MINERAL DEPOSITS
of the
FORT APACHE INDIAN RESERVATION,
ARIZONA
by
Richard T. Moore, Geologist

THE ARIZONA BUREAU OF MINES
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THE UNIVERSITY OF ARIZONA
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FOREWORD

This report by Dr. Richard T. Moore, Geologist, Arizona Bureau of Mines, presents the finding of a survey made by the Arizona Bureau of Mines, University of Arizona, for the United States Department of the Interior, Bureau of Indian Affairs.

The basic purpose and essential scope of the work were those of conducting a geological survey of the Fort Apache Indian Reservation of Arizona to ascertain what potentially valuable metallic and non-metallic (industrial) mineral and rock deposits occur within the boundaries of the Reservation.

Permission to publish the findings as a technical bulletin of the Arizona Bureau of Mines kindly has been granted by the United States Department of the Interior, Bureau of Indian Affairs.

J. D. Forrester, Director
Arizona Bureau of Mines
University of Arizona, Tucson
September, 1967

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INTRODUCTION

GENERAL STATEMENT

Scope of Report

The study upon which this report is based was begun in September, 1965, and was undertaken by the Arizona Bureau of Mines to fulfill the conditions of a contract entered into by the Arizona Board of Regents with the Bureau of Indian Affairs, U. S. Department of the Interior.

Under the terms of the contract, the Arizona Bureau of Mines has made an extensive examination of the Fort Apache Indian Reservation with regard to the distribution, geologic occurrence, character, probable extent, and potential economic importance of the various mineral substances that have been found on the Reservation. Although an attempt has been made to estimate the relative importance of the several mineral substances discussed and suggestions are offered for further exploration and development, no attempt has been made to assign tonnage or dollar values to any of the deposits.

Previous Studies

Reconnaissance geologic studies were made of the area now occupied by the Fort Apache Indian Reservation during several of the early geographic explorations of the region. Endlich (1878)* described the geology of the White River district in the Hayden Report, and Gilbert (1875) and Marvine (1875) reported superficially on parts of the Fort Apache region in the Wheeler Reports. The first comprehensive report on the geology and natural resources of the Fort Apache region, however, was that prepared by Reagan (1903).

In more recent years, numerous papers have been published on many specialized aspects of the geology and mineral resources of the Fort Apache Indian Reservation. Some of the more comprehensive articles include the stratigraphic studies of Huddle and Dobrovolny (1945, 1952), Shride (1961), and Winters (1963); the asbestos studies of Stewart (1955, 1956) and Wilson (1928); and the work on the Apache Iron deposits by Burchard (1930), Harrer (1964), and Stewart (1947).

*See list of literature cited, page 83.
An extensive bibliography of the literature concerning the geology and mineral resources of the Fort Apache Indian Reservation is contained in the section titled LITERATURE CITED.

**Acknowledgments**

During the course of this investigation, all members of the Arizona Bureau of Mines staff have contributed their efforts, both in the field and in the laboratory, toward making this report as complete as possible.

Mr. Robert E. Robinson, Superintendent of the Fort Apache Indian Reservation, was most cooperative during the study and gave generously of his time and the facilities of his office. Mrs. Eileen Rolfe and Mr. Hal Booher, also of the Bureau of Indian Affairs staff at Whiteriver, spent several days assisting in the review of mining-claim and lease data, and Mr. James Stevens, of the Reservation Highway Department, made copies of the Reservation highway base maps available for field use.

Dr. John N. Faick, Consulting Geologist, reviewed and abstracted much of the literature on the geology of the Reservation.

Appreciation is due Mr. James R. Brooks, Geologist, CF&I Steel Corp. and Mr. R. J. Allison, Consulting Geologist, both of whom contributed from their specialized knowledge of the iron deposits on and near the Reservation.

The contributions of Mr. Jay C. Dotson, Professor of Mining Engineering, College of Mines, University of Arizona, who engaged in the study of the iron resources of the Reservation and collected samples of several commodities for laboratory study, are recognized.

**PHYSICAL FEATURES**

**Location and Extent**

The Fort Apache Indian Reservation consists of approximately 1,681,000 acres in east-central Arizona. It extends from the Mogollon Rim, south to the Black and Salt Rivers, and from the crest of the White Mountains, west to near the longitude of the Navajo County-Coconino County boundary. (See Fig. 1.) It includes parts of Apache, Gila, and Navajo Counties. In an east-west direction it measures approximately 113 miles and from north to south it has a maximum extent of 70 miles.

**History of Establishment**

The Fort Apache Indian Reservation is the official "home" of the White Mountain Apache Tribe and occupies the northern part of a tract of some 5,000,000 acres in east-central Arizona which was established in 1870, by the War Department, as a reservation for several tribes of Apache Indians. This tract has been known both as the "White Mountain Apache Reservation" and as the "Apache Indian Reservation."

Two important executive orders issued by President Ulysses S. Grant relate to the Reservation. The first, on November 9, 1871, formally established the White Mountain Apache Reservation, essentially as outlined by the War Department, and the second, on December 18, 1872, established the "San Carlos Indian Reservation" from that portion of the White Mountain Indian Reservation lying south of the Salt and Black Rivers.

By Act of Congress of June 30, 1919, certain unallotted lands on Indian Reservations in Arizona were thrown open to prospecting for metalliferous minerals, and deposits so found became subject to claim and lease.
By Act of Congress of March 3, 1921, on and after twelve o'clock noon, on April 15, 1921, all lands opened under Sec. 26 of the Act of 1919 also became subject to exploration for deposits of magnesite, gypsum, limestone, and asbestos, and these could then be claimed and leased under the same terms as metallic minerals.

In the years following the 1872 Executive Order, considerable confusion arose concerning the correct names of the two reservations, and this was of real concern to the prospectors and miners who were interested in negotiating leases.

Thus, in October, 1928, the Commissioner of Indian Affairs was prompted to write letters of clarification which stated, in part, "The northern part [of the White Mountain Indian Reservation] was designated as the Fort Apache Indian Reservation and the southern as the San Carlos Indian Reservation. These are the proper designations."

In the years following the opening of the Indian lands to mineral location, both the procedures for obtaining leases and the lease terms have varied for lands on the Fort Apache Indian Reservation, and, therefore, anyone wishing to claim and lease mineral lands on the Reservation should apply for current information to either the Area Director, Bureau of Indian Affairs, Phoenix, Arizona, or to the Superintendent, Fort Apache Agency, Whiteriver, Arizona.

**Topography and Physiography**

The broad topographic relations on the Reservation are shown on Plate 1. In general, the land surface slopes to the south and southwest and the relief is rather high, exceeding 8,800 feet. Elevations range from a high of 11,590 feet above sea level on Baldy Peak, near the east boundary of the Reservation, to a low of near 2,700 feet above sea level where Salt River leaves the Reservation on the west.

A detailed discussion of the topography of the Reservation is beyond the scope of this report. A major part of the area, however, is depicted on large-scale topographic quadrangle maps which are available from the U. S. Geological Survey. The names and locations of the pertinent map sheets are shown on Figure 2. Additionally, a large-scale aerial-photographic survey of the Reservation was made by Hammon, Jensen, and Wallen Mapping Services, under contract for the Bureau of Indian Affairs. As a result of that survey, a set of detailed planimetric maps, having a scale of 4 inches equals 1 mile, was produced. Information on the availability of both the maps and the photographs can be secured from the Area Director, Bureau of Indian Affairs, Phoenix, Arizona.

On a regional scale, the Fort Apache Indian Reservation extends into two major physiographic provinces (Fig. 3). The western three-quarters of the area lies in the Transition Zone (Wilson and Moore, 1959) and the eastern one-quarter is in the Plateau province. The Plateau province also borders the western portion of the Reservation along its northern boundary, the Mogollon Rim.
In a more restricted view, four physiographic sub-provinces can be defined, on the basis of local landforms. (See Fig. 4.)

West of the White River and Arizona Highway 73, a badlands topography has been incised into a south-southwest facing slope, here referred to as the Carrizo Slope. It extends from the Mogollon Rim, south to near Salt River. The numerous canyons which cut this slope have been carved by generally south-flowing streams but locally, as in the case of southeast-flowing Carrizo Creek, major exceptions are present as the result of geologic structural complexities. The surface of the slope is also...
modified locally by the presence of cliffs and benches which have resulted from differential erosion controlled by differences in hardness of the rock layers upon which the slope is carved. The harder sandstone and limestone layers, because they are more resistant to erosion, form the caps of benches, and the cliffs that mark the edges of mesas; they protect the softer, more easily eroded silty and shaly layers which form the concave slopes, beneath the benches.

South and west of the Carrizo Slope, a second sub-province is defined by the deep canyons of Salt River, Canyon Creek, and the lower portions of their tributary canyons. This sub-province is referred to as the Canyon Creek-Salt River Canyon area on Figure 4.

East of State Highway 73 and a line connecting Seven Mile Canyon with Poker Mountain, large volumes of volcanic rock in the form of flows and pyroclastic material have been extruded and piled up to form the White Mountains, which culminate at Baldy Peak. The third sub-province embraces this alpine terrain and is designated the White Mountain area.

The fourth sub-province lies south of White River and west of the line between Seven Mile Canyon and Poker Mountain. Here the surface is a gently rolling plain floored by basalt flows which extend far to the south, into the San Carlos Reservation. The surface is only slightly dissected, with the deeper channels being restricted to the area immediately bordering Black River. Locally, the area is referred to as Bonito Prairie, and appropriately, that name is here applied to the physiographic sub-province (Fig. 4.)

Climate and Vegetation

Climatic conditions vary markedly in different parts of the Reservation. In the vicinity of Salt River, summer temperatures and humidity are relatively high and winters are mild. In the central reaches of the Reservation, as for example, near Cibecue, summers are mild and the winters are on the chilly side. In the northeastern part of the Reservation, in the White Mountains, cool summers and very cold winters are characteristic, and minimum temperatures near -50°F have probably occurred on Mount Baldy.

The data in Tables 1 and 2 have been abstracted from Sellars (1964), and are representative of the precipitation and temperature ranges that can be anticipated for various parts of the Reservation.

The distribution of vegetational types, as might be expected, is linked closely to the variations in climate, which in turn are related, at least in part, to the variations in topography encountered on the Reservation. In the lower regions, along the Salt and Black Rivers and in the valleys and canyons tributary to Salt River, chaparral and oak woodlands predominate. Palo verde, mesquite, acacia, creosote bush and mesquite grass, and various types of cacti are common to this region. At somewhat higher elevations, as in the vicinity of Cibecue and of Cedar Creek, pinyon and juniper occur extensively, intermingled with scrub varieties of oak and various types of grass. At still higher elevations, as along the northern border of the Reservation and in the White Mountains, ponderosa pine and several varieties of spruce make up the bulk of the vegetation, although grassy, alpine meadows and extensive stands of aspen are also common.

Markets, Transportation, and Power Facilities

Both the distance to market and the related factor, availability and nature of transportation facilities, must be considered when evaluating the mineral resources of an area. The location of the Fort Apache Indian Reservation with respect to important railheads and major highways is shown on Figure 5. Rail distances from Globe and Holbrook to various potential markets are given in Table 3.

The Reservation road-net is shown on Figure 6. Globe and Holbrook, both, are connected with the Reservation by hard-surface, all-weather highways and the mileages to various points on the Reservation are

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**Table 1. Precipitation Data for Selected Stations**

<table>
<thead>
<tr>
<th>STATION</th>
<th>PRECIPITATION TOTALS (inches)</th>
</tr>
</thead>
<tbody>
<tr>
<td>NO.</td>
<td>NAME</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Cibecue</td>
</tr>
<tr>
<td>2</td>
<td>McNary</td>
</tr>
<tr>
<td>3</td>
<td>Springerville</td>
</tr>
<tr>
<td>4</td>
<td>Whiteriver</td>
</tr>
<tr>
<td>5</td>
<td>Young</td>
</tr>
</tbody>
</table>

**Table 2. Temperature means and extremes (°F)**

<table>
<thead>
<tr>
<th>STATION NO.</th>
<th>ELEV. (feet)</th>
<th>MEAN VALUES (°F)</th>
<th>EXTREME HIGH</th>
<th>MEAN OF DAYS ABOVE 90°</th>
<th>MIN. BELOW 2°</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>DAILY MAX. MIN.</td>
<td>ANNUAL</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>5300</td>
<td>72.2</td>
<td>36.3</td>
<td>54.2</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>7320</td>
<td>62.3</td>
<td>30.8</td>
<td>46.5</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>6964</td>
<td>65.8</td>
<td>31.5</td>
<td>48.7</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>5280</td>
<td>72.2</td>
<td>37.2</td>
<td>54.8</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>5050</td>
<td>79.3</td>
<td>36.2</td>
<td>57.8</td>
<td></td>
</tr>
</tbody>
</table>

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shown on the Mileage Chart (Fig. 6). Also, rail transportation is available between Holbrook and McNary on the lines of the Apache Railroad. The rail distance is approximately 72 miles.

Table 3. Representative rail distances from Globe and Holbrook (in miles)

<table>
<thead>
<tr>
<th>Location</th>
<th>Globe</th>
<th>Holbrook</th>
</tr>
</thead>
<tbody>
<tr>
<td>Albuquerque, New Mexico</td>
<td>—</td>
<td>257</td>
</tr>
<tr>
<td>Amarillo, Texas</td>
<td>—</td>
<td>565</td>
</tr>
<tr>
<td>Denver, Colorado</td>
<td>—</td>
<td>781</td>
</tr>
<tr>
<td>El Paso, Texas</td>
<td>322</td>
<td>462</td>
</tr>
<tr>
<td>Gallup, New Mexico</td>
<td>—</td>
<td>96</td>
</tr>
<tr>
<td>Los Angeles, California</td>
<td>733</td>
<td>640</td>
</tr>
<tr>
<td>Phoenix, Arizona</td>
<td>361</td>
<td>343</td>
</tr>
<tr>
<td>San Diego, California</td>
<td>748</td>
<td>—</td>
</tr>
<tr>
<td>San Francisco, California</td>
<td>—</td>
<td>937</td>
</tr>
<tr>
<td>Santa Fe, New Mexico</td>
<td>—</td>
<td>348</td>
</tr>
<tr>
<td>Tucson, Arizona</td>
<td>237</td>
<td>467</td>
</tr>
<tr>
<td>Yuma, Arizona</td>
<td>488</td>
<td>—</td>
</tr>
</tbody>
</table>

23,000 volts. This system is served by a 69,000-volt line from Holbrook to McNary and a 7.9 megawatt steam generating plant at McNary.

Natural gas service extends by pipe line to both Globe and Holbrook. Globe is served by 6½ and 8½ inch lines, and Holbrook by a 4½ inch line.

GENERAL GEOLOGY

Rock Units

Rocks ranging in age from Older Precambrian through Quaternary are present on the Fort Apache Indian Reservation. Not all of the units recognized, however, necessarily occur at the same localities and the distribution of the several units, or formations, is depicted on Plate 2. The formations are listed with a brief characterization of their lithology and range of thickness in Table 4. More detailed descriptions of the formations, where germane to a knowledge of the mineral resources of the Reservation, are included with the pertinent areal descriptions.

Structure

DEVELOPMENT

The geologic environment of any area is a reflection of the sum of all its geologic history. The broad relations of the sequence of events that have occurred in Arizona are shown in Table 5.

Certainly, not all of these events were centered near the Reservation, and thus, they are not necessarily recorded on the Fort Apache Indian Reservation through their primary effects. For example, no intrusive rocks associated with the Laramide Revolution have been found on the Reservation, nor are the thrust faults and tight folds that are found in southern Arizona, and are considered by many geologists as characteristic of that
Figure 6. Highway system and mileage chart for Fort Apache Indian Reservation, Arizona.
orogeny, common to the Reservation. The passage of many of the events 
is recorded on the Reservation, however, by their secondary effects, such 
as the effect they have had on the type of sediments deposited, and even 
as to whether sedimentation or erosion would be the dominant process 
at a given time. Also, areas on the fringe of a structurally disturbed region 
will be affected, even if slightly, by folding and faulting, and such is the 
side with the area of the Fort Apache Indian Reservation.

FOLDS
During Older Precambrian time, the rocks that now form the base- 
ment complex of the Fort Apache Indian Reservation were tightly folded 
and squeezed, intruded by granitic rocks, and metamorphosed to schist 
and greenstone. During the latter part of the Younger Precambrian Era, 
additional folding and warping distorted the Troy Quartzite and older 
units. The results of this disturbance can be seen in the tilted Precambrian 
rocks in Chediski Ridge, a prominence on the Precambrian terrane that 
passes under Paleozoic sedimentary rocks along the west flank of Canyon 
Creek.

During most of Paleozoic time, the area in the vicinity of the Reser­
vation was essentially stable, with only gentle, intermittent uplift and 
downwarping. After the close of the Paleozoic Era, perhaps during 
the Laramide diastrophic interval, sharp local folding again occurred, as 
exemplified by the monoclinal flexure in upper Canyon Creek and by the 
northwest-trending folds near Carrizo Creek. (See Plate 2.)

FAULTS
Extensive faulting occurred during Younger Precambrian time, either 
accompanying, or immediately preceding the intrusion of diabase. As a 
result, the diabase commonly occupies portions of the fault planes.

A much later episode of faulting is recorded in Canyon Creek and 
in Carrizo Creek, where Paleozoic rocks have been displaced. In Carrizo 
Creek, several faults crop out, striking approximately S.50°E. and can 
be traced intermittently along strike, to near Amos Wash. (See Plate 2.) 
In Canyon Creek, the main fault strikes nearly north-south, and can be 
traced for over 40 miles along strike.

MINERAL COMMODITIES

General Statement
The mineral commodities occurring on the Fort Apache Indian 
Reservation include both metalliferous and nonmetalliferous varietics, 
and mineral fuels. Among the substances which have been most actively 
sought in past years are asbestos, iron, manganese, and, during the 1950's, 
uranium. In addition to these commodities, large reserves of nonmetalli- 
erous materials of value in the construction industry are available on

| Table 4. Correlation of rock units on the Fort Apache Indian Reservation |
|-----------------|--------------------------|-----------------|
| ERAS            | PERIODS AND EPOCHS | FORMATION | GENERAL CHARACTER AND APPROXIMATE THICKNESS (IN FEET) |
| CENOZOIC        | Quaternary          | Alluvial clay, sand, and gravel 0-100+ Basalt flows, agglomerate, and interbedded gravels 2000+ |
|                 | Tertiary            | “Rim Gravel”* | Sand and gravel 1000+ |
| MESOZOIC        | Cretaceous          | Sandstone, limestone, and shale; minor coal 0-150 |
|                 | Permian             | Kaibab      | Limestone and sandstone 0-100 |
|                 | Permian             | Coconino(?) | Sandstone 0-200 |
|                 | Permian             | Supai       | Siltstone, sandstone, and limestone 1500 |
|                 | Permian             | Naco        | Limestone and shale 400-800 |
|                 | Mississippian       | Redwall     | Limestone 30-300 |
|                 | Mississippian       | Martin      | Limestone, sandstone, and shale 50-400 |
|                 | Cambrian(?)         | Tapeats(?)  | Sandstone 0-30 |
|                 | Cambrian(?)         | Unconformity | Arcosic sandstone and quartzite 20-300 |
|                 | Cambrian(?)         | Troy        | Dolomite, limestone, and siltstone 300-500 |
|                 | Younger             | Mescal      | Arcosic siltstone and sandstone 300-700 |
|                 | Younger             | Dripping Spring | Siltstone and mudstone 100-400 |
|                 | Younger             | Pioneer     | Angular discordance |
|                 | Younger             | Pioneer     | Granitic rocks; schist and greenstone |

*Name used locally but having no official standing.
Table 5. Sequence of geologic events in Arizona

<table>
<thead>
<tr>
<th>ERAS</th>
<th>PERIODS AND EPOCHS</th>
<th>MILLIONS OF YEARS AGO</th>
<th>MAJOR EVENTS IN GEOLOGIC HISTORY</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Recent, Pleistocene, Clastic sedimentation; volcanism</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1</td>
<td>Block faulting</td>
</tr>
<tr>
<td></td>
<td>Recent, Pleistocene</td>
<td>1</td>
<td>Block faulting</td>
</tr>
<tr>
<td></td>
<td>Pliocene</td>
<td>1</td>
<td>Block faulting</td>
</tr>
<tr>
<td></td>
<td>Miocene</td>
<td>1</td>
<td>Laramide Revolution: Folding and faulting; granitic intrusion; mineralization; volcanism</td>
</tr>
<tr>
<td></td>
<td>Oligocene</td>
<td>70</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Eocene</td>
<td>225</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Late Cretaceous</td>
<td>225</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Early Cretaceous</td>
<td>225</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Jurassic</td>
<td>225</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Triassic</td>
<td>225</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Permian</td>
<td>225</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Pennsylvanian</td>
<td>225</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Mississippian</td>
<td>225</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Devonian</td>
<td>225</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Silurian</td>
<td>225</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Ordovician</td>
<td>225</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Cambrian</td>
<td>225</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Younger Precambrian</td>
<td>600</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>1200</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Older Precambrian</td>
<td>600</td>
<td></td>
</tr>
</tbody>
</table>

the Reservation, and, as the economy and population of the State increase, a growing market for these items can be expected. The commodities studied during this investigation are listed below, and a brief statement on their occurrence is given. Detailed discussions with relative evaluations of each commodity are given in the section titled AREAL DESCRIPTIONS.

