FIELDNOTES

From The State Of Arizona
Bureau Of Geology And Mineral Technology

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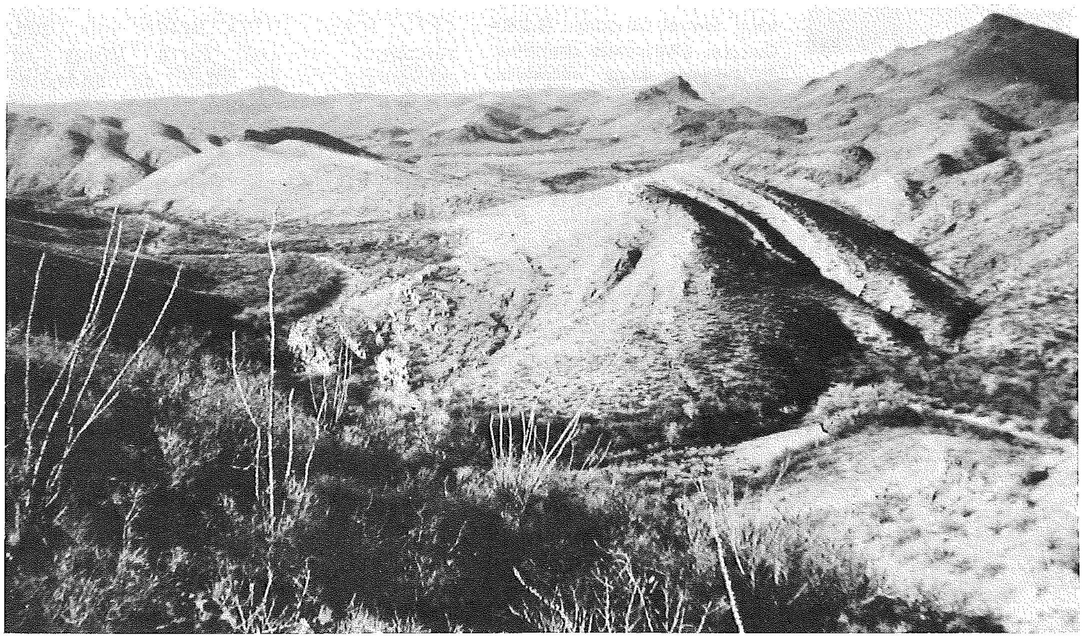


A 10,000 ft. thick eastward-dipping clastic Oligocene sequence lies in the southern Galiuro Mountains, and is overlain by less severely-deformed mid-Tertiary volcanics in the center skyline. Deformation to this degree is typical of Cenozoic rocks throughout southern Arizona.

Photos: R.B. Scarborough

CENOZOIC HISTORY AND URANIUM In Southern Arizona

by Robert B. Scarborough

Our changing perception of the geologic history of Arizona is no less profound than the influence of the new ideas of global tectonics upon the evolution of the whole North American continent. This report is an attempt to outline the Cenozoic history of southern Arizona within the perspective of the new plate tectonic strategy, and to discuss new findings relating to the occurrence of uranium in this region.*

INTRODUCTION

Cenozoic rocks and events in the Basin and Range country of Arizona (the southwest half of the state) may be displayed on a space-time plot, such as Figure 1, which projects groups of sediments and volcanic rocks to a NW-SE line, extending from the Lake Mead area to near the Chiricahua Mountains. This information is plotted against presently-known ages of rocks to produce a diagram which shows the transgressive nature of certain erosional and depositional phenomena described below. For the purpose of this discussion, the Cenozoic rocks of Figure 1 may be subdivided into five stratotectonic groupings, each with characteristic sediments, attendant tectonic style and volcanic chemistry. As shown on Figure 1, these groupings are composed of the following subdivisions: A) a group of Eocene (?) to Oligocene subaerial fluvial and lacustrine sediments with subordinate andesite flows and silicic ash flow; B) a voluminous group of Oligocene and Miocene calc-alkalic volcanics with locally thick accumulations of redbeds

The Bureau of Geology, in conjunction with the Laboratory of Isotope Geochemistry in the Geoscience Department of the University of Arizona, has recently completed a USGS-funded study of uranium occurrences in pre-basin fill Cenozoic sediments of the Basin and Range Province.

In this issue

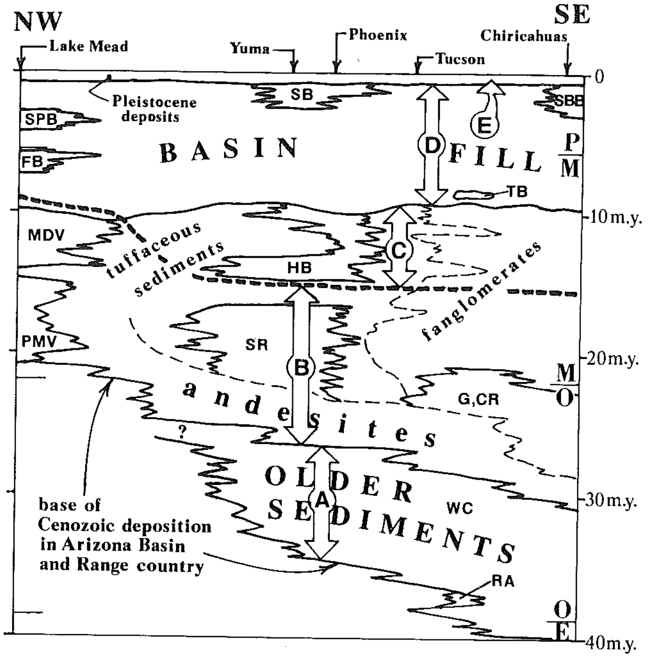


Figure 1, *Cenozoic*. NW-SE cross section through Arizona Basin and Range country with salient features projected to the cross section line at right angles. denotes transition from high to low Sr isotope ratios in volcanic rocks. Letters **A-E** refer to text. **E**=Eocene; **O**=Oligocene; **M**=Miocene; **P**=Pliocene; **RA**=Rillito andesite, Tucson Mts.; **WC**=Whitetail Conglomerate, east central Arizona; **G,CR**= Galiuro, Chiricahua rhyolites; **PMV**=Patsy Mine volcanics; **MDV**=Mt. Davis volcanics; **HB**=Hickey basalts; **TB**=Tablelands basalt, Galiuro Mts.; **SR**=Superstition rhyolites; **SBB**=San Bernardino basalts; **SB**=Sentinel basalts, Gila Bend; **FB**=Fortification basalt, Lake Mead; **SPB**=Sandy Point basalt, Lake Mead.

of diverse petrology; C) a diverse assemblage of middle to late Miocene fanglomerates, tuffaceous sediments, and basalts, best exposed in the central part of the state; D) fluvial and lacustrine sediments with minor basalts which have infilled the basins created by the middle to late Miocene Basin and Range disturbance; and E) Pleistocene sedimentary veneers which cap the basin fill. The most easily tracked dividing line in this scheme is that which separates the mostly undeformed units D and E from the progressively more deformed older units. Eberly and Stanley (1978) in an excellent contribution to the Cenozoic geology of southwestern Arizona, use this boundary to separate their Group I and II sediments.

As noted in Figure 1, the boundaries of units A and B become younger to the NW and intersect the base of unit D, thus "pinching out" unit C volcanics and sediments. The rationale for this is based upon the premises that the inception of basaltic volcanism, as defined below, also becomes younger to the NW, while the initiation of Basin and Range tectonics and hence basin filling, is a synchronous event statewide.

VOLCANIC STYLES

An apparently fundamental change in volcanic chemistry forms the time transgressive boundary between groups B and C of Figure 1, (groups 1 and 2 of Figure 2) at about 15-13 m.y. ago (Miller, and others, 1977; Eberly and Stanley, 1978; Keith, 1978). Before this time, volcanoes spewed forth suites of calc-alkalic rocks such as andesites (including the so-called "Turkey Track" andesites) and voluminous silicic ash flow sheets (ignimbrite flare-up of Coney, 1976) and related pyroclastics. These older rocks are now assumed by their high Sr isotope composition to represent partial melting from a certain depth range along a piece of ocean lithosphere which was being subducted beneath the westward-advancing North American plate.

This volcanic style ceased in approximate coincidence with the inception of the San Andreas transform margin of the western U.S., which triggered an event called the Basin and Range disturbance. The tensional shear stresses of this action literally ripped portions of seven western states apart, and caused such deep fracturing of the continental crust so as to allow the upward leakage of upper mantle-derived, low strontium isotope ratio basaltic magmas, which are found in groups, C, D, and E of Figure 1, and are plotted as age groups 2, 3, and 4 of Figure 2. Major eruptive centers of these magmas contain only small amounts of silicic differentiates, in strong contrast to the previous ignimbrite eruptions, and so hint at the name of a "basalt-rhyolite association" for this volcanic style. This volcanism continues to recent times throughout the state in a space-time pattern seen in Figure 2.

CENOZOIC HISTORY OF BASIN AND RANGE COUNTRY

In Arizona, the Cenozoic Era was heralded in by the Laramide orogeny, which, by its termination at about 50 m.y. ago, had left behind such features as numerous copper-bearing porphyries and pre-existing rocks affected by powerful ENE-WSW compressive tectonics (Coney, 1976).

Eocene – Early Oligocene History

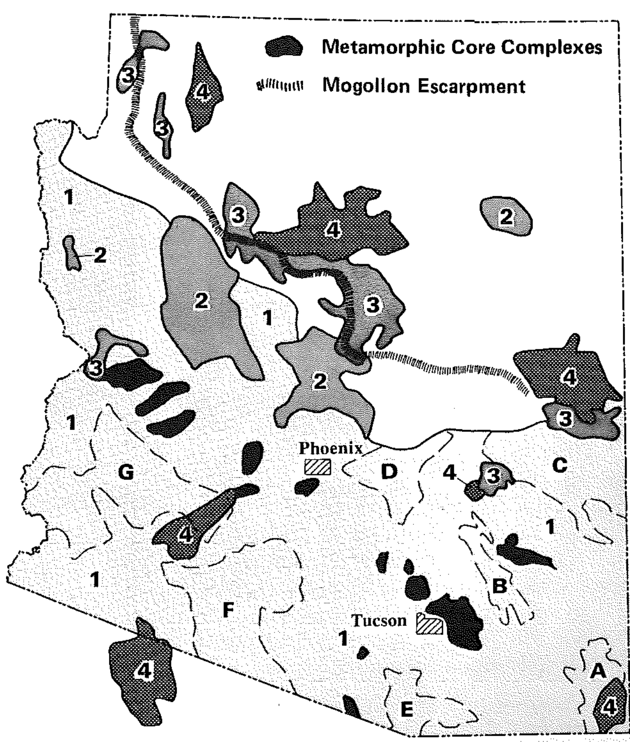
During Eocene and early Oligocene time (50-32 m.y.), a very large, perhaps subcontinental-sized area of the western U.S. was eroded to what some consider a peneplain in the classic sense (Epis and Chapin, 1975). Very little is known of

Figure 2, *Cenozoic*. Generalized ages of Cenozoic volcanic rocks in Arizona. Note a trend of younger volcanics encroaching the Colorado Plateau. Also shown are the Cenozoic "metamorphic core complexes" (Data compiled by Jan Wilt).

