast, Sierra Leone, British Guiana, Brazil, Borneo, and India. (17, p. 323)

"In 1835 the great British scientist, Sir David Brewster, stated that, 'Were the diamond not as a gem the head of the mineral kingdom, it would have attained the same distinction from its great utility in the arts.' World War II has certainly proved the truth of this statement. There is no important war weapon that does not employ the diamond in its manufacture." (28, p. 1567)

Diopside. In five of the 33 desert sands studied by White, diopside was reported.

Dolomite is a fairly common cement in sandstones. It is reported by Russell as a common constituent of Mississippi River sediments.

Enstatite is reported by White from five desert sands.

Epidote. Frequent but not always abundant in desert sands. (52) In the Mississippi River sediments up to 10% of the heavy minerals. (41, p. 1328)

Fluorite. Rare in two desert sands studied by White. (52)

Garnet is the coloring mineral in red sands which are common on the Great Lakes and the oceans. Condit (8) reports its common occurrence in glacial sands of Ohio and in the Triassic sandstones of Connecticut and New Jersey. He also suggests that the rarity of garnet in certain pre-Triassic sandstones, such as those of Ohio, is evidence of non-metamorphic sources. Gault (12, p. 132) reports garnets of several colors in the Mansfield sandstone. White found garnet "frequent, but not omnipresent" in the 33 desert sands studied. (52, p. 745) Russell reports three varieties of garnet, one at times up to 17% of the heavy minerals, in the Mississippi River sediments studied.

Glauconite (green sand) occurs in rocks of nearly all ages. Because of its appreciable per cent of potassium, glauconite is frequently used as a locally obtained fertilizer. Its origin has aroused the interest of some of the best mineralogists, but as yet there is no unanimity of opinion. Two schools of thought may be briefly summarized: (a) the glauconite is formed in the presence of organic matter from ferrous sulphide, clay, a potassium compound and water; (b) the glauconite is the result of the progressive decomposition of biotite under marine conditions. (48, p. 402) Glauconite is reported by Russell as never common in the Mississippi River sediments, although it is not an uncommon mineral in the rocks of the upper Mississippi valley (E.R.S.) and in the Tertiary sediments through which the Mississippi flows. (41, p. 1327)

Glaucophane is reported from one desert sand by White.

Gold. Native gold is the ore mineral of placer gold deposits, be they marine sands, present stream deposits or deposits from the geologic past. Placer gold was the gold of the '49 gold rush and the Klondike. It is still the mecca of the lone prospector. For a number of years, however, somewhat less than ⅓ of the U. S. production has been placer gold. (28) A good prospector can see an unbelievably small speck of gold or "color", as he calls it, in his pan. Lindgren (25, p. 253) states that a particle of gold worth 1/2000 cent at the old price ($20 per oz.) can be spotted. Even so, more specimens of "fool's gold" than of real gold are sent in to state geologists for identification. However, once in a while, even in Indiana, real gold is found. Especially in Morgan and Brown Counties, the "gold counties", a good many thousands of dollars worth of gold have been recovered by farmers in "off seasons", by men out of work or by the butcher, the baker, the candle-stick maker, with gold-panning as a hobby. This gold, like the chlorastrolite, the copper, the diamonds and the silver, was brought down from the north by the great Pleistocene ice sheets. A state inspector of concrete aggregate saw his chance when sand and gravel were being washed from Big Walnut Creek in Putnam County, Indiana, for the new U. S. No. 40 four-lane highway. Twice a day, he would put a strip of Brussels carpet, 27 inches by 48 inches, in the washing flume. When the washer was stopped at noon and in the afternoon, he would take out the strip of carpet, dry it by the fire, and beat it out over a piece of brown paper. Together with much quartz and magnetite sand, at the end of five weeks, he had over $250 worth of gold. In my desk, also, are three grains of gold washed out by David Taylor, a Putnamville H. S. boy, from Mosquito Creek just south of Putnamville, Ind.

Gypsum. The widely known white sand dunes of Otero County, New Mexico, appearing from a distance like white-caps on an inland sea, are largely composed of nearly pure granular gypsum. It had been eroded from "ribs" of Permian gypsum rising at intervals above the saline flats. (16) Gypsum is also a common constituent of the salts deposited in desert playas.

Halite. Thoulet (45) has reported minute amounts of halite in desert sands outside of playas, but in playas it is so abundant as to have been the basis of the Grabau-Walther theory of the origin of great salt deposits.

Hematite. Condit (8, p. 159) reports that hematite is found as inclusions in quartz and as a cement in red sandstone. White (52, p. 745) noted hematite as a common constituent of desert sand. Surprisingly, Russell (41, p. 1328) reports hematite as more common than limonite in the sediments of the lower Mississippi.

