FIELDNOTES

From The State Of Arizona
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by Susan M. DuBois

Seismic risk in the state of Arizona is poorly understood. A relatively sparse population and a pervasive attitude within the state that earthquakes are a California problem have resulted in the lack of public response to potential earthquake hazards in Arizona. In fact, a detailed earthquake study on a state-wide basis has never been published in Arizona. Further research of the state's earthquake record is a necessary first step in evaluating seismic risk in this area.

On May 3, 1887, an estimated magnitude 7.5 (Sbar, pers. commun.) earthquake shook an area of at least 720,000 sq mi (Sturgul and Irwin, 1971) forming a 35 mile-long fault scarp and maximum offset of approximately 14 ft (Sumner 1977). Most of Arizona was affected by shaking ground. Secondary rock falls and groundwater disturbances were reported throughout southeast Arizona. The epicenter was south of the Arizona-Mexico border in the San Bernardino Valley along the western front of the Sierra Maderas Mountains (Figs. 1 and 2). In terms of magnitude, surface faulting and damage, this event is comparable to the Hebgen Lake, Montana earthquake of August 17, 1959 and the Dixie Valley, Nevada event on December 16, 1954. None of the historical earthquakes in Utah have been as large as the Sonoran event. Thus, it ranks among the most severe earthquakes on record in the western United States (exclusive of California).

A few damaging earthquakes have also occurred over the past century near Flagstaff, Yuma and Prescott, Arizona. However, the relationship of these recent seismic phenomena to zones of crustal weakness in Arizona is not known.

What is an Earthquake?

When a sudden rupture occurs within the earth's crust, an earthquake is generated (Fig. 3). As rock surfaces grind past each

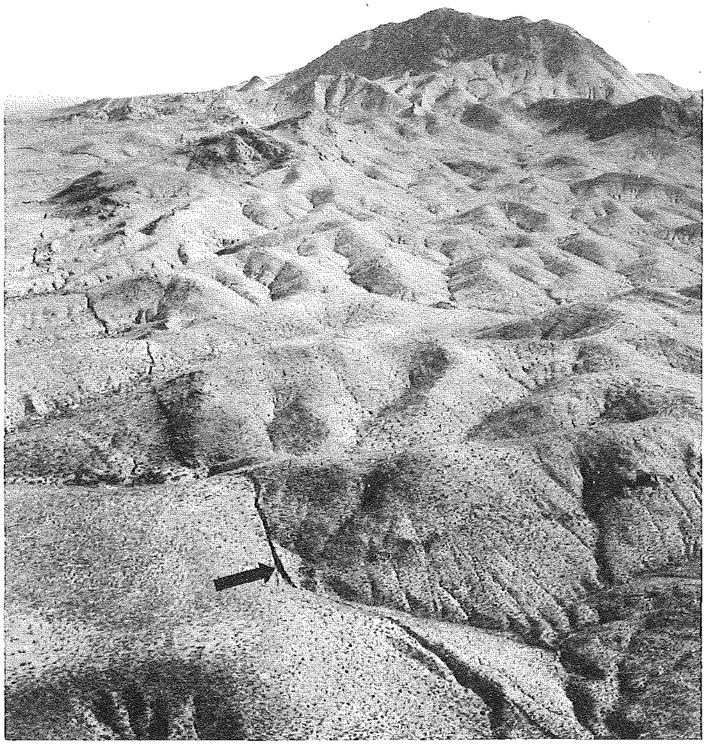


Fig. 1 Aerial view of 1887 fault scarp in Sonora. Fault begins roughly 5 miles south of Arizona border and continues 35 miles to Colonia Moreles in the San Bernardino Valley (photo courtesy of Pete Kresan).

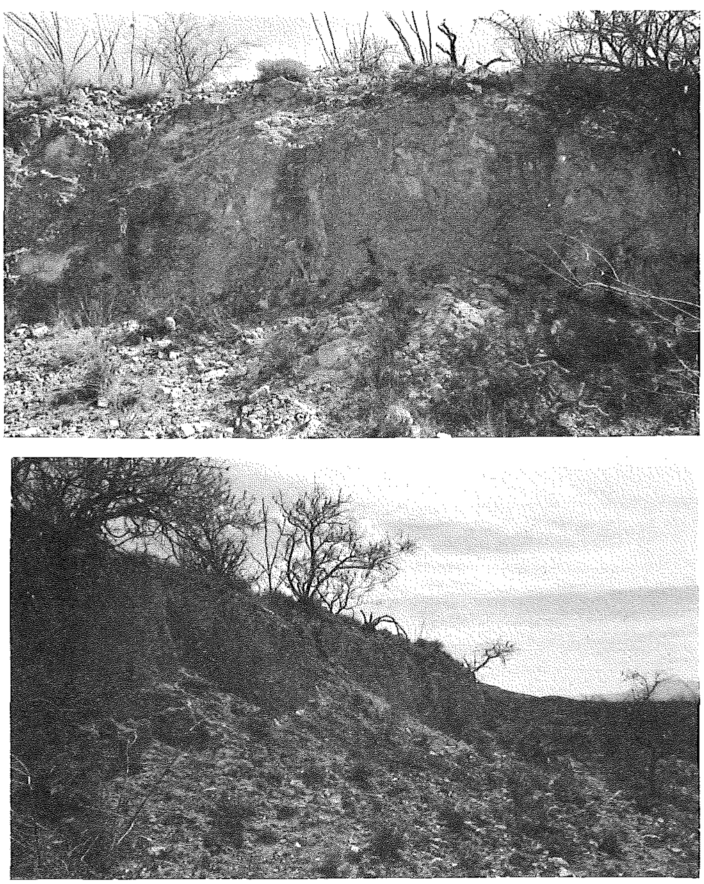


Fig. 2 Close-up views of 1887 fault scarp in Sonora.

other along a fault zone, shock waves are transmitted in all directions. Various intensities of earth shaking occur at the surface (Fig. 4), depending upon the extent of the break, the type of material through which the shock waves travel and the distance from the source of the break.

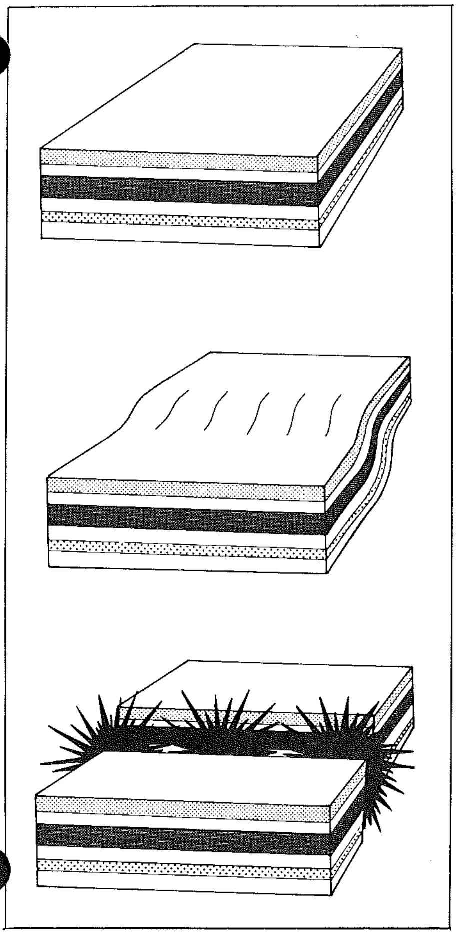
Seismologists have developed methods for measuring earthquake characteristics. Two scales are commonly used today: The Richter magnitude and the Modified Mercalli Intensity scales (Fig. 5). The former is a measurement of the quantity of energy released during an earthquake at the point of breakage. It is a logarithmic scale, such that an increment of one indicates a 31-fold increase in the amount of energy released by the earthquake, and roughly a 10-fold increase in the amplitude of waves sent out from the source. For example, a magnitude 6.0 event releases 31 times the amount of energy released by a magnitude 5.0 earthquake. Richter magnitude is determined from seismograph record analysis of incoming shock waves at various stations. Ideally, the magnitude value assigned to a particular earthquake is mainly a function of breakage along a fault in the earth's crust, and thus can be used objectively as a standard for comparing earthquake size. Theoretically, it has no upper limit, although the largest earthquake ever recorded had a Richter magnitude of 9.5 (Chile, 1960). However, in terms of human hazards from earthquakes, the Richter scale is not sufficient. A magnitude 7.0 earthquake, if located far from population centers is not necessarily damaging. On the other hand, a magnitude 5.0 event could cause considerable damage if located directly beneath a large metropolitan center on unstable ground (for example, a saturated alluvial valley).