Unit 1 Volcanic Fields
A – Chiricahuas
B – Galiuros
C – White Mountains
D – Superstitions
E – Tumacacori-Atascosas
F – Ajo field
G – Kofa field

Ages of Volcanics

Groups of Figure 1		
D,E	4	4-0 m.y.
D	3	9-4 m.y.
C	2	15-9 m.y.
B	1	30-13 m.y.



this event except that regional evidence of massive amounts of erosion and sedimentation is suggestive of a large scale, perhaps epeirogenic uplift, one whose effects perhaps may be seen as, among other things, a still uplifted Colorado Plateau. On Arizona's portion of this plateau is found an extant northeastward-dipping surface of low relief that angularly truncates sediments as young as Cretaceous, and upon which rests the pre-28 m.y. old (Peirce and others, in press) "rim gravels" of McKee (1951). Hence this is identified as an early Tertiary surface of transport upon which the southwestwardly-derived "rim gravels" were shed, perhaps as far northeastward as the four corners region. In the central Arizona source area for these sediments, Mesozoic and early Cenozoic erosion (Peirce and others, 1977) has stripped away the entire Phanerozoic cover to expose the Precambrian in a 50-100 mile-wide, NW-SE elongate swath parallel to the Mogollon Rim (Colorado Plateau edge). This stripped area is referred to loosely as the Mogollon highland.

This erosion-sedimentation cycle was followed by an erosional and/or faulting episode which differentially lowered Southern Arizona beginning in Oligocene time, the real nature of which is the subject of continuing debate. Whatever the event, a Mogollon Rim barrier of sufficient magnitude was created to act as a northeastward limit of deposition for the subsequent large mass of Oligocene and younger deposits.

In southern Arizona, a variety of tectonically disturbed prevolcanic sediments (category A of Figure 1) date from early Oligocene time (37-29 m.y.), such as the Whitetail Conglomerate in the Globe-Winkelman area, some Galiuro Mountain redbeds (see photo on page 1), the Sil Murk Formation near Gila Bend (Figure 3), and some redbeds in the Yuma area. Since these are pre-volcanic in age, they are distinguished by the absence of volcanic clasts in their clastic units. Sediments of this age are not recognized northwest of the Bill Williams River where early Miocene materials were deposited directly upon Precambrian rocks. Lithologies of these sediments are diverse, and include fanglomerates, extensive fluvial overbank (flood plain) deposits, some lacustrine units, and rare aeolian sandstones. Hints of vertical relief comparable to southern Arizona today come from the inclusion of locally abundant, spectacular "megabreccia" gravity slide masses into fluvial and lacustrine units. Color of units range from light gray to intense red-browns. Included volcanics are minor, and consist of andesite flows and silicic ash flow tuffs.

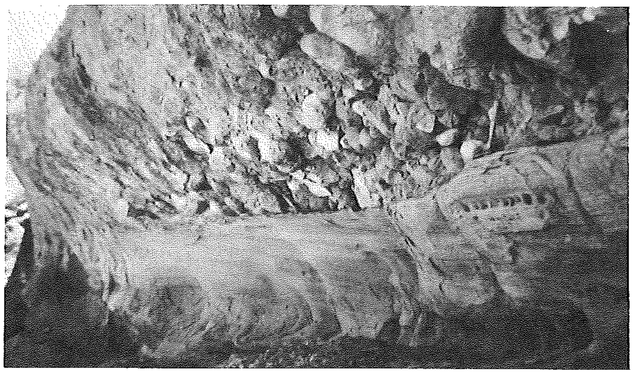


Figure 3, *Cenozoic.* Contact of fanglomerates over aeolian sandstone beds of the Sil Murk Formation, north of Gila Bend. These Oligocene redbeds were deposited on Precambrian granites of the Maricopa batholith.

Ignimbrite Flare-Up

During later Oligocene and earlier Miocene times (30-13 m.y.) massive amounts of calc-alkalic volcanic rocks were erupted into southern Arizona in the form of andesites and voluminous ignimbrite sheets (group B of Figure 1, group 1 of Figure 2). This volcanic episode, first termed the "mid-Tertiary orogeny" by Damon (1964) was felt over a large part of the western U.S., and is viewed in plate tectonic terms by some geologists as the surface expression of the now rapidly foundering Benioff Zone which had previously slid under the continental lithosphere during a greatly accelerated, Laramide-aged surge of continent-ocean collision. Note a distinct younging trend for the inception of volcanism going from SE to NW, as seen in Figure 1.

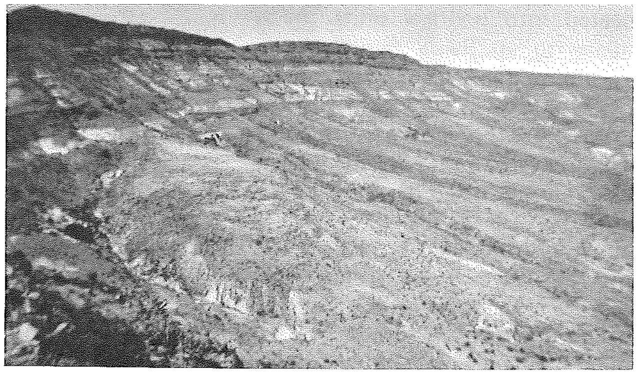


Figure 4, *Cenozoic.* In the Cave Creek area, a series of mildly-deformed Miocene basalts, tuffs and mudstones are capped by 15 m.y. old "Hickey" basalts.

Figure 2 outlines the seven largest fields of this age in Arizona. Large calderas have been hypothesized to exist in the Chiricahua field and the Superstitution field. As a rule, one or more volcanic cycles in each field consist of earlier andesitic flows and later explosive and voluminous ignimbrite sheets. Patterns of sedimentation accompanying this volcanism suggest local volcanic damming of river systems in and around the major volcanic fields and, perhaps, an important cycle of thick, red clastic deposits forming adjacent to the future sites of the central and southeast Arizona metamorphic core complexes (Figure 2). General patterns of stream transport directions for group A and B sediments suggest flow from the Plateau margin out into the present day Basin and Range

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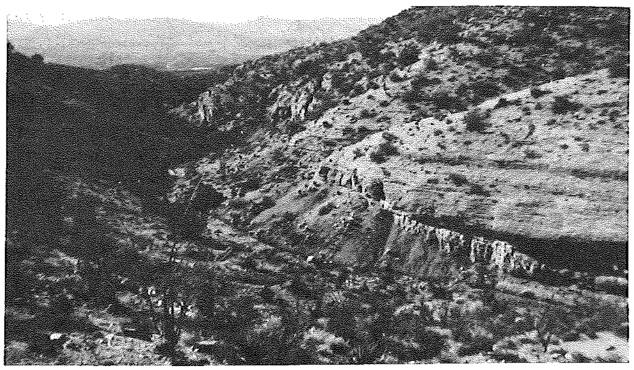

Figure 5, *Cenozoic.* Big Sandy Valley, northeast of Wikieup. Deformed Miocene mudstones and limestones in canyon bottom are unconformably overlain by conglomeratic basin fill, here 150 ft. thick and graded to the main trunk stream of the valley in the distance.

LAND

by H. Wesley Peirce

Preface

The following article, assembled by H. Wesley Peirce, is an outgrowth of informal discussions between members of the Bureau staff and colleagues. We would like to share with our readers some of our thoughts on a particularly complex topic. It is not our intention to espouse a hierarchy of subjective values; we simply hope to present some views gained from our experiences with the earth in general and Arizona's land in particular. If we succeed in conjuring up some provocative images on land not previously considered by the reader, then quite possibly we will have contributed a glimmer of insight, a way of thinking that might be of use when contemplating land-related issues.

Introduction

Land is a four letter word so loaded with diverse, subtle meaning that when we are asked to select from its many values and potential uses, it is apt to become an explosive issue. As a territory, land is often delineated into political units. As a storehouse, it provides sustenance to all living things. As a landscape, it assumes aesthetic connotations. Controversy arises when values are in conflict. The resolution of such conflicts can indeed be a divisive political process. As we will attempt to point out, all such problems, however resolved, are necessarily tinged with arbitrariness. Because of this, politics often has more effect on decisions than does objective science.

Recognizing our own limitations and the need to whittle down this subject to manageable proportions, we propose to emphasize land as a storehouse of raw materials (including energy). Because our earth-related professions specifically focus on how Arizona is put together, what it has in it, and how to get it out, we will use the state to illustrate a point or two that might be of interest.

A Perspective

Arizona is the sixth largest state in the country. Its land area is a common statistic (113,900 sq. mi.) but its volume is not. Technically, can you visualize Arizona's true shape? First, it would help to figure out where its bottom is. Is Arizona's greatest "land" dimension the radius of the earth? Arizona, considered as a shape having volume, or a three-dimensional piece of land, consists largely of the mysterious region beneath us. One might ask, "What is down there?", while another person might be indifferent to the question. Why is it important to know these things? When we begin to view the state's land mass in a three-dimensional manner, we realize that our present reservoir of knowledge about Arizona is rather limited. As a result, society, to the extent that it perceives two-dimensional surface values, often conducts its land affairs in the dim light of a persistent knowledge void. Consequently, many decisions are unavoidably accompanied, as already suggested, by some arbitrariness. Recognition and sensitivity to this fact should be a strength and not a weakness.

An Ecological Imperative

Ecology, an often misused and misunderstood word, is the science of interrelationships. As such, its totality is not known or understood by anyone. These interrelationships form a complex total network which is difficult to conceptualize into patterns. Frustrations arise when we attempt to comprehend the total ecological spectrum. Here too, we operate in a knowledge and awareness void. However, it is possible to generalize and, from this, gain insights that are absolutely necessary if we are to have any chance of consciously recognizing the essential factors that support the existence of modern human societies.

Communities are like trees – they have *roots* that provide the daily means for survival and growth. These roots, so to speak, always lead back into the land in some respect. It seems clear that the further the root is stretched and the more complex the entire root network, the more vulnerable is the organism. In order to emphasize the point being made, perhaps a question or two will provide orientation. Can you trace Arizona's energy roots? Phoenix and Tucson's? Yours? Even if you don't know exactly where these roots go, you are one step closer to understanding this concept if you realize that most of these roots terminate somewhere in the land. Some of our energy roots end several thousands of feet beneath the land surface and not necessarily always on this continent.

Once again, one of the ecological imperatives that we think warrants emphasis is the profound dependence that modern industrial societies have on raw materials that are ultimately derived from the land, especially that part of land that is out of sight beneath the surface. Ecological question: Why is it not possible to be an employed lawyer, doctor, teacher, mechanic, truck driver, geologist, mining engineer, metallurgist, etc. without abundant and varied utilization of land-derived raw materials?

The Root Concept

Hopefully, we can encourage some of our readers to learn to apply the root analogy at appropriate times. As an example, Charles Park, former Dean of Mineral Sciences at Stanford University, says the following in the preface to his book, *Affluence In Jeopardy:* "The purpose of the book is to bring to the attention of intelligent citizens the place of minerals and energy in a modern industrial economy, pointing out the limitations on the supplies and sources of these materials as well as the absolute necessity to use domestic resources effectvely and to develop and keep open lines of international trade. Access to supplies of mineral raw materials, many of which are obtained in isolated and undeveloped corners of the world, is essential to the survival of modern civilizations as we know it." Dr. Park is implying that the roots that maintain the status quo of our society, reach into lands both foreign and domestic.

