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A VIEW OF SUBSIDENCE

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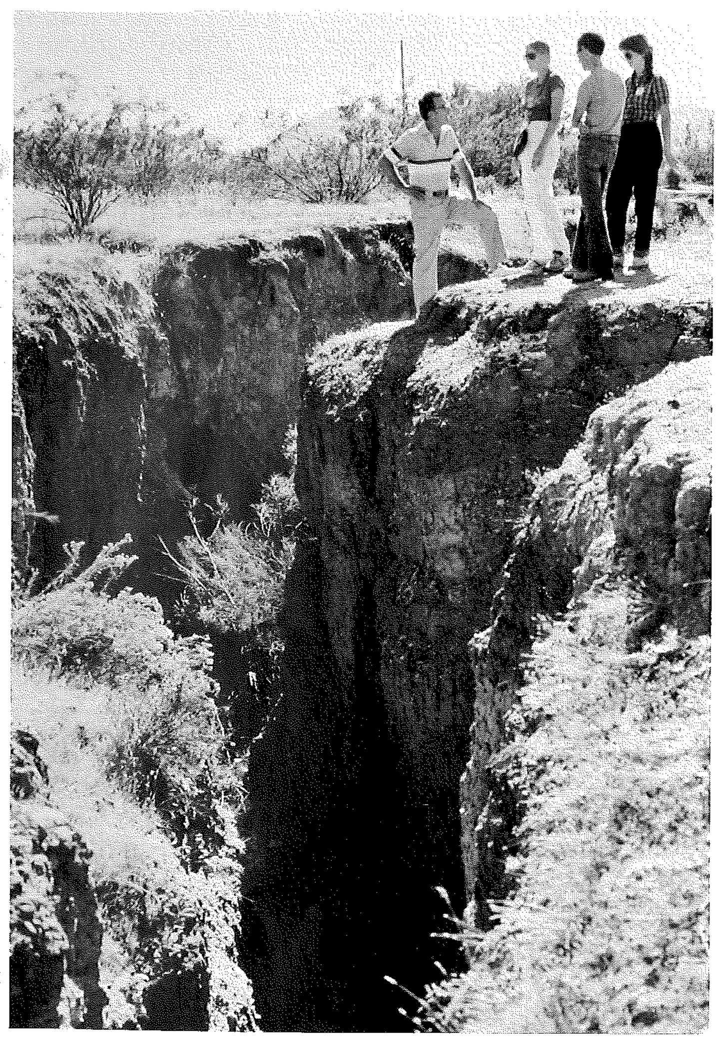

Figure 1. Giant earth fissure near Chandler Heights, Arizona. Earth fissures begin as tiny cracks, but become enlarged by water erosion and collapse of adjacent soils. This fissure is related to subsidence due to ground-water withdrawal. Photo taken on October 21, 1983 by Larry D. Fellows.

INTRODUCTION

Subsidence, the gradual settling or sinking of the earth's surface, is occurring in many areas of Arizona as a result of declining ground-water levels. Rates of subsidence have exceeded 0.6 foot per year and earth fissures, or cracks in the earth's surface, are proliferating (Figures 1, 2, and 3). In some areas, the total amount of subsidence has increased from 12.5 feet, measured in 1977, to about 16 feet.

Subsidence can be caused by natural geologic processes or by man's activities, such as the removal of subsurface fluids. In Arizona, subsidence is mostly due to large-scale withdrawal of ground water from subsurface reservoirs. The fluid pressure of ground water partially supports the material above. As the water is pumped out, that support is lost, causing compaction of the grains of earth material and lowering, or subsidence, of the earth's crust.

Earth fissures usually form around the margins of subsiding areas and may be related to distribution and thickness of basin-fill sands and gravels, buried bedrock topography, or other factors. It is not possible to predict specifically where fissures will form. It may be possible, however, to identify zones where fissures *might* form.

Land-elevation changes caused by subsidence can be determined by repeated, precise, survey leveling to fixed reference points or bench marks. Bench marks are usually brass caps encased in concrete and set a few inches above the ground surface. Precise surveys determine elevations of bench marks within the subsiding area by comparing them with stable bench marks set in bedrock *near* the subsiding area. Reference bench marks must remain stable to provide an accurate, common base for all measurements; therefore, they are located in bedrock.

Problems related to subsidence, especially differential subsidence and the formation of earth fissures, have been known for years. The issue itself is complex; numerous papers have been published to explain causes, identify problems, and offer solutions. A list of papers that describe specific subsidence areas and problems in Arizona is included at the end of this article.

It is not the purpose of this article to summarize or describe the extent of subsidence throughout Arizona, although a plan for monitoring subsidence in the State is discussed. This article does, however, describe the results of the National Geodetic Survey (NGS) precise leveling conducted in the Phoenix metropolitan area from 1980 through 1981 (Winikka, 1981). It also identifies subsidence areas and discusses uses of the NGS level datum.

THE PHOENIX AREA

The NGS Level Line

The 1980-81 NGS retracement of the 1967 NGS level line in Arizona was done as a segment of the current network of NGS transcontinental leveling, which extends through all States from coast to coast. In the Phoenix area, where several subsidence areas were crossed, numerous new bench marks were established in bedrock to preserve the precise leveling results. Consequently, more convenient stable elevations are now available to all users, particularly those who measure or monitor subsidence. The 1980-81 NGS leveling identified and measured subsidence that had occurred since 1967.

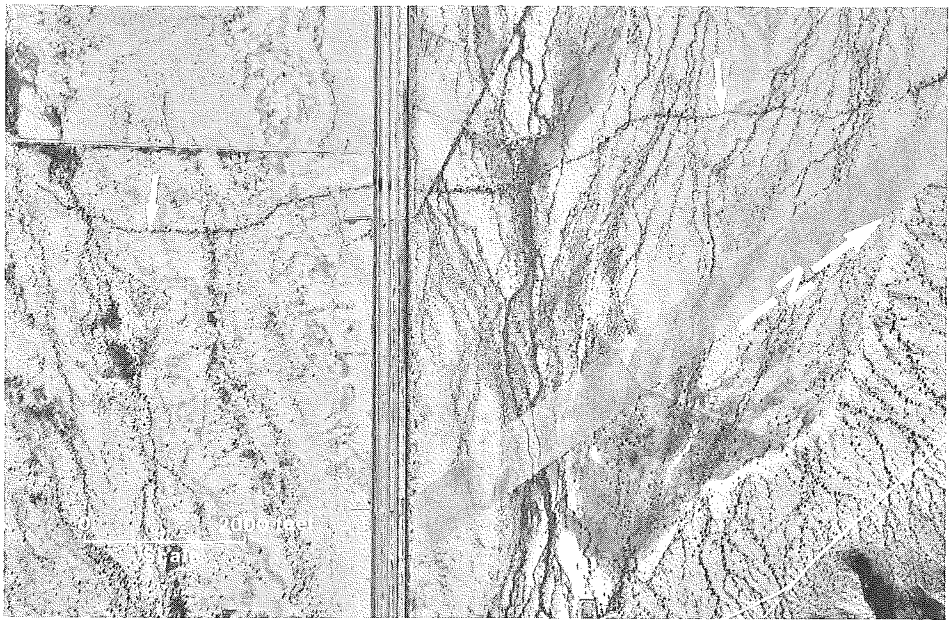

Figure 2. Aerial view of earth fissure crossing Interstate Highway 10 (I-10) between the town of Picacho and Picacho Peak. Photo taken on December 9, 1963 by the Arizona Department of Transportation.

