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THE GEOLOGICAL EXPLORATION OF ARIZONA
An Historical Perspective of the State Geologic Map

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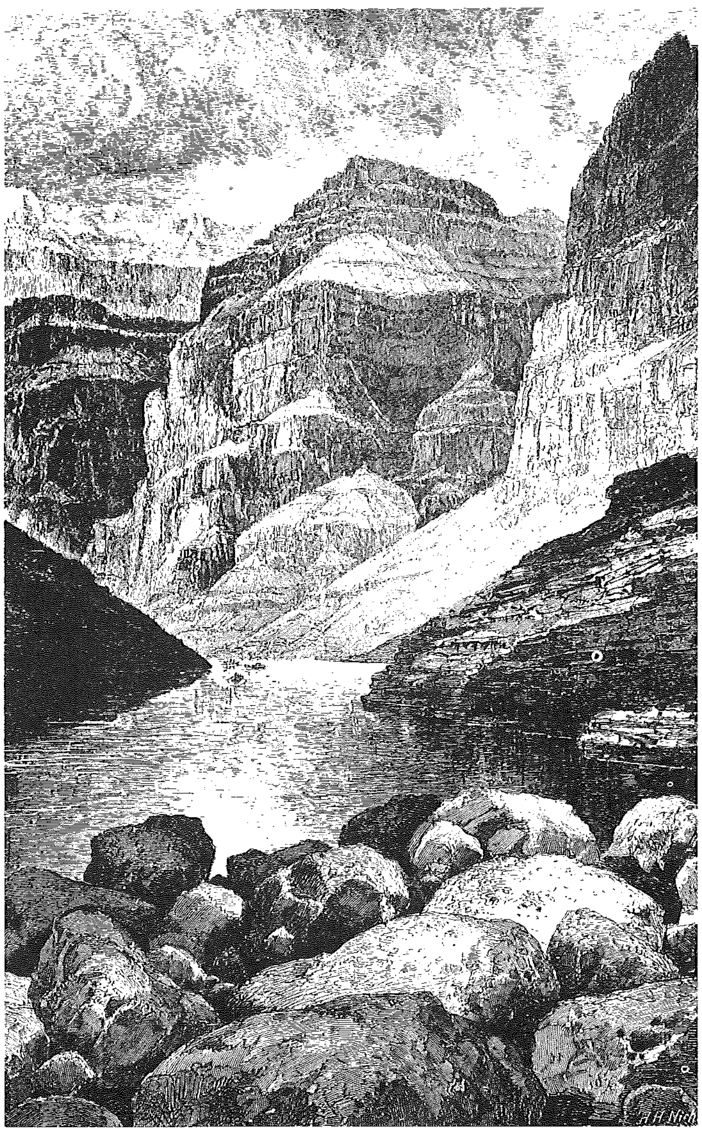

Figure 1, *State Map.* "Head of the Grand Canyon," a woodcut drawn by Thomas Moran (*from* Dutton, 1882, p. 212).

INTRODUCTION

The geological exploration of Arizona was pioneered in the latter half of the 1800s by geologists, such as John Wesley Powell, who accompanied the early expeditions into the territory. These geologists found the region to be a wild and untamed frontier. They were confronted by enormous problems—uncharted mountains and canyons, lack of dependable transportation (mules included), and occasional encounters with unfriendly Indians. By necessity, many of the early geologists were as much interested in the weather, watering holes, wildlife, and human inhabitants of the region as they were in the geology. Their reports make fascinating reading and provide a vivid perspective on the Arizona of yesterday.

As the early geologists explored Arizona, they encountered many new and exciting geologic features that had not been previously described. In order to fully document the size, shape, and characteristics of these features, they constructed geologic maps, drew elaborate sketches (figure 1), and wrote pages of detailed descriptions. The geology of Arizona became more understood through these efforts. Eventually, enough was known to produce a geologic map of the entire state. The first state geologic map was published in 1924, only 12 years after Arizona's statehood; it has been revised only once in the last 57 years. This revision was published in 1969, but it has become significantly outdated by more detailed geologic studies.

The Bureau of Geology and Mineral Technology is currently in the initial phases of a major project aimed at revising and updating the 1969 state geologic map. The need for a new state geologic map will greatly increase in the future as our society makes additional demands on the earth and its limited resources.

THE ESSENCE OF A GEOLOGIC MAP

A geologic map is a graphic representation of the rock units and geologic features that occur at the surface of the earth. Each area of the earth's surface is unique and must be individually examined and mapped. Geologic mapping can be quickly accomplished in regions of relatively uncomplicated geology, such as the Colorado Plateau of northern Arizona. In contrast, mapping can be excruciatingly slow in southern Arizona where the geology is very complex. In either case, the information gained from geologic mapping is essential to our modern-day society and its dependence on things geologic (Peirce, 1981).

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Some of the main attributes of a geologic map are illustrated by comparing figures 2a and 2b. Figure 2a is a high-altitude aerial photograph that shows a number of geologic features in the San Francisco volcanic field north of Flagstaff, Arizona. The most striking feature is a dark-colored lava flow that dominates the right half of the photograph. The nearly circular feature at the south end of the lava flow is S.P. Crater, a well-preserved cinder cone from which the lava flow was erupted. Surrounding S.P. Crater are seven additional dark-colored patches; these are cinder cones that are older and not as well preserved as S.P. Crater.

Another obvious geologic feature on the photograph is the large, light-colored gray region in the center of the image. In this area, light-colored Kaibab Limestone is exposed at the surface. Surrounding the limestone exposures are dark gray volcanic rocks that are older than S.P. Crater and its associated lava flow. The older volcanic rocks and adjacent limestones are traversed by conspicuous, linear features, such as valleys and ridges. Many of these linear features are fault zones where the rocks have been broken and displaced.

Figure 2b is a geologic map of the region covered by the aerial photograph. The map is highly simplified, but accurately portrays the general geologic features of the area. It shows the distribution of the following four rock units: 1) volcanic rocks comprising the S.P. lava flow; 2) cinder cones, including S.P. Crater; 3) other volcanic rocks; and 4) Kaibab Limestone.

In essence, the map outlines areas where each rock unit is exposed at the surface. Contacts between different rock units are depicted with a thin, unbroken line, whereas a thicker line is used to show the location of fault zones. Each asterisk on the map (figure 2b) indicates the position of a volcanic vent within a cinder cone. The legend of the geologic map gives the relative ages of the rock units.

In addition to locating the main geologic features, the map in figure 2b provides a basis for interpreting the area's geologic history. The oldest rock unit exposed is the light-colored Kaibab Limestone, which was originally deposited in an ancient sea that covered much of Arizona about 260 million years ago. In contrast, most of the volcanic rocks were erupted within the last million years. S.P. Crater and its associated lava flow were formed by an eruption less than 100,000 years ago and are, therefore, relatively recent by geological standards. Faulting has visibly affected all but the youngest volcanic rocks. The relatively young age of the faulting and volcanism may help explain why the region experiences occasional small earthquakes.

Figure 2b is but one example of a geologic map. Geologic maps can portray the geology of either large or small areas. For example, the geology of North America can be shown in a highly simplified manner on a single, standard-sized map; such a map is referred to as a small-scale map. On the other hand, a large-scale map may be needed to accurately depict the geology of a small, geologically complex hill. The scale chosen for a particular map is largely dependent upon its intended use. A small-scale map would be used for showing the distribution of active volcanoes of North America, whereas a more detailed, large-scale map would be needed for evaluating the mineral potential (e.g., gold) of a small area. Most geologic maps are produced at a scale that is intermediate between the two extremes discussed above; geologic maps at the scale of standard U.S.G.S. 15 minute and 7.5 minute quadrangles are perhaps most common.

There are two types of geologic mapping: reconnaissance and detailed. In reconnaissance mapping, a geologist has a limited amount of time in which to map the geology of a relatively large area. Around 1920, N. H. Darton of the U.S. Geological Survey mapped nearly one third of Arizona in a scant 20 months. Darton's mapping, by neccesity, showed only the main geologic features of the region. However, other geologists are known to have spent their entire professional careers mapping in detail the geology of a single mine or mining district. The choice between a detailed map and a reconnaissance map is dictated by its intended use and by time and financial constraints. A detailed map provides more information than a reconnaissance map, but requires more time, effort and money.