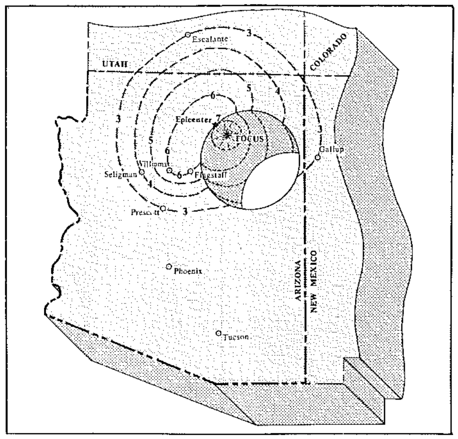
The Modified Mercalli Intensity scale is used to measure observed earthquake effects and damage. Intensity values vary according to distance from the epicenter, the type of material at the site occupied by the observer and the nature of intervening geologic structure (i.e., bedrock variations, faults, folds, etc.). As the seismic waves attenuate (dissipate) throughout the medium surrounding their source, effects noticed by people and other animals also diminish. Fill and "made" land, especially water-saturated, are known to transmit much greater intensity of motion than nearby bedrock outcrops. Natural unconsolidated deposits are also potentially dangerous when water is present.

Figure 5 is a rough correlation of the Richter magnitude and Modified Mercalli Intensity scales. Because intensity is so dependent on the geologic foundation and building conditions of a particular area, it may vary at two points equidistant from the epicenter. Thus it is often erroneous to equate magnitude with estimated intensity. Each earthquake has one Richter magnitude value (Arabic number) and possibly several Modified Mercalli Intensity (MM) ratings (Roman numerals) which generally decrease in value away from the epicenter. The distinction between these scales is important, but commonly misunderstood. Intensities are assigned to quantify the surface effects at various points within the "felt" area of an earthquake, whereas the magnitude value measures the amount of energy released at the origin of the shock waves. The intensity scale is thus a better indicator of actual damage, although it is highly variable and subjective.

Where Do Earthquakes Occur?

On a world-wide basis, earthquakes occur most frequently along the margins of rigid crustal plates which move on top of a semi-plastic layer of material which begins at a depth of 15-50 kilometers. Approximately 98% of all earthquakes today occur in the zones shown in Figure 6. These seismic belts are believed to





← Fig. 3 A sudden rupture in the earth's crust causes an earthquake (modified from Hamblin, 1975).

Fig. 4 Isoseismal patterns of an earthquake north of Flagstaff on Aug. 19, 1912.

Fig. 5 Modified Mercalli intensity ratings (left and center) have been roughly correlated to Richter magnitude and maximum intensity at the epicenter. Even so, the correlation is often erroneous because of the many factors which determine intensity values (from Steeples, 1978). →

	Modified Mercalli Scale	Richter Magnitude Scale
I	Detected only by sensitive instruments	1.5
II	Felt by few persons at rest, especially on upper floors; delicately-suspended objects may swing	2
III	Felt noticeably indoors, but not always recognized as earthquake; standing autos rock slightly, vibration like passing truck	2.5
IV	Felt indoors by many, outdoors by few, at night some awaken; dishes, windows, doors disturbed; motor cars rock noticeably	3 3.5
V	Felt by most people; some breakage of dishes, windows, and plaster; disturbance of tall objects	4
VI	Felt by all, many frightened and run outdoors; falling plaster and chimneys, damage small	4.5
VII	Everybody runs outdoors; damage to buildings varies depending on quality of construction; noticed by drivers of automobiles	5
VIII	Panel walls thrown out of frames; fall of walls, monuments, chimneys; sand and mud ejected; drivers of autos disturbed	5.5
IX	Buildings shifted off foundations, cracked, thrown out of plumb; ground cracked; underground pipes broken	6 6.5
X	Most masonry and frame structures destroyed; ground cracked, rails bent, landslides	7
XI	Few structures remain standing; bridges destroyed, fissures in ground, pipes broken, landslides, rails bent	7.5
XII	Damage total; waves seen on ground surface, lines of sight and level distorted, objects thrown up into air	8

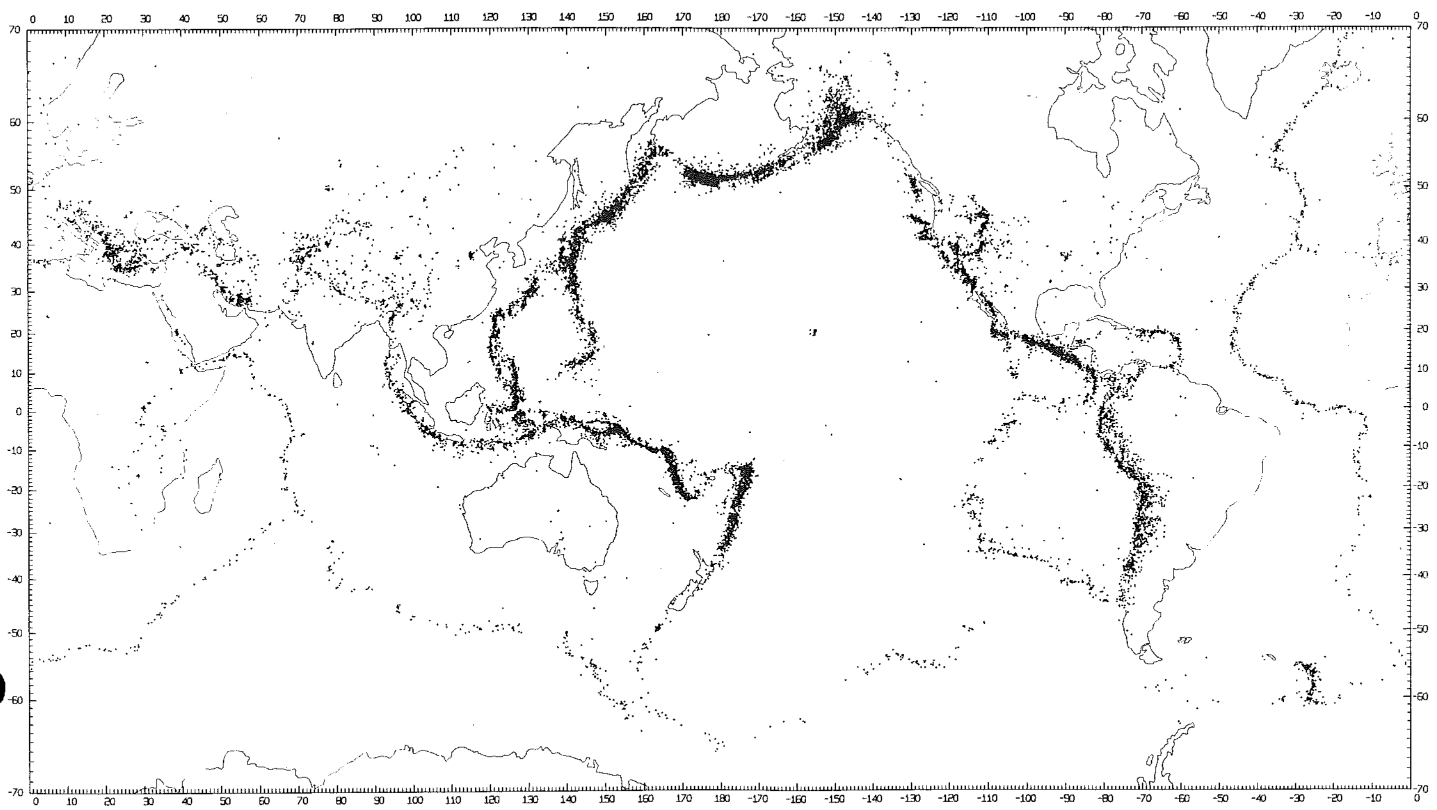


Fig. 6 World seismicity patterns. Earthquakes during the period 1960-1967 have been plotted (from Sbar, 1977).