Another example is excerpted from a speech given by J. Hugh Liedtke, Chairman of the Board, Pennzoil Company, at the 1979 annual meeting of shareholders: ". . . Daily we become more dependent upon crude oil supplies from the Middle East and other politically unstable areas. Disruptions of supply from these politically volatile areas, whether through revolution, terrorist attack or intervention by countries whose interests are in direct conflict with ours, at any moment can cause not simply a tightening of supply, less heat and air conditioning, less gasoline for driving, but a major lack of fuel for our factories, throwing thousands out of work. This is not just the stuff from which

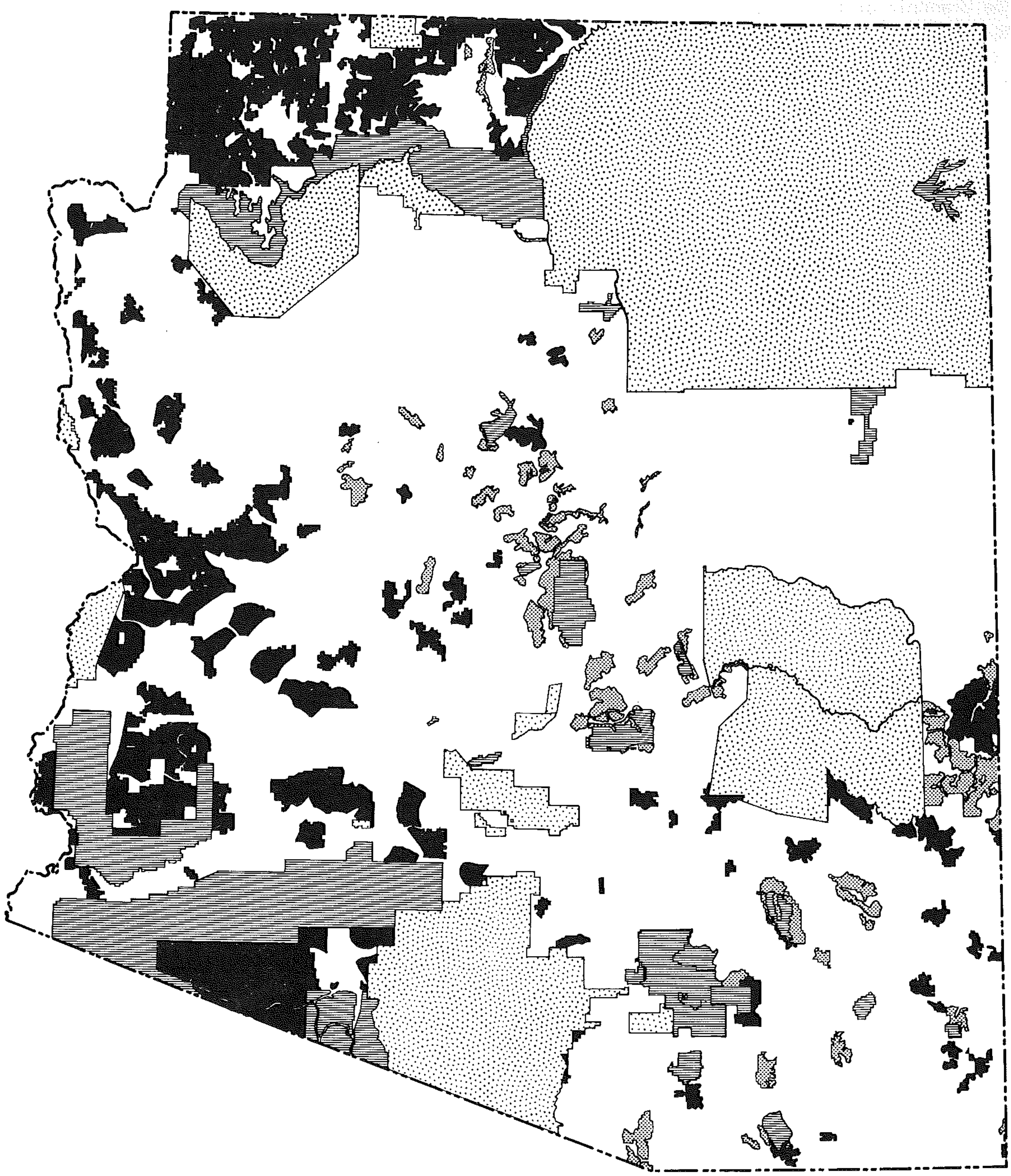

Figure 1, *Land.* Land Status in Arizona, as of August 1979.

Military, National Parks & Monuments, National Forest Wilderness: Permanently closed to mineral/energy exploration and production (State Park lands [approx. 30,000 acres] and urban withdrawn lands in Tucson vicinity not shown on map).

Indian Reservations and U.S. Forest Service RARE II roadless areas (non-wilderness and further planning categories): Restricted use. Negotiations necessary with tribe or agency for mineral/energy entry purposes.

BLM withdrawn wilderness areas, U.S. Forest Service proposed & recommended wilderness: Temporarily closed to energy & mineral exploration/production while wilderness potential is studied. An undetermined amount of this acreage will acquire permanent wilderness status (BLM will announce its eliminations from further wilderness consideration in late September 1979).

Federal, State and Private lands potentially open for exploration & production.

Procedure for entry and mineral exploration varies according to ownership. Federal and private lands with federal mineral rights claims are staked. State lands require a prospecting permit and mineral rights lease. Private lands with private mineral rights (constitute 1-3% of Arizona land) are accessible for entry and exploration only through negotiation with the individual owner, usually by means of a fee or royalty.

economic depressions are made; it is the stuff of war. I am not attempting to be dramatic or to alarm you. The Secretary of Energy is telling this daily to the Congress. So are our military leaders. So are others in our industry . . ."Again the analogy of roots ending beneath foreign lands seems dramatically appropriate. If these roots are severely tampered with, then what? Currently, this is the question before several nations, including those of Western Europe, Japan and our own. Are you directly affected in any way? If you realize that you are, then you can visualize a strand of the root ending in your own gas tank, the other end perhaps being several thousands of feet below the land surface of Saudi Arabia, Nigeria, or somewhere in the U.S.

Land, the Storehouse

The domestic land resource strength of the nation is but the sum of the individual strength of the 50 states. It is most important to recognize that no two states are alike in their indigenous land resource base. As a consequence, it takes a cooperative effort to make both the parts (states) and the whole (nation) viable. No state is an island capable of independence without drastic changes. Today, even our nation could have rapid independence only if willing to accept associated chaos. This is so because of the complexity and extent of the existing international root network. To be independent would mean a total restructuring of root patterns such that they be replanted in our own land. The President's energy plan is an excellent example of advocating the shifting of roots. Where will these roots end? Most probably, they will end in those states having the appropriate raw materials in their three-dimensional land base.

Certain vital raw materials are often concentrated in relatively small land volumes. Regarding raw materials, it is the location of reserves that counts because tomorrow's production must come from today's reserves. How far should a nation, or state for that matter, look and plan ahead? How far should a raw materials industry look ahead? How far should our land planners be looking into the future? If there is concern for the longer range picture that surrounds the development of raw material reserves, then some analysis must ensue.

Regarding unusual concentrations of resources, these examples come to mind: Saudi Arabia and oil, and Arizona and copper. This concentration in Arizona, not fully recognized when the state was first defined, is so unusual that it has been called a planetary resource (Fieldnotes, v.2, n.4, p.1). Copper is Arizona's prime mineral resource and unique contribution to the world. Arizona's copper deposits supplied 62% of the nation's domestic copper production in 1978. Although Arizona consists of 14 counties, the known large copper deposits are restricted to nine counties. Those without known large deposits are the Plateau counties of Navajo, Apache, and Coconino, as well as the Basin and Range counties of Yuma and Maricopa. Less publicized than copper is molybdenum, a most important coproduct in many copper deposits of Arizona. Arizona is second only to Colorado in molybdenum production.

Why is there so much oil in Saudi Arabia and so much copper and molybdenum in Arizona? Some would say that it is more important to know where the deposits are than to know why they are there. Such logic is fine in the short run, but when the easily found deposits are gone, what then?

Raw material deposits, in order to be useful at a given time and place, have unusual physical-chemical attributes and/or a strategic location relative to economic factors, such as transportation arteries, water supplies, energy sources, consuming centers, and so on. All earth materials, whether unusual or not, initially have an environment of origin. Deposits, by analogy with the biosphere, occur in geologic *habitats* peculiar to the material involved.

What is in the land and where it is located has assumed an importance to political and industrial leaders that has increased with the growing complexities of industrial societies. Today, it would take many books to describe how land derived materials are utilized. It would take many more to describe where substances occur and why they are where they are. Dr. Park states the following: ". . .People in the United States are accustomed to the belief that theirs is a rich and independent country; yet, of the 100 minerals most important to its industries, the United States possesses within its national boundaries adequate supplies of only about a dozen. It [the United States] is today [1968] a have-not nation where raw materials are concerned."

Arizona Land

Fundamental to utilizing land are the attendant laws and regulations. Figure 1 is an attempt to depict the various lands in Arizona where entry for raw material purposes currently is either forbidden or severely restricted. It is estimated that about one-half of Arizona's acreage remains relatively open to legitimate exploration and possible development. The significance of this in terms of the potential effect on future raw materials development cannot be directly evaluated unless some correlation is made between the *habitat* of various raw materials and the three-dimensional geologic environments that characterize the withdrawn or restricted lands. One thing is certain; the narrower the search territory, or jurisdiction, the more it will be inevitable that opportunities be restrained.

Geologists trained in Arizona geology can appreciate and understand the significance of the state's great diversity of geologic environments. Environments are interpreted from rock relationships and, these in turn are the subjects of geologic maps and diagrams. What controls the locations of the large Arizona copper deposits? Why, out of 50 states, should nine counties in Arizona have such an unusual amount of copper? Are there deposits yet to be discovered in Arizona? Where might they be?

How about energy materials in the lands we call Arizona? What can be said about their positions and potential? There are interesting distinctions to be made in the ways of looking at each of the big three: coal, petroleum and uranium. Each involves a different habitat and serves to illustrate the absolute controls of environment on what might form and where.

Figure 2 is intended to show the following: 1) the position of Arizona's significant coal reserves in the Plateau region of northern Arizona on the Navajo Indian Reservation, 2) the position of known oil production in Arizona, again on the Navajo Reservation, and 3) the position of holes drilled in search of petroleum in Arizona. Coal reserves, in order to be exploited by stripping technology, must be relatively close to the surface, within 200 feet or so. In addition, exploitable deposits tend to be horizontally spread out because of the controlling or layered environment in which they formed. In Arizona, exploitable coal deposits are restricted to one particular age group, the one that contains much of the coal known to the Rocky Mountain states in general. Past geologic mapping in Arizona reveals the distribution of these particular rocks, which places limits on where associated coal might potentially occur. Knowing these geologic (land) limits leads to the conclusion that Arizona's significant coal reserves are restricted to Black Mesa.

