PRESIDENTIAL ADDRESS

". . . SUCH QUANTITIES OF SAND"

JOHN B. PATTON, Indiana Geological Survey, Bloomington, Indiana 47401

The surface bedrock in the earth's land areas is mostly sedimentary, and the sandstones, which consist of sand grains cemented or otherwise lithified into solid form, are the second most common, after shales, of the sedimentary rocks. In additional huge tracts the surface bedrock, whatever it may be, is covered with unconsolidated sand (Fig. 1).

Sand is a product of weathering and winnowing. In simplest terms it is defined as a loose material consisting of small but easily distinguishable grains, most commonly of quartz, resulting from the disintegration of rocks. The phrase "most commonly of quartz" masks a host of variants. Many sands are a heterogeneous mixture of quartz and numerous other mineral and rock fragments. Some consist entirely of non-quartz minerals, and of these a number consist essentially of a single mineral. Sands occur in all hues and colors, and through a wide variety of chemical compositions, many of which have special economic uses.

Sand grains range in size from one-sixteenth of a millimeter to two millimeters. The next smaller size is termed silt, and the next larger sizes are called granules and pebbles.

The abundance and importance of sand are reflected in cultures past and present, in history, in political boundaries, in literature, and in our technology and economy. We do not have to seek far to understand the abundance of sand, and particularly quartz sand. Ninety-five percent of the earth's continental crust is granite, which in turn consists, by definition, of quartz and feldspar. Quartz is the most common single mineral in the crust, although the group of minerals called the feldspars is more abundant in total.

The earth's sand and sandstone deposits have been formed through some combination of the geologic processes called weathering, erosion, sedimentation, and lithification. Mineral and rock debris is sorted by the transporting agencies of running water, the wind, marine currents, and wave action. Larger fragments are reduced to sand size (or smaller) or left behind, and material finer than sand size is carried away to be deposited elsewhere. Stream action produces alluvial deposits, in many instances consisting of mixed sand and gravel, in channels, valleys, and floodplains. Wind energy forms aeolian deposits, in the form of dunes or sheet sands. And marine forces distribute sands on the sea floor and as beaches.

As an ingredient sand has been used throughout much of human history in the form of sandstone for construction (Fig. 2). Sandstones offered excellent characteristics of workability and are still widely

FIGURE 1. *Along the south shore of Lake Michigan, longshore currents and wave action deposit and remove beach sand in a never-ending cycle, and aeolian activity forms and modifies dunes landward from the beaches.*

used as dimension stone, but sandstone carving (Fig. 3) has become a lost art as concern about silicosis has developed with the use of power tools. The warm-hued sandstones fashionable today are colored by varying amounts of iron oxide. An old mining expression says that a pound of iron will color a mountain, and indeed the iron content of sandstone need not be high to lend rich tones.

Another use for sand in its native form is as the fine aggregate in mortar and concrete. Mortar is one of those unappreciated factors in the aesthetic satisfaction to be found in good masonry. The color and texture of the mortar, and the thickness and tooling of the joints, combine to give a total visual effect which is belatedly being taken into account by experts in architectural preservation. Mortars may be made from sands that are coarse or fine grained (or ungraded), sharp or rounded, and monochromatic or of mixed hue, and the possible differences in appearance are great. The wrong mortar is just as destructive to the total artistic result as is the wrong typeface in a book, but the effect is rarely diagnosed by the casual observer.

FIGURE 2. *St. Meinrad Archabbey in Spencer County illustrates nineteenth-century sandstone masonry at its best. Sand is also a principal constituent of the mortar and the chief ingredient of the stained-glass and other windows.*