Hornblende. Condit (8, p. 158) reports the hornblende in Ohio sandstone as being much weathered. Sandstones with considerable hornblende would be considered as graywacke. Gault reports hornblende as a sporadic mineral in the Mansfield sandstone of Indiana. (12, p. 133) Russell (41, pp. 1319, 21, 23, 25) found hornblende up to 15% of the heavy minerals. According to White, half of the 33 desert sands studied showed hornblende and it was abundant in two samples. (52, p. 745)

Hypersthene was found in glacial sands by Condit; common in a few desert sands by White; fairly common (up to 3% of the heavy minerals) by Russell.

Ilmenite, whose local abundance in beach sands of Florida has given those sands economic importance, is one of the heavy minerals. To its black color, not that of magnetite, is due the name "black sands" of the heavy-mineral sands of Florida. These heavy minerals have been carried by streams and shore currents from the states between Virginia and Georgia down to Florida. Since the heavier minerals tend to be dropped first, unless they are markedly finer grained than the average, the sparsity of such minerals as ilmenite in the beach sands from Virginia to Georgia poses, in the opinion of the writer, a very real geomorphological problem. Is it not very probable that in the Pleistocene the drainage from the source states was directly to Florida instead of into the Atlantic farther north? Further evidence of the reasonableness of such a suggestion is the distribution of the heavy minerals on both sides of the Florida peninsula. In the Mansfield sandstone of Indiana, Gault reports ilmenite as making up 5-20% of the heavy minerals. (12, p. 133) In the Florida deposits 43%. (34) It is frequently abundant in desert sands. (52, p. 745) Mississippi River sediments contain high, although variable, percents (6-50% of the heavy minerals) of ilmenite. (41, p. 1328)

Iolite was reported from the dune sand of Holland. (36)

Iridosmine. This natural alloy of iridium and osmium is derived chiefly from placer deposits.

Kaolinite. Various clay minerals are reported disseminated and in "clay balls" in sands and sandstones.

Kyanite. About one-third of the desert sands studied by White contained kyanite. (52, p. 745) Russell reported kyanite as rare up to 1% of the heavy minerals in the lower Mississippi sediments.

Leucoxene is a heavy mineral, decomposition product of ilmenite and found associated with that mineral in the Mansfield sandstone of Indiana, 40-70% of the heavy minerals; (12) not common in desert sands; (52) 1-7% of the heavy minerals in the lower Mississippi sediments; (41) and astonishingly not listed from Florida by Phelps. (34)

Limonite is regarded by Condit as equally omnipresent with quartz, although usually not over 3-4%. It is the cement in brown sandstones, such as the famous stone of the "brown-stone-fronts", so widely built along our eastern seaboard at the end of the last century.

Magnetite is the common mineral of black sands (not Florida) and can be separated out with a magnet. It is generally not of economic importance because of its low tenor and also its high percent of titanium due to associated ilmenite. In gold panning, the gold is usually found with a magnetite residue in the bottom of the pan. One dune sand from California contained 15% magnetite. (38, p. 385) For economic reasons, the Japanese are said to have concentrated and utilized marine sands as iron ore. White reports that magnetite was not common in desert sands studied. It is but a sporadic mineral in the Mansfield sandstone of Indiana. (12) Russell reports that the percent of magnetite in the heavy minerals in the Mississippi sediments varies between 0.9 and 42%. (41, p. 1318 et seq.)

Marcasite is not commonly reported in sands and may be mistaken for pyrite.

Microcline. Discussions of albite and orthoclase apply to microcline, although it is reported by H. R. Wanless as the most resistant of the feldspars.

Monazite sand is the chief commercial source of the "rare earths"—thorium, cerium, lanthanum, praseodymium and neodymium. With the decline in the use of thorium for Welsbach mantles, other uses for thorium and the other rare earths have been sought. Resulting uses include glass, ceramics, alloys, printing and dyeing, and moth- and rot-proofing of textiles. (28, p. 767)

Muscovite is a common mineral, although not in large amounts, in sands and sandstones. Both rust-stained muscovite and bleached biotite have been mistaken for gold. In the Mansfield sandstone of Indiana, muscovite forms 1-10% of the heavy minerals. (12, p. 132) Muscovite is one of the uncommon minerals in the lower Mississippi sediments.

Nephelite.

Olivine was found in one desert sand by White and rare to fairly common in the lower Mississippi sediments by Russell.

Orthoclase is reported in the sands of Ohio as usually more altered than albite. (8, p. 158) Russell reports (41, p. 1326) orthoclase up to 3% of the total minerals on the 100-mesh sieve. He shows surprise at the amount of fresh feldspar in these lower Mississippi sediments.

Platinum. In peace times, only a small part of the world production of platinum comes from placer deposits. Such sources, however, can be so rapidly increased in time of war that they provide much greater amounts during the war years. The absence of platinum from the Canadian "shield" is indicated by its absence from the glacial deposits in the "gold counties" of Indiana, etc.

Pyrite. White reports pyrite in one of 33 desert sands studied. Gault reports it as sporadic in the Mansfield sandstone of Indiana. Russell found pyrite from rare to 45% of the heavy minerals in the Mississippi river sediments. (41, p. 1318 et seq.)