EARTHQUAKE TERMINOLOGY

earthquake — shaking of the earth caused by sudden displacement of rocks below the earth's surface

epicenter — the point on the ground surface nearest to the source of the shock waves

fault — a break within the earth's crust along which rock surfaces have slid past each other

felt area — the entire area in which effects of an earthquake are noticed

focus — the origin of the shock waves, the point at which sudden rupture occurs

groundshaking — vibrating ground motion caused by seismic wave travel

isoseismal lines — lines of equal intensities

liquefaction — the process in which unconsolidated materials are made to behave as a liquid. Sudden motion caused by shock waves causes individual grains to be suspended in the pore water between them. Thus the material loses its internal strength. Earthquake fountains, sand craters and mud volancoes are examples of liquefaction

Modified Mercalli (MM) — scale used to measure intensity of shock waves based on observed effects

Richter Magnitude — scale used to measure the energy released at the earthquake focus

secondary effect — any effect at or near the surface caused by shock waves rather than actual fault movement. A fault scarp is a primary effect. Liquefaction, landslides, earth fissures and most building damage are secondary effects.

seismic — related to or caused by earthquakes

seismograph — An instrument used to record the arrival time, size and duration of incoming shock waves. Usually a rotating drum, covered with paper, on which a pen, highly sensitive to shock waves continuously records earth vibrations.

tectonic — of or pertaining to rock structure resulting from the deformation of the earth's crust.

define the boundaries of continental and oceanic plates which are shifting their position relative to one another, according to one of the geometries illustrated in Figure 7. Stresses imposed in the rocks at these margins cause faulting to occur.

The plates have moved throughout geologic time. Thus, former positions of converging, diverging and transform boundaries have caused faults which may or may not be active today. The mechanisms of faulting and the causes of most specific faults are not well understood. Even the well-studied San Andreas fault in California still baffles scientists in terms of predicting damaging earthquakes along its great length. Much of the seismic activity in Arizona is likely associated with movement along ancient crustal zones of weakness which have been selectively reactivated throughout geologic time by episodes of tectonic disturbances. The Laramide orogeny, occurring 90 to 40 million years ago, is an example of a former convergent plate phenomena involving the western edge of north America, including Arizona. Most recently, Basin and Range faulting related to a broad transform boundary between the North American Plate and the Pacific Plate has had a great influence on seismicity in Arizona. The seismic activity in

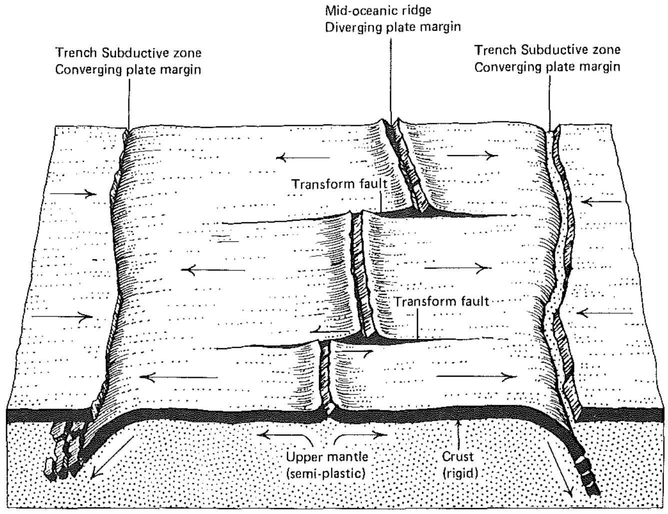


Fig. 7 Diagram showing converging, diverging and transform boundaries of the crustal plates (modified from Hamblin, 1975).

Arizona today is believed to be related to the complex and diffuse nature of shearing movement on structures subparallel to the San Andreas transform boundary between these two plates. According to one hypothesis, the area of greatest tectonic activity in Arizona, evidenced by faulting, seismicity and volcanism, has progressed from southwest to northeast over the past 15 million years. Again, the extent and specific location of currently-active faulting in the state is unknown.

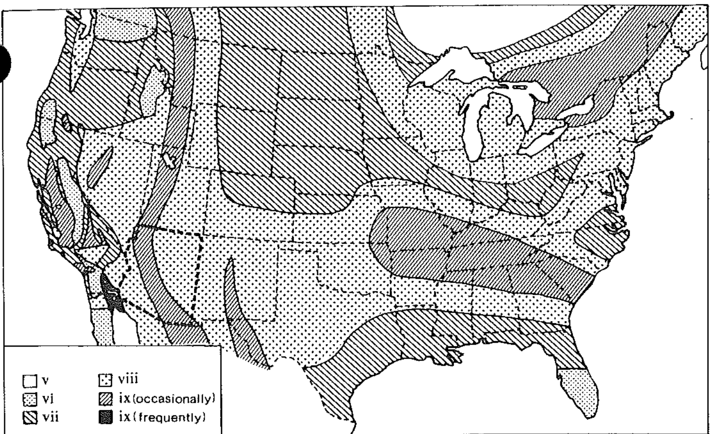
Can Seismic Risk Be Determined?

Assessment of earthquake risk is a complex problem. Knowledge of earthquake frequency, earthquake size (magnitude) and expected intensity variations (isoseismal patterns) within a given region is necessary to evaluate seismic hazards. Several attempts have been made to delineate seismic hazards throughout the United States. Two examples of national risk maps are shown in Figure 8. For many regions of the country, including Arizona, little is known about faulting and earthquake history. The conflicting risk ratings shown for the state are based on inadequate information concerning its geologic structures and recent seismicity. Further research on historical earthquakes is fundamental to obtain any of the parameters used to assess seismic risk.

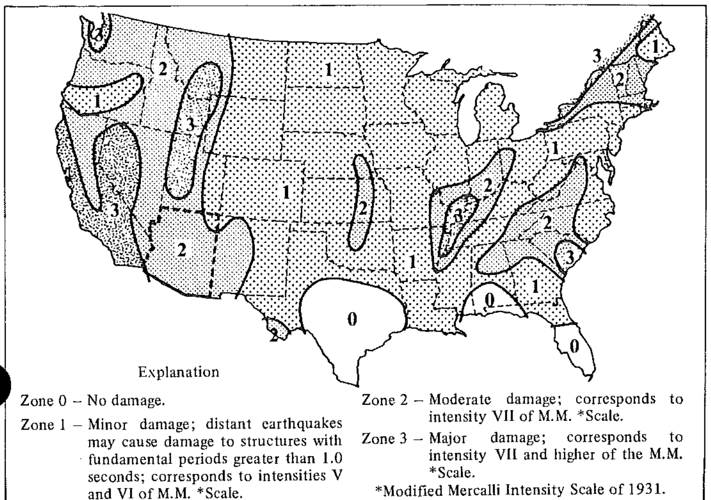
Why Are Seismic Risk Studies Needed In Arizona?

