FIELD NOTES FROM THE ARIZONA BUREAU OF MINES

Vol. 6, No. 2 *Earth Sciences and Mineral Resources in Arizona* *June, 1976*

Arizona's Water Supply

–Some Reflections

by H. Wesley Peirce, Geologist

Introduction

The Camino del Diablo (Devil's Highway) is a historical route that passed through the low, hot, desert region between Ajo and Yuma, Arizona. The present dirt tracks through the Cabeza Prieta territory overlap portions of this old route, especially near the few, widely separated natural watering places. Occasional grave sites offer testimony to the hardships associated with insecure water supplies during earlier days of slow travel.

The Tinajas Altas (High Tanks) area is one of these historically famous desert watering places. Abundant grinding holes in granite near this watering site suggest its vital role in an ancient culture. Today, Big Horn sheep droppings collect in some of these shallow holes and indicate a continued mammalian reliance on this surface rarity. Here, too, there are numerous grave sites, and there are stories of persons having clawed fingers to the bone trying to climb the steep granite slopes to reach higher plunge pools when the lowermost were dry. Such stories suggest rather high, water-based anxiety levels.

Today, a combination of ingenuity, technology, energy resources, and money makes it possible to produce and distribute the water supplies that support the various activities of over two million residents. In spite of the reality that most Arizonans live in a desert, a place where evaporation exceeds precipitation, few of us (as long as we pay our water bills) have ever been subjected to water shortages — yet. Our respective cups continue to runneth over.

However, the logistics that attend a continuing, adequate, and dependable water supply for our rapidly increasing population are becoming ever more complicated. Pressures are building, cost and anxiety levels are rising, and calls are heard for voluntary and/or legislative changes in the way we do things. This is understandable because more and more of us perceive the fact that we are using substantially more water than is being replenished from natural sources. Knowledgeable persons express this awareness by comments such as "our water account is being overdrawn," or "we are mining water."

Water is a so-called renewable resource. This is true only insofar as it is not used faster than it is re-supplied. In this context, Arizona's present water supply is a *nonrenewing resource.* Arizona is out of ecological balance in this essential aspect.

However vaguely perceived and understood, Arizona's natural water endowment is the sum effect of all geologic history, about 2 billion years of which is recorded in known Arizona rocks. Every drop of water is dependent upon factors set into motion billions of years ago. Cause and effect relationships extend from the present as far back as our minds can "see," and beyond. Really, this is the substance of true ecology and recognition of this fact should *tend* to humble and lead us to the threshold of wisdom.

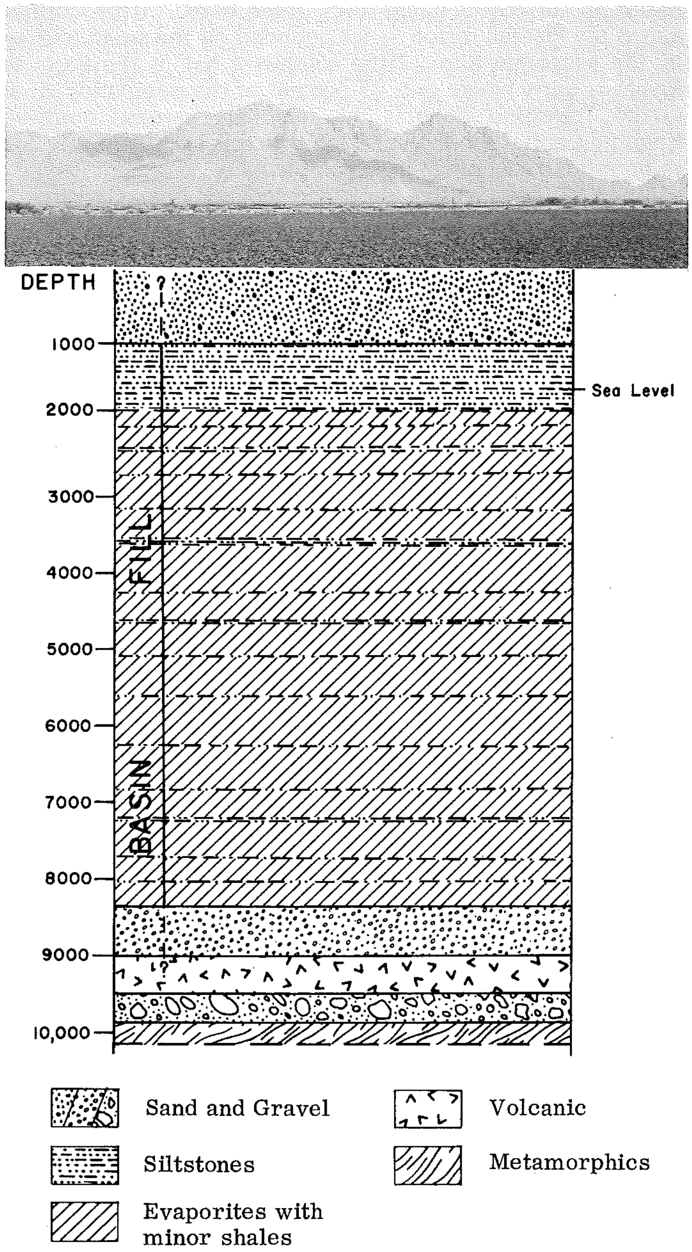


Figure 1. Scene in Basin and Range province looking eastward towards the Picacho Mountains from the adjacent irrigated valley. Earth materials depicted to underlie the valley are those encountered by a rare deep hole drilled in 1972. Important ground-water resources are limited to the sands and gravels in the top part of the sequence.

Some Generalities

Arizona is much more than just the topographic configuration of the land surface. How do you answer these questions: "How deep is Arizona?" or, "what is Arizona like down there 5, 100, 1000 feet, or even 2 or more miles?" or, "what difference does it make?"

Topographically, "relief" is the vertical dimension of the surface variation. Beneath our feet the vertical dimension is "down." Relative to our existence, most of planet earth is out of sight. For most of us, it also is out of mind.

Today, most of Arizona's indigenous water supply comes from the mysterious regions of "down." The high interest in so-called "black boxes," geophysical tools, and dowsers is a manifestation of a desire to "see" where otherwise our eyes fail.

Descriptions of Arizona's general physical setting emphasize, based on surface characteristics, three parts: (1) the northeast half is the Plateau region — it's bounded on the south and west by the Mogollon Rim; (2) the southwest half is the Basin and Range country where over 75 percent of the population is; and (3) the Transition Zone is the relatively narrow, northwest-trending Central Mountain region which is considered by some to be more basin/range-like than plateau.

Much has been written about the geologic characteristics and histories of these regions. They are very different and the differences exert a fundamental control on population distribution. Mineral, soil, water, climate, and terrane parameters are so enhanced in the Basin and Range country that for centuries people have congregated there. In the last 10 years the state has grown by about 630,000 persons, 80 percent of whom took up residence either in Maricopa (Phoenix area) or Pima (Tucson area) counties in the Basin and Range region of southwestern Arizona.

The terms "Plateau" and "Basin and Range" usually are intended to apply to physiographic provinces. However, more fundamentally they are geologic provinces in which there are many basic contrasts, each of which could be used to designate a province characteristic — physiography being just one. For instance, relative to the Plateau region, the Basin and Range country is an agricultural province because, in turn, it is the province with good soils and "big" water. In contrast, the older, cemented, clay-deficient sandstones of the Plateau do not make good soils nor is there widespread "big" water. On the other hand, the Plateau is Arizona's fossil energy materials province (coal, minor oil and gas; FIELDNOTES, Vol. 4, No. 1).

Flagstaff is the largest city on the Plateau, with a population of about 35,000. It is unlikely that Flagstaff could support, from water supply considerations alone, a city the size of Phoenix (785,000) or even Tucson (332,000). Both Phoenix and Tucson are desert cities while Flagstaff is at 7,000 feet in the tall pines at the foot of the highest peak in Arizona (12,655 feet). Why does the desert have "big" water and the Flagstaff region apparently doesn't? The answer is in the geology of the mysterious "down" region because, like the state as a whole, Flagstaff is moving more and more to the development of ground water because its needs have exceeded the developable surface waters.

Surface waters are a relatively knowable resource and water use in Arizona has far surpassed these amounts. The most recent and comprehensive data source relative to Arizona water is contained in the Arizona Water Commission's 1975 report, "Inventory of Resource and Uses," Phase I of an Arizona State Water Plan.

According to this report, surface waters in Arizona account for about 40 percent of water withdrawals and water pumped from underground accounts for about 60 percent. Therein lies the roots of a problem, and the Phase I report puts it this way:

"Arizona's principal and also its most fundamental water problem is that of imbalance between supply and use. For years Arizonans have been using water more rapidly than Mother Nature has replenished it. This is possible only through the massive borrowing of waters banked as ground water reserves in past geologic ages. In many areas of Arizona, natural replenishment rates are very small and the mining of ground waters is analogous to the mining of oil in other parts of the country."

Among the major Phase I findings are these:

1. Substantial amounts of ground water remain in storage. However, the annual rate of recharge of this important resource is very limited and most of the water stored in the ground is available only for one-time use.
2. Agriculture currently consumes 89 percent of all water used in the state, municipal and industrial users, 10 percent, and fish and wildlife, 1 percent.
3. The principal water problem in the state is one of imbalance between dependable (renewable) supply and consumption. Arizonans, statewide, are consuming approximately 2,200,000 acre-feet more water annually than is replenished. The largest numerical overdraft of ground water resources occurs in Maricopa County, with an estimated 902,000 acre-feet per year; second is Pinal County with 620,000 acre-feet per year; third is Cochise County with 268,000 acre-feet per year, and fourth is Pima County with 267,000 acre-feet per year.
4. The ratio of consumption to dependable supply, however, is most pronounced in Pima County where use is 4.7 times supply. Uses for municipal and industrial purposes alone exceed total supply in Pima County by a factor of 1.8 to 1.
5. In Maricopa County, even though a substantial dependable (renewable) supply is available as surface water, depletion is taking place at 1.9 times the replenishment rate. The impact on Maricopa County ground waters alone, however, is much more severe with depletion amounting to over 30 times the rate of natural recharge. Similarly, in Pinal County, depletion is 3.4 times supply, while depletion of ground waters alone is at a rate of 12 times replenishment.
6. Rates of depletion approach 100 times the magnitude of dependable supply in some of the smaller hydrologic basins.
7. In the three Arizona counties of Maricopa, Pinal, and Pima, the estimated annual overdraft is 1.8 million acre-feet. The estimated long-term water supply that will be imported to central Arizona via the Central Arizona Project is 1.2 million acre-feet per year or two-thirds the current rate of overdraft.
8. Approximately 94 percent of total state water consumption occurs in the twenty-four hydrologic basins in which data are sufficient to permit reasonably accurate estimates of current water conditions, including dependable water supply, depletion, and overdraft.
9. In the forty-three remaining basins of the state, available data are inadequate to permit reasonable approximations. There is a need to expand the data collection program in these areas.
10. An upgrading of ground water pumpage data is warranted throughout the state.