Quartz. Although, as pointed out, to be sand, a sand does not have to be even over half quartz, it is the chief constituent of practically all sands. It is so frequently over 95% as to suggest the correctness of the general impression that sand is quartz.

Rutile was found in about one-third of the desert sands studied by White. (52, p. 745) It is not common in the lower Mississippi sediments. Gault reports that rutile is 1-10% of the heavy minerals in the Mansfield sandstone. (12, p. 133) Phelps reports it as the third commonest (10-26%) of the heavy minerals in the Florida deposits. (34, p. 168)

Serpentine.

Sillimanite. Of 33 desert sands studied by White, five showed sillimanite, one in abundance. (52) Sillimanite was reported as rare to less than 1% of the heavy minerals in the samples studied from the lower Mississippi. (41, p. 1330)

Silver. Wade reports that one of his students found a specimen of native silver in the gravels of Fall Creek, Indianapolis. On analysis, the resemblance to Keweenaw-Peninsula silver was striking—another evidence of direction of ice movement. (49) Silver is frequently found in placer deposits, but in much smaller amounts than gold.

Spinel.

Spodumene was reported in two desert sand samples studied by White. (52)

Staurolite is found in sands derived from metamorphic regions. It is reported by White to be frequent, but not omnipresent, in desert sands; (52, p. 745) and by Phelps sporadic in Florida sands. (34)

Sylvite occurs in minute quantities in some desert sands and in larger amounts in playa deposits.

Titanite is uncommon in desert sands (52) and up to 3% in lower Mississippi sediments. (41, p. 1318 et seq.)

Topaz was reported by White in two desert sands, none in the lower Mississippi sediments studied by Russell.

Tourmaline is reported by Phelps as a minor constituent of Florida heavy sands; by Gault in the Mansfield sandstones, as 5-20% of the heavy minerals; by White as widely distributed in amounts less than 1% in desert sands; by Russell as widely distributed in amounts less than 2% in the lower Mississippi sediments.

Vesuvianite is reported in two desert sands studied by White.

Xenotime.

Zircon was reported in desert sands by White; as second commonest (13-26%) heavy mineral in the Florida deposits by Phelps; (34) 20-50% of the heavy minerals in the Mansfield sandstone by Gault; (12, p. 133) by Russell (41, p. 1330) up to 9% of the heavy minerals in the lower Mississippi sediments; by Wade (49) as colorless to violet crystals in Indiana glacial sands.

Zoisite was reported by White as rather common in small quantities in desert sands; (52) and by Russell in small amounts in all samples of Mississippi sediments. (41)

The preceding list is certainly not complete, yet it is believed to contain most of the minerals which have been reported from sands.

Shape of Sand Grains

The most complete study of sand grains ever carried out was by Ries and Conant of Cornell Univ. (38) Certain of their conclusions follow:

Sands produced by weathering of igneous or metamorphic rocks would probably be angular and rough; glacial, stream and beach sands may also be angular because of brevity of the grinding processes. Volcanic sands would usually show volcanic glass or pumice and have an angular or splintery form. Transportation may cause rounding of the grains either by corrasion or, as pointed out by Galloway, if in water, by solution. (10) In water, the contact grinding is counteracted to some extent by the film of water surrounding the grains, which acts as a cushion—the cushioning effect being greater, the smaller the grains. Galloway notes that rounding due to solution will be more important, the finer the grain. (10)

In wind-blown sands the rounding due to corrasion may affect smaller grains than in the case of water-borne sands. Although Galloway (11) states that, if over 50 per cent of the grains are well rounded, the sand is wind-blown, Ries and Conant report many wind-deposited sands with comparatively few well rounded grains. Rounding of hard grains is evidently a very slow process for few marine or river sands show a large percentage of rounded grains. Of 58 river sands, only 22 showed rounded grains and abundant in only a few. Of 59 marine sands, only 19 showed rounded grains. Even in these cases some of the rounded grains may show characteristics inherited from a previous wind-blown environment. (38) The sand from West (sic) Palm Beach mentioned above was described by Shaler (43) as having mostly subangular grains, though the material has been transported for many miles along shore from the Piedmont region to the north.

E. M. Kindle has pointed out that sand grains are rounded by passage through the bodies of marine animals such as sea urchins. (23, p. 431)

The question arises, "How round is a sand grain?" Trowbridge and Mortimore (46, p. 405) used the terms: "well rounded," "fairly well rounded," "sub-angular," "angular," but the use of such descriptive terms will vary with the individual. Wentworth suggested methods of study and classification which could be used on pebbles and larger rocks. (51) E. P. Cox (9, p. 180) suggests a definition of roundness, the circularity of a two-dimensioned figure, which may be measured in a decimal fraction in the following manner:

$$\frac{\text{Area}}{(\text{perimeter})^2} = \text{constant},$$

which is $\frac{1}{4\pi}$ for a circle. Therefore, the above equation multiplied by $4\,\pi$ gives

$$\frac{\text{Area} \times 4\pi}{(\text{perimeter})^2} = \text{K}.$$

K is a constant that is dependent upon the shape of the figure, being 1 for a circle and less than 1 for any other shape, but it is the same for all figures of the same shape regardless of size. K for a figure of any given size represents the percentage ratio that the area of the figure holds to the area of a circle with the same perimeter. The constant for a square is 0.785, for a given right isosceles triangle, 0.54—the percentage roundness of those two figures.

