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Mineral and Energy Resources:

Assessing Arizona's Potential

by Larry D. Fellows

INTRODUCTION

Arizona holds a distinguished place among the mineral-producing giants of the world. In 1981 an eighth of the world's mined copper was produced within the State. These same ores contain significant amounts of molybdenum, silver, and gold, which are recovered as byproducts and coproducts. In addition, Arizona's mines yield a variety of other metals (lead, zinc, tungsten, etc.), nonmetals (lime, gypsum, salt, etc.), and energy resources (coal, oil, etc.).

Prospectors have examined nearly every square foot of Arizona and have discovered most of the minerals that are visible at the surface. The *subsurface,* however, is largely unexplored. Exploration for hidden mineral and energy resources may require years and millions of dollars, with no guarantee of new discoveries. Because of the State's proven record of mineral- and energy-resource production, because much of Arizona's geology is complex and poorly understood, and because the subsurface is virtually unexplored, the potential for discovery of new mineral and energy resources is great. Future discoveries could be important to the Nation, as well as the State.

Congress has passed a number of bills governing the management of Federal lands, most of which are in the western United States. The Wilderness Act of 1964 and subsequent congressional acts specified that the U.S. Geological Survey (USGS) and U.S. Bureau of Mines (USBM) would assess the mineral- and energy-resource potential of some of these lands. Congress intended to use these assessments, together with evaluations of other factors, to assist them in making informed policy and land-management decisions.

Recently, attention has been focused on "roadless" areas identified within lands that the U.S. Forest Service administers. The USGS and USBM were directed to assess the mineral and energy potential of those areas recommended for wilderness status or further planning. The original plan for management of these areas (RARE II) was invalidated by a court decision. A legislative solution will be followed instead. An Arizona wilderness bill is currently before Congress. The bill covers more than one million acres of Forest Service and Bureau of Land Management (BLM) lands within the State. Although the USGS and USBM have completed their required assessments, mineral and energy potential have not been assessed in about half of the areas included in the Arizona bill. These areas had previously been recommended for multiple use, rather than wilderness or further planning; therefore, mineral and energy assessments were not required.

In the following paragraphs, Arizona's status as the Nation's leading

Figure 1. Ruins of Alto, a post office and mining camp in the southwestern Santa Rita Mountains, now within the Coronado National Forest. According to Varney (1980, p. 82), gold discoveries were made in the Alto area as early as 1687, but modern-era mining did not begin until 1875, when the Gold Tree Mine caused the establishment of the community known as El Plomo. "Plomo" means "heavy" in Spanish and refers to the lead deposits present in the area. Silver was the primary metal obtained from the mine. The post office, which served a community of several hundred, was active from 1907-1933. Photo: L.D. Fellows.

producer of nonfuel minerals is summarized; a few of the many sources of information about these resources and related geologic factors are identified; and the mineral- and energy-assessment process and limitations are discussed. Emphasis is given to the process as it relates to proposed Forest Service wilderness areas.

MINERAL AND ENERGY PRODUCTION IN ARIZONA

Historical Perspective

Numerous ruins and ghost towns, once lively mining camps during the late 1800's and early 1900's, are gaunt reminders of Arizona's mineral-resource heritage (Figure 1). Minerals were important to those living in this region, however, long before then.

Indians were the first to make use of minerals, primarily nonmetals such as stone, adobe, clay, pigments, and salt. In the late 1500's, Indian residents led Spanish explorers to mines in what is now northern Arizona. In the 1600's and 1700's, the Spanish discovered and mined silver and gold in the mountains adjacent to the Santa Cruz River, south of present-day Tucson. They abandoned the mines long before American prospectors entered the region in the mid-1800's.

Arizona became part of the United States in two stages: the land north of the Gila River was ceded to the United States in 1848, after the Mexican War; the area south of the Gila was acquired through the Gadsden Purchase in 1853. Prior to 1853, word of the abandoned Spanish silver mines had been spread throughout America by trappers, prospectors, explorers, and Boundary Commission surveyors and scientists. These mines, called "antiguas," were known to be present in the Oro Blanco, Patagonia, Santa Rita, Sierrita, Tucson, and Santa Catalina Mountains.

As soon as the Gadsden Purchase lands were opened for exploration and settlement, prospectors began to arrive. In 1854 a San Francisco company, the Arizona Mining and Trading Company, opened a copper mine near Ajo. In 1856 Charles D. Poston and Samuel P. Heintzelman organized the Sonora Exploring and Mining Company in Cincinnati, specifically to reopen the old Spanish silver mines. Their 1857 stockholders' report listed title to 78 mines (25 near Arivaca, 24 in the Santa Rita Mountains, and 29 surrounding Cerro Colorado), and two veins southwest of Tubac (North, 1980, p. 30).

Exploration and development largely ceased during the Civil War and did not significantly resume until the early 1870's, when the "boom" began. Prospectors covered practically every square foot of Arizona and the West, except for those few areas that were too rugged for man's encroachment. Many surface and near-surface mineral deposits were discovered, and mining camps developed around them. Most of these camps are now ghost towns and ruins; only a few have survived. Mineral deposits have been found intermittently since the 1870's, culminating with the discovery of the large copper deposits south of Tucson in the 1950's.

Current Production

Arizona led the Nation in 1981 in total production value of nonfuel minerals, including metals and nonmetals (Table 1). Copper, molybdenum, silver, gold, and lead were among the metals produced. Nonmetals included portland cement, sand and gravel, crushed stone, lime, masonry cement, gemstones, industrial sand, gypsum, clays, perlite, pumice, pyrites, and salt. The value of nonfuel mineral production for 1981 was $2.57 billion, a record high (Burgin, 1983, p. 55). Mineral fuels (coal and oil) were also produced.

The leading mineral commodity produced in Arizona in tonnage and value is copper. Copper from Arizona mines amounted to almost 68 percent of total U.S. production in 1981, and *13 percent* of the *world* total (Table 2). Mines in only one *country,* Chile, yielded more copper than those in Arizona in 1981.

Some of Arizona's copper ores also contain molybdenum, silver, gold, lead, zinc, and other metals. Thirty percent of total U.S. production of molybdenum in 1981 came from Arizona, which ranked second nationally, behind Colorado. In production of silver, Arizona, with 20 percent of the U.S. total, ranked second behind Idaho. Gold produced from Arizona mines accounted for 7 percent of the U.S. total and placed Arizona fourth nationally (Burgin, 1983, p. 55). These metals - molybdenum, silver, and gold -were mostly recovered as by-products or coproducts of copper production. The presence of these metals has helped to offset the low copper prices that have prevailed during the last several years and has enabled the copper mines to stay in operation. In 1981, when the price of molybdenum rose dramatically, a number of "copper" mines became "molybdenum" mines, because the value of molybdenum produced exceeded that of copper.

In 1982 mine-copper production in the United States dropped from 1,538 to 1,140 thousand metric tons, the lowest level since the 1960's. At the same time, Chile's production increased from 1,080 to 1,241 thousand metric tons (Jolly and Edelstein, 1983, p. 272, 303). Thus, the United States slipped from first to second place among the world's mine-copper producers, for the first time in at least 50 years.

