MAPS

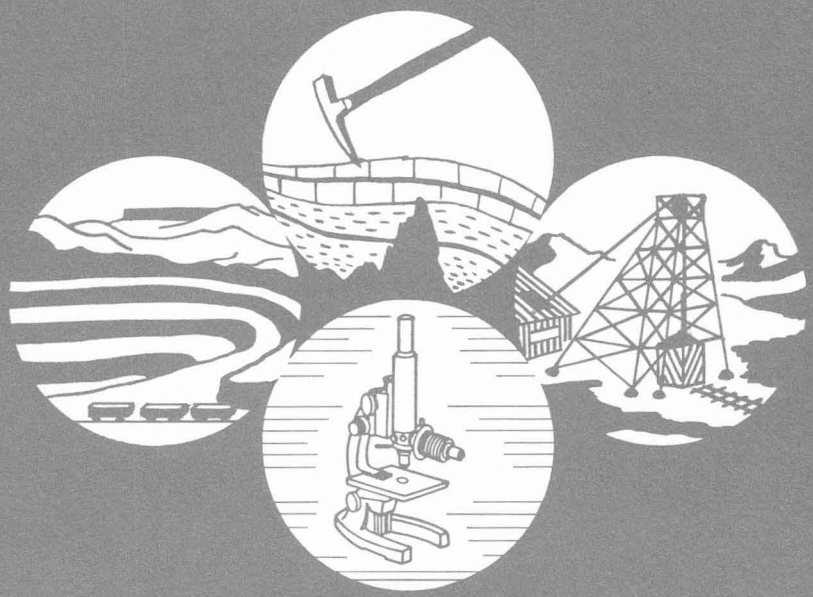
with special reference to the

GEOLOGIC AND MINERAL MAPS OF ARIZONA

By
J. D. Forrester, Director, *and*
Richard T. Moore, Associate Geologist

THE ARIZONA BUREAU OF MINES

Bulletin 170
1962



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FOREWORD

This bulletin of the Arizona Bureau of Mines about the nature and use of maps has been prepared for two purposes, namely;

1. To assist the reader in comprehending how a given map may be used and interpreted most satisfactorily to gain full knowledge of the information being portrayed by the map.

2. To give supplementary account about the several maps that are component parts of the Folio of Geologic and Mineral Maps of Arizona, issued by the Arizona Bureau of Mines and, also, to serve as a companion piece with Bulletin 171 of the Arizona Bureau of Mines, titled; "A Résumé of the Geology of Arizona," prepared by Eldred D. Wilson, Geologist.

J. D. Forrester, Director
Arizona Bureau of Mines,
University of Arizona, Tucson.
August, 1962.

INTRODUCTION

A map is a symbolic or pictorial representation of particular features that may be either natural or man-made and which exist throughout a given portion of the earth's surface or crust. This being the situation, it follows logically as a precept of map-making, that it (the map) always should be designed to show to the best advantage possible the specific phenomena which the map is designed to portray.

The more common types of maps are those that diagrammatically depict conditions as they would appear on the surface when viewed from above, as from an airplane. These maps, showing the relative positions of features in a horizontal plane, are called "plan maps" or "areal maps." Other, more specialized diagrams may be developed also to present a sectional picture such as that of an end-view or a side-view of given phenomena. Thus, these drawings show conditions which reach in depth rather than throughout a horizontal extent, as is the case of plan maps. When they are made to depict an end-view, they are called "cross-sections" or, sometimes, "elevations"; when the diagram is prepared to demonstrate a side-view, it is designated as a "longitudinal-section" or a "profile." There are several individual areal maps and cross-sections among the collection of the Folio of Geologic and Mineral Maps issued by the Arizona Bureau of Mines, but there are no longitudinal-sections.

Before proceeding further with a discussion of the maps and cross-sections that have been assembled by the Arizona Bureau of Mines, it will be helpful perhaps to the non-professional reader to review some of the general or elementary rules which apply to map-making and to map interpretation. Therefore, the following general rules are presented about maps and cross-sections:

1. As noted above, a given map always is developed to depict specifically a condition or feature of particular interest. That is, some areal maps are made especially to show geologic conditions as they occur on the earth's surface; some are made fundamentally to demonstrate topographic features; and others are constructed to depict roads and

highway systems. Therefore, each would be designated respectively as a "geologic map," a "topographic map," and a "road map." The classification in each case is made on the basis of the fundamental feature which the map is designed to illustrate. Another type of map may be planned to show real estate boundaries, such as are used in defining residential sub-divisions and, in other instances, the map may be made to demonstrate the existence of underground or surface mine excavations and it would be identified accordingly as a "mine map."