Developing a Perspective

One of the statistics cited is an estimate (2,200,000 acre-feet) of the amount of water used in the state each year in excess of that which is renewed or replenished. How much water is this? Take an area the size of a normal football field and extend its boundaries upward far enough to contain this amount of water. How high would the sides be? Conveniently, a football field is almost one acre in size. This being the case, the sides would have to be 2,200,000 feet high — 416 miles! Over 80 percent of this (1,789,000 acre-feet — 340 miles) is accounted for by ground water overdraft in just three of the desert Basin and Range counties: Maricopa, Pinal, and Pima.

Most of the water within the bounds of Arizona is stored as ground water and has been for geologic time. The answer to the question "where is the nearest water?" usually is "down."

As a matter of principle, the ultimate in wise use is living within one's means. Good business involves both borrowing and paying back. There is no scientifically sound line of reasoning that leads to the conclusion that Arizona is living within its water means. Available evidence seems clearly to indicate that it is not. The concept of "borrowing" geologically-stored water has been expressed, but this seems valid only if the borrower intends to pay back so that borrowers of the future will have something to borrow. However, we seen to be taking without *any* intention of repaying or replacing. Mother Nature eventually will replace, but only after her rates of replacing exceed our rates of taking.

So much for principles. This is a pragmatic world and regularly we compromise principle for the sake of the here, now, or near future. The next generations will have to make the best of it. Besides, there are huge volumes of underground water in storage, so much in fact that our problems will be staved off for hundreds of years. Right? It all depends upon the cooperation of that mysterious region of "down." How much do we really know about such things? Who can "see?"

There is evidence that some progress is being made towards public recognition of the fact that ground water is geologically controlled. The following excerpts were taken from an editorial that appeared May 14, 1976, in the *Arizona Daily Star:*

"Leaming is also on shaky ground in returning to the time-worn myth that there is enough water underneath Tucson to supply its residents for hundreds of years. There may be a lot of water down there — no one knows for sure. But what is becoming known is that much of it cannot be brought to the surface with existing technology. There is serious question about the accuracy of past well sampling and computer projections of underground supplies that do not adequately consider the capriciousness of geologic structure.

"MUM (Metropolitan Utilities Management) knows that it has been digging test wells in various parts of the city where water was believed to exist and has been finding only dust. MUM also knows that litigation between Indians, city, mines and farms in the Sahuarita area could shut off a good portion of the city's present supplies."

Another factor mentioned is MUM's concern for the possibilities of land subsidence within the city where water levels are declining due to withdrawal. Alternative water sources away from the city are desirable so as to arrest the rate of decline — to delay the possibility of significant, disruptive surface subsidence.

The substance of the material just cited is neither accepted or rejected here. However, it seems important to recognize how easy it is to generalize and oversimplify water-related matters that are, in fact, immensely complex. To do so may be a disservice. It would be helpful to be able to separate the known from the unknown. Frequently, it appears as though we expect more than we should from so-called "experts." Expertise is only relative and no one person or group is in possession of ultimate knowledge. It is constantly necessary to make "best guesses" and it is a problem to know when a "best guess" is not good enough. Making a "best guess" even better means spending some money. Learning much about the region of "down" certainly is expensive, yet that is where most of the answers to Arizona's water storage questions are to be found.

Basins — The Containers

Most of Arizona's water is withdrawn and used in the Basin and Range Province. Roughly, it constitutes the southwestern, deserty half of the state in which surface water is scarce to absent. The word "basin" is used in different ways, and in "Basin and Range" it is interchangeable with valley. Much of the area of the province is valley or basin surface, topographic lowlands between generally long, narrow, protruding ranges. Many of these now are occupied by intermittent drainages that are a part of the integrated Gila subsystem of the larger Colorado River system, which in turn drains to the Gulf of California south of Yuma, Arizona.

Basins, as water containers, must first contain earth materials capable of accepting and giving up water. Too, because there are economic limits to pumping lifts, storage must be relatively near the surface in most cases. Because water responds to the influence of gravity it seeks low points. Drainage from mountains flows downhill onto valley floors, and the spongy, loose sands and gravels allow water to seek still lower levels beneath valley surfaces. Because this has been going on for geologic time, water tends to occupy all available storage. Obviously, the critical factor in storage capacity is the volume of earth material capable of accepting water. Too, the geometry of the storing materials is important. For purposes of drilling and pumping a well it is better to have a thicker saturated zone spread over less area than to have a thin zone spread over a wide area. The thin zone, everything else being equal, will cease to provide water to a well sooner than the thicker one even if the overall volumes of material are the same.

The nature and distribution of earth materials underlying valley surfaces is a function of geologic history, especially the processes and conditions that were operative over a relatively lengthy time period. Many buried stream deposits are of coarse texture and the pores, or open spaces, if not filled with other substances, are available to be occupied by water. As a rule, the older the material the more likely it is occupied, in whole or in part, by foreign substances that cut down on the capacity of the material to accept water.

In contrast to stream deposits, those that accumulate in ponds, lakes, or otherwise sluggish waters tend to be fine-grained silts and/or clays. If large volumes of standing water are subject to evaporation then evaporite deposits such as gypsum, anhydrite (calcium sulfates) and/or salt (sodium chloride) tend to form. The fine-grained deposits, such as silts and clays, hold abundant water (high porosity) but do not give it up to wells (low permeability). Waters in and near deposits of these types tend to be of inferior chemical quality because of dissolved solids. Resulting thicknesses are a function of process rates and elapsed time.

It should be emphasized that all earth materials form in response to a set of conditions prevailing at a place and time, that is, an environment. Ground waters today are controlled in their positions, quantities, and qualities by the products of past environments and processes. It is essential that such things be studied. The mere development of a water well does not mean that much of scientific value was acquired during the process.

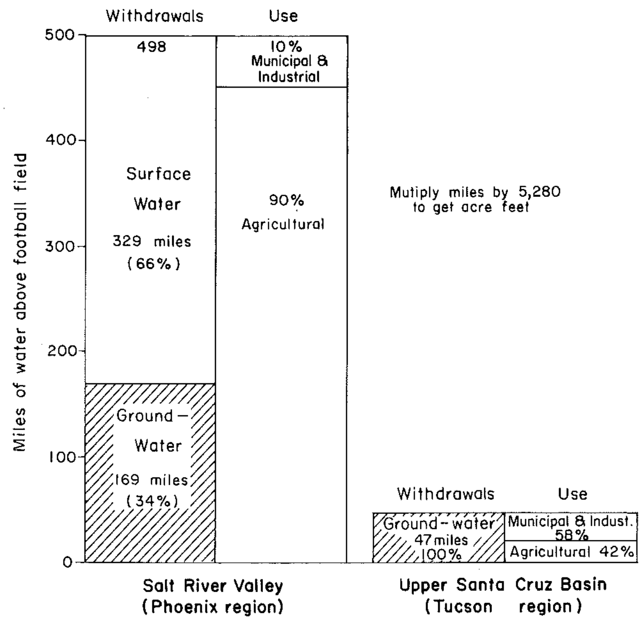


Figure 2. Comparison of withdrawals from water supply (1970) and uses -- Phoenix and Tucson regions. (Basic data are estimates from Arizona Water Commission Phase I study.)

Harshbarger (1958), former head of the U.S. Geological Survey Water Resources Division in Arizona, said:

"Attempts to arrive at a quantitative value for the effective storage or the specific yield of a basin are rather difficult because of the number of variables that control these factors. It is impossible to arrive at any reasonable estimate of storage without detailed knowledge of geologic conditions, such as the interrelationships of the various strata and their structural setting .... With sufficient knowledge of geologic conditions and factors, it would be possible to determine the amount of water that could be withdrawn within certain depths."

Harshbarger is suggesting that it takes a three-dimensional understanding of a basin before reasonable estimates of storage are possible. How can such understanding come about? It can come about only by virtue of a conscious, systematic, on-going commitment to a program of data gathering and interpretation. Such a program requires coordination, well-trained manpower, and *money*. Continuity of manpower is important because familiarity with the region of "down" comes slowly, and under such circumstances rapid turnover of trained personnel would be inefficient. Better that such studies be viewed as lifetime tasks and programs be developed that encourage such stability.

Because all Arizona citizens, and visitors, have a vested interest in the "down" portion of Arizona, it seems essential to maximize the opportunities for governmental researchers to learn about it. As it is, enormous amounts of potentially important below-surface information are lost because, time being money, we do not always take any more time than is necessary to determine whether or not a hole will produce water. The quickest, easiest and cheapest way to learn about earth materials penetrated by the bit is to take good samples at regular intervals and make these available to researchers. Unfortunately, there is no state-wide program to obtain samples from water well drilling as there is for oil, natural gas, helium, and geothermal exploration. Some samples are obtained by the voluntary efforts of some drillers in cases where the client is in agreement.

There are practical economic limits to drilling depths as well as geologic limits to large quantities of stored, good-quality water. Although it always means higher costs, deeper does not automatically mean more and better. According to the Phase I study, 700 feet and 1200 feet currently (1975) are considered the practical pumping limits for agricultural and municipal water supplies, respectively. Even though talk of some basins containing thousands of feet of sedimentary materials is true, one should ask what the character of the sediments might be as well as the costs attendant to pumping large volumes of good water (should they exist) from deep levels. There are numerous examples of basins that are, from the bottom up, largely filled with nonwater-producing materials with an overlying relatively thin zone of water-bearing rocks (Figure 1). In fact, it seems to be a rule of thumb that basin-filling materials become finer-grained downward. Again, caution should be invoked before accepting as fact any casual pronouncement to the effect that the answer to an enlarged Basin and Range water supply is to be found in drilling to significantly deeper depths within basins. The evidence does not support this likelihood.

The depths to the bottoms of most basins are not accurately known. This is because many are deep, containing in excess of 5,000 feet of basin-filling materials. Deep drilling does not take place unless the effort and costs can be justified. Exploration drilling depths for petroleum have exceeded 25,000 feet. The deepest hole in Arizona is 12,571 feet, and was drilled in 1972 by Exxon Corp. (formerly Humble Oil and Refining Co.) near Tucson for purposes of evaluating petroleum potential in a deep part of the Tucson basin. Drilling in connection with copper exploration often extends to depths over 5,000 feet in Arizona.

Evaporite materials such as salt (sodium chloride) and gypsum-anhydrite (calcium-sulfates) contaminate fresh-water and therefore are undesirable in and around water supplies. Deeper drilling in certain basins discloses that these constituents frequently are associated with fine-grained sedimentary deposits. West of Phoenix, near Luke Air Force Base, the upper part of a huge salt mass rises to within 880 feet of the surface beneath land formerly used for agriculture and now used to produce commercial salt (see FIELDNOTES, Vol. 5, No. 3). Near Picacho, beneath agricultural land, some bedded salt has been encountered at a depth of 1940 feet, which, in turn, overlies almost 6,000 feet of anhydrite with thin interbeds of siltstones (see FIELDNOTES, Vol. 3, No. 2). Another huge salt mass thousands of feet thick occurs in the Red Lake Basin north of Kingman and was encountered at a depth of about 1,500 feet (see FIELDNOTES, Vol. 2, No. 1). These products of evaporating waters are called "evaporites" and are more extensively developed within basins than previously suspected. Salt and gypsum have been encountered in the Safford Basin, where the surface supports an extensive agricultural area. Evaporites occur near Chandler beneath agricultural country. In the Tucson region gypsiferous materials are known to be as shallow as 800 feet beneath the surface.