The total value of crude nonfuel minerals produced in Arizona de-

Table 1. Value of nonfuel mineral production in the United States and principal nonfuel minerals produced in 1981 (Ballard, 1983, p. 5).

Rank	State	Value (thousands)	Percent of U.S. total	Principal minerals in order of value
1	Arizona	$2,565,840	10.19	copper, molybdenum, cement, silver
2	Minnesota	2,151,871	8.55	iron ore, sand and gravel, stone, lime
3	California	1,975,016	7.85	cement, boron minerals, sand and gravel, stone
4	Florida	1,725,589	6.85	phosphate rock, stone, cement, clays
5	Texas	1,658,203	6.59	cement, sulfur, stone, sand and gravel
6	Michigan	1,438,355	5.71	iron ore, cement, magnesium compounds, salt
7	Colorado	965,766	3.84	molybdenum, cement, sand and gravel, silver
8	Missouri	870,326	3.46	lead, cement, stone, lime
9	Georgia	804,455	3.20	clays, stone, cement, sand and gravel
10	Utah	783,232	3.11	copper, gold, molybdenum, potassium salts

Table 2. Major copper mining countries, 1981 (Butterman, 1982, p. 302-303).

Rank	Country	Production (thousand metric tons)
1	United States (Total)	1,538.2
2	Chile	1,080.0
	(ARIZONA)	(1,040.8)
3	U.S.S.R.	950.0
4	Canada	718.1
5	Zambia	588.0
	(United States, excluding Arizona)	(497.4)
6	Zaire	497.0
7	Peru	327.6
8	Poland	315.2
9	The Philippines	289.3
10	Mexico	230.5
11	Australia	223.2
12	Republic of South Africa	208.7
13	People's Republic of China	200.0
	WORLD TOTAL	8,171.1

clined by 36.8 percent from 1981 to 1982. Even so, Arizona retained its first rank among the States in value of minerals produced. Arizona's copper production fell to its lowest point since 1975, molybdenum to its lowest point since 1976, silver to its lowest point since 1980, and gold to its lowest point since 1893. The downturn in metal production was directly related to the sharply reduced copper production and significantly contributed to the severe drop in value of nonfuel mineral output in the State (Burgin, 1984a, p. 4).

Preliminary production figures for 1983 indicate a further decline in total value of mineral production in Arizona (Burgin, 1984b).

As Figure 2 indicates, metals have been produced from mines throughout Arizona, but have been concentrated in the western and southern parts of the State. This map shows metallic mineral districts from which production has either been recorded or is probable. The map has been generalized and reduced from a 1:1,000,000-scale map included in a report on metallic mineral districts and production in Arizona (Keith and others, 1983). Mineral districts shown on the original map were classified by age and style of mineralization and type of metallic minerals produced. Production statistics for each district, compiled from the USBM and other sources, are included in the report. Some deposits are small; some are gigantic: some have long been abandoned; others are currently being mined. Neither Figure 2 nor the original map shows active mines. The Arizona Department of Mineral Resources, however, maintains a directory of active mines in Arizona (Greeley and Niemuth, 1983).

A summary of Arizona's various metallic, nonmetallic, and mineral fuel resources appears in "Mineral and Water Resources of Arizona" (U.S. Geological Survey and others, 1969).

Available Information

Much has been written about Arizona's mineral resources, including detailed geologic reports on mineralized districts, specific ore bodies, and the State's geologic framework. These reports are prepared by geologists, geophysicists, geochemists, mining engineers, and others from mineral exploration and mining companies, State and Federal agencies, and universities. Many have been published by the USGS, USBM, Arizona Bureau of Geology and Mineral Technology*, Arizona Geological Society, and numerous professional societies. The USBM has collected mineral production statistics since the early 1900's. Its min-

*Known as the Arizona Bureau of Mines until 1977. The Bureau's Geological Survey Branch is the Arizona Geological Survey. All but a few states have state geological surveys, which provide basic geologic data, maps, and reports.

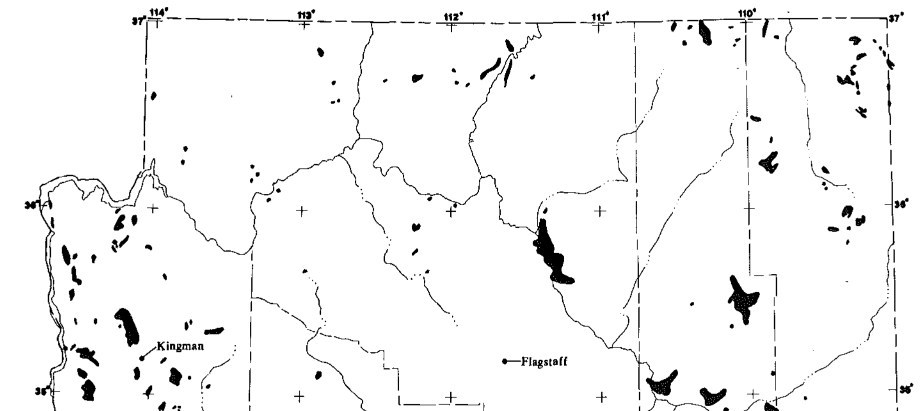


Figure 2. Metallic mineral districts in Arizona. These are areas from which metals have been produced or are currently being produced, or in which ore bodies have been identified and production is expected. This map was generalized and reduced from a 1:1,000,000-scale map included in Arizona Bureau of Geology and Mineral Technology Bulletin 194 (Keith and others, 1983).

Table 3. Publications that relate to mineral and energy resources in Arizona, released since 1944 by the Arizona Bureau of Geology and Mineral Technology. Those that are out-of-print (Bulletins 155, 156, 158, and 187) are available only through selected libraries. The others may also be purchased from the Bureau. A price list with ordering instructions will be sent on request.

Number	Title
Bulletins	
137	Arizona lode gold mines and gold mining (1934; revised 1967)
155	Arizona nonmetallics (1949; Out-of-Print)
156	Arizona lead and zinc deposits, part I (1950; Out-of-Print)
158	Arizona lead and zinc deposits, part II (1951; Out-of-Print)
168	Gold placers and placing (1961)
173	Bibliography of the geology and mineral resources of Arizona, 1848-1964 (1965)
177	Mineral deposits of the Fort Apache Indian Reservation (1968)
179	Mineral deposits of the Gila River Indian Reservation (1969)
180	Mineral and water resources of Arizona (1969)
182	Coal, oil, natural gas, helium, and uranium in Arizona (1970)
187	Index of mining properties in Cochise County, Arizona (1973; Temporarily Out-of-Print)
189	Index of mining properties in Pima County, Arizona (1974)
190	Bibliography of the geology and mineral resources of Arizona, 1965-1970 (1974)
191	Index of mining properties in Santa Cruz County, Arizona (1975)
192	Index of mining properties in Yuma County, Arizona (1978)
194	Metallic mineral districts and production in Arizona (1983)
Circulars	
19	A survey of uranium favorability of Paleozoic rocks in the Mogollon Rim and Slope region, east-central Arizona (1977)
23	Geothermal resources in Arizona - a bibliography (1982)
Maps	
4-2	Map of known metallic mineral occurrences in Arizona, excluding base and precious metals (1969)
5	Map of known nonmetallic mineral occurrences in Arizona (1965)
15-2	Geothermal resources of Arizona (1982)
Open-File Reports	
78-3	The geology of Arizona: its energy resources and potential (1978)
79-1	A study of uranium favorability of Cenozoic sedimentary rocks, Basin and Range Province: Part 1, general geology and chronology of pre-late Miocene Cenozoic sedimentary rocks (1979)
81-1	Radioactive occurrences and uranium production in Arizona (1981)
83-12	Geothermal energy in Arizona - final report (1982)
83-13	Earth materials evaluation - Arizona RARE II areas (1983)

erals yearbook series summarizes annual mineral production by commodity and by State, and computes U.S. totals.