Geologic maps are used for numerous purposes. A good geologic map is essential for evaluating potential geologic hazards, such as volcanic eruptions and earthquakes, because it helps identify sites of recent volcanism and faulting. Geologic maps also play a key role in exploration for energy, mineral, and water resources. For example, a geologic map might indicate where oil-bearing rocks are exposed at the surface or, if buried, how deep they might be. Areas with high geothermal energy potential might also be located by examining a standard geologic map. Engineering applications are too numerous to list.

Arizona is well known for its important copper industry. Nearly all of the large copper deposits in the state are associated with gran-

Figure 2a, *State Map.* High-altitude aerial photograph (U-2) of part of the San Francisco volcanic field north of Flagstaff, Arizona.

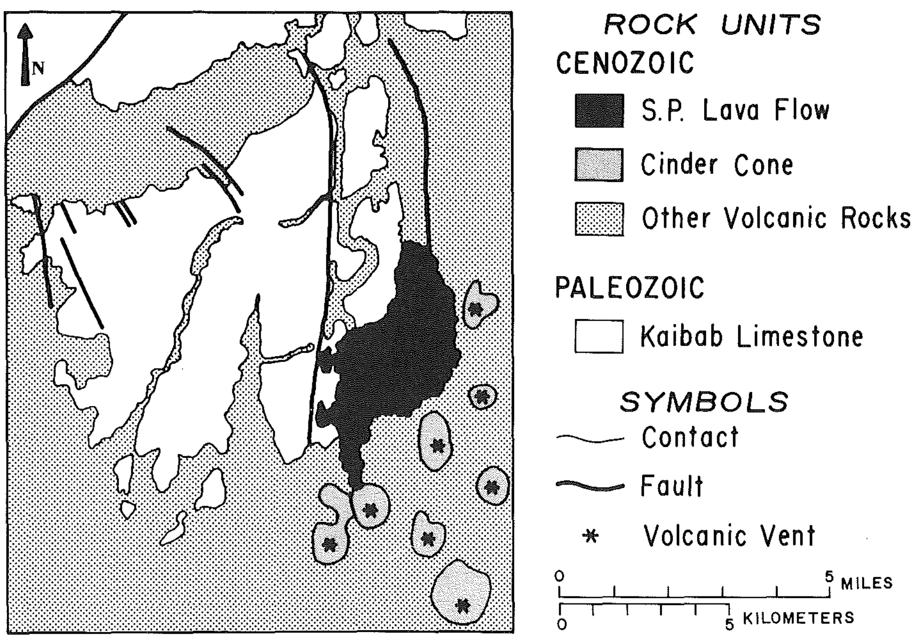


Figure 2b, *State Map.* Simplified geologic map of the area covered by photograph in Figure 2a.

ites of a particular age (60 to 75 million years old). For the most part, granites of this age are specifically identified on the present "Geologic Map of Arizona." Areas near these granites are probably most favorable for the discovery of additional copper deposits. Geologic maps are used in analogous ways for exploration of other types of mineral resources. Lastly, good geologic maps are important for reconstructing the natural history of the earth, including national and state parks, monuments, and wilderness areas.

HISTORICAL DEVELOPMENT OF THE STATE GEOLOGIC MAP

The Great Western Expeditions and Surveys (1853–1879)

The origins of the Geologic Map of Arizona can be traced to the great expeditions and surveys that explored the southwestern United States between 1853 and 1879. The illustrious journeys of John Wesley Powell down the uncharted Colorado River in 1869 and 1871 are perhaps the most familiar to Arizonans. However, geologists accompanied other expeditions, including those headed by Lt. Amiel W. Whipple, Lt. Joseph C. Ives, and Capt. George M. Wheeler. In fact, some of the most famous geologists of the 19th century were involved in the early geological exploration of Arizona and surrounding regions. These geologists included Jules Marcou, J. S. Newberry, G. K. Gilbert, C. E. Dutton, and, of course, John Wesley Powell. They had to explore unfamiliar terrain and surmount tremendous difficulties while "geologizing" the countryside. In spite of the imposing obstacles and the limited time available, these geologists made many keen observations and conclusions that remain valid to this day. Some of the most fundamental concepts of geology were first developed during those early surveys.

One of the first geologists to enter Arizona was Jules Marcou. He accompanied the 1853 Whipple expedition as it crossed northern Arizona, exploring for a railroad route along the 35th parallel. Marcou's observations were severely hampered by a series of winter storms that concealed the rocks beneath a shroud of snow. Nevertheless, he described vast areas containing petrified wood near the present-day location of Petrified Forest National Monument and noted that the San Francisco Mountains were extinct volcanoes.

The second geologist to visit the San Francisco Mountains was J. S. Newberry of the 1857–58 Ives Expedition. This expedition departed from Fort Yuma and sailed up the lower Colorado River in a steamship. It then traveled overland toward the San Francisco Mountains and on to Fort Defiance in the eastern part of the state. Newberry was exuberant upon reaching the forested Colorado Plateau, after traversing the "volcanic and desert region of the lower Colorado" (Newberry, 1861). He states (p. 59):

> We had all been wearied by the monotonous prevalence of the products of a single destructive force [volcanism]; and the varied and beautiful volcanic minerals so profusely scattered over the Colorado basin, devoid of all traces of organisms, and associated with the death-like sterility now pervading all that area, had ceased to excite a pleasurable scientific interest, and had even produced a positive thirst for *life!*; a longing to reach some region where nature's vital fires had not burned out; where the varied forms of recent animal and vegetable life adorned the earth's surface, and the rocks below contained in their fossils a record of its prevalence on sea and shore from the earliest ages.

This same lack of fossils in much of western Arizona continues to frustrate geologists to this day.

Newberry's observations regarding the San Francisco Mountains are totally in accord with those of modern geologists. In reference to some of the most recent volcanic features, he states: "...showing by all their surroundings that they have been in action, as it were but yesterday, and might be again tomorrow." This is undoubtedly one of the first statements published concerning potential volcanic hazards of Arizona. Newberry also characterizes some of the more recent lava flows as being "as little affected by the action of the elements as slag fresh drawn from a furnace." He likened the appearance of the San Francisco Peaks above the surrounding plateau to "some rocky island rising from the surface of the sea," and indicated that the main peak is "volcanic throughout, and is, in fact, a huge volcano whose fires have been but recently extinguished." The San Francisco volcanic field indeed contains one of the most recently active volcanic areas in Arizona. Newberry's writings also reveal his surprise upon encountering the deceptively hidden gorge of the Little Colorado River. While traveling upon what he thought was a "smooth and grass-covered plain," he suddenly found himself on the brink of "a series of cañons...forming a labyrinth of difficulties effectually arresting our progress in the line we had hoped to follow." (p. 61).

In honor of Newberry's pioneering spirit, and that of his commander, Lt. J. C. Ives, many physiographic features of Arizona and California bear their names (Granger, 1960).

In 1853, a few years before the Ives expedition, the U.S. government negotiated the Gadsden Purchase from Mexico and dispatched surveys to explore the newly acquired land. Only a minor amount of geologic work was done in conjunction with these surveys. However, C. C. Parry, a scientist on the Emory Survey, made the following key observation:

"...copper is quite frequently found in connexion [sic] with porphyritic rocks." (Parry, 1857, p. 21). This observation is an uncanny anticipation of our modern-day understanding that nearly all of Arizona's large copper deposits are directly associated with porphyritic rocks (i.e., a type of granitic rock that contains both large and small crystals). In fact, the association is so strong that the deposits are commonly called *porphyry coppers*. It is important to remember that the first large copper mines at Ajo and Bisbee had not yet been developed when Parry made his incisive observation.

The next important geologist to arrive on the Arizona scene was John Wesley Powell. Powell is probably best known for his pioneering exploration of the Colorado River and Grand Canyon. However, he remained an influential figure in Arizona geology long after his initial trips down the Colorado River in 1869 and 1871. He was in charge of a government-sponsored survey that continued to explore northern Arizona until around 1879. Powell was instrumental in the creation of the U.S. Geological Survey (U.S.G.S.) and served as its second director (Bartlett, 1962).