It should now be apparent to the reader that the possible range of types of maps is very great.

In addition to the separate phenomena for which a given map is constructed, it is often feasible and desirable to depict supplementary features. Thus, for example, many geologic maps frequently will indicate also accessory topographic and cultural details, such as streams, hills, roads, and mines.

2. An important precept to be observed in all map-making is that the dimensions on which the map diagram is developed must be large enough to accommodate the degree-of-exactitude and fineness-of-detail which are needed to show the features being portrayed. That is, if considerable detail is required, it is not possible to satisfactorily or properly demonstrate the relations if the size (area) of the map is too small compared with the area of the region it represents. The map-maker always must take this matter into account.

It follows logically that a "Scale" must be indicated on a map in order for a reader successfully to interpret the relationships of how distances on the map are representative of distances on the ground or surface. This is done for areal maps by using any one of three methods, as follows:

Verbal Scale: Such as, for example, by a statement on the map that One (1) inch equals Six (6) miles.

Graphic or Bar Scale: A diagram, where distance units which are the equivalent of field extents, are depicted as a type of "ruler." A Graphic or Bar Scale is shown in Figure. 1.

Ratio or Fraction Scale: Such as, for example, where 1 : 375,000 (ratio) or $\frac{1}{375,000}$ (fraction) is used. Each of these mathematical expressions means that a distance of one unit (inch or foot, etc.) on the map is equal to 375,000 similar units in the field.

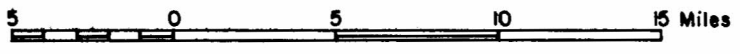

Fig. 1. Graphic or Bar Scale.

On cross-sections or profile diagrams, a horizontal scale should be identified and shown by one of the above methods and, also, because some exaggeration of the vertical range of the section often is required, it is necessary that the vertical scale be stated. This is done commonly by indicating the vertical distances by means of unitized "tick marks" along the side limits of the diagram. For further details of this matter, the reader is referred to the later discussion (page 7) about Geologic Cross-sections and to the several cross-sections which constitute a part of the Folio of Geologic and Mineral Maps of Arizona.

3. A map should have a "Title" which describes the map's identity and the phenomena it portrays. Also, the map should be dated, and the agent responsible for the map should be indicated.

In the matter of a cross-section or profile, which usually is made in vertical projection, the bearing (horizontal direction) of the plane-of-projection should be defined either in the title of the plat or at some other strategic position on the diagram.

4. In addition to the Title, every map diagram should have an "Explanation" or "Legend" which defines the symbols that have been used to portray the various features for which the map has been designed.

The distinctions of geologic phenomena on the County Geologic Maps issued by the Arizona Bureau of Mines, have been accomplished chiefly by using colored line-symbols and patterns. The lighter, pastel shades of colors like yellow, pink, etc. have been used, in general, to indicate the occurrence of sedimentary rocks whereas the vivid, more intense color patterns, such as deep red, purple, etc. have been employed for igneous and metamorphic rock materials. This system is similar to the one employed on most geologic maps that are issued by various Federal and State agencies. The reader will gain further knowledge of the various relationships by studying the Explanation presented on each of the County Geologic Maps.

Whenever other features of a map may require a definition of their meaning or significance, then such items should be explained. For example, on a topographic map where the relative land relief (presence of streams, hills and valleys) is shown by means of contour lines, the "Contour Interval" or "C.I." should be stated. A "Contour Line" is a line on the map along which all points, as they occur in the field, are at the same elevation with respect to some datum of reference, such as sea level. A contour line, therefore, represents a horizontal line in the field, and the contour interval is the vertical distance existing between adjacent contour lines.