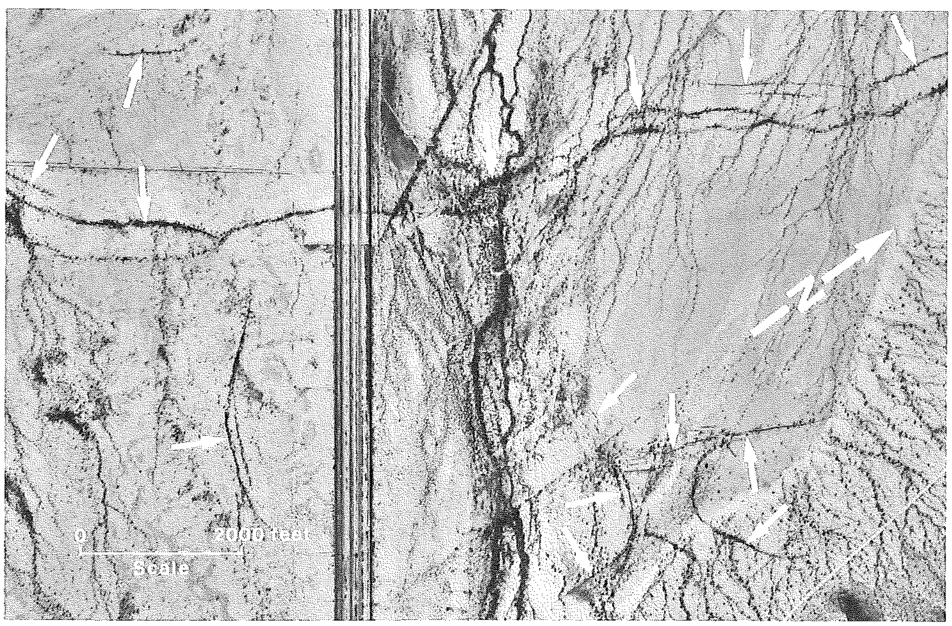

Figure 3. Aerial view of same area shown in Figure 2, taken 14 years later. Proliferation of earth fissures is indicated by arrows. Note that subsequent fissuring near the original fissure is all on the basin (west) side. Other fissuring, which may be due to buried bedrock topography, is evident to the east. Photo taken on January 9, 1978 by the Arizona Department of Transportation.

Final NGS elevations will not be available until the transcontinental leveling network is adjusted to account for numerous, influencing factors. The need to utilize the NGS leveling results, however, was great in the Phoenix area. To fill this need, the Arizona Department of Transportation (ADOT) used the NGS field information to make an accurate, preliminary, least-squares adjustment, which held NGS elevations previously established on bench marks in bedrock.

Because many bench marks set in 1967 and earlier years had been destroyed, new marks were set during 1980 and 1981 to establish a bench mark approximately every mile. Additional stable bench marks were established in rock to preserve ties to the NGS level datum for subsequent surveys. Enduring, subsiding bench marks, however, are equally important for continuity in subsidence monitoring. Figure 4 shows the location of the NGS level line through metropolitan Phoenix, the bench marks in bedrock, and the areas of measured subsidence.

Subsidence Areas

The greatest subsidence directly measured in the Phoenix area has occurred in the vicinity of U.S. Highway 60 and Bush Highway/Power Road. From 1948 to 1981, more than 5 feet of subsidence were measured just east of the junction, and several other points in the vicinity had subsided from 1 to 4 feet. The maximum subsidence rate in this area is approximately 0.2 foot per year. By indirect measurement, subsidence greater than 6 feet was determined to have occurred from 1943 to 1981 along Power Road, 1/2 mile south of U.S. Highway 60 at NGS bench mark W281. Because W281 was destroyed sometime between 1967 and 1970 and reset in 1970, a gap in information existed. The measured subsidence value was added to the projected value for the 1967-70 time period to obtain the total measure of subsidence.

The next highest measure of subsidence was obtained west of Phoenix along the Beardsley Canal, from U.S. Highway 60 south to the junction of Perryville Road and McDowell Road. Total subsidence from 1948 to 1981 exceeded 4 feet at the Beardsley Canal near both Bell Road and Peoria Avenue. Analysis of subsidence rates along the Beardsley Canal shows an increase in the annual rate at each of six bench marks north of Glendale Avenue. The approximate annual rate of 0.08 foot from 1948 to 1967 increased by 50 percent to 0.12 foot from 1967 to 1981. From Glendale Avenue south, on the other hand, the subsidence rate *decreased* at each of four bench marks. The approximate annual rate of 0.10 foot decreased by 50 percent to 0.05 foot during the corresponding time periods (Table 1). Although the definite cause of this variation in subsidence rates is currently unknown, the difference is most likely due to a change in ground-water pumping influenced by dewatered alluvial material.

Other areas in which subsidence was measured include the following:

(1) Along the Arizona Canal where it crosses the Salt River Indian Reservation (maximum 1948-81 measurement is 0.9 foot at Dobson Road and at Mesa Drive);
(2) Along portions of Beardsley Road from I-17 west (maximum 1967-81 measurement is 0.45 foot at 83rd Avenue); and
(3) Along I-17 from the Arizona Canal north to Beardsley Road (maximum 1967-81 measurement is 0.28 foot at Thunderbird Road).

Although subsidence measurements are given for the specific areas listed above, subsidence was measurable only where reliable bench marks were recovered. Many bench marks had been destroyed during the rapid growth and development in the Phoenix area; thus, a tie to past leveling information was lost. To either side of the level line, subsidence exceeding the values listed above is very probable.