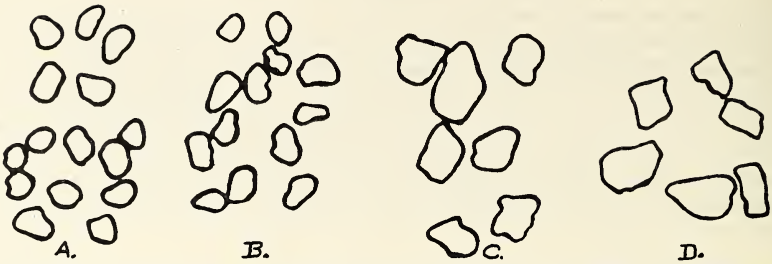

Fig. 4. Tracings of photographs of sand grains diagnosed by Trowbridge and Mortimore as (A) "rounded," (B) "fairly well rounded," (C) "subangular," and (D) "angular." A mathematical study of these tracings according to the Cox method (9, p. 181) indicates an average sphericity of A—0.902; B—0.85; C—0.88; D—0.76. This would indicate that grains called "subangular" by Trowbridge and Mortimore are more rounded than those called "fairly well rounded."

Several methods for measuring these values for a set of grains are suggested by Cox. Where thin sections or photographs have been made, project the image on a screen. Loose grains may be sprinkled on a lantern slide previously covered with a thin layer of mucilage and the image projected on a screen. The area may be measured by a planimeter and the perimeter by a map-cyclometer. The suggestion is made to substitute the map-cyclometer for the pointer of the planimeter, the results set on slide rule and the ratio read off directly as the figure denoting "roundness."

It is suggested that the above equation overlooks the factor of roughness which, unless "smoothed out," would markedly increase the denominator. Of course, where a particle has been transported far by either wind or water, a surface originally rough due to differential chemical or physical weathering would be somewhat smoothed in the rounding process.

Sherzer (44, p. 634) quotes a table from Mackie (26) indicating, possibly too "roughly," the "roundability" (*psephicity*) of the common sedimentary minerals in water and in air.

Table IV. Relative *Psephicity* of Sedimentary Minerals in Water and Air (Sherzer after Mackie)

Quartz	.23	.38	Orthoclase	.29	.40
Labradorite	.29	.45	Hornblende	.39	.57
Biotite	.70	1.05	Muscovite	.86	1.30
Magnetite	.70	.86	Garnet	.39	.53
Tourmaline	.30	.43	Zircon	.45	.59
Rutile	.51	.68			

In addition to roundness, sand grains which have been transported and eroded by wind frequently assume the appearance of ground glass. Where grains with this type of surface are found in water-laid sediments, as in the Pleistocene marls of Florida, it is concluded that they show evidence of an earlier airborne cycle.

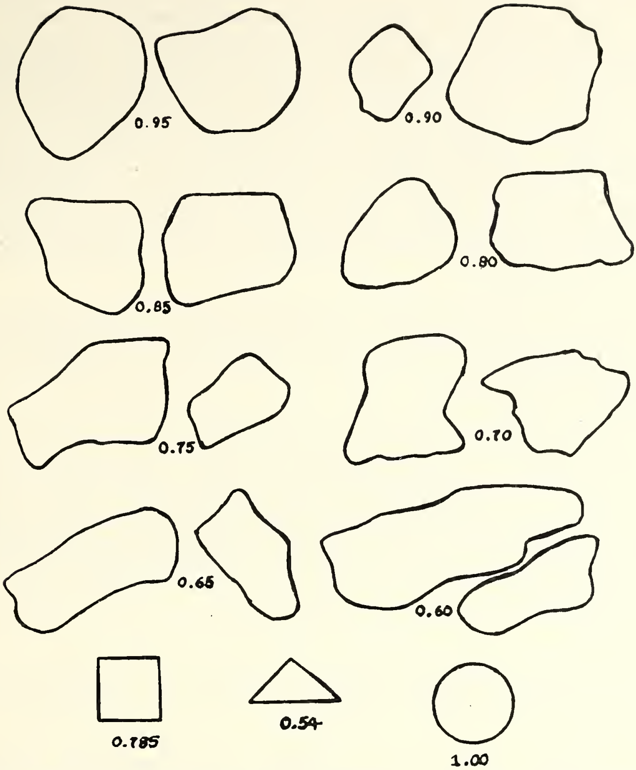

Fig. 5. Mathematical Statement of Sphericity of Two Grains Each of Several Degrees of Roundness with Three Simple Geometrical Forms for Comparison. (9)

The Classification of Sands Based on Origin

A number of classifications of sands based on origin have been made, notably by Sherzer (44) and Grabau. (13, p. 288) The classification by Grabau is the more complete. With the more technical terms omitted, it is given in Table V.

