MINERAL AND WATER RESOURCES OF ARIZONA

Part I
GEOLOGY AND MINERAL RESOURCES
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GEOLOGY AND TOPOGRAPHY
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INTRODUCTION

In order to describe the occurrence and extent of Arizona's mineral and water resources, some knowledge of the geology of the region is fundamental. The character and structure of the rocks near the earth's surface not only control the kinds of resources that may be found, but exert a strong control on the topography which in turn affects the climate, the accessibility, and the probable extent of human activities. The following general outline of Arizona's geology and topography with a brief résumé of economic mineral resources is intended to provide this background.

More detailed résumés of the geology of the State were written by Darton (1925) and Wilson (1962), and popularized accounts were given by Cross and others (1960) and Cooley (1967). Review articles on diverse aspects of the geology of sizable parts of the State are present in guidebooks edited by Shrid (1952), Thume (1952), Cooper (1955), Anderson and Harshbarger (1958), Heindl (1959), Weber and Peirce (1962), Trauger (1967), and Titley (1968). An indexed bibliography (Moore and Wilson, 1965) lists most papers published on the geology and mineral resources of Arizona through 1964, and will aid the reader wishing further details on specific subjects.

TOPOGRAPHY

Arizona, which encompasses 113,009 square miles, is the sixth largest state (Van Zandt, 1966, table 3, p. 263-265). Parts of two distinct topographic or physiographic provinces are included within the State, the Basin and Range province in the south and along the western edge of northern Arizona, and the Colorado Plateaus province in most of northern and central Arizona. These provinces and their subdivisions are illustrated in figure 4.

The Basin and Range province, characterized by generally north-to-northeast-trending isolated ranges separated by aggraded desert plains, can be subdivided into three principal subprovinces or sections: the Mexican Highland section in southeastern Arizona; the Sonoran Desert section in southwestern Arizona; and, what is here termed the Mohave section along the western edge of northern Arizona. Mountains make up nearly half of the area of the Mexican Highland section and include many timber-clad ranges with peaks more than 9,000 feet high such as the Santa Catalina, Santa Rita, Huachuca, Chiracahua, the Pinaleno Mountains, most of which rise 5,000 feet or more above the adjacent valleys. The ranges in the Sonoran Desert section are lower and narrower and make up less than a fourth of the area of the section. Though not as high, many of the ranges and peaks in the section are rugged and rise abruptly from the surrounding desert as exemplified by the precipitous 7,730-feet high Baboquivari Peak. The Mohave section is similar topographically to the Mexican Highland section except that both the valley floors and mountain peaks are lower in overall elevation and are, thus, more desertlike.

The Colorado Plateaus province is divisible into four subprovinces or sections: the Grand Canyon section on the northwest includes block plateaus up to 9,000 feet in elevation entrenched more than 5,000 feet by the awesome Grand Canyon; the Navajo section on the
Information on the Mesozoic stratigraphy of northern Arizona is extensive but is well summarized in papers by Gregory (1917), Repenning and Page (1956), McKee and others (1956, 1959), Harshbarger and others (1957), Stewart and others (1959), and in some of the guidebooks cited on page 35. Mesozoic stratigraphy of the southern part of the State is not as well known nor as well documented, but much of the pertinent literature on the subject is cited by Stoyanow (1949) and in review papers by Tittley (1968). Cooley and Davidson (1963) summarized Mesozoic history of the State as a whole.

CENOZOIC ROCKS

(By Rodger B. Morrison, U.S. Geological Survey, Denver, Colo.)

Rocks formed during the last 70 million years, or the Cenozoic Era, underlie more than half the surface of the State. During the Cenozoic, Arizona was the scene of much faulting, folding, and volcanism and the Cenozoic rocks and sediments strongly reflect that activity.

The oldest Cenozoic rocks in Arizona are volcanic rocks of early Tertiary age that erupted during intense mountain building activity in the Basin and Range province. Following this was an interval of weathering, erosion and eventual accumulation of coarse sediments in valley areas. In the Colorado Plateaus region, broad, gentle warping continued that had begun in Late Cretaceous time, but only minor local sedimentation is recorded—most of the sediment was washed from the southern highlands northward and northeastward to Utah and New Mexico.