An increasing demand for seismic risk data in Arizona has resulted indirectly from rapid industrial growth and population expansion over the past three decades. Total population has increased nearly six-fold since 1940 and approximately 75% of that growth has taken place in Maricopa and Pima counties. Current population figures indicate that a metropolitan corridor inhabited by nearly two million people is being formed between the cities of Tucson and Phoenix.

Urban growth has extended to previously-unoccupied areas: namely floodplains, wash channels and bedrock slopes of mountain ranges, all of which are susceptible to various geologic hazards. Government design regulations for structures such as dams, reservoirs, hospitals and nuclear reactors have caused an increase in requests for earthquake hazard information. The



Seismic risk map, developed in 1958 by Charles Richter, shows maximum expected seismic intensities (redrawn).



Seismic risk map of the United States, redrawn from map issued in 1969 by S.T. Algermissen of the U.S. Coast and Geodetic Survey (now with U.S.G.S.

Fig. 8 National Seismic Risk Maps (from Perkins, 1974).

critical nature of these facilities requires that they be built to withstand the largest conceivable earthquake likely to occur during their lifespan.

The risk to residential dwellings should also be seriously considered. Unlike most other areas of the United States, a common construction material for residential use is adobe brick. Masonry, in general, is much more susceptible to earthquake damage than wood-frame construction because of its inability to yield with the earthquake stresses. Of all types of masonry, adobe brick is probably the weakest material since it is either sun-dried clay or low-fired brick. When subjected to seismic wave stress, it easily cracks and crumbles. A heavy clay tile roof is also potentially hazardous because it might collapse into the building if the walls become separated at the roof line because of differential resistance to shock wave forces. During a moderate-to-severe earthquake, most building damage results mainly because horizontal stresses are exerted against structural designs conceived to withstand only vertical forces. In Arizona, wood-frame homes are rare. Very few structures are steel-reinforced or braced with timber. In fact the buildings occupied by many Arizona citizens today are quite similar to those damaged or destroyed in the 1887 Sonoran earthquake (Fig. 9), in terms of materials and design. Unreinforced adobe dwellings in Guatemala, Iran and other parts of the world have been hard hit during recent devastating earthquakes.

A preliminary epicenter map of earthquakes in Arizona (Sumner, 1976) illustrates known earthquakes that have occurred throughout the state (Fig. 10). A revised version of this map will be published after the Bureau concludes its current earthquake study. It is vital that geologists continue the study of areas in Arizona where earthquakes are generated as well as maintain an ongoing investigation of the potential damage in the state from secondary earthquake effects. The problem of earthquake-induced surface phenomena is of particular concern in southeast Arizona where numerous accounts of rock falls, sand craters, earth fissures, groundwater disturbances and ground

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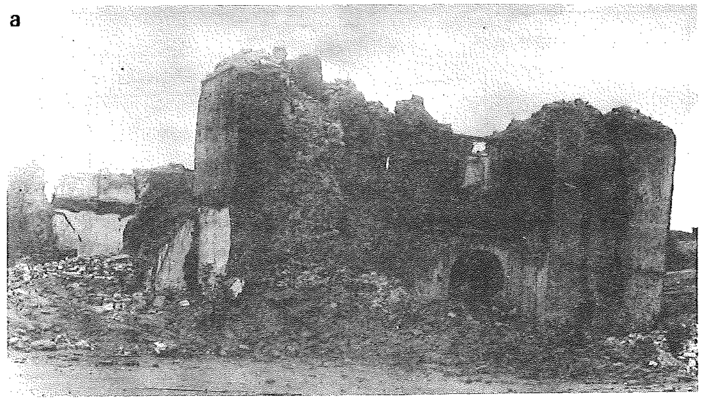

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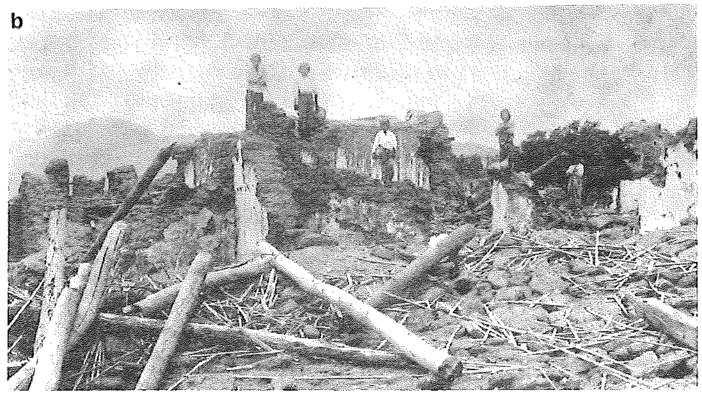

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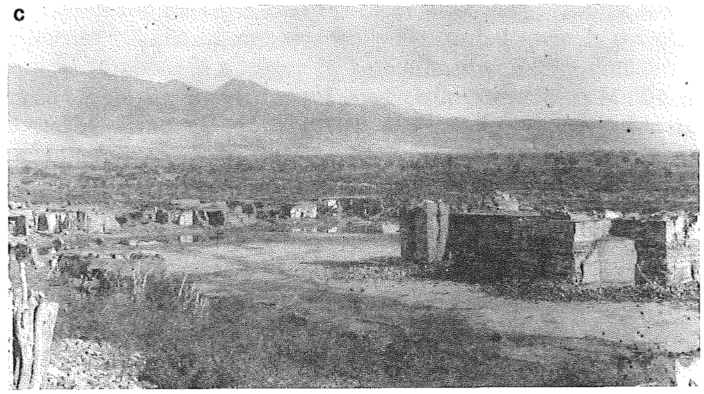

Fig. 9 Photos of building damage in Bavispe, Sonora during the May 3, 1887 earthquake: a) Church where 42 people were killed when the roof collapsed. Adobe walls were 24 inches thick. The building itself was 200 years old at the time of devastation; b) Destroyed home in Bavispe; c) View of village of Bavispe in which most of the adobe homes were demolished. The town was situated on an alluvial terrace in the valley of the Rio de Huachinera, 24 miles south of the fault scarp (photos courtesy of the Arizona Pioneer Historical Society, Tucson, Az).

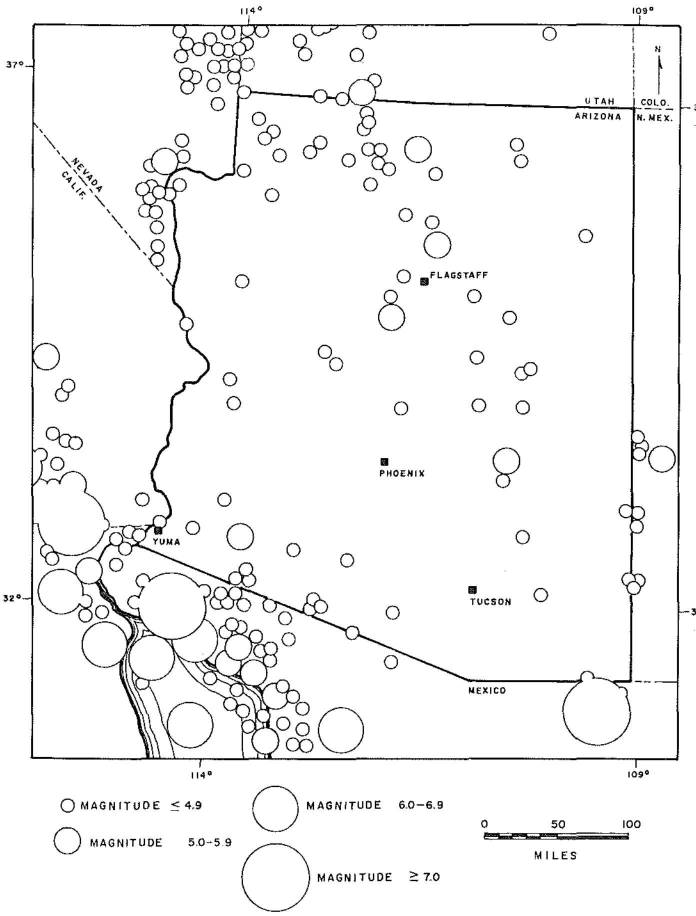

Fig. 10 Map of earthquake epicenters and sizes in or near Arizona (from Sumner, 1976).

shaking associated with the May 3, 1887 earthquake exist. Most of the towns throughout this region are situated on basin fill up to 3,000 meters thick, generally at sites where groundwater is available at shallow depths. The stability of such environments, when subjected to earthquake vibrations, has not yet been reviewed on a regional basis. Eventually, the Geological Survey Branch hopes to address this problem.