Table V. Classification of Sands Based on Origin (mod. after Grabau)

A. Clastic Sands	
1 Glacial	2 Volcanic
3 Residual	4 Aqueous
5 Eolian	6 Artificial[3]
B. Non-clastic Sands	
7 Organic	8 Concentration (Precipitation, E.R.S.)
9 Snow and firn (névé)[3]	10 Igneous[3]

A brief, but fairly complete, discussion of types 1-5 and 7-8 is given by Sherzer. (44, pp. 628-650)

[3] Added to Sherzer Classification by Grabau. (13, p. 288)

The Production and Uses of Sand

Although, as discussed above, the word sand as a natural product covers merely a given size of grain, under the production and uses of sand a more or less pure quartz sand is implied. In order of amount of production in 1943, the chief uses of sand are listed in Table VI. The value per ton usually indicates the purity (mineralogical or bachteriological) required for a particular use. In the United States, in 1943, some 31,000 men were employed in the production of sand and gravel. This does not, of course, include the large numbers employed in the industries dependent on the sand and gravel.

Usually for *building* and *paving* purposes a sand should be "sharp," (with angular grains) and free of clay and organic materials. Otherwise, a reasonable per cent of quartz, possibly 70 per cent, is the minimum requirement.

Foundry sands (37, p. 749) are the siliceous and other sands used in making forms for casting metals. To the foundryman a "sharp" sand is one that is free of a bond. Naturally bonded sands contain a variable (3-25 per cent) amount of clay. Synthetic foundry sands are mixtures of "sharp" sand with required amounts of clay or bentonite as a bonding material. If used in the cores, the bond may be oil, cereal, resin, pitch, etc.

Table VI. Sand Production in the United States in 1943 (28, p. 1324)

	Production (1)	Price Per Ton	Total Value (2)
Building	30,911	$ .60	$18,662
Paving	23,440	.61	14,305
Foundry	8,925	1.36	12,094
Glass	3,972	1.86	7,377
Engine	2,862	.69	1,983
R. R. Ballast	1,320	.31	412
Abrasive	838	1.71	1,428
Furnace	395	1.37	539
Filter	159	1.63	259

(1) Production in thousands of short tons.

(2) Total value in thousands of dollars.

The important properties are fineness and bonding strength. A foundry sand may contain particles ranging from 3 mm. (granule in the Wentworth classification, Table II) down to clay. The grains may be smooth or rough, clean or stained. Some foundry sands contain compound grains, which have been suggested as possible causes of small explosions in casting. (38, p. 392)

Bonding strength is determined by the amount of clay, the amount of water and the angularity and roughness of the grains.

Sintering Point, the point of incipient fusion, is not now considered by foundrymen to have much importance. *Durability*, life or number of times a molding sand may be used, is much less important than formerly because of the much increased use of the so-called synthetic sands. In fact, some foundries now are even using granite pulverized to the desired fineness with added binder. Foundrymen are also questioning the importance of *permeability* because the gases pass away from the mold face through vents and because it has become common practice to coat the mold face with a clay wash.

In recent years the practice has been introduced of using a sand with a high content of zircon either: (a) throughout, or (b) at points where quick chilling of the cast is important, or (c) as a wash on the mold face. The reasons for this are: (a) the low thermal expansion of zircon as compared with quartz; (b) its high thermal conductivity; and (c) its high melting point (3650° C.—3850°C.).

Glass Sand. (37, p. 754) The requirements for glass sand are a fineness of 100-20 mesh and chemical composition determined by the use to which the glass will be put. Tab. VII gives chemical specifications for four typical uses of glass sand.

Table VII. Specifications for Chemical Composition of Glass Sands (Ries after Weigel)

Quality	SiO_2 Min.	Al_2O_3 Max.	Fe_2O_3 Max.	CaO,MgO Max.
First quality, optical glass	99.8	0.1	0.02	0.1
Fourth quality, plate glass	98.5	0.5	0.06	0.5
Sixth quality, green glass containers and window glass	98.0	0.5	0.3	0.5
Eighth quality, amber glass containers	98.0	0.5	1.0	0.5

Filter Sand. (37, p. 757) Sand is used by communities and large industrial users of water to remove sediment and bacteria. The essentials are: (a) fineness 35-14 mesh; (b) uniformity of size; (c) of such a composition as not to be decomposed or disintegrated by water (high in quartz); (d) shape not flattened or elongated; (e) freedom from organic and bacterial impurities.

A decrease in production of filter sand beginning in 1930 is probably due to: (a) cleaning and re-use of sand; (b) considerable use of granular anthracite coal; and (c) use of a thinner sand bed with gravel beneath.