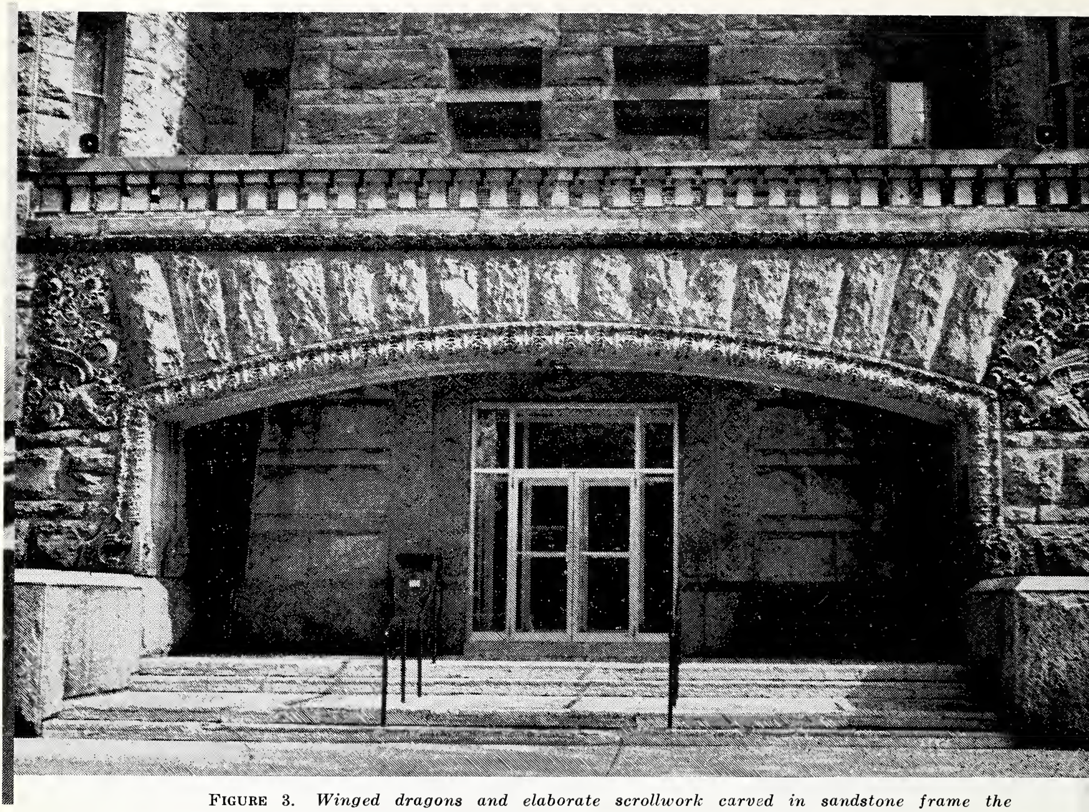

FIGURE 3. *Winged dragons and elaborate scrollwork carved in sandstone frame the main entry to the Wood County Courthouse at Bowling Green, Ohio.*

For other purposes in which sand is used as an ingredient, texture and certain other initial characteristics are lost, and perhaps the best example is the use in glass and for other ceramic purposes. High-silica sandstone, consisting almost entirely of the mineral quartz, is the principal ingredient of both historic and modern glass. The other raw materials include oxides or carbonates of calcium and magnesium and such additional substances as feldspar, borax, soda ash, and salt cake, some of which serve as fluxes to reduce the melting temperature of the mix. Cullet (broken glass) is an essential constituent of the furnace batch. Each ingredient affects the character of the final product.

Glass is a commodity essential to our civilization, and possessed of remarkable qualities. It is almost completely inert, can be transparent or opaque, can be colored, blown, molded, cut, and engraved, and is remarkably cheap. To the homeowner, the architect, the artist, and of course, the gourmet, glass provides a multitude of amenities and conveniences. Scientists and teachers should remember their special debt to glass. In microscope, telescope, and camera (and in many new, complex instruments), the optical qualities of glass have made a unique contribution to knowledge (nor should we forget that universal blessing

—eyeglasses). We remember Newton's apple; another common object told his genius truths that no-one else had heard:

> "In the beginning of the year 1666 . . ." he said (he was then 23) ". . . I procured me a triangular glass prism to try therewith the celebrated phenomena of colors . . ."
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> *Philosophical Transactions* vi, 3075

Biological and medical studies are accurate because glass can be sterilized. Chemical and physical studies rely on its capacity to be formed in accurate and complex laboratory shapes. The botanist depends on glass to transmit light while excluding cold and wind. We must ask ourselves whether modern science could have developed without glass.

The glass mirror deserves recognition, too, because it is much clearer than polished bronze, more convenient than the pond or pool which so entranced Narcissus, and gives us—at least outwardly—the gift of seeing ourselves as others see us.

The drinking glass, superseding the pail and dipper and the shared beer mug, is one of the countless uncelebrated factors in improving public health.