The above are cited as examples of products of environmental conditions that prevailed at times past during the infilling of the respective basins involved. These products, and the environments represented, are not compatible with the occurrence of large volumes of good-quality stored water. Though ground water supplies now being utilized generally overlie these phenomena, they serve to suggest that usable ground water supplies are not necessarily to be found by drilling ever deeper. There are downward geologic limits and it seems important, in the name of realistic thinking, to recognize this fact and also to learn what these limits are in the various basins of southern Arizona. It is one thing to have a few specialists that know about limits to water storage and quite another to have both a knowledgeable citizenry and a body of knowledgeable elected officials.

Here is another angle: to what extent is potential differential land subsidence in an urban area a limiting factor in the withdrawal of stored water? Assume that beneath a city there is a zone of stored water that is 500 feet thick that occurs in interlayered gravels, sands, silts, and clays, and that this zone is being heavily pumped for basic supplies. Suppose you know from experience elsewhere that land surface elevations begin to noticeably adjust after the upper 100 feet of water is withdrawn. How would you calculate the available water reserves beneath the city? Would you plan on removing the entire 500 feet or might you hesitate long enough to wonder if wholesale, indiscriminate dewatering is the best long range policy? Surely, you'd ask yourself several questions related to projected consequences of such action. Because the answers would be related to things geological you might not be able to obtain unequivocal data. This is often the case when a community has been unwilling to expend monies for studies that to the average citizen might seem unimportant. Nevertheless, you have to make a decision — to what extent is the apparent maximum water reserve limited by subsidence potential? Obviously, there is room for contrasting opinions, therefore disagreement. On the one hand, the "nonexpert" could cite a gross water reserve number while a more sensitive "expert" might suggest that the practical reserve is much less than the gross number. If water supply is thus limited by such considerations, it means a long-range plan of development of alternative supplies, preferably not beneath an area destined to become urbanized or industrialized.

Concluding Remarks

Water in Arizona is limited climatically, geologically, economically, and legally. These factors combine differently from place to place so that contrast is the rule, not the exception. Legislatively, the trick is to produce policy that is sensitive to the physical inequalities that characterize the state.

Continued on page 16

Slope Form and Stability

in the Northwest portion of the Mount Lemmon Quadrangle, Pima County

by Bruce J. Murphy
Assistant Field Geologist

Introduction

During the past two decades, the public has become increasingly aware of catastrophic events involving the mass movement of rock and soil within urban areas. The problem of landslides has been particularly severe in the Greater Los Angeles region. In one period in 1952, two people were killed and over 100 houses were damaged there by landslides; the monetary loss was almost 7.5 million dollars. Up until that time, landslides had constituted only a minor hazard, but with the advent of denser housing on steeper slopes, massive slides of rock and soil were triggered by an abnormally rainy season.

The study of landslides in urban areas has been gravely neglected for years by both professional and public groups alike. As one of the deans of engineering geology, Charles P. Berkey, wrote prophetically in 1937:

> "I am convinced that the question of landslides is a matter of much larger importance than is usually assumed. Recent experience lends to the belief that it is of special significance in connection with many practical problems, particularly those connected with engineering projects. In my own case, some of these features were for a long time overlooked, and it is clear that a better understanding of them would have been useful." (Personal communication to C.F. Sharpe, March 31, 1937).

Yet it wasn't until after the devastating landslides of 1952 that responsible elected officials acknowledged the need to limit construction on unstable ground by enacting restrictive legislation. Special grading codes, designed to withhold building permits from hillside lots until conditions were shown to be safe by the geologist and civil engineer, were initiated. These restrictions have since resulted in a marked reduction in damage and in most cases a decrease in surface erosion.

Following the example made in past years by officials from the West Coast, individuals and groups in other parts of the country have forseen the need to delineate potentially unstable slopes. Arizona, witnessing the fastest growth rate in the nation and a decrease in suitable land for development within urban locations, is no exception. Future developments on steeper slopes and ridge lines necessitate the need for a thorough site examination to maximize safety and eliminate destructive erosion. The Arizona Bureau of Mines is currently exploring this topic of potentially unstable slopes with a grant provided by the U.S. Geological Survey. The project is designed to study a group of related geologic hazards, including slope stability, whose impact on Arizonans must be examined.

Area of Study

A portion of the Mount Lemmon 15-minute quadrangle was one such area chosen for a slope stability analysis (see Figure 6). The growing communities of Oro Valley and Vista Catalina are located within this quadrangle. Construction of single dwellings and large, tract-type housing developments is progressing rapidly. The area covers approximately 61 square miles, and is bounded by the Coronado National Forest on the east, the Pinal County line to the north, and Ina Road to the south. Physiographically, the region encompasses a wide range of geomorphic features, including the floodplain of the Canada del Oro and the steep, precipitous cliffs of the Santa Catalina forerange. Altitudes range from 2480 feet to 4400 feet above sea level, and local relief is highly variable. Home sites can be found on various terrain features, ranging from major floodplains to steep mountain ridges in the Tortolita Mountains. The general area is expected to have a large population influx by the year 2000.

The study region thus represents a unique situation whereby the dependency of home sites upon the geologic environment can be analyzed for future safety and design criteria.

Geology of the Area

The geology of the study area is comprised almost wholly of unconsolidated sediments, although some crystalline bedrock crops out locally. An understanding of the relationships between the types of materials present and the stability of the natural slopes in the area is critical in order to objectively assess the potential for hazardous conditions. A brief review of the rock and soil units recognized in the area follows.

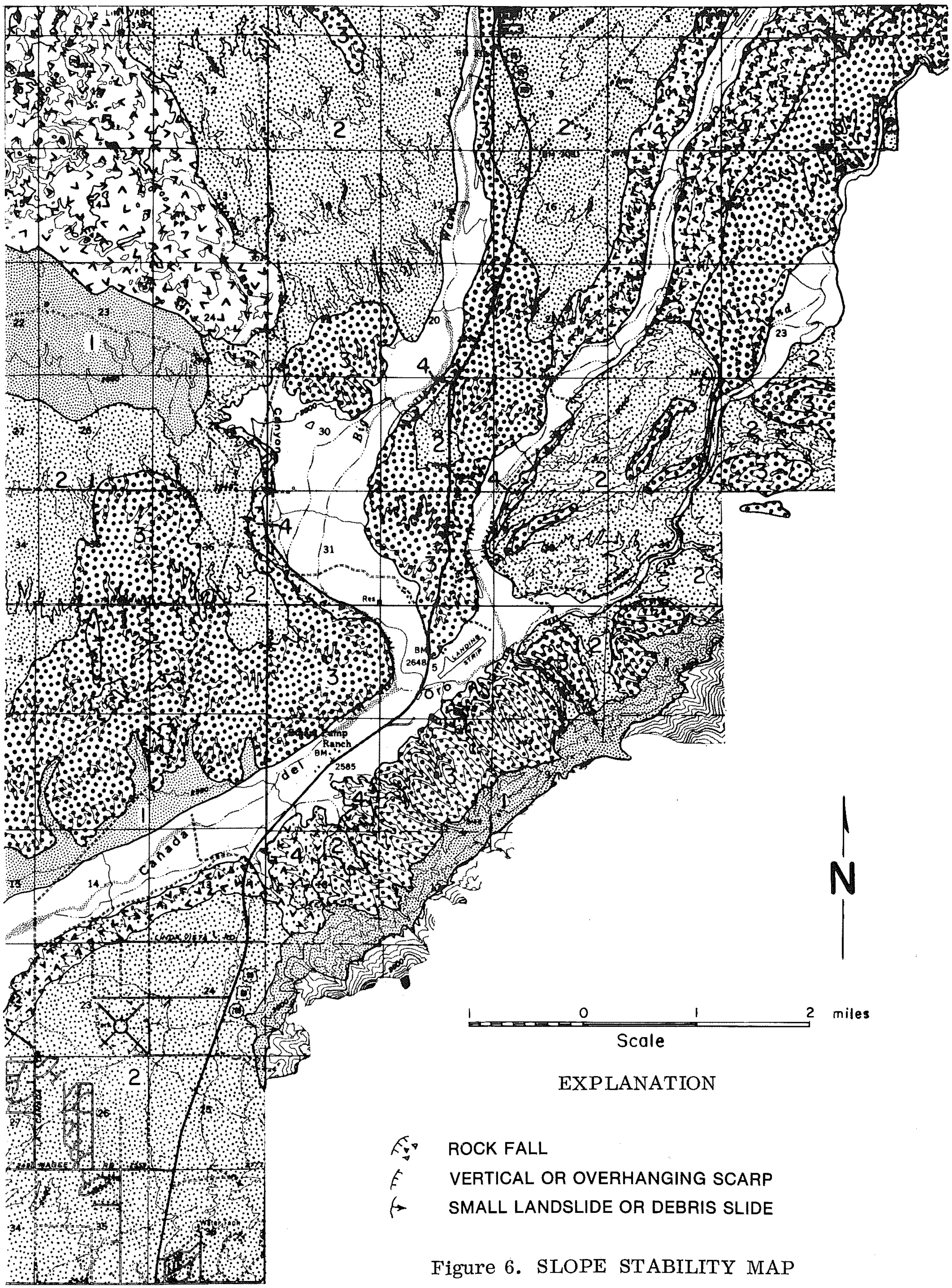
Tinaja beds. The Tinaja beds are only exposed along the margins of the Santa Catalina front where erosion has removed the overlying coarse gravels. The maximum thickness of the beds is unknown but is thought to be as great as 5,000 feet in some areas (Davidson, 1973). These beds unconformably overlie the Pantano Formation and in turn are unconformably overlain by the Fort Lowell Formation. Correlation of the Tinaja beds with the Rillito 2,3 formation of Pashley (1966) seems probable.

Generally, the Tinaja beds consist of sand and gravel, gypsiferous clayey silt, and mudstone. Basaltic andesite flows and dacite tuffs also occur within the unit. In the Mount Lemmon quadrangle the beds exposed are thought to be the uppermost part of this formation and are collaborative with Rillito 3 of Pashley. These beds contain abundant granitic fragments in a feldspathic, clay-sand matrix. The unit is poorly bedded, but locally dips up to 28° toward the mountain front have been observed. No structural deformation was found in the Mt. Lemmon quadrangle although the typical section, found in the Tucson Basin, contains numerous faults.