The Arizona Bureau of Geology and Mineral Technology has published a variety of reports and maps that relate to Arizona's mineral resources. These include geologic bibliographies, an index of published geologic maps, four county reports on geology and mineral resources, mineral occurrence maps, and a summary report on metallic mineral districts and production (Table 3). Although much of this information is technical, *Fieldnotes,* the Bureau's quarterly research publication, has presented less technical overviews of Arizona's mineral resources (Table 4).

Many other reports and maps have not been published, but have been placed on "open file." Students from many universities have completed master's theses or doctoral dissertations on Arizona's geology. Reports and maps mentioned in this section and some theses may be examined in the libraries of various organizations, such as the Arizona Bureau of Geology and Mineral Technology (Tucson); Arizona Department of Mineral Resources (Phoenix); USGS (Flagstaff and Denver); USBM (Denver); University of Arizona (Tucson); Arizona State University (Tempe); Northern Arizona University (Flagstaff); and some city libraries.

THE ASSESSMENT PROCESS

Basic Tenets

Assessments of mineral- and energy-resource potential, together with evaluations of other factors, are used to assist those who make policy and land-management decisions. Because the assessment process is fraught with uncertainty, the persons who make the assessments and those who make decisions based on them must keep in mind the following concepts:

1. *Data are essential.* Conclusions about mineral- and energy-resource potential must be consistent with available data. If data are nonexistent or inadequate, the mineral-resource potential is properly described as "unknown." Lack of data does not mean that mineral-resource potential is low. In addition, assessments based on subjective interpretations, rather than objective data, should be stated as such.

2. *Researchers must be skilled.* Assessment of mineral-resource potential can be no better than the person who makes the assessment. This is especially true when the "simple subjective" method of assessment is used (see next section). Any credible assessment must involve skilled, experienced professionals.

3. *Potential will change.* No one can see hidden mineral resources or anticipate changes that will affect resource potential. Economic conditions will change; technology will change; geologic concepts will change; potential will change. Change is the rule, rather than the exception. Conclusions about the

mineral- and energy-resource potential of any area are based on *current* knowledge.

4. *Repeated assessment is necessary.* Mineral deposits are generally "very small needles in very large haystacks." Areas must often be explored and reexplored in response to new geologic concepts, new technologies, and new economic conditions. The exploration process requires access to lands, demands imagination, is very expensive, may take years to complete, and rarely leads to discovery.

The following example illustrates this point: In 1922 the Commissioner of the General Land Office concluded that the E ½ sec. 36, T. 16 S., R. 12 E (northeast flank of the Sierrita Mountains) was nonmineral in character (Commissioner, 1922). In response to a strong demand for copper in the post-World War II years, however, extensive mineral exploration programs were launched, using the latest geologic concepts and geophysical exploration techniques. After a number of years of exploration and expenditure of millions of dollars, the Pima copper deposit, part of which lies within the tract in question, was discovered. In 1981, *five* of the Nation's 25 leading copper mines were within 12 miles of this tract.

Geologic and Economic Factors

Mineral and energy resources have formed at many times during the geologic past through various physical and chemical processes acting in specific geologic environments. Assessment of mineral potential is, therefore, based on general knowledge and understanding of the processes of mineral formation, and specific knowledge and understanding of the geologic framework and mineral occurrences in the assessment area. To make a mineral or energy assessment, one must consider several factors: the regional geologic setting; time of mineral formation; mineralogy and mineral assemblages; amount and types of past mineral production; character and distribution of host rocks; type and distribution of associated rock structures (folds, faults, etc.); and processes that may have modified minerals since their formation.

Persons who attempt to assess mineral potential must review existing reports, mineral production statistics, and geologic maps. They will probably make field observations, do geologic mapping, or collect samples as well. Their objective is to identify areas in which the geologic characteristics are similar to those of areas with known mineral deposits. Singer and Mosier (1981, p. 1,008) called this the "simple subjective" method, whereby estimates of mineral and energy potential are made by one or more individuals on the basis of their experience and knowledge. Although other assessment methods are used, the simple subjective method is the most widely used. Assessment is done on the basis of current geologic concepts, current technologies, and current demand (prices) for minerals. These factors (concepts, technologies, and demand) constantly change; and as they do, so do conclusions about mineral potential.

Some geologic concepts in vogue today had not been developed 5 or 10 years ago; still others will be developed and tested in the future. In their search for new deposits, geologists are using new "models" and more sophisticated exploration techniques, such as computer modeling and computer-enhanced imagery from satellites. Innovative mining, milling, and processing procedures have been developed that allow exploitation of lower-grade ores. In addition, research has identified new uses for some materials.

Both mining and mineral exploration are driven by economics. When the demand (price) for a mineral commodity increases, so does exploration. For example, when the price of gold and silver reached record highs a few years ago, many individuals and companies started exploring for gold and silver. Today the demand for copper is low, mines are not operating at full capacity, and virtually no exploration is taking place.

The United States imports large quantities of many mineral commodities for a variety of reasons. Some minerals are not present or are not abundant enough to be produced in this country; others can be imported more cheaply than they can be domestically produced. Political instability in the exporting countries could limit mineral availability and thus, raise prices. In turn, increased import prices could lead to changes in the U.S. price structure: mineral substitutes might be developed, or the mining of lower grade ores might become more profitable. These are but a *few* of the factors that could trigger changes in mineral supply and demand, and in turn, affect conclusions about the mineral potential of an area.

Brobst and Goudarzi (1984), p. 7) emphasized that because geologic concepts, technology, and economics are tightly intertwined, mineral-resource potential must be periodically assessed:

> Assessments of mineral-resource potential are of a dynamic nature regardless of how they are conducted, or of the methods that are used. Final, once-and-for-all assessments of mineral-resource potential cannot be made. Areas should be reassessed periodically as new data become available, as new concepts of the factors that influence the concentration of minerals are developed, as new uses and extractive technologies for minerals are devised, and as the world's economy changes. For these reasons, the Congress specified that recurring mineral surveys of the wilderness lands should be made.

Table 4. Articles on Arizona's mineral and energy resources that have appeared in *Fieldnotes*, 1971-1984. References are listed under volume-number, page. For example: "Asbestos: 13-1,1" means an article on asbestos appears in volume 13, number 1, page 1.