In addition to its use as an ingredient, sand is an agent and enabler for many of our needs and processes. We owe to it our ability to fabricate a wide variety of items used in the household, in the kitchen, in industry, and in transportation: bells, kettles, skillets, candlesticks, stoves, motor blocks, locomotive wheels, and, as the handbills for country auctions say "other articles too numerous to mention". The feature common to these and many others is that they are transformed from molten metal to a useful object in foundry processes. Modern molding sands must conform to very tight specifications and perform to extremely close tolerances. Imagine, if you will, a sand mixture that can be pressed to extremely detailed shape and hold this form while heavy molten metal fills the openings—all of the openings, not just some of them—without any collapse or change in shape of the mold. And then consider the requirement that the mold must separate cleanly from the casting, remembering that sand occupies space *within* the casting as well as around it, and the fact that if the body bakes to a firm, bricklike consistency it will be the casting that is broken instead of the mold. Early foundry sands, and indeed those used well into this century, were principally natural mixtures in which sand of just the right texture and the correct amount of binder gave the required wet strength, green strength, and dry strength at the various stages of the molding and casting process. To reduce the amount of milling and finishing required for more precise specifications, molding sands of finer and finer texture have come to be used. Modern foundry sands are mainly mixed products that begin with a clean and carefully graded quartz sand to which are added the other necessary ingredients, such as clay.

One of the reasons that quartz sand and other silicious sands are suitable for molding is that quartz is refractory: it will withstand high temperatures without deformation or alteration and without becoming part of the product. Because of its refractory character, sand is used in the troughs through which molten metal is run from furnaces and smelters to other locations for casting or further processing (Fig. 4). Silica brick, made with sand, is one of the leading refractory substances for lining furnaces, kilns, cupolas, and other chambers for high-temperature processing, as is shaped dimension sandstone.

In volume, sand is the most extensively used of all abrasives. Natural sandstones in which the grains are firmly cemented together are used for grindstones, whetstones, and shaped abrasive tools. Sand is used even more in granular or powdered form. Common sandpapers consist of sand-size grains of quartz or feldspar or garnet cemented to a flexible backing. Sanding belts, sanding discs, and sanding blocks are merely variants in the manner of fabrication and use. The abrasive agent in many commercial cleansers and scouring powders is silica flour made by pulverizing quartz sand. The wiresaw used for cutting stone depends upon the abrasive quality of the sand or other granular material that adheres to the wet, moving wire.

The abrasives market has changed greatly within our time, and many of the industrial abrasives of the present day are synthetic materials or special blends of natural materials. The choice of abrasives for industrial processes is determined by some combination of the

FIGURE 4. *The Indiana dune sands along the shore of Lake Michigan have been so useful for runner sand, engine sand, and other industrial uses, and especially for fill, that much of the remaining unspoiled duneland is treasured as State and National recreation and preservation areas.*

method of use and the optimum hardness. Quartz is too hard for some of these purposes and not hard enough for others. A popular misconception exists that abrasives must be much harder than the materials that they are to abrade, but this is not true. Particularly where extremely fine and smooth finishes or polishes are desired, the abrasive should be softer than the material that is to be abraded; jeweler's rouge is an example. Most grinding and abrasive finishing processes are actually attrition; like the gingham dog and the calico cat, the two materials eat each other up, and it is the controlled relative rate that determines the quality of the product. A special variant of the abrasive action of sand is to be found in its use for traction aid, as under locomotive wheels and on snowy roads.

Having reviewed the uses of sand as ingredient and agent, let us consider sand as a barrier—political, geographic, and protective. The earth's deserts have been natural boundaries because they are barriers to tribal migration and invasion. The sandy deserts are more effective barriers than the rocky deserts; to the impediments of any forbidding terrane, the sandy desert adds the ultimate one—instability. Roadways cannot be maintained, and landmarks disappear. It is apparently inevitable that the barrier regions themselves, although intrinsically worthless, become the battlefields in which countless lives are lost fighting for land that neither adversary really wants but that each feels it must hold. The sand deserts have served as barriers to foot troops, horse troops, and mechanized forces. Rommel's mastery of desert terrane in North Africa was ended, in the view of some, not by superior forces but through an understanding of the desert made possible by the work of a British engineer named R. A. Bagnold, who published his knowledge and conclusions in a volume entitled *The Physics of Blown Sand and Desert Dunes.* The homely sandbag symbolizes Man's use of sand as a barrier against flood and gunfire.

At the far end of the spectrum from the hostile desert is the sand beach, almost a symbol of recreation. Beloved of swimmers, surfers, sunbathers, shell collectors, girl watchers, and small children with shovels and pails, the beach offers the two requirements for building sand castles—sand and leisure time. For the city child, the kindergarten sandbox brings indoors or to the playground a sample of the great natural world, along with the plasticine as a substitute for mud, and the rabbit in the cage. The sand trap on the golf course represents the human instinct to amuse ourselves by creating artificial difficulties.