5. Wherever possible, every map should be oriented with reference to the controls of latitude and longitude. For an areal or plan map this

means the diagram is made so that north-south and east-west lines of reference are shown. Also, the common practice of map-making is to draw it (the map) so that the top of the map sheet is North. Therefore, West is to the viewer's left, East is to the right, and South is toward the bottom of the sheet.

In the case of a cross-section or profile, the top of the diagram is comprised, of course, of the upper phenomena being portrayed. The left-hand and the right-hand sides or ends of the sketch are fixed respectively by the direction in which the view of the features has been taken.

GEOLOGIC AND MINERAL MAPS OF ARIZONA

Inasmuch as this treatise on maps has been prepared with special reference to the Geologic and Mineral Maps of Arizona which, for most convenient use, have been assembled as a complete collection in the "Folio of Geologic and Mineral Maps of Arizona," the following discussion is presented in the sequence of four broad categories; each being a component part of the Folio, as a whole. The reader should understand, of course, that individual copies of the maps may be obtained also as separate items from the Arizona Bureau of Mines.

The map categories are:

A. Geologic Maps.
B. Geologic Cross-sections.
C. Outcrop Maps.
D. Mineral Occurrence and Mining District Maps.

A. Geologic Maps.

A Geologic Map is an areal map and is one made fundamentally to depict the occurrences of rock materials and geologic structures existing at the surface of the earth in a particular region. Because some of these natural phenomena may be older than others, and, as some are of different types, the distinctions that are defined on a given map are basically those of; 1. Establishing the kinds of rocks and/or structures which occur; and 2. Classifying the relative ages of such features with respect to other associated phenomena that are present within the area encompassed by the map. These distinctions, as has been explained previously, are accomplished by explanatory or legend symbols.

There are fourteen counties in Arizona and each has been mapped so that the geologic environment has been suitably and conveniently represented on a scale of 1 : 375,000. A separate map has been made for each county except in those cases where the size and shape of contiguous

counties have efficiently permitted a procedure where two counties can be depicted together as a map unit.

Therefore, the individual County Geologic Maps of Arizona which have been issued by the Arizona Bureau of Mines are as follows:

1. Coconino County
2. Cochise County
3. Gila County
4. Graham-Greenlee Counties
5. Maricopa County
6. Mohave County
7. Navajo-Apache Counties
8. Pima-Santa Cruz Counties
9. Pinal County
10. Yavapai County
11. Yuma County

Although the primary purpose of presenting the County Geologic Maps has been to demonstrate the geologic relationships, it has been possible to depict also, in a more or less subdued manner, the topography and some cultural or man-made features. Thus, without unduly distracting the reader's attention or hindering his interpretation of the geology, it has been feasible to show some roads and towns and, also, major "land relief" features such as the occurrences of significant valleys, streams, hills, and mountains. These latter natural phenomena have been portrayed by using contour lines on a contour interval (C.I.) of 500 feet, a practice which has been explained previously (page 3). To have such a combined map showing not only the geologic conditions but the topographic features, as well, often is of special value in comprehending the natural physical picture of a given area. That is, the map which thus is available for interpretation, frequently can be used to good advantage to determine the inter-relations of the land relief and the geologic complexities and, on the basis of the following rules, it is often possible to read almost at a glance, the significance of the essential natural phenomena as they occur on the surface. The general rules are:

1. Narrow, ribbon-like, lineated geologic exposures commonly indicate the presence of inclined, tabular rock materials and structures. Such phenomena may be those of stratified (layered) masses or they may represent the occurrence of veins (ore deposits), faults, and dikes (igneous, tabular structures). For examples of this type of phenomenon, the reader is referred to the Geologic Maps of Coconino County (36°30′ Lat. — 111°30′ Long.); Apache County (35°30′ Lat., near the extreme eastern border with New Mexico); and Cochise County (extreme southwest corner).

2. Flat-lying rock masses, particularly those of recent, surficial nature, such as have been accumulated in valley areas, generally have irregular lines of demarcation and long, tongue-like extents where they approach the base of adjacent higher lands. Illustrations of these features may be seen to especially good advantage in the northwest portion of the Geologic Map of Gila County and in the southwest part of Cochise County and, also, in various other sections of the State.