**Metalliferous Varieties**

**IRON**

Mineralization of apparent commercial importance occurs in Younger Precambrian rocks cropping out in upper Canyon Creek.

**MANGANESE**

Manganiferous veins and replacements occur in Cenozoic conglomerate in lower Canyon Creek, and as replacements and residual deposits, associated with Kaibab Limestone, near the Mogollon Rim.

**GOLD**

Lode gold occurs in very minor amounts in quartz veins near Canyon Creek. Placer gold reportedly occurs in gravels capping Cibecue Ridge, and in stream gravels in Diamond Creek, White Mountains.

**SILVER**

Small amounts of silver are contained in the manganese deposits in lower Canyon Creek.

**COPPER**

More or less copper is found in several localities on the Reservation. It is found in association with the manganese and the iron, in quantities up to a few tenths of one per cent, and in minor quantities in the Supai Formation throughout several square miles.

**COBALT**

Cobalt has been reported from Salt River Canyon, but the occurrence was not confirmed during this study.

**URANIUM**

Several radioactive anomalies were discovered in 1954 and traces of uranium mineralization have been found in lower Canyon Creek.

**ZINC**

Zinc has been reported from Salt River Canyon, but the occurrence was not confirmed during this study.

**Nonmetalliferous Varieties**

**ASBESTOS**

Numerous deposits of asbestos occur in Salt River Canyon, in the Mescal Formation, and commercial-quality fiber still can be obtained from many of them.
GYPSUM
Large reserves of gypsum occur on the Reservation, in the Supai Formation, near main transportation routes.

LIMESTONE
Limestone in large quantities is widely distributed on the Reservation. Much of it is suitable for the manufacture of cement and lime.

BUILDING STONE
Sandstone is available as flagstone and blocks from several localities, and marble and serpentine are available, in limited quantities, in Salt River Canyon.

SAND AND GRAVEL
Large reserves of sand and gravel are widespread on the Reservation and have been exploited to a minor degree in road construction.

SILICA
Silica-sand occurs in large quantities near the north boundary of the Reservation on U. S. Highway 60.

CLAY AND SHALE
Clay and shale suitable for adobe and common brick are present in parts of the Cretaceous rock occurrences.

CINDERS
Large quantities of cinders are located in the northeastern part of the Reservation. These have been used for road metal and railroad ballast. Other possible uses include light-weight aggregate and soil conditioning agents.

SALT
Moderate quantities of salt are being deposited by springs at Salt Banks. These have a potential local usage as a livestock supplement.

TURQUOISE
Small quantities of turquoise occur in the Dripping Spring Quartzite, in lower Canyon Creek.

DECORATIVE AND NOVELTY MATERIALS
Materials suitable for use in the production of novelty items, such as costume jewelry and book ends, include travertine, serpentine, and jasper.

Mineral Fuels

COAL
Low-grade lignite and bituminous coal occur in thin-beds in the Cretaceous rocks.

OIL AND GAS
A potential for oil and gas production from the Reservation appears to exist, but it has not been proved as yet.

AREAL DESCRIPTIONS

CANYON CREEK-SALT RIVER CANYON AREA

Location and Topography

The Canyon Creek-Salt River Canyon area comprises an "L"-shaped strip, up to 9 miles in width, which extends south along Canyon Creek, between the west boundary of the Reservation and the contact which occurs between the Paleozoic and Precambrian rocks near the top of the scarp east of Canyon Creek, from the Mogollon Rim to Salt River, and thence east, along Salt River Canyon, to the near the junction of Carrizo Creek with Salt River (Fig. 7).

Relief in the area is steep (Plate 1), and ranges from about 6,000 feet at the top of the escarpment east of Canyon Creek, to less than 2,700 feet at Salt River. Numerous side canyons are tributary to both Canyon Creek and to Salt River and these cause the north boundary of the area, along Salt River, to be quite sinuous.

Historically, the Canyon Creek-Salt River Canyon area has been the most important part of the Reservation from the standpoint of commercial mineral production and mineral prospecting. The more important mineral commodities found in this area include asbestos, iron, and manganese.

Rock Units

OLDER PRECAMBRIAN
The oldest rocks cropping out on the Fort Apache Indian Reservation, as shown in Table 4, are Older Precambrian granitic and related crystalline, intrusive, igneous rocks, and a greenschist-metadiorite complex which developed through the metamorphism of a sequence of ancient sedimentary and volcanic rocks.

Although exposed only in the Canyon Creek-Salt River Canyon area (as far as the Reservation is concerned), similar rocks are presumed to underlie the entire Reservation.
Figure 7. Map showing limits of areas described.
**Greenstone and metadiorite.** Exposures of these rock types are limited to several small outcrops near Medicine Butte, where they occur as intimately mixed complexes of very finely crystalline greenstone and "injection" masses of medium- to fine-grained metadiorite. The greenstone consists predominantly of fine-grained chlorite and ferromagnesian minerals intermixed with minor quantities of plagioclase feldspar. The metadiorite, which occurs both as pod-like lenses, and as swirled masses in the greenstone, is composed of approximately 75 per cent plagioclase feldspar and 25 per cent of a dark ferromagnesian mineral which probably is hornblende.

This unit is tentatively correlated with the Pinal Schist, an Older Precambrian metamorphic rock, which occurs extensively in southern and east-central Arizona.

**Granite.** A coarse- to medium-grained granite, tentatively correlated with the Ruin Granite which occurs near Globe, Arizona, is extensively exposed in lower Canyon Creek. It is composed essentially of nearly equidimensional grains of quartz and feldspar with lesser amounts of biotite. Along steeper parts of the canyons, this granite weathers to smooth, well-rounded, hard, boulder masses which are defined by a persistent pattern of joints. On flatter surfaces, weathering has produced a cover of soft, pulverulent, disintegrated granite which ranges up to several feet in thickness. On fresh, hard surfaces, the granite is light gray in color. In those areas containing an appreciable cover of disintegrated material, the predominant colors are light brown to reddish brown.

**Younger Precambrian**

Immediately overlying the Older Precambrian crystalline rocks are sedimentary rocks of Younger Precambrian age (Table 4; Plate 2). The lowermost of these is the Apache Group which has a total thickness of as much as 1,400 feet and consists of, in ascending order, the Pioneer Shale, Dripping Spring Quartzite, and Mescal Limestone. Lying unconformably upon the Apache Group is the Troy Quartzite. The youngest of the Precambrian rocks exposed on the Fort Apache Indian Reservation is intrusive diabase which extensively invaded the entire series of older rocks.

The following formational descriptions conform closely with the divisions established by Shride (1961) but only those features characteristic of the various formations as they occur on the Reservation are discussed.

**Pioneer Shale.** The Pioneer Shale consists of from 100 to 400 feet of grayish-red siltstone and silty mudstone that commonly includes abundant grains of fine sand. The Scanlon Conglomerate, which varies from 1 to 8 feet in thickness, lies at the base of the siltstone series. Formerly, the

Scanlon was considered to be a separate formation (Ransome, 1903), but it is now considered to be the basal conglomerate of the Pioneer Shale.

On the Fort Apache Indian Reservation, exposures of the Pioneer Shale are limited to the lower Canyon Creek area, where it crops out at the base of the cliff extending north from Mustang Ridge to Willow Creek.

**Dripping Spring Quartzite.** This formation, which lies disconformably on the Pioneer Shale, consists of three members, all of which are feldspar-rich rocks of clastic, sedimentary origin. Total thickness of the Dripping Spring Quartzite ranges from approximately 300 feet to slightly more than 700 feet.

The basal unit, the Barnes Conglomerate, is commonly between 5 and 20 feet thick, and is composed largely of well-rounded, quartzose pebbles and cobbles in a medium- to coarse-grained, feldspar-rich matrix. As in the case of the Scanlon Conglomerate, the Barnes Conglomerate was originally defined as a separate formation (Ransome, 1903). As currently defined (Shride, 1961), however, it is considered to be the basal conglomerate of the Dripping Spring Formation.

The middle unit typically consists of from about 140 feet to nearly 370 feet of thin- to thick-bedded, massive, flesh-colored, feldspar-rich sandstone or orthoquartzite.

The upper unit of the Dripping Spring Quartzite is a thinly stratified, dark-colored, dense, arkosic siltstone, intercalated with minor units of thin-bedded, fine-grained quartzite and arkose. Abundant scour-and-fill structures occur in the silty strata and they commonly attain dimensions of between 20 and 100 feet. The entire upper unit ranges in thickness from about 180 feet to nearly 400 feet.

**Mescal Limestone.** The Mescal Limestone, like the Dripping Spring Quartzite, which lies unconformably upon which it unconformably lies, also is divisible into three members. These are a lower, thin- to medium-bedded, flat-bedded unit consisting of interbedded dolomite and limestone; a middle, massive dolomitic limestone member that includes spheroidal structures that have a concentric, shell- or saucer-like form and that have been interpreted as relics of algae colonies; and an upper member which consists of thin-bedded, fine-grained quartzite and arkose. Abundant scour-and-fill structures occur in the silty strata and they commonly attain dimensions of between 20 and 100 feet. The entire upper unit ranges in thickness from about 180 feet to nearly 400 feet.
The middle, or algal member, because of the distinctive, saucer-like structures that it contains, is the most easily recognized of the three members, and is nearly as extensive in outcrop as the lower member. It, too, is exposed along much of the length of Canyon Creek and can be traced to the east, along Salt River Canyon, to within 3 or 4 miles of the Stansbury property.

The upper member is not nearly as extensive on the Reservation as are the lower two units. In many areas, as in Salt River Canyon east of the Highway 60 bridge and in the upper reaches of Canyon Creek, the upper unit was completely removed prior to the deposition of overlying formations. In some places, Troy Quartzite rests on beds in the algal member and in others, Devonian Martin Formation is in depositional contact with beds in the basal member.

**Troy Quartzite.** Shride (1961) recognizes three units in the Troy Quartzite and all three are present in the Canyon Creek-Salt River Canyon area. However, all are not necessarily present in the same localities.

Two factors are responsible for this inconsistency in the distribution of the three units. One cause is the fact that the rocks of the underlying Apache Group were warped, and in places deeply eroded, prior to the deposition of the Troy Quartzite; thus, the basal unit of the Troy was not deposited everywhere. As a result of post-Troy warping and differential erosion, the upper member locally has been removed and this constitutes the second factor.

The basal member of the Troy Quartzite is a fine- to medium-grained, firmly cemented arkose, generally having a pale red to grayish-red color. The component strata are conspicuously cross-bedded on a large scale. The unit varies greatly in thickness over relatively short distances — it crops out as a conspicuous cliff in Rock Canyon, 3 or 4 miles east of Canyon Creek, but apparently wedges out to the north, within 4 or 5 miles.

The middle, or Chediski Sandstone member of the Troy was originally named by Burchard (1930) because of its prominent outcrop on Chediski Mountain (Plate 1). Shride (1961), however, has extended the use of the name to apply to the entire middle member.

In the upper reaches of Canyon Creek, where the Chediski Sandstone rests on the Mescal Limestone, it ranges from 20 to 270 feet in thickness and is composed of subrounded to well-rounded, poorly sorted, pitted and frosted quartz grains which vary from fine to very coarse in size. In the fine-grained portions, the matrix, which consists of sericite and white clay, forms an appreciable part of the rock. As the grain size increases, however, the amount of matrix material decreases. The upper 1/3 of the unit is a coarse-grained sericitic sandstone which is cross-bedded on a medium to large scale and frequently displays graded-bedding in individual cross-laminae.

East of Canyon Creek, the unit becomes dominantly quartzitic, although the typical, light-colored, friable sandstone can be recognized as far east as the lower reaches of Cibecue Creek.

The upper member of the Troy Quartzite, which is present only sporadically on the Reservation, is a medium-grained quartzite, generally light gray to pale red, or grayish red-purple in color. It is cross-bedded on a small to medium scale. Flaggy to slabbly partings are conspicuous in the upper member.

**Diabase.** The youngest Precambrian unit recognized on the Reservation is diabase which occurs as sills and, less commonly, as dikes. It is intrusive into all the pre-existing rocks exposed in the area but is most abundant in the Mescal Limestone.

The relations between multiple sills, discordant sills, and cross-cutting dikes suggest that there were as many as three stages of diabasic intrusion.

The volume of diabasic material injected is appreciable and is about equivalent to the volume of the Younger Precambrian sedimentary rocks deposited in the area.

In general, the diabase is a dark-colored, fine- to coarse-grained, crystalline rock, but both aplite and pegmatitic varieties are recognized, and in some areas, large, granitic differentiates have been implanted. Radiometric age determinations have been made on suitable minerals in the granitic fractions (Silver, 1960) and these indicate a probable age for the diabase of 1,200 million years.

**CENOZOIC**

In the southwestern part of the Reservation, extending from Medicine Butte to Mustang Ridge, coarse conglomerate of Quaternary and/or Tertiary age rests on an erosion surface of moderate relief that was cut on the Older Precambrian basement rocks.

In most exposures examined, the conglomerate is moderately well-indurated and consists of poorly sorted pebbles, cobbles, and boulders in a sand and silt matrix. The composition of the gravel is varied although fragments of Precambrian granite and quartzite predominate. A basalt flow and associated tuffaceous materials are locally prominent in the upper part of the conglomerate.

Gravels and conglomerates with associated volcanic flows that are related to the conglomerate at Medicine Butte occur discontinuously up Canyon Creek to at least as far as its confluence with Ellison Creek. As this unit is traced to the north, however, the size of the gravel fragments tends to decrease.
Quaternary sand and gravel along stream channels, and recent alluvium near Gleason Flat are representative of the youngest deposits in the area.

**Structure**

**FAULTING**

The major structural feature in the Canyon Creek-Salt River Canyon area is the Canyon Creek fault zone which extends, on strike, for over 40 miles. It can be traced from its northern end, near Chediski Farms, south to Salt River, and thence beyond the southern limits of the Reservation for several more miles.

Evidence for two distinct periods of movement, with opposite sense, has been cited for the Canyon Creek fault (Finnell, 1962). The early movement relatively raised beds of Pennsylvania age in the west block as much as 1,800 feet, and the later movement raised (relatively) Cenozoic rocks in the east block nearly 1,300 feet. The net displacement (stratigraphic throw in the rocks of Pennsylvania age) varies from about 800 feet near Chediski Farms to approximately 500 feet near Cliff House Canyon.

Between Chediski Farms and Willow Creek, the fault is essentially a single break striking N.10°W. and dipping nearly vertical. South of Willow Creek, the displacement is distributed across a zone which also strikes approximately N.10°W. but in which the individual faults are of two sets. In the first set, the faults strike N.15°E. and dip 80°-85°E. This set lies in an en-echelon pattern and offsets faults of the second set which strike N.5°W. and dip 80°W.

The first episode of movement is obviously post-Pennsylvania in age and may be even younger, although older than the Cenozoic rocks disrupted during the second period. The second period of movement is younger than the Cenozoic rocks and probably is related to the Basin-Range period of block faulting.

Numerous faults of lesser extent occur in rocks of the Apache Group that crop out in Canyon Creek. These faults strike generally east-west and have displacements that range from a few feet to more than 300 feet. They appear to be related to the intrusion of Precambrian diabase which is thought to have forcibly dilated the Apache Group by as much as 100 per cent.

Low-angle, reverse faults occur locally in the Mescal Limestone. These are particularly prevalent near the asbestos deposits.

A fracture system occurs in the Cenozoic gravels, near Medicine Butte which consists of two sets of fractures, one striking N.10°W., and the second striking N.35°E. Both sets have steep to vertical dips. A third fracture set, which cuts the Older Precambrian basement rocks in the vicinity of Medicine Butte, but was not traceable into the overlying gravels, strikes N.50°W. and has steep to vertical dips.

**FOLDING**

As mentioned in the discussion of the Troy Quartzite, regional warping, which resulted in some local, sharp flexures, took place during at least two periods prior to the start of the Paleozoic Era. The results of those episodes are shown in their effect on the deposition of the Troy Quartzite.

More obvious than the Younger Precambrian warping, however, is the flexing which formed the monoclinal fold at the north end of Canyon Creek fault. North of Chediski Farms, Canyon Creek fault passes into a monocline on which the east side is relatively downwarped and the stratigraphic throw is about 600 feet (Finnell, 1962). Farther north, the displacement decreases, in part being taken up along east-west faults, and in part being dissipated in the thick sequence of sediments occurring at the Mogollon Rim.

**Metalliferous Mineral Deposits**

Several metals are known to occur, or have been reported to exist, in the Canyon Creek-Salt River Canyon area of the Fort Apache Indian Reservation. These include cobalt, copper, gold, iron, manganese, silver, uranium, and zinc. Of this group, iron and manganese are potentially of greatest economic importance; followed in order by uranium, silver, gold, and copper. The occurrence of cobalt and zinc was not confirmed during the study.

**IRON**

*Based, in part, on a report by Jay C. Dotson, Professor of Mining Engineering, College of Mines, University of Arizona.

LOCATION AND EXTENT. Iron deposits, principally hematite, occur in the far western part of the Reservation along upper Canyon Creek and its tributaries. The better deposits are exposed in a belt extending in width approximately one mile on either side of Canyon Creek, and in length from the Mogollon Rim, south to the line between Navajo and Gila Counties. Only small, isolated exposures have been observed on the Reservation outside this belt. Deposits similar in character to the better deposits on the Reservation, however, occur some three miles west of the Reservation.

According to Harrer (1964), the Canyon Creek iron deposits are part of an iron-rich region in east-central Arizona which is perhaps 36 miles wide and over 90 miles long, extending from Globe, north-northwest to beyond Young.

**History.** Hematite deposits, with their reddish brown, sometimes bright coloration, are rather conspicuous, and those in Canyon Creek, even
though remote, have been known since an early date. Records indicate that the deposits were noted in the 1890's by H. S. Colcord, who, with others, returned to the area in the early 1920's and made several lode locations (Stewart, 1947). However, the Indian Agency states in regard to these claims that, "no assessment papers were filed, no lease agreement was ever made, and no rent was paid."

Although no commercial production of iron has been made from these deposits, interest in the area has continued. In 1929, the U. S. Geological Survey (Burchard, 1930) examined and reported on several of the deposits. The U. S. Bureau of Mines made extensive tests on the Apache deposit in the early 1940's (Stewart, 1947) and, in 1964, issued a comprehensive summary of previous studies (Harrer, 1964).

Since 1960, several of the iron deposits have been under lease by CF&I Steel Corporation (see Plate 1) and after extensive exploration, the Company started mining on a trial basis in 1966 and has been shipping the ore to Pueblo, Colorado, for testing (Brooks, 1966).