Uses of the NGS Datum

In the Phoenix area, the establishment of NGS bench marks, especially those set in

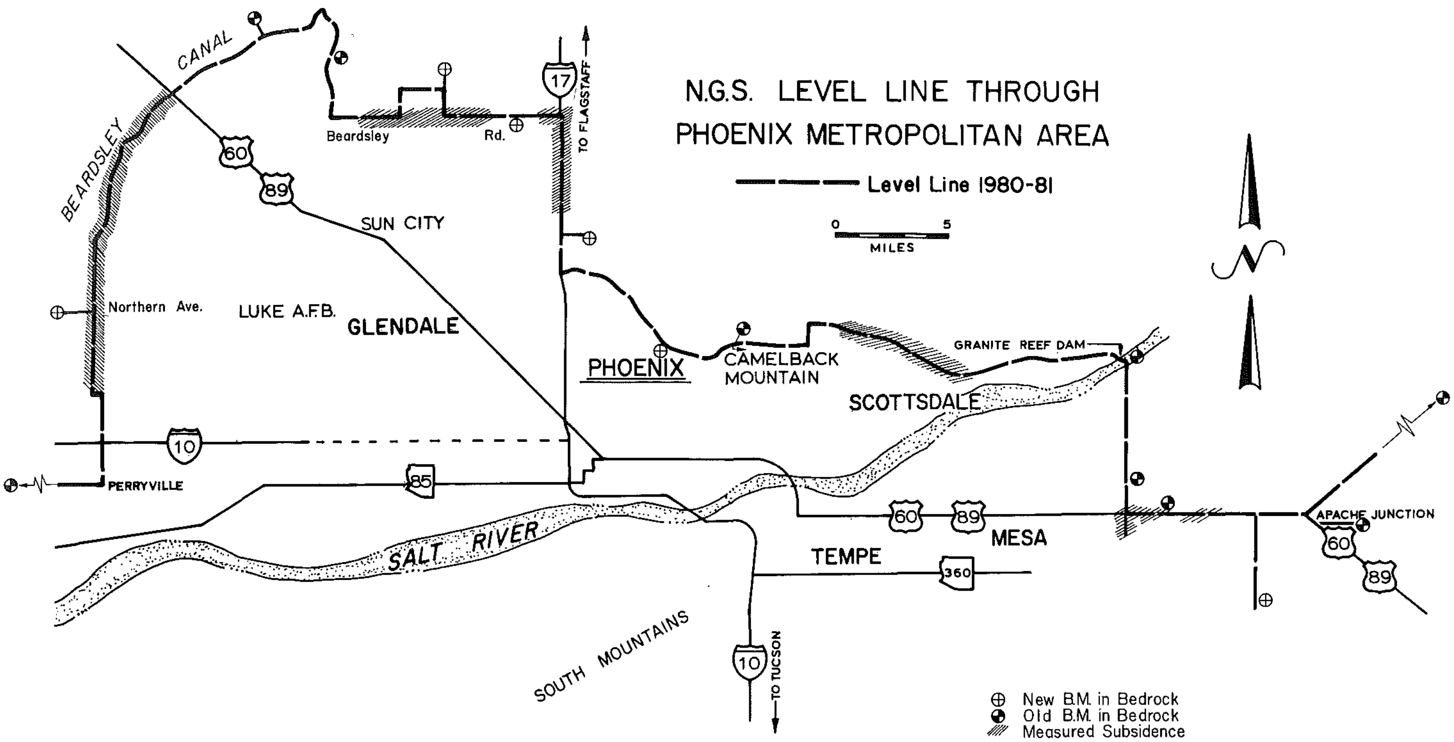

Figure 4. Location of the NGS level line run through Phoenix area during 1980-81. Old and new bench marks established in bedrock are shown, as well as areas of measured subsidence.

stable rock, has enabled the ADOT and others to detect and monitor subsidence for various purposes.

The U.S. Bureau of Reclamation (USBR) annually runs control levels along the Central Arizona Project (CAP) aqueduct to detect and monitor subsidence. West of Apache Junction, the design of the aqueduct accommodates subsidence in areas crossed by the structure. Monitoring provided essential information used in the design and will continue after the aqueduct becomes operational.

The Arizona Department of Transportation periodically runs a level circuit that includes the future extension of the Superstition Freeway east of Power Road. The freeway and its extension cross several areas of subsidence, including one that is also crossed by the CAP aqueduct. In this instance, common bench marks are used by the ADOT and USBR to obtain more frequent data from this critical area.

The city of Phoenix is experiencing subsidence-related problems with several sewer lines in Paradise Valley, where more than 3 feet of subsidence were measured and monitored from 1965 to 1982 (Harmon, 1982). Phoenix has recently engaged a geotechnical engineering consultant to analyze the problems and suggest solutions in this area, where the annual subsidence rate has reached 0.35 foot. All leveling to monitor subsidence is tied to NGS bedrock bench marks. Use of this consistent datum is particularly important because elevations and grades affect the capacity of the sewer system, which presently drains by gravity.

The city of Gilbert is planning to extend its sewer system considerably east of present development to accommodate future needs. A consulting firm on the project has used recent, precise, ADOT levels that rely upon NGS bench marks. These levels, which extend from the Superstition Freeway south along Power Road to Germann Road, have confirmed that approximately 3 feet of subsidence have occurred. Because this amount of subsidence, as well as the projected subsidence rate, was significant, city officials decided to alter the plan for the wastewater collection system.

Without question, the new NGS datum in the Phoenix area is becoming the base accepted by all levels of government and several private firms. The older level datums will still be used indefinitely, even though their inadequacy for subsidence monitoring is evident. Lines begun and ended within a subsiding area are of questionable value because they are not tied to stable, nonsubsiding bedrock. Measurements become even more inaccurate if the lines are tied to bench marks that have subsided at different rates. A precise level line with bedrock ties, such as the NGS line through the Phoenix region, is invaluable for conducting surveys in subsiding areas.

Table 1. Subsidence along the Beardsley Canal.

Bench mark	Crossroad	Total Subsidence (ft) 1948–67	1967–81	1948–81	Rate (ft/yr) 1948–67	1967–81
R265	Union Hills	1.171	1.237	2.408	0.0616	0.0884
Q265	Bell Road	1.887	2.186	4.073	0.0993	0.1561
P265	Greenway Road	1.932	(bench mark destroyed)		0.1017	—
N265	Waddell Road	1.919	(bench mark destroyed)		0.1010	—
M265	Cactus	1.706	1.598	3.304	0.0898	0.1141
L265	Peoria	1.578	2.513	4.091	0.0830	0.1795
K265	Olive	1.207	1.081	2.288	0.0635	0.0772
J265	Northern	1.244	1.304	2.548	0.0655	0.0931
H265	Glendale	2.067	1.189	3.256	0.1088	0.0849
G265	Bethany Home	1.433	0.469	1.902	0.0754	0.0335
F265	Camelback	2.152	0.633	2.785	0.1133	0.0452
E265	Indian School	1.866	0.581	2.447	0.0982	0.0411

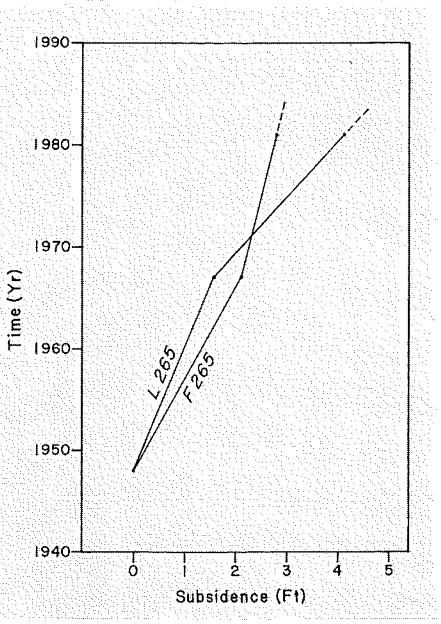

Figure 5. Total subsidence and subsidence rate changes for bench marks L265 (Peoria) and F265 (Camelback), listed in Table 1. Note that the subsidence rate for each bench mark increases until 1967, after which the rate for L265 accelerates, whereas the rate for F265 *decreases*. This graph illustrates that subsidence rates are not static.