These grayish-white beds contain a large amount of montmorillonite clay and are only poorly consolidated and weakly cemented. The average slope stands at 15 percent and is easily eroded, as evidenced by extensive rilling and gullying.

Fort Lowell Formation. The Fort Lowell Formation, referred to as "basin fill" by Pashley (1966), outcrops extensively along the margin of the Santa Catalina Mountains where up to 400 feet have been removed by post-Fort Lowell erosion (Davidson, 1973). The formation may be as much as 1,200 feet in the valley, and it thins toward the mountains and headwaters of Canada del Oro. The similarity in lithology between the base of the Fort Lowell and the top of the Tinaja beds makes delineation difficult in most areas.

The Fort Lowell Formation can be identified on the basis of its grain size, lithology, and to a certain extent its color. The deposit is generally flat-lying, crudely bedded, and reddish-brown in color. The lithology of the basin fill reflects the nature of the surrounding bedrock outcrops, and consists primarily of gneissic and granitic cobbles in a sandy gravel matrix. The beds are generally moderately to poorly cemented, weakly packed, and very porous. Imbrecation directions on a statistically significant number of samples indicate a direction of deposition in a closed basin environment into a series of low-lying lakes and playas. Structurally, the beds are gently dipping and relatively undeformed.



EXPLANATION

ROCK FALL

VERTICAL OR OVERHANGING SCARP

SMALL LANDSLIDE OR DEBRIS SLIDE

Figure 6. SLOPE STABILITY MAP

Map Unit	Remarks
Zone 1	Highest stability — near-flat to moderate slopes (<25%) underlain by hard rock. Locally bare to thin cover of surficial material. No significant downslope movement of material.
Zone 2	Hign stability — gentle to moderately gentle surficial alluvial slopes (5%-15%); moderate slopes (15%-25%) underlain by Fort Lowell Formation consisting of moderately cemented coarse gravel, sand, silt, and clay. Small probability of downhill movement of material except in areas adjacent to incised streams which have eroded a vertical erosional scarp. Undercutting of the scarp's toe will produce a total loss of stability on an intermittent but continuing basis.
Zone 3	Moderate stability — very steep competent rock slopes up to 100%; slopes in poorly-consolidated fine-grained alluvium up to 45%; loose, well-rounded, surficial deposits overlying moderate (15%-25%) to steep (25%-45%) well-cemented Fort Lowell Formation. Slopes subject to minor debris slides in well-rounded alluvial material; minor soil slumps in fine-grained deposits where highly saturated with water.
Zone 4	Generally low stability — moderate slopes (up to 25%) in poorly consolidated fine-grained alluvial deposits containing a high percentage of clay material. Subject to slumping and high soil erosion during saturation. Very steep slopes (up to 100%) bordering floodplain scarps or deeply incised highland drainages. Block glide soil failure in moderately cemented alluvium; soil fall in nonresistant soil; rotational block slump failure rare but may be locally present. Soil failure on slopes with vegetation, producing small terrace-like features or terracettes. Very steep rock slopes containing a thin surficial deposit of taluvium (rock rubble and weathered soil-size particles).
Zone 5	Low stability — very steep to precipitous slopes in highly fractured and weathered rock. Subject to rock falls which in some instances may produce large volume of material. Debris flows common.

SLOPE MAP UNIT	GEOLOGIC MAP UNIT				
	BEDROCK		ALLUVIAL DEPOSITS		
	Metamorphic rocks		Tinaja	Ft. Lowell	Surficial
	Tortolita granodiorite	Catalina gneiss/granite			
less 5%	1	1	2	1	2
5- 15%	1	1	2	1	2
15- 25%	1	1	3	2	3
25- 45%	2	2	4	3	4
45-100%	4	3	5	4	5

Surficial deposits. Surficial deposits (locally-derived alluvium deposited by fluvial processes) cover much of the mapping area and can be differentiated on the basis of this relationship to older units. Deposition of these units reflects a change in basin morphology from a closed basin environment to a through-going drainage system. These deposits were laid down on an erosion surface resulting from the lowering of the base level of nearby streams (Smith, 1938). Surficial alluvium up to 50 feet in thickness can be found locally overlying all units in the area; the alluvial deposits generally pinch out toward the mountain fronts.

The surficial deposits generally reflect detritus being presently eroded from the nearby mountain fronts. These sediments are mainly coarse gravel and gravelly sand with local lens of sandy silt. Cobbles up to 2 feet in diameter are sporadically encountered. Granite and gneiss fragments dominate, although minor amounts of volcanic and sedimentary fragments are also represented. The principal basis for differentiating the surficial sediments from the older material is their characteristic weathered, yellow-brown stained surface.

The first to divide these surficial deposits into definable groups was Smith (1938), who identified four primary sequences as: University, Cemetery, and Jaynes terraces, and bottomland. These units, lying in an erosional trough on basin fill or older sediments, can be identified on the basis of their topographic relationships. Generally, in the area studied, the Cemetery terrace covers the largest area. The eastern pediment of the Tortolitas contains gravels tentatively correlated with this sequence. The University terrace is found in two areas: the Cordonnes region, where it lies on top of the Fort Lowell Formation, and in an exposure on the high dissected foothills buttressing the west side of the Santa Catalina Mountains. Identification was based on a thick caliche bed that is characteristic of the University terrace, and a coarse, bouldery, highly dissected surface. The Jaynes terrace and bottomland are usually found adjacent to the main tributary drainages, though one or two isolated exposures occur next to Canada del Oro.

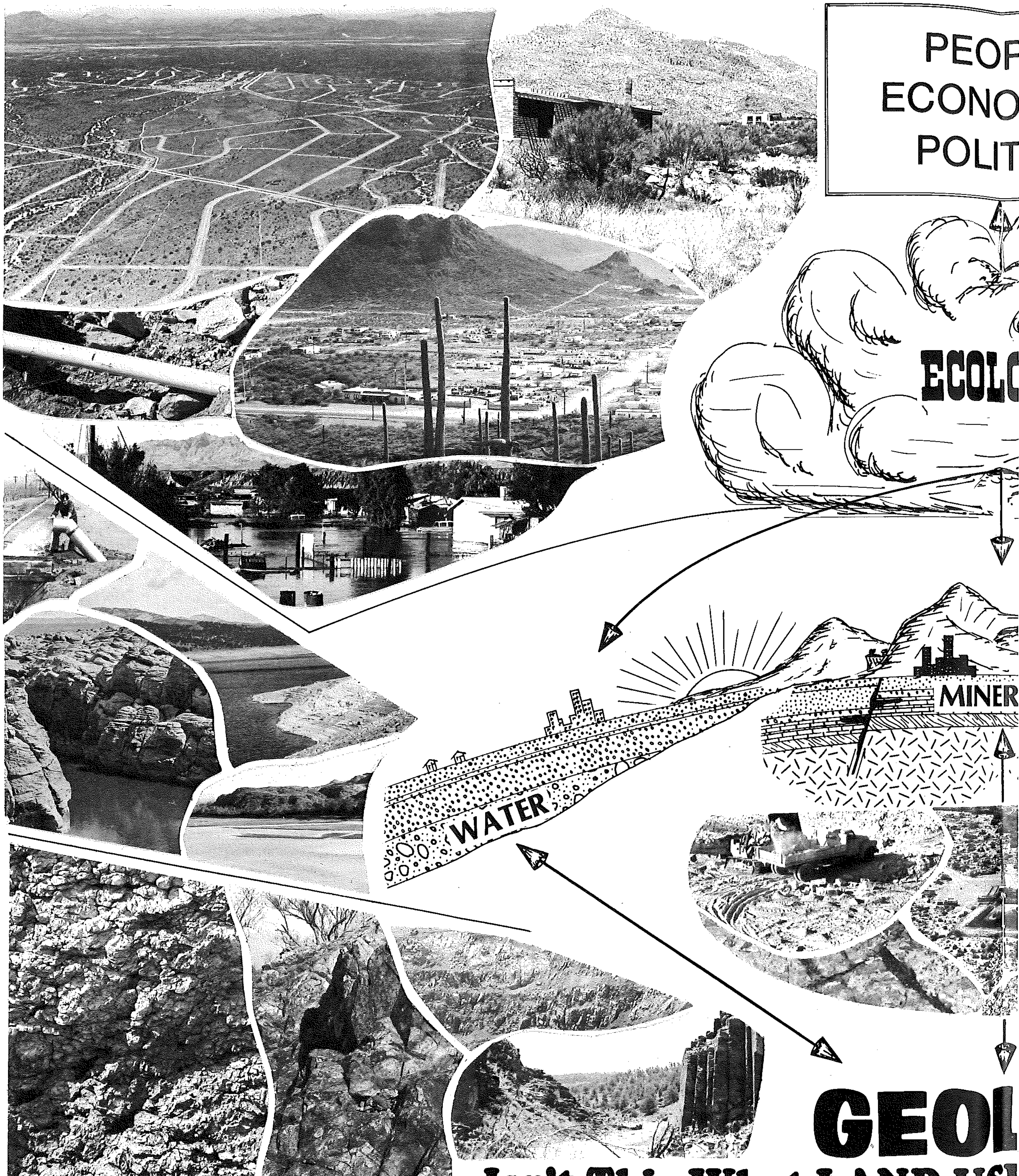
The degree of cementation and packing of the deposits generally decreases from oldest to youngest. While the University terrace is well cemented and packed, the Cemetery and especially the Jaynes and younger deposits are essentially unconsolidated. The high porosity and permeability allows these gravels to be well drained.

Two Approaches to a Slope Stability Analysis

The analysis of slope stability is of interest to both geologists and engineers, but from differing viewpoints. Whereas the geologist examines slopes from the point of view of shape and the process by which they were formed, engineers take a quantitative approach and examine such problems as maximum angle of excavation, landslide potential and prevention, and methods of stabilizing existing slopes. In order to reach a valid conclusion regarding the stability of a slope, a combination of both approaches is needed. The quantitative determinations of the engineer must be based on a thorough geologic examination of the structure and form of the slope-forming materials, and the geologist will benefit from the results of physical tests made of the soil and rock materials by the engineer.