During middle and late Cenozoic time orogeny in the Basin and Range province created down-faulted basins and up-faulted mountain ranges. The faulting took place intermittently from early middle through late Cenozoic time, but was most active between 30 million and 6 million years ago. Terrestrial sediments, commonly several thousand feet thick, were laid down in the intermontane basins. An episode of intense volcanism 30 million to 20 million years ago produced widespread dacitic, andesitic, and rhyolitic flows and tuffs, commonly several thousand feet thick, that now cap many of the mountain ranges in the Basin and Range province. Another episode of intermittent volcanism, when mainly basalt and andesite was erupted, took place during the late Cenozoic at centers both in the Basin and Range province and in the Colorado Plateaus province.

The faulting and volcanism repeatedly disrupted drainage patterns in the Basin and Range province and caused many of the intermontane basins to be closed off from drainage to the sea. The entire State lay closer to sea level than now, and until very late in the Cenozoic, seawater from the Gulf of California intermittently invaded the basins in the southwesternmost part of the State.

The Quaternary, the second and last period of Cenozoic time, is estimated to have started between 2 and 3 million years ago. Although the Quaternary is the shortest of all the geologic periods, much of the shaping of the present landscape of Arizona took place during it, mainly by forces of erosion. Faulting and local warping continued, but in gradually diminishing intensity. Volcanism also gradually diminished, and became restricted to fewer localities.

With diminishing tectonism and volcanism, drainage systems became progressively better integrated, proceeding northward from the Gulf of California, along the Colorado and Gila Rivers. Most of the middle and upper parts of the Salt River system probably became integrated by the close of the early Quaternary, but the middle and upper parts of the Gila River system did not join the Gila River until middle Quaternary time; some basins in the Basin and Range province still remain closed. The Colorado River probably became established in its present course through the Grand Canyon region between 11 and 2 million years ago during general uplift of the Colorado Plateau region in Pliocene and early Quaternary time. Breaching of the formerly closed basins by through-flowing streams initiated active dissection of the basin-interior deposits, drained the playas and lakes, and, at certain times, caused development of widespread surfaces that slope toward the axial streams.

Arizona was little affected by the great Quaternary glaciations that covered so much of northern North America. The only glaciated areas in the State were the higher parts of San Francisco Mountain near Flagstaff and the White Mountains in southern Apache County.

Cenozoic rocks of Arizona, which contain most of the ground water, much construction material, and other valuable mineral deposits are described in numerous papers, which are cited in bibliographies, summaries, and guidebooks listed on p. 35 and cited in McKee, Wilson, Breed, and Breed (1967).

INTRUSIVE IGNEOUS ROCKS

Intrusive igneous rocks are those which have crystallized from molten magma beneath the surface and they may vary greatly in composition and other characteristics. (Igneous rocks that were extruded onto the surface are volcanic rocks and were treated in "Stratigraphy," p. 37. Because most major deposits of base-metal ores and certain other minerals of economic importance are either directly or indirectly related to bodies of intrusive rock, some knowledge of this important class of rocks is basic to an understanding of the distribution of many types of mineral deposits. Widespread emplacement of intrusive rock took place in Arizona during at least five geologic time intervals. From oldest to youngest, these intrusive intervals are briefly described below.

OLDER PRECAMBRIAN INTRUSIVES

Intrusive granodiorite that is older than the lower Precambrian metamorphosed sedimentary and volcanic rocks is known in Yavapai County. Somewhat younger igneous rocks of several distinct ages that are intrusive into lower Precambrian metamorphic rocks but are older than the upper Precambrian layered rocks are widely distributed in Arizona and are present in nearly every area where lower Precambrian rocks are exposed. These intrusives range in composition from granite to gabbro but rocks of granitic composition are more prevalent. Major copper deposits are associated with older Precambrian intrusives in Yavapai County.
Sources of Supply

Sand and gravel deposits occur in all counties of Arizona but the amount and quality of the deposits vary greatly between localities because of the different geologic, topographic, and climatic conditions.

Based on the characteristics of the sand and gravel deposits, Arizona can be divided into three regions—referred to here as the plateau, mountain, and basin regions, respectively.

The northeastern part, referred to as the plateau region, includes most of Apache, Navajo, Coconino, and northern Mohave counties (fig. 6), and is marked by wide plateaus drained by broad stream valleys, scattered buttes, mesas, and a few volcanic peaks and mountains. In the western part of the region, the plateau uplands are deeply incised by the canyons of the Colorado River system. The predominant rocks are essentially flat-lying sandstone and limestone but along the southeastern border, in southern Coconino, southern Apache, and southeastern Navajo Counties, extensive basaltic flows and cinder cones cover the sedimentary rocks. The average altitude is more than 5,000 feet and there is considerable daily and seasonal climatic variation. Except in local high elevations, rainfall generally averages less than 15 inches per year and the vegetation is sparse and scrubby.