Powell's initial journey down the uncharted Colorado River in 1869 is a hallmark of adventure, courage, and persistence. Powell and his companions never knew what dangers lay before them, what evil tidings were borne by the distant rumble of rapids, or whether their provisions and patience would hold out for an unknown number of days. In his fascinating book, *Canyons of the Colorado*, Powell (1895) writes (p. 247):

> The flour has been resifted through the mosquito-net sieve; the spoiled bacon has been dried and the worst of it boiled; the few pounds of dried apples have been spread in the sun and reshrunken to their normal bulk. The sugar has all melted and gone on its way down the river. But we have a large sack of coffee....
>
> We are three quarters of a mile in the depths of the earth, and the great river shrinks into insignificance as it dashes its angry waves against the walls and cliffs that rise to the world above; the waves are but ripples, and we but pigmies, running up and down the sands or lost among the boulders.
>
> We have an unknown distance yet to run, an unknown river to explore. What falls are there, we know not; what rocks beset the channel, we know not; what walls rise over the river, we know not. Ah, well! We may conjecture many things. The men talk as cheerfully as ever; jests are bandied about freely this morning; but to me the cheer is somber and the jests are ghastly.

In spite of such unavoidable apprehensions, Powell was always carefully observing the geology of the canyon. His thoughts were generally occupied by the large-scale features and problems, rather than by the specific characteristics of a single rock type; his vision and imagination were uncluttered by detail. While pondering some fairly recent lava flows that had spilled over the sides of the canyon, Powell envisioned the following: "What a conflict of water and fire there must have been here! Just imagine a river of molten rock running down into a river of melted snow. What a seething and boiling of the waters; what clouds of steam rolled into the heavens!"

A number of features in the canyon were originally named by Powell and his men. These include Bright Angel Creek, Marble Canyon, and Lava Falls.

After his two river excursions, Powell organized a survey to explore the Colorado Plateau around the Grand Canyon. The Powell Surveys included two famous geologists, Clarence E. Dutton and G. K. Gilbert. Dutton's 1882 treatise on the Grand Canyon is replete with eloquent, flowing prose and exquisite illustrations. A few of Dutton's vivid passages are quoted below.

In reference to cliffs formed of Jurassic Navajo Sandstone, Dutton wrote (p. 36):

> It might be imagined that such fronts would be monotonous and tame, and once seen would soon lose all interest. Let us not underrate the versatility and resources of Nature, nor question her good taste, for she has made these walls as full of life, variety, and expression as any others, and yet has conserved the noble dignity of which simplicity is an essential part...[the sandstones] often weather into domes and half-domes of bald, white rock which look [sic] a calm defiance of human intrusion. Occasionally, the austerity of these forms is exchanged for those of the opposite extreme, as if nature were tired and impatient of all this solemn dignity, and the proverbial step from the sublime to the ridiculous is actually taken...we shall perceive numberless rock-forms of nameless shapes, but often grotesque and ludicrous, starting up from the earth as isolated freaks of carving or standing in clusters and rows along the white walls of sandstone. They bear little likeness to anything we can think of, and yet tease the imagination to find something whereunto they may be likened. Yet the forms are in a certain sense very definite, and many of them look merry and farcical. It is a singular display of Nature's art mingled with nonsense.

Upon examining the extinct volcanoes along the north rim of the Grand Canyon, Dutton comments (p. 83): "We wonder what their age may be; what time has elapsed since they vomited fire and steam."

In reference to Point Sublime on the north rim (which Dutton first named), he writes (p. 142): "Great innovations, whether in art or literature, in science or in nature, seldom take the world by storm. They must be understood before they can be estimated, and must be cultivated before they can be understood."

Dutton's 1882 monograph is heartily recommended to anyone who is interested in 100-year old descriptions and illustrations of the Grand Canyon.

A contemporary of the Powell Survey was the U.S. Army's Wheeler Survey that explored parts of northern and eastern Arizona. At one time or another, the survey was accompanied by several geologists, including G. K. Gilbert. Like other surveys, the Wheeler expedition had its share of difficulties. Around Canyon De Chelly, the Wheeler Survey encountered rain storms, fields of mud, rattlesnakes, and poisonous, five-inch-long centipedes that had a tendency to take refuge in their bed clothes (Bartlett, 1962, p. 360). In addition, several of Wheeler's men were killed in an ambush by Mohave Indians. Nevertheless, the science and exploration went on.

In 1879, the various surveys were consolidated into the U.S. Geological Survey. The Powell and Wheeler Surveys were discontinued, bringing to a close the first phase of geological exploration in Arizona.

Geologic Studies Between 1879 and 1924

Creation of the U.S. Geological Survey in 1879 resulted in greatly intensified study of the geology and mineral resources of Arizona. Much research was also carried out by scientists and engineers of the University of Arizona from 1891 onward. T. B. Comstock, first President of the University, wrote several articles on Arizona geology and emphasized—in 1895—the need for a geologic map of the territory. Arizona became a state in 1912 and the Arizona Bureau of Mines, predecessor to the present Bureau of Geology and Mineral Technology, was established in 1915, with offices at the University of Arizona. The Bureau and the U.S.G.S. jointly published the first "Geologic Map of the State of Arizona" in 1924.

A number of exceptional geologic studies were completed between 1879 and 1924. Many of their conclusions have been verified by 60 to 100 years of additional scientific research. The classic publications of F. L. Ransome, Waldemar Lindgren, N. H. Darton, and L. F. Noble are representative of this time period. Geologic studies of this era may be subdivided into four general types:

1) Regional geologic reconnaissance
2) Geologic research on mineral deposits and their surrounding areas
3) Regional reconnaissance concerning water supplies
4) Detailed research on rock units, minerals, and fossils

These four types of geologic studies are discussed in more detail below.

The first type, regional geologic reconnaissance, consisted of a more-or-less cursory examination of a large area. These studies included a variable amount of detailed investigation of the rocks and their relationship to mineral deposits and water resources. By necessity, the geologic maps produced by these pioneering regional geologists were quite generalized and thus subject to later refinements. However, these maps were the first all-important step toward accurately depicting the geology of the state. Such reconnaissance maps formed the basis for the first state geologic map.

An excellent example of this type of regional study is N. H. Darton's 1910 reconnaissance of northern Arizona and northwestern New Mexico. Darton's report contains a geologic map of a 100-mile strip of land from Albuquerque to Kingman. It is in this report that Darton (1910) first proposed the names Kaibab Limestone, Coconino Sandstone, and Supai Formation for the upper rock layers of the Grand Canyon. These names have been used by geologists ever since.

Northern Arizona was the site of two other regional geologic studies during this period. H. H. Robinson mapped and described the geology of the San Francisco Mountains, focusing on the abundant volcanic features. The three periods of volcanism recognized by Robinson (1913) are still discussed today. Robinson spent much time pondering whether the volcanic field was extinct or simply dormant. This haunting question remains unanswered. East of the San Francisco Mountains, H. E. Gregory was investigating the regional geology of northeastern Arizona. Gregory (1917) describes the countryside as having few roads, virtually no satisfactory maps, only minor amounts of safe water, and an unfriendly Indian population. He goes on to state (p. 9): "Geological field work in such a country is necessarily reconnaissance; some of it, in fact, is exploratory."

The second type of geologic study was concerned with mineral deposits and their surroundings. These studies generally included detailed mapping of the surface and subsurface geology of the individual mines or mining districts. In several notable cases, the region surrounding the mines was also mapped in relative detail. F. L. Ransome's geologic maps of areas around Globe, Ray, Bisbee, and Oatman have remained untarnished by 60–70 years of additional research. In addition, many geological formations originally named by Ransome (1903, 1904) are still widely recognized. For example, Ransome named the Pinal Schist, Apache Group and Bolsa Quartzite, rock units that are familiar to most Arizona geologists. A contemporary of Ransome was Waldemar Lindgren, a famous economic geologist. Lindgren's 1905 geologic map of the Clifton-Morenci area has likewise survived years of scrutiny. Ransome's and Lindgren's maps were incorporated, virtually without modification, into both the 1924 and 1969 state geologic maps.

The third type of geologic study examined the relationship between regional geology and water supplies. The resulting reports generally described in detail the locations of watering holes, but were less concerned with the geology. In those days, water was a more immediate concern than rocks. Good examples of this type of study are the publications of W. T. Lee (1905, 1908), C. P. Ross (1923), and H. E. Gregory (1916). Lee (1908) examined the water resources of northwestern Arizona and summarized his findings as follows: "Conditions were found so unfavorable for water development in this region that the economic results of the work are unimportant, or at best have negative value."