3. Except in cases which the specialist will understand, the line-of-outcrop of a geologic formation usually "bends" upstream when the rocks or structure are incised or cut by a transverse valley or stream channel. This sometimes gives the appearance of a "sawtooth" effect on the geologic map. Examples of this condition may be observed in the Geologic Maps of Coconino County (northwest portion); Navajo- Apache Counties (36°30′ Lat. — 110° Long.); and Graham County (33° Lat. — 110° Long.).

4. Where faulting has occurred to appreciably disturb the rocks of the earth's crust, the older formations of the geologic sequence which has been involved in the adjustments usually are on the relative upthrown side of the fault trace. Good illustrations of this type of phenomenon occur on the Geologic Maps of Apache County (36°15′ Lat., approximately 10 miles west of the New Mexico border); Gila County (northwest section); Yavapai County (north central portion); and Mohave County (northern section).

5. Irregular, often more or less circular, elliptical, or pod-like rock outcrops are those forms generally assumed by large igneous masses such as granite occurrences that now are exposed at the surface. These phenomena are demonstrated in the Geologic Maps of Yavapai County (34°45′ Lat. — 112°45′ Long.); Graham County (33° Lat., about 10 miles east of the Pinal County border); Pinal County (33°15′ Lat. — 111° Long.); and Mohave County (35° Lat. — 114°30′ Long.).

6. A given sequence of stratified rocks, if it has been deformed into an upwarp or "anticline" after original deposition of the strata, depicts older rocks bounded progressively by younger ones. Conversely, the presence of a downwarp or "syncline" is evidenced by younger rocks bounded progressively by older materials. These relations may be seen respectively on the Geologic Map of Navajo-Apache Counties at 35°45′ Lat., near the New Mexico-Arizona border, and at 36°05′ Lat. — 110° Long. Also, an anticlinal structure is similarly defined on the Coconino County map in the vicinity of 36°30′ Lat. — 112° Long.

7. In the case of Contour (topographic) Maps, the following rules apply:

A. Contour lines never cross each other except in very unusual

circumstances, such as where overhanging cliffs extensively exist in the field.

B. When a contour line is platted across a stream or valley, it bends or migrates upstream.

C. Contour lines "arc" around abutting hills and, depending on the nature of the high land and the contour interval being used, they may form closed, more or less circular or elliptical patterns near the tops of the hills and mountains.

D. The closer that adjacent contour lines are together, the steeper the slope of the ground or surface. Conversely, the wider the space (horizontal) between them, the more gentle the slope they represent.

The application of the above rules, together with some others of more technical nature, to the reading of geologic and topographic maps can be an extremely interesting and entertaining activity and it is hoped the above rather elementary discussion will cause the reader to be attracted to further interest in acquiring more complete knowledge of events that have occurred in the earth's crust. Arizona shows a remarkable range of geologic and topographic phenomena and it is a veritable field laboratory which is available at first hand to the professional geologist and layman alike.

B. Geologic Cross-Sections.

As previously noted, a cross-section is an end-view diagram or elevation plat and, therefore, it generally is represented as a vertical slice or cut that has been taken along a given line on the surface. It has a vertical attitude which is in marked contrast to the horizontal projection of an areal or plan map.

The geologist, by using a geologic-topographic map as a base reference, often can make salient cross-sectional interpretations of the geologic relations which exist beneath the earth's surface. Therefore, given a suitable base map, it is possible to construct a vertical diagram which depicts the profile of the ground and, also, the position and character, in depth, of geologic features that have been observed and recorded on the surface.

The procedure of making a cross-sectional interpretation is as follows:

1. A decision is made as to the selection of a line on the surface of the areal map along which the cross-section will be constructed. This line is known as the "line-of-section." It usually is chosen because the geologist considers it will constitute a good control that will result in a cross-sectional diagram which will portray especially significant or interesting phenomena beneath the surface. Thus, it is apparent the line along which

the cross-section is made can be fixed wherever desired in order to show particular relations of special interest, for one purpose or another.

2. In the next step, by an engineering process of correlating the elevations of the ground occurring along the line-of-section with an interpretation of the geologic relations, it is possible to design a depth projection which forms the geologic cross-section. In order to accomplish such a process of interpretation and construction, and to depict satisfactorily the various relations, it often is necessary to exaggerate the vertical scale of the diagram. If some exaggeration is not done, even though the process results in a degree of distortion of the true picture, the vertical range is so limited that it usually is not possible to show the details of the geologic phenomena with sufficient clarity.