THE TUCSON AREA

Within the Tucson metropolitan area, subsidence due to ground-water declines has begun (Strange, 1983). In some sections, the water table has been lowered by more than 100 feet, the magnitude at which subsidence can be expected to commence. The U.S. Geological Survey is conducting a study of aquifer compaction in the Tucson area. Survey geologists have installed seven compaction recorders in wells to detect subsidence in the upper 1,000 feet of the earth's surface. To date, the highest subsidence rate that has been measured is approximately 0.02 foot per year.

Results of NGS leveling through the area show a maximum subsidence of 0.4 foot, a measurement that was obtained by comparing the 1951 results with the 1980 results. This subsidence occurred at a bench mark between Davis Monthan Air Force Base and Interstate 10.

SUBSIDENCE RATES

As the above examples suggest, for the planning and design of civil-works projects, the subsidence rate is at least as important as the total amount of subsidence. Subsidence in Arizona is not static, but changes both in rate and locus. Continued subsidence, particularly at increasing rates, proves that the problem cannot be ignored. Until recently, subsidence was a phenomenon that lacked impact. As subsidence increases in developed areas, however, its importance will also increase.

As bench marks in subsiding areas are identified and subsidence rates are recorded, the dynamics of continuing movement are conveyed to users. By knowing locations, amounts, and rates of subsidence, users will have a rational basis for decisions to use or reject the use of subsiding bench marks.

Total subsidence and the subsidence rate are well illustrated by simply plotting subsidence against time at an appropriate scale (Figure 5).

A SUBSIDENCE-MONITORING PLAN

Spurred by the NGS leveling results in the Phoenix area and the realization that severe subsidence and earth fissures are occurring in Arizona, the Arizona Mapping Advisory Committee and its member agencies recognized the need for a statewide plan to monitor subsidence. At the request of Governor Bruce Babbitt, the National Geodetic Survey prepared the plan, which was completed in 1983 (Strange, 1983). The plan was the result of a comprehensive effort by the NGS and the interagency Ad Hoc Land-Subsidence Committee of the State. The committee, which was chaired by a representative of the Arizona Department of Water Resources, included members from State, Federal, and local government groups, universities, and private industry. Although the plan still lacks operational funds, copies are available for purchase from the NGS.

The NGS Global Positioning System (GPS), which utilizes satellites and geodetic receivers, was recommended in the subsidence plan. The system was recently tested to evaluate its possible use in Arizona. Numerous bench marks, subsiding as well as stable, were measured. Leveling to most of these bench marks to determine present elevations was done for comparison. If the GPS results yield elevations accurate to within 0.2 foot, as expected, this system may prove to be an efficient monitor of subsidence.

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Late Cenozoic Deformation in Arizona

The Arizona Bureau of Geology and Mineral Technology recently released four open-file reports (83-19 through 83-22) on Quaternary and late Cenozoic deformation in Arizona. These reports summarize the results of an investigation of neotectonic activity in the State, conducted by Christopher Menges, Philip Pearthree, and Robert Scarborough, and funded by the U.S. Geological Survey and the Bureau. The primary goal of this study was to increase the understanding of the distribution and nature of Quaternary faulting and the seismic hazard in Arizona. Evidence for late Cenozoic, Basin and Range deformation was also compiled to provide a more extensive view of tectonic activity.

Open-File Report 83-19 discusses late Cenozoic tectonic activity, focusing on evolution of the Basin and Range disturbance. Open-File Report 83-20 discusses the tectonic and seismic-hazard implications of late Quaternary faulting in Arizona.

Open-File Reports 83-21 and 83-22 are 1:500,000-scale maps that show Basin and Range tectonism and late Pliocene-Quaternary deformation, respectively. The former is a compilation of post-15-m.y. (million-year) structures and basalt-dominated volcanism, with volcanic rocks differentiated into several age categories. Open-File Report 83-22 is primarily based on interpretations of statewide aerial photography and reconnaissance field studies of more than 50 Quaternary faults, which are classified according to age of most recent movement. This study includes fault displacement data.

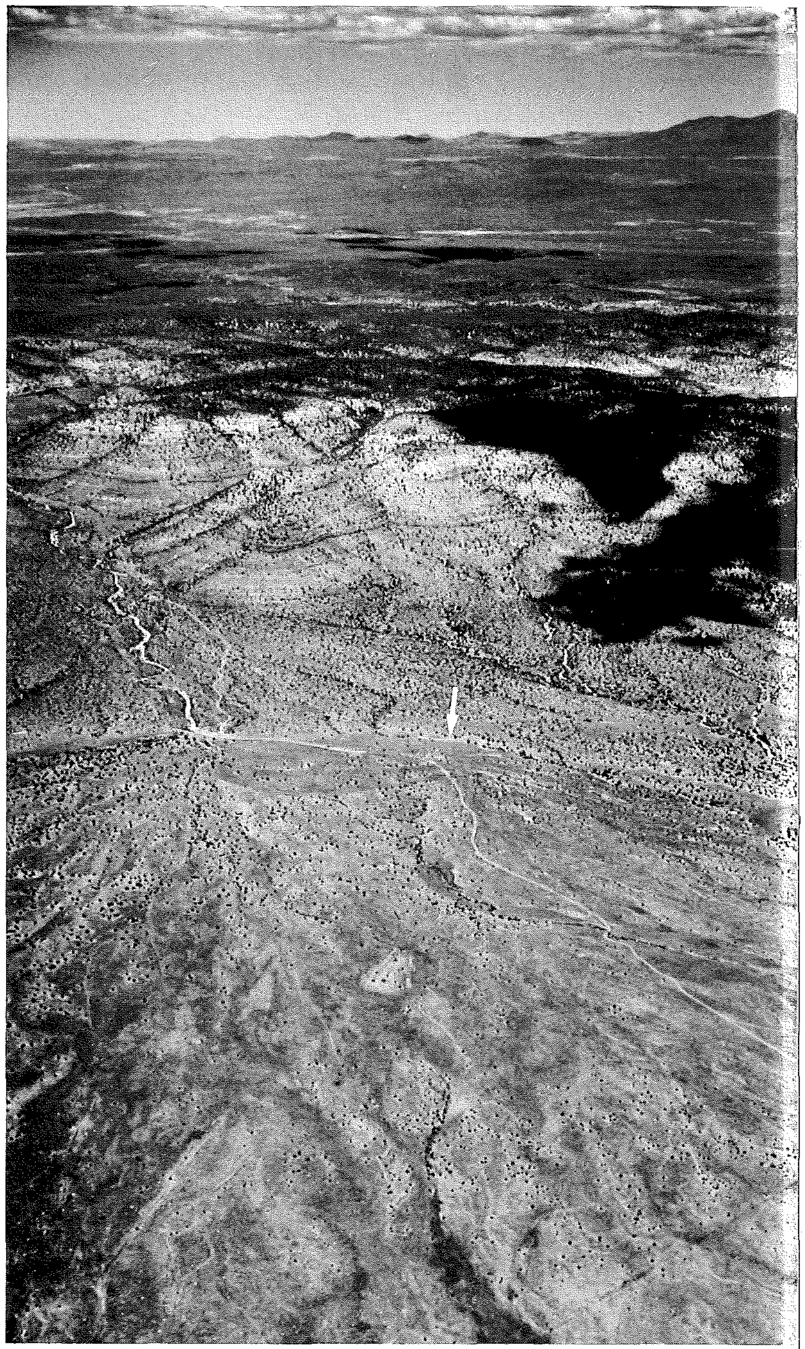
All four reports, which are listed below, may be examined in the Bureau library or checked out and copied at local blueprint or reproduction companies. They may also be purchased. Prepayment is required on all orders, with checks made payable to the Arizona Bureau of Geology and Mineral Technology.