One of the more interesting water-related studies was Kirk Bryan's 1925 report on the geology and water supplies of the Papago country of southern Arizona. In addition to geology, Bryan's report contains excellent descriptions of the landscape, vegetation, and wildlife. Bryan refers to the Gila Monster as "a big clumsy lizard...[that is] sluggish and difficult to annoy but has a brutish temper and a grip like a bulldog." He describes the pack rat as a "bold marauder in camps" that will carry off anything that is loose, returning with "rubbish of various kinds which he leaves in place of the pilfered articles, hence one of his names is 'trade rat.'" Bryan discusses kangaroo rats in the following manner (p. 51): "...several [kangaroo rats] came into camp which was lighted by a large fire. In spite of being shot at several times they persisted in coming back, and one was finally caught in the hand. The fore limbs are much smaller than the hind limbs, but are doubtless used more in walking than one would judge by the tracks. Certainly these individuals, when investigating the Survey camp, went on all fours." Clearly, Bryan's scientific curiosity was not limited to geology.

The fourth type of geologic study was the detailed description and analysis of rocks, minerals, and fossils. C. D. Walcott's research in the Grand Canyon from 1880 to 1895 is exemplary of this type of detailed study. Walcott published a number of articles discussing the rock units and fossils of the canyon. Several important rock units in the canyon are still recognized by names that were originally proposed by Walcott.

The 1924 State Geologic Map

The years 1918 to 1924 represent an important time period in the history of the state geologic map. In 1918, geologist G. M. Butler replaced prominent mining engineer C. F. Willis as director of the Arizona Bureau of Mines. At that time, Butler was also Dean of the College of Mining and Engineering at the University of Arizona. Under Butler's direction, the Bureau began to assume its present role as a state geological survey. The Bureau restructured its priorities and directed most of its efforts toward production of a reconnaissance geologic map of the entire state. In 1919, the Bureau and the U.S. Geological Survey entered into a cooperative agreement to jointly produce the map. The U.S.G.S. assigned its most experienced reconnaissance mapper, N. H. Darton, to coordinate the project. Darton spent a total of 20 months in the field between 1919 and 1922, and, in the process, mapped the geology of approximately a third of the state. Darton was assisted by several Bureau geologists, including Eldred D. Wilson, Carl Lausen, and Olaf P. Jenkins. Lausen and Wilson are credited with mapping nearly all of southwestern Arizona. For northeastern Arizona, Darton relied extensively on the previous geologic mapping of H. E. Gregory. As mentioned earlier, the geologic maps of Ransome and Lindgren were incorporated into the state map without major modification.

The field work for the map was finished in 1922 and the map was published in 1924 (Darton and others, 1924). The map is mostly a reconnaissance geologic map, although not labeled as such. Much of the geologic mapping was done from horseback, horse and wagon or Model T. Due to the limited time and access, several mountain ranges in southwestern Arizona were probably mapped in a single day, or less. In areas of most difficult access, the geology may have been sketched from a distance using binoculars. There was simply too much area, too few geologists, and too little time to feasibly map every range in the detail or accuracy desired. For example, a large number of mountain ranges in western Arizona are simply shown on the 1924 map as "granite." More detailed mapping in some of these ranges has revealed the predominance of other rock types, such as limestone, sandstone, and volcanic rocks. However, the geology of other areas was shown almost exactly as we know it today! In all, the 1924 state map is a remarkable accomplishment considering the circumstances under which it was produced. Its chief compiler and contributor, N. H. Darton, will long be remembered as one of the foremost geologists to have worked in Arizona.

Geologic Studies Between 1924 and 1969

Publication of the state geologic map in 1924 was an important milestone in the geological exploration of Arizona. The entire state had now been mapped, albeit in a very cursory and over-simplified way. Geologists finally had a map of the whole state that they could study while trying to unravel Arizona's geologic history. The slow and deliberate process of improving and updating the state map could now proceed. Between 1924 and 1969, nearly all areas of the state were remapped in more detail. The resulting 1969 "Geologic Map of Arizona" (Wilson and others, 1969) bears little resemblance to its 1924 predecessor.

An appropriate point of departure in this discussion is Darton's 1925 publication entitled, "A Resume of Arizona Geology." In this report, Darton summarizes the geologic history of Arizona and presents many cogent observations that he made while mapping. Darton wrote the text in 1923 immediately after completing field work on the state map. The resume, in conjunction with state map, provides a useful record of what was known about Arizona geology in 1923–24. It is a remarkable scientific work that remains an important contribution to Arizona geology. To this day, Darton's descriptions and cross-sections constitute the only published information for certain parts of western Arizona. Modern-day geologists still have much to gain by reading this classic summary of Arizona geology.

Arizona experienced a surge of geological activity after 1924. The U.S. Geological Survey, Arizona Bureau of Mines and University of Arizona were responsible for most of the geological research published between 1924 and 1969. Geologic studies conducted by the U.S.G.S. during this time period fall into several distinct categories. First, the Survey mapped a number of key quadrangles near important mining districts in southern and central Arizona. Representative examples of this type of study are the publications of James Gilluly (1937) on the Ajo area, C. A. Anderson (1950, 1951), on Jerome and Bagdad, J. R. Cooper (1960) on southeastern Arizona, and N. P. Peterson (1962) on the Globe-Miami area. Important quadrangles were also mapped by M. H. Kreiger, S. C. Creasey, P. T. Hayes, J. R. Cooper, and H. Drewes. These quadrangle studies provided essential information about Arizona's mineral deposits and their geologic setting.

The second type of U.S.G.S. study was concerned with the relationship between geology and water resources. The publications of M. E. Cooley, J. W. Harshbarger, L. C. Halpenny, and C. A. Repenning established much of what we presently know about the layered rocks of northeastern Arizona (Harshbarger and others, 1957). U.S.G.S. geologists L. A. Heindl and D. G. Metzger contributed much information about the relatively recent geologic histories of southern and western Arizona, respectively.

The Arizona Bureau of Mines continued its emphasis on geologic mapping. In 1933, Eldred D. Wilson published a map and discussion of the geology and mineral resources of southern Yuma County. Wilson mapped this hitherto unknown area of southwestern Arizona from 1929–1932. In the process, he discovered a new set of mountains that had been overlooked by previous geologists and explorers. He named this range the Butler Mountains after G. M. Butler, former Director of the Bureau and Dean of the College of Mining and Engineering (Wilson, 1931). Wilson was the first person to describe and map the geology of a large number of mountain ranges in southwestern Arizona. The data from Wilson's 1933 geologic map were incorporated into the 1969 state geologic map.

J. D. Forrester became director of the Bureau in 1956 and supported intensified work on a new state geologic map. Bureau geologists, E. D. Wilson, R. T. Moore, and H. W. Peirce, began mapping selected areas in more detail. As before, the U.S.G.S. agreed to cooperate on the state map project.

The University of Arizona continued its tradition of research on the geology and mineral resources of Arizona. Professors A. A. Stoyanow, E. D. McKee, B. S. Butler, J. F. Lance, E. B. Mayo, and their students contributed many important ideas.

An important development in the geological exploration of Arizona was the advent of radiometric techniques for determining the actual ages of rocks in millions of years. The contributions of University of Arizona professor Paul E. Damon cannot be overemphasized in this regard. He and his colleagues have determined the ages of hundreds of rock units throughout the state. In many cases, these age determinations have drastically modified our perception of the geologic history of Arizona. Future geologic maps of the state will be significantly different from previous maps, simply because of these new age assignments. L. T. Silver of the California Institute of Technology and R. F. Marvin and E. H. McKee of the U.S.G.S. have also been important in determining the ages of some Arizona rocks.