Abrasive Sand, (37, p. 759) with a wide variety of uses such as stone-sawing, glass-grinding, quartz, garnet and emery papers, and sand-blasting, tends to be replaced by artifical abrasives such as carborundum. For some uses ground-up garnet and emery are preferred.

Where large deposits of garnet sand are available, as at a few localities in Florida, it would seem to the writer that they could be used to good advantage, especially in garnet paper. Size of grain and hardness are the chief prerequisites for use of sand as an abrasive.

Engine Sand (37, p. 761) is used to prevent the driving wheels of locomotives from slipping. The chief requirements are a sand high in silica and of size roughly 80-20 mesh.

Furnace Sand resembles fine-grained molding sand and is used to line open-hearth steel furnaces. It may run as low as 80 per cent quartz and, if lacking in a clay bond, plastic fire-clay is added.

Oil- and Gas-Sand

One of the prime prerequisites for the economic concentration of oil and gas is a reservoir rock. This is usually called oil- or gas-"sand," although it may be limestone, dolomitic limestone, fractured shale, fault breccia, or porous or fractured igneous rock, as well as sand or sandstone. Until about 1932, it was almost universally believed among oil men and even yet it is frequently stated that the factor which makes the "oil-sand" a reservoir is its porosity. Actually, as pointed out by Nevin, (29, p. 374) "permeability and not porosity is the controlling factor." "Aside from the fact that a substance must be porous to be permeable, porosity and permeability have no relation. A sand with low porosity may have relatively high permeability, and the high porosity of many shales (30-40 per cent) is coupled with a very low permeability. The porosity of an oil sand is the ratio of the pore space to the volume of the sand."

The Handbook of Foundry Sand Testing, 5th Edition, (p. 26) defines permeability and discusses the determination of the "permeability number" specifically as it applies to foundry sands, but actually as it applies to the study of permeability of a rock wherever such information is desirable.

Permeability is the physical property that permits the passage of gases or fluids. Sands and sandstones are tested for the permeability number with an air-flow apparatus. The permeability number is the volume of air in cc. that will pass per minute under a pressure of one gram per sq. cm. through a specimen one cc. in volume.

$$P = \frac{v \times h}{p \times a \times t}, \text{ when}$$

P=permeability number
v=volume of air in cc.
h=height of specimen in cm.
p=air pressure in cms. per sq. cm.
a=cross-sectional area of specimen in sq. cm.
t=time in minutes.

Standard testing methods require 2,000 cc. of air to be forced through a specimen 5.08 cm. in height and 20.268 sq. cm. in area.

The fallacy (29, p. 374) of considering porosity and permeability as synonymous, or as being interrelated, or of using porosity as a short cut to permeability is indicated by examination of the following data from three tests of the Bradford, Penn., sand by Nutting (31, p. 44) as given by Nevin:

Table VIII. Relation Between Permeability Number and Porosity

Permeability Number	Porosity
A 7.9	15.3%
B 1.1	15.9%
C 1.2	19.4%

Specimen A, with a permeability number of 7.9, has a porosity of 15.3 per cent, while specimen B, with a permeability number of but 1.1, has almost the same porosity as A—15.9 per cent. On the other hand, specimen C, with nearly the same permeability number as B has a porosity about one-fourth greater.

The permeability of an "oil-sand" determines: (a) the correct spacing of wells for complete economical production; (b) the possibility of economical repressuring of an "oil-" or "gas-sand" by delay of drilling the central well in "five-spot" repressuring, if there are permeable streaks in the midst of "tight" reservoirs; etc.

Nevin concludes that, although a thin layer of oil or water is adsorbed by the sand grains, permeability to air gives reliable results, as a similar layer of air is adsorbed by the sand.

Quicksand

From a human point of view, one of the most interesting and important phases of sand is quicksand. Such interest is evinced in its repeated use by the novelist in the development of a plot—"Toilers of the Sea," "Moonstone," "The Bride of Lammermoor," "Assignment to Brittany," "The Hound of the Baskervilles," and "Lorna Doone." It is also the central theme in cartoons such as that in a recent "New Yorker," in which a very English explorer up to his arm-pits in quicksand, looking at his wrist watch, remarks to his compatriot, "Not so *very* quick, it it?"

The economic importance is indicated by the large number of horses, cattle and sheep which are lost each year in quicksand deposits. In one body of quicksand, to which my attention was recently called, three cattle had been engulfed in the last few years. To protect the rest of his herd, the owner spent considerable time drawing logs and brush into this area possibly 150 feet across. (24) It is reported that, through the years, many ships have been swallowed up after running aground on quicksands. In 1875, a train was engulfed after running off a bridge near Pueblo, Colo., and was never recovered, although the quicksand was probed to a depth of 50 feet.

What makes quicksands quick? A remarkable phase of the answer to this question is that the geologist has lain down so comfortably alongside his ignorance of the solution of a problem, at once so full of human interest and economically so important. Evidence of the truth, that the geologist has not solved the problem, is that a careful search of bibliographies of American geological literature, 1785-1941, revealed but one rather brief paper in a rather unimportant geological publication. (6) This paper, on further investigation, presented the theory which seems nearest the truth, but was based almost entirely and without proper credit on a rather obscure set of remarks on four words in a paper on the cost of excavating one level in the Erie Canal.