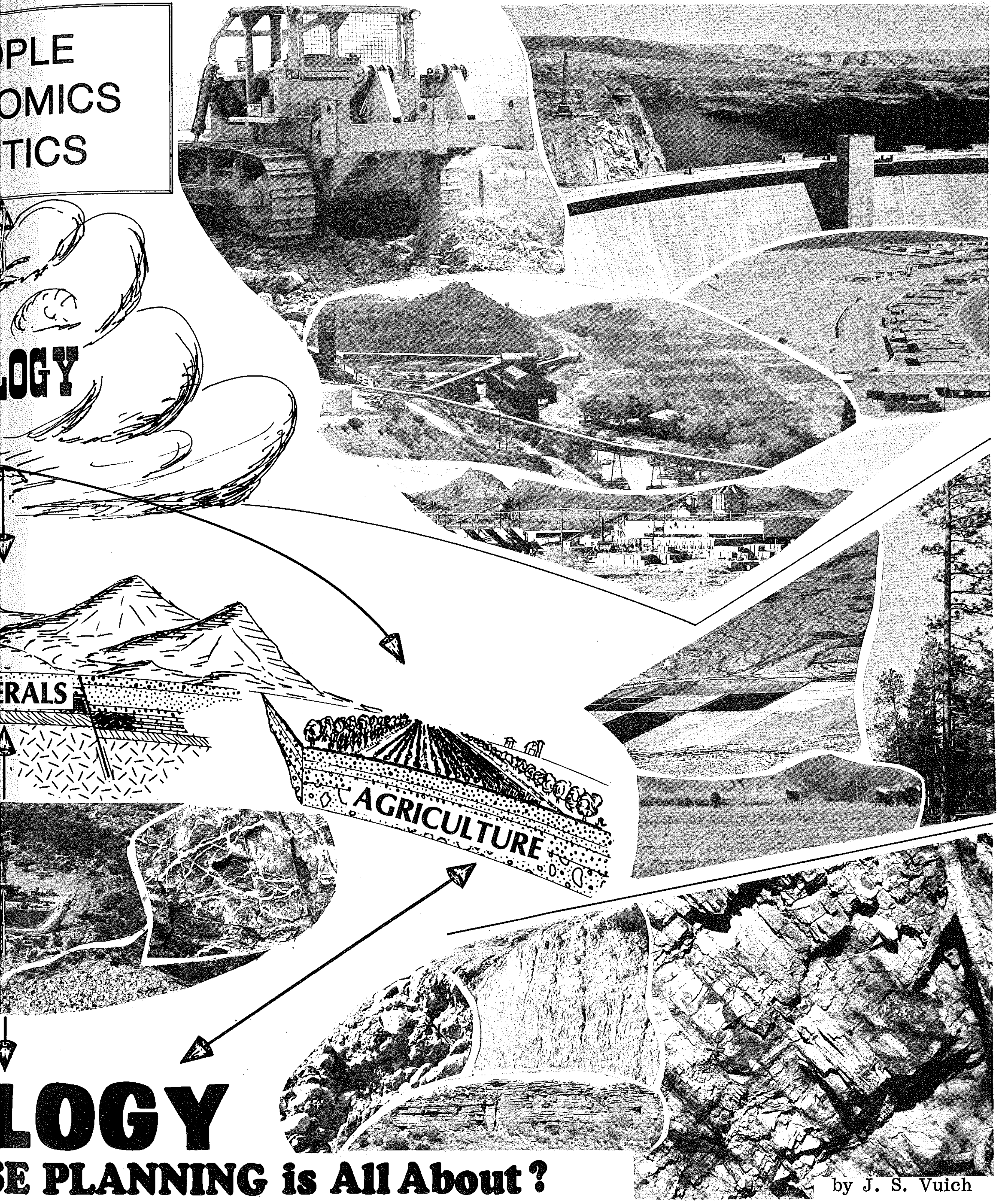
Geomorphological approach to slopes. The geomorphologist, a geologist who studies the physical characteristics of the landscape, is interested in the form and processes which control the shape of the terrain. The configuration of any slope is eventually determined by the relationship

Continued on page 10



GEOL

Isn't This What LAND USI



LOGY
E PLANNING is All About ?

by J. S. Vuich

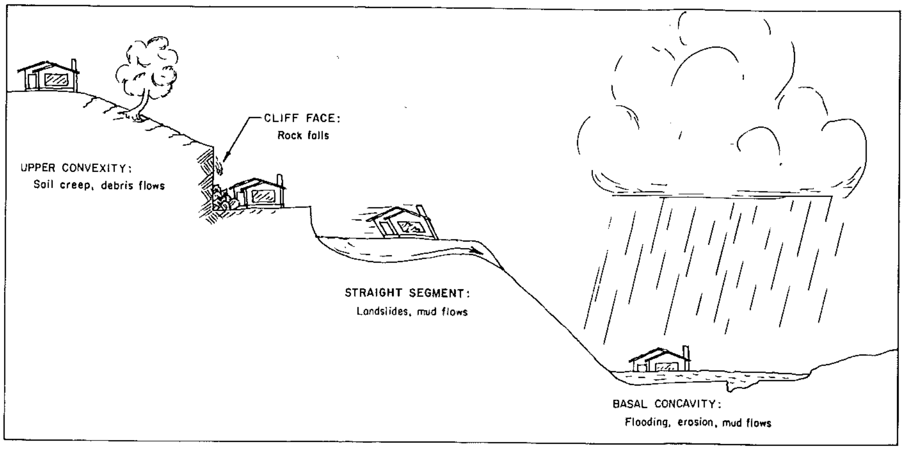


Figure 1. Idealized slope profile showing major components and processes likely to occur for that segment.

Slope Stability *continued*

between the disintegration of the underlying material and the rate of removal of this debris from the sloping surface. The erosional processes of water, wind, and mass movement further control the shape of a slope. These properties may work in combination or independently on any segment of the slope. Thus, a stream cutting the base of a hillside may exercise the dominant control on the actual form assumed by the surface. By using a qualitative and sometimes quantitative examination of slope forms and processes, conclusions can be reached on the evolution and stability of hillside elements.

Investigators of slope form are often interested in the profile of the land surface. In this case, measurements are recorded along selected lines of traverse, and the corresponding slope profile is then drawn up for inspection and interpretation. An idealized slope profile containing four components was used by Wood (1942) for an attempt to arrive at a general theory of slope formation in arid and semi-arid climates (Figure 1). Though much controversy has resulted from his classification, it still provides the user with a general scheme in which to study slope profiles. In the following section, each component of his classification will be briefly discussed and analyzed for the indirect evidence it provides in a slope stability study. These components are an upper convexity (waxing slope), cliff face (free face), straight segment (constant slope), and basal concavity (waning slope).

Upper convexity. Arid topography is characteristically stepped, with a succession of low-gradient surfaces separated by steep slope segments above and below. Two types of upper convexity, or waxing slopes, can be observed (though many intermediate steps may be present). These are: (1) a convexity bounded between two straight segments, and (2) a convexity at the upper edge of a scarp. Due to the action of such weathering processes as rain splash and sheetwashing, the rate of surface-lowering must increase toward the steep cliff face. The process of rainsplash operating on the slope will thus remove the material at a rate comparable to that of soil creep. Though mass movement on this particular segment is not generally as prominent as on other segments (straight segments, for instance), the constant wearing back of this slope can increase the surface gradient, thus affecting its stability.

Cliff face. Probably the most dominant and striking slope segment found in semi-arid climates is the cliff face (see photograph 1). In terms of hillside stability, this segment contributes much debris to lower slopes in the form of rock falls. Weathering processes will tend to weaken the strength of the material along such geologic features as joints and faults. The size of the boulders released is therefore dependent upon the spatial relationship of the planes of weakness, and ranges from small granular particles to large individual blocks. Depending upon the strength of the material and the distance of falling, the rock will remain either relatively intact or disintegrate into a myriad of smaller pieces upon impact. Accumulation of this debris will form a talus, or loose rock slope, at the base of the cliff. Active retreat of the cliff face only occurs when the slide rock accumulation can be removed and bare rock slopes at the base are again established (Koons, 1955).

The precipitous cliff faces on the western side of the Santa Catalina Mountains lack appreciable talus slopes at their bases. It is therefore presumed that active rock falls can be anticipated in the future. Due east of the town of Vista Catalina, two varieties of rock falls are seen. The first is exfoliation of the granitic outcrops which resemble the layers of an onion. Sheets of rock up to four feet thick and tens of square feet in area have been shed from the underlying slopes. The second type involves the differential weathering of the rock into spherical boulders. These pieces of rock may be attached to the underlying surface by only a few inches of material. Many have evolved to such an extent that they are no longer connected to the underlying surface and any disruption of the block will set them into motion. A few single residences have already been built below this zone.

On the eastern side of the Tortolita Mountains, unstable rock slopes where the material falls into blocky rubble are widespread and similar hazardous conditions exist (see photographs 2 and 3).

The straight segment. The straight segment, situated below the cliff face, is similar in appearance to a talus slope but differs in that the boulders on it usually form only a veneer on a slope which otherwise consists of bedrock (Carson, 1972) (see photograph 1). The gradient of this segment is slightly less than the angle of repose or angle at which the material will come to rest under a given set of physical conditions. The physical conditions responsible for maintaining this angle are the angularity, composition, production or detachment of fragments from the bedrock, and climatic conditions. Measured angles of debris-covered hillsides within the Tucson basin peak at two values: 28.5 degrees and 34 degrees (Melton, 1965). Both stability angles seem to be related to the frictional properties of the material. The lower value coresponds to the static friction angle and the upper value to the sliding friction angle. Thus, on the upper and steeper slopes, only the mechanism of gravity would be required to set debris into motion, whereas on the more gentle segment, hydraulic forces predominate. As the slope angle flattens, the hydraulic factor becomes more important in the mass movement of surface material. Thus, straight-slope segments constitute potentially unstable areas where mass movement of material would be more likely to occur; construction on a straight-line slope usually requires cuts for roads and housing pads. This tends to oversteepen the slope both above and below the site, resulting in accelerated erosion and landsliding.

Lower concavity, or break in slope. In the region surrounding Tucson, the lower concavity is the most important landform in terms of area involved. Concave desert plains may consist of thick, alluvial accumulations or may have a nearly smooth bedrock plane, called a pediment, close to the surface. These low gradient slopes are more affected by surface

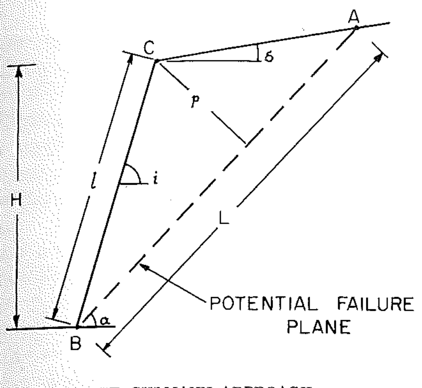


Figure 2a. A quantitative approach to slope stability assuming a potential plane failure passing through the toe of the slope.

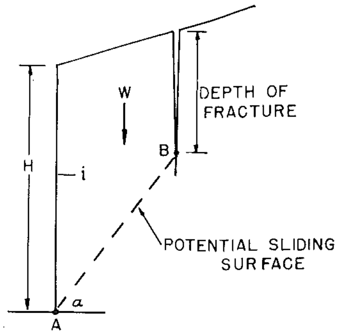


Figure 2b. Tension features developing parallel to the edge of the slope will intercept the failure plane and reduce the critical height of the slope.

drainage systems than by any other erosional process. Mass movement on these slopes is nil except where streams have been deeply incised. In this situation, planar failure of soil, whether in stream channels or in cut slopes behind houses, constitutes the main type of mass movement.