Geology. The iron formation is composed principally of hematite with silica, much of which is in the form of chert, and minor amounts of magnetite, sericite, and apatite. When the iron formation is of ore grade, that is, when it contains more than 45 per cent iron, it ranges from a soft, pulverulent, red material to a hard dense, dark-blue material. Some specularite is present in the iron formation and magnetite occurs in lesser amounts. The hematite is in bedded deposits varying in thickness from a few feet to more than 30 feet and these beds are often interlayered with chert, jasper, sandstone, and shale (Butler, 1943). Con­torted or wavy bands of chert and jasper occur both above and below the hematitic beds.

The Canyon Creek deposits are in the highly silicified portion of the middle member of the Mescal Limestone similarly as the distribution of genetically related iron deposits (Shride, 1961) seems to be associated with silicification in the middle member of the Mescal Limestone on a regional scale. Generally, the deposits are immediately below a prominent algal unit which, where it overlies the iron, is characteristically mottled red in color and often contains specular hematite. Elsewhere the same algal unit is usually light gray to brown (Brooks, 1966).

North and east of the area in Canyon Creek in which the iron is exposed, the Younger Precambrian host rocks are overlain by a thick sequence of Paleozoic and younger formations and in that region the iron formation, where present, is deeply buried.

These hematitic formations have been interpreted to be contact-metamorphic or pyrometasomatic replacement deposits in the Mescal Limestone, closely related to the diabase intrusion (Butler, 1943; Stewart, 1947; Harrer, 1964). Recent observations, however, tend to discount any significant relationship between the intrusion of diabase and the origin of the iron deposits. In the Split Rock deposit (Plate 1 and Fig. 11) a diabase dike intrudes the Mescal Limestone, the iron formation, and the Chediski Sandstone. It has metamorphosed to a minor degree all three units. In fact, the iron deposit has been slightly enriched with magnetite. Here, the diabase intrusion is clearly post Troy as well as post hematite formation. In several places, pebbles of the iron formation occur in the basal conglomeratic units of the Chediski Sandstone indicating that the hematite formation was formed prior to the deposition of the Chediski, and thus prior to diabase intrusion.

Apache deposit. The Apache iron deposit (Fig. 8) is located in Secs. 10, 15, and 16, T.9N., R.15½E.* It has been known also as the Alsace Lorraine, the name applied to a group of 7 claims (Mineral Survey 3711) located by R. L. Keith in 1920-22 (Plate 1). Two occurrences, separated by Canyon Creek, have generally been recognized as being a part of this deposit. The East Apache (or Swamp Creek Mountain) deposit crops out in Canyon Creek in Sec. 16, and can be traced northeast along Swamp Creek Mountain more than 12,000 feet; the West Apache (or Bear Spring Mountain) deposit is a continuation of the East Apache deposit and can be traced from the outcrop in Canyon Creek, northwest along Bear Spring Mountain, and west up Bear Spring Creek Canyon for about a mile. The iron formation appears to be cut off at each end by erosion, and there is evidence of faulting with minor displacement along the outcrop.

According to Harrer (1964, p. 74):

"The Apache hematite zone is conformable with the sedimentary rocks of the section. The attitude of the outcrops suggests an anticlinal structure plunging south and complicated by flexures and faulting. The hematite zone is near the boundary between white Chediski sandstone of the Cambrian Troy formation and the Mescal limestone formation, just below a silicified algal zone. At the Apache deposit the ore ranges from nearly pure red to bluish-black hematite and some specularite to beds interlayered and mixed with chert, jasperoid, sandstone, and shale. Much of the hematite is fine-grained and massive, containing as much as 1-percent apatite and 3- to 5-percent sericite. The hematite ranges in texture from hard to dense to soft and earthy. The lower grade hematite is generally harder and more massive."

"The Apache hematite deposits were explored by the Bureau during 1941-45 with 51 trenches, aggregating 4,111 feet along 12,000 feet of outcrop, and 22 core-drilled holes, totaling 8,985 feet.

"The average of all trench sampling and core drilling done was 46.8 *All protractions used in this report are based on those shown on the U. S. Dept. of the Interior, Bureau of Indian Affairs, Fort Apache Indian Reservation map, dated 1938.
percent iron. Three carloads of ore mined from the best appearing outcrop area at East Apache contained 63.96 percent iron, 0.06 percent titania, 0.038 percent sulfur, 0.186 percent phosphorus, 6.88 percent silica, 0.46 percent lime, 1.15 percent alumina, and 7.36 percent insoluble.

“Spectrographic analysis indicates the presence of 1 to 10 percent aluminum; 0.1 to 1.0 percent calcium, magnesium, and titanium; 0.01 to 0.1 percent manganese and nickel; and 0.001 to 0.01 percent copper and vanadium.”

The character of the iron formation, based on analyses of composite samples made by the U. S. Bureau of Mines is shown in Table 6.

Table 6. Analyses of Federal Bureau of Mines composite samples, Apache hematite deposits (after Harrer, 1964, Table 19)

<table>
<thead>
<tr>
<th>SAMPLE</th>
<th>Fe</th>
<th>Mn</th>
<th>TiO₂</th>
<th>P</th>
<th>S</th>
<th>SiO₂</th>
<th>CaO</th>
<th>MgO</th>
<th>Al₂O₃</th>
<th>Al₂O₃</th>
</tr>
</thead>
<tbody>
<tr>
<td>Composite of 41 channel samples from trenches; taken in 1942.</td>
<td>58.53</td>
<td>0.05</td>
<td>-</td>
<td>0.214</td>
<td>0.020</td>
<td>12.14</td>
<td>0.38</td>
<td>-</td>
<td>2.12</td>
<td></td>
</tr>
<tr>
<td>Composite of 15 channel samples between above; taken in 1942.</td>
<td>42.96</td>
<td>0.05</td>
<td>-</td>
<td>0.191</td>
<td>0.018</td>
<td>30.60</td>
<td>0.51</td>
<td>-</td>
<td>2.55</td>
<td></td>
</tr>
<tr>
<td>Composite of 41 core samples from 8 core-drill holes; taken in 1944-45.</td>
<td>43.35</td>
<td>0.04</td>
<td>0.15</td>
<td>0.220</td>
<td>0.054</td>
<td>27.23</td>
<td>1.28</td>
<td>0.29</td>
<td>2.92</td>
<td></td>
</tr>
</tbody>
</table>

The anticlinal structure suggested by Harrer, was further substantiated by the drilling program of the U. S. Bureau of Mines, which indicated that a sharp flexure, complicated by faulting, carries the hematite formation to about 350 feet below Canyon Creek at which depth the formation flattens out. Further exploratory drilling by CF&I Steel Corporation (Brooks, 1966) has confirmed the southward extension of the Apache deposit to near the vicinity of the Pyramids (Fig. 8).

CF&I Steel Corporation obtained the Apache deposit by lease in 1960 and constructed a haul road from the Young-Heber road to Canyon Creek via Red Lake Forest Service administration site. By mid-1966, a small-scale, open-pit mining operation had been started and ore was being shipped to Pueblo, Colorado, for testing.

Chediski deposit. This iron deposit is in the Chediski Indian Farms area (also called Marley Ranch) in Secs. 27, 34, and 35, T.9N., R.15½E., between Lost Tank and Mountain Lion canyons (Fig. 9), and is approximately 3 miles down Canyon Creek from the Apache deposits. Here, a bed of hematite crops out for over a mile on the east slope of Chediski Ridge to the west of, and 300 to 700 feet above, the floor of Canyon Creek. A less conspicuous, thinner outcrop of hematite crops out along the northeast side of Canyon Creek, just above stream level and about 0.3 mile upstream from the confluence of Willow Creek (Fig. 9).

The Chediski deposit was investigated by the U. S. Geological Survey in 1929 (Burchard, 1930) and by the U. S. Bureau of Mines in 1942 (Stewart, 1947). The first claims in this area, the Chediski, Black Iron, and Iron Mountain groups of lode claims, were staked in 1921-26 by H. S. Colcord, and others.
This deposit is similar mineralogically and stratigraphically to the Apache deposits. It is a hematite-rich formation, interbedded with low-grade ferruginous chert and sandstone. Here, as at the Apache deposits, the iron formation occurs near the top of what remains of the silicified, middle member of the Mescal Limestone, and is overlain by the Chediski sandstone which makes a conspicuous marker for the iron-bearing horizon below.

The iron formation on Chediski Mountain appears to dip slightly to the west, into the ridge. To the northwest, it is cut off by a fault. This same horizon can be traced to the south for several miles but the outcrop of its southern extension consists chiefly of low-grade ferruginous to barren material interlayered in a few places with high-grade hematite. The ridge above the outcrop rises steeply and covers the hematite beds in most places with from 300 to over 700 feet of Troy quartzite and younger rocks.

Trenching and sampling of the outcrop was done here by the U. S. Bureau of Mines in 1942. A minable thickness (+5 feet) of outcrop over 2000 feet in length has an average thickness of 18.7 feet and an average grade of 49.21 per cent iron (Stewart, 1947, p. 16). The average composition of the trenched outcrop of the Chediski hematite, exclusive of interbedded low-grade material and barren rock, is 48.92 per cent iron, 23.02 per cent silica, 0.10 per cent manganese, 0.212 per cent phosphorus, 0.105 per cent sulfur, 1.01 per cent lime, and 2.26 per cent alumina (Harrer, 1964, p. 80).

No exploratory drilling was done here by the U. S. Bureau of Mines, as had been done at the Apache deposit, apparently because results of examination of the outcrop at Chediski were somewhat less promising than those at Apache. However, ore estimates that may be inferred from this area add materially to the economic potential of the larger iron-bearing region of the western part of the Reservation.

Oak Creek deposit. This deposit crops out along the east side of Oak Creek Valley, a few hundred feet below the rim, in Sec. 31, T.8N., R.16E. (Fig. 10). The most prominent outcrop is exposed in a road-cut, about 1 mile northeast of Oak Creek ranch. Here, the iron formation strikes N.30°E. and dips 30°SE., and reportedly is exposed for more than a mile to the north of the road (Stewart, 1947, p. 22). The outcrop of this deposit is generally thinner and of lower grade than deposits described above. Like the others, this deposit occurs in the Mescal Limestone beneath the Chediski Sandstone. Here, however, the Chediski has been metamorphosed to quartzite by the nearby intrusion of diabase.

A character sample taken by the U. S. Bureau of Mines was cut across an 8-foot bed, including 1.5 feet of lean chert and 1.0 foot of low-grade material. The sample contained 36.70 per cent iron, 38.60 per cent silica, 0.1 per cent manganese, 0.212 per cent phosphorus, and 0.416 per cent sulfur (Stewart, 1947, p. 22). A few small lenses of hematite appear comparable in grade to the hematite of the Apache and Chediski deposits but most of the bed is clearly poorer, owing to abundant intermixed chert.
The Split Rock deposit is similar in occurrence to the Chediski and Apache deposits; the hematite occurs in the silicified Mescal Limestone and is overlain by Chediski sandstone, except locally, where recent erosion has stripped the iron deposits of most of their cover. Structurally, the Split Rock area is complicated by numerous east-west and north-south trending faults. In at least one place, faulting has locally caused the hematite beds to be repeated, and these exposures have been interpreted by some observers to represent two different hematite beds (Harrer, 1964, p. 81). Like the Apache deposits, the Split Rock deposits are near massive sills of diabase. In the southern part of the area a diabase dike intrudes the hematite bed, locally metamorphosing and enriching it by the introduction of magnetite.

A character sample taken by the U. S. Bureau of Mines in 1961 contained 67.9 per cent iron, 2.4 per cent silica, 0.4 per cent manganese, 0.2 per cent titania, 0.14 per cent phosphorus, and 0.05 per cent sulfur (Harrer, 1964).

The area encompassing the Split Rock deposits is currently under lease to CF&I Steel Corporation. (See Plate 1)

These deposits appear to have significant reserves of both high- and low-grade iron ore and much of the hematite east of Canyon Creek is sufficiently shallow to permit mining by open pit. West of Canyon Creek, however, the iron deposits are more deeply buried.

**Split Rock deposit.** Hematite-rich beds of varying quality and thickness crop out intermittently along the Canyon Creek watershed from its confluence with Bear Canyon, on the north, to below its confluence with Gentry Creek, on the south (Fig. 11). In this area the hematite formation occurs intermittently exposed on both sides of Canyon Creek in thicknesses on the outcrop of from a few feet to more than 30 feet.

**Cow Creek deposit.** An apparently small, isolated bed of hematite in the Mescal Limestone has been reported to occur between the forks of Cow Creek, about 2 miles north of the Apache deposits, in Sec. 3, T.9N., R.15½E. (Fig. 8). This deposit lies near the northern limit of the region of intense silicification outlined by Shride.

**Rock Canyon deposit.** Outcrops of ferruginous Mescal Limestone are exposed near the confluence of Rock Creek and Bear Creek, on the north side of Rock Creek, and on the southwest side of Bear Creek, about half way up the steep canyon walls (Fig. 11).

The iron formation is relatively thin, seldom more than a few feet in thickness, and crops out as discontinuous bands of low-grade material that can be traced for about 3000 feet (Stewart, 1947, p. 23).

The Rock Canyon deposit lies just to the north of the Split Rock deposits, and about 4 miles south of the Chediski deposit. It is geologically similar to those previously described.

**Marley-Grasshopper deposit.** This apparently small deposit is located in Sec. 12, T.8N., R. 15½E., about 2 miles southeast of Chediski Indian Farms (Marley ranch) and south of the Marley-Grasshopper road. Here, a hematite bed, 10 to 12 feet thick, is exposed for a short distance along the bottom of a stream.
Ore Reserves. Harrer (1964, p. 189) gives the iron ore reserves of the Fort Apache Indian Reservation as being slightly over 14,000,000 tons of ore containing 46 per cent iron, and the inferred iron ore potential is in excess of 100 million tons containing from 20 per cent to 67.9 per cent iron. This reserve estimate applies to all the principal deposits on Canyon Creek, as described above.

MANGANESE

Location and extent. Manganiferous veins occur in the extreme southwestern part of the Fort Apache Indian Reservation scattered over an area of 3 or 4 square miles in the vicinity of Medicine Butte (Fig. 12). Mine workings lie between 3,000 and 4,000 feet above sea level. A gravity concentrating plant, which was dismantled when the area was visited in 1967, has been operated at Gleason Flat (Plate 1).

History. No record was found concerning the discovery of these deposits, but the first development work was undertaken by L. A. Kuehne and G. L. Noel, who obtained at least two blocks of land under lease from the Indian Agency in 1939. Operations during the ensuing years have been sporadic and under the direction of a number of lessees. Perhaps the greatest production of ore, approximately 12,000 tons, was made by Al Stovall in 1955 and 1956.

Geology. The manganese occurs as psilomelane and wad, filling fractures, and as cementing material in Cenozoic conglomerate. In the vicinity of the manganese mineralization, the conglomerate rests on a surface of considerable relief that was carved on Older Precambrian crystalline rocks. Locally, the conglomerate exceeds 300 feet in thickness. About 200 feet above the exploited manganese, a basalt flow caps the conglomerate and in some places is interbedded with the conglomerate.

Apache Manganese deposit. The Apache deposit is located in a southdraining draw, approximately a quarter of a mile east of Medicine Butte (Fig. 12).

According to Farnham (1961):

"The principal manganese exposures on the property lie in four zones along a northerly trending belt some 2,000 feet long. Intervening areas are largely covered with alluvium and debris. This covering obscures the correlation of the different exposures and conceals any further extent they may have. The deposits occur in steeply dipping fracture zones that range in strike from northwest to northeast. The zones differ in width, the manganese oxide minerals occurring in narrow veins, interlacing seams, and small nodular masses distributed erratically in the sheared and shattered gravel boulders.

"Psilomelane and minor amounts of the softer oxides are the chief manganese minerals. The gangue is composed largely of quartz, unplaced pebbles, and fragments of gravel.

Figure 12. Map showing location of Apache and Accord manganese deposits.

"In the exploited deposit near the southern end of the property, the mineralized zone was about 25 feet wide and was exposed in an open cut about 60 feet along its southeastward strike. The face of the cut was approximately 12 feet high and contained three enriched veins ranging from 1 to 2 feet in width. These higher grade veins extended from the surface to the bottom of the opening and were separated by lower grade material composed of a network of narrow seams, stringers, and small bunches of manganese minerals. Near its face, the opencut had broken into some old adit workings driven on one of the higher grade veins, which probably was the source of some of the ore produced in 1941. Overburden surrounded the opencut and concealed the further extent of the deposit along the strike.

"A few hundred feet farther south, stripping had exposed scattered spots of manganese minerals in an irregular area about 150 feet long and 50 feet wide. The exploratory work had not been completed, and the extent of the deposition in this area was not evident when the property was visited.

"Approximately 250 feet north of the first-described zone, the largest and most productive of the deposits was exposed in opencut workings about 500 feet along its northerly trend. In this area the deposit appeared to be at least 60 feet wide near the south end of the cut and not more than 20 feet wide at the north end. This zone contained veinlike strands and irregular masses of higher grade ore, surrounded by interlacing seams and stringers of psilomelane filling the minor fractures in the shattered gravels. The opencut workings reached a maximum depth of some 25 feet. Old reports indicate that some ore was mined in 1941 from this zone in deeper adit workings underlying parts of the present opencut."
"About 150 feet north of the opencut, a 30-foot adit had been driven along a well-mineralized vertical fracture striking N.25°E. and ranging from 1 to 2 feet in width. Here also the gravel adjacent to the higher grade fracture was impregnated with seams and stringers of manganese minerals. The full width of this lower grade material was not exposed. A few scattered shallow opencuts and pits had explored the zone for some 200 feet along its strike to the northeast.

"The northernmost deposit is about 1,000 feet north of the largest opencut. In this area the manganese minerals occurred along a vertical fracture zone striking N.65°E. It ranged from 10 to 25 feet in width and was exposed in an opencut about 100 feet along the strike. To the northeast, beyond the face of the cut, the deposit was covered with 15 to 20 feet of detritus. Some of this covering had been stripped, exposing the top of the deposit for an additional 60 feet. Some stripping also had been done along the trend of the zone southwest of the cut, but no appreciable amount of ore was exposed by the work. The ore minerals in this deposit, as in the others, occurred in enriched strands and irregular bunches separated by a network of seams and stringers of psilomelane surrounding the pebbles and other constituents of the gravel.

"Large grab samples were taken from piles of broken ore remaining in the three principal opencuts. The sample from the south opening contained 9.0 per cent manganese, that from the largest opencut assayed 8.5 per cent, and the sample from the northernmost deposit contained 8.4 per cent manganese.

"Bench-scale physical beneficiation and sulfur dioxide leaching tests were made on a composite of four grab samples of broken ore from the three major opencuts on the property. The composite sample weighed about 400 pounds and contained 8.4 per cent Mn, 3.6 per cent CaCO₃, and 0.19 per cent Cu. Visual and microscopic examination identified the ore as a coarse-grained sandstone cemented with psilomelane and small quantities of pyrite and wad. Spectrographic analysis showed the presence of a trace of cobalt and some copper which was inherent in the manganese minerals. Although high-grade psilomelane as coarse as ¹/₄-inch was found in the ore, grinding to minus-100-mesh was required for complete liberation of the psilomelane from the quartz.

"Physical beneficiation of the sample by sink and float and by flotation was investigated. The ore was crushed to minus-5/₈-inch and screened on a 10-mesh sieve for the sink-float tests. Separation of the minus-5/₄-inch, plus-10-mesh fraction at 2.94 specific gravity yielded a sink product assaying 38.2 per cent Mn and 0.6 per cent Cu and recovered 69.6 per cent of manganese. Sink-and-float separation of minus-¹/₄-inch feed did not give a better grade of product."