83-19 The neotectonic framework of Arizona—implications for the regional character of Basin-Range tectonism, 109 p. $10.75, plus $4.00 for postage and handling.

83-20 Distribution, recurrence, and possible tectonic implications of late Quaternary faulting in Arizona, 51 p. $7.75, plus $2.00 for postage and handling.

83-21 Map of Basin and Range (post-15-m.y.a.) exposed faults, grabens, and basalt-dominated volcanism in Arizona, 25 p., two maps, scale 1:500,000. Text: $3.75; maps: $3.00 each; postage and handling: $2.00.

83-22 Map of neotectonic (latest Pliocene-Quaternary) deformation in Arizona, 48 p., two maps, scale 1:500,000. Text: $7.00; maps: $3.50 each; postage and handling: $4.00.



Aerial view of part of the Big Chino fault scarp (follow arrow) in north-central Arizona. Colorado Plateau is in background. Recurrent fault movement is evidenced by greater vertical displacement of increasingly older, Quaternary deposits. The most recent movement probably occurred 5,000-15,000 years ago. Photo: C. Menges.

Geometry of Low-Angle Normal Faults in West-Central Arizona

by Jon E. Spencer

Editor's Note: During the past 3 years, Bureau geologists Jon Spencer and Steve Reynolds have been mapping in the Granite Wash, Little Harquahala, and Harcuvar Mountains, and the surrounding areas. This research is part of an ongoing effort to update the geologic map of Arizona and to evaluate the relationships between mineral deposits and the geologic framework. In the following article, Dr. Spencer outlines some questions that have surfaced as a result of his and Dr. Reynolds' research, and offers some working hypotheses for the geometry of major low-angle normal faults in west-central Arizona.

As a result of extensive field work conducted during the past 10 years in western Arizona and southeastern California, geologists now recognize that mid-Tertiary low-angle normal faults are probably the most fundamental structural features in this region. Initial recognition of these faults, commonly referred to as "detachment" faults, led to the hypothesis that low-angle normal faults in adjacent mountain ranges were exposed segments of a single fault surface (e.g., Whipple Mountain detachment fault and Buckskin-Rawhide detachment fault, as described by Davis and others, 1980; Figure 1). In this single-fault hypothesis, warping or later faulting was required to explain the observed geometries of the exposed fault segments. As more detachment faults were discovered, however, increasingly complex, undulatory or broken and segmented fault geometries were required by the single-fault hypothesis. Although such geometries exist, we are now considering the possibility that major detachment faults are not necessarily connected to each other, but are arranged in imbricate, shingled fashion.

Figure 2 illustrates two hypotheses for the geometry of detachment faults in part of west-central Arizona. Scarborough and Meader (1983) suggested that an east-dipping detachment fault in the northern Plomosa Mountains wraps around the southern part of the range, and where it is last exposed, projects northwestward beneath La Posa Plain toward the nearby Moon Mountain detachment fault (Figure 1).