By comparatively studying the diagrams of Figures 2 and 3, the reader will comprehend some of the effects which ensue when exaggeration is, or is not, undertaken.

Figure 2 shows a cross-section where no exaggeration has been made. Therefore, the horizontal and vertical scales are equal at 1 : 375,000. This is the scale (horizontal) of the County Geologic Maps that have served as the work bases for construction of the geologic cross-sections which have been prepared by the Arizona Bureau of Mines.

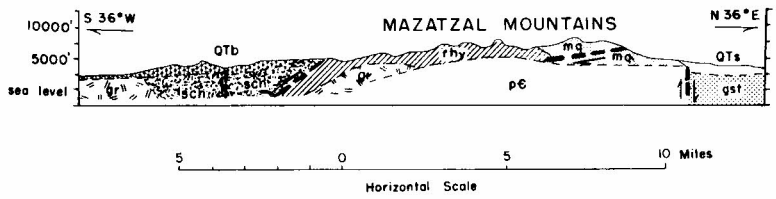

Fig. 2. Geologic Cross-section.

Figure 3A is a diagram where the horizontal and vertical scales are equal but now are both expressed as a ratio of 1 : 187,500. This diagram is four times the area of Figure 2 and, thus, it affords considerably more space for the drafting procedure.

Figure 3B represents a cross-section assembled on a horizontal scale of 1 : 187,500 and on a vertical scale where one inch equals 5,000 feet. It is of such dimensions that it has been possible to satisfactorily demonstrate the various geologic and topographic phenomena.

The reader will see that neither Figure 2 nor Figure 3A is entirely suitable for the purpose of showing the details which are desired. Figure 2 is too small to permit the expression of geologic and topographic relation-