As the copper content exceeds the allowable limits for metallurgical-grade manganese ore, physical beneficiation is not adequate to produce a marketable product and it appears that chemical methods will be required. In this regard, further testing was done by the U. S. Bureau of Mines and Farnham (1961) reports:

"Representative samples of the ore were treated by agitation leaching of finely ground charges and by percolation leaching of coarse charges using sulfur dioxide. The agitation leach was made on pulps of minus-100-mesh ore. A gas comprising 10 per cent SO₂ in air was fed to the pulp, which contained 32 per cent solids, at the highest feed rate commensurate with utilization. The ore leached rapidly and completely. About 97 per cent of the manganese was recovered in a 2-hour leach with a sulfur dioxide consumption of 2.2 pounds per pound of manganese dissolved. Dithionate formation in the test was 0.7 pound per pound of manganese extracted, which was more than ample for successful recovery of the manganese from the pregnant solutions by precipitation with hydrated lime as practiced in the dithionate process.

"As copper in dithionate leach solutions can be rejected before precipitation and recovery of the manganese hydroxide, the Apache sample can be leached successfully to recover a metallurgical grade product. Leaching the ore appears to be the only practical method of treatment at present."

**Accord Manganese deposit.** This property is located approximately 1.25 miles west of the Apache deposit (Fig. 12). In 1940 and 1941 it was held, along with the Apache deposit, by L. A. Kuchne under lease from the Indian agency. However, there is no record that any production has ever been realized from the property.

In most respects, the mineralization is similar to that at the Apache claims. According to Farnham (1961), the chief manganese minerals are psilomelane and wad which occur as veinlets and small lenses along two northerly trending veins about 300 feet apart. In most places the veins are enclosed in gravel or conglomerate beds, but at some places they cut intrusive volcanic rocks. The better mineralized parts of the veins range from 1 to 2.5 feet in width and dip steeply westward. The east vein can be traced about 400 feet along the surface by infrequent outcrops, and the west vein is exposed some 70 feet along the strike.

Farnham (1961) further stated that at the time of his visit in 1957, the workings comprised three adits along the east vein and a 15-foot shaft and two shallow opencuts on the west vein. One adit followed the east vein about 50 feet; the two farther north were caved and inaccessible.

**Exploitation.** Under present (1967) market conditions, the Medicine Butte manganese deposits do not represent commercially attractive properties. Their relatively small apparent size, remote location, and requirement for more or less sophisticated metallurgical procedures for the removal of copper, all mitigate against them. In the case of a national emergency, however, they may again be economically workable.

**URANIUM.**

Although uranium has not been produced commercially from the Fort Apache Indian Reservation, uranium mineralization is known to occur, and reportedly, the Tribe has received nearly $40,000 in payments on leases and prospecting permits issued between 1950 and 1955.

Uranium mineralization has been reported to occur in Canyon Creek approximately one-half mile south of the region of iron mineralization, and small quantities of secondary uranium minerals have been
found at the "Turquoise mine" (Plate 1; Fig. 13). In 1954, the U. S. Atomic Energy Commission made several airborne radiometric surveys, and on one of these, three anomalies were located on the Reservation (Plate 1).

All of the occurrences of uranium thus far reported from the Reservation are in areas in which the Dripping Spring Quartzite is found, and this is in accord with the geologic relations that prevail to the west, in the Sierra Ancha Mountains, where nearly a hundred uranium deposits are known to occur in that formation. An understanding of the geologic relationships at those deposits will serve to aid in prospecting for similar deposits on the Reservation.

According to Granger and Raup (1959), in the region of uranium deposition, the Dripping Spring Quartzite has been extensively intruded by diabase, and the siltstone in the formation has been recrystallized to hornfels. The rocks have been strongly affected by structural features associated with the intrusion of diabase and also by faults and strong joint systems that are later than the diabase. One prominent joint system consists of two sets of fractures that strike about N.20°E. and N.70°W., respectively. The longest dimension of nearly all the deposits trends either north-northeast or west-northwest parallel to these fractures.

All of the known uranium deposits are in the silty upper member of the Dripping Spring, and most of them are between 100 and 130 feet above the base of the member. Both normal siltstone and siltstone recrystallized to hornfels adjacent to diabase are favorable host rocks. The primary deposits are found along favorable beds and fractures near diabase contacts. Some of the richest uranium deposits are in metamorphosed parts of the upper member where it is intruded by pinkish potassium-feldspar-rich aplitic dikes.

Uraninite is the primary uranium mineral and it often is associated with pyrite, marcasite, chalcopyrite, and, more rarely, with galena and sphalerite. Pyrrhotite and molybdenite have been recognized in a few deposits. Secondary uranium phosphates and silicates are found in the weathered portions of the deposits, and they are usually associated with limonite, secondary copper minerals, gypsum, and hyalite.

Genetically, the uranium mineralization appears to be closely related to the diabase — in deposits of the Sierra Ancha region a close spatial relationship exists, and a time relationship is suggested by the results of radiometric age-dating techniques. Both the uranium mineralization and the diabase yield ages of about 1,200 million years (Silver, 1960).

GOLD AND SILVER

Persistent, but unconfirmed reports of gold and silver are common to most areas, and the Fort Apache Indian Reservation is no exception. In the Canyon Creek-Salt River Canyon area, 13 quartz veins cutting the Precambrian granite were noted (see Plate 1), and 9 of the veins were sampled and assayed for gold.

Ten of the exposures are distinct veins, ranging from a few inches to several feet thick, having steep to vertical dips, and falling into two groups on the basis of strike; N.30°-35°W. and N.30°-40°E. All veins show more or less red, brown, or yellow iron stain on fractures and about half of them show black, sooty to dendritic, manganese stains.

The results of the assays, as shown below, do not indicate favorable economic possibilities.

<table>
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<th>Sample*</th>
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<th>Au-2</th>
<th>Au-4</th>
<th>Au-5</th>
<th>Au-6</th>
<th>Au-8</th>
<th>Au-9</th>
<th>Au-10</th>
<th>Au-11</th>
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<td>0.00</td>
<td>0.00</td>
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<td>per ton</td>
<td>Trace</td>
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<td>Trace</td>
<td>Trace</td>
<td>Trace</td>
<td>Trace</td>
<td>Trace</td>
<td>Trace</td>
<td>Trace</td>
</tr>
</tbody>
</table>

*Numbers refer to Plate 1.

Silver occurs in minor amounts, associated with the manganese deposits near Medicine Butte. At the Apache manganese deposit, a grab sample from a two-foot-wide manganese vein striking N.35°E. and occurring in gravels, assayed 0.1 ozs. of silver per ton.
COPPER AND COBALT

Copper and cobalt both have been detected in small quantities in manganese concentrates produced at the Apache manganese deposits (Farnham, 1961). Assay reports on concentrates sent to Arkansas for blending showed as much as one per cent copper. Neither metal, however, occurs in sufficient quantities to be commercial.

Small amounts of copper reportedly occur in diabase in Canyon Creek, and copper also has been found associated with the iron deposits where these lie near diabase. A small showing of copper occurs in diabase in the NW1/4 Sec. 36, T.5N., R.17E. None of these occurrences, however, is of sufficient size or grade to be of commercial interest.

Cobalt, as cobalt bloom (erythrite), has been reported by Galbraith (1959) from a locality approximately one-half mile upstream from the Oxbow Bend (Mule Shoe) of Salt River, but this occurrence was not confirmed.

ZINC

Reagan (1903) reported that low-grade zinc occurs in a dike or vein crossing Salt River near the Salt Banks. This report was not confirmed.

Nonmetalliferous Mineral Deposits

Nonmetalliferous mineral commodities occurring in the Canyon Creek-Salt River Canyon area include asbestos, building and decorative stone, clay, salt, sand and gravel, and turquoise. Of these, asbestos has by far the greatest economic potential. The remaining commodities, either because of low-unit value, or because of limited quantity, are considered to be economically marginal to noncommercial at this time.

ASBESTOS

Location and extent. Asbestos deposits on the Fort Apache Indian Reservation have been found extensively in what is here defined as the Canyon Creek-Salt River Canyon area. Known deposits are exposed along Salt River from the eastern end of the area to near the mouth of Canyon Creek, and up Canyon Creek to the vicinity of Ellison Canyon (Plate 1).

History and production. The first discovery of asbestos in the vicinity of the Fort Apache Indian Reservation was probably that made in 1872 by Charley Newton (Melhase, 1925) who found asbestos cropping out near what is now the Grandview mine, located some 2 miles southwest of the Salt River Bridge on U.S. Highway 60. It was not until 1921, however, that active exploration for asbestos took place on the Reservation. In March of that year, the previously closed Indian lands were opened to asbestos prospecting and leasing, and within a very short time at least 6 groups, totaling 21 claims, had been located. By mid-1967 there were 17 groups, totaling some 2,000 acres, covering asbestos deposits.

Shortly after the Reservation was opened to asbestos mining, the fiber market collapsed, and very little production was made between 1923 and 1935. Between 1935 and 1955, approximately 1,500 tons of crude and milled ore were produced, and total production for the years 1921 through 1967 is estimated to have been between 4,000 and 5,000 tons of crude ore.

Geology. The general geologic characteristics of the central Arizona asbestos province, to which the deposits located on the Fort Apache Indian Reservation belong, have been described in detail by Bromfield and Shride (1956), and by Stewart (1955, 1956). The following discussion has been abstracted largely from those papers.

Commercial asbestos deposits on the Reservation are restricted to the lower member of the Mescal Limestone and occur only where it is closely associated with thick sills and narrow dikes of diabase that intruded and metamorphosed the limestone. The asbestos is generally in thin veins of cross fiber in zones of limestone 6 to 18 inches thick that have been altered to serpentine. Most asbestos deposits are flat, or nearly so, but may be inclined parallel to the dip of the enclosing strata. In mining, it is generally necessary to remove 25 to 35 tons of rock per ton of asbestos produced.

Four geologic factors are essential in order that asbestos be formed in sufficient quantities to be mined. These factors according to Bromfield and Shride (1956) are: (1) favorable stratigraphic units (certain favorable limestone beds), (2) proximity of the diabase to these beds, (3) thrust and bedding-plane faults, and (4) small open folds in the limestones.

Deposits of sufficient areal extent and thickness to warrant mining exist only in, or adjacent to, the thickest and most massive beds of the lower, flat-bedded member of the Mescal Limestone. According to Shride and Bromfield (1956, p. 642), the beds along Salt River Canyon that are favorable to concentrations of asbestos occur within the following stratigraphic units:

1. The uppermost 2 to 7 feet of the lower member of the Mescal Limestone or, in other words, the limestone beds immediately below the massive middle (algal) limestone member.

2. A 10 to 12-foot-thick section of limestone beds about 30 feet below the top of the lower member. This unit is made up of limestones that are 8 inches to 3 feet thick; partings between beds include minor amounts of shale or clay.
(3) A section of beds that is as much as 20 feet thick, approximately 40 feet above the contact between the Mescal Limestone and the underlying Dripping Spring Quartzite. Thus, the zone is about 100 feet below the algal member. A few beds in this unit are 1 to 3 feet thick, but most of the beds are only 3 to 6 inches thick.

The favorable units which exist 30 and 100 feet, respectively, below the top of the lower member are readily recognized, according to Bromfield and Shride (1956, p. 642), because they crop out as prominent ledges, in contrast to the bulk of the lower member which is poorly exposed. Also, the tops of the beds are 2 feet above, or below, a diabase sill. The favorable units which exist 30 and 100 feet, respectively, below the top of the lower member are readily identified because the beds are thin and silty and seldom contain minable quantities of asbestos. Asbestos was formed in considerable quantities only where sills or dikes of diabase were intruded into, or near, the favorable limestone beds. Therefore, few minable deposits are more than 25 feet above, or below, a diabase sill and most of the significant deposits are directly associated with diabase intrusions that cut across the favorable limestone beds.

Pre-mineral bedding-plane faults and thrust faults which transect the beds at small angles, were probably the most significant factor in determining the areal extent of the asbestos deposits and the larger deposits generally occur where bedding-plane adjustments over considerable lateral extent prepared the limestone to receive asbestos mineralization. Also, small open folds, caused by intrusion of the diabase, are favorable loci for localization of serpentine and asbestos bodies.

Chrysotile asbestos, like that occurring on the Reservation, has a wide range of physical characteristics. High quality fiber, known as soft fiber, is soft, silty, very flexible, and usually has high tensile strength. Low quality fiber, or harsh fiber, is brittle and relatively inflexible and thus, it has very limited use.

Enders mine. This property is located in Sec. 23, T.5N., R.17E., approximately one mile northeast of the Salt River Bridge on U. S. Highway 60. The property can be reached by traveling 5.5 miles on a poorly maintained mountain road that leaves the main highway 5.4 miles north of the bridge.

The property has variously been known as the Horse Shoe No. 1 and No. 2, the White Tail No. 1 and No. 2, and now is called the Enders No. 1 and No. 2. The two claims were originally located in 1921 (Mineral Survey 3820) and were worked for a time by the San Carlos Asbestos Mining Company, Inc. Arthur Enders held the property under lease from 1937 to 1957, when it reverted to the Reservation. Since that time, it has been idle.

The two claims are on a prominent ridge projecting southward from the rugged northern slopes of Salt River Canyon and include two deposits, both of which occur in the same segment of Mescal Limestone which is about 150 feet thick. The upper half of the limestone segment consists of strata of the algal member, and the lower half is composed of units of the thinner bedded, lower member. Thick diabase sills overlie and underlie the limestone. Asbestos deposits occur in zones that have been disturbed by both thrust and normal faulting.

According to Stewart (1955), at the Enders No. 1 claim, three asbestos-bearing zones are present in the upper part of the lower member of the limestone. Immediately under the base of the algal member, a 6-inch thick zone of serpentine contained veinlets of the fiber having an aggregate thickness of about 3 inches. At a maximum, there was about 4 inches of fiber in a 2½ foot thick serpentine zone. This zone was stopped along its strike for a distance of more than 100 feet, and near the point of the ridge, some stopes were worked through to the east side. The other mineralized zones, respectively 1½ and 3 feet lower in the section, contained short fiber, and were discontinuous and unimportant. Above the small stopes in the upper mineralized zone, some asbestos was mined from a "thrust fault" occurrence that is 20 feet above the base of the algal member. This was mined to a depth of 30 feet in a stope about 100 feet long. A near-surface pillar of ore reveals a zone of fractured and sheared serpentine about 5 feet thick which contained more than 100 asbestos veinlets, some being of slip fiber nature.

At the Enders No. 2, on the eastern side of the ridge, Stewart (1955) reports that a 6-foot wide, northeast trending, vertical diabase dike crosses the limestone between the thick upper and lower diabase sills. Thin sills branch out from the dike and extend into the limestone for considerable distances. In the hill, about 900 feet back of the outcrop, a thick, low-angle, cross-cutting diabase sill has intruded the limestone, and raised a segment of it about 250 feet, thus repeating the contact between the algal and lower member.

At this deposit, asbestos-bearing strata are localized at the top of the lower limestone member, immediately beneath the algal unit and about 60 feet above the underlying diabase. These asbestos-bearing beds have been slightly deformed by thrust faults, and an ore body, associated with them, was found near the east side of the vertical dike. This ore body was developed through 2 adits and a small stope to a depth of 115 feet. The asbestos is distributed somewhat erratically in concentrations...
up to 3½ inches thick. The quality varies from soft to semi-soft but a little harsh fiber was found in the face of the stope.

The mineralized zone in the block of ground west of the dike was explored by the U. S. Bureau of Mines in 1943 (Stewart, 1955) and three narrow veins of soft fiber, about 1 foot apart, were revealed. A little stoping subsequently was done on these veins. The Bureau also explored the favorable contact in the upper, or uplifted, detached segment of the limestone but only minor amounts of harsh fiber were found in slightly serpentinized beds.

Very little production data are available for this property. Wilson (1928) reports that considerable asbestos was obtained in 1922 and 1923, but none in 1924 and 1925, and that only a small amount of fiber was shipped in 1926 and 1927. Total production from 1935 to 1967 has been slightly under 150 tons of milling ore.

Roadside mine. This property consists of 4 mining claims located approximately in Sec. 19, T.5N., R.18E., at an elevation of 4,350 feet. The claims are at the end of an access road, one-half mile long, which connects from the west with U. S. Highway 60, approximately 3 miles north of the Salt River Bridge. The claims include the old Prochnow or Cibeccue workings.

According to Stewart (1955), the claims cover a 3,000-foot-long segment of Mescal Limestone which crops out above the highway around a small semicircular valley. The limestone is overlain by a discordant diabase sill and is underlain by another diabase sill which cuts discordantly across the limestone and meets the overlying sill on each side of the valley, thus terminating the limestone block.

About 400 feet west of this adit, a bench-cut and 3 short adits, driven in the early 1950’s, exposed an 8-inch-thick serpentine zone in algal limestone about 55 feet above its base. The serpentine zone contained fiber having a maximum total aggregate thickness of about 3 inches. This fiber, like the asbestos found in all the other deposits on the Roadside property, is harsh and of low tensile strength.

Bluff mine. In 1921 and 1922, four Mineral Surveys (3807, 3808, 3812, and 3823) defining the Orange Grove, Big 3 No. 1, Cyax and Bluff groups, and the Big 3 group were made, and these now are all considered as the Bluff mine (Plate 3). Stewart (1956) examined the property in some detail and reported:

"The claims are on the north side of Salt River Canyon upstream from the bridge. For ½ mile from the bridge where the canyon runs east, Dripping Spring Quartzite forms the gorge of the river, above which about 175 feet of lower Mescal Limestone forms steep cliffs. A diabase sill above the limestone forms a bench over which the highway passes. The remainder of the Mescal Formation above the highway is intruded by several thick sills of diabase, and Troy Quartzite caps the canyon wall."

"One-half mile east of the bridge the river swings southeast around a ridge projecting southward from the main mountain mass, at which point the Dripping Spring Quartzite is cut out by a thick sill coming up from below river level. Except for some upward warping near this discordancy, the lower Mescal Limestone strata continue relatively level but are in discordant contact with the underlying sill and also with the continuation of the previously mentioned overlying sill. The limestone is greatly wedged out by the union of the two sills but appears again between the sills as a reverse wedge which forms the end of the ridge."

"Of interest to this report are the asbestos-bearing serpentine zones that are present at various places in the segment of lower Mescal Limestone that is below the highway.

"Considerable benching and opencut work have been conducted just south of the highway approximately 1 road mile upstream from the bridge. The limestone beds are wedged out at road level by a discordant diabase structure that dips northward. Near the top of this limestone wedge an asbestos-bearing serpentine zone has been exposed and partly mined out by opencut work. On the north side of the remaining limestone knob and 2 feet below diabase a 9-inch serpentine band contains nearly 4 inches of fairly harsh asbestos in 1/16- to 1/4-inch veinlets. About 50 feet southward, on the opposite side of the knob, the same zone, which here is 14 feet below the diabase, exposes nearly 2 inches of soft fiber, in shallow opencuts, some of which is No. 1 length. This mineralization is about 175 feet above the top of the Dripping Spring Quartzite and at an approximate altitude of 3,700 feet."

"The present operators (October 1944) are dozing a bench to another zone said to be 40 feet lower in the section. The outcrop of this zone was not seen by the writer because of dump material from the work above. During this work a lens of mineralization was uncovered about 15 feet below the upper zone. It contained up to 2 inches of harsh fiber but was of very limited extent."

"One-half mile southeast of the above-described work, on the west side of a ridge, minor asbestos-bearing zones occur in the limestone between two thick diabase sills. About midway along the ridge and a few
feet below the upper sill, a shallow cut exposes 1½ inches of fairly harsh fiber in a poorly serpentinized zone. This occurrence is 18 feet above a 10-foot sill that has been intruded in beds 50 feet above the underlying diabase.

"Farther south, where the limestone is only 30 feet thick between discordancies of both major sills, a 3-foot zone of serpentinized material contains several discontinuous and erratically disposed veinlets of soft asbestos. This zone, 5 feet above the underlying diabase contact, has been prospected by 3 bench cuts for a lateral distance of 80 feet. The fiber content is distributed in several veinlets, none of which is more than ½ inch thick."