The 1969 State Geologic Map

The Arizona Bureau of Mines, in cooperation with the U.S.G.S.,

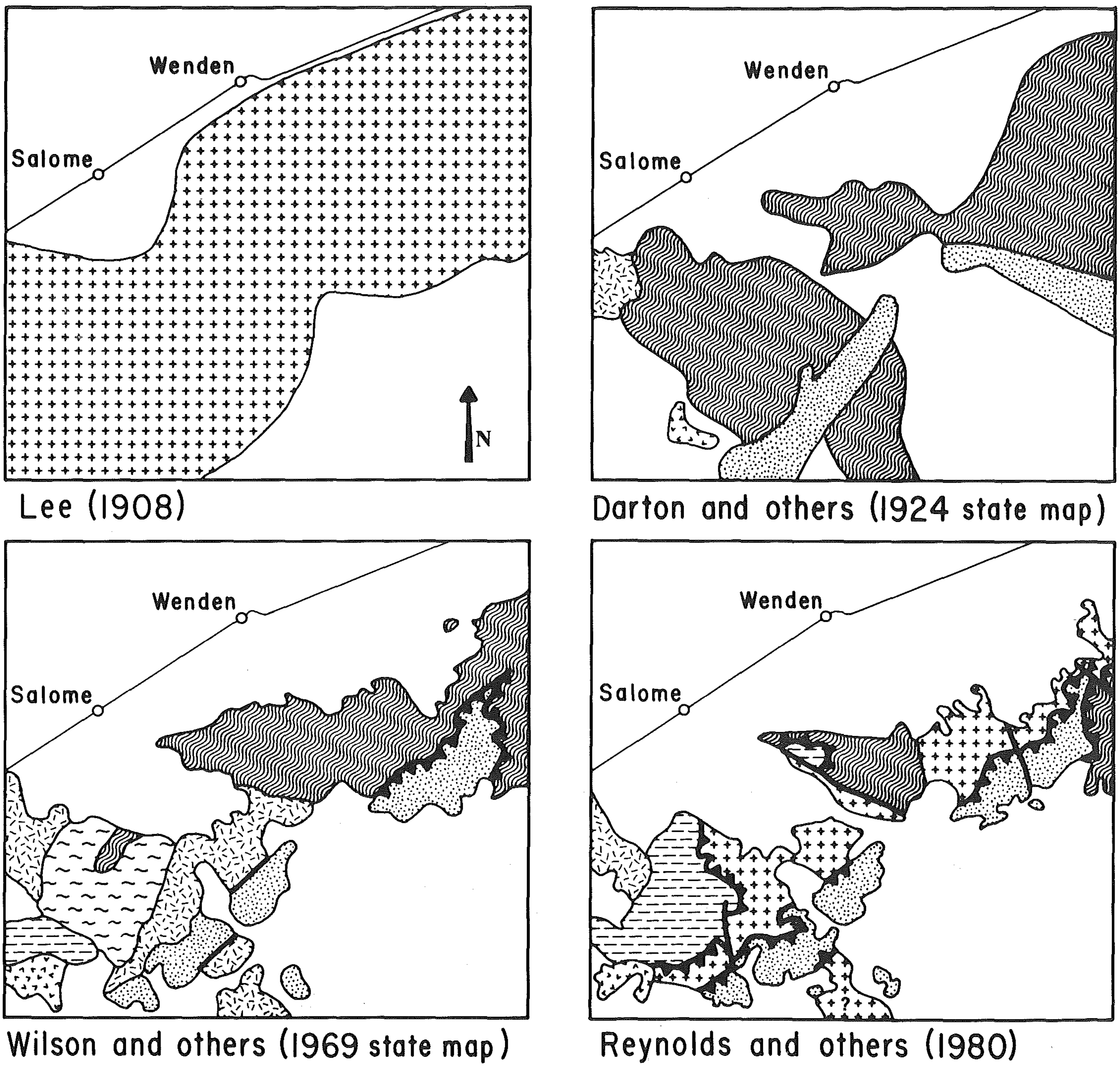
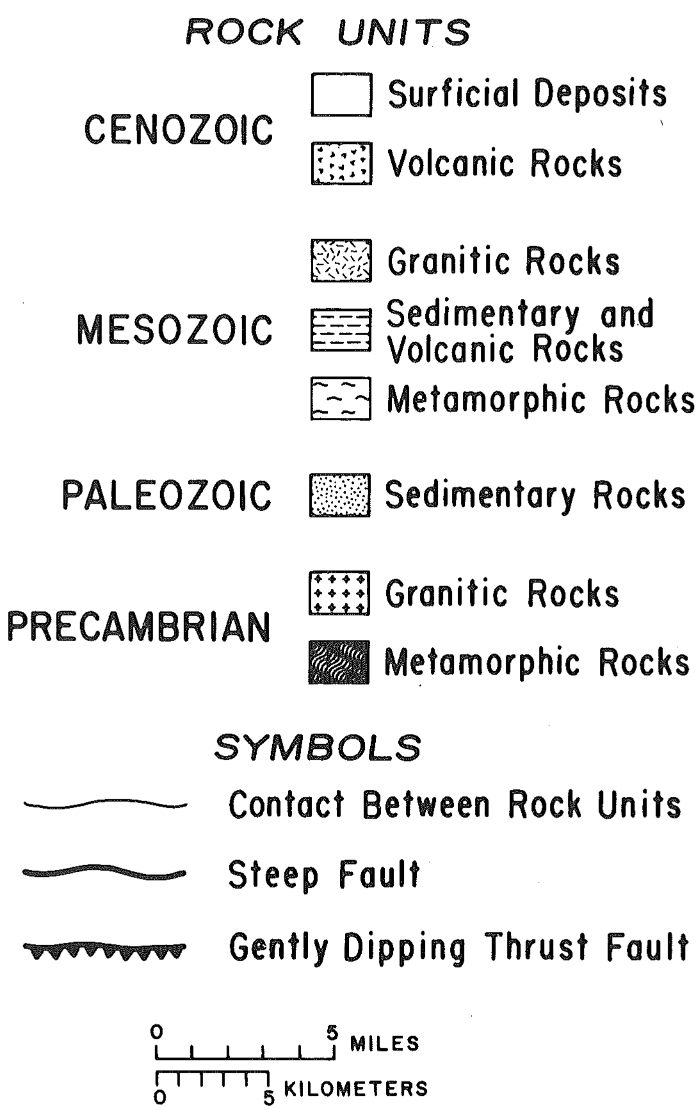


Figure 3, *State Map.* Evolution of geologic mapping for the western Harquahala and Little Harquahala Mountains, west-central Arizona.

started work on a new state geologic map in 1956. Both agencies agreed to map certain areas, with much of the state ultimately being mapped by Bureau geologists Eldred D. Wilson and Richard T. Moore. Due to the limited time and personnel available for the project, the mapping was still only broad reconnaissance in many areas. Most of the mapping was done from vehicles or on foot, although horses and aerial photographs were used on occasion. As always, geologic mapping was not without its hazards. One Sunday, two Bureau geologists had permission to map on the Air Force gunnery range in southwestern Arizona. Suddenly, they were strafed by machine-gun fire from military jets. Unsubstantiated reports suggest that the jet pilots missed the Bureau vehicle on purpose, intending only to scare away the "intruders." In spite of such incidents, the geologic mapping of southwestern Arizona and the rest of the state was completed by 1960.

In order to release the mapping results as rapidly as possible, the Bureau decided to publish geologic maps of each county, or of two adjoining counties, as they were completed. Bureau geologists spent months in the office, transferring the geology from their field maps onto county base maps. The county base maps available to the Bureau were somewhat inaccurate, and topography on the maps had to be substantially modified for many areas. Bureau geologists did all of the drafting and color separation for the published county maps. Bureau mineralogist, R. T. O'Haire, used modified phonograph needles and other improvised drafting tools to prepare the maps for printing. The entire folio of county geologic maps was published by 1960, only four years after initiation of the project. In 1962, Eldred Wilson's version of "A Resume of the Geology of Arizona" was published to accompany the county map series.



The U.S.G.S. was responsible for compiling a state geologic map from the county maps provided by the Bureau. The Survey modified the reconnaissance geology on the county maps with more recent Survey mapping when it was available. The resulting "Geologic Map of Arizona," published in 1969 by the Arizona Bureau of Mines and the U.S. Geological Survey (Wilson and others, 1969), was a great improvement over the original 1924 state map.

THE FUTURE OF THE STATE GEOLOGIC MAP

What does the state map's past foretell of its future? The map's history would predict that the present version of the "Geologic Map of Arizona" will become outdated by additional observations and more detailed geologic mapping. In fact, this has already occurred. A number of dramatic new discoveries have been made since the most recent state map was published in 1969. These discoveries have nearly rendered the 1969 map obsolete for many areas of southern and western Arizona.

The geological exploration of Arizona has greatly accelerated in the last decade. Geologic mapping is being carried out by a number of geologists from the U.S.G.S., the Arizona Bureau of Geology and Mineral Technology, and various universities. These ongoing studies are providing a view of Arizona geology that did not previously exist. Earlier geologists would have been highly skeptical of the geologic features currently being described in southern Arizona.