Asbestos:	13-1,1
Basic geologic concepts:	8-3,1; 11-2,6
Coal:	4-1,3; 5-4,1
Copper:	1-1,9; 2-4,1; ;8-1,9; 9-2,1
Economic factors:	1-3,1; 8-1,2; 13-3,1; 13-4,6
Geothermal:	2-2,9; 11-2,1; 13-4,1
Helium:	13-2,2
Industrial minerals (nonmetals):	10-2,1
Mineral exploration:	1-2,1; 3-4,1; 4-2,1
Molybdenum:	10-3,1
Oil and gas exploration:	1-4,6; 4-1,3; 9-1,10; 10-1,1; 11-1,1; 12-2,1
Salt:	2-1,4; 3-2,1; 11-4,1
Uranium:	6-1,7; 7-1,1; 9-3,1; 10-4,1
Zeolites:	8-4,1

WILDERNESS AREAS

The RARE Program

The Wilderness Act of 1964 and subsequent acts specified that the USGS and USBM would assess the mineral potential of approximately 16 million acres of Federal land and submit a report to Congress on the suitability or unsuitability of these lands as wilderness areas. By the end of 1980, the assessment areas had been increased to 45 million acres. Most of these lands are administered by the U.S. Forest Service (USFS).

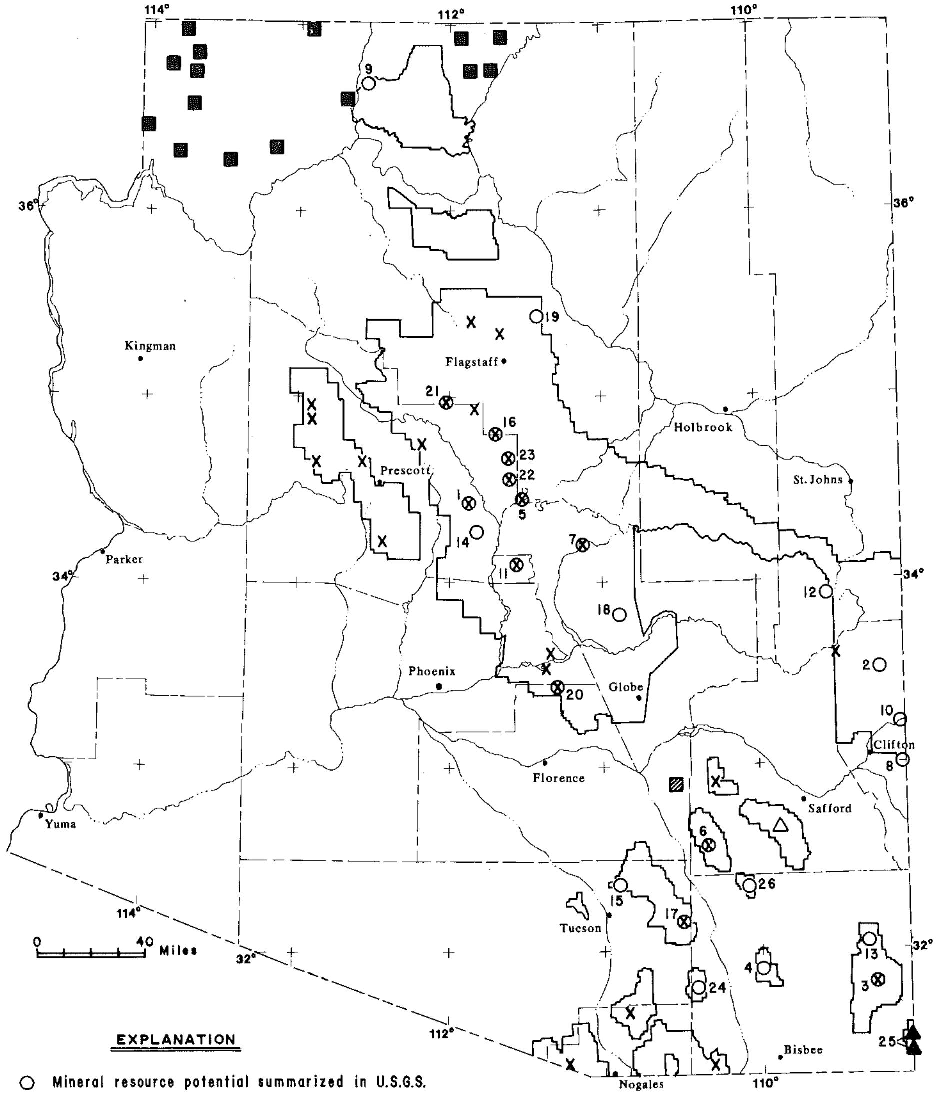
The Roadless Area Review and Evaluation (RARE) program was launched by the USFS in the early 1970's. In a follow-up effort called RARE II, which was begun in 1977, the Forest Service sought input from the public to assist them in determining whether the "roadless" areas should be managed as wilderness or non-wilderness, or be given further study. The USGS and USBM were to complete mineral surveys of the areas recommended for wilderness status or further study before final designations were made.

In 1979 California challenged the adequacy of the RARE II environmental statement as the basis for decisions to manage 46 areas in California as "other than wilderness." In October 1982, the U.S. Ninth Circuit Court of Appeals upheld the lower court decision that the RARE II environmental statement was inadequate. To avoid further delays and the expense of a third RARE evaluation, a decision was made to resolve legislatively the management of "roadless" areas. State bills are now being prepared.

The Arizona Wilderness Act of 1984

On February 1, 1984, Representative Morris K. Udall (D-Ariz.) introduced the Arizona Wilderness Act of 1984 (H.R. 4707). Senator Barry Goldwater (R-Ariz.) introduced an identical bill in the Senate (S. 2242). Hearings were held in February by the House Committee on Interior and Insular Affairs, Subcommittee on Public Lands and National Parks. The bill, with amendments, was passed and was subsequently approved by both the House Committee and the full House. As of this writing, Senate Committee hearings have not been held.

In addition to some 700,000 acres of Forest Service lands, H.R. 4707 covers the Aravaipa Canyon wilderness area (6,670 acres - BLM lands); areas included in the Arizona Strip Wilderness Bill (394,900 acres - BLM and Forest Service lands); and a segment of the Verde River, which is designated as a "Wild and Scenic River." These areas are shown in Figure 3.



○ Mineral resource potential summarized in U.S.G.S. Professional Paper 1300

X Area designated as wilderness in Arizona Wilderness Act of 1984

⊗ Mineral resource potential summarized in U.S.G.S. Professional Paper 1300 and area designated as wilderness in Arizona Wilderness Act of 1984

▲ Mineral resource potential summarized in U.S.G.S. Professional Paper 1300 and area designated for further study in Arizona Wilderness Act of 1984

△ Area designated for further study in Arizona Wilderness Act of 1984

▨ Aravaipa Canyon wilderness area (BLM administered), included in Arizona Wilderness Act of 1984

■ Arizona Strip wilderness area (BLM administered) included in Arizona Wilderness Act of 1984

National Forest System Lands

Figure 3. Areas for which mineral and energy potential were assessed by the U.S. Geological Survey and U.S. Bureau of Mines and areas included in the Arizona Wilderness Act of 1984. References to the detailed mineral and energy assessments for each numbered area are listed in Table 5.