History and literature demonstrate a curious human quirk: the tendency to admire gold—which is actually of very little use to us—more than humbler mineral products essential to our daily life. The statistical standard which I have chosen to describe this trait I have elsewhere called the Midas Index. It is derived by consulting the appropriate literary concordances and dividing the number of references to gold by the number of references to the essential mineral, in this case sand.

Chaucer speaks 12 times of sand and 184 times of gold; his Midas Index for sand is 15.3 (for clay it is 92). Shakespeare speaks 201 times of gold—27 times of sand: *his* Midas Index for sand is 7.44. Milton's index is 10.2; Pope's 5.9; and Shelley's 2.5. Taking an average, we find that the 14th, 16th, 17th, 18th, and 19th centuries, in the persons of leading poets, show a Midas Index, for sand, of 8.26. Before any statisticians object to my cavalier juggling of random figures, let me remark that entire national policies have been and still are based on a smaller statistical sampling than this. I would sleep more easily at night if we had a national minerals policy based on so solid and scientific a foundation.

Sand is a useful daily servant, and without it we would lack many luxuries which we have come to consider necessities, but too often in our speech and writing we speak of it disparagingly. Sand is indeed an enemy to the mariner—though only one of many—as Shakespeare's few but graphic lines recall:

> "I should not see the sandy hour-glass run
> But I should think of shallows and of flats;
> And see my wealthy *Andrew* dockt in sand,
> Vailing her high-top lower than her ribs,
> To kiss her burial . . ."
>
> *Merchant of Venice* I i

and

> ". . . wrackt three nights ago on Goodwin Sands . . ."
>
> *King John* V iii

Sand is also an enemy to the slogging infantryman—an enemy all too often associated with the broiling sun and, of course, thirst.

Shakespeare wrote

> "How mightily sometimes we make us comforts of our losses".
>
> *All's Well That Ends Well* IV iii

Perhaps we should reverse that line (so perverse and ungrateful is human nature!) and say "How mightily sometimes we make us losses of our comforts". We are annoyed, for example, by sand in the bathtub or sand in the gears; we should be grateful that sand has made it possible for us to *have* bathtubs and *have* gears.

Expressing the inexpressible concept of infinite number has daunted poets and scientists alike. A Hoosier homeowner, in October, might express infinite number in terms of fallen leaves, and in northern climes, infinite number might well be imagined in terms of the numbers of snowflakes which have fallen since Time's beginning. But in our symbolism, sand has been chosen to define most strikingly the infinity of number:

> ". . . many, as the sand which is by the sea in multitude . . ."
>
> *I Kings* 4:20

> "Who can number the sand of the sea . . ."
>
> *Ecclesiasticus* 1:2

The innumerable grains of sand, and their small size, together exemplify a recognized truth: that many small things add up to great:

> "Think naught a trifle, though it small appear;
> Small sands the mountain, moments make the year"
>
> *Love of Fame,* Edward Young

In an effort to embody, to visualize, the fleeting of Time, poets have written some of the most shining and most poignant lines in our noble literary tradition. In what terms does one imagine something invisible, inexorable, indefinable, omnipresent, which is known but not felt, measurable but eternal, by which our lives are ruled, of which each of us has been apportioned an unknown share?

Western poets have found in the hourglass a universal symbol. The handful of sand—out of the endless infinities of handfulls of sand—flowing at a measured rate in a container both brittle and unchangeable—expresses both the brevity of life and the immensity of Time. Boswell, in his *Life of Johnson,* wrote:

> ". . . there is for every thought a certain nice adaptation of words which none other could equal, and which, when a man has been so fortunate as to hit, he has attained, in that particular case, to the perfection of language."

Just so, for many thoughts there is a certain nice adaptation of symbol which none other could equal, and which, when hit upon, attains a perfection of meaning. The hourglass is intuitively accepted as beautifully expressing Time's swift progress and Life's uncertain measure: a very unpretentious device to carry so solemn a meaning.

When we consider how our lives are blessed by sand as a material, as an ingredient, as an aid and assistant, as a protection, as recreation, and as a symbol, we must be most critical of the Walrus and the Carpenter for the lack of judgment and appreciation that they displayed when they ". . . wept like anything to see such quantities of sand".