Disintegration of rock is carried out mainly by diurnal changes in temperature, freezing and thawing, intermittent rainfall, and wind. Transportation of the disintegration products is mainly by stream flow, sheetwash, and wind. In general, the rocks produce sand but little gravel. The best commercial deposits occur along the streams and washes in local bars and terraces but they are rather thin and limited in area. Some industrial quality sand occurs mainly in the Bigdohoi Formation, both in the Apache and in the Navajo Indian Reservation, and in the Navajo and Navajo Counties (Kiersch, 1955, p. 93-98). In 1968, a sand deposit a few miles northwest of Houck (No. 23) was being mined and processed for hydrofrac and sand blasting purposes. The sand is unconsolidated, fairly coarse grained, well rounded and sized, and is nearly pure quartz. Local dune and terrace deposits, of Quaternary age, also are known. Although too impure for glass manufacture, many of these sands may be acceptable for other industrial uses (Kiersch, 1955, p. 93-98).

The mountain region is an irregular belt that trends diagonally across the middle of the State. The topography is rugged, remnants of plateau features are present locally on interstream ridges, and a few areas such as the Chino and Tonto basins have topography that resembles the southern part of the State. Closely spaced steep-sided ridges and valleys with relatively high stream gradients are characteristic of this region. The surface rocks range from Precambrian to Cenozoic in age and include sandstone, quartzite, shale, schist, limestone, dolomite, granite, and diabase intrusives, and basaltic and dacitic flows. Altitudes generally are less than 5,000 feet.

Climatic conditions are similar to those of the plateau region except for higher rainfall and more abundant vegetation. Such conditions permit the accumulation of good quality, but generally small, alluvial deposits of sand and gravel along the stream channels and in terraces along the valley sides. Such deposits generally contain a high gravel to sand ratio with little or no silt or clay.

Most of southern and western Arizona, the basin region, is marked by scattered mountain ranges, containing numerous indurated rock types, separated by broad, flat, debris-filled valleys and plains. Thick and extensive beds of poorly consolidated gravelly and silty outwash, derived from the mountain ranges, are common in the basin areas. These valley and basin fills are mostly Cenozoic in age and consist mainly of sand and silt capped in many places by a thick, near-surface layer of caliche. Gravel, if present, is either sparsely scattered through the sand and silt or locally occurs in terraces and relatively small buried bars and old stream channels, generally near the mountain fronts.

Rainfall generally is sparse and occurs mostly in sporadic local thunderstorms and cloudbursts. Transportation and deposition of much fragmental material is by sheetwash. Vegetation is scanty and diurnal temperature changes are fairly extreme, except in the mountains. The best deposits of sand and gravel occur in alluvial fans along the mountain ranges where intermittent streams constantly supply new detritus and rework the older deposits. Stream channels and dry washes have yielded a large part of the sand and gravel production but in general the deposits have a high sand to gravel ratio and considerable washing and screening is required to produce acceptable high quality products.

Resource Summary

Arizona has ample reserves and resources of sand and gravel for constructional purposes but the remoteness from markets and the limited accessibility of many deposits limits their exploitation.

In the plateau region good sand is plentiful and some of it is of industrial quality, but good gravel is scarce, particularly near population centers or along main transportation routes. Fortunately, volcanic cinders and scoria are available and more accessible and, thus, are used extensively as a substitute for gravel. The production of industrial sand in Arizona presently is small but the resources are large and could supply a greatly expanded market.

In the mountain region are fairly abundant local resources of sand and gravel but the deposits in most parts are inaccessible and too far from the major markets.

In the basin region, particularly in the Phoenix and Tucson areas, where the principal markets exist, the best and most accessible alluvial deposits have been or are being exploited. These deposits generally are thin but are frequently recharged with new material by intermittent stream action. The sand content greatly predominates and gravel generally occurs only in local lenses and bars. Processing almost always is required and a large amount of material is rejected as waste. Another serious problem for producers is conflict with urban growth. As the cities expand, sources of sand and gravel are eliminated by restrictive zoning and increased land values. Thus, sand and gravel producers are forced to find deposits that are less satisfactory in quality or quantity or are more distant from the markets. Such problems in the Tucson area are described by Williams (1967) and in the United States by Davidson (1953). Generally, however, Arizona has great resources of