The ability to determine the age of rocks has greatly modified our understanding of Arizona's geologic history. Some large volcanic fields shown on the 1969 map as Quaternary (less than 2 million years old) are now known to be more than 10–15 million years old. It is essential to sort out such discrepancies before we can properly assess the potential for volcanic hazards, geothermal energy related to young volcanism, or other features. Recent age determinations have also demonstrated that volcanic rocks throughout much of western Arizona are 15–25 million years old, rather than 70 million years, as inferred by earlier geologists. We now know that these volcanic rocks are young enough to have buried valuable mineral deposits that may have been exposed at the surface prior to volcanism. The early geologists simply did not have the benefit of such age determinations. Consequently, they presented their best educated guesses and took their chances. However, nature still had some major surprises in store for them. For example, many geologists thought that mountain ranges in western Arizona were composed of some of the oldest rocks in the state. They observed that these rocks had undergone complex histories and had been subjected to high temperatures and pressures. They logically concluded that the rocks must be very old. However, we now know that these supposedly "old" rocks are startlingly young. Some, in fact, are as much as 1.7 billion years younger than originally thought. Such major revisions in the ages of rock units will drastically modify how they are depicted on any future geologic map.

Clearly, geologic mapping is a process of continuous refinement via progressively more detailed study. Figure 3 reveals how one area has been mapped by four successive geologists. Each geologist was able to spend more time in the area than his predecessors. Additional detailed mapping in this area has demonstrated that the most recent map shown on figure 3 is already out of date.

The Arizona Bureau of Geology and Mineral Technology is preparing to embark on a project to revise the present state geologic map. The forthcoming state map revision project will differ significantly from previous efforts because we plan to re-map only selected areas of the state. The U.S.G.S. and other organizations are currently mapping several key areas that will not have to be re-mapped. In other areas, only the age designation of rock units will have to be changed from the present map. However, most of western Arizona will have to be re-mapped in more detail because the region is geologically complex and somewhat remote. To this day, western Arizona remains *terra incognita*. It is not known how long this mapping will take or when a revised state map will be published. One thing is certain—for much of western Arizona, the next state map will bear little resemblance to either of its predecessors.

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Natural Gas Storage In Arizona Salt

by H. Wesley Peirce

Arizona already has two energy materials (LPG)* storage facilities in salt and a third is being planned. Southwest Gas Corporation intends to have a natural gas storage operation on-line for the heating season of 1983–84.

The project site is in a part of Arizona seldom visited. Many would call the Hualapai Valley of northwestern Arizona hostile and desolate. Geologically, it is a fascinating place. Within this valley, northeast of Kingman, is one of Arizona's two playas, Red Lake. The other is Willcox playa in the southeastern part of the state. No doubt there once were many others, but the persistent enlargement of the Colorado River drainage system has long since eroded them away. Only these two have escaped destruction.

That common rock salt exists beneath the surface of Hualapai Valley was confirmed in 1958. In that year the Kerr-McGee Corporation drilled close to 1,300 feet of salt, the top of the salt being about 1,500 feet beneath the valley surface. This drilling stopped in salt, so true salt thickness was not obtained. Then, in 1970, El Paso Natural Gas Co. drilled a 6,000 footer that cut 4,200 feet of salt. Again, the hole was terminated while still in salt. To date, no drill has penetrated the entire salt body. However, on the basis of geophysical evidence, it is estimated that this deposit could be as much as 10,000 feet thick. It has also been estimated that there could be 100 cubic miles of rocksalt beneath the Hualapai Valley (Peirce, 1972).

Southwest Gas Corporation has submitted plans to the Federal Energy Regulatory Commission (FERC) and is negotiating with the Bureau of Land Management (BLM) for a land exchange. The plan calls for the washing out (dissolving) of two caverns in salt with a capability of storing 4.4 billion cubic feet of natural gas. Such storage is to be used as backup for peak use during the winter months. The largest communities affected will be Las Vegas, Nevada and Tucson, Arizona. Stored supplies will be traded with El Paso Natural Gas pipeline supplies at appropriate places as needed.

The two washed caverns will be 1,000 feet in length vertically and between 4,000 and 5,000 feet below the valley surface. Water will be supplied from local wells, and tentative plans call for brine to be stored and evaporated at the surface of the Red Lake Playa. It is expected that 1.7 million tons of salt will be accumulated at the surface. The handling of this salt is one of the parameters under study.

Although not widely known, Arizona's depths contain several large bodies of salt. It is anticipated that others will be discovered beneath our valley floors. Already, two of these masses influence southwestern U.S. energy logistics, and it seems likely that a third will soon be added.

*liquified petroleum gas

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COSUNA

by Rex Knepp

This past summer, COSUNA came to the Bureau of Geology and Mineral Technology. The Bureau has joined twenty-five other state geological surveys in this nationwide project. COSUNA, an acronym for Correlation of Stratigraphic Units of North America, is a continuing project of the American Association of Petroleum Geologists (AAPG).COSUNA's present purpose is the improvement of stratigraphic correlation in the United States, an extension of a similar project carried out by the Geological Survey of Canada in the late 1960s. The survey plans to revise and update the Canadian correlations as an extention of the COSUNA Project. Correlations by Mexican geologists will extend the work into Central America.

The final outcome of COSUNA's U. S. national project will consist of two parts: First, the AAPG will publish more than 600 stratigraphic columns grouped on fifteen regional charts. The columns will show five basic facts about each stratigraphic unit: name and stratigraphic rank, dominant rock type, thickness or range of thicknesses (where known), types of contacts and geologic age. The initial chart is scheduled for publication in the Fall of 1982. Second, each stratigraphic unit will be described in more detail in a computerized storage and retrieval system at the University of Oklahoma, where data about fossil content, economic uses, radiometric ages, key references and other pertinent information will be stored.

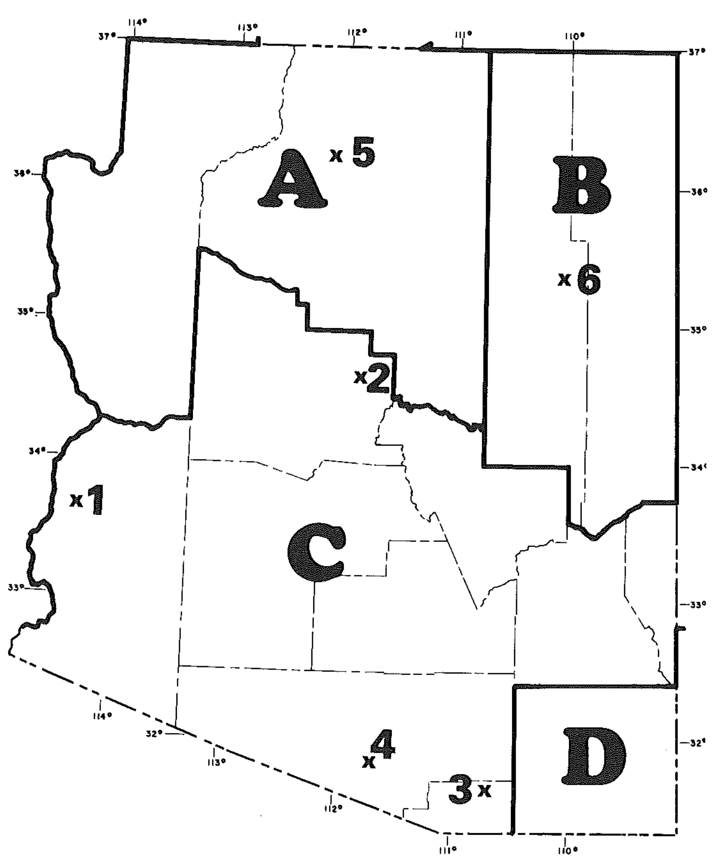


Figure 1. COSUNA provinces and sites (X) of the Arizona columns. Letters A–D refer to the provinces: A = Plateau Province, B = Black Mesa Basin, C = Southern Basin and Range Province, D = Pedregosa Basin. Numbers 1–6 refer to the stratigraphic column sites: 1 = Quartzsite; 2 = Verde Valley area; 3 = Sonoita area; 4 = southern Papago Indian Reservation; 5 = Grand Canyon area; 6 = Black Mesa Basin composite.

To accomplish this major feat, COSUNA has divided the lower forty-eight states and Alaska into twenty regions, each consisting of one or more geological provinces. COSUNA has used a base map compiled by the AAPG Committee on Statistics of Drilling (CSD) which separates these provinces along county lines in order to facilitate information storage. In western states with larger counties, this method of division may only approximate the actual physical boundaries of the provinces.