Engineering Approach to Slope Stability in Soil

We have seen in the previous section how a geologist's understanding of the shape of slopes can lead to indirect conclusions regarding the stability of the material. But what will happen if the natural shape, or angle of the slope, is altered by man? Soil engineers have long been interested in the problems of mass movement of material in cases where it becomes necessary to modify natural slopes or create new ones, as in embankment cutting and other excavations. By creating new slopes which are higher or steeper, landslides can be induced because the shear stresses in the soil mass are increased. An understanding of the mechanics of mass movement and the physical properties of various soil materials has thus enabled the engineer to redesign slopes for maximum safety.

The most prominent and widespread type of slope failure within the study area is slab failure. The simplest example of this process is the slumping of bank material along a stream channel or from a cut bank excavated for a highway cut or homesite (see photograph 4). The reason that river banks or cut slopes can remain vertical and do not become unstable up to certain heights is that they possess cohesion. There remains, however, a maximum height at which the soil will stand before it fails. Various methods have been designed in the attempt to predict their maximum height for an embankment. Assuming that we have a planar failure passing through the toe of the slope, the Culmann method (Terzaghi, 1967) can be used to determine this critical height (Figure 2a). Important parameters used to determine this critical height is the cohesion (C), angle of internal friction (Ø), bulk weight of the material, and angle of the sloping surface (i).

The results of this method can be interpreted in two ways. As the slope angle (i) becomes increasingly steeper, the critical height (Hc) will become smaller. Secondly, the critical angle becomes smaller as the cut becomes increasingly deeper.

Therefore, as the potential failure plane is inclined at a higher angle, a smaller depth of slope is necessary to produce a mass movement. But within the Mt. Lemmon quadrangle area, we find many vertical slope (scarps) which have been cut by incising streams or artificial excavations. Thus, the value of slope angle (i) is 90° and tension cracks may develop. These cracks will intercept the failure plane before the critical height is reached, and will reduce the height by 50 percent (see Figure 2b).

Substituting physical testing parameters in this method can sometimes accurately predict the maximum height of a cliff or embankment. Lohner and Handy (1968), for instance, working in the loess area of Iowa, found close agreement between actual and theoretical height based on the above method.

The application of the above case is limited to certain models. Slopes that fail in circular arcs, or in rock, would be treated differently. As we will see later, the effects of the water pore pressure is an important parameter determining the stability of slopes. Regardless of the present difficulty in duplicating actual field conditions in the laboratory, soil mechanics offers the most realistic quantitative basis for analyzing slopes in engineering terms.

Slope Failures Caused By Artificial Modifications

Man's modifications of natural slopes for construction purposes is the chief cause of many mass movements in rock and soil. The use of design methods

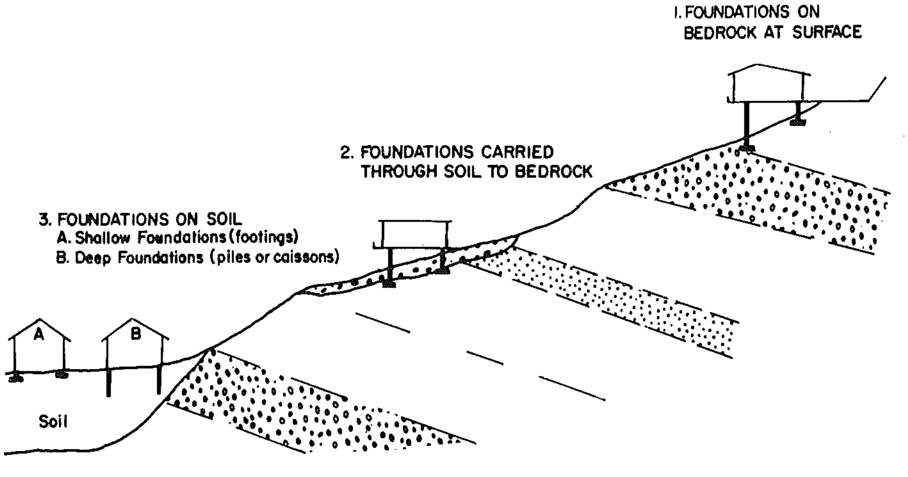


Figure 3. THREE GENERAL GROUND CONDITIONS FOR ESTABLISHING SAFE STRUCTURAL FOUNDATIONS ON NATURAL SLOPES.
CASE 1. Stable bedrock exposed at ground surface or close to it; foundations can be shallow.
CASE 2: Stable bedrock lies below deposits of unconsolidated soil; foundations are carried through the soil which might be remnants of a soil failure or an old stream; other alternatives are stablizing the soil and placing shallow foundations or removing the soil in the process of building a multi-level house.
CASE 3. Stable bedrock lies too deep to reach economically with foundations; foundations needed might be shallow as in House A. where high bearing strength has been determined by soils engineer, or deep as in House B where poor soil conditions exist (after Leighton, 1966).

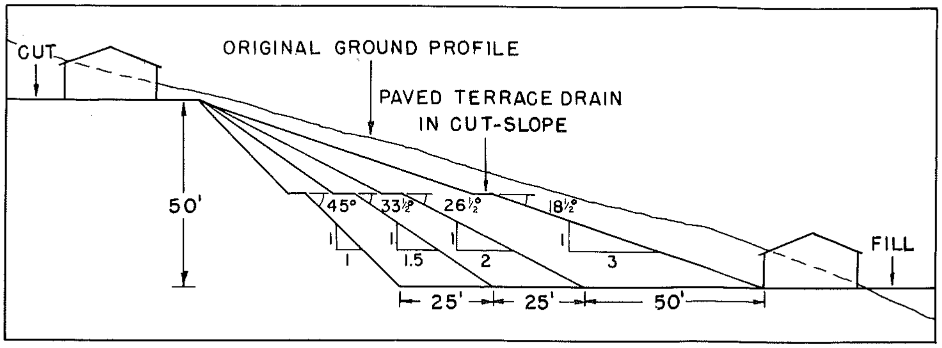


Figure 4. FOUR DIFFERENT CUT-SLOPE ANGLES (1:1, 1.5:1, 2:1, and 3:1). A 2:1 slope has a horizontal length twice the vertical height. A safe cut slope angle is the most vital requirement for stability. Some cut slopes in residential development are stable at 1:1, others at 1.5:1, others at 2:1, or 3:1 and still others have to be even flatter (or retained). The steeper the cut slope angle, the more level lot pad space is created and the more material has to be excavated. Grading in most residential hillside developments involves cutting the hilltops and placing this material in the canyons and along the lower hillside slopes as fill. In most cases civil engineers believe that it is more economical to produce cut and fill lots by earth-work than to construct tracts of homes on the natural slopes (after Leighton, 1966).

presented previously can help an engineer to estimate areas of potential failure. The construction of houses or engineering structures on relatively stable ground can alter conditions to such an extent that failure is likewise inevitable. Three construction conditions that will have an effect on the stability are loading, cutting, and filling of a slope.

Loading. The placing of a weighted mass on a slope, such as a fill to extend the backyard of a house, is the most common type of overloading. The increased loading can cause the formation of surfaces of rupture in underlying soil and rock, resulting in failure. Structures also are loading factors (see Figure 3). In places where soil conditions are weak, foundations must be properly reinforced to distribute the weight of the structure evenly to avoid concentrating stress and thus initiating a failure.

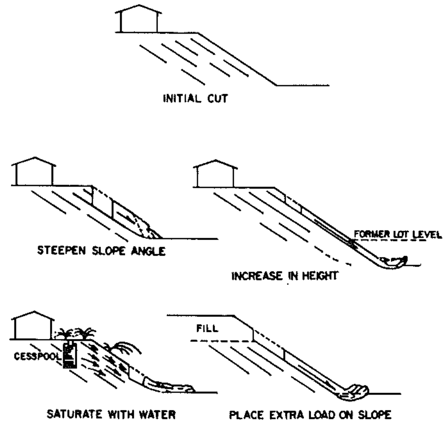


Figure 5. FOUR WAYS TO MAKE A STABLE CUT SLOPE UNSTABLE. The small slides shown have developed from the stable initial cut at the top by man's modification of the slope (after Leighton, 1966).

Cutting into a slope. Because the valley floors of the region are sometimes rather narrow, excavation at the foot of a slope to make more flat ground is very common. The prime requirement for the stability of cut-back slopes is that they are graded at a safe angle (Leighton, 1966). Proper design of the cut should minimize rilling and gullying while at the same time yield the greatest possible area for the housing surface (Figure 4). It is obvious from the figure that by steepening the cut, more flat area can be developed for a given lot size. In the Mt. Lemmon study area, the Fort Lowell Formation can stand at 1:1 while the maximum angle of cut for the surficial deposits is 1:1½ or 1:2. The Tinaja beds elsewhere in the Tucson basin will remain stable at 1:1 but in the study area only at 1:3 due to its weathered condition and the presence of clay. Slides that occur after grading are often an indication that the problem was not detected during excavation. Four ways that a stable cut slope can be made unstable are illustrated in Figure 5.

Fills. The improper design of fills on which foundations are placed can result in severe settlement of the structure (see photographs 5 and 6). This can be caused by

(1) Situating the fill on existing vegetation or compressible soil;

(2) Inadequate drainage of the fill, causing seepage and saturation of the building site;

(3) Improper compaction of the fill.

In order to avoid excessive erosion of the fill, vegetation should be planted as quickly as possible. Placing fragments of rock to minimize surface erosion on the sloping sides should be avoided, as this will tend to initiate small-scale failures on poorly consolidated fill.

Slope Stability Map

A relative slope stability map was prepared for the northwest quarter of the Mount Lemmon quadrangle (see Figure 6). The ability of a slope to remain stable is dependent on the slope angle, type of material, geologic structure, and water table condition. Slope stability was classified into 5 major groups, from most stable to least stable. Interpretation was based on field observation of hillsides subject to failure and their probable response to excavations. Slopes seemingly stable in natural cuts were many times found to be rendered unstable during excavation.

The relationship between stability units and geologic material is outlined in the table.

Generally, the stability of slopes in the study area is considered high when compared to areas outside the arid southwest. Although unstable conditions in some areas are widespread, landsliding phenomena as encountered in California and on the East Coast have not been observed in the Mt. Lemmon area. This may be due to the following factors:

(1) An analysis of the natural slope angles indicates that the alluvium is in a period of equilibrium. Coatings of desert varnish, staining some surficial alluvium, indicate that they have remained in place for at least a few hundred years.

(2) There is a general lack of clay in the sediments. Clay has a high tensile strength when dry and almost no strength when wet. This material, in the wet state, acts as a lubricant and is often the triggering mechanism in landslides.

(3) Rainfall is relatively low. Water can serve as a cumulative driving force by causing seepage, adding weight, and lubricating or hydrating clay minerals.

Conclusion

The development of hillside areas in Southern Arizona will continue to increase as the availability of flat-lying areas decreases. The construction problems encountered when building on flat, low-lying land are only magnified when applied to sloping regions. The stability of the natural slopes, then, should be a prime consideration during the preconstruction phase in order to minimize costly problems in the future.