**Snake Hill mine.** According to Stewart (1955):

"The Snake Hill deposit is at the bottom and on the north side of Salt River Canyon, 1.5 miles east of the Salt River Bridge on U. S. Highway 60, or double that distance along the course of the river. The property was leased from the Fort Apache Indian Reservation in 1922 by William G. Shanley and partners, and exploration was conducted in 1923-24. As far as can be determined, no work has been done since that time.

"The reservation map indicates this location to be in approximate Section 30, T.5N., R.17E., unsurveyed. The prospect can be reached from Highway only by a hard climb down the north canyon wall; there is no trail. At the time of operations, access to the workings was by a trail down to the river on the south side, thence across the gorge by a car suspended on a cable. The bare cable, some 40 feet above the river, is still in place.

"Steep cliffs of Mescal Limestone lie above a diabase sill that forms the bottom 100 feet of the north canyon wall of Salt River at this point. The main adit, at an altitude of approximately 3,600 feet, is situated midway between two nearly parallel, north-northwest-trending, vertical faults that have dropped and tilted an 80-foot-wide block within the limestone strata. The east side of the block has dropped 25 feet, the west side only 10 feet. From the fault block east the limestone bedding is folded upward against a cross-cutting discordancy in the diabase. West of the block the diabase is concordant and relatively level.

"The fault block has been shattered by minor fault adjustments and bedding-plane slips. Asbestos mineralization is present for a few feet at the portal of the adit. The asbestos zone is 23 feet above the sill and 26 feet below the base of the algal member. A second serpentinized zone, barren of fiber, is 5 feet lower in the section.

"An adit into this deposit indicates that the best mineralization was localized to a depth of about 30 feet along a shattered zone that was only a little wider than the drift. In this distance there appears to have been a total of 3 to 4 inches of soft fiber distributed throughout a 12- to 16-inch serpentine zone. The adit was extended N.20° to 30°E. for 50 feet beyond the productive lens, but only minor stringers of asbestos were encountered.

"A second exploration was conducted about 40 feet west of the fault block in relatively undisturbed, level limestone bedding, where a lens of 1-inch soft fiber was present in the lower serpentine band. Carried at floor level, this asbestos vein split into narrow stringers and pinched out completely at the face of the 60-foot adit. Twenty-five feet from the portal crosscuts were driven 30 feet right and left, but they disclosed only irregular, minor veinlets of soft fiber in a 24-inch serpentine zone. The upper serpentine zone, 5 feet higher, contained up to 2 inches of short, spicular, somewhat harsh fiber only in a 10-foot lens near a small thrust fault at the intersection of the drifts."

**Stansbury mine.** This property, which is known also as the KM Lease, consists of 2 claims situated about 15 miles east of the Salt River Bridge approximately in Secs. 29 and 30, T.5N., R.19E. The deposit was first located in 1923 (Mineral Survey 3849) by E. D. Reidhead as the Apache Nos. 1 and 2. (See Plate 1.) No work was done on the property, however, until 1951, when a lease was secured by Stansbury, R. Reidhead, and O'Dell. Mining was begun in 1953 by the Arizona Asbestos Mining Company, and by 1955, the ore zone was developed by 2 open cuts, 2 shallow inclined shafts, and 2 adits. In 1958, the property was mined for a short period by the Phillips Asbestos Company and for a short period in 1966 by Western Asbestos Mfg. Corp. Total production from 1953 through 1966 has been approximately 340 tons of crude ore.

The deposit is on a point of land formed by a sharp bend in Salt River. The stratigraphic sequence on the point consists of 50 feet of Dripping Spring Quartzite at the base, overlain by 75 feet of Mescal Limestone, which in turn is overlain by 75 feet of diabase. Devonian Martin Limestone rests unconformably on the diabase.

Numerous asbestos veins occur in a zone from 25 to 30 feet below the diabase and appear more or less continuously along the northern side of the point over a length of nearly 2,500 feet. Along this extent, the attitude of the limestone is quite constant, the strike varying between N.20° to 30°E. and dipping from 20° to 30°SE.

**Apache mine.** The Apache property consists of a group of 20 claims and a fractional claim situated on the west side of Salt River Draw in approximate Sections 7 and 8, T.5N., R.17E. The main working, which is at an altitude of 3,850 feet, can be reached from the Salt River Bridge by traversing 9 miles of road down the north side of Salt River thence 3½ miles north on the mine road.

The property originally was known as the Seven Star group of claims and was located by Roy Reidhead in 1923. It was relocated and leased to Dr. A. J. McIntyre in about 1938 under the name of Apache Asbestos Mines, Inc. In June 1953, the Crown Asbestos Mines, Inc., acquired the lease on the mine.

There are two sets of mine workings known as No. 1 and No. 2. According to Stewart (1955), the main, or original workings, on claim 5, developed a mineralized zone about 500 feet long with a maximum
stoped width of 250 feet. The ore zone consists of asbestos-bearing serpentine, from 8 to 18 inches thick, and closely spaced veinlets of asbestos having an aggregate thickness ranging from 1 to 3½ inches. This ore zone is contained in a limestone unit from 10 to 12 feet thick and lies 3 feet below a diabase sill. The limestone unit dips about 3° northwest but has been moderately deformed by thrust faulting.

The No. 2 mine, which is located about half a mile north of No. 1, developed an asbestos-bearing serpentine zone about 8 or 10 inches thick. This occurs about 5 feet below a diabase sill and is enclosed in a limestone zone that is from 12 to 15 feet thick. The total aggregate thickness of fiber veinlets in the serpentine is about 2 inches. The ore zone is localized in a zone of moderate thrust faulting.

About half a mile south of the No. 1 mine, some moderately harsh fiber was produced from an open cut and two short adits that exposed an asbestos-bearing serpentine zone about 20 inches thick. This occurs about 20 feet below the top of a sliver of limestone which is nearly 250 feet long. The limestone is overlain by a concordant diabase sill and is cut off on each end by discordant bodies of diabase. Each of the two adits driven from the face of the open cut showed evidence of decreasing mineralization away from the portal and each encountered discordant diabase bodies at a depth of about 40 feet.

The fiber in the No. 1 and No. 2 mines is soft and of excellent tensile strength. In 1954, a mill capable of treating 6 tons of mill rock in an 8-hour period was built on the property to produce a crude concentrate to be shipped to custom mills for fiberizing.

Apache Extension mine. The Apache Extension group of 10 claims is situated on the steep eastern side of Salt River Draw approximately in Sec. 8, T.5N., R.17E. The property can be reached from U. S. Highway 60 by following the Indian Service road 6 miles down Salt River Canyon to the Salt River Draw, thence north up the Draw one mile to the end of the road. From the road, the mine workings, which are at an altitude of about 4,000 feet, can be reached by about 1 mile of steep trail.

In the steep canyon of Salt River Draw, the entire stratigraphic section of the Mescal Limestone is exposed. It is underlain by Dripping Spring Quartzite and is overlain by a thick diabase sill which separates it from the overlying Troy Quartzite. Two generally discordant sills have split the lower member of the Mescal. The upper sill is 50 feet thick and the lower one is 10 feet thick; and between these sills is a 10-foot thick limestone stratum that encloses the mineralized zone. The limestone unit is exposed for 400 feet along the canyon wall; elsewhere it is concealed by overburden.

The known mineralized zone consists of a 12-inch thick asbestos-bearing serpentine band about midway between the two concordant sills. Near the north end, it has been explored by a short adit and a small stope which developed fiber having an aggregate thickness from 1 to 2 inches, the thickest veinlet having fibers with a maximum length of about three-fourths of an inch. Shallow prospect pits have exposed thin zones of fiber at points 150 feet and 350 feet southeast of the main working.

Except in the weathered zone, all of the fiber in this deposit is very soft and of excellent tensile strength.

Loey and Lena mine. The Loey and Lena property is a 62-acre tract situated in Salt River Draw, approximately 1 mile north of the junction of Cibecue Creek and Salt River. The mine workings are at 4,300 feet altitude, approximately in Sec. 5, T.5N., R.17E. The property can be reached by following the Indian Service road 6.2 miles west from the Salt River Bridge on U. S. Highway 60, thence 1.2 miles up Salt River Draw to the old camp of the Apache mine. From this camp, a steep trail leads northward to the Loey and Lena workings.

The Loey and Lena claim was originally located by C. O. Reidhead before 1928. It was worked in 1928-29 and intermittently from 1935 to 1940 and a few tons of hand-cobbled fiber was produced. By 1955, the deposit had been developed by 3 shallow cuts and 2 small stopes about 50 feet long and 20 feet wide.

The asbestos-bearing zone crops out for a horizontal distance of about 200 feet and is immediately under the base of the algal unit. There is locally a second mineralized zone about 2 feet lower in the stratigraphic section and a diabase sill lies approximately 25 feet below the mineralized zone.

The upper mineralized zone is 8 to 10 inches thick and contains veinlets of asbestos having a total aggregate thickness of about 1½ inches. The lower zone locally contains veinlets having a total thickness of about ½ inch. The fiber is soft and of high tensile strength except near the eastern end of the deposit where the fiber is harsh.

Fiber King (Salt Bank or Riverside) mine. The Fiber King mine is about one mile north of the Salt River approximately in Sec. 13, T.5N., R.16E. and is 8.2 miles west on the Indian Service road which branches off U. S. Highway 60 about 0.1 mile north of the Salt River Bridge.

The claims covering this area were first located in 1921 as the Salt Bank group by W. G. Shanley. Late in 1927, three claims were relocated by Roy and C. O. Reidhead as the Riverside group. In 1941, Charles Ireland and Gladys Eakers secured a lease on 5 claims and in 1942, John Bacon leased the two adjoining Victory Claims. In 1946, the Globe Asbestos Co., a subsidiary of Rheem Research Products, Inc., operated
the property. The lease reverted to the Fort Apache Indian Reservation in 1951.

The Fiber King group of claims is situated astride a relatively narrow ridge which projects southward from the steep, deeply sculptured north side of Salt River Canyon. On each side of the ridge, about 100-foot-thick sections of the lower and algal members of the Mescal Limestone are exposed, and the limestone is overlain and underlain by thick diabase sills. Two mineralized zones have been explored; one is immediately beneath the algal limestone, the other is nearly 100 feet lower in the section and only a few feet above the underlying sill. The lower zone, which is at an altitude of about 3,500 feet, is the more important of the two zones.

The lower asbestos deposit is localized near the underlying diabase sill, which cuts discordantly upward from the east, becomes concordant westward for about 30 feet and again rises, cutting off the mineralized beds in that direction. The mineralized zone is in massive-bedded limestone, about 5 feet above the concordant part of the sill. The average trend of the structure which localizes the asbestos is about N.20°W. The deposit has been developed by an adit about 220 feet long and the ore zone was stoped about 25 feet west of the adit and about 90 feet east of it. In the adit, the dip of the limestone and the concordant part of the sill is about 5° north for 80 feet, beyond which it is virtually level. Near the diabase-limestone contact, the serpentinized zone is from 18 to 24 inches thick and usually contains several veinlets of short fiber having a total thickness of about 2 inches. The serpentine zone becomes progressively thinner toward the east, thinning to from 5 to 9 inches in the faces of the eastern stopes; the fiber is very short and many zones are absent.

On the south side of a canyon located about 400 feet north of the main workings, asbestos is exposed in outcrop for a distance of 50 feet. It has been explored for 20 or 30 feet by a short adit and small stope. This mineralized zone is about 5 feet above a concordant diabase sill. Across the canyon, about 100 feet northeast of this prospect, a short adit penetrates a very small deposit of harsh fiber which apparently has little value.

On the Victory claim, approximately 2,000 feet southwest of the Fiber King deposit, a serpentine zone about 8 inches thick has been explored by a short adit. The zone contains asbestos having a total thickness of from 1 to 2 inches. It is about 5 feet above the underlying sill but is cut off by a discordant sill about 65 feet from the portal of the adit. A second adit driven about 65 feet farther west, encountered similar relationships and established the trend of the discordant contact as being about N.70°W. In both adits, the fiber virtually pinched out where the dip of the beds changed from 8°-10° to nearly horizontal.

About 300 feet N.40°W. from the Fiber King workings, and 100 feet higher, the upper mineralized zone is exposed for an outcrop length of 50 feet. This zone occurs in beds 2½ feet below the base of the algal limestone and 30 feet above a discordancy with the same diabase sill that underlies the main Fiber King workings. Asbestos occurs in serpentine localized near the apex of a wedge of gouge formed by thrust faults. A short adit driven N.18°W. shows fiber up to 1½ inches thick at the top and ½-inch thick at the bottom of the serpentine zone. Small amounts of fiber were found in other prospects in the same area.

Most of the asbestiform material discovered on the Fiber King property is soft and has good tensile strength, but most of it is short.

Asbestos Explorations Co. leases. Between 1955 and 1960, mining leases were issued to Asbestos Explorations Co. on 6 parcels of land near Canyon Creek, between Ellison Canyon and Keystone Ridge. (See Plate 1.)

On the White Hill and Double Buttes prospects, bulldozer-cuts have exposed a 10- to 20-foot-thick bed of massive, even-bedded algal limestone in which a serpentine zone has been developed, 5 to 10 feet above a concordant diabase sill. Within the serpentine zone, thin veinlets of soft, weak fiber up to 1½ inches long are separated by dull, white partings of waste. No fiber has been produced from these prospects, insofar as is known.

On the Tankhouse, Box Canyon, and Sloan Creek leases very little topographic expression is present, and prospecting has been carried out only with shallow bulldozer-cuts and trenches. The Mescal Limestone that is exposed is apparently the same horizon as that worked at the Sloan Creek mine, west of the Reservation, where it has been described by Stewart (1955) as being the uppermost favorable zone in the lower member. Only minor quantities of fiber were exposed and there is no record of production.

The Canyon Creek Gate mining lease is located at the bottom of the canyon on the east bank of the stream. Several cuts in diabase and thin lenses of limestone are exposed but no fiber was observed.

Exploitation. Considerable high-grade fiber still remains in many of the deposits discussed, and undoubtedly, good fiber, in as yet undiscovered deposits, remains to be developed. Prospecting should be governed by the ore controls enumerated in the preceding sections and the search-area logically should be restricted to the outcrops of Mescal Limestone in Salt River Canyon and its tributaries.
Although good fiber brings a high price, a fair average gross return on mine-run asbestos-rock would be close to $30.00 per ton, which brings it into the same range as other small, underground mining operations. On this basis, the problem of attracting reliable operators and lessees will be a difficult one if some concessions in lease terms are not granted.

SALT

Numerous salt springs and seeps occur near Salt River, but the springs at Salt Banks are probably the best known. Efforts were made in the 1870's to produce salt from this area to be used in the metallurgy of the silver ore then being mined at McMillanville. The silver operations closed down, however, before the salt could be brought into production.

The springs at Salt Banks emerge from fractures in both the Dripping Spring Quartzite and the diabase. The exact source of the salt is not known but it has been suggested that it is being leached from the lower unit of the Mescal Limestone.

Feth (1954) estimated that dissolved solids, mostly sodium, were being added to Salt River from springs at the Salt Banks at the rate of 140 tons a day, or about 50,000 tons a year. The chemical quality and discharge of water near Salt Banks, as reported by Feth (1963), are given in Table 7.

The salt is not considered to be of commercial value at this time. It is, however, a possible source of salt for livestock use and could be developed, with a minimum of capital, and by using local personnel.

Two, shallow quarries, about 1,000 feet apart, have been cut into the deposit and the turquoise occurs as small blebs and coatings along bedding planes and in fractures. The host rock is the upper member of the Dripping Spring Quartzite which here consists of fine-grained, flesh-colored, ortho-quartzite.

On the basis of anomalous radioactivity detected at the site of this deposit during the surveys flown by the U. S. Atomic Energy Commission in 1954 (see Plate 1), a particular search for uranium minerals was made at the quarry during the present survey. As a result, very small quantities of the copper-uranium-phosphate mineral, metatorbernite, were found.

Inasmuch as turquoise is a copper-aluminum-phosphate, the association with metatorbernite seems reasonable, and it is suggested that prospecting for turquoise can be aided materially by using radiometric methods. In this regard, at least two additional anomalies were discovered during the Atomic Energy Commission surveys (see Plate 1), and these should be critically examined for turquoise.

CONSTRUCTION MATERIALS

Building stone. Stone, suitable for building purposes, is found in several parts of the Canyon Creek-Salt River Canyon area; but in most cases, the deposits are situated so that the stone can be considered only as economically suitable for local use.

Flagstone, with partings of from 1 inch to 5 inches, occurs in several horizons in the Troy Quartzite. The color is variable both within deposits, and from one deposit to another, ranging from white to gray through shades of tan and reddish brown. Notable deposits were observed at the rim of Gentry Creek Canyon, in Sec. 25, T.9N., R.15E.; on Chediski Mountain, in Secs. 33 and 34, T.9N., R.15½ E. and Secs. 11 and 12, T.9N., R.15½ E.; on Swamp Creek Mountain, in Sec. 15, T.9N., R.15½ E.; and at several localities near the top of the rim east of Canyon Creek.

Locally, along Salt River and lower Canyon Creek, the upper part of the Dripping Spring Quartzite also has color, grain size, cementation and splitting properties such that it might be considered for flagstone or dimension stone.

Granite in lower Canyon Creek is too greatly fractured to be considered for dimension or monument stone and its only use would appear to be for riprap.

Extensive deposits of limestone, dolomite, marble, and serpentine are present in the Mescal Limestone where it crops out in Salt River Canyon, and the bedding is such that dimension stone could be quarried.

Table 7. Chemical quality and discharge data near Salt Banks, Salt River, Arizona

<table>
<thead>
<tr>
<th></th>
<th>Springs on Top of Salt Banks</th>
<th>Slough, East End of Salt Banks</th>
<th>Spring at River's Edge</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Sodium (ppm)</strong></td>
<td>8,400</td>
<td>11,600</td>
<td>13,100</td>
</tr>
<tr>
<td><strong>Sulfate (ppm)</strong></td>
<td>758</td>
<td>968</td>
<td>1,100</td>
</tr>
<tr>
<td><strong>Chloride (ppm)</strong></td>
<td>13,000</td>
<td>17,600</td>
<td>20,100</td>
</tr>
<tr>
<td><strong>Dissolved Solids (ppm)</strong></td>
<td>24,000</td>
<td>31,600</td>
<td>36,400</td>
</tr>
<tr>
<td><strong>Discharge (cfs)</strong></td>
<td>0.02</td>
<td>0.01</td>
<td>0.02</td>
</tr>
</tbody>
</table>
Facing and decorative materials can be produced from both the serpentine and the algal member of the Mescal. The serpentine, when polished, attains a smooth, satiny finish, in pale shades of green, gray, and black. The algal limestone can be polished to bring out the concentric or contorted structures in the rock and thus, make an attractive facing stone.

Sand and gravel. Abundant sand and gravel occurs along Salt River in the present channel and on local terraces, and for short distances up tributary streams. The inaccessibility of most of the deposits, however, preclude their development for other than local use.

Clay and adobe. Deposits of adobe clay of very limited size occur locally at the bottoms of the broader segments of the valleys of Oak and Canyon Creeks, and these deposits were exploited to a small degree by the early cliff-dwelling Indians of the region. These deposits are suitable for local use only.

Impure clay occurs in parts of the Chediski Sandstone near the iron deposits (see Plate 1), and in the disintegrated granite in lower Canyon Creek. Neither source is considered suitable at this time for the production of clay products. A potential use for the disintegrated granite is as impervious fill in earth dams and stock tanks.

CARRIZO SLOPE-MOGOLLON RIM AREA

Location and Topography

The Carrizo Slope-Mogollon Rim area comprises nearly one-half of the Fort Apache Indian Reservation (Fig. 7) and extends from the Canyon Creek-Salt River Canyon area, north to the Mogollon Rim and east to White River. It embraces essentially all of the physiographic subprovince defined earlier (page 6) as the Carrizo Slope and also it includes those portions of the Mogollon Rim escarpment lying within the Reservation.