Petroleum, on the other hand, is an entirely different matter. It is exploited, under proper circumstances, from depths greater that 20,000 feet. Because of this, in contrast to most coal, the

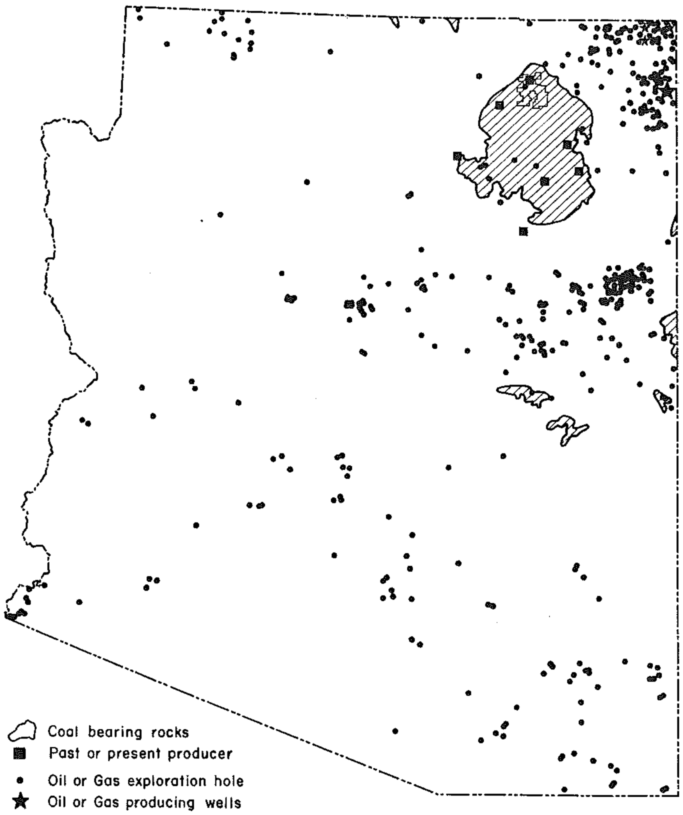

Figure 2, *Land.* Coal, Oil and Petroleum Reserves.

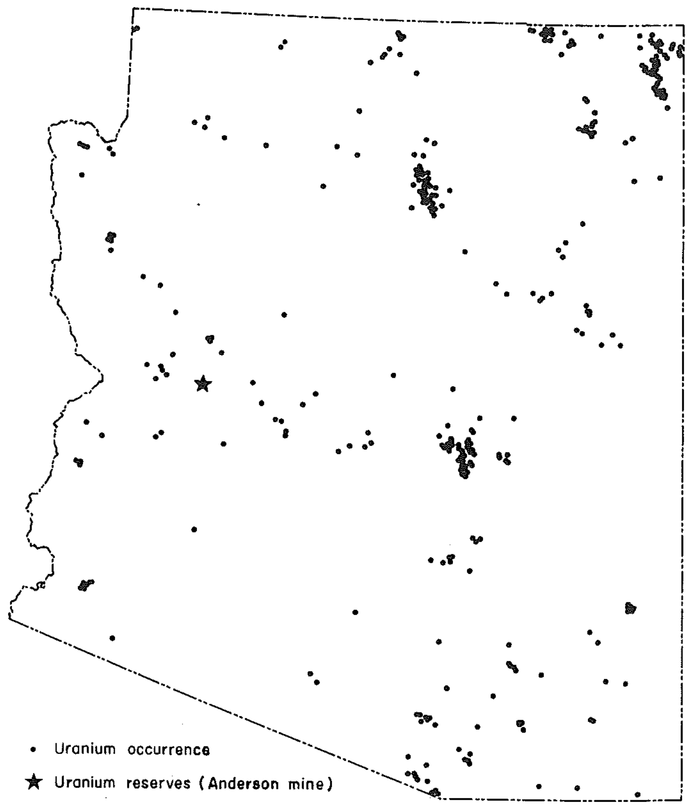

Figure 3, *Land.* Uranium Occurrences.

geologic condition of the earth at considerable depths must be studied if petroleum potential is to be effectively and fairly evaluated. Thus far, Arizona rock (land) has yielded only about 16 million barrels of oil over a span of 16 years – an amount equivalent to about two days of present crude oil imports. Arizona's latest and largest oil field thus far, was discovered in 1965 in northeast Arizona at a depth of about 3,500 feet. Figure 2 might give the impression that the state has been fairly well tested and found wanting in petroleum potential. How, then, should one explain the present petroleum-based land play, the largest in Arizona's history, extending across the southern part of the state where there has been nothing but dry holes drilled before? Although a combination of factors is involved, the geologic basis is a revolutionary idea, an idea that can be either conclusively vindicated or rejected only by deep drilling (Fieldnotes, v. 9 n. 1 p. 10). Likely, only geologists with experience in the geology of southern Arizona and elsewhere can appreciate fully why it is possible in this day to come up with anything new in this region. All of the previously-drilled holes indicated in Figure 2 in southern Arizona are too shallow to have tested the new model, which is based principally in deep seismic testing, not surface studies. Deep vibratory soundings represent technological refinement. The expense involved in this play, including the anticipated deep drilling, is made possible only by current petroleum prices. The above leads to a conclusion well known to business people – the economic climate changes, and with it, judgements are altered on where to look for new discoveries of raw materials. Opportunities wax and wane and when conditions are right, new frontiers are sought, frontiers beneath the land surface. Today's "waste" may be tomorrow's ore, providing there are ample potential habitats within which to carry out the hunt.

Figure 3 depicts some of the known uranium occurrences in Arizona. The star indicates the position of the largest presently known concentration of reserves in the state. If nothing else, a simple depiction like this illustrates that uranium occurrences are not uncommon; and further, it suggests that there are valid reasons for exploring Arizona lands for this energy mineral. Probing the uranium story a little more reveals a shifting of geologic emphasis with time and with economic and political changes. In the first uranium boom of the fifties, about 18 million pounds of U_3O_8 (uranium oxide), was produced, mostly from the northeastern part of Arizona, again on the Navajo Indian Reservation (at an average price of less than $5.00/lb.). With the rise in demand for nuclear fuels derived from the anticipated growth of a nuclear powered electrical industry, another boom was initiated across the country in the seventies. In Arizona, emphasis was shifted to off reservation geologic targets where little experience was gained during the earlier boom. Higher prices encouraged deeper drilling for lower grade ores. As a consequence, it is believed that new reserves discovered in geologically more complex terrain amount to more than the total previous production in Arizona. Again, this illustrates the fact that time and circumstances can change the exploration activity. Such could not happen without flexibility of opportunity. Although no one can forecast the future with certainty, it is possible that, in spite of the present unpopularity of the nuclear option, circumstances will probably conspire to encourage further development in the future. If so, we might well need the nuclear fuels represented by the yet undiscovered uranium deposits of Arizona and other western states.

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Mine Reclamation Center

by Mary Jane Michael

The state of Arizona Mining and Mineral Resources Research Institute (MMRRI) has established the Mine Reclamation Center (MRC) at the University of Arizona. The MRC is located in the Arid Lands Information Building where it will provide a focus for University of Arizona research and institutional and service competence in reclaiming arid and semiarid mined lands.

The MRC Advisory Committee to the Director of the MMRRI, Dr. William H. Dresher, consists of Dr. Kennith E. Foster, Director of MRC; Dr. Ervin H. Zube, Director, School of Renewable Natural Resources and Associate Dean of the College of Agriculture; Dr. Fred Matter, Assistant Dean of the College of Architecture; Dr. Thomas J. O'Neil, Head of the Department of Mining and Geological Engineering, College of Mines; and Dr. Jack D. Johnson, Director, Office of Arid Lands Studies.

The specific objective of the MRC is to provide a focal point for interdisciplinary expertise on the University of Arizona campus that addresses the problems of mine reclamation in the Southwest. The depth of research and the technical expertise represented by project personnel from various colleges form a large base of research competence at the University of Arizona.

A number of mine reclamation research programs are presently planned or underway at the University of Arizona. Highlights of some of these projects include:

- Three-dimensional techniques for mine site modelling as a dynamic representation of pertinent features of mined areas. Contact: Dr. Fred Matter or Dr. Kenneth Clark, College of Architecture, or Dr. Thomas J. O'Neil, Department of Mining and Geological Engineering.

- Feasibility analysis to determine the potential for reclaiming precious metals from mine dumps prior to initiation of land reclamation. Contact: Dr. David Rabb, Bureau of Geology and Mineral Technology.

- Application of water harvesting techniques to coal mine spoils on Black Mesa for farming. Contact: Dr. John Thames, School of Renewable Natural Resources, or Dr. C. Brent Cluff, Water Resources Research Center.

- Feasibility of using RussianThistle for bioconversion. Contact: Dr. Aden Meinel, Optical Sciences Center, or Mr. William H. Brooks, Office of Arid Lands Studies.

- Use of remote sensing data and automated image analysis to provide an initial inventory of mines and mine wastes and to provide data to estimate reclamation costs for these areas. Contact: Dr. Robert Schowengerdt, Office of Arid Lands Studies, or Dr. Charles Glass, Department of Mining and Geological Engineering.

The MRC also produces a quarterly literature reporting service, SEAMALERT, and maintains SEAMINFO, a cumulative bibliographic data base of references to mined land reclamation literature. The SEAMINFO computer terminals and the editing offices of SEAMALERT are housed in the Arid Lands Information Building as is the State of Arizona Bureau of Geology and Mineral Technology.

Computer services available to the MRC also include a data base of all proposed and ongoing research at the University of Arizona. With the information from this data base the MRC can determine which research projects and personnel from the University of Arizona are most suited to assist mined land projects in the southwestern United States.

The MRC, through interdisciplinary cooperation with various Colleges and Departments at the University of Arizona offers expertise which can:

- prepare integrated land rehabilitation programs for mining operations;
- develop monitoring programs in watershed hydrology, meteorology and air quality;
- provide impact evaluation of proposed land disturbances;
- conduct research in techniques and methods of reclamation;
- plan alternative development strategies;
- develop land management plans; and
- conduct demonstration projects of innovative land rehabilitation concepts.

Organizations that would like additional information about mined land reclamation expertise available at the University of Arizona can contact project personnel directly. Inquiries may also be addressed to: Dr. Kennith E. Foster, Mine Reclamation Center, Arid Lands Information Building, 845 N. Park Avenue, Tucson, Arizona 85719, (602) 626-2086.