Mineral and Energy Assessments

Early in 1984 the USGS released Professional Paper 1300 (Marsh and others, 1984), which was prepared in cooperation with the USBM. This two-volume set includes *summaries* of mineral and energy assessments that were completed by the two agencies from 1964 to 1984. These studies cover about 45 million acres in nearly 800 areas in 32 States. The Arizona chapter (v.1, p. 46-132) covers 25 areas, including existing wilderness and areas that the Forest Service, through RARE II, recommended for wilderness or further planning. In the introduction to Professional Paper 1300, Brobst and Goudarzi discuss the reason for assessing wilderness mineral and energy potential, the nature of mineral-resource assessments, classification of mineral resources and mineral-resource potential, assessment pro-

Table 5. Detailed mineral and energy assessments made by the U.S. Geological Survey and U.S. Bureau of Mines and summarized in USGS Professional Paper 1300 (Marsh and others, 1984). Numbers in left column coincide with those in Figure 3. Abbreviations used: MF (Miscellaneous Field Study; includes map and pamphlet); B (Bulletin); and OFR (Open-File Report). USGS publications can be purchased from the Branch of Distribution, USGS, Box 25286, Federal Center, Denver, CO 80225. USBM open-file reports can be obtained through interlibrary loan by writing to Chief, Circulation and Interlibrary Loan, National Resources Library, U.S. Department of the Interior, Washington, DC 20240; or by calling 202-343-5815.

Area Number	Area	USGS Assessment	USBM Assessment
1	Arnold Mesa	MF 1577-A, 1983	OFR 31-81, 1981 11 p., map
2	Blue Range	B 1261-E, 1969 91 p., map	
3	Chiricahua Mountains	B 1385-A, 1973 53 p., map	
4	Dragoon Mountains	MF 1521-B, 1983	OFR 35-82, 1982 8 p., map
5	Fossil Springs	MF 1568-A, 1983	
6	Galiuro Mountains	B 1490, 1981 94 p., two maps	
7	Hells Gate	MF 1573-A, 1983	OFR 139-82, 1982 13 p., map
8	Hells Hole	MF 1344-E, 1983	OFR 137-82, 1982 22 p., map
9	Kanab Creek	MF 1627-A, 1984 (in press)	
10	Lower San Francisco	MF 1463-C, 1982	
11	Mazatzal Mountains	MF 1573-A, 1983	OFR 56-82, 1982 12 p., maps
12	Mount Baldy	B 1230-H, 1967 14 p.	
13	North End	MF 1412-D, 1983	OFR 1-83, 1982 21 p., map
14	Pine Mountain	B 1230-J, 1967 45 p., map	
15	Pusch Ridge	MF 1356-B, 1982	OFR 118-82, 1982 19 p., map
16	Rattlesnake	MF 1567-A, 1983	OFR 133-82, 1982 5 p.
17	Rincon Mountains	B 1500, 1978 62 p., maps	
18	Sierra Ancha	MF 1162-H, 1981	
19	Strawberry Crater	MF 1394-C, 1982	
20	Superstition Mountains	OFR 83-472, 1983	OFR 136-82, 1982 25 p., map
21	Sycamore Canyon	B 1230-F, 1966 19 p., map	
22	West Clear Creek	MF 1555-A, 1983	
23	Wet Beaver	MF 1558-A, 1983	OFR 134-82, 1982 5 p.
24	Whetstone Mountains	MF 1614-A, 1984 (in press)	OFR 129-82, 1982 20 p., map
25	Whitmire Canyon and Bunk Robinson	MF 1425-B, 1983	
26	Winchester Mountains	OFR 82-1028, 1982 7 p.	

cedures, the need for continuing assessments, and the legislative history of wilderness surveys.

Figure 3 shows the general locations of the areas included in Professional Paper 1300, as well as the areas included in H.R. 4707. As this figure indicates, all of the areas summarized in Professional Paper 1300 are not included in H.R. 4707. Also, some areas considered in the bill have not been assessed for mineral potential by the USGS or USBM.

The area summaries in Professional Paper 1300 are based on more detailed reports, many of which were not published but can be reviewed in various libraries (Table 5). Each summary includes a map that shows areas with "substantiated" or "probable" mineral-resource potential. The term "substantiated" is based on "a record of past production or the occurrence of identified resources, and (or) an assemblage of geologic data that strongly indicate the presence of undiscovered mineral resources." The term "probable" is based on "an assemblage of data that support the interpretation that undiscovered mineral resources may be present" (Brobst and Goudarzi, 1984, p. 4). The remaining areas on the maps either do not have identified mineral resources or lack evidence of mineralization that would indicate the presence of mineral resources.

Brobst and Goudarzi (1984, p. 7) explain the principles behind these assessments:

> Activity by the mineral industry is one factor that must be considered in the assessment of an area. The presence of known deposits is a favorable attribute for any area, but the absence of known deposits does not necessarily indicate that the area has no mineral-resource potential. Even the lack of evidence of mineral development and exploration may not be a negative sign about mineral-resource potential, especially for remote areas in which high costs discourage activity, or for areas in which newly recognized types of deposits can now be postulated. The studies summarized in these volumes assumed that undiscovered mineral deposits might be present in any area until information indicated that there was little likelihood for the occurrence of resources. Thus, a positive approach was maintained and the resource potential of areas was not reduced merely because adequate data were unavailable.

In other words, areas on the assessment maps that were not judged to have "substantial" or "probable" resource potential have either *unknown* or *low* potential. These two types of potential (unknown and low) are not differentiated on the maps or in the reports.

BLM Wilderness Study Areas

With the exception of the Aravaipa Canyon and Arizona Strip wilderness areas, BLM-administered lands are not included in the Arizona Wilderness Act of 1984. Figure 4 shows the general location of BLM wilderness study areas. The USGS and USBM are currently assessing the mineral potential of these tracts. Presumably these studies will be completed in time for them to be considered by those who determine the final land-management categories.

CONCLUSION

Rocks in much of Arizona have been highly mineralized, as substantiated by current and past production of a variety of metallic resources. Nonmetallic and energy resources are also present. For a number of years, Arizona has ranked first among the States in production of nonfuel minerals. In 1981, an eighth of the *world's* mined copper came from Arizona. In short, Arizona's mineral resources are important to the State, the Nation, and the world. Furthermore, the potential for finding additional mineral resources in Arizona is great. Future discoveries could be of national significance, as they have been in the past.

Mineral deposits are geologic phenomena. Much is known about Arizona's geologic framework and the included mineral deposits, but far more has yet to be learned. Knowledge consists of what is learned from laboratory studies, field work, and geologic mapping, and what is *interpreted* about the subsurface. The amount of available surface information far exceeds that of the subsurface. Furthermore, geologic knowledge of the State is not uniform across regions. The geologic framework of western and southern Arizona is more complex, but less understood, than that of the northern part of the State.