Elevations in the area range from 7,400 feet above sea level at various points on the north boundary of the Reservation to 5,000 feet on the rim above Salt River Canyon. A dendritic drainage pattern has been carved into the surface of Carrizo Slope by generally south and southeast flowing streams, and locally, relief is quite steep in canyons cut in the more competent rocks flooring the Slope.

Rock Units

Precambrian

The Precambrian rocks which crop out in the Canyon Creek-Salt River Canyon area (Table 4; Plate 2) extend under the Carrizo Slope, and, as far as is known, form the basement of the entire area. Prior to the deposition of the Paleozoic sediments, the surface of the Precambrian terrane was eroded into ridges and valleys which trend north to northeast. Relief on the Precambrian surface was at least 300 feet in some areas, and the occurrence of this undulating surface had a marked effect on the local distribution and lithology of the basal Paleozoic rocks.

Basal Paleozoic

The first Paleozoic rocks accumulated in the region of the Reservation were clastic sediments deposited in the valleys, basins, and channels carved on the Precambrian surface. These rocks are considered to be of Cambrian age by some geologists and of Devonian age by others. This problem is largely one of academic interest, however, and for the purposes of this paper, they are considered to be the basal part of the Devonian Martin Formation.

Devonian

The Martin Formation, of Devonian age, consists of a series of limestones, sandstones, and shales which grade into one another both horizontally and vertically. In spite of this variability, the formation is divisible into three members, based on its gross lithologic characteristics.

The lower member, which ranges up to 200 feet in thickness, consists of a basal conglomeratic sandstone that grades upward into a dark-colored dolomitic limestone which, in turn, is overlain by a thin- to medium-bedded dense dolomitic limestone.

The middle member of the Martin Formation is composed of a cross-bedded sandstone and a cliff-forming limestone, and ranges in thickness from 50 to 177 feet.

The upper member of the Martin ranges from 30 feet to 195 feet in thickness, and consists of sandstone, limestone, and shale. In general, it is more calcareous than the lower members.

At the top of the upper member, a green shale occurs in a zone that ranges from 6 feet to 75 feet in thickness, and forms a distinctive marker horizon.

The overall thickness of the Martin Formation is approximately 400 feet, but locally, as near the tops of buried Precambrian ridges, it may be missing entirely.

Mississippian

In the vicinity of the Fort Apache Indian Reservation, the Mississippian period is represented by the Redwall Limestone. It consists mainly
of light gray to white, dense to coarsely crystalline, thin- to thick-bedded limestone. The coarsely crystalline beds contain an abundance of segments of crinoid stems; the dense limestone is generally oolitic.

On the Reservation, the Redwall is divisible into 3 principal units. The lower unit is gray-brown, thick-bedded impure limestone 50 to 70 feet thick. It is sandy at the base and locally contains quartz geodes. The middle unit is made up of massive beds of dense, generally oolitic, cliff-forming limestone. The massive beds locally grade laterally into a rubble-breccia of large, angular to rounded, limestone blocks and angular chert blocks, separated by thin seams of red, sandy mudstone.

The upper unit of the formation is a thin- to medium thick-bedded, slope-forming limestone with gray to white nodules of chert in the lower and middle parts.

The thickness of the Redwall is quite variable, ranging from 300 feet on Black River to only 30 feet near Grasshopper (Huddle and Dobrovolny, 1952).

The rubble-breccia and mudstone is believed to represent solution channeling and consequent collapse-debris formed prior to the deposition of the overlying Pennsylvanian sediments.

Pennsylvanian

The Naco Formation of Pennsylvanian age, ranges from 400 to 800 feet in thickness and consists of a sequence of interbedded limestones, shales, and sandstones which form a ledge-and-slope topography. The limestone is dense, and generally light gray to brown in color, but locally, red-, purple-, and green-colored units are present. The beds vary greatly in thickness and are commonly nodular and shaly. The presence of red and reddish-brown chert in the limestone is one of its most persistent characteristics.

The base of the Pennsylvanian Naco Formation is a residual, red, sandy shale, and chert breccia. The zone ranges up to 60 feet in thickness, but in places is absent. In the basal 100 feet of the Naco Formation, there are stringers and lenses of conglomerate and some of these contain pebbles of chert and limestone apparently derived from the Redwall Limestone.

In the upper part of the Naco, a zone of gray limestone which weathered light brown can be recognized over a wide area. The limestone is dense to finely crystalline, silty, and generally thin-bedded. Brown limestone nodules are abundant, and most of them are partly or completely replaced by translucent red chert.

The contact between the Naco and the overlying Supai Formation is gradational and is arbitrarily drawn at the top of a sequence of gray limestones and shales, and below a sequence consisting of red sandstone and shale containing a few thin beds of limestone.

Pennsylvanian-Permian

In the Fort Apache area, the Supai Formation consists of 1,300 feet of alternating beds of reddish brown sandstone, siltstone, and mudstone; gray limestone; white gypsum; and a few beds of light-colored claystone. It is the result of nearly continuous flood-plain, deltaic, and near-shore marine sedimentation, which began near the end of Naco time, and lasted well into Permian time.

The Supai Formation is divisible into three members. The upper and lower members are predominantly clastic in nature and the middle member is composed of limestone. The formation is extensively exposed on the Fort Apache Indian Reservation, and forms the surface of much of the Carrizo Slope.

The lower member is about 800 feet thick, and consists of fine-grained sandstone and siltstones with small scale cross-bedding, and reddish brown mudstones and siltstones, locally containing channel-fill deposits. It also contains stringers and beds of gypsum and thin limestone and calcareous claystone units.

The middle member is the Fort Apache Limestone member. It is a wide-spread, easily recognized, cliff-forming unit, consisting of nearly 130 feet of medium- to thin-bedded, gray limestone.

The upper member is about 370 feet thick, and is very similar in lithology to the lower member. It does, however, contain a higher per cent of limestone units.

Permian

Permian rocks above the Supai Formation are grouped into two formations; the Coconino Sandstone, and the Kaibab Formation.

Coconino Sandstone. The Supai is immediately overlain by a sequence of sandstone beds which range in color from buff, through pale yellow, to gray white. The individual beds, which range from 1 to 3 feet in thickness, consist of medium- to fine-grained, flat-bedded, quartzose sandstones, lightly cemented with silica. Headward erosion, toward the Mogollon Rim, has removed the unit from most of the Reservation, and it is present only near the northern boundary of the Carrizo Slope-Mogollon Rim area. (See Plate 2.)

To the west, this apparent stratigraphic interval is occupied by the Coconino Sandstone, a distinctively cross-bedded unit of considerable lateral extent, and although the sandstone in the eastern portion of the Reservation is not cross-bedded, it is considered in this report to be correlative to the Coconino Sandstone.
**Kaibab Limestone.** On the Reservation, the Kaibab Limestone crops out in a narrow, discontinuous band along the Mogollon Rim, and in the ridges that extend from it. (See Plate 2.) It has a maximum thickness, on the Reservation, of about 100 feet and consists of pale-gray, massive, fine-grained limestone, in beds 2 to 6 feet thick, interbedded with an occasional unit of brown to white, friable, non-calcareous sandstone.

**Cretaceous**

Rocks of Cretaceous age rest with angular unconformity on upper Paleozoic rocks on the Fort Apache Indian Reservation. Near the northern boundary of the Reservation, the Cretaceous is in contact with the Kaibab Formation. As the unconformity is followed to the south, however, it brings the Cretaceous into contact with the successively lower Coconino Sandstone, and then, the Supai Formation. (See Plate 2.)

The Cretaceous rocks, which are unnamed on the Reservation, consist of an alternating series of yellow sandstones, gray and yellow shales, and buff to yellow calcareous sandstones. At least two layers of bituminous to sub-bituminous coal occur near the middle of the sequence, and, locally, the sandstone is very fossiliferous.

**Cenozoic**

“Rim Gravels.” Poorly to firmly consolidated gravels and conglomerate, cap many of the ridges, such as Cibecue Ridge and Spring Ridge, and can be traced to the Mogollon Rim, where they blanket large areas. These gravels were derived from the uplifted area of central Arizona, and consist of pebbles, cobbles, and boulders representative of all the older rocks in the region. The name “Rim Gravels” is applied informally to these gravels because of their abundance in the Mogollon Rim region.

**Basalt.** Basalt occurs as flows, dikes, and plugs in the Kelley Butte, Sawtooth Mountain, and Tsay-se-zhin Butte area; and in the Cow Pasture Butte area. The flows are underlain in part by “Rim Gravels,” and in part by the Supai Formation.

**Alluvium.** Recent alluvium blankets many small areas, particularly near streams, in the Carrizo Slope-Mogollon Rim area, and some larger areas, such as in the vicinity of Kinishba, are covered to a depth of several tens of feet with impure clay and soil of recent origin.

**Structure**

**Faulting**

Faults of minor displacement and small extent are common in the Carrizo Slope-Mogollon Rim area, but these are of only very local significance.

Faults of major significance (Plate 2) are confined to a zone, some 4 or 5 miles wide, which extends from the head of Carrizo Creek at the northwest corner of the area to the vicinity of Tsay-se-zhin Butte to the southeast. It is very probable that the zone continues in a southeasterly direction, but it could not be traced under the basalt cover on Bonito Prairie.

The sense of displacement on individual faults in the zone is not constant, but the net displacement across the entire zone drops the country to the south relative to that to the north.

**Folding**

Several monoclinal folds occur associated with the southeast-trending zone of major faulting. Notable examples of these can be seen in Carrizo Creek, near its confluence with Mud Creek, and in the area 4 miles south of Cedar Creek, near Sec. 18, T.5N., R.21E.

A sharp monoclinal flexure trends north-south, between Blue House and Spotted Mountains, and can be traced for several miles south from the Cibecue-Grasshopper road. Stratigraphic throw on this fold, on which the beds to the west have been relatively uplifted, amounts to about 500 feet.

**Metalliferous Mineral Deposits**

**Manganese**

Manganese, in small amounts, is widespread in the Kaibab Formation (Plate 2) in western Navajo County, and has been found on the Reservation at the base of the Kaibab, in Buckskin Canyon, on the west edge of T.10N., R.17E. (See Plate 1.) Reportedly, a zone 2 to 3 feet wide consisting of narrow veins of manganese oxides occurs in the canyon immediately west of Buckskin Canyon; it has been explored by an adit approximately 30 feet long.

The manganese deposits in the Kaibab have proved to be characteristically small and discontinuous. The so-called “ore bodies” consist of fragments and masses of manganese oxide scattered sporadically through residual soils that cover the bed rock, and as seams along bedding planes and fractures in the bed rock. Manganese minerals usually present, include psilomelane, pyrolusite, and wad (a mixture of hydrous manganese oxides with clay and iron oxides).

Additional prospecting in the Buckskin Canyon area probably will expose other manganese deposits. Under existing market conditions, however, it is doubtful that they will be commercially attractive.

**Copper**

Minor quantities of copper have been found in the Supai Formation in four locations on the Reservation (locations Cu-1-Cu-4, Plate 1). Two exposures are located on East Cedar Creek, near Big Canyon Tank No. 2 (Sec. 11, T.6N., R.21E.); one is on Middle Cedar Creek, near I-19 Tank (Sec. 2, T.6N., R.21E.); and the fourth is near Cowboy Spring on
the Cibecue road (Sec. 24, T.7N., R.18E.). The airline distance between the East Cedar Creek exposures and the Cibecue road exposure is 17 miles. This suggests that, although the mineralization is not necessarily continuous, it is quite widespread.

In all four of the mineralized areas, the visible copper mineralization occurs as malachite (copper carbonate) along bedding planes and in minute fractures in a thin bed of dark gray to black, fissile siltstone.

A shallow surface trench was cut across the mineralized zone exposed in East Cedar Creek, and the following section was measured and sampled:

<table>
<thead>
<tr>
<th>Unit number</th>
<th>Thickness feet</th>
<th>Lithology</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 (top)</td>
<td>1.0</td>
<td>dense, gray siltstone; beds (\frac{1}{4}'') to 2''</td>
</tr>
<tr>
<td>2</td>
<td>1.0</td>
<td>soft, red mudstone</td>
</tr>
<tr>
<td>3</td>
<td>0.8</td>
<td>dense, light- to dark-gray mudstone</td>
</tr>
<tr>
<td>4</td>
<td>0.6</td>
<td>dense, dark-gray mudstone</td>
</tr>
<tr>
<td>5</td>
<td>0.5</td>
<td>interlaminated gray and red siltstone</td>
</tr>
<tr>
<td>6</td>
<td>1.0</td>
<td>soft, red mudstone</td>
</tr>
<tr>
<td>7</td>
<td>0.4</td>
<td>dense, light-gray to dark-gray siltstone, copper mineralization visible on bedding planes</td>
</tr>
<tr>
<td>8</td>
<td>1.0</td>
<td>thinly laminated, gray shale, visible copper stain</td>
</tr>
</tbody>
</table>

Units 7 and 8 were assayed for copper and contained 0.15 and 0.01 per cent, respectively.

At the exposure on Cibecue road, visible copper mineralization was found along partings in a \(\frac{1}{2}''\)-inch-thick zone of dark-gray, carbonaceous siltstone at the base of an 18-inch-thick unit of light- to medium-gray, thinly bedded siltstone. A sample of the \(\frac{1}{2}''\)-inch-zone assayed 0.58 per cent copper, and a channel sample of the 18 inch unit assayed 0.19 per cent copper.

All of the deposits occur at about the same horizon in the Supai Formation, between 350 to 400 feet below the Fort Apache Limestone. (See Plate 1.) The mineralization is stratigraphically controlled and, although no commercial importance is attached to the exposures thus far discovered, the possibility of finding additional deposits of better grade in the same horizon should be considered.

GOLD

Reagan (1903, p. 306) reported the presence of placer gold in Quaternary gravel on Cibecue divide and stated that it was not mined because of a lack of water.

Cenozoic gravel caps several of the main ridges that extend south and southeast from the Mogollon Rim and these gravels were derived from the Precambrian terrane of central Arizona which is known to contain lode gold deposits. Thus, the possibility of placer gold occurring in the gravel is well-founded. The problem of obtaining water with which to work such deposits, however, still exists, and, because of the distance from the original source area, it is doubtful if gold deposits of sufficient size and grade are present to warrant the capital expense that would be necessary to furnish an adequate water supply.

Nonmetalliferous Mineral Deposits

The nonmetalliferous mineral deposits occurring in the Carrizo Slope-Mogollon Rim area are potentially among the greatest mineral assets owned by the White Mountain Apache Tribe, and they are essentially undeveloped.

Gypsum

Location and extent. Known gypsum occurrences on the Ft. Apache Indian Reservation are limited to the Permian Supai Formation. (See Plate 2.) This formation, approximately 1,300 feet thick in the area of the Reservation, has been subdivided into three parts: (1) upper Supai, (2) Ft. Apache Limestone, and (3) lower Supai. Although gypsum strata are present in both the upper and lower parts of the formation, the thickest beds are found in the upper Supai (Fig. 14). Preliminary reconnaissance indicates that potentially large near-surface deposits of good quality gypsum are present in close proximity to existing transportation routes.

History. Gypsum was observed on the Reservation as early as 1873 by Gilbert (1875), who recognized a 10-foot-thick bed of massive gypsum a few miles east of the White River and Reagan (1903) reported its occurrence in a number of localities near the communities of Whiteriver and Fort Apache. Gypsum in the form of selenite plates of considerable size was reported on that part of the Reservation within Navajo County by Blake (1904). He indicated it was found at three localities and in such quantity that it was proposed to use it in the construction of houses for the Indians.

Geology. Gypsum, a relatively soft substance, is a hydrous calcium sulfate \((\text{CaSO}_4 \cdot 2 \text{H}_2\text{O})\) when pure, but most deposits contain more or less impurities such as clay, silica, iron oxide, and calcium carbonate. The massive type of gypsum found among the strata of the Supai Formation owes its origin to accumulation as a response to evaporation of waters that contained the ingredients necessary to form gypsum. North of the Reservation, the upper Supai contains abundant evaporite materials that

*Modified from a report by Dr. H. W. Peirce, Associate Geologist, Arizona Bureau of Mines.*
include chlorides as well as sulfates (Peirce, 1966). The gypsum strata within the upper Supai of the Reservation tend to thicken in the direction of this center of evaporite accumulation.

The Supai Formation contains some gypsum throughout much of the Reservation, but probably not more than an aggregate of 7 per cent of its suggested total thickness of 1,300 feet. Although gypsum was found to occur in at least three zones within the Supai, the zone of principal interest, from the standpoint of thickness, apparent quality, ease of access, and possible exploitation sites, occurs in the upper Supai Formation approximately 200 feet stratigraphically below the overlying light-colored, resistant sandstone frequently referred to as the Coconino Sandstone (Fig. 14).

**Upper Gypsum Zone.** The “upper gypsum zone” is the interval in the upper Supai that contains gypsum. The zone, because of repetition by faulting, occurs in two roughly parallel belts that trend northwest-southeast. The belt to the northeast is upthrown and thus, is termed the “upper block.” The belt to the southwest is downthrown and is called the “lower block.”

Within the upper block, there are three principal gypsum localities. In Hop Canyon (locality G-1 on Plate 1), 8-10 miles west of U. S. Highway 60, the upper gypsum zone contains at least 40.0 feet of gypsum, including two units 16.0 feet and 11.0 feet thick, separated by 2 to 3 feet of reddish siltstone (Fig. 15). This zone was traced eastward to an area approximately one mile west of U. S. 60, in the north half of Sec. 33, T.9N., R.21E. (locality G-2), where only the extreme top of the zone is fleetingly exposed, thus requiring careful inspection to detect its presence. The gentleness of the local topography, the probability of thick deposits of good quality near the surface, and the accessibility and proximity to U. S. Highway 60 all combine to indicate that locality G-2 is the most favorable locality on the Reservation in which to conduct immediate additional exploration, should gypsum be judged of economic interest. A single shallow (less than 100 feet) core hole is all that would be required to firmly establish the thickness of the gypsum that could be exploited by surface mining methods.

Approximately 12 miles to the southeast, the upper gypsum zone is present in the headwaters of East Cedar Creek, near C-Dart Spring in Sec. 16, T.7N., R.22E. (locality G-3, Plate 1). Two gypsum beds, 14 and 30 feet thick, were measured in a steep, side-slope exposure (Fig. 15b). Although the 30 foot bed is the thickest single gypsum bed observed on the Reservation, it is judged not to be exploitable by open cut mining methods at this locality.

![Figure 14](image-url)  
**Figure 14.** Stratigraphic position of gypsum zones and gypsum localities visited in the Permian Supai Formation.

![Figure 15](image-url)  
**Figure 15.** Selected Sections of Zone 1 gypsum.
Attempts during this study to locate the upper gypsum zone in the vicinity of Highway 73 near Whiteriver, to the east, were not successful. Its absence is explained by a discontinuity in deposition created by a region of higher energy sedimentation, represented by red sandstones. Such belts or regions of active clastic deposition probably represent barriers that effectively cut off segments of saline waters that were subsequently subjected to evaporation and the accumulation of gypsum.

In the lower or down-dropped block, the position of the upper zone gypsum was examined at five localities (G-4 through G-8). Gypsum was not detected at locality G-4, along Cibecue Ridge. At localities G-5, G-6, and G-7, in Limestone Canyon, the south end of Snake Ridge, and just north of Bull Pasture Tank, respectively, the gypsum zone is less than 3.0 feet thick. At locality G-8, in Middle Cedar Creek, the upper zone is approximately 80 feet thick. This occurrence is an erosional remnant perched on top of a hill above the elevation of Cedar Creek. Additional exposures of the relatively thick upper gypsum zone might be found within the down-dropped block to the northwest and southeast of locality G-8.

These data indicate that the upper zone gypsum is exposed along two approximately parallel belts that trend northwest-southeast for a distance of about 30 miles. The gypsum in the upper block is, overall, thicker than it is in the lower block that is farther to the southwest. However, relatively thick gypsum is included in the southeastern half of the lower block in the vicinity of the lower reaches of Middle Cedar Creek.