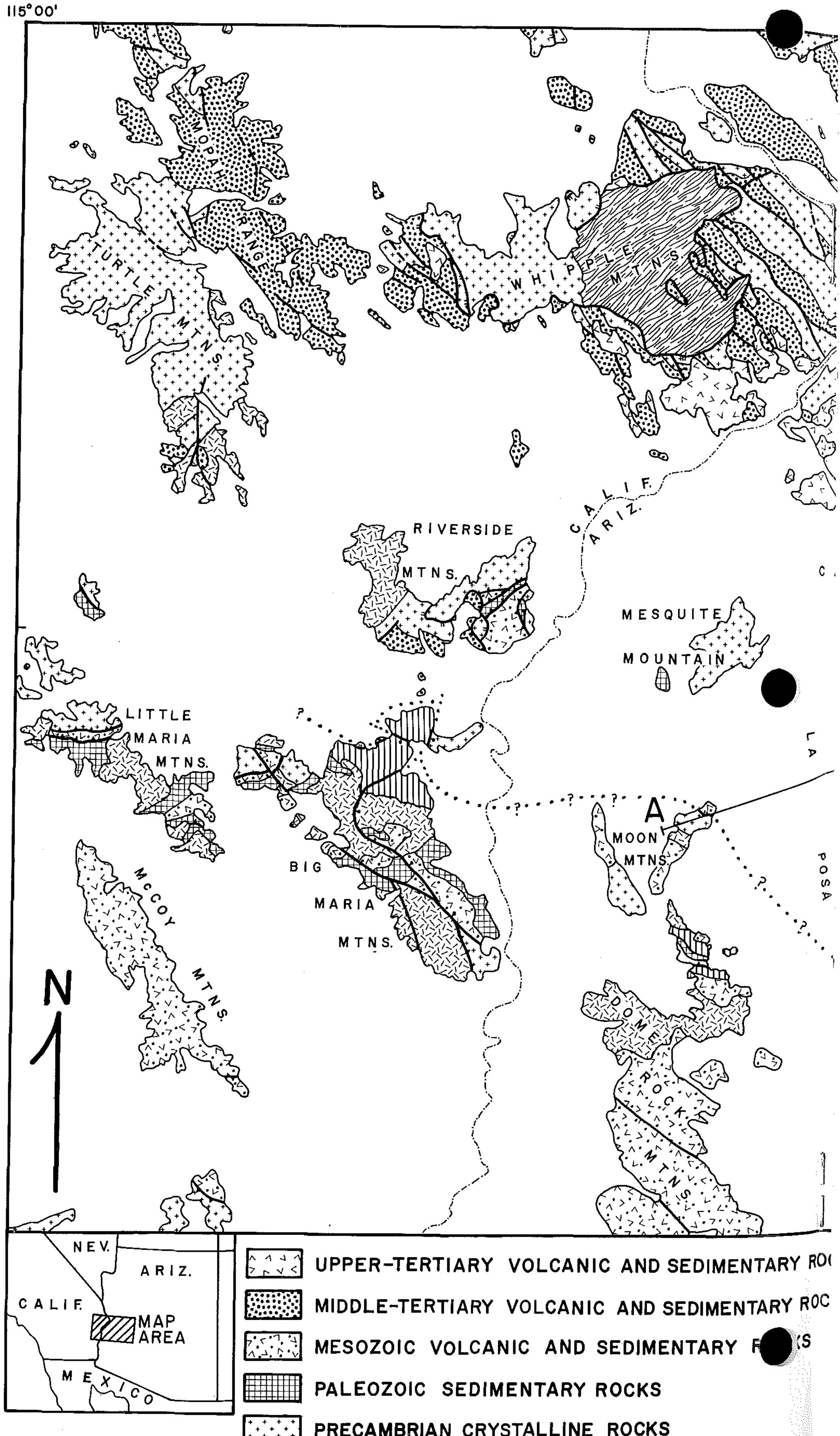
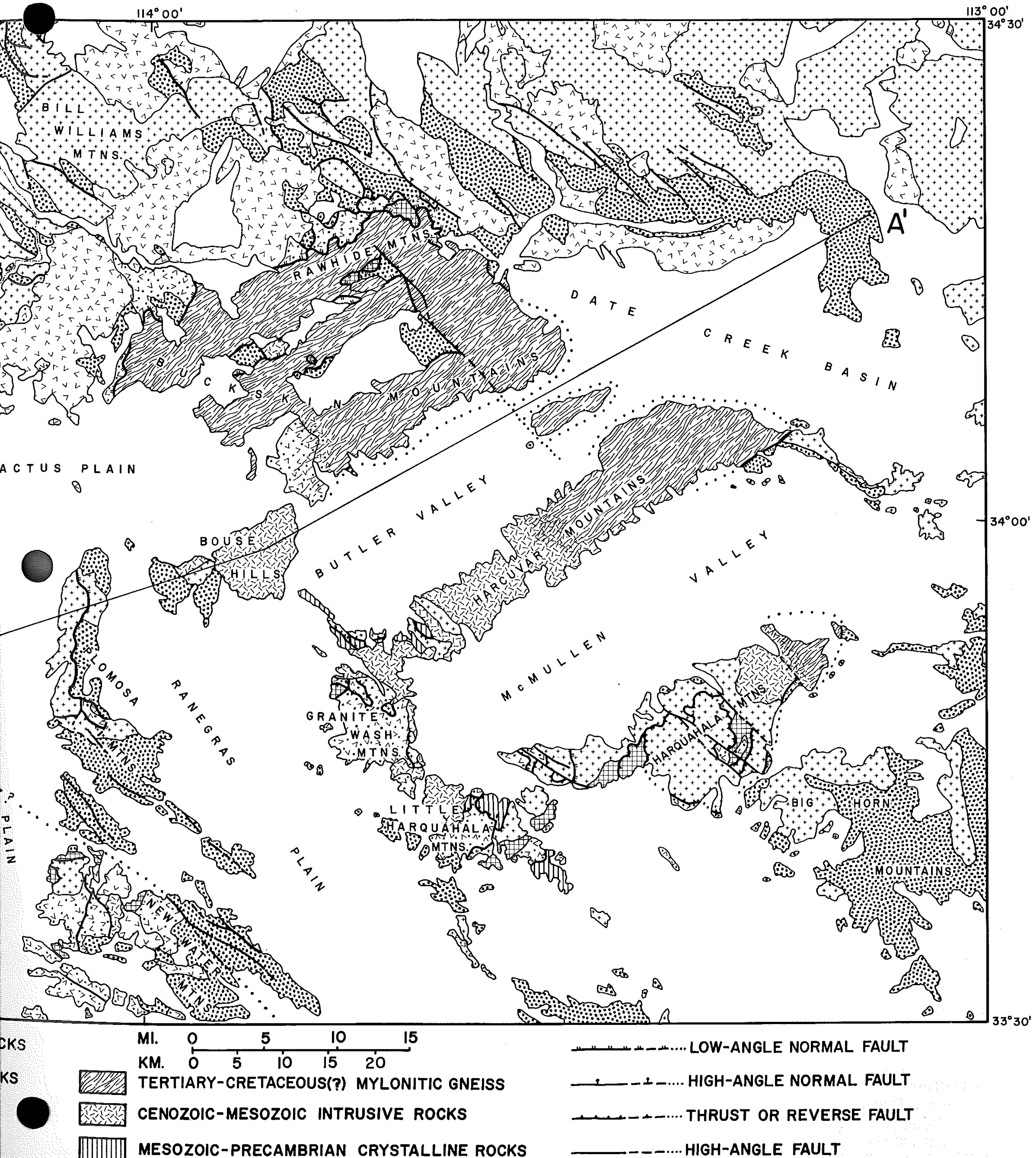


Figure 1. Compilation geologic map of west-central Arizona and southeastern California. Areas without pattern are Quaternary surficial deposits. Faults are dashed where inferred, dotted where concealed.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BUTLER VALLEY
BOUSE HILLS
HARCUVAR MOUNTAINS
McMULLEN VALLEY
PLOMOSA MTNS.
RANEGRAS PLAIN
GRANITE WASH MTNS.
HARQUAHALA MTNS.
LITTLE HARQUAHALA MTNS.
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NEW WATER MTNS.
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CENOZOIC-MESOZOIC INTRUSIVE ROCKS
MESOZOIC-PRECAMBRIAN CRYSTALLINE ROCKS
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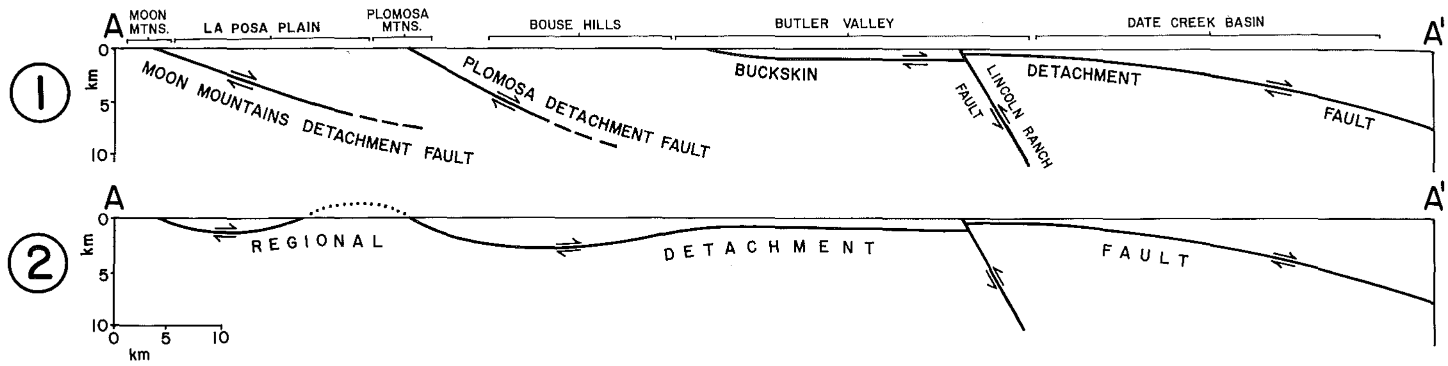

Figure 2. Hypothetical cross sections for part of west-central Arizona. Location of cross sections is shown in Figure 1.