ROCKFALLS IN ARIZONA during the 1887 earthquake

Damage from earthquakes generally results from secondary effects at the ground surface. Landslides, liquefaction, tsunamis and earth fissures all are examples of potentially-harmful phenomena triggered by the motion of seismic waves as they travel to or across the earth's surface. In Arizona, possible hazards from such effects have not been investigated. Throughout the Basin and Range Province and other areas where steep topographic slopes exist, the risk of seismically-induced mass movements, in particular, should be considered.

Historical precedent for numerous rockfalls in southeast Arizona is found in reports of the May 3, 1887 earthquake, centered just south of the state boundary. Figure 1 illustrates the widespread nature of the debris slides on that occasion.

Excerpts of eyewitness accounts provide interesting descriptions of effects experienced by persons within sight of various mountain slopes:

From Bisbee

"The effects of the shock was (sic) seen for a radius of ten miles; clouds of dust were seen to rise from the mossy head of the San Jose Mountains; big boulders of several ton weight disengaged

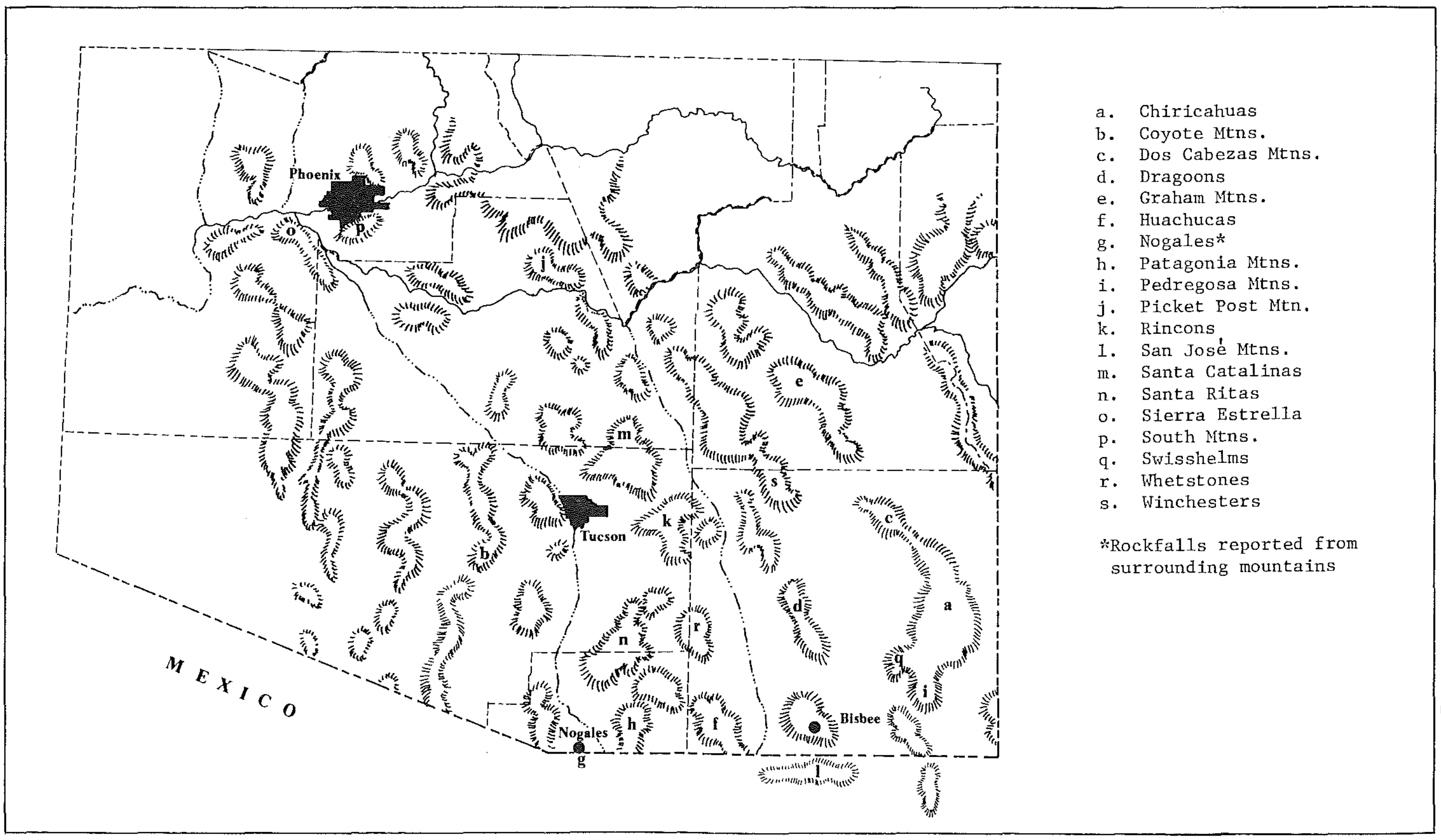

Fig. 1 General locations (a, b, c, . . .) of rockfalls in southeastern Arizona reported during the 1887 Sonoran earthquake.

themselves from the cliff-bound hills of Bisbee, followed by clouds of dust and rumbling and grumbling, some of the smaller boulders reaching into the upper streets of the town; one boulder some two feet and a half square lodged against Surveyor Hoadley's chimney" (Tombstone Prospector, May 5, 1887).

"The surface of the steeper waste dumps seemed to be actually in motion, rocks were in many places dislodged and thundered down the hillsides in a cloud of dust" (Engineering and Mining Journal, June 11, 1887).

Near Pantano
"I heard a rumble and saw a dense smoke near the window in the rock, then there came a crash. Heard afterward that the top of the mountain broke off" (Alexander J. Davidson, Reminiscences, Arizona Pioneer Historical Society).

In the Santa Ritas
"Under a tree setting in Arroyo, ground commenced to heave rumbling sound, thought it was a reptile from sound, and cattle and horses heads up in air, *rocks falling* . . . he stopped to rest in a canyon. The canyon was about four feet deep . . . On reaching level ground he heard and saw rocks falling down the sides of the hills and knew he had been in an earthquake." Rocks kept falling about 5 minutes (J.S. Andrews, Reminiscences, Arizona Pioneer Historical Society).

In Tombstone
"Loose rock from the hanging walls of the Toughnut mine crashed down noisily, striking sparks as they hit the hard footwall" (Staunton, W.F., 1918, Effects of an earthquake in a mine in Tombstone, Arizona, BSSA, v. 8, p. 26).

From Pinal
"As I stood there I saw huge rocks tumble down the north side of Picket Post Mountain, about a quarter mile distant" (Perry Wildman, Reminiscences, Arizona Pioneer Historical Society).

From Solomonville
"At the moment of the shake great clouds of dust were seen to rise from three or four places on the Graham mountains" (Tucson Daily Star, May 7, 1887).