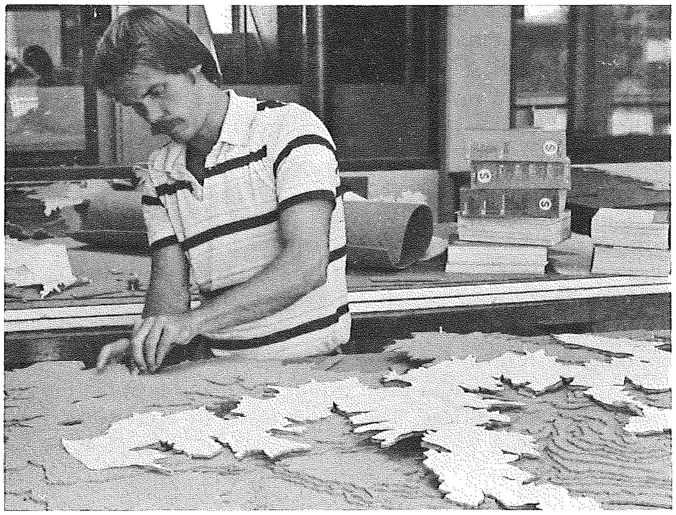
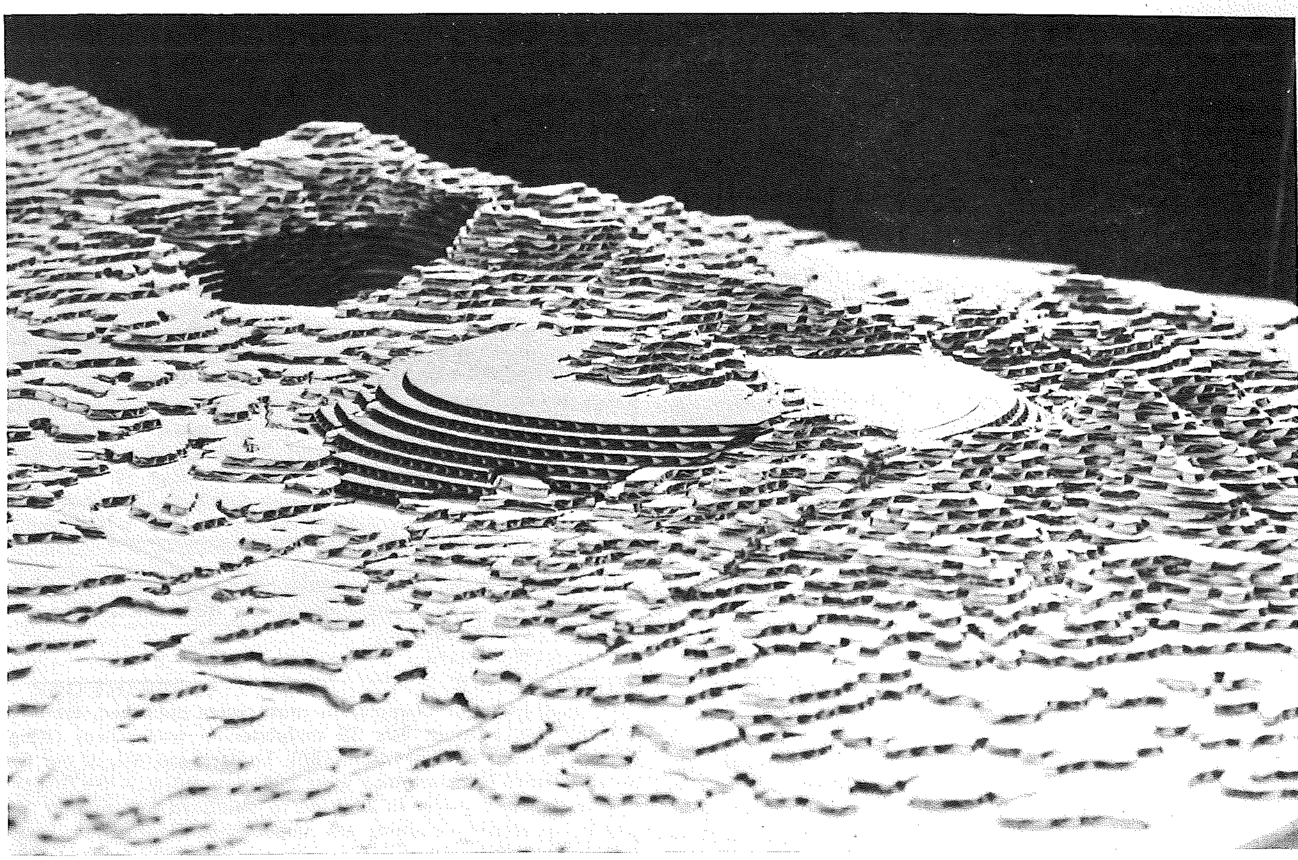
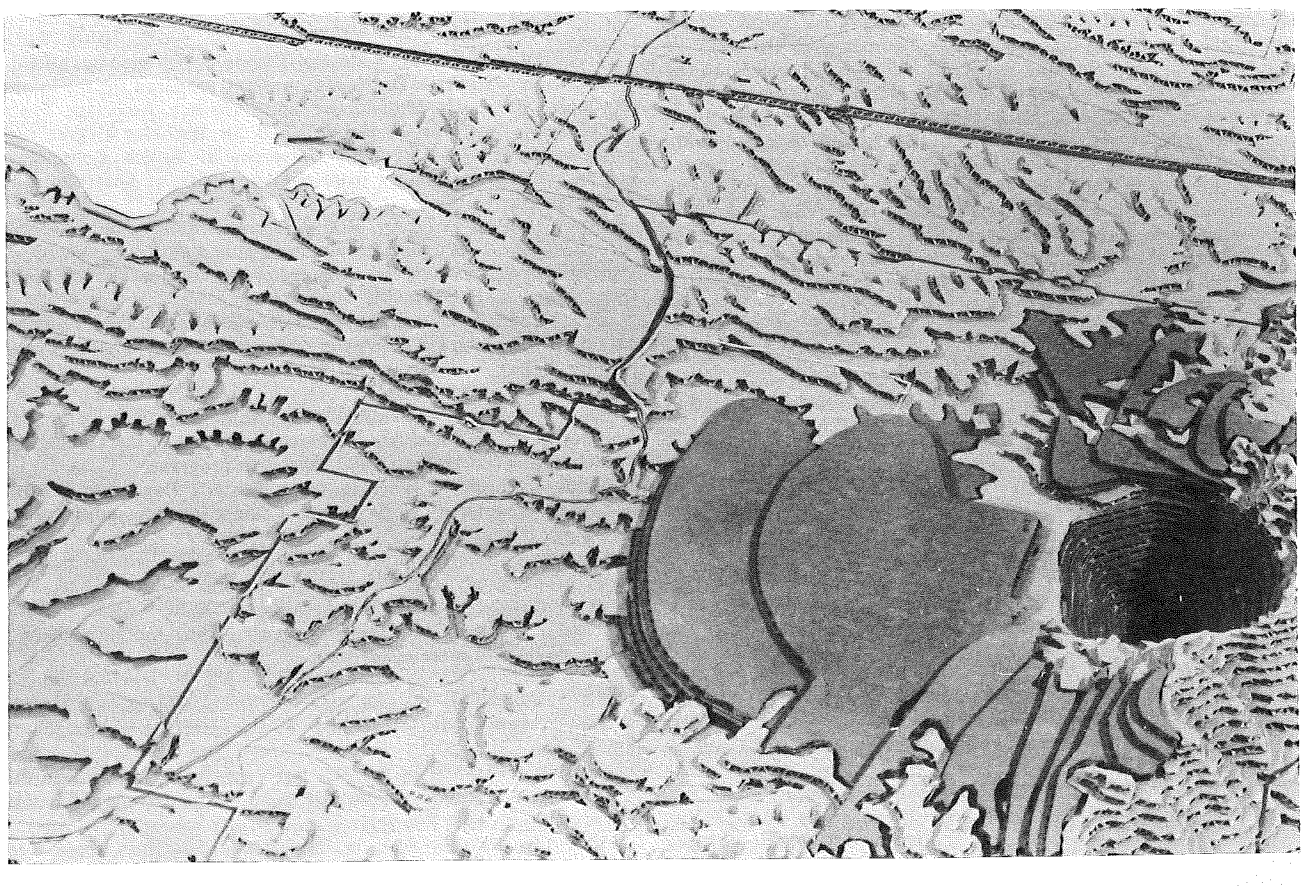


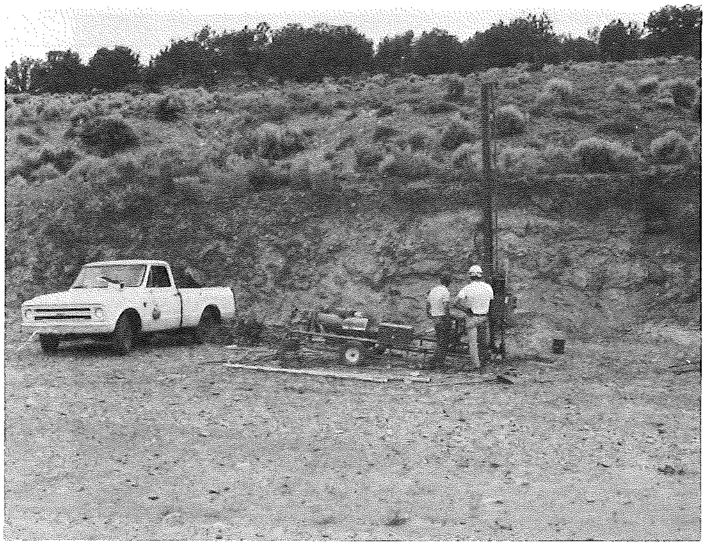
Photo: Tom McGarvin

Mike Nelson, College of Architecture researcher, working on the construction of a cork topographic model designed for minimal environmental and visual impact to surrounding terrain.

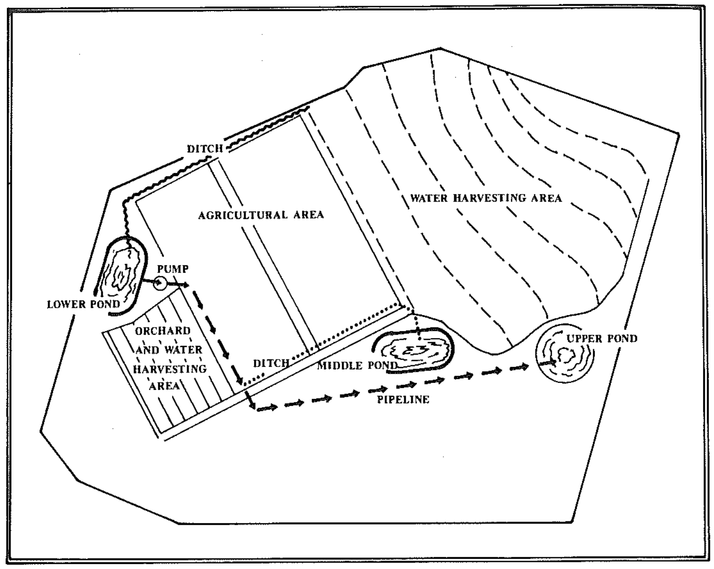


Topographic models of mine dumping patterns and tailing ponds, scaled at 1:1,000 and constructed of corrugated cardboard by U of A College of Architecture researcher. Photos: Mike Stanley





Mine Reclamation Center.
U of A, College of Agriculture, Dept. of Renewable Natural Resources. Researchers drilling observation wells along a Black Mesa stream bed in order to assess the effects of coal mining on the water quality in shallow aquifers. Photo: U of A College of Agriculture



Mine Reclamation Center.
U of A, College of Agriculture. Water-harvesting Agro-system designed for mine reclamation at the Black Mesa Mine of the Peabody Coal Company.

WATER CONTROL PLANS ADVANCED

The second in a series of planning sessions of the Technical Advisory Group (TAG) to the Central Arizona Water Control Study was held on July 24, 1979. This study is headed jointly by the Bureau of Reclamation and the Army Corps of Engineers, whose first major goal is to make strategic decisions regarding both Central Arizona Project (CAP) regulation storage facilities for the CAP canal and central Arizona flood control measures for the benefit of the Phoenix metropolitan area. These decisions are to be incorporated into a final environmental impact statement by the Secretary of the Interior in May, 1982.