In spite of these limitations in geologic knowledge, mineral- and energy-resource potential can be assessed. The quality of the assessment, however, depends on the skill of the assessor and on the quantity and quality of available data. In those areas where data are unavailable or inadequate for one to make an assessment, the mineral and energy potential are simply unknown. Unknown potential does *not* necessarily mean low potential. Assessment of mineral and energy potential is based on concepts, technologies, and economic factors that continually change. The assessment process, therefore, is never final.

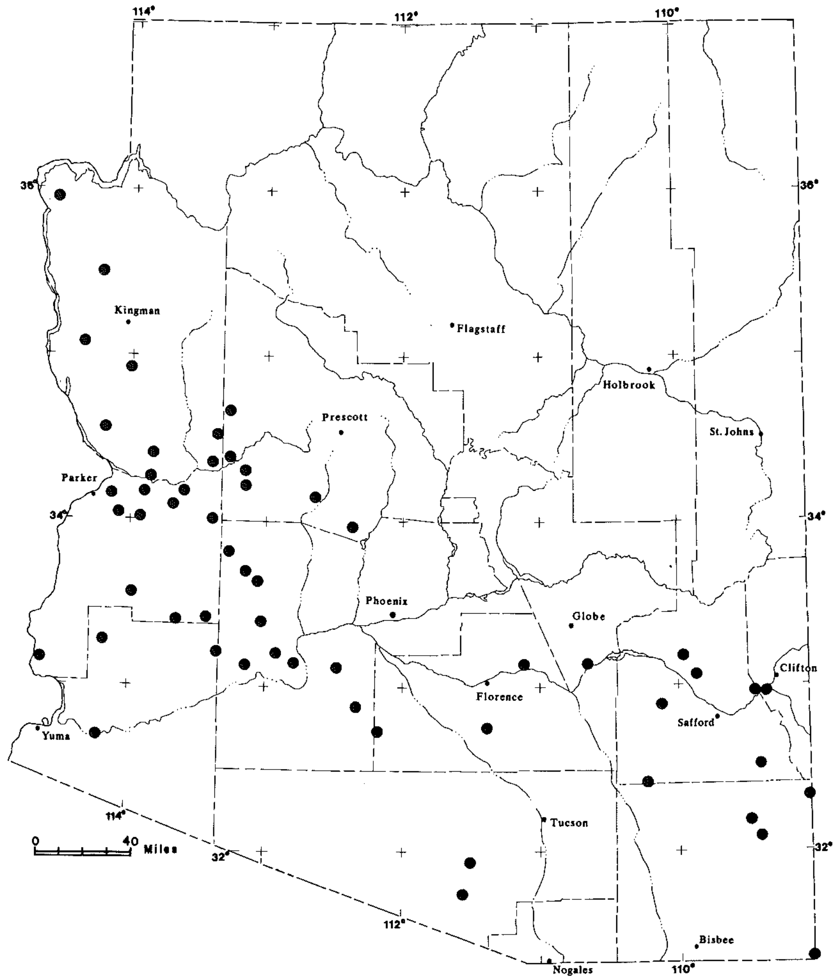


Figure 4. Wilderness study areas administered by the U.S. Bureau of Land Management.

Those who make land-management decisions that involve mineral- and energy-resource potential have access to a considerable amount of data. Mineral and energy assessments are among the most important data: they provide information that is essential to any land-management decision. Before such decisions are made, therefore, each area's potential for mineral and energy resources and its importance to *national* interests must first be considered.

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REQUEST FOR PROGRAM IDEAS

The 21st annual meeting of the Forum on the Geology of Industrial Minerals will be held in Tucson, April 9-12, 1985. Although the theme, "Arizona (AZ) - Aggregates to Zeolites," will focus on Arizona, the forum will also embrace surrounding States and Mexico.

H. Wesley Peirce, Principal Geologist at the Arizona Bureau of Geology and Mineral Technology (Bureau), is the general chairman of the forum. Dr. Peirce is soliciting agenda ideas and can be reached by writing or calling the Bureau.

1983 Drilling Activity

by A.K. Doss
Executive Director
Arizona Oil & Gas Conservation Commission

It was a bad year for the oil and gas industry throughout the country. The slump that began in late 1982 continued through 1983. The March 1984 issue of *Western Oil Reporter* contains an article that shows how depressed the industry has been in the Rocky Mountain States. Activity in the region has declined by as much as 37 percent, and the prognosis for 1984 varies from one "expert" to another. The optimists predict that 1984 will be a boom year for exploration drilling because drilling costs have dropped considerably below those of previous years, which will allow a greater margin of profit for producing wells. Other industry analysts predict that conditions will remain flat.

The following table shows the drop in drilling activity in Arizona during 1983. The high figures for 1981 and 1982 reflect the drilling of numerous, shallow, geothermal gradient holes. No geothermal gradient holes were drilled in 1983.

Two test holes drilled in 1983 hold promise for oil production in areas outside of the Navajo Indian Reservation. The Dowling Petroleum 1-A State, 9 miles south of Yuma, has casing set at approximately 5,002 feet. Although no completion attempts have been made yet, the hole could become a gas/gas condensate producer. The other possible producer, drilled 8 miles north of Show Low by Resource Operating, Inc., has logged promising gas shows in the Tapeats Sandstone (Cambrian). No completion attempts have been made, however, because of the lack of a pipeline connection and the glut in the natural gas market.

Predictions for 1984 are difficult to make. A number of oil operators have indicated that they have plans to drill in Arizona during 1984; however, the economic picture may have to improve greatly before these plans can become realities. Cam-Roy Research and Development Corporation plans to rejuvenate the two, deep, geothermal wells, which Geothermal Kinetics Services drilled some 10 years ago on the Power Ranch near Higley. Cam-Roy plans to move a rig there as soon as possible. If production tests prove favorable, the company may propose additional drilling and initiate a large development project.

	1980	1981	1982	1983
Number of drilling permits issued	14	73	48	12
Total number of test holes drilled	8	51	42	8
Total footage drilled	32,775	65,400	76,708	28,875
Number of oil-test dry holes	7	9	16	7
Number of oil producers	0	6	1	1

IN MEMORIAM

Anne Maria Candea, managing editor of *Fieldnotes,* died of cancer March 6. She was 40 years old.

Anne had been employed by the Arizona Bureau of Geology and Mineral Technology since February 1979. She coordinated the production of Bureau bulletins, circulars, special papers, and open-file reports. Her chief responsibility, however, was editing *Fieldnotes.*

Prior to joining the Bureau staff, Anne had worked in various writing, editing, and administrative capacities. She served for more than 5 years as Public Relations Director of the Cleveland Division of Air Pollution Control, where she coordinated numerous activities in environmental education. She also served as Youth Program Director for the Cleveland YWCA, and as a physician liaison for the Cleveland Academy of Medicine, where she helped to establish a county medical data bank.

Anne was active in the Association for Women Geoscientists and edited the newsletter for the Tucson chapter. She received a B.A. in English and sociology from Kent State University in 1965, and an M.A. in management from the University of Phoenix in 1982.

We, the members of the entire Bureau staff, wish to express our sorrow at Anne's death. She enthusiastically pioneered the Bureau's editorial program. The foundation she built should serve us well.