Before presentation of this theory, a list of other theories with brief discussion will serve to clarify the problem.

Rounded grains. The writer, in common with many others, started out with the theory that quicksand was simply a sand almost entirely composed of spheroidal grains, which, when lubricated with water, would roll out from under the submerging body, permitting it, especially if it struggled, to be engulfed. A number of considerations make this position untenable, the chief of which is the study of sand grains by Ries and Conant (38) which pointed out, after the study and photographing of literally hundreds of specimens of sands and sandstones, that practically never does a sand or sandstone exist with over 50 per cent rounded grains and that, where any considerable per cent of the grains are rounded, it is evidence of the desert origin of the sand. Another question arises—in the case of large bodies, what would become of the sand that rolled out of the way of the body?

Loose-pack-close-pack. A possible answer to this second question was proposed by Bancroft. (1) In places where, due to up-welling currents of water, the sand grains were "loose-packed," that is, grains of roughly equal size were arranged in straight horizontal and straight vertical rows, there would be a maximum of pore-space, approximately 38 per cent. A struggling body would tend to jar these grains into a close-packed arrangement, in which alternate layers would fit down into the hollows between the grains in the layer below, leaving a pore-space of approximately 26 per cent. The difference of 12 per cent would permit entrance of the struggling body. This theory has been accepted by others. Bancroft's failure, however, to find any supporting evidence caused him to abandon the search of what makes quicksand quick.

Other theories have been: a coating of clay on the sand grains to increase the mobility; a similar coating of decaying organic matter; and the presence of mica grains.

In 1927, in the Pan-American Geologist, (6) Burt discussed the origin of quickness in sands, following very closely a discussion by Hazen (15) in 1900. The Hazen discussion dealt with four words, "Quicksand (rounded sand grains)." Hazen picked up those four words from a previous engineering publication and in five pages laid the basis, not only for Burt's paper, but also for present engineering theory on the question.

In brief, the Hazen theory is that quicksand is found where there is a spring with sufficient upward water movement to *lift the sand grains apart*, so that the practical result is that a body goes down into water, somewhat handicapped by sand, rather than into sand lubricated by water. Quicksand is not a material, nor even a type of deposit, but rather a condition of equilibrium, or lack of equilibrium, between the materials of the deposit and the ground-water. Tab. IX is excerpted from the table of velocities of upward moving water necessary for the lifting of quartz grains of given diameter:

Table IX. Velocity of Water Necessary to Lift Quartz Grains Apart

Vel. of Water in ft. per hr.	Diameter of Quartz Grains in mm.
1.5	0.03
4.	0.05
16.	0.10
65.	0.20
148.	0.30
262.	0.40
410.	0.50

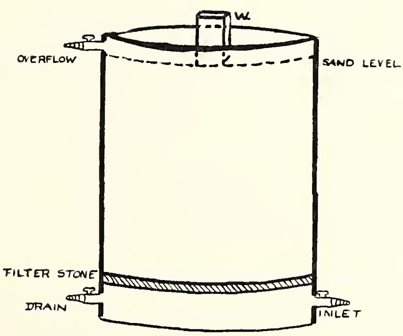

Fig. 6. H. T. Jenkins Apparatus to Illustrate "What Makes Quicksand Quick."

Figure 6 is a sketch of a device by H. T. Jenkins of Cornell University to illustrate the Hazen theory of the cause of quicksand. With dry sand the weight (w) remains in place, no matter how much effort is exerted to bury it in the sand. Even when water is admitted through the bottom inlet valve and the sand is entirely wet, still the weight cannot be buried in the sand. The fact that sand makes a good foundation for a great dam was utilized in the dam over the Mississippi River near Alton, Illinois, where the dam, footings and all, were placed in and on sand. (39) However, when the water is admitted at a rate sufficient to lift the grains apart, the weight buries itself in the sand almost as if it were a person diving into a swimming pool. Then, if the water is shut off and the weight is extricated and again placed on the sand, the sand is again stable and the weight does not sink in. Sand which had formerly been quick is so no longer, although it feels slightly quick to the fingers.

Table IX also indicates why quicksand is invariably fine grained. Velocities of spring are seldom sufficient to lift any but fine sand grains apart.

A number of questions regarding this Hazen theory arise:

If springs are always associated with quicksand, that fact should be indicated in the summer months by the temperature of the water as compared with the ordinary stream water. Last spring, under the guidance of Mr. J. T. Christie, I located a quicksand deposit on the Heber Ellis farm in Long Branch some four miles west of Greenscastle, Indiana. This quicksand was on both sides of a fence crossing the stream, so that it could be relocated absolutely accurately at a later date. In August, I returned to the place. There was no quicksand; it was gravel; there had been a number of very heavy rains this summer. However, the temperature of the water in the gravel (formerly quicksand) was 3°F. cooler than anywhere else tested in a half-mile of the stream—indicating, it seemed to me, a spring, even though there was no quicksand there in August.