Several topics were discussed at the TAG meeting. Two contracts have been awarded, one to the Dames and Moore Company for the study of environmental, social and economic impact of the overall project and the second to the Natelson Company for a flood control economics study. Several proposed damsites, such as the Tangle Creek on the Verde River, the Coon Bluff and Klondyke Buttes on the Salt River, have been eliminated from further consideration. Preliminary planning continues on a new Waddell Dam on the Agua Fria, a new Bartlett Dam on the Verde, an enlarged Roosevelt Dam, a new Granite Reef Dam on the Salt and a new Buttes Dam on the Gila River. An important study of the overall impact of the project, termed "The Future without the Study" has been initiated, which will attempt prediction of events, assuming no action be taken by this project.

The Bureau of Reclamation and the Army Corps of Engineers, by initiating involvement in this project at all levels of local management, are "trying to eliminate surprises" when the final EIS is drafted.

Questions, inquiries or subscriptions to the mailing list for information pamphlets can all be solicited from Marty Rozelle at 271-0915 (Phoenix) or write Manager, Arizona Projects Office, Bureau of Reclamation, Attention: Code-170, 201 N. Central Ave., Suite 2200, Phoenix, Az. 85073.

Bureau Initiates Statewide Molybdenum Study

On April 1, 1979, the Bureau of Geology began a systematic statewide molybdenum survey. The six-month project is being sponsored by a $15,000 U.S. Geological Survey grant. The purpose of the study directed by Stanley B. Keith is to compile all published and available unpublished information about the occurrence of molybdenum in Arizona for the U.S. Geological Survey Computerized Resources Information Bank (CRIB). When completed, the study will be incorporated in a Bureau of Geology publication.

Although Arizona is well known as a major source of world copper, the State's rank in world molybdenum production (third in the world) is not acknowledged. Much new chemical and geological data about Arizona molybdenum occurrences have accumulated in the last several years. A comprehensive listing of molybdenum occurrences in the state has not yet been published. For example, the most recent published statement about Arizona molybdenum lists 39 molybdenum occurrences (King, 1969, Arizona Bureau of Mines Bull. 180). To date, Jan Wilt of our Geological Survey Branch has assembled some 300 occurrences in the first five weeks of the Bureau's study. In addition to published information, we would greatly appreciate obtaining any unpublished information, such as that from mining company files or other sources. Anyone who wishes to contribute such data should contact Jan Wilt at the Geological Survey Branch.

NEW STAFF

Senior Research Metallurgist

The Bureau of Geology's Mineral Technology Branch has added Douglas J. Robinson to its staff. Dr. Robinson is well prepared for the joint position of Senior Research Metallurgist and Adjunct Associate Professor of Metallurgical Engineering. He obtained his Bachelor Degree in Applied Sciences (Metallurgy) from the University of British Columbia in 1967 and his PhD in Metallurgy from the University of Sheffield, England in 1970.

From 1970 to 1977, Dr. Robinson was employed by Cominco Ltd. in British Columbia as a research metallurgist and pilot plant engineer. During the last two years he served as senior process engineer at Air Products and Chemicals, Inc., in Greenville, Pennslyvania.

Dr. Robinson's area of responsibility includes coordinating communications and cooperative research between engineers in industry.

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Graduate Research Assistant

Marie Slezak has been selected by the Bureau of Geology and Mineral Technology to be Graduate Research Assistant at the Geological Survey Branch during the 1979 to 1980 fiscal year program.

Marie is currently working on a Master's Degree in Environmental Geology at the U. of A. She plans a career in metropolitan and regional land use planning.

During her internship with the Bureau, Marie will be developing her thesis proposal on bank erosion in Tucson, to be used as a model in proposed floodplain ordinances in Arizona. Dr. William B. Bull will be the principal advisor on this project and Dr. Edgar McCullough and Dr. H. Wesley Peirce will serve as advisors.

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Editor

Anne Candea has joined the Bureau staff as Editor of technical publications.

Prior to her arrival in Arizona last year, Anne coordinated the public information and public relations program at the Cleveland Division of Air Pollution Control for five years.

Anne received her B.A. in English and Sociology from Kent State University (1965). Currently, she is enrolled in a Master's Program in Management with the University of Phoenix.

Arizona Geological Society Digest 11: *Porphyry Copper Symposium Proceedings*

The Arizona Geological Society's most recent Digest, volume XI, contains the proceedings of the Porphyry Copper Symposium held in Tucson in March of 1976. Digest 11 consists of 18 papers which discuss the geology of the following Arizona areas: Safford, Cyprus Johnson, Copper Creek, Cyprus Pima and Sierrita-Esperanza. Other discussed areas include Pinos Altos, New Mexico; Lights Creek, California; MacArthur and Copper Canyon, Nevada; and La Verde, Michoacán, Mexico. Geophysical exploration, root zone characteristics, structural reconnaissance, production costs, a Sonoran metallogenic map, Neogene metalogenesis in Chiapas, Mexico, and the evolution of porphyry copper exploration in the Southwest are also covered. Digest 11 also includes nine abstracts of papers given at the 1976 porphyry copper symposium covering Pilares, Nocozari, Mexico and these locations in Arizona: Kalamazoo, Ray, Vekol Hills, Bagdad, San Xavier, San Xavier North and Twin Buttes.

Digest 11 was edited by Judith P. Jenney and Helen R. Hauck and put into a new 8½ by 11 inch format which allows for larger diagrams. The editors have produced a very high quality publication which should be on the "must have" list of all economic and regional geologists.

This publication is available for $7.00 by mail from the Arizona Geological Society Publications, P.O. Box 40952, Tucson, Arizona, 85719, and over the counter from the Bureau of Geology and Mineral Technology.

OPEN FILE REPORTS

The Bureau announces the publication of a USGS—funded study on uranium favorability in southern Arizona. *A Study of Uranium Favorability of Cenozoic Sedimentary Rocks, Basin and Range Province, Arizona (Part I): General Geology and Chronology of Pre-late Miocene Cenozoic Sedimentary Rocks* was compiled by Bureau Geologists, Robert B. Scarborough and Jan Carol Wilt, in conjunction with the Laboratory of Isotope Geochemistry at the U of A. The 101-page report (open file report #79-1429) is now available for purchase from the Bureau of Geology for $12.00 (over the counter) or $14.00 (postpaid).

A synthesis of Arizona's geology and energy resources has been published in a recent *Interstate Oil Compact Commission Committee Bulletin* (Vol. xx, No. 2). The paper, entitled "Geology of Arizona: Its Energy Resources and Potential", was presented in December 1978 by J. Dale Nations, Commissioner of the Arizona Oil and Gas Commission. Dr. Nations is also an Associate Professor of Geology at Northern Arizona University in Flagstaff, Arizona.

Also included in the bulletin is an investigation of thermal gradients in shallow wells, by Sal Giardina, Jr., a geologist with the Commission. The title of the study is "Thermal Gradient Anomalies – Southern Arizona."

Both of these reports are available for review in the Bureau of Geology and Mineral Technology's Open File.

NAU THESES 1975-1977

Emily C. Bradshaw: MS
Structure in the Mazatzal Quartzite, Del Rio, Arizona. 67 p. 1975.

Thomas M. Daneker: MS
Sedimentology of the Precambrian Shinumo Sandstone, Grand Canyon, Arizona. 195 p. 1975.

W. Norman Kent: MS
Facies Analysis of the Mississippian Redwall Limestone in the Black Mesa Region. 186 p. 1975.

Thomas D. Light: MS
Geology of the Board Creek Area, Yavapai County, Arizona. 62 p. 1975.

Peter Henry Lufholm: MS
The Geophysical Analysis of the Gray Mountain Area, Coconino County, Arizona. 54 p. 1975.

Randi S. Martinsen: MS
Geology of a Part of the East Verde River Canyon, Near Payson, Arizona. 117 p. 1975.

Sandra D. McDonald: MS
Use of Geophysical Measurements to Assess Cinder-Aggregate Potential of Volcanic Cinder Cones. 104 p. 1975.

Reginald E. Reid: MS
Geologic Hazards in a Portion of East Flagstaff, Coconino County, Arizona. 120 p. 1975.

Kenneth Charles Scott: MS
Hydrogeologic and Geophysical Analysis of Selected Diatremes in the Hopi Buttes area, Arizona. 129 p. 1975.

Thomas W. Auld: MS
Facies Analysis of the Virgin Limestone Member, Moenkopi Formation, Northwest Arizona and Southwest Utah. 83 p. 1976.

Gary Clyde Harrison: MS
Facies Analysis of the Devonian of the Black Mesa Basin, Arizona. 57 p. 1976.

William R. Henkle, Jr.: MS
Geology and Engineering Geology of Eastern Flagstaff, Coconino County, Arizona. 57 p. 1976.

David B. Koval: MS
Structural Analysis of the Lake Mary Field Area with the Hydrologic Interpretations, Coconino County, Arizona. 123 p. 1976.

John Joseph Matthews:
Paleozoic Stratigraphy and Structural Geology of the Wheeler Ridge Area, Northwestern Mohave County, Arizona. 144 p. 1976.

Ronald Gordon McCain: MS
Relationship Between Water Loss from Stream Channels and Gravity and Seismic Measurements: Beaver Creek Watershed 7, Coconino County, Arizona. 101 p. 1976.

Robert William Pope: MS
An Analysis of the Carbonate Facies of the Hermosa Formation (Pennsylvanian) of Northeastern Arizona. 134 p. 1976.

Stephen V. Reed: MS
Stratigraphy and Depositional Environment of the Upper Precambrian Hakatai Shale, Grand Canyon, Arizona. 163 p. 1976.

Douglas L. Flynn: MS
The Geology of the Cerro Macho Area, Sonora, Mexico. 62 p. 1977.

James Carlo Himanga: MS
Geology of the Sierra Chiltepins, Sonora, Mexico. 99 p. 1977.

Charles L. Lane: MS
Pennsylvanian-Permian Stratigraphy of West-Central Arizona. 120 p. 1977.

James W. Langman: MS
The Shinarump Member of the Chinle Formation in Northern Arizona and Southern Utah. 106 p. 1977.

Ralph U. Pugmire: MS
The Geology of Bill Williams Mountain, Coconino County, Arizona. 97 p. 1977.