Lower Zone. The lower zone gypsum occurs within the lower Supai Formation within a stratigraphic interval of approximately 100 feet, the top of which is approximately 200 feet below the base of the Ft. Apache Limestone Member of the Supai Formation. It consists of from 1 to 3 gypsum beds ranging in thickness from 1 to 12 feet each, and each separated by from 20 to 40 feet of clastic strata. Exposures of the lower zone gypsum are known in both the upper and lower blocks, but are more extensively exposed in the lower block. Localities G-9 through G-13 are points where the lower zone gypsum was examined. This zone is more extensively developed, areally than is the upper zone, but individual gypsum beds are notably thinner.

Localities G-9 (upper block, East Cedar Creek area), G-10 (lower block, road to Cibecue), and G-11 (lower block, Highway 60 near Long Tom Canyon) represent outcrops of the lower gypsum in steep canyon walls not subject to open cut mining methods. Localities G-12 and G-13 contain benches of gypsum at least 10.0 feet thick. The area of locality G-13 is the most favorable occurrence of the lower gypsum zone as regards accessibility, proximity to a transport route, thickness, and amenability to surface mining practices.

Locally, a third gypsum zone occurs about 50.0 feet below the base of Ft. Apache Limestone. In this position it is believed the gypsum cannot be exploited by open cut mining methods.

Exploitation. In 1965, there were five recorded gypsum mining operations in Arizona: three in Pinal County along the San Pedro Valley, one near Camp Verde in Yavapai County, and one in the Harquahala Mountains in Yuma County. Use included: (1) retarder in cement, (2) soil supplement, and (3) the manufacture, in Phoenix, of gypsum wallboard and lath. In 1965, Arizona produced 103,000 short tons of gypsum valued at $540,000 for an average of about $5.25/ton for all uses.

As gypsum is a relatively low-priced commodity, the workability of deposits is subject to stringent economic factors. At the present time, the larger existing markets for gypsum are supplied by deposits more favorably situated than the deposits on the Fort Apache Indian Reservation. The Apache Railroad at Taylor is approximately 26 miles, via State 77, from the proposed gypsum exploration site at locality G-2.

Market possibilities, because of the several occurrences of gypsum in Arizona, and with the exception of possible local applications, are seemingly limited to considerations of industry along the route of the Santa Fe Railroad. Reservation deposits will have to compete on the basis of size, accessibility, mining expense, grade, and transportation costs.

LIMESTONE

Large reserves of limestone occur on the Fort Apache Indian Reservation, particularly in the Redwall, Naco, and Kaibab Formations. Analyses indicate that deposits suitable for production of lime and cement are easily accessible. In Table 8 are listed the locations of 24 limestone samples taken for analysis. Tables 9 and 10 give the results of the chemical analyses.

Cedar Mesa deposit. In the vicinity of Cedar Mesa Tanks, northeast of Carrizo (see Plate 1 and Fig. 16), several hills are capped by fossiliferous limestone ranging from 15 to 80 feet in thickness. On the hills to the west of the tanks, the limestone is a fine-grained, dense, medium-bedded rock, up to 50 feet thick. (See sample L-22, Tables 8 and 10, and Plate 1).

Northeast of the tanks, a broad, low hill is capped by limestone above the 5,600 foot contour over an area approximately ¾ mile long by ¼ mile wide. The limestone has a maximum thickness of 80 feet and an average thickness of 25 feet. (See samples L-23 and L-24, Tables 8 and 10, and Plate 1.) This deposit contains more than 6 million cubic yards of limestone that is covered with only a few feet of alluvium. The deposit is well situated for mining, and is easily accessible. Highway 60
is about 1½ miles to the east by a jeep trail which could be improved to serve as a haul road.

**West Faught Ridge deposit.** Kaibab Limestone occurs in an isolated fault block, cutting a north-trending ridge near the west end of Faught Ridge (Plate 1 and Fig. 17). Samples L-16 and L-17 (Tables 8 and 10) are representative of the deposit.

It is estimated that the deposit contains some 1½ million cubic yards of limestone. Overburden consists of a thin covering of soil and, therefore, no initial stripping would be required. Subsequent stripping would be controlled by the condition of the rock bordering the limestone on the north and south.

This deposit, situated as it is, lends itself to mining with “dozers” instead of by power-shovel. The blasted limestone could be pushed to side hill ramps, on either side of the ridge, for loading into trucks. The maximum length of push-hauling would be 500 feet.

Spoil disposal would present no problem because of the small amount of overburden and the large canyons available to either side of the ridge. Although little level ground is available nearby for plant facilities, an operation of the size required to exploit this deposit would not require large servicing and supply areas.

**East Faught Ridge deposit.** In Sec. 22, T.8N., R.22E. (Sample L-21), near the east end of Faught Ridge (see Plate 1), limestone reserves estimated at over 4 million cubic yards are overlain by up to 100 feet of friable sandstone. The volumetric ratio of sandstone-overburden to limestone is 1.25, and there do not appear to be any major technical problems attendant to the mining of the deposit. The chief drawback at this site is its remoteness from possible markets.

**Horse Mesa region.** In the area of Flying V Canyon and Horse Mesa (see Plate 1 and Fig. 18), 15 limestone samples (Nos. L-1 through L-15) were taken, and analyses indicate that lime could be produced from the limestone in several of the horizons represented. However, the area is remote from markets, and therefore, is not considered to be commercially competitive at this time.
Summary. The four deposits described above do not represent by any means the total reserves of exploitable limestone on the Reservation. They are, however, representative of the quality of this type of material which is available, and they are indicative of the type of deposits that occur on the Reservation from the point-of-view of mining methods that would be required in their development.

Figure 18. Maps showing location of Flying V Canyon and Horse Mesa limestone deposits.
The distribution of the Redwall Limestone, Naco Formation, Fort Apache Limestone member of the Supai Formation, and the Kaibab Formation are shown on the Geologic Map (Plate 2); this should serve as an aid for future prospecting that may be undertaken to discover limestone deposits.

CLAY AND SHALE

Clay and shale deposits are abundant on the Reservation, and many of them are suitable for the manufacture of common and red brick. Two deposits are apparently of high enough grade to be used for white-ware or ceramic-ware.

Table 11 lists the locations of 19 samples that were taken from some of the clay deposits and Table 12 lists the results of burning tests. None of the samples tested were found to have bloating properties.

### Table 11. Location of clay deposits

<table>
<thead>
<tr>
<th>SAMPLE NO.</th>
<th>SEC.</th>
<th>LOCATION</th>
<th>T.N.</th>
<th>R.E.</th>
<th>REMARKS</th>
</tr>
</thead>
<tbody>
<tr>
<td>C-1</td>
<td>19</td>
<td>8</td>
<td>21</td>
<td>Creataceous shale</td>
<td></td>
</tr>
<tr>
<td>C-2</td>
<td>36</td>
<td>10</td>
<td>20</td>
<td>Creataceous shale</td>
<td></td>
</tr>
<tr>
<td>C-3</td>
<td>24</td>
<td>8</td>
<td>20</td>
<td>Kaolin from Creataceous, clayey sandstone (see S-3)</td>
<td></td>
</tr>
<tr>
<td>C-4</td>
<td>34</td>
<td>9</td>
<td>22</td>
<td>Alluvial clay, 6 feet thick where exposed</td>
<td></td>
</tr>
<tr>
<td>C-5</td>
<td>35</td>
<td>10</td>
<td>19</td>
<td>Creataceous clay</td>
<td></td>
</tr>
<tr>
<td>C-6</td>
<td>33</td>
<td>9</td>
<td>21</td>
<td>Alluvium derived from Supai</td>
<td></td>
</tr>
<tr>
<td>C-7</td>
<td>15</td>
<td>8</td>
<td>22</td>
<td>Alluvium derived from Supai</td>
<td></td>
</tr>
<tr>
<td>C-8</td>
<td>10</td>
<td>7</td>
<td>23</td>
<td>White Creataceous clay</td>
<td></td>
</tr>
<tr>
<td>C-9</td>
<td>26</td>
<td>7</td>
<td>23</td>
<td>Thin lense in Tertiary sediments, high CaCO3</td>
<td></td>
</tr>
<tr>
<td>C-10</td>
<td>2</td>
<td>9</td>
<td>21</td>
<td>Creataceous clay</td>
<td></td>
</tr>
<tr>
<td>C-11</td>
<td>27</td>
<td>7</td>
<td>23</td>
<td>Kaolin from Creataceous, clayey sandstone</td>
<td></td>
</tr>
<tr>
<td>C-12</td>
<td>10</td>
<td>7</td>
<td>17</td>
<td>Upper Naco shale</td>
<td></td>
</tr>
<tr>
<td>C-13</td>
<td>21</td>
<td>8</td>
<td>22</td>
<td>Creataceous, carbonaceous shale (upper)</td>
<td></td>
</tr>
<tr>
<td>C-14</td>
<td>21</td>
<td>8</td>
<td>22</td>
<td>Creataceous, carbonaceous shale (lower)</td>
<td></td>
</tr>
<tr>
<td>C-15</td>
<td>19</td>
<td>8</td>
<td>21</td>
<td>Alluvial clay in stream bed</td>
<td></td>
</tr>
<tr>
<td>C-16</td>
<td>19</td>
<td>8</td>
<td>21</td>
<td>Alluvial clay in stream bed</td>
<td></td>
</tr>
<tr>
<td>C-17</td>
<td>19</td>
<td>8</td>
<td>21</td>
<td>Alluvial clay in stream bed</td>
<td></td>
</tr>
<tr>
<td>C-18</td>
<td>19</td>
<td>8</td>
<td>21</td>
<td>Alluvial clay in stream bed</td>
<td></td>
</tr>
<tr>
<td>C-19</td>
<td>19</td>
<td>8</td>
<td>21</td>
<td>Alluvial clay in stream bed</td>
<td></td>
</tr>
</tbody>
</table>

Samples C-3 and C-11, which come from widely spaced exposures of the same stratigraphic horizon, are of particular interest because the clay fraction, on the basis of X-ray analysis, is high-purity kaolin.

Treatment of the material from these deposits will include washing (see sand-slime separation; Sample S-3, page 75), but this will not require unduly complicated equipment, and it is recommended that additional, detailed examination of these deposits be made to determine their size and amenability to mining and treatment on a commercial scale.

### Table 12. Results of burning clay made into bricks

<table>
<thead>
<tr>
<th>SAMPLE NO.</th>
<th>PER CENT SHRINKAGE</th>
<th>COLOR</th>
<th>FIRING TEMP. (°C)</th>
<th>QUALITY</th>
<th>COMMENTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>C-1</td>
<td>7 2 White</td>
<td>1200</td>
<td>good</td>
<td>white</td>
<td></td>
</tr>
<tr>
<td>C-2</td>
<td>3 2 Light buff</td>
<td>1200</td>
<td>good</td>
<td>common brick</td>
<td></td>
</tr>
<tr>
<td>C-3</td>
<td>4 3 Cream-white</td>
<td>1200</td>
<td>good</td>
<td>ceramic ware</td>
<td></td>
</tr>
<tr>
<td>C-4</td>
<td>9 1 Red</td>
<td>1200</td>
<td>good</td>
<td>common brick</td>
<td></td>
</tr>
<tr>
<td>C-5</td>
<td>4 2 Off-white</td>
<td>1200</td>
<td>good</td>
<td>common brick</td>
<td></td>
</tr>
<tr>
<td>C-6</td>
<td>5 3 Buff</td>
<td>1200</td>
<td>no good</td>
<td>poor workability</td>
<td></td>
</tr>
<tr>
<td>C-7</td>
<td>7 2 Buff</td>
<td>1200</td>
<td>good</td>
<td>common brick</td>
<td></td>
</tr>
<tr>
<td>C-8</td>
<td>5 2 Off-white</td>
<td>1200</td>
<td>no good</td>
<td>high silt</td>
<td></td>
</tr>
<tr>
<td>C-9</td>
<td>5 2 Off-white</td>
<td>1200</td>
<td>no good</td>
<td>high CaCO3, red brick</td>
<td></td>
</tr>
<tr>
<td>C-10</td>
<td>10 3 Red</td>
<td>1200</td>
<td>good</td>
<td>red brick</td>
<td></td>
</tr>
<tr>
<td>C-11</td>
<td>4 3 Cream-white</td>
<td>1200</td>
<td>good</td>
<td>ceramic ware</td>
<td></td>
</tr>
<tr>
<td>C-12</td>
<td>5 3 Cream-pink</td>
<td>1200</td>
<td>fair</td>
<td>common brick</td>
<td></td>
</tr>
<tr>
<td>C-13</td>
<td>6 4 Buff</td>
<td>1200</td>
<td>good</td>
<td>common brick</td>
<td></td>
</tr>
<tr>
<td>C-14</td>
<td>7 4 Light buff</td>
<td>1200</td>
<td>good</td>
<td>common brick</td>
<td></td>
</tr>
<tr>
<td>C-15</td>
<td>3 2 Off-white</td>
<td>1200</td>
<td>no good</td>
<td>brittle</td>
<td></td>
</tr>
<tr>
<td>C-16</td>
<td>4 2 Off-white</td>
<td>1200</td>
<td>good</td>
<td>common brick</td>
<td></td>
</tr>
<tr>
<td>C-17</td>
<td>6 3 Light buff</td>
<td>1200</td>
<td>good</td>
<td>common brick</td>
<td></td>
</tr>
<tr>
<td>C-18</td>
<td>6 4 Buff</td>
<td>1200</td>
<td>fair</td>
<td>soft</td>
<td></td>
</tr>
<tr>
<td>C-19</td>
<td>5 3 Light pink</td>
<td>1200</td>
<td>good</td>
<td>common brick</td>
<td></td>
</tr>
</tbody>
</table>

### Table 13. Locations of special sand deposits

<table>
<thead>
<tr>
<th>SAMPLE NO.</th>
<th>LOCATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>S-1</td>
<td>27 8 20</td>
</tr>
<tr>
<td>S-2</td>
<td>2 9 20</td>
</tr>
<tr>
<td>S-3</td>
<td>24 8 20</td>
</tr>
<tr>
<td>S-4</td>
<td>10 8 21</td>
</tr>
<tr>
<td>S-5</td>
<td>10 8 21</td>
</tr>
<tr>
<td>S-6</td>
<td>10 6 22</td>
</tr>
</tbody>
</table>

In all areas examined, the "coal" horizon of the Creataceous sequence of rocks contains considerable amounts of clay and shale. Localities C-5, C-13, and C-14 (Plate 1; Table 11) are representative of this horizon. As indicated in Table 12, good brick was produced from samples obtained at all 3 of these localities, and the physical characteristics of the brick which was produced from Samples C-13 and C-14 suggest that fire-brick could be made by regrinding and re-firing the first bricks made.

SPECIAL SAND

Several commercial categories of sand exist, and depending upon the requirements, various physical and chemical specifications have been
established for them. A few examples of these specialized categories would include foundry sand, glass sand, filter sand, and plaster sand.

Considerable quantities of sand, some of which appears to meet various of the many specialized requirements, are found on the Reservation, and 6 samples were taken from 6 different sand deposits for testing. The locations of the deposits are given in Table 13.

The results of the various tests were as follows:

Sample S-1

Screen analysis:

<table>
<thead>
<tr>
<th>Mesh: thru - on % weight</th>
<th>% wt., cumulative</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>—</td>
<td>20</td>
<td>17.8</td>
</tr>
<tr>
<td>20</td>
<td>35</td>
<td>13.0</td>
</tr>
<tr>
<td>35</td>
<td>48</td>
<td>11.2</td>
</tr>
<tr>
<td>48</td>
<td>65</td>
<td>15.8</td>
</tr>
<tr>
<td>65</td>
<td>100</td>
<td>25.7</td>
</tr>
<tr>
<td>100</td>
<td>200</td>
<td>13.5</td>
</tr>
<tr>
<td>200</td>
<td>3.0</td>
<td></td>
</tr>
</tbody>
</table>

Grains are rounded to sub-angular.

Chemical composition: (per cent)

<table>
<thead>
<tr>
<th>Fe</th>
<th>Ca</th>
<th>Al₂O₃</th>
<th>Mn</th>
<th>Na+K</th>
<th>SiO₂</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.075</td>
<td>Trace</td>
<td>0.1</td>
<td>1.0</td>
<td>Trace</td>
<td>98+</td>
</tr>
</tbody>
</table>

Microscopic examination shows dark inclusions which are believed to be in part MnO₂ and in part gas and liquid inclusions.

Sample S-2

Screen analysis:

<table>
<thead>
<tr>
<th>Mesh: thru - on % weight</th>
<th>% wt., cumulative</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>—</td>
<td>20</td>
<td>12.3</td>
</tr>
<tr>
<td>20</td>
<td>35</td>
<td>55.1</td>
</tr>
<tr>
<td>35</td>
<td>48</td>
<td>15.9</td>
</tr>
<tr>
<td>48</td>
<td>65</td>
<td>3.6</td>
</tr>
<tr>
<td>65</td>
<td>100</td>
<td>5.8</td>
</tr>
<tr>
<td>100</td>
<td>200</td>
<td>6.1</td>
</tr>
<tr>
<td>200</td>
<td>1.2</td>
<td></td>
</tr>
</tbody>
</table>

The quartz grains have submicron inclusions.

Chemical composition: (per cent)

<table>
<thead>
<tr>
<th>Fe</th>
<th>Ca</th>
<th>Al₂O₃</th>
<th>Mn</th>
<th>Na+K</th>
<th>SiO₂</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.11</td>
<td>Trace</td>
<td>0.10</td>
<td>1.0±</td>
<td>Trace</td>
<td>98+</td>
</tr>
</tbody>
</table>

A sand-slime separation was made after scrubbing the sample for 3 minutes and the following products were obtained:

<table>
<thead>
<tr>
<th>Product</th>
<th>% weight</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sand</td>
<td>74.4</td>
<td>High-grade quartz (rounded grains)</td>
</tr>
<tr>
<td>Middling</td>
<td>4.5</td>
<td>Mixture of fine, silica-sand and clay</td>
</tr>
<tr>
<td>Slime</td>
<td>20.9</td>
<td>X-Ray analysis shows high-grade kaolin clay with very low quartz.</td>
</tr>
</tbody>
</table>

The slime fraction was tested for clay application. (See Sample C-3, page 72.)

Screen analysis:

<table>
<thead>
<tr>
<th>Mesh: thru - on % weight</th>
<th>% wt., cumulative</th>
</tr>
</thead>
<tbody>
<tr>
<td>—</td>
<td>20</td>
</tr>
<tr>
<td>20</td>
<td>65</td>
</tr>
<tr>
<td>65</td>
<td>100</td>
</tr>
<tr>
<td>100</td>
<td>8.3</td>
</tr>
</tbody>
</table>

Samples S-4 and S-5

Screen analysis:

<table>
<thead>
<tr>
<th>Mesh: thru - on % weight</th>
<th>% wt., cumulative</th>
</tr>
</thead>
<tbody>
<tr>
<td>—</td>
<td>35</td>
</tr>
<tr>
<td>35</td>
<td>48</td>
</tr>
<tr>
<td>48</td>
<td>65</td>
</tr>
<tr>
<td>65</td>
<td>100</td>
</tr>
<tr>
<td>100</td>
<td>65.4</td>
</tr>
</tbody>
</table>

Sand is high-grade silica in rounded to slightly sub-angular grains.

The 5 samples tested are not presumed to be representative of all the sand and sandstone deposits on the Reservation. However, they do indicate, for example, that high-grade silica-sand is abundant in the area and the basic tests recorded above will serve as an indication to potential users of the type materials which are available.