In all, the United States has been subdivided into more than 100 provinces, and COSUNA will publish one or more stratigraphic columns for each. All or part of four of these provinces fall within the state of Arizona: the Pedregosa Basin, Southern Basin and Range Province, Black Mesa Basin, and Plateau Province. Six Arizona columns will be published on COSUNA's Southern Rocky Mountains chart, two of which (the Grand Canyon area and the Black Mesa Basin) come to COSUNA from Dr. Harry C. Kent of the Colorado School of Mines, coordinator of the Southern Rockies-Colorado Plateau Region. The four remaining columns (the results of a research project at the Arizona Bureau of Geology and Mineral Technology) fall within the Southern Basin and Range Region, coordinated by Dr. Frank E. Kottlowski of the New Mexico Bureau of Mines and Mineral Resources. The four columns depict the stratigraphy of the Sonoita area (Pima, Cochise, and Santa Cruz Counties), the southern portion of the Papago Indian Reservation, the Verde Valley area north of Phoenix, and near Quartzsite in Yuma County.

Compilation of COSUNA's Arizona columns is another step toward describing the complex geologic history of the southwestern United States. Although the stratigraphy of the Colorado Plateau and the Pedregosa Basin have been described previously, this project marks the first attempt to systematize the stratigraphy of the southern Papago Reservation and of far western Arizona. The Bureau plans to publish the Arizona columns separately, along with brief discussions and partial bibliographies of the four columns from the Basin and Range Province.

The Arizona contribution to the COSUNA Project has been directed by Stephen J. Reynolds of the Arizona Bureau of Geology and Mineral Technology. The national COSUNA program is directed by Orlo E. Childs who is also the Director of the Arizona Mining and Mineral Resources Research Institute, and lists among his many accomplishments the past presidencies of the American Association of Petroleum Geologists, the Rocky Mountain Association of Geologists, and the Colorado School of Mines; as well as vice president of research at Texas Tech University.

Rex Knepp, a graduate student in Geology at the University of Arizona, served as a Research Assistant for the Bureau of Geology on the COSUNA project.

Historical Perspective in Mine Health and Safety

by Mel Garcia

BACKGROUND

Throughout recorded time, descriptions of mines and working conditions have appeared in print. Early writings on mines are attributed to Galen, a second century Greek physician. Later, in 1556, the classic volume on mining, smelting and refining. *De Re Metallica*, was published by a German scholar, George Bauer. Although unsafe working conditions were noted, little was attempted to correct them, because the consigned miners were composed of slaves, serfs, criminals and war prisoners.

LEGISLATION

At the turn of the 20th century, the U.S. government enacted unprecedented legislation regarding mine health and safety. The U.S. Bureau of Mines was created in 1910 and Public Law 61-179 became effective. This law permitted the Bureau to conduct research on mining accidents and associated illnesses. The Bureau was allowed to inspect the workplace and to give advice concerning control measures.

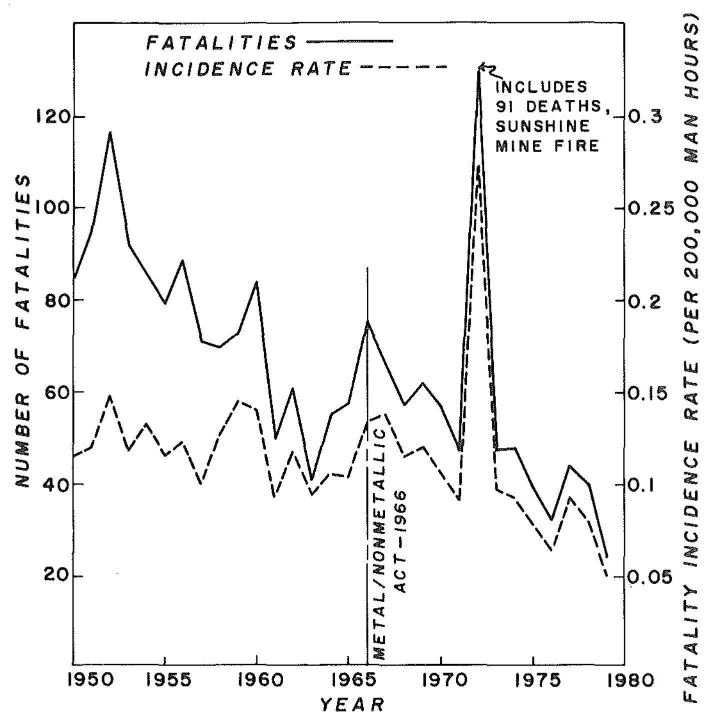
in 1966, Public Law 89-577 established the Federal Metal and Nonmetallic Mine Safety Act, which required federal inspectors to make one mine investigation each year at each underground mine, and to issue notices of violation and orders of withdrawal. Reporting of injuries was made mandatory and education and training program requirements were increased. In the same year, Public Law 89-376 was passed to expand inspection to and citation of violations in underground coal mines.

Next, the Federal Coal Mine Health and Safety Act of 1969 (Public Law 91-173) was enacted to extend the enforcement power of the U.S. Bureau of Mines for underground and surface coal mines, and to set in motion means by which standards for health and safety could be promulgated. This may have been the most revolutionary legislation to affect the American mining industry.

The Federal Mine Safety and Health Act was passed in 1977, thereby amending the Federal Coal Mine Health and Safety Act of 1969 and repealing the Metal and Nonmetallic Mine Safety Act of 1966. Enforcement responsibilities were transferred from the Department of Interior's Mining Enforcement and Safety Administration (MESA) to the Department of Labor's Mine Safety and Health Administration (MSHA). This act covered both coal and noncoal miners, expanded the rights of miners, and increased the number of annual inspections to four in underground mines and two inspections in surface mines. During the past ten years, safety and health standards have changed the way mines operate.

The federal safety and health regulations have had little impact on the accident rates in metallic mining operations. This is demonstrated in Figures 1 and 2.

The Federal Mine Safety and Health Act of 1977 leaves no question that health will be given greater emphasis in the future. To accomplish this, the Act has significantly strengthened the standard-setting procedures for health, and has charged the National Institute for Occupational Safety and Health (NIOSH) to do research on and develop health standards, to survey the workplace in the mines in order to identify the presence of all toxic substances and harmful physical agents, and to evaluate specific health hazards at individual mines. The Act gives NIOSH the same right of entry at all mines and right of access to information that MSHA has.



Number of Fatalities and Incidence Rates, Metallic Mining 1950–1979

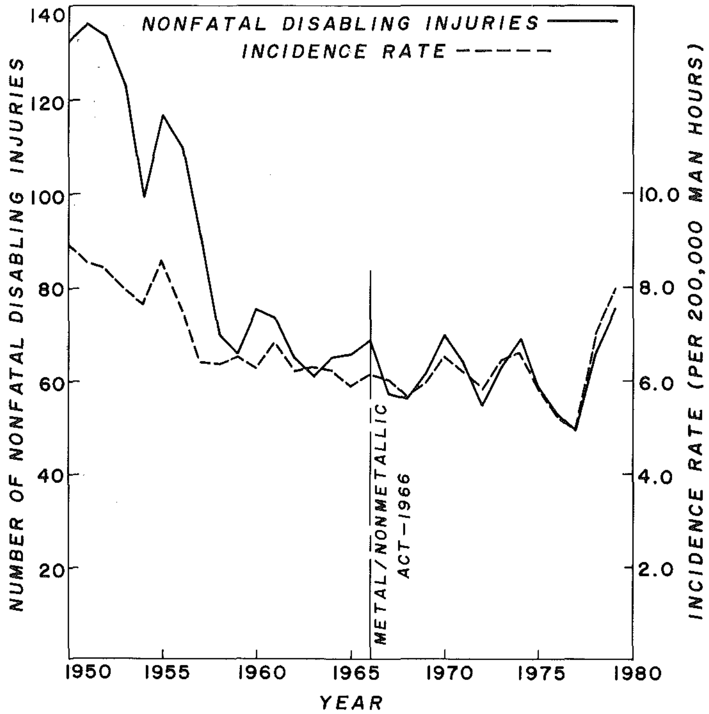
Figure 1, *Mine Safety*. The number of fatalities in metal mines has steadily declined during the past three decades.

NIOSH has identified 800 potentially hazardous substances and physical agents. Reliable data have been obtained concerning exposure to 40 of these 800 agents, and many exposure studies can be expected to take place in selected mines. Some of the studies underway or being proposed include those on exposure to oxides of nitrogen and other components of diesel engine exhaust, silica dust, coal dust, asbestos and other fibrous minerals, as well as Raynauds Disease (i.e., a numbness of the fingers due to work with vibratory hand tools).

Standards being prepared or considered for preparation involve mine sanitation practices, emergency medical care, noise, oxygen-deficient atmospheres, heat stress, and carbon monoxide.