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ASU THESES

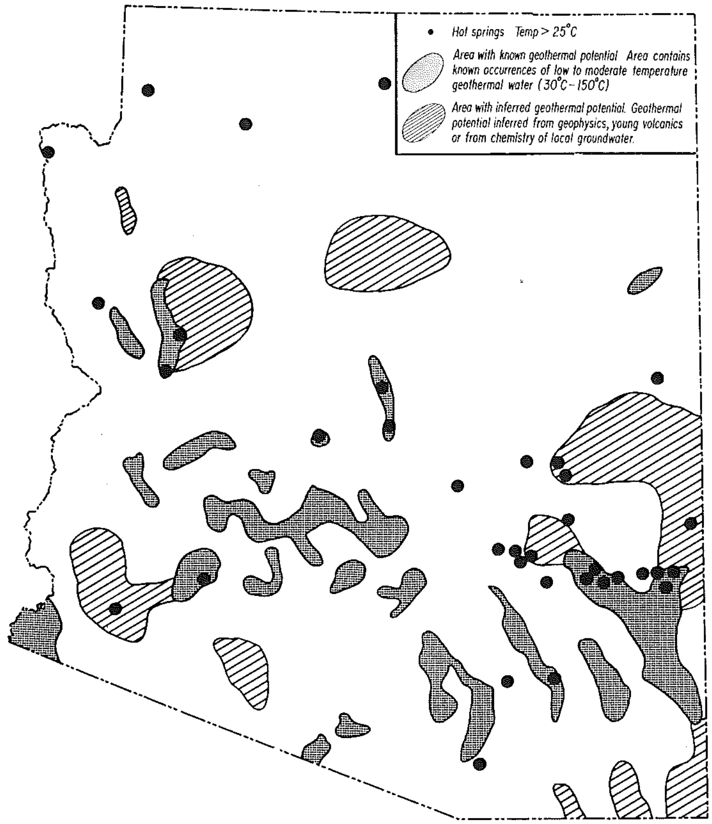
Edward N. Agurkis: MS
"Depositional History of the Piankasha Sequence (Upper Devonian), Southern Arizona, and Southwestern New Mexico." 1977

Randall Groves Updike: Ph.D.
"The Geology of the San Francisco Peaks, Arizona." 1977

Dennis G. Welsch: MS
"Environmental Geology of the McDowell Mountains Area, Maricopa County, Arizona: Part II." 1977

Jeffery V. Holway: MS
"Environmental Geology of the Paradise Valley Quadrangle, Maricopa County, Arizona: Part I." 1978

GEOTHERMAL RESOURCES - *what to look for in arizona*



by Nile O. Jones

Since the early part of the twentieth century, steam produced by the earth's heat has been used to drive generators to produce electricity. Consequently, there is a tendency to think that electrical generation is the only application for geothermal resources. Spurred by the ever-increasing costs of petroleum today, there is a concerted effort to bring geothermal and other alternative energy resources into greater prominence.

The application or use of Arizona's geothermal resources requires an understanding of the geological setting. The conventional model of a geothermal field requires a near-surface heat source, such as a magma intrusion or igneous point source (Figure 1). Heat from the cooling magma radiates upward and outward through conductive heating of the adjacent rocks. Faults and fractures in the bedrock may provide avenues for deep circulation of groundwaters. Such circulation would result in the heating of the water and the transfer of heat by convective processes. Should the heated water quickly come to the surface, hot water springs, fumerals and possibly geysers would result.

In addition to these surface phenomena, certain chemical characteristics of the water, along with geophysical observations would suggest an igneous heat source. For example, the presence of free hydrogen in escaping steam implies temperatures in excess of 200°C. Certain trace metals might also be interpreted as having an igneous source, while isotopic ratios of sulfur or oxygen may also lead to the same conclusion. Helpful geophysical techniques include microearthquakes, gravity, seismic reflections and heat flow measurements.

Consider for a moment the natural increase of temperature with depth. Figure 2 shows this relationship for a suite of temperature gradients. In practice, the observed or measured gradients do not form straight, linear relationships because of groundwater circulation, convective heat flow and varying thermal properties of differing lithologies. Nonetheless, the *average* thermal gradient of a region can be represented as a straight line. The shaded area in Figure 2 represents an approximation of the non-thermal areas in the world. In order to obtain temperatures with power-generating potential within this zone, one would be required to drill to a depth of at least 6 or 7 km, compared to direct-use thermal waters which may be encountered at 2½ to 3 km.

The Bureau has conducted studies over the past two years, establishing data that the deeper basins throughout the state have average gradients in excess of 30°C per km. For example, we consider 37°C per km as the average basin-wide gradient for the Tucson Basin. This leads the Bureau to infer that boiling temperatures can routinely be expected at 3 km. We may in turn suppose that we could produce electricity from 150°C waters (as now occurs in a Raft River Mountains pilot plant) at depths of 2½ to 3 km and regional gradient temperatures of between 45 and 55°C per km.

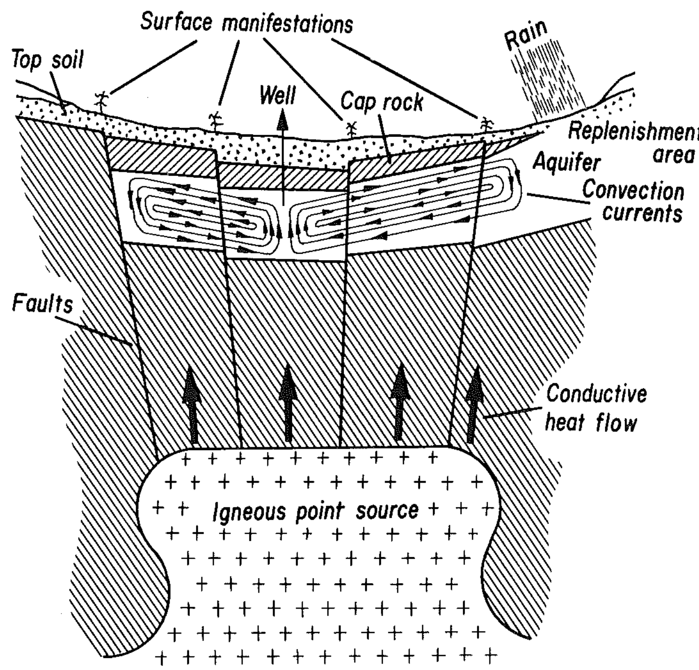


Figure 1, *Geothermal.* Igneous point source for geothermal energy in a Basin and Range setting (Armstead, 1978).

How do we know the temperatures are there and what can we do with them? We test existing wells and drill exploratory holes to determine the volume and temperature. There are seven wells in the state that have temperatures of over 100°C. With one exception, all wells have a gradient in excess of the 30°C per km value. One well near Chandler is well over the assumed deep basin gradient, as is the occurrence in San Simon.

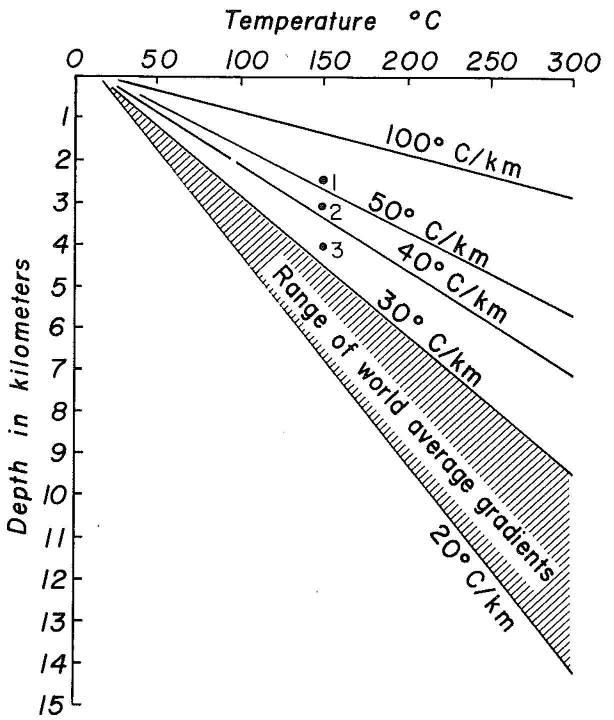


Figure 2, *Geothermal.* Temperature/depth relationships for various temperature gradients (mean average temperature=20°C).
1=minimum electricity producing temperature for 2½ km
2=minimum electricity producing temperature for 3 km
3=depth required for minimum electricity producing temperature using 37°C/km gradient (Armstead, 1978).

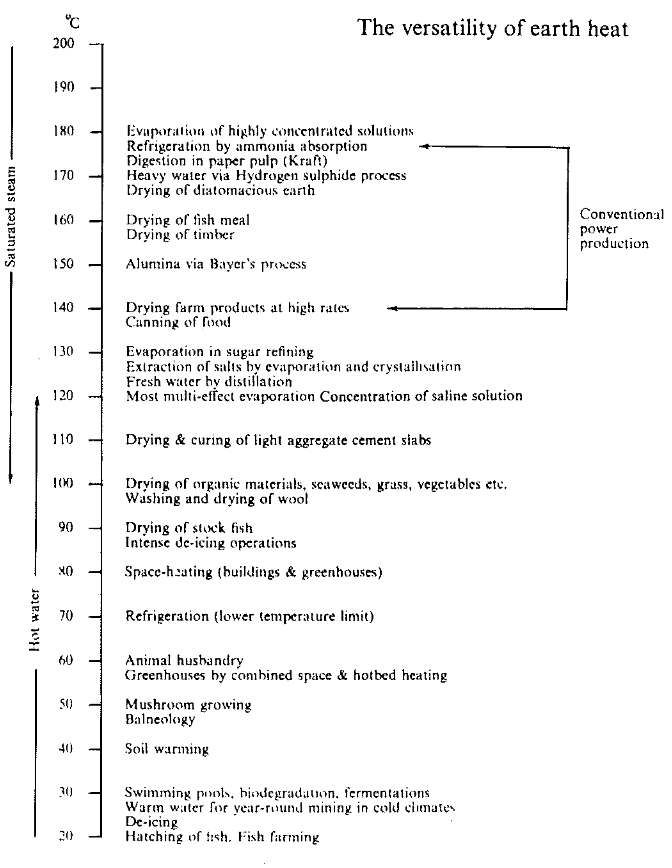


Figure 3, *Geothermal.* Approximate temperature requirements of geothermal fluids for various applications (Lindal).

Assuming no electricity can be produced at these lower temperatures, the potential application of geothermal power still remains quite extensive. Figure 3 lists some of the processes that are already being tried, along with their temperature requirements. Additional applications geared to existing Arizona business activities would include: citrus concentration, pumping of irrigation water, cotton seed oil production, mineral processing and milk pasturization. One application that is currently being evaluated would be to provide the prison facilities at Safford with geothermal heating and cooling.

The existence of low to moderate temperature waters throughout the state allows for a multitude of applications. Indeed, the uses for geothermal energy are limited only by the imagination of those who wish to put it to work.

References

Armstead, H.C.H., 1978, Geothermal Energy, Halsted Press, New York, 357 p.

Giardina, S., and Conley, J.N., 1978, Thermal Gradient Anomalies in Southern Arizona: Arizona Oil and Gas Conservation Comm. Report 6.

Hahman, W.R. and others, 1978, Geothermal Map No. 1.Bureau of Geology and Mineral Technology

Lindal, B., 1973, Industrial and other applications of geothermal energy, UNESCO, 135 p.

Land continued

Conclusions

An industrial society consumes vast quantities of a wide variety of raw materials derived from land. By analogy, such societies are supplied, like a tree, by a complicated network of *roots* that terminate in land, somewhere. Once dependent upon this network, an organism is easily disrupted when changes occur. Regardless of consumptive rate, even if slowed down by design or shortages, future discoveries of materials will still be needed in order to provide reserves for purposes of economic planning. The tendency, as more and more demands are made upon the land for specific uses, is for exploration to occur and development land to disappear. Increasing land pressures, thus, should inspire an awareness of the need for careful and responsible planning that recognizes a hierarchy of land needs, which includes material and energy substances for the future. Because of the difficulty of always knowing what is below us, land decisions necessarily are made somewhat arbitrarily. Hopefully, a long range perspective accompanied by recognition of the ever present need for *roots* will combine to serve the state and nation well.

An adequate land data base should include an inventory that depicts surface geologic environments (geologic maps) which, in turn, hold the best key to the potential presence of raw materials and energy resources habitats. We must continue to strive to acquire a better understanding of the land, all of it, including that beneath our feet. Our future depends on it.