An analysis of hillside elements in the Mt. Lemmon quadrangle indicates that a much larger area of potentially unstable slopes exists than was previously realized. Further development of interpretive maps, as provided in this text, will benefit both engineers and land-use planners in future decision-making roles. Enactment of local slope ordinances should strive to meet both the safety and economic requirements of the public.

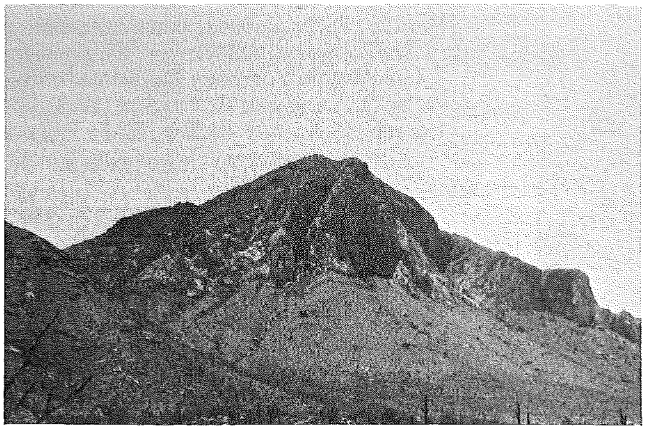


Photo 1. Shear cliff face in Santa Catalina Mtns. with straight segment below.

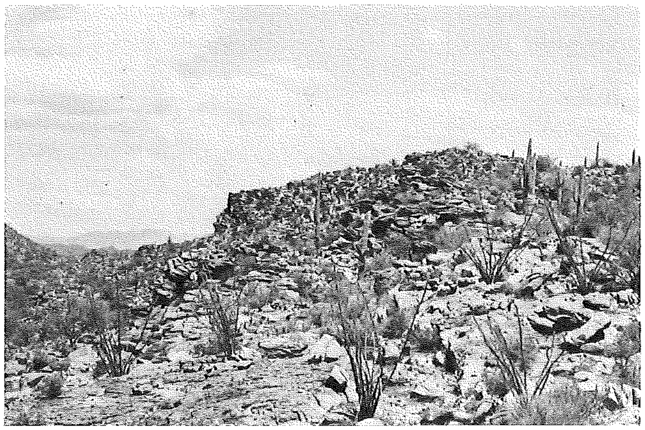


Photo 2. Slope in Tortolita Mtns. Debris slides predominate in this material.

Photo 3. Slide in undifferentiated Tortolita granodiorite.

Photo 4. Failure of a cut-back slope. During the summer rains of 1973, many tons of material were released into the backyard. Rilling and piping erosion is now causing further instability.

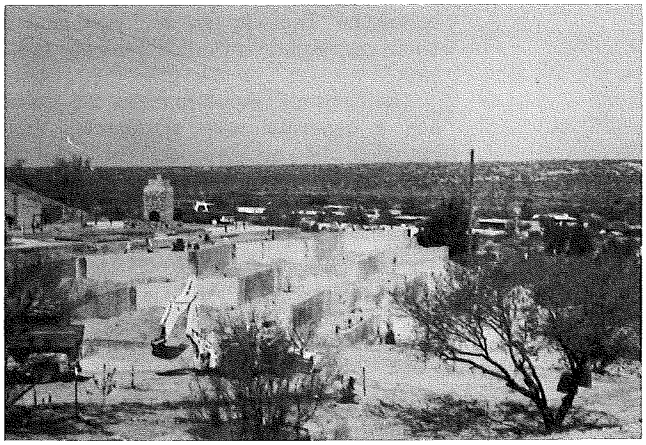


Photo 5. Series of retaining walls to stabilize fill slope. Home being constructed on fine-grained recent alluvium overlying Ft. Lowell Formation in map unit 4.

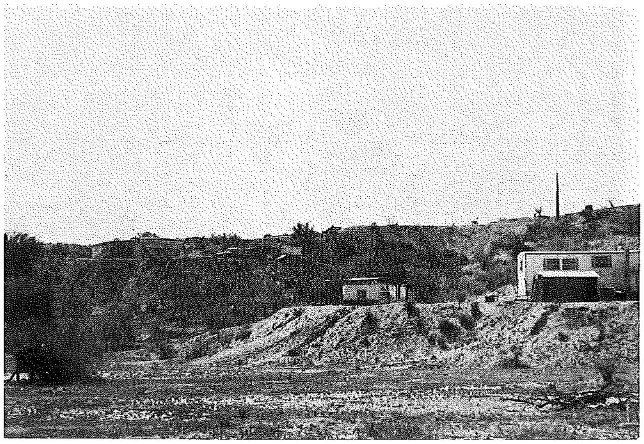


Photo 6. Improper maintenance of fill sites. Erosion of the slope may cause future instability, while lowering the aesthetic value of the property.

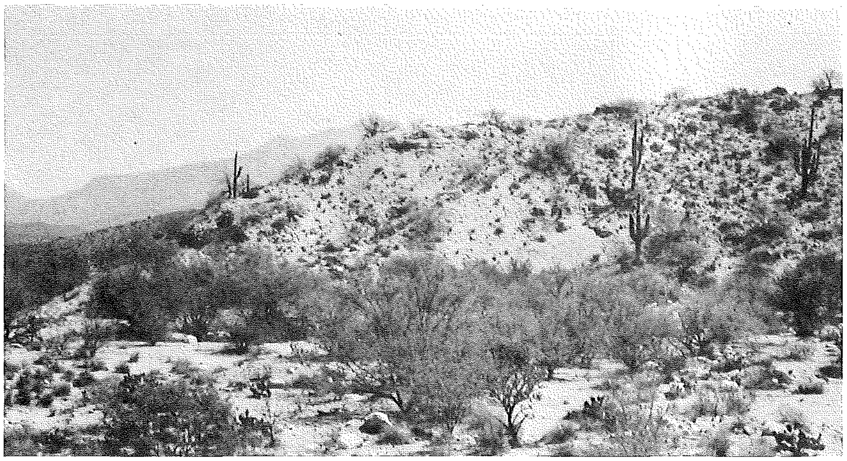


Photo 7. Landslide in surficial alluvium. Failure of material similar to model in figure 2a.

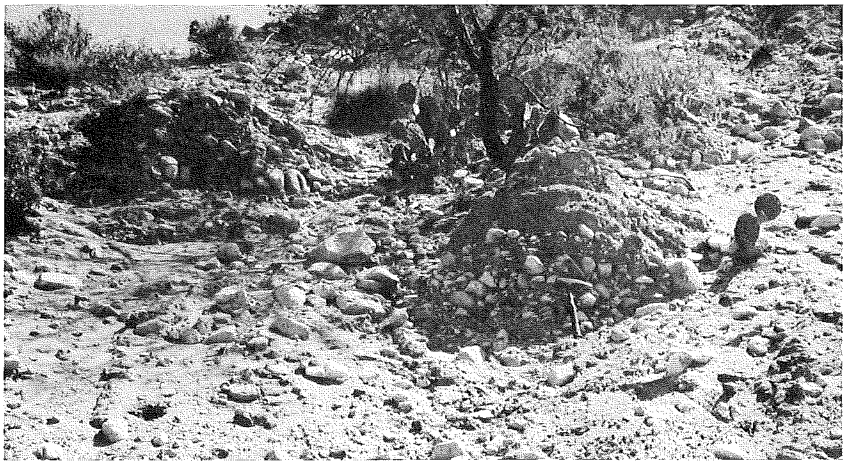


Photo 8. Close-up of photo 7. Looking into failure plane. More resistant flatlying coarse beds remain in place. Failure plane inclined at 35°

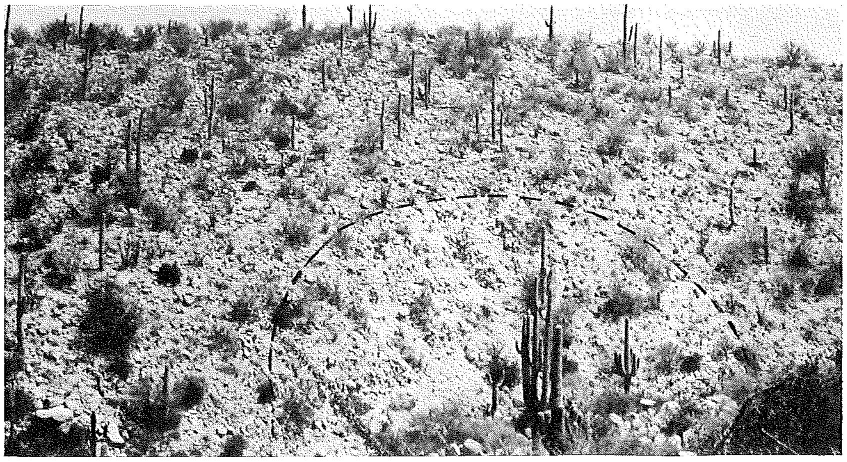


Photo 9. Outline of slope failure in Fort Lowell Formation adjacent to Pusch Ridge, Santa Catalina Mtns.

References

Berkey, C.P., personal communication to C.F. Sharp (1937); *in* Engineering Geology in Southern California; edited by R. Lung and R. Proctor (1966)

Carson, M.A., and Kirkby, M.J., Hillside form and process; Cambridge University Press (1972)

Davidson, E.S., Geohydrology and water resources of the Tucson Basin, Arizona; U.S. Geological Survey water-supply paper 1539-E (1973)

Koons, D., Cliff retreat in the Southwestern United States; *in* American Journal of Science, v. 253 (1955)

Leighton, F.B., Landslides and hillside development; *in* Engineering geology in Southern California; edited by R. Lung and R. Proctor (1966)

Lohnes, R.A., and Handy, R.L., Slope angles in friable loess; *in* Journal of Geology, v. 76 (1968)

Melton, M.A., Debris-covered hillslopes of the Southern Arizona desert — consideration of their stability and sediment contribution; *in* Journal of Geology, v. 73 (1965)

Pashley, E.F., Structure and stratigraphy of the central, northern, and eastern parts of the Tucson Basin, Arizona; University of Arizona, Ph.D. dissertation (1966)

Smith, G.E.P., The physiography of Arizona valleys and the occurrence of groundwater; University of Arizona Agricultural Experiment Station Technical Bulletin 77 (1938)

Terzaghi, C., Soil mechanics in engineering practice (1967)

Wood, A., The development of hillside slopes; *in* Proceedings of the Geologists' Association, v. 53 (1942)

AGS Publishes Tectonic Digest

The Arizona Geological Society has published the "Tectonic Digest," Volume X in their continuing series of geologic bulletins.

The Tectonic Digest contains 430 pages, has a separate map supplement, and includes 19 articles on tectonics in Arizona.

Digests may be ordered by mail from the Arizona Geological Society, Box 4054, Tucson, AZ 85717, at a cost of $11.50 each, which includes postage. They also are being sold over the counter at the Arizona Bureau of Mines' offices at 845 North Park, Tucson for $10.50 each.