CONCLUSIONS

Mining, by its very nature, is not now and never has been the safest occupational activity. Judging from the past, it appears that attention to health and safety problems has been crisis oriented. Improvements in machine and mine design, as well as work procedures, have done much to improve the physical elements of the work environment. However, these corrective measures have not had as much effect in reducing deaths and injuries as was hoped. What is needed is a way to change the behavior of both miners and management so they will accept their responsibilities and be



Number of Nonfatal Disabling Injuries and Incidence Rates, Metallic Mining 1950–1979

Figure 2. *Mine Safety.* The actual reduction in number of and incidence rates for nonfatal disabling injuries occurred before 1960.

committed to working safely, while improving their productivity. It is commonly accepted that unsafe acts committed by the worker account for 80% of all industrial accidents. Also, the government and organized labor must learn to work cooperatively rather than in an adversary relationship with the employer to accomplish realistic safety performance goals. By focusing on performance standards, rather than specification standards, regulatory agencies should concentrate on the real causes of accidents, not on the number of citations issued.

Mel Garcia is Assistant Director for Mine Health and Safety in the Department of Mining and Geological Engineering at the University of Arizona, and is also Industrial Hygienist with the Bureau of Geology and Mineral Technology.

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INDUSTRIAL MINERAL NEWS

Bureau Geologist, H. Wesley Peirce, attended the 17th Annual Forum on the Geology of Industrial Minerals that was held in Albuquerque, New Mexico, May 12–15, 1981. The program was sponsored by the New Mexico Bureau of Mines and Mineral Resources and chaired by George S. Austin, Assistant Director of the New Mexico Bureau. The theme for this meeting was "Industrial Rocks and Minerals of the Southwest."

Field trips were offered prior to, during and after the meeting. The pre-meeting trip provided a rare opportunity for both husbands and wives to go underground into one of the Carlsbad potash mines. Currently, there are seven operations in the district that together supply about 80% of the national needs for potash (potassium) fertilizers. The surface milling and processing facilities were also visited. The potash bearing minerals occur as mixtures with common rock salt. Salt mines are dry and salt dust is not a health hazard. The district was opened in 1931 and is now laced with thousands of miles of underground workings.

Two days of technical papers were highlighted by a banquet talk given by Robert L. Bates. Bob writes the popular "Geologic Column" that appears on the last page of *Geotimes.* His presentation, titled, "A View from the Column," elicited much laughter.

The spouses' activities, handled by Marjorie Austin, were reported to have been most rewarding. All in all the meeting was a big success.

Next year, the annual meeting will take place in Hoosier country. The Forum comes to Arizona in 1985; it's not too early to start thinking about technical papers for this one.

PENROSE CONFERENCE

Stephen J. Reynolds, geologist for the Bureau, recently attended a Geological Society of America Conference on the "significance and petrogenesis of mylonitic rocks." The conference was held in San Diego on April 28–May 2 and was preceded by a three-day field trip through the San Gabriel Mountains, the Santa Rosa Mountains and the Peninsular Ranges of southern California. G.S.A. Penrose Conferences are designed to bring together a select group of geoscientists that have expertise on a certain subject. Reynolds was invited to the conference on the basis of his research on mylonitic rocks of Arizona and other western states. The conference was attended by approximately 75 geoscientists from all parts of the U.S. and from eight foreign countries, including Australia, Switzerland, Norway and France.

NATIONAL/REGIONAL/LOCAL EVENTS

Planning Association of Arizona—Annual Conference, Flagstaff, AZ, September 16–18, 1981

Arizona Science Teachers Association—Annual Meeting, Scottsdale, AZ, October 16, 1981

American Geophysical Union—Symposium (Geophysics and Groundwater), San Francisco, CA, December 7–11, 1981

American Institute of Mining Engineers, Arizona Conference—Annual Meeting, Tucson, AZ, December 7, 1981

Quartzsite Improvement Association—16th Annual Gem & Mineral Show, Quartzsite, AZ, February 4–8, 1982

Tucson Gem & Mineral Society—28th Annual Gem & Mineral Show, Tucson, AZ Wholesale Show & Manufacturers' Exhibits, February 11–14, 1982
Retail Show (open to public), February 12–14, 1982

American Association of Petroleum Geologists—Annual Meeting, Pacific Section, Los Angeles, CA, April 7–9, 1982

Geological Society of America & Seismological Society of America—Annual Meeting, Cordilleran Section, Anaheim, CA, April 19–21, 1982

Colorado School of Mines—International Conference (Geological Information), Golden, CO, May 24–28, 1982

WILLIAM P. COSART has been selected to be Acting Dean of the College of Mines and Acting Director of the Bureau of Geology and Mineral Technology for the fiscal year 1981–82, replacing William H. Dresher. Dr. Cosart joined the University of Arizona faculty in 1968 and became Assistant Dean in 1972. In addition to his teaching, he has been active in University programs, i.e., student advisory committees (curriculum, scholarship, admission, Indian advisory, etc.) and with research and development.

Dr. Cosart received a Ph.D. in Chemical Engineering from Oregon State University (1973) and a B.S. and M.S. from Stanford (1958, 1960). From 1959 to 1962, Cosart served as Lieutenant in the U.S. Army Chemical Corps, and from 1962–64, Research Associate at the Oregon Primate Research Center.

In 1972, he was the recipient of the Good Teaching Award, sponsored by Standard Oil; in 1978, Dr. Cosart received the Outstanding Student Chapter Counselor Award from the American Institute of Chemical Engineers.

Effective last July, **WILLIAM G. DAVENPORT** became head of the Department of Metallurgical Engineering at the University of Arizona and Assistant Director of the State of Arizona Bureau of Geology and Mineral Technology, in charge of the Mineral Technology Branch.

Since 1964, Dr. Davenport has held numerous faculty positions at McGill University (from Assistant Professor to Associate Dean of Engineering). He has been a consultant to many Canadian mineral industries and has acquired a working familiarity with virtually all smelters and refineries in Canada, as well as with metallurgical operations in Australia, Japan and the U.S.

Dr. Davenport received his Ph.D. in Extractive Metallurgy from the Royal School of Mines, University of London (1964) and his B.S. and M.S. in Metallurgical Engineering from the University of British Columbia (1959, 1960).

ANNOUNCEMENTS

Arizona Geological Society Digest XIV, "Relations of Tectonics to Ore Deposits in the Southern Cordillera" has been released and is available for purchase ($15.00) from AGS (P.O. Box 40952, Tucson, AZ 85717). This volume contains the proceedings of a symposium held on March 19–20, 1981 at the University of Arizona. Digest XIV has been mailed to symposium registrants. Note: Digest XIII is still in preparation.

The Bureau of Reclamation (BuRec) has reclaimed its original name and will no longer be known as the Water and Power Resources Service (WPRS).

Daniel N. Miller, former director of Wyoming's Geological Survey, has been appointed Assistant Secretary of the Department of Interior for Energy and Minerals. Miller will have jurisdiction over the U.S.G.S., the U.S. Bureau of Mines and the U.S. Office of Surface Mining.

MINERALOGY CORNER

by H. Wesley Peirce and Robert T. O'Haire

The mineral *conichalcite,* $CaCu(AsO_4)(OH)$, was identified by Bureau mineralogist Bob O'Haire from petrified wood collected by Wes Peirce and Larry Fellows. The wood was found as float boulders in the stream bottom downstream from Bath Tub Tank in Adobe Canyon, Santa Rita Mountains, Santa Cruz County.

Conichalcite, identified by composition and x-ray pattern, occurs along fractures as small greenish masses having a radial fibrous structure. It occurs in association with chrysocolla and unidentified iron oxides. Vanadium and/or phosphorous can substitute for arsenic (Palache and others, 1951). Spectroscopic examination confirms the presence of some vanadium, and qualitative chemical testing indicates some phosphorous. Additional testing is necessary to more precisely determine the chemical composition.

Miller and Schwab (1966) noted the occurrence of "silicified tree trunks" in Lower Cretaceous strata in Adobe Canyon. Drewes (1972) mapped the region and named the nearly vertical, tilted strata in the Bath Tub Tank area, the Turney Ranch Formation—the stratigraphically highest unit in the Lower Cretaceous Bisbee Group.

Conichalcite is a relatively rare mineral in southern Arizona having been recognized only in a few copper mining regions, such as Bisbee, Ajo and Globe (Anthony and others, 1977). This occurrence of conichalcite in petrified wood (not associated with a mining property) seems unique.

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Fieldnotes

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