In Hog Canyon (Between Tucson and San Carlos)
"All at once a great boulder ... mountain peak, toppled and . . . down to the valley below, carrying in its wake a thousand others, fortunately of less dimensions. The cattle becoming alarmed stampeded at the approach of the rocks and thus escaped being killed" (Arizona Weekly Citizen, May 14, 1887).

In White Water Canyon (tributary to San Simon)
"First it looked as though the top of a mountain peak away to the north had fallen off, then a great cloud of dust and smoke appeared there; almost immediately the nearer peaks acted the same and rocks were rolling off the hills on all sides . . . the frightened horses jerked away, disappearing into the black fog of smoky dust that now surrounded us, making it as dark as pitch. It was an alarming experience to be thus suddenly enveloped in darkness. The rocks in falling off the peaks had evidently set many fires, and mingling with the dust raised as a natural consequence of the falling debris, all was as dark as night . . . It was about the third day thereafter that the air cleared up enough to allow one to find his way about as usual . . . " (John Pleasant Gray Collection, Arizona Pioneer Historical Society).

From the Huachucas
"The rocky ledges along the sides of the Huachucas rose up and fell outward, breaking into all sizes of boulders that rolled down the mountain sides, snapping off all the trees and brush that were in their path. The friction of the rocks set fire to the grass and pretty soon, not only Huachucas, but the Dragoon and San Jose mountains, which I could see from where I was, burst into flames" (J.G. Wolf, "When the West was Young," Arizona Highways, April 1940).

From Fort Huachuca
4:30 p.m. A heavy pall of smoke hung over San Jose Mountains (30 mi SE of post).
5:00 p.m. A heavy column of smoke began to ascend the highest peak in the Whetstone Range (17 mi N of post).
8:30 p.m. The top of the cone is aflame.
An exploring party sent out by General Forsythe returned and "reported that several fires had started in different locations apparently at the same time. A mass of rocks at the bottom of the mountains led them to believe that sparks from the falling rocks ignited the extremely dry brush" (Letter by Commander at Fort Huachuca, Arizona Pioneer Historical Society).

In the Dragoons (1½ miles from Middle Pass)
" . . . near the top of the mountain and in the midst of the shock, which was quite severe, he heard a great noise as the report of numerous cannons one after the other, following which he saw an immense volume of smoke arising. He started towards the place and when about ¾ mi from it, he was met with huge boulders of rock which were being hurled down the mountain side with great force by some unknown power. He saw a large crevice in the mountain side from which smoke was issuing . . . Mr. Durran would not venture any closer on account of the flying missiles . . . " (Tucson Daily Star, May 8, 1887).

In the Santa Catalinas
"The old 'castle' on the Santa Catalina was badly shaken up by the quake, and parties who were near the Rillito and saw it take a tumble describe it as an awful scene of confusion in which the mountain peaks seemed to be dancing the racquet" (Perry Wildman, Reminiscences, Arizona Pioneer Historical Society).

"A party that has just returned from the Santa Catalina Mountains report that a good effect of the earthquake is the opening of 2 large gold veins which were discovered in the Santa Catalina Mountains at the point where the whole side of the mountain slid down. Several prospecting parties have left to locate water and claims" (Mining and Scientific Press – May 21, 1887).

"There are plenty of evidence of a big shock up in the Santa Catalina Mountains as there have been numerous slides and large quantities of rock and earth detached, hurled to the base of the mountains" (Observer from Oracle, Tucson Daily Star, May 8, 1887).

Although some of the reports may have been colored by exaggeration, the occurrence of rock slides throughout a wide region cannot be doubted. Little damage was caused by the debris falls, probably because population was sparse and lifestyle was simpler. For example, roads were unpaved and less heavily

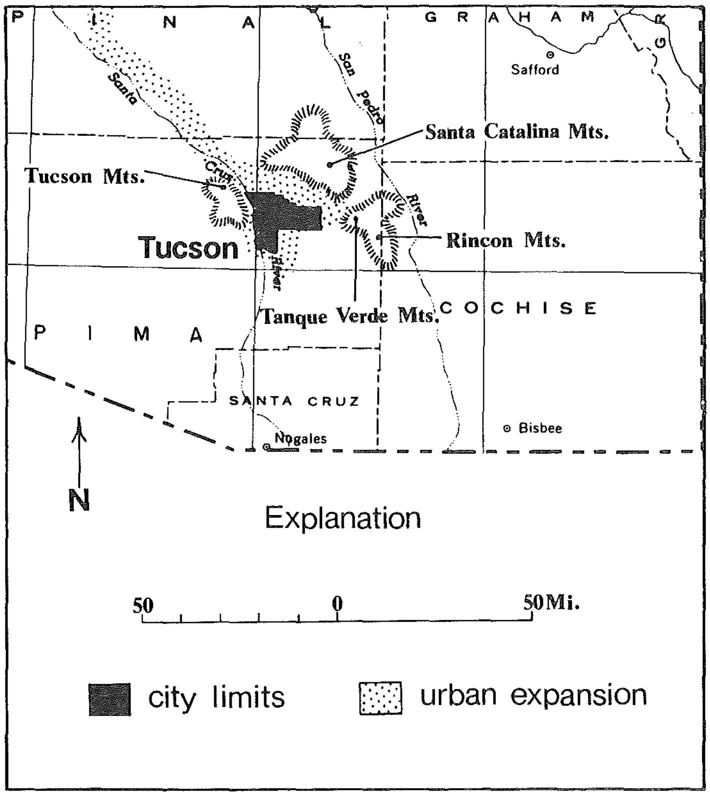

Fig. 2 Urban expansion encroaching upon the mountains surrounding Tucson.

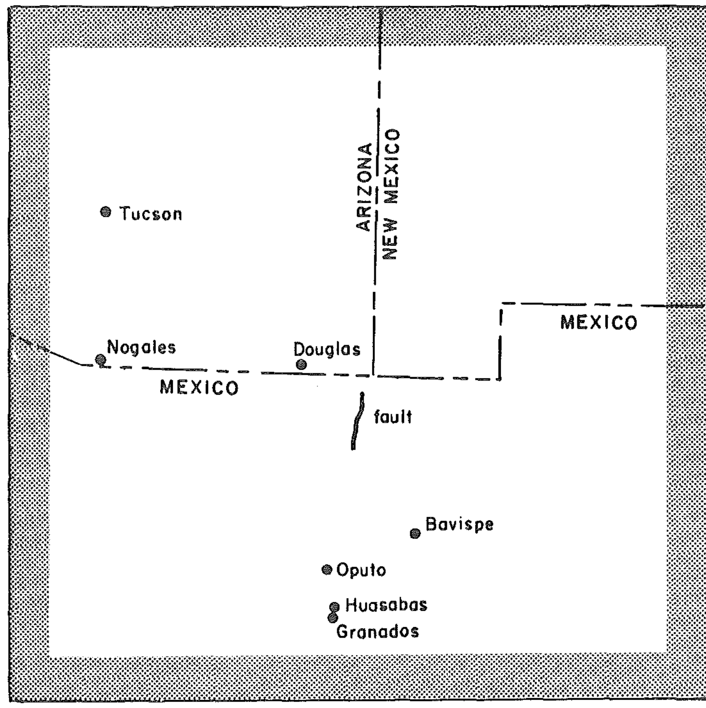

Fig. 1 Twelve people were reportedly killed in Huasabas and many homes destroyed in the village on December 19, 1923. Heavy building damage was also reported from Granados as a result of the earthquake.

traveled. Airports, reservoirs, utility lines, communication networks and many other facets of our present lifestyle which would have been adversely affected by the earthquake were not in existence. Consider then, how travel and communication would be affected by heavy dust clouds, widespread rockfalls, and resulting brush fires if a similar earthquake were to occur today.