Articles in the Digest include "The Age of Basin-Range Faulting in Arizona," "Free-Air Gravity Anomaly Map of Arizona," "Elements of Paleozoic Tectonics in Arizona," and "Late Devonian Tectonics in Southeastern Arizona."

Bureau Sponsors Geologic Study in Harquahala Mountains

by Robert J. Varga

The west-central and southwestern portions of Arizona are poorly known geologically. The understanding of this part of the Basin and Range Province is, however, critical to the evaluation and extension of current tectonic models to southeastern Arizona. The Harquahala Mountains, located 35 miles east of Quartzsite, Arizona, lie within this critical terrain and display important geologic relationships.

The writer mapped an area of approximately 16 square miles in the western Harquahala Mountains. Major rock types in the study area include: 1) biotite augen-gneiss, 2) post-Triassic granite, and 3) Cambrian-Triassic sedimentary rocks. Structures in crystalline rocks include foliation and lineation in the gneiss and pervasive jointing in granite. Sedimentary rocks are structurally dominated by large-scale folding and low-angle faulting.

A major conclusion of the study confirms the existence of a considerable section of Paleozoic rocks in the Harquahala Mountain area. Up to 4130 feet of Paleozoic section is recognized in the western Harquahala Mountains, although this thickness should be interpreted as an extreme maximum due to the folding which pervades these rocks. Because of the paucity of fossils, correlation of the stratigraphic units to known formations is based primarily on lithologic similarity and stratigraphic sequence. Recognized formations are: 1) Cambrian Bolsa Quartzite (350 feet), 2) Mississippian Redwall Limestone (380 feet), 3) Pennsylvanian-Permian Supai Formation (1200 feet), 4) Permian Coconino Sandstone (1100 feet), and 5) Permian Kaibab Limestone (1100 feet). Approximately 1000 feet of the Triassic Moenkopi Formation is also exposed in the study area which supports the contention of earlier workers that the Moenkopi Formation once continued south of its previously recognized southern limit in the Mogollon Rim area.

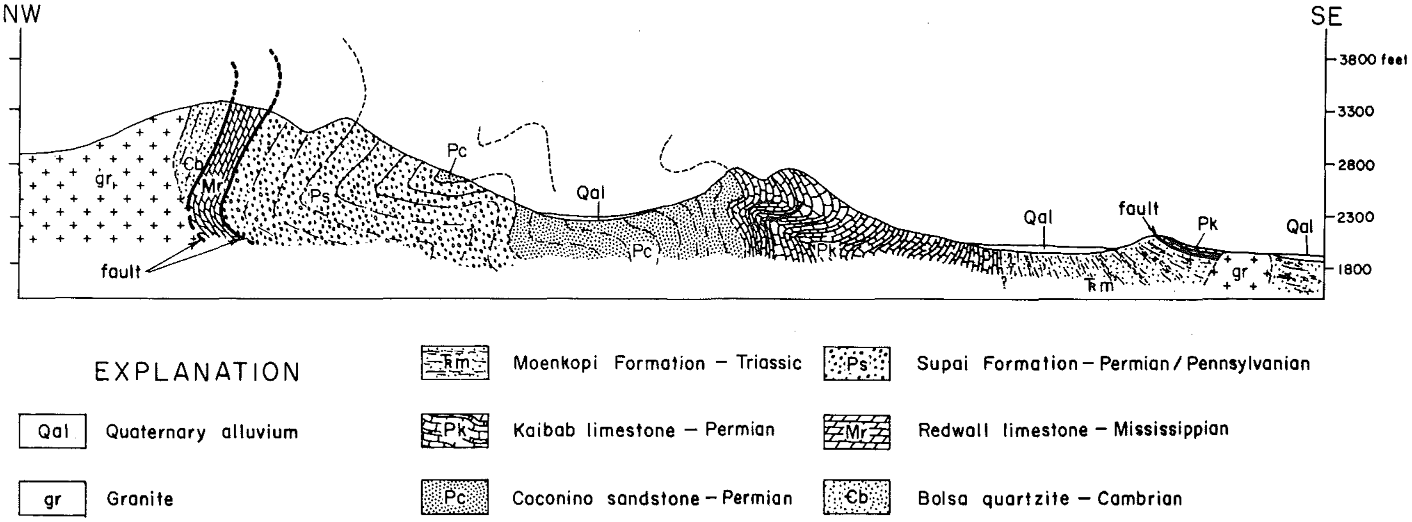
Deep erosion of the Paleozoic sedimentary rocks provides excellent exposures of large-scale "cascade" folds (Fig. 1). These folds have a general sense of overturning to the southeast and are interpreted as the response of southeast-directed gravitational gliding in post-Triassic time. Low-angle faults formed concomitantly with folding and place younger strata over older strata.

Formation of "cascade" folds was followed by intrusion of a large granitic body. This granite is characterized by the presence of large potassium-feldspar phenocrysts. Many abandoned gold mines and prospects are located near the granite-Bolsa Quartzite intrusive contact.

Movements on NW-trending, oblique-slip faults in post-middle Miocene(?) time postdates granite intrusion. Separation across these faults is in a right-lateral sense. Gentle flexuring of the earlier-formed "cascade" fold axes occurred at this time and is interpreted as the result of the right-lateral component of slip during faulting.

Evidence is lacking in the western Harquahala for a period of compressional tectonics. This is in contrast with previous tectonic models which extend the thrust belts of the Sevier Orogeny (late Jurassic-late Cretaceous) and Laramide Orogeny (late Cretaceous-early Tertiary) into southeastern Arizona through this west-central portion of the state.

Robert Varga is the recipient of the Arizona Bureau of Mines Research Assistantship for 1975-76. He is a graduate student in geology at the University of Arizona.



News from the Department of Mineral Resources

Energy Minerals Development Encouraged

The Department of Mineral Resources' role in the energy crunch is to encourage the prospecting for and development of Arizona's energy minerals. One of the methods of encouragement is working with individual "small mine" prospectors.

In order to assist the small miner, and make use of small deposits, the possibility of establishing custom buying stations is being discussed with several companies. As a preliminary step, the Department held meetings in Tucson, Globe, Wickenburg, and Phoenix. Representatives from a uranium broker spoke to the prospectors and small miners about possibilities of establishing buying stations, the escalating prices of uranium mine-mouth prices to miners, and rapidly changing marketing problems.

The Department is taking a look at locations for central leaching pads and sites for buying stations. Nothing firm has developed at this time, but the future does look encouraging for a rejuvenated uranium industry in Arizona.

Continued on page 16

Arizona's Water Supply *continued*

Perhaps the most important contrast in physical setting is between the Salt River Valley (SRV), or Phoenix region, and the Upper Santa Cruz Basin (USC), or Tucson region, the two largest and fastest-growing metropolitan centers in Arizona, if not the entire U.S. The Phoenix region is developed on large basin or valley surfaces adjacent to the central mountains where there is surface water storage. The Tucson region is developed in a relatively smaller single basin or valley surface far removed from the central mountain surface water influence. Figure 2 summarizes the basic water supply-use aspects of these two contrasting regions by representing water quantities in terms of water column heights, in miles, above a football field, and percentages. All data are estimates cited in the Phase I report for "normalized 1970 conditions."

In the SRV, total water withdrawal was 2,631,000 acre feet (498 miles), 894,000 acre feet (169 miles) of which was surface water and 1,737,000 acre feet (329 miles) ground water. Irrigated agriculture used 90 percent (448 miles) and municipal/industrial uses accounted for the remaining 10 percent (50 miles).

In the USC basin total water withdrawal was 246,000 acre feet (47 miles), all of which represents ground-water pumpage. Irrigated agriculture used 103,000 acre feet (19 miles — 42 percent) and municipal/industrial uses accounted for 143,000 acre feet (27 miles — 58 percent).

Even though all of the withdrawal numbers for the USC basin are much smaller than for the SRV, it should be recalled that the former is being depleted at 4.7 times replenishment rate whereas the latter is being depleted (combined surface and ground water) at 1.9 times replenishment rate. (In the SRV, much ground-water recharge is traded for reservoir storage in the central mountain region, which explains why the ground water component in the SRV is being depleted at 30 times the replenishment rate.) The interested reader is invited to make his or her own comparisons of the data presented.

The logistics of satisfying growing urban and industrial demands, coupled with the reality of limitation to the size of Arizona's indigenous water supply, most of which is out of sight, bring increasing complexities to water policy decision making. Because our water resources largely are out of sight it is difficult to arrive at a common awareness as to future possibilities and probabilities. One thing is certain, however, and it is that human activity in Arizona, as presently constituted, has far surpassed the point of ecological balance with regard to water use and replenishment, especially in the Basin and Range desert region. We are pressuring the inherited geologic and desert condition beyond its ability to endlessly sustain us in a manner to which we have become accustomed. How long will we go on as we are? Not for long, because water-related changes take place every day. Conservation practices are being initiated and will be speeded up as inevitably higher water-related costs take effect. Water use patterns will change as we become educated to the fact that water in Arizona's desert regions cannot long continue to be treated as having no tangible value above the costs of delivering it to its desired end use.

Are we running out of water? Certainly, the state has much less water within its jurisdiction than it once had. However, it seems more precise to say that we are running out of cheap water. For some of those most dependent upon large volumes of low-cost water, it has run out.

Legal access to water is an important consideration that can limit available water supplies. As we begin to look elsewhere for water reserves, it is inevitable that legal-political conflicts will arise.

Water in Arizona has been taken for granted by most citizens for a long time. Although it is a complex and difficult subject it seems likely that in the future it will command much more of our attention that it has in the past.

How high a value do you place on water in our desert country?

References

Arizona Water Commission, Arizona State Water Plan, Phase I: Inventory of Resource and Uses; 224 p. (1975)

Harshbarger, J.W., Use of ground water in Arizona: *in* Climate and man in the Southwest; University of Arizona Press (1958)

DMR News *continued*

Custom Mill Hoped for in Mohave County

DMR is working with the Board of Supervisors of Mohave County to determine the feasibility of establishing a custom mill in Mohave County.

The funds for study come through Federal Comprehensive Employment Training Act (CETA). Vernon Dale, registered mining engineer and land surveyor with the Department, will function as project engineer.

The first phase of the project will be the establishment of a permanent "mining file" library. This collection of data will be available for future use by all interested parties.

The Department of Mineral Resources hopes to have the study completed by October 1976.

FIELDNOTES

Volume 6, No. 2 *June, 1976*

State of Arizona
Governor .... Hon. Raul Castro
University of Arizona
President .... John P. Schaefer
Arizona Bureau of Mines
Director .... William H. Dresher
Editor .... Judi Goodpaster

ARIZONA BUREAU OF MINES
THE UNIVERSITY OF ARIZONA
TUCSON, ARIZONA

ARIZONA BUREAU OF MINES
THE UNIVERSITY OF ARIZONA
845 NORTH PARK AVE.
TUCSON, ARIZONA 85719

INE 2032

[redacted]