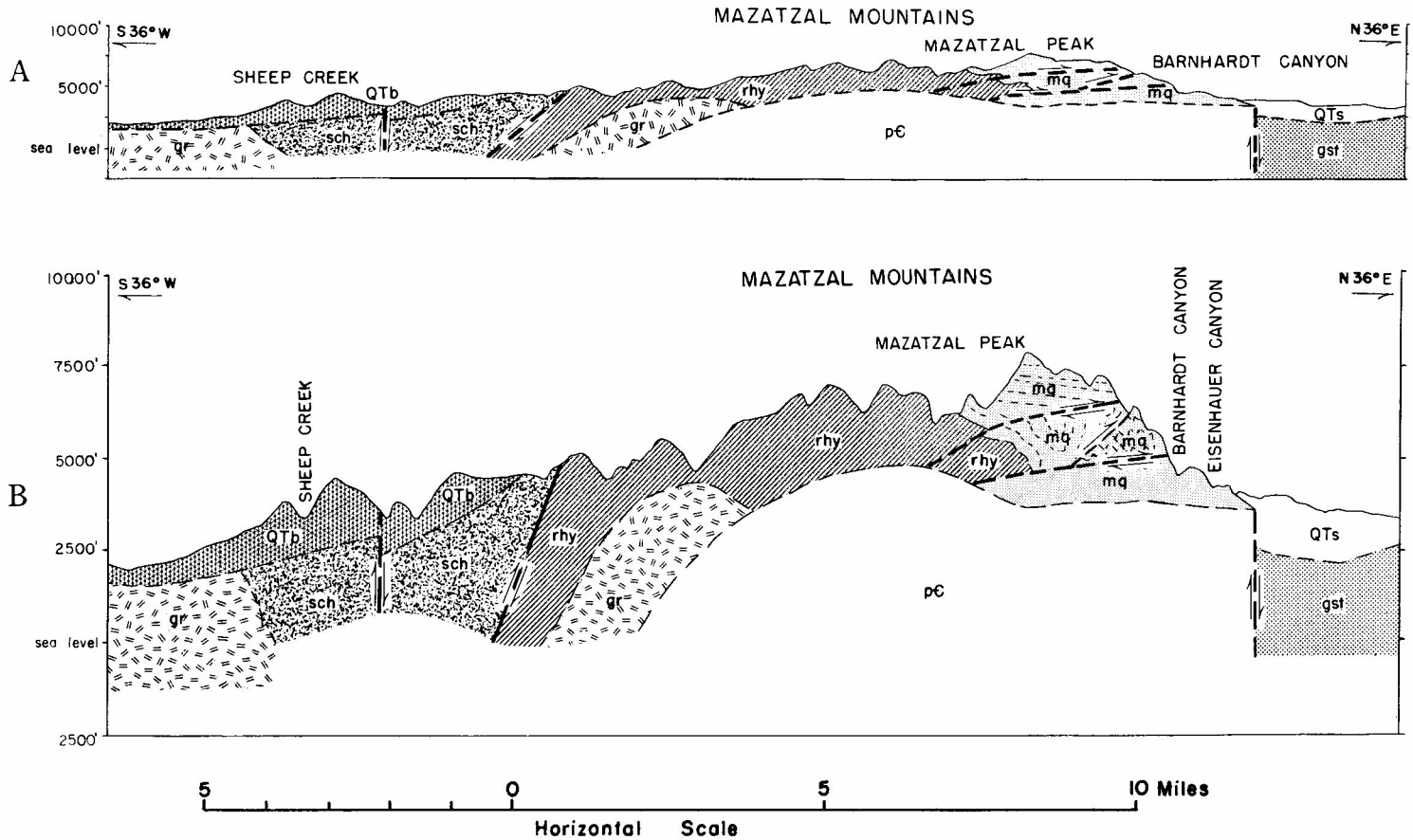

Fig. 3A and 3B. Geologic Cross-sections.

ships with sufficient clarity. For example, it is not possible to display the complex pattern of faulting known to be present in the eastern part of the Mazatzal Mountains and considerable generalization is required. In Figure 3A, although the major faults are shown, the details of folding in the rocks must be omitted because there is insufficient vertical space to allow for the plotting of these features. Therefore, in order to depict the sectional relations to proper advantage, the horizontal and vertical scales which have been applied in Figure 3B have been used for constructing the Geologic Cross-sections issued by the Arizona Bureau of Mines. This has been deemed necessary even though considerable distortion of the attitude of the rocks and structural features has been introduced by the approximately three-fold exaggeration of the vertical scale.

The cross-sectional diagrams assembled by the Arizona Bureau of Mines have been made along several lines-of-section in the State and they are incorporated in the Folio of Geologic and Mineral Maps of Arizona. They have been designated as Sections 1 through 8 and each has been selected to demonstrate especially strategic information concerning the sub-surface geologic relations. The direction-of-view in all of the cross-sections is in a northerly direction.

An Index Map, showing the various lines-of-section, has been developed as a plan map and it is made available also so the reader can readily identify the significance and scope of each of the sections.

C. Outcrop Maps.

The Maps of Outcrops of various rock materials in Arizona are a type of areal map and they have been developed as a convenient means whereby the present occurrence and distribution are shown of rocks formed during particular times of the geologic past. Thus, each of these maps depicts only the current existence of rocks which were deposited at some definitive time interval of the earth's history. The chief value of such a map lies in the fact that the reader is able to grasp "at a glance" the geographic distribution of certain rock materials because the picture of their occurrence is not complicated by the illustration of rocks formed during either an earlier or a later age.

The Outcrop Maps of the Folio of Geologic and Mineral Maps of Arizona are:

1. Map of Outcrops of Precambrian Rocks in Arizona.
2. Map of Outcrops of Paleozoic and Mesozoic Rocks in Arizona.
3. Map of Outcrops of Laramide (Cretaceous-Tertiary) Rocks in Arizona.
4. Map of Outcrops of Tertiary and Quaternary Igneous Rocks in Arizona.

The further significance of each of the above maps is treated in the discussions of Bulletin 171 of the Arizona Bureau of Mines, titled; "A Résumé of the Geology of Arizona."

D. Mineral Occurrence and Mining District Maps.

Three separate areal maps, each on a scale of 1 : 1,000,000, which is the equivalent of one inch (map) to approximately 16 miles (field), have been issued by the Arizona Bureau of Mines to assist the reader in gaining a knowledge of the distribution of some of the economic mineral substances in Arizona. These maps are:

Map of Known Metallic Mineral Occurrences in Arizona.