Population has increased in many of the towns in southeast Arizona since 1887. Most of them are situated near mountain ranges. Tucson, for example, is surrounded by mountains. Residential developments have reached the bedrock outcrops of the Santa Catalina, Tanque Verde and Tucson Mountains, with similar expansion anticipated at the base of the Rincons in the near future (Fig. 2). When the possible consequences of another 1887-type earthquake are analyzed, potential risks of widespread rockslides should also be seriously considered. The Geological Survey Branch has applied for USGS funding to aid in the study of secondary earthquake effects in Arizona. Field investigations are already underway to determine exact locations of reported 1887 rockfall occurrences. It is hoped that eventually, parameters such as quantity of material, distance traveled and susceptibility of various rock types may be documented for some of the rock slides which are still preserved.

Earthquake Research:

A Lesson in Historical Detective Work

Over the past six months, hundreds of reports of felt effects and damage caused by various earthquakes occurring throughout Arizona and the surrounding area have been added to the earthquake research file at the Geological Survey Branch. Although more data must be collected and analyzed before the proposed Arizona Earthquake Catalog can be published, a description of the techniques used to trace earthquake clues reveals several significant findings at this time.

The first step in gathering earthquake data involved the compilation of a master list of dates and locations regarding reported events by various authors (Sturgul and Irwin, 1971; Fugro, Inc., 1975; NOAA, annual listings; Townley and Allen, 1939; Sumner, 1976; BSSA, annual volumes). Secondly, the references cited by these authors were checked for further documentation. During this stage of data gathering, several inconsistencies in dates, times, locations and assigned intensities were discovered. The most intriguing research is currently underway – the search for original reports.

Whereas an abundance of original, independent and accurate accounts for every earthquake is desired, inevitably the historical earthquake record remains biased: sparcity of data and questionable reliability of reports will be most noticeable in the early portions of the record. By comparison, the more recent the event, the more complete and reliable the reports tend to be. Generally, the largest events, because of the extensive area affected, can be better documented than small events that may not have been noticed.

Instrumental verification of earthquake occurrences cannot be relied upon prior to the 1920's. Even after the establishment of reliable seismic recording devices, actual damaging earthquake effects are better-estimated from historical accounts of felt intensities than from a magnitude value. However, existing superstitions, attempts to sensationalize and the often-humorous style of early journalists resulted in sometimes-exaggerated and inaccurate reports, presenting an additional problem for scientific interpretation. Given these variables, it becomes necessary to perform as thorough a search as is possible for all available earthquake information in Arizona.

Contemporary local newspapers, pioneer journals and diaries, old memoirs and manuscripts, Spanish Mission records and other sources of eyewitness accounts are being reviewed at the University of Arizona libraries and the Pioneer Historical Society in Tucson. Old military post records will eventually be searched in the national archives.

Recently, a microfilm copy of the unpublished Harry Fielding Reid card file of world-earthquakes prior to 1925 was purchased from the National Earthquake Information Service in Denver. A vague reference to a damaging Sonoran earthquake in 1923 was found in this file. No listing of the event had been found in any of the national or regional earthquake catalogs or other published scientific literature. Finally, a search for documentation was made in local newspapers, covering the dates December 19 – January 3, 1923. Front page coverage of earthquake damage in Huasabas, Granados and Oputo villages of northeast Sonora (Fig. 1), on December 19, 1923, was found in Douglas, Tucson and Phoenix, Arizona papers. Twelve people reportedly were killed and many adobe homes devastated during this event. The shock was felt in Douglas. Although the affected area was much smaller than that of the May 3, 1887 earthquake, the severe local intensity of the shock should not have escaped attention of seismologists. The rediscovery of the 1923 earthquake indicates that other serious omissions in published catalogs may exist. It also suggests that damaging earthquakes in that region of Sonora may be more frequent than previously believed.

Some of the earliest reported earthquakes occurred near Yuma. Entries from the diary of Major Heintzelman in 1852 and 1853 describe severe effects of a series of earthquake shocks felt at Fort Yuma. Geysers, mud volanoes, earth cracks, major building damage, slumping along the river banks and disturbance of the water in the Colorado River were some of the phenomena observed by personnel at the military post at that time (U.S. Bureau of Reclamation, 1976).

Original accounts of earthquake effects from an event approximately 35 miles southwest of Yuma on July 31, 1891 were found at the Arizona Pioneer Historical Society. Earth fissures, mud volcanoes, "tidal wave" (sic) on the Colorado River, and heavy shaking were all reported by an exploring party sent to investigate the area by the San Francisco Examiner.

Other interesting findings have resulted from conversations with various resource personnel in Arizona. An 1887 newspaper article on archeological findings in Tempe reported that earthquakes had caused ancient Indian tribes to move out of the Salt River Valley in 1400 AD. Disputing this account, Dr. Emil Haury, archeologist at the University of Arizona, stated that the report was based on only one observation by the Hemenway expedition which took place in the late 1880's near Phoenix. The excavation of a human skeleton in 1887 at the site of the ancient village of Los Muertos revealed that a person had been killed by a falling wall. Several non-seismic reasons for such a happening could be postulated.

Dr. Haury also provided helpful information concerning a rockfall shown to him in 1938 by a Papago Indian who had witnessed the 1887 earthquake effects in the Coyote Mountains. Field investigations are currently in progress to document the actual location and extent of the reported debris slide caused by the earthquake.

A version of an Indian legend regarding an earthquake felt in the early 1880's in the San Pedro Valley was found with the aid of Mr. Ed Heylmun (an independent geological consultant) and Dr. Vance Haynes (geo-archeologist at the University of Arizona). According to a story told by Escanolea, a medicine man of Cochise's band, the earth shook and a loud rumbling noise was heard coming from the southwest: "Indians who were on the side of the Dragoon Mountains, overlooking the San Pedro Valley said that the whole earth split open from one side of the valley to the other, sending forth a blue smoke heavenward for a mile . . . " (Tevis, 1954). After a rain storm that lasted several days, "a crack in the earth about a mile long, five feet wide, and from ten to twenty feet deep, remained" (Tevis, 1954).

Another event, on August 19, 1912 near Flagstaff, reportedly caused an earthcrack north of the San Francisco volcanic peaks (BSSA, 1912). William Breed and Katherine Bartlett of the Northern Arizona University Museum provided original newspaper accounts of the earthquake effects. A Navajo Indian reported an earthcrack several miles long in the vicinity of Lockett Tanks and Tuba City resulting from the shock. Preserved evidence of this phenomenon has not yet been investigated.

The above examples illustrate the type of resources and detective methods used to gather historical earthquake data. Information collected this year will be analyzed. Significant reports will be included in an earthquake catalog which will list events by date and location. Revised intensity ratings and magnitude values will also be assigned to events based on any additional evidence. It is hoped that partial funding for the continuation of earthquake hazards research will be provided by the U.S. Nuclear Regulatory Commission and the U.S. Geological Survey.

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Earthquake References:

Bulletin of the Seismological Society of America (BSSA), quarterly volumes, Seismic Notes section.

Colton Collection: MS 207-107-3, v. 29, n. 39, p. 1, col. 4, Museum of Northern Arizona Manuscript Collection.

Fugro, Inc., 1975, Preliminary Safety Analysis Report for Palo Verde Nuclear Generating Station Units 1, 2, and 3.

Hamblin, W.K., 1975, The Earth's Dynamic Systems: Burgess Publishing Co., Minneapolis, Mn.

National Oceanic and Atmospheric Association (NOAA) and formerly the U.S. Coast and Geodetic Survey, annual volumes, Earthquake History of the United States.

Perkins, D.M., 1974, Seismic Risk Maps: Earthquake Information Bulletin, Nov-Dec, v. 6, n. 6.