This interpreted fault geometry is consistent with the correlation between the Plomosa detachment fault and the Moon Mountains detachment fault, as shown in cross section 2 (Figure 2). Recent geologic mapping (Deborah Stoneman, University of Arizona M.S. Thesis, in preparation) suggests that the Plomosa detachment fault does *not* wrap around the south end of the Plomosa Mountains, but probably continues along the east side of the range. If this latter interpretation is correct, the geometry shown in cross section 1 (Figure 2) would be the favored alternative. Additional detailed mapping in the area south of Plomosa Pass could resolve this problem.

Our recent geologic field mapping indicates that the Bouse Hills are in the upper plate of the Plomosa detachment fault. This arrangement requires one of two possible relationships between the Plomosa detachment fault and the Buckskin detachment fault, which projects over crystalline rocks in the Buckskin Mountains (Figures 1 and 2). If the Plomosa detachment fault continues at depth below the Buckskin Mountains, then the Buckskin and Plomosa faults are separate, imbricate faults (Figure 2, cross section 1). If the two faults are segments of a single fault (Figure 2, cross section 2), the Plomosa fault must return to the surface in the alluvium-filled gaps between the Bouse Hills and Buckskin Mountains, and between the Bouse Hills and Granite Wash Mountains (Figure 1). Based on our reconnaissance mapping, we have been unable to correlate rocks across either of these gaps. This lack of correlation is consistent with the interpretation shown in cross section 2. Detailed mapping of this area during the coming year could eliminate one of the two hypothetical fault geometries shown in Figure 2.

Ultimately, determination of the large-scale geometry of detachment faults in west-central Arizona will increase understanding of the kinematics and geometries of extensional orogens. This information will have practical applications as well, because detachment faults are locally associated with significant copper and gold mineralization (e.g., Wilkins and Heidrick, 1982). Improved understanding of detachment-fault geometry will permit more accurate assessment of the location and distribution of undiscovered ore deposits. Detachment faults are undoubtedly present beneath Butler Valley, Cactus Plain, Ranegras Plain, and La Posa Plain. The lateral extent of potential ore-bearing horizons could be enormous in these areas. Further exploration and research is needed, however, to determine if these ore deposits are close enough to the surface or of sufficiently high grade or tonnage to warrant production.

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What's in a Name?

If an individual were seeking specific information about geology, mining, or mineral resources in Arizona, whom should he or she contact? Two State agencies deal with these subjects. Although their names may sound similar, their purposes and missions are distinctly different.

Through recent legislation, the name of the Arizona Department of Mineral Resources was changed to the Arizona Department of Mines and Mineral Resources, and the agency's duties were more clearly outlined. The Department promotes the development of Arizona's mineral resources by providing information and assistance in a variety of ways.

The Arizona Bureau of Mines is the former name (until 1977) of the Arizona Bureau of Geology and Mineral Technology. The Bureau was established to do research on, and provide information about, Arizona's geologic setting, geologic hazards and limitations, and mineral and energy resources, including mineral-resource exploration, mining, and processing.

To guide prospective seekers of geologic, mineral-resource, or mining information, each agency's distinct history, purpose, objectives, and duties have been outlined below.

Arizona Department of Mines and Mineral Resources

(formerly Arizona Department of Mineral Resources)

The Department of Mineral Resources was established by the State legislature in 1939, as a result of efforts by the Arizona Small-Mine Operators' Association (ASMOA). ASMOA was formed the year before by a group of citizens who were concerned that the number of small, producing mines in Arizona had declined from 2,200 to 1,200 between 1935 and 1937. The group concluded that solution of the problems that led to this decline would require effort far beyond their capabilities. ASMOA proposed that a State agency be established to aid in the promotion and development of mineral resources. Legislation was drafted, passed by the State legislature, and signed by Governor Robert T. Jones on March 1, 1939.

The Department is under the authority of a five-person Board of Governors appointed by the Governor of Arizona. The board determines the program and policies of the Department and appoints a director to execute them.

With the passage of Senate Bill 1048, which was signed by Governor Bruce Babbitt on May 2, 1984, the Department's name was changed to Department of Mines and Mineral Resources. Objectives and duties of the Department, as modified in the bill (Title 27, Chapter 1, Article 1, Arizona Revised Statutes), are summarized below.

Objectives

To promote development of Arizona's mineral resources by sponsoring technical and educational activities and by providing mining, metallurgical, and other technical information and assistance to prospectors, small-mine operators, the mineral industry, and others interested in the State's mineral resources.

Duties

(1) To participate in conferences, seminars, forums, speaking engagements, news-media gatherings, and other public functions.
(2) To conduct studies on the economic problems of prospectors and small-mine operators and assist in their solution.
(3) To maintain the following:
 (a) An information bank and library of mineral and mining information, including books, periodicals, films, videotapes, and individual mine files.
 (b) A repository of underground-mine maps and mine data.
 (c) A mineral museum as the State depository of ores, gemstones, lapidary material, and other valuable mineral specimens.
(4) To provide mining data, evaluations, and assistance related to mineral development to the legislature and other State and county agencies.
(5) To make surveys of potential economic mineral resources and conduct field studies and other investigations that may interest capital in the development of Arizona's mineral resources.
(6) To serve as a mining information center and monitor current mining and exploration activities.
(7) To publish and disseminate information and data.
(8) To cooperate with the State Land Department to encourage mining activity on State lands.
(9) To cooperate with the Corporation Commission in its investigations and administration of laws related to the sale of mining securities.
(10) To cooperate with the Arizona Bureau of Geology and Mineral Technology and deliver to the Bureau problems that are within its scope of activities.
(11) To cooperate with Federal and other agencies in matters related to mineral-resource development in Arizona.
(12) To oppose congressional acts that favor reciprocal or duty-free imports of foreign minerals.
(13) To use its authority in other ways to assist in more extensive exploration and development of mineral resources in Arizona.

For additional information about the Department, contact Mr. John H. Jett, Director, Arizona Department of Mines and Mineral Resources, Mineral Resources Building, Fairgrounds, Phoenix, AZ 85007; (602) 255-3791.