CONSTRUCTION MATERIALS

Clay, sand, and gravel. Deposits of common clay, sand, and gravel are widespread in the Carrizal Slope-Mogollon Rim area. Thick accumulations of alluvial material can be found in practically every major stream valley in the area, and most of these accumulations contain materials that can be screened and washed to produce sand and gravel for road construction, and for use as aggregate in concrete.
The "Rim Gravels," such as those capping Cibecue and Spring Ridges, contain sand and well-rounded cobbles and small boulders that are of suitable character for use in fills and as feed for crushed-rock plants.

Many of the clay deposits described under the classification of brick and pottery clay contain material that could be used in the manufacture of adobe.

Alluvial clay, such as that sampled in Forestdale Valley (locality C-15, Plate 1), is available in parts of most of the valleys, and can be used for such things as adobe block, or impervious core-material in earth-fill dams and dikes.

None of these materials can be considered for other than local use. **Building stone.** A variety of types of stone are available in this area for use as building stone, and some could develop enough demand that they could be shipped economically to other areas.

West of Jump Off Canyon, more or less typical, cross-bedded Coconino Sandstone is exposed in the south-facing scarp of the Mogollon Rim. Flagstone and slab material are produced in quantity from the Coconino Sandstone near Ashfork and Seligman, and to a smaller degree, from near Taylor. The rock is regularly shipped by truck to Tucson and Phoenix, where it sells for from $40.00 to $60.00 per ton, depending upon size and color. Flagstone is shipped to the Los Angeles area by rail from Ashfork, for decorative facing, particularly for exterior walls and fireplaces.

Thin- to medium-bedded sandstone, suitable for dimension stone, occurs in several other formations, but in most cases it is not distinctive enough to consider shipping for any distance. Examples of this type material can be found in the lower member of the Supai Formation, in the occasional sandstone beds in the Kaibab Formation, and in several parts of the Cretaceous section.

Locally, as at locality B-1 (Plate 1), colorful diffusion-banding marks the flat-bedded Coconino(?) Sandstone east of Jump Off Canyon, and this considerably enhances its marketability.

Limestone suitable for use as dimension stone can be found in the Kaibab and Naco Formations, and in the Redwall Limestone.

Portions of the Redwall Limestone are clean, fine- to medium-grained crystalline material, which ranges from light gray to pink in color. This type limestone has a potential market as crushed rock for roofing granules.

Beds of siltstone from near the base of the Supai Formation in the Cedar Creek area (locality B-2, Plate 1), exhibit speckles and random splotching of gray, red, and brown, which would, perhaps, lend a limited appeal to the material as a decorative stone.

**Crushed rock.** Many of the limestones in the area, and particularly the Redwall, are well suited for the production of crushed rock. This material, however, probably would have only a local market.

**DECORATIVE MATERIALS**

A large number of mineral substances are found in the Carrizo Slope-Mogollon Rim area that can be used as decoration or novelty items.

Materials suitable for cutting and polishing include petrified wood from the Cretaceous rocks near the north boundary of the area, banded gypsum from the Supai Formation, Mexican onyx and travertine from spring deposits on Carrizo Creek, onyx marble from cave-deposits in the Redwall Limestone, and jasper from the Naco Formation. Numerous other materials are available for this type of use and the possibilities are limited only by the limits of the imagination of the individuals working with the materials.

Some "exotic" items which potentially would be of value to collectors, include the "cannonball" concretions of barite found in the Cretaceous sandstone on Mud Canyon Ridge, crystalline barite in the solution cavities in the Redwall Limestone, quartz-geodes at the base of the Redwall, and red, silicified fossils in the Naco Formation.

Items such as the above do not have large commercial value, but they do afford an opportunity for individuals to develop small businesses of their own.

**Mineral Fuels**

**COAL**

Probably the first report of coal occurring in the region now occupied by the Fort Apache Indian Reservation was that of Gilbert (1875) in the Wheeler Survey. He described the Cretaceous rocks that crop out some 16 miles north of Fort Apache and observed that they contain layers of bituminous coal interbedded with yellow shales. Reagan (1903) reported the coal occurring near Forestdale, and Veatch (1911) described the coal beds in the Cretaceous section near Pinedale, just north of the Reservation.

In a typical exposure near Pinedale (Veatch, 1911), the coal occurs in two seams from 10 to 15 feet apart. The upper bed is 12 feet thick and of poor quality. The lower bed is very good sub-bituminous coal from 2 to 3 feet thick. The seams lie nearly horizontal, and are workable near the surface.

The Cretaceous rocks which contain the coal crop out in several localities on the Reservation, and coal has been found at about the same
Table 14. Per cent ash in selected “coal” samples

<table>
<thead>
<tr>
<th>SAMPLE NO. (Plate 1)</th>
<th>LOCATION</th>
<th>THICKNESS (feet)</th>
<th>PER CENT ASH</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>SEC.</td>
<td>T.N.</td>
<td>R.E.</td>
</tr>
<tr>
<td>D-1</td>
<td>29</td>
<td>10</td>
<td>19</td>
</tr>
<tr>
<td>D-2</td>
<td>35</td>
<td>10</td>
<td>19</td>
</tr>
<tr>
<td>D-3</td>
<td>8</td>
<td>7</td>
<td>23</td>
</tr>
<tr>
<td>D-4</td>
<td>32</td>
<td>9</td>
<td>20</td>
</tr>
<tr>
<td>D-5</td>
<td>21</td>
<td>8</td>
<td>22</td>
</tr>
<tr>
<td>D-6</td>
<td>21</td>
<td>8</td>
<td>22</td>
</tr>
</tbody>
</table>

Table 15. Spectroscopic analyses of “coal” ash

<table>
<thead>
<tr>
<th>SAMPLE NUMBER (Plate 1)</th>
<th>ELEMENT</th>
<th>D-1</th>
<th>D-2</th>
<th>D-3</th>
<th>D-4</th>
<th>D-5</th>
<th>D-6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Silicon</td>
<td>high</td>
<td>high</td>
<td>high</td>
<td>high</td>
<td>high</td>
<td>high</td>
<td>high</td>
</tr>
<tr>
<td>Aluminum</td>
<td>high</td>
<td>high</td>
<td>low</td>
<td>low</td>
<td>moderate</td>
<td>low</td>
<td>low</td>
</tr>
<tr>
<td>Iron</td>
<td>low</td>
<td>low</td>
<td>trace</td>
<td>trace</td>
<td>low</td>
<td>low</td>
<td>low</td>
</tr>
<tr>
<td>Magnesium</td>
<td>moderate</td>
<td>low</td>
<td>trace</td>
<td>trace</td>
<td>low</td>
<td>low</td>
<td>low</td>
</tr>
<tr>
<td>Calcium</td>
<td>low</td>
<td>low</td>
<td>low</td>
<td>low</td>
<td>low</td>
<td>low</td>
<td>low</td>
</tr>
<tr>
<td>Copper</td>
<td>trace</td>
<td>trace</td>
<td>trace</td>
<td>trace</td>
<td>trace</td>
<td>trace</td>
<td>trace</td>
</tr>
<tr>
<td>Manganese</td>
<td>trace</td>
<td>trace</td>
<td>trace</td>
<td>trace</td>
<td>trace</td>
<td>trace</td>
<td>trace</td>
</tr>
<tr>
<td>Titanium</td>
<td>trace</td>
<td>trace</td>
<td>trace</td>
<td>trace</td>
<td>trace</td>
<td>trace</td>
<td>trace</td>
</tr>
<tr>
<td>Nickel</td>
<td>trace</td>
<td>trace</td>
<td>trace</td>
<td>trace</td>
<td>trace</td>
<td>trace</td>
<td>trace</td>
</tr>
<tr>
<td>Boron</td>
<td>trace</td>
<td>trace</td>
<td>trace</td>
<td>trace</td>
<td>trace</td>
<td>trace</td>
<td>trace</td>
</tr>
<tr>
<td>Vanadium</td>
<td>trace</td>
<td>trace</td>
<td>trace</td>
<td>trace</td>
<td>trace</td>
<td>trace</td>
<td>trace</td>
</tr>
<tr>
<td>Molybdenum</td>
<td>trace</td>
<td>trace</td>
<td>trace</td>
<td>trace</td>
<td>trace</td>
<td>trace</td>
<td>trace</td>
</tr>
<tr>
<td>Yttrium</td>
<td>trace</td>
<td>trace</td>
<td>trace</td>
<td>trace</td>
<td>trace</td>
<td>trace</td>
<td>trace</td>
</tr>
</tbody>
</table>

With the exception of sample D-4, the material which was tested contains too much ash to be considered for the uses applied to most coal deposits.

OIL AND GAS

Although no production of oil or gas has been recorded from the Fort Apache Indian Reservation, two stratigraphic units are considered as favorable. These are the Fort Apache Limestone member of the Supai Formation, and certain of the limestone members of the Martin Formation.

In all exposures of the Fort Apache Limestone examined on the Reservation, the rock emits a petrolierous odor when broken, and this characteristic seems to persist beyond the Reservation. Frazier (1961) suggests that further exploration of the Fort Apache Limestone is warranted, and that improved treatment of drill-holes may help bring in production from that unit.

The unevenly bedded, dark limestone near the base of the lower member of the Martin Formation also gives off a petrolierous odor when broken, and the nature of the lower contact of the Martin Formation is conducive to the formation of stratigraphic traps. As pointed out earlier, ridges of Precambrian rocks penetrate up into the Devonian sedimentary deposits, and stratigraphic pinchouts and reef structures are common. Exploration for oil in this region should include seismic studies, directed toward locating the buried Precambrian ridges, and drilling on the flanks of the ridges in an effort to hit suitable traps.

WHITE MOUNTAIN-BONITO PRAIRIE AREA

Location and Topography

The White Mountain-Bonito Prairie area embraces that portion of the Fort Apache Indian Reservation which lies to the east and south of the North Fork of White River, and includes approximately one-half of the land area of the Reservation (Fig. 7). This area occupies the higher, mountainous regions of the Reservation (11,590 feet on Baldy Peak). As a result, large portions of the White Mountains are closed by snow during several of the winter months.

Rock Units

Rocks of the Supai Formation, Coconino Sandstone, and the unnamed Cretaceous sequence (Plate 2), crop out in the region immediately east of White River and form a platform upon which the Cenozoic clastic-sediments and volcanic rocks, which cover the surface of most of the area, were deposited. These Paleozoic and Mesozoic rocks are similar in character to their counterparts occurring to the west, and descriptions of their lithologic characteristics are included in the discussion of the Carrizo Slope-Mogollon Rim area.

CENOZOIC

Sedimentary rocks. The lower portion of the Cenozoic sequence consists of sedimentary material that locally is more than 1,000 feet thick. It ranges in composition from claystone to conglomerate, but mudstone, siltstone, and sandy siltstone are the predominant rock types.

Volcanic rocks. The sedimentary rocks are overlain by volcanic rocks composed chiefly of basaltic andesite flows, agglomerate, and aggregates of pyroclastic material. These rocks form a pile that in places is more than 2,000 feet thick. Locally, dikes and plugs, which are the rock materials now filling the original vents or orifices through which the
volcanic material was extruded, forming ridges and buttes extending above the general land surface.

Younger basaltic flows and cinder cones border the central part of the White Mountains, and in places overlie the andesitic rocks. In some places, basalt flowed down valleys and canyons for great distances. In the canyon of White River, a flow extends about 30 miles from its source at McKays Peak to a point almost at the junction of the White and Black Rivers.

Structure

Folding induced by structural deformation was not recognized in the White Mountain-Bonito Prairie area.

Individual flows in the White Mountains may have dips of as much as 25°, but in most cases, this proves to be initial dip and is the result of the inclination, or attitude, of the surface upon which the flow was extruded.

Faulting is frequently difficult to detect in monolithic areas and this is the case in the White Mountain volcanic field. Directions of faulting in the basement rocks can be inferred, however, from the alignment of cinder cones and other vent phenomena, inasmuch as faults acted as the passages through which the molten lava coursed upward to the surface. The inferred fault directions common to the White Mountain-Bonito Prairie area are north-south, N.45°W., N.60°W., and N.70°E.

Mineral Deposits

Mineral production in the White Mountain-Bonito Prairie area has been limited to cinders for road-metal and railroad ballast; rock for riprap; clay, sand, and gravel for locally situated earth-fill dams; and, reportedly, some placer gold from Diamond Creek.

GOLD

Unconfirmed reports indicate that placer gold has been produced from gravels on Diamond Creek and that as much as $4.00 a day of raw gold was obtained.

The presence of gold in stream deposits in the White Mountains is quite plausible. The gravels found in the present-day drainages of the area have been reworked from the older gravels underlying the volcanics, and these gravels are thought to be related to the "Rim Gravels" and, like them, to be derived from the gold-bearing Precambrian rocks of central Arizona.

It is doubtful if gold occurs in sufficient quantities in either the "Rim Gravels" or the present stream gravels to be commercially attractive.

CINDERS

The term "volcanic cinders" is applied to clinker-like lava-rock characterized by marked vesicularity, dark color, and a texture that is partly glassy and partly crystalline. Cinders are volcanic ejecta, the fragments of which range from 4 to 32 millimeters in diameter. These are derived from magmas having the composition of a basalt, and a large gas content which, when it escapes, leaves a vesicular mass. Cinders generally occur in cone-like deposits built up around a central vent from which the material was forcibly ejected. The deposits may contain large blocks of lava-rock and both fine and coarse cinders, but the deposits are nearly always unconsolidated.

At least 40 cinder cones have been located on the Reservation (Plate 1), and a number of these have been quarried for road-metal and railroad ballast.

Several tests were made on a representative sample of cinder material from location F-1 (Plate 1) with the following results:

SCREEN ANALYSIS

<table>
<thead>
<tr>
<th>MESH (INCHES)</th>
<th>WEIGHT %</th>
</tr>
</thead>
<tbody>
<tr>
<td>on 1.0</td>
<td>0</td>
</tr>
<tr>
<td>thru 1.0</td>
<td>7.6</td>
</tr>
<tr>
<td>0.75 thru 0.312</td>
<td>41.0</td>
</tr>
<tr>
<td>0.312 thru 0.263</td>
<td>13.0</td>
</tr>
<tr>
<td>0.263 thru 0.185</td>
<td>21.6</td>
</tr>
<tr>
<td>0.185</td>
<td>16.8</td>
</tr>
</tbody>
</table>

CHEMICAL ANALYSIS

<table>
<thead>
<tr>
<th>CONSTITUENT</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>SiO₂</td>
<td>45.3</td>
</tr>
<tr>
<td>FeO</td>
<td>20.5</td>
</tr>
<tr>
<td>CaO</td>
<td>2.2</td>
</tr>
<tr>
<td>MgO</td>
<td>8.1</td>
</tr>
<tr>
<td>Al₂O₃</td>
<td>17.6</td>
</tr>
<tr>
<td>Na</td>
<td>&lt;2.0</td>
</tr>
<tr>
<td>K</td>
<td>&lt;2.0</td>
</tr>
</tbody>
</table>

Microscopic examination showed that small amounts of magnetite, olivine, and zircon occur as discrete crystals.

The material sampled has a bulk density (dry basis) of 44.7 pounds per cubic foot, suggesting that it may be usable as aggregate in cinder blocks. When used in the manufacture of block, the cinders are usually crushed and screened into two or more sizes and blended to obtain a desirable mix. Considerable home building, both public and private, is being done on and near the Reservation and this would apparently indicate a ready market for such a product.

In residential developments, cinders are used also as roofing granules and to cover walkways and patios.

Cinders which are ground smaller than 12 mesh are frequently marketed as soil conditioning agents. In such application, the material serves to hold the soil open, and to keep it friable. Little or no nutritive value or plant food benefit is claimed.
CONSTRUCTION MATERIALS

Clay, sand, and gravel. Small, thin deposits of clay, silt, sand, and gravel, younger than the volcanic rocks, occur in many of the valleys of the White Mountains and in most of the basins or cienegas of both the White Mountain and the Bonito Prairie portions of the area. Depositional sorting of these materials during their accumulation was generally poor; it seems to have been controlled largely by the source of supply and by the amount and vigor of the water which governed the depositional activity. Deposits of coarse-grained sand and gravel occur along the courses of larger streams and in narrow canyons along the reaches of small streams. Silt and clay predominate in the larger valleys. In some wide valleys, there is a gray-brown alluvial material that is less permeable than the younger deposits.

Sand and gravel reserves are immense in the Cenozoic sedimentary deposits underlying the volcanic rocks. Extensive deposits are exposed in the Seven-Mile Hill area, along the middle reaches of Diamond Creek, and along the upper parts of the North Fork of White River.

These materials, with proper treatment, are suitable for use in local highway construction, as earth-fill for dams being constructed in the development of recreational facilities, and, with appropriate sizing and washing, they serve well for concrete aggregate.

Building stone. Several varieties of stone occurring in the White Mountain-Bonito Prairie area are suitable for use as building stone. None, however, are considered exceptional enough that they could support the cost of transportation beyond very local markets.

On East Fork of White River, the Fort Apache Limestone member of the Supai Formation crops out near road level in beds ranging from 6 inches to several feet in thickness. This rock could be used for dimension stone.

Large quantities of basalt suitable for use in exterior walls and in fireplaces are available in the White Mountains.

Flaggy and slabby sandstone beds in the Supai Formation crop out at several localities east of North Fork of White River. These are usable as dimension stone, light duty paving stone, facing material, and flagstone.

Medium-bedded sandstone in the Coconino(?), occurs below the Lower Logging Road in Sec. 27, T.7N., R.23E. This rock could be used as rough dimension stone for local consumption.

POTTERY CLAY

A clayey sandstone unit in the Cretaceous rock sequence, similar to that sampled at location C-3 (Plate 1) and probably representing the same horizon, occurs near the Lower Logging Road (Location C-11, Plate 1). The clay fraction is of ceramic grade, when separated from the sand.

DECORATIVE MATERIALS

Mineral substances suitable for the manufacture by local artisans of decorative or novelty items also occur in this area.

A large deposit of travertine crops out along the North Fork of White River, on the road to the Alchesay Fish Hatchery. This deposit, known as the Alchesay Spring deposit, is linear in shape, covers about 800 acres, and is as much as 250 feet thick. Banded material occurs locally and it can be cut and polished to make book ends, desk sets, and similar items.

Although not encountered during this investigation, it is possible that segregations of olivine constituting sources of peridot occur associated with the younger basaltic rocks. The areas in the vicinity of cinder cones would be likely places to prospect for these segregations.

LITERATURE CITED


Melhase, John, 1925, Asbestos deposits of Arizona: Engineering and Mining Journal, v. 120, no. 21, pp. 805-810.


Veatch, A. C., 1909, Coal deposits near Pinadel, Navajo County, Arizona: U. S. Geol. Survey Bull. 431, p. 239-242


Recent alluvium and stream deposits.

Basaltic flows and pyroclastic material.

QTb: andesitic to basaltic flows, tuff, and agglomerate; QTti: basaltic plugs and dikes.

“Rim Gravels.” Predominantly sand and gravel.

Kaibab Formation.

Coconino Sandstone.

Supai Formation.

Naco Formation.

Diabase

Troy Quartzite. Locality: sandstone of Cam!.

Mescal Limestone.

Lower Apache includes in descending Dripping Spring Quartzite and Pioneer Shale.

Greenstone and mafic dykes.
Apache Group, undifferentiated.

Includes in descending order, the Dripping Spring Quartzite and Pioneer Shale.

Troy Quartzite. Locally may include sandstone of Cambrian age.

Mescal Limestone.

Lower Apache Group. Includes in descending order, the Dripping Spring Quartzite and Pioneer Shale.

Apache Group, undifferentiated.

Diabase

Greenstone and metavolcanic.
GEOLOGICAL MAP OF THE FORT APACHE INDIAN RESERVATION, ARIZONA

CONTOUR INTERVAL 200 FEET
Scale 1:250,000

by
Richard T. Moore, and H. Wesley Peirce.
1967

Sources of Data

4. Peirce, H. Wesley, this report.

Legend:
- Contact, Dashed where approximately located
- Fault, Dashed where approximately located
- U, upthrown side; D, downthrown side
- Strike and dip of beds
  - Axis of monocline
- Undifferentiated