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Liedtke, J. Hugh, 1979. Pennzoil company first quarter report, March 31, 1979 and report of the annual meeting of shareholders, May 7, 1979, p.18.

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Cenozoic continued

country, and also a pattern in southeast Arizona of northwest-directed flow parallel to the long trend of the present position of the metamorphic core complexes. However, any mass transport linkage of the Oligocene sediments to those of the Claron Formation of southwest Utah (Rowley and others, 1978) must await further studies.

Metamorphic Core Complexes

Recent studies (Davis and Coney, 1979 and GSA memoir volume, in press) have shed considerable light on the Cenozoic evolution of the "metamorphic core complexes," such as the southern Santa Catalina Mountains near Tucson or South Mountain near Phoenix. Those core complexes found in Arizona lie in a NW-SE zone parallel to the Mogollon escarpment (Figure 2) and tend to divide the ignimbrite volcanics into the fields shown in Figure 2. Most of the Arizona complexes apparently share four geologic events: a) several contain a core of a middle-Eocene two-mica granite which intruded in an asymmetric, sill-like fashion into the country rock to cause the banding observed in the metamorphic carapace (gneissic) rocks; b) a very consistent late Oligocene radiometric "refrigeration age" for many of the core complex rocks, probably related to uplift and cooling of the complex; c) particularly well-exposed examples of a "dislocation surface" upon which unmetamorphosed cover rocks of all ages down to middle Miocene were sometimes tilted along listric faults, and were transposed unknown lateral distances, and below which intense shattering of the metamorphic carapace rocks took place; and d) the formation of late stage ENE-WSW arches or elongate domes in most complexes which has played a major role in giving the exposed complexes their characteristic physiography.

Miocene Volcanism And Sediments

Following this main pulse of mid-Tertiary volcanism, true basaltic volcanism and diversified sedimentation (category C of Figure 1) ensued. The Hickey basalt field of central Arizona north of Phoenix is the most massive volcanic pile of this age in the state. Associated sedimentation ranged from fanglomerates and fluvial deposits in the southeastern part of the state to tuffaceous, fluvial and lacustrine deposits throughout the west-central and northwest parts of the state (Figure 4 and 5). Indications are that in many places these depocenters bore little resemblance to the basins of today, which were created later by the Basin and Range disturbance – a point of considerable importance in the section on uranium occurrences.

Figure 6, *Cenozoic.* Red soil developed on Pleistocene gravel-capped basin fill at Allen Flat, southern Galiuro Mountains. Many of the southern Arizona valleys, such as here, have not been breached by a late Pleistocene stream downcutting event, and thus have retained their aggrading character.

Miocene Tectonics

In west-central Arizona, recent work has uncovered two prominent yet unexpected Miocene-aged tectonic events. The dislocational or sliding event(s) noted in conjunction with the metamorphic core complexes is now suspected to have produced allochthonous terrains at some distances away from the complexes, with the full regional impact of this deformational style yet to be measured. Several earlier workers clearly described local tectonics without grasping the regional implications.

In addition, the regional nature and importance is surfacing of tracts of land which contain unidirectionally-tilted Oligocene-Miocene aged sections. Broad NW-SE zones containing alternating NE and SW-dipping sections of these sediments were hypothesized to exist by Rehrig and Heidrick (1976), who suggested that the consistent dip directions resulted from rotational sliding along listric faults off of NW-SE elongated broad domes of low amplitude which in turn were created by "widespread magmatic or heat ingress into the crust during Miocene time." The overall picture may be more complex than this model because limited field observations suggest that an undescribed Oligocene tilting event of a more unknown character was overprinted by a Miocene tilting event. The late Oligocene event produced tilted and folded tracts of Oligocene sediments and volcanics which need further examination for correct classification. The Miocene event is bracketed between 17 and 12 m.y. (Damon and others, 1973). If accountable by the listric fault mechanism, this event may be genetically tied very closely to the subsequent high-angle Basin and Range block faulting event (discussed below), since both may be envisioned as rifting events sponsored by general ENE-WSW pull apart tectonics.

Basin And Range Disturbance

The Basin and Range disturbance is used here in the restricted sense, as defined by Gilbert in 1875, to apply to that high-angle faulting episode which blocked out the essence of the present-day Basin and Range physiography. It has been suggested (Scarborough and Peirce, 1978) that the careless application of the term "Basin and Range faulting" accounts for the extension of this episode far back into the Cenozoic, resulting in a forfeiture of information which is valuable to understanding Cenozoic tectonics. At present, it appears that the Basin and Range faults are younger that 13 m.y. (Eberly and Stanley, 1978) and may be about 10 m.y. old in certain locations. In places, however, Basin and Range faults appear to have close links in space to listric faults, and it remains to be seen just how separable these two types of faulting are in time and space. Indeed, the dislocational event, the listric faulting, and the terminal basin-producing event caused by high angle block faulting may be three manifestations of the same regional crustal-thinning tectonics commonly thought to have existed in the entire Basin and Range Province in Miocene time.

However, the tectonic importance of a few discrete thrust faults indicating NE-SW compressive pulses in the Miocene is not clear. These thrust faults are found in the Rawhide-Buckskin Mountains (Shackelford, 1976) and in the Ray-Superior area (S. Keith, pers. comm.).

Basin Fill

The sediments that filled the collapsed basins created by the Basin and Range disturbance is termed basin fill. Recent studies (Peirce, 1976; Scarborough and Peirce, 1978) suggest the presence in the state of one or more drainage networks which filled upland basins with predominately clastic sediments, while other lower elevation basins of the respective networks produced gypsum and finally sodium chloride salt pans, following evaporation of mineral-laden waters. Examples of evaporite-rich basins are in the Picacho and Phoenix areas. Basin fill thickness in some areas is in excess of one mile. The Tucson Basin contains at least 7,000 feet of fine-grained clastic basin fill at the site of a 1973 Humble stratigraphic test hole. Basin fill deposits, unlike older deposits, are mostly undeformed, are graded to the present-day trunk streams of their respective valleys (Figure 5) and invariably exhibit fine-grained, predominately floodplain facies in a zone parallel to the trunk stream. The Basin and Range faults are usually found parallel to the mountain fronts, but displaced some distance away from them out in the valleys. These buried bedrock shoulders or pediments between the faults and the mountain fronts attest to the amount of mountain front retreat since the beginning of Basin fill time due to weathering and removal of detritus by the trunk streams and their tributaries.

Pleistocene

Basin fill deposits are capped in most areas by a thin veneer of Pleistocene deposits. A regional stream downcutting episode initiated late in Pleistocene time has exhumed the valleys containing the most active rivers of the region, but large areas of the state contain still-aggrading valleys or unexhumed valley surfaces capped by mature, red, Pleistocene soils (Figure 6).

URANIUM IN BASIN AND RANGE COUNTRY

In the U.S., 97% of all uranium reserves (exploitable at current conditions) are in sedimentary rocks, and 39% of all U.S. reserves are in sediments of Cenozoic age. Most of the productive sediments are, however, sandstones of Mesozoic through Eocene age, as in some of the New Mexico and Wyoming deposits.

Past production in Arizona has been almost exclusively limited to the Colorado Plateau, with a total of 18,000,000 lbs. of U_3O_8 shipped from mines located mostly in Mesozoic sediments. The lack of past productivity in the Basin and Range country is perhaps most related to the structural complexity of the region when compared to the Colorado Plateau portion of the state. However, with the discovery of major reserves at the Anderson Mine in western Yavapai county, much exploration interest has focused on the Basin and Range.

Uranium associations in Cenozoic sediments of Arizona Basin and Range country have a unique flavor and consist mainly of fine grained, lacustrine and paludal shales, mudstones, cherty limestones and uncommon dolomite beds. There is also a recognized association of uranium with varicolored silica replacement bodies which are at times structurally related.

The sediments of unit A (Figure 1) contain only occasional uranium occurrences which have thus far not proven to be attractive for development, primarily because of the scattered, low grade nature of the uraniferous materials and the fact that their state of tectonic deformation precludes inexpensive mining operations. An example of this age group is the homoclinal, eastward-dipping Mineta formation of the Rincon Mountains, which contains in its basal arkosic conglomerate, uraniferous shale lenses cropping out discontinously over a strike distance of several miles. Other prospects in the northern Plomosa Mountains and north and east of Yuma present similar problems.

Together, the sediments of units B and C (Figure 1) were deposited during the intensive mid-Tertiary volcanic episode. A series of early-middle Miocene fine-grained sediments in a broad region of central and western Arizona deserve particular interest since they have acted as geochemical concentrators of uranium. For example, at the Anderson mine of western Yavapai county, (now approaching production status, and described by Peirce, 1977), uranium is associated with silicified black organic rich shales of early to middle Miocene age. This area of the Date Creek Basin now contains an estimated 30,000,000

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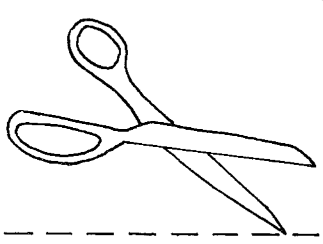

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pounds of $50 U_3O_8 reserves and about twice that amount of probable and possible uranium resources. Many other western Arizona uraniferous localities which are in sediments now suspected of being this age have had some exploratory drilling. Examples include the Artillery Peaks area 20 miles west of the Anderson Mine and the Black Butte area of the westernmost Vulture Mountains. It is challenging to uncover new information on the potential of this area since it appears from facies relationships that the position of any early-to-middle Miocene depocenters has been obscured by Miocene tectonism; hence, the position of the present valleys offers few clues regarding exploration targets. Coarse arkosic redbeds of Oligocene-Miocene age in the region are not uraniferous except where fault or hydrothermal control is obvious.

Some areas of central and west-central Arizona contain Miocene-aged mixed volcanic flows, distal tuffs and fluvial sediments (Figure 5) which are capped by Hickey basalts, as seen along the Phoenix-Flagstaff freeway around Black Canyon City. In several areas there are isolated outcrops of lacustrine or paludal sediments, some of which bear a number of dolomitic units which are variably uraniferous. Similar lithologies and some age dating control of these outcrops suggest they may have once been a continous depository for uraniferous sediments. Thus the area assumes some importance for further studies. Other uranium occurrences around Horseshoe Dam on the Verde River are in Miocene water-laid tuffs and limestones but appear to be structurally related. Uranium also occurs in a Miocene and/or Pliocene limestone section northeast of Lake Pleasant along the Agua Fria River. Some exploration has been carried out in various mudstone and limestone facies of basin fill. To date, searches of various valleys in the state have resulted in the location of low grade and subeconomic disseminated mineralization.

Several possibilities exist for the source of uranium now found in Cenozoic sediments of the Arizona Basin and Range country. A variety of alkali-rich igneous rocks in the state display anomalous uranium values or radioactivity, including some Precambrian granites, some Triassic-Jurassic igneous rocks of southern Arizona, and some high-potash Miocene ignimbrites of the central and western part of the state. Through weathering, each of these has had ample opportunity to have contributed uranium to one or more of the described sedimentary deposits. Once the uranium is leached from the source material, it remains mobile in the aqueous environment until fixed by geochemical agents associated with the sediment.

The newly-discovered uranium reserves in Miocene sediments at the Anderson Mine have brought considerable attention to the Basin and Range country as significant source of this important commodity. And certainly the search for uranium has broadened our knowledge and appreciation of the complex Cenozoic geologic history of this region.

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