Road Logs Provide Self-Guided Tours of Arizona Geology

The breathtaking vistas and variety of landscapes in Arizona fascinate both residents and visitors alike. This fascination often leads to questions about how such masterpieces were created. Highway geology guidebooks and road logs can provide some insights.

A geologic road log provides information on the geologic factors that control landscape features observable from a given road. The guidebook might also describe the climate, vegetation, wildlife, industries, and towns along the route, and relate such information to the local geologic setting.

With a highway geology guidebook, a road trip can become as interesting and exciting as a treasure hunt. The guidebooks are generously sprinkled with maps, diagrams, and photographs. Mileage readings, rather than X's, "mark the spots," where the "buried treasure" is a wealth of new information about the land.

Numerous agencies and individuals have compiled and published geologic guidebooks and road logs for Arizona. A bibliography of these can be found in the *Index to Road Logs and River Logs in Arizona,* listed below. The Arizona Bureau of Geology and Mineral Technology (Bureau) has published some road logs; these are also listed and described below.

To simplify location of specific features, road logs often use highway mileposts as reference points. Those published by the Bureau also list mileage between consecutive observation sites. In addition, *Geologic Guidebooks 1* through *4* record mileage for both directions of each route, allowing the user to take the trip in either direction.

Geologic Guidebooks 1 through *4* and *Roadside Geology of Arizona* were designed to satisfy varying degrees of interest, ranging from those of the general public to those of professional earth scientists and engineers who seek regional geologic overviews. These guidebooks can be especially useful to the Arizonan out for an educational Sunday drive or the vacationer who wants more than just scenic photographs. The *Guidebook to the Geology of Central Arizona* and the *Guidebook to Field Trip 15,* which are highly technical and detailed, were designed for use by professional geologists. Nevertheless, they also provide excellent information for the truly interested layperson.

Shipping and handling charges for guidebooks published by the Bureau are as follows:

Amount of Order	Shipping & Handling
$ 1.00 - $ 5.00	$ 1.50
5.01 - 10.00	2.00
10.01 - 20.00	4.00
20.01 - 30.00	4.50
30.01 - 40.00	6.00
40.01 - 50.00	7.50
50.01 - 100.00	10.00

Orders under $1.00, add $.75; over $100, add 10 percent; foreign, add 40 percent. Prepayment is required on all orders. Make check payable to Arizona Bureau of Geology and Mineral Technology (845 N. Park Ave., Tucson, AZ 85719). Orders are shipped UPS. Street address is requested. Please allow up to three weeks for delivery.

Aerial view of Highways U.S. 60 and Arizona 77 crossing the Salt River in Salt River Canyon. View facing east. Photo taken on May 22, 1981. *Geologic Guidebook 2* describes State Highway 77.

PUBLISHED BY THE ARIZONA BUREAU OF GEOLOGY AND MINERAL TECHNOLOGY

Index to Road Logs and River Logs in Arizona, 1950-1980 (Circular 22), J.R. LaVoie and T.G. McGarvin, 1981, 14 p. ($1.50).

This useful reference guide provides a comprehensive list of geologic logs for Arizona's roads and rivers, published by several agencies, including the Bureau. References for 94 road logs and five river logs are organized into major groups according to year of publication. To easily match roads and rivers with their corresponding logs, several maps are included, which show both the routes and the accompanying numbered references in the index. Many of the logs included in Circular 22 are in the Bureau Library and may be examined on the premises during Bureau working hours or photocopied under certain conditions.

Geologic Guidebook 1 — U.S. Highway 666 (Bulletin 174), E.D. Wilson, 1965, 68 p. ($1.50).

This guidebook, and the three listed immediately after it, are ideal for geologists and generalists alike. These portable, "geologist-in-a-pocket" booklets contain useful reference material, such as index and profile maps, geologic time scales, glossaries, and bibliographies.

Geologic Guidebook 1 covers U.S. Highway 666, which extends for some 381 miles through eastern Arizona. Its southern terminus is the Mexican border just south of Douglas. It crosses Cochise, Graham, Greenlee, and Apache Counties, ending its Arizona trek at the New Mexico boundary, east of Lupton. Major towns along the route include Douglas, Willcox, Safford, Clifton, Springerville, and St. Johns. The section of this highway from Clifton to Alpine is part of the Coronado Trail, the route that the Spanish explorer, Francisco Vásquez de Coronado, followed in his search for the Seven Cities of Cibola.

U.S. Highway 666 traverses the two major physiographic provinces in Arizona: the southerly Basin and Range Province and the northerly Colorado Plateau Province, which are separated by a comparatively narrow Transition Zone. From the highway, one can see dramatic contrasts in scenery. A roller-coaster landscape of mountain ranges and broad, plain-like basins ramble through the south, while deep, steep-walled canyons and flat-topped mesas sculpt the land to the north.

U.S. Highway 666 provides views of various industries: farming near Douglas and Safford; cattle raising near Willcox; and mining near Douglas, Clifton, Morenci, and other towns. The highway also passes within a few miles of Stronghold Canyon, the burial site of the famous Chiricahua Apache, Chief Cochise; over the White Mountains, an area of volcanic rocks and cinder cones; and through the Navajo Indian Reservation.

Geologic Guidebook 1 was compiled in 1965 and does not include highway changes made since then.

Geologic Guidebook 2 — Arizona Highways 77 and 177 (Bulletin 176), H.W. Peirce, 1967, 73 p. ($1.25).

State Highway 77 extends some 272 miles, from Oracle Junction on the south to the northern terminus on the Navajo Indian Reservation, about 60 miles north of Holbrook. It passes through or near the towns of Mammoth, Winkelman, Globe, Show Low, Snowflake, and Holbrook, and the trading post of Bidahochi. As the highway crosses from the Basin and Range Province to the Colorado Plateau Province, one can enjoy a kaleidoscope of changing landscapes: the San Pedro Valley; the Gila River Canyon; the Salt River Canyon; the red beds of the Supai Formation; the pine forests of the Fort Apache Indian Reservation and the Sitgreaves National Forest; the Mogollon Rim; the Little Colorado River; and the vast open spaces of the Navajo Indian Reservation, the largest Indian reservation in the country. This guidebook contains a fold-out profile map and cross section along the highway, showing principle rock units, geographic features, and vegetative types.

Various industries can also be seen from State Highway 77: both active and inactive mines near San Manuel and Mammoth, containing copper, gold, silver, and other minerals; copper mines near Christmas; an inactive asbestos mill near Globe and mines in the Salt River Canyon area; a pulp and paper mill near Snowflake; inactive uranium mines on the Navajo Indian Reservation; and numerous ranches, farms, and lumber mills. Several fossil localities can also be found along State Highway 77.

State Highway 177 covers about 32 miles, from Winkelman, where it joins State Highway 77, northwest to Superior, where it joins U.S. Highway 60-70. The highway passes through Hayden, Kearney, and Kelvin. Industries along this route include a copper mill and smelters in Hayden, copper mines in the Mineral Creek District near Ray, and copper mines in the Pioneer Mining District around Superior.

Geologic Guidebook 3 — Arizona Highways 85, 86, and 386 (Bulletin 183), S.B. Keith, 1971, 80 p. ($1.00).