Another question arises: If a spring is necessary for quicksand, how can it be possible that pockets of quicksand vary in position from time to time? The truth of this movement is attested to by several fishermen of my acquaintance. An hypothetical answer is suggested: In two miles of a stream, there are five springs—a, b, c, d, and e. At b and d the sediments are sufficiently fine on May 1 to be quicksand; at a, c and e, there is gravel. Late in May, there is a flood, as a result of which gravel is deposited on all springs but e; so there is no quicksand when the fisherman wades the stream June 1 at either b or d, but there is at e; he decides that the quicksand has moved down from d to e, which it may or may not have done.

Hazen gave as an illustration of sand becoming quick with upward water movement the Western Union Building in New York City. It was constructed with a load of 3¾ tons per sq. ft., safely sustained. Sometime later, wells on adjoining land being pumped began to show cloudiness and the building began to settle. When the pumping was stopped, the building no longer settled.

In addition to the loss of life in quicksand, it also presents a problem which demands the best of the well driller, the builder and the excavation engineer. Prelini (35, p. 188) suggests that the necessary procedure in tunneling quicksand is to drain away the water and prevent the collapse of the sand by strutting the sides with tight boards. In ditching for agricultural tile, a shield may be pushed ahead of the tile to keep the quicksand back. In streams in the cattle-states of the West, where there is abundant quicksand, the cattlemen believe that the quicksand problem can be temporarily solved by driving a herd of cattle rapidly through the quicksand patch, thus packing it down and shutting down the flow of water.

A topic of considerable discussion regarding quicksand is as to whether cattle or men are ever completely engulfed. An article in Science News Letter (42, p. 232) was entitled: "You're safe in quicksand, if you keep still" and presented the following argument: "If you ever have the misfortune to fall into quicksand, don't get panicky and thrash around. If you keep quiet, allow yourself to go down feet first and keep your arms outstretched, you will soon find yourself resting at a depth just below your armpits. . . . You stop sinking when your weight equals that of the quicksand you displace. As a matter of fact, quicksand will support you twice as easily as water." The above suggestion was made by Laurence Pirez, director of the Soil Mechanics Laboratory at Cooper Union, in New York.

Not all soils physicists agree with Pirez. Jenkins contends (19) that the buoyant effects of the quicksand is due only to the water present plus the very slight uplifting by the upward movement of the water.

That the estimate by Pirez was of doubtful validity is indicated by comparison of the two statements—"you will soon find yourself resting at a depth just below your armpits" and "quicksand will support you twice as easily as water." If the latter statement is true, the body would come to rest slightly above the waist instead of just below the armpits.

The advice not to thrash around, thus weakening you, is good, as animals, including man, will drown due to exhaustion, or heart failure may result. As to whether an animal will be engulfed will be determined by the specific gravity of its body.

In the previous discussion, it has been assumed, following Hazen, that the only cause of lifting in quicksand is spring water. Sand grains or any soil particles may be made quick by lifting apart by rising gas. This effect is shown especially in the "cratering" of an oil or gas well out of control. After the crater has been formed by the initial explosion, the gas continues to rise through the soil and changes what had been a sound base for drilling equipment into terrifically quick material which may swallow up hundreds of tons of drilling rig, casing, engine, etc. (14)

Sonorous Sand

Under this name, may be included singing, squeaking and barking sands. I have not tested and see no way to test theories of the cause of these phenomena. Several articles by H. C. Bolton and A. A. Julien toward the end of the last century dealt with theories of causes. (3, 4, 5) Singing sand gives off a sound akin to that of a sawmill; squeaking sand, a rather shrill note; barking sand is described as emitting a hoot-like note as the heel is lifted in walking across the sand, or, if the sand is confined in a bag, when the two ends are folded together. Singing sand is considered by Bolton and Julian to be necessarily dry sand, either siliceous or calcareous, giving off the note on being blown by the wind. Their theory was that all types of sonorousness are due to thin films of air, as elastic cushions between the grains. These cushions are capable of considerable vibration, thus emitting the sound. Kegel (21) attribues the singing of sand in desert regions to change in position of the constituent grains caused by difference in temperature between day and night. Bolton and Julian state that they have records of over 1,000 localities with singing sand.

Squeaking and barking sands are always moist and lose their sonority on drying. The most famous example of barking sand is on the island of Kauai, Hawaii, (4) but it is reported (33) that much better barking sand is found near Beaufort, N. C. That on Kauai is highly calcareous, the individual grains very angular. **(E.R.S.)**

Conclusion

Although the path which we have trod is but little of it new, we have built into our route parts from many other trails, and all from whom we have asked help or guidance have been quick to respond. We have not even dodged the quicksands, nor the biological sands, even though full of disease they may be.

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