Arizona Bureau of Geology and Mineral Technology
(formerly Arizona Bureau of Mines)

The Bureau was established in 1915 by the State legislature as the Arizona Bureau of Mines, a research, information, and public-service agency. It was placed under the authority of the Board of Regents of the University and State Colleges of Arizona, who assigned its administrative duties to the University of Arizona. The Arizona Bureau of Mines essentially continued work that had previously been done by the Territorial Geologist from 1888 to 1912 and by the University of Arizona School of Mines Testing Laboratories from 1893 to 1915. The director of the Bureau was also dean of the College of Mining and Engineering from 1918 to 1940, after which the college was divided into the College of Mines and the College of Engineering. Since 1940 the dean of the College of Mines has also served as director of the Bureau.

In 1977 the Bureau's enabling legislation was updated. The name was changed to Arizona Bureau of Geology and Mineral Technology to convey more clearly the meaning of the Bureau's mission. In addition, two branches, the Mineral Technology Branch and the Geological Survey Branch, were established. The Geological Survey Branch is the Arizona Geological Survey.

From 1915 to 1977, the Arizona Bureau of Mines published 191 technical reports and bulletins on geology, economic geology, mineralogy, metallurgy, mineral technology, and mine safety. Twenty of them are still available for purchase and still list the Arizona Bureau of Mines as the publisher.

Purpose, objectives, and duties of the Arizona Bureau of Geology and Mineral Technology, as specified by State statute (Title 27, Chapter 1, Article 4, Arizona Revised Statutes), are summarized below.

Purpose

The Bureau is a scientific, investigative, and information agency whose purpose is to conduct research and provide information for use by the legislature, governmental agencies, industry, and the public.

Objectives

(1) To inform the public about matters that concern the geologic environment and the development and use of Arizona's mineral resources.
(2) To encourage the wise use of lands and mineral resources.
(3) To provide technical assistance and advice on geology and mineral technology to other State and local agencies, industry, and the public.

Duties

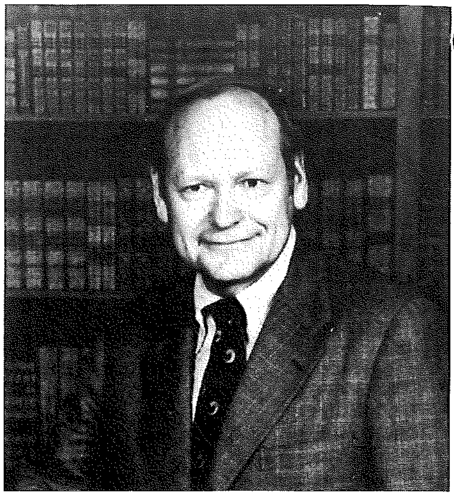
(1) To investigate, describe, and interpret Arizona's geologic setting, natural hazards and limitations, and mineral resources.
(2) To conduct research-and-development activities that relate to mineral exploration, mining, and ore processing in Arizona.
(3) To publish, or otherwise make available, the results of all geologic, mineral-technology, and related Bureau research.
(4) To operate and maintain a public-access, central repository of reports, books, maps, and other publications on the geology, mineral resources, and associated technologies present or practiced in Arizona.
(5) To operate and maintain a public-access, central repository of rock cores, well cuttings, and related subsurface samples and data.
(6) To provide lectures, talks, and displays for the general education of the public.

For additional information about the Bureau, contact Dr. Richard A. Swalin, Director, Arizona Bureau of Geology and Mineral Technology, Civil Engineering Building, University of Arizona, Tucson, AZ 85721; (602) 621-6594.

BUREAU RELEASES NEW MAP

Map of outcrops of Laramide (Cretaceous-Tertiary) rocks in Arizona and adjacent regions, S. B. Keith, 1984, scale 1:1,000,000. ($3.00, plus $1.50 for shipping and handling.)

Bureau Welcomes New Director



The new director of the Bureau of Geology and Mineral Technology brings to the job a blend of experience from both the public and private sectors.

Dr. Richard A. Swalin (pronounced Swah LEEN), corporate vice president for research and development at the Allied Corporation in Morristown, New Jersey, assumed the position of director of the Bureau on September 1. He will also serve as dean of the College of Mines, interim dean of the College of Engineering, and professor of metallurgical engineering, material science, and technology development at the University of Arizona.

At Allied Corporation, where he had worked since 1980, Dr. Swalin supervised research-and-development activities in seven corporate laboratories: Molecular and Applied Genetics; Energy and Chemical Process; Materials; Polymer; Analytical Sciences; Chemical and Polymer Development; and Agricultural Products. Prior to this position, he served as vice president of technology at Eltra Corporation of New York, which was merged into Allied Corporation in 1979.

In addition to his industrial posts, Dr. Swalin has held university administrative and teaching positions. He was dean of the Institute of Technology at the University of Minnesota for 6 years, from 1971 to 1977, and associate dean from 1968 to 1971. The Institute of Technology comprises the College of Engineering; Schools of Mathematics, Architecture, Earth Science, Physics and Astronomy, Chemistry, and Computer Science; St. Anthony Falls Hydraulics Laboratory; Mineral Resources Research Center; and Minnesota Geological Survey.

He was a visiting scholar at Stanford University in 1976; guest scientist at Lawrence Radiation Laboratory at the University of California in Livermore in 1967; guest scientist at the Max Planck Institut für Physikalische Chemie in Göttingen, Germany in 1963; head of the School of Mineral and Metallurgical Engineering at the University of Minnesota from 1962 to 1968; professor of materials science at the University of Minnesota from 1960 to 1977; assistant and associate professor of the department of metallurgy at the University of Minnesota from 1956 to 1960; member of the technical staff at the General Electric Research Laboratory in Schenectady, New York from 1954 to 1956; and research fellow at the Physical Electronics Laboratory at the University of Minnesota from 1952 to 1954.

Dr. Swalin has chaired or been a member of numerous university and professional committees, and is a current or past member of the board of directors of 10 organizations. He is the author or coauthor of more than 50 scientific papers published in a variety of international journals, and has written a well-known textbook on metallurgical thermodynamics.

He graduated with distinction from the University of Minnesota in 1951 and received his doctorate there in 1954. He was appointed a full professor at the age of 31.

Dr. Swalin succeeds Dr. William P. Cosart, who has served as acting director of the Bureau and acting dean of the College of Mines for 3 years. Dr. Cosart will serve as associate director of the Bureau and associate dean of the College of Mines and will remain on the university faculty.

PROFESSIONAL MEETINGS

Geological Society of America, with associated societies. Annual meeting, Reno, Nevada, November 5–8, 1984. Contact Jean M. Latulippe, GSA headquarters, Box 9140, Boulder, CO 80301; (303) 447-2020.

International Association of Hydrogeologists. 17th International Congress (Hydrogeology of Rocks of Low Permeability), Tucson, Arizona, January 7-12, 1985. Contact Eugene S. Simpson, Dept. of Hydrology and Water Resources, University of Arizona, Tucson, AZ 85721; (602) 621-1855 or (602) 621-3131.

Fieldnotes

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State of Arizona ..... Governor Bruce Babbit
University of Arizona ..... President Henry Koffler
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