To aid the traveler in identifying desert flora, this guidebook offers an extensive, highly descriptive list of typical Sonoran Desert vegetation. The booklet also gives background information on the culture and history of the Papago Indians, who maintain a reservation through which these routes travel, and whose language has embroidered the names of towns, geographic features, vegetation, and wildlife.

State Highway 85 extends 81 miles from Gila Bend southward, through Ajo and Why, to Lukeville on the Mexican border. The route follows the eastern edge of the hottest and driest, large desert area in the country. This "desert," interestingly, consists of mountains, plateaus, and plains dotted with green vegetation. Points of interest include numerous volcanic mountains, the large open-pit copper mine, mill, and smelter at Ajo, and the Organ Pipe Cactus National Monument.

State Highway 86 extends 120 miles eastward from Why, where it joins State Highway 85, through the Papago Indian Reservation, to its junction with U.S. Highway 89, just south of Tucson. The route provides an excellent overview of the Sonoran Desert, with its expansive desert basins punctuated by rugged mountain ranges.

Towns along the route include Wahak Hotrontk, Quijotoa, Sells, and Robles Junction. Driving this route is like turning the pages of a history book: the traveler passes by deserted ranches, stage stations, and mining camps, as well as inhabited Indian settlements.

State Highway 386, 38 miles west of Tucson, is a short spur off State Highway 86. In 12 miles, it climbs 3,580 feet to Kitt Peak National Observatory at the top of the Quinlan Mountains, offering spectacular views along the way. Kitt Peak, a sacred Papago Indian spot, holds an astronomical museum and numerous telescopes, including the world's largest solar telescope. Some of the installations may be open to the public.

Geologic Guidebook 4 — Arizona Highways 87, 88, and 188 (Bulletin 184), C.F. Royse, M.F. Sheridan, and H.W. Peirce, 1971, 66 p. ($.75).

This guidebook covers a 140-mile scenic loop northeast of Phoenix, defined by portions of three highways: State Highway 88, also known as the Apache Trail, from Apache Junction to Roosevelt Dam; State Highway 188, from Roosevelt Dam to its junction with State Highway 87; and State Highway 87, also called the Beeline Highway, from this junction to the Scottsdale-Mesa area. Although this route is scenic, it is also isolated, passing through a mere handful of villages, such as Tortilla Flat, Roosevelt, Punkin Center, and Sunflower.

Most of the route lies within the Tonto National Forest and is essentially a wilderness area. No industries or large mines exist along the route, nor is farming prevalent. Cattle ranching is common, however.

Numerous mountain ranges, canyons, lakes, creeks, and valleys along the highways await the scenery-starved traveler. The Salt River Project, an extensive system of dams and reservoirs on the Salt River, its tributaries, and several lakes, provides water and power for much of central Arizona. Theodore Roosevelt Dam is the world's highest masonry dam, and its reservoir, Roosevelt Lake, is a major recreational area.

This guidebook includes a concise account of the geologic history of the Tonto Basin and the Superstition volcanic field, both of which can be studied along the route.

Guidebook to the Geology of Central Arizona (Special Paper 2), D.M. Burt and T.L. Péwé, eds., 176 p. ($6.00).

This guidebook, which is not intended for the geologic layperson, is a compilation of technical papers presented at the 74th Cordilleran Section Meeting of the

Geological Society of America. Papers cover various geologic aspects (e.g., stratigraphy, morphology, mineralogy, etc.) of specific locales in central Arizona. A road log, with descriptions based, in part, on the author's own research, accompanies each paper.

Road logs and geologic reports for the following areas are included: (1) the lower Salt River Valley, with accompanying river terraces, between Tempe and Saguaro Lake; (2) the Pinacate volcanic field in northwestern Sonora, Mexico; (3) the White Picacho pegmatite district in Maricopa and Yavapai Counties; (4) the Pike's Peak iron-formation in Maricopa and Yavapai Counties; (5) the active ASARCO Sacaton copper mine near Casa Grande; (6) the Superstition volcanic field along the Apache Trail (State Highway 88); (7) a groundwater recharge project in Phoenix; (8) the Precambrian metavolcanic rocks of Squaw Peak in Phoenix; (9) earth fissures and land subsidence along Hunt Highway, near Chandler Heights; (10) the area surrounding the Palo Verde Nuclear Generating Station, 40 miles west of Phoenix; (11) the Naco Formation along State Highways 87 and 260, highlighted by a trip to the Kohl Ranch locality, one of the most prolific fossil areas in Arizona; (12) Meteor Crater, near Winslow; and (13) the Peridot Mesa Vent in the San Carlos volcanic field near San Carlos.

Guidebook to Field Trip 15, Phoenix—Black Mesa—Page, Arizona (Open-File Report 79-4, H.W. Peirce and W.J. Breed, 1979, 45 p. ($4.50).

Intended for professional and student geologists, this informal guidebook and road log were assembled to accompany a specific two-day field trip. The route covers about 333 miles, not including several possible side trips along the way. The trip provides an overview of the classic Basin and Range Province, the Colorado Plateau Province, and the Transition Zone between the two.

Beginning in Phoenix, the route travels, in sequence: northward on Interstate 17 to Flagstaff; northward on U.S. Highway 89 to its junction with U.S. Highway 160; northeastward on U.S. Highway 160 to the Black Mesa-Kayenta coal-mining complex; backtracking, southwestward on U.S. Highway 160 to its junction with State Highway 98; and northwestward on State Highway 98 to Page.

In addition to the coal-mining complex, the trip includes Arcosante, one architect's "concrete" concept of the community of the future; Humphreys Peak, the highest point in Arizona; Sunset Crater; and the Painted Desert.

Geologic Features of Northeastern Arizona (Fieldnotes, v. 12, no. 1), S.J. Reynolds, 8 p. (Free).

This concise article, which is an excellent overview for the general public, provides a short summary of the geology of northeastern Arizona, followed by descriptions of the best-known features (e.g., Grand Canyon, Monument Valley, Painted Desert—Petrified Forest, Sunset Crater, etc.). Although it includes several maps and photographs, this article is *not* a highway geology guidebook or road log. It is included in this list because it neatly summarizes the geology of the most visited scenic areas in Arizona.

PUBLISHED BY MOUNTAIN PRESS PUBLISHING COMPANY

Roadside Geology of Arizona, H. Chronic, 1983, 314 p. ($9.95).

Written for the inquisitive non-geologist, this lucid book provides geologic overviews of the national parks and monuments within Arizona and areas that flank the State's major highways. An introductory chapter explains the basic concepts of geology and how they apply to Arizona's topography. Geologic jargon is explained within the text and in a separate glossary. Unlike the Bureau guidebooks mentioned above, this book does not describe the geologic setting at specific observation points, nor does it give exact mileage between these points. Instead, it uses obvious geographic landmarks and highway mileposts to locate and describe general geologic features.

Roadside Geology of Arizona is published by Mountain Press Publishing Company (Box 2399, Missoula, MT 59806), and can be purchased directly from the publisher or at various bookstores. It can *not* be purchased from the Bureau, but is included in this list because of its readability and suitability for the general public.

Fieldnotes

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