This map shows the general distribution of metallic mineral materials occurring in the State of Arizona. The various known occurrences of different mineral substances are depicted and distinguished by means of color-block symbols which are defined by a reference legend and index on the map. The information imparted by this map gives no measure of potential quantity or relative value of the deposits of the different substances. Twenty-nine separate types of metallic materials are platted.

Map of Known Nonmettalic Mineral Occurrence in Arizona.

This is a companion piece to the Map of Known Metallic Mineral Occurrences of Arizona and its format is very similar. That is, by means of color symbols which are comprehensively indexed, the occurrence of 50 types of economic nonmetallic or industrial mineral substances is demonstrated over the State. Just as in the case of the Map of Known Metallic Mineral Occurrences, this chart gives no ready measure of the relative quantity of the various mineral commodities.

Map and Index of Mining Districts in Arizona.

The Map and Index of Mining Districts of Arizona has been compiled to serve as a reference whereby the general location and specific names of the several mining districts of the state can be identified. Because of the complex and overlapping nature of the many districts, it has not been practicable to delineate the individual boundaries of the units.

The records of mining claim locations and mineral property ownerships occurring within the limits of the respective counties of Arizona generally are kept in the County Recorder's office at the County Seat. Therefore, to give assistance in identifying places where such records repose, the county borders and the names of the county seats have been defined in red on the map.

ARIZONA BUREAU OF MINES

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SERVICES AVAILABLE FROM ARIZONA BUREAU OF MINES THE UNIVERSITY OF ARIZONA, TUCSON, ARIZONA

The Arizona Bureau of Mines, which functions as a part of the University of Arizona, Tucson, is conscious of its opportunities and responsibilities to render continuing service about mineral resources to the people of Arizona; accordingly it has a program of operation designed to contribute as many sound benefits as possible. The broad objectives of this program are to:

1. Prepare and publish bulletins and circulars containing authoritative information on a wide range of topics of interest to prospectors, miners, and others concerned with the development of Arizona's mineral resources and industries. The bulletins are distributed free of charge to residents and at cost to non-residents of Arizona upon request.

2. Classify mineral and rock specimens. Besides identifying rocks and giving the composition of minerals, the Bureau makes qualitative tests for important elements and answers inquiries concerning the probable market for and the economic value of material similar to samples submitted. This service is furnished free of charge providing the specimens originate within the State of Arizona; a charge of $1 per specimen is made for samples submitted from outside the State. When spectrographic analyses or detailed microscopic determinations are desired, they are furnished at established rates, a schedule of which will be submitted on request.

3. Conduct laboratory and pilot-plant metallurgical testing of mineral substances in cooperation with industries and individual mine operators in the State. Such tests are conducted on the basis of nominal charges to compensate for wear and depreciation of equipment needed in the experimentation.

4. Make geologic investigations of mining districts and counties and compile geologic maps and reports. Geologic maps of each county, on a scale of 1:375,000, have been issued. As a product that will result from the compilation of data for the county map issues, a new Geologic Map of the State, as a whole, will be established on a scale of 1:500,000. It is hoped that this map can be finished in 1962.

5. Maintain a working file of statistical records of mineral production in Arizona.

6. Develop well-log storage facilities and a library of data pertaining to oil and water wells drilled in Arizona.

7. Conduct state-wide commodity studies as to modes of occurrence and potential industrial value of various mineral materials.

8. Collect and file items relating to Arizona mines and minerals that appear in Arizona newspapers and in many technical periodicals.

The basic philosophy which obtains in the operation of Arizona Bureau of Mines is that of providing for the people of Arizona mineral services which cannot be readily secured elsewhere. That is, the Bureau gives advice and service which cannot be obtained conveniently from commercial sources. Competition with industrial concerns is not engaged in and therefore, any work of this nature, such as assaying, is not pursued. An inquiry addressed to the Director, Arizona Bureau of Mines, the University of Arizona, Tucson, will bring a prompt response if further information is desired about the services which are available.

All communications should be addressed and remittances made payable to the Arizona Bureau of Mines, The University of Arizona, Tucson, Arizona.