Sbar, M.L., 1977, Bureau receives earthquake-recording equipment: Fieldnotes, v. 7, n. 3-4.

Staunton, W.F., 1918, Effects of an earthquake in a mine in Tombstone, Arizona: BSSA, v. 8, p. 26.

Steeples, D.W., 1978, Earthquakes: educational pamphlet published by the Kansas Geological Survey, Lawrence, K.S.

Sturgul, J.R. and Irwin, T.D., 1971, Earthquake history of Arizona, 1850-1966: Arizona Geological Society Digest, v. 9.

Sumner, J.R., 1977, The Sonora earthquake of 1887: BSSA, v. 67, n. 4, pp. 1219-1223.

Sumner, J.S., 1976, Earthquakes in Arizona: Fieldnotes, v. 6, n. 1.

Tevis, J.H., 1954, Arizona in the 50's: University of New Mexico Press, Albuquerque.

Townley, S.D., and Allen, M.W., 1939, Earthquakes in Arizona – 1850 to 1928: BSSA, v. 29, p. 293-97.

U.S. Bureau of Reclamation, 1976, Earthquakes in the Yuma Area-Yuma County, Arizona and Imperial County, California 1776-1976: Special Report, July.

THE GREAT SOUTHWESTERN ARIZONA OVERTHRUST OIL AND GAS PLAY

by Stanley B. Keith

The following article, assembled by Bureau Geologist, Stanley B. Keith, is an attempt to interpret the geological thinking behind the largest petroleum lease play in Arizona's history. However, the interpretive diagrams in this article are not necessarily representative of the geological opinions held by geologists at the Geological Survey Branch.

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Friday, February 16, 1979 – dateline Tucson: "The City of Tucson has refused to give a Denver-based exploration firm a lease to look for oil and gas on the city's eastside. The land in question is being considered for a new golf course. The Anschutz Corporation already has some eight million acres of land in Arizona under oil and gas leases." This was the text from a news item broadcast on the KOLD Channel 13 evening news in Tucson. Within a few months the Anschutz Corporation will announce the first of what are expected to be many test wells for oil and gas (petroleum) in southern Arizona's Basin and Range Country according to Floyd C. Moulton, a geologist with Anschutz.

The lease play is by far the largest oil and gas (petroleum) exploration play in the history of Arizona. Figure 1 shows the area within the state where most of the lease action on public lands is taking place. "All of the state's public acreage available for oil and gas leasing (4.1 million acres) is gone," said Moulton. Anschutz has also leased the maximum allowable federal public acreage they can obtain in the state, some 260,000 acres. Anschutz's total Arizona land holdings are about 4.3 million acres, a figure considerably less than that cited in the KOLD report. Other federal land is available for petroleum exploration, and speculation on it by competitors is being vigorously waged. "As of January 19th, 3.5 million federal acres of public BLM managed land was under lease or applied for," said officials of the BLM office in Phoenix. According to Moulton, more than one-half of all available federal land has been leased. The heaviest lease activity is in the Kingman region of Mohave County and in the Cochise County area. Officials at the BLM regional office in Safford have been swamped with lease applications.

Like the land play, petroleum exploration activity is intense and unprecedented in scale. Five-thousand line miles of seismic geophysical surveys over the next two years are planned to help define the nature of Arizona's crust as well as to delineate drilling targets. Organizations reported to be participating in various group shoots (cooperative seismic surveys) are Anschutz Corporation, Phillips Petroleum, Gulf Oil, Atlantic Richfield, Texaco, Mobile, Kansas-Nebraska, Canadien, AMOCO, and Exxon. Areas which may possibly be drilled within the year by Anschutz are in the vicinity of the Palomas Plain about 50 km west-north-west of Gila Bend and various areas in southern Arizona southeast of Tucson. The first drill tests are expected to be in the 15-16,000 foot range according to Moulton. The deepest drill hole in Arizona to date is Exxon's 12,500 footer drilled in 1972 just southeast of Tucson. "Other kinds of exploratory surveys are also being conducted," said Moulton. Anschutz and its partner, Natural Gas Pipeline, a subsidiary company of Peoples Oil and Gas, a Chicago-based utility firm, are prepared to drill "dozens of test wells over the next several years," said Moulton. Anschutz sold Natural Gas Pipeline half of the action in its lease play for a reported amount near 20 million dollars. It may be fairly stated that this new interest in Arizona's petroleum possibilities was generated by the Anschutz people. Who and what is Anschutz, and why are they looking for oil and gas in the southwestern Arizona Basin and Range Province?

The oil and gas intrigue began in 1975, not in Arizona, but in northern Utah and southwestern Wyoming. Then, American Quasar discovered petroleum in an area near the southwest corner of Wyoming, an area from which AMOCO had walked away. Shortly thereafter, AMOCO contacted Anschutz about a joint seismic shoot in similar structures north of the American Quasar discovery at Anschutz Ranch. Subsequent drilling encountered a major gas discovery. AMOCO and Anschutz each now share one-half interest in the field. Ironically, Anschutz had originally bought the property strictly for cattle raising some 13 or 14 years before. However, Anschutz has been in both the oil and cattle raising business for decades. Serendipity strikes again?

Reaction by the rest of the petroleum community was swift; and, today, at least 14 oil and gas fields have been announced in a NNE-trending zone which extends from Pineview, Utah to Evanston, Wyoming. Proven reserves of natural gas at Anschutz Ranch currently totals in the 150-200 billion cubic foot range. Forty to 60 trillion cubic feet of natural gas are now being

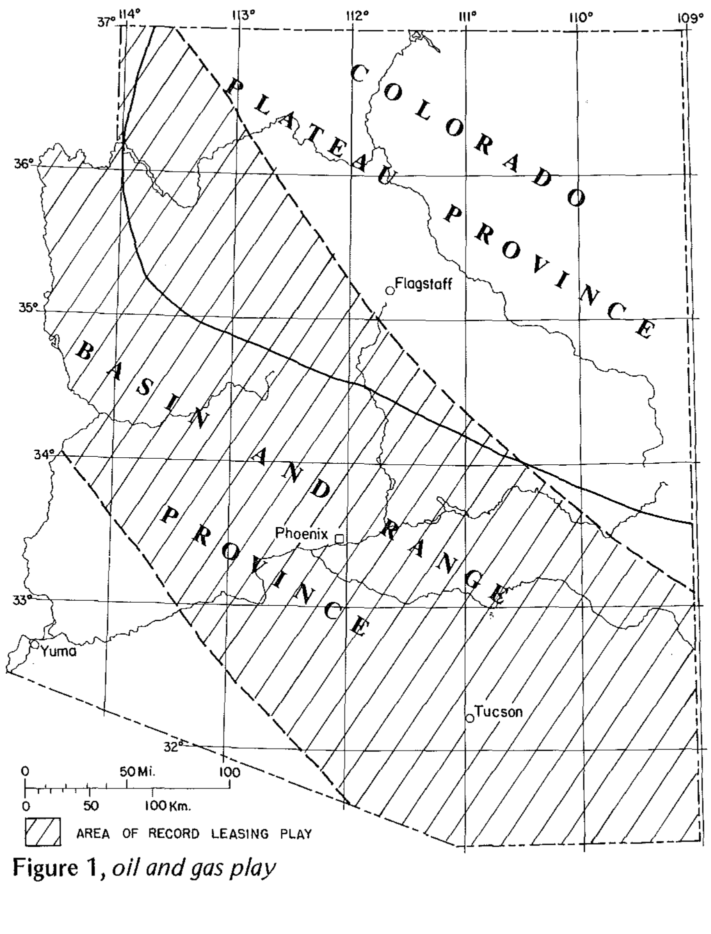


Figure 1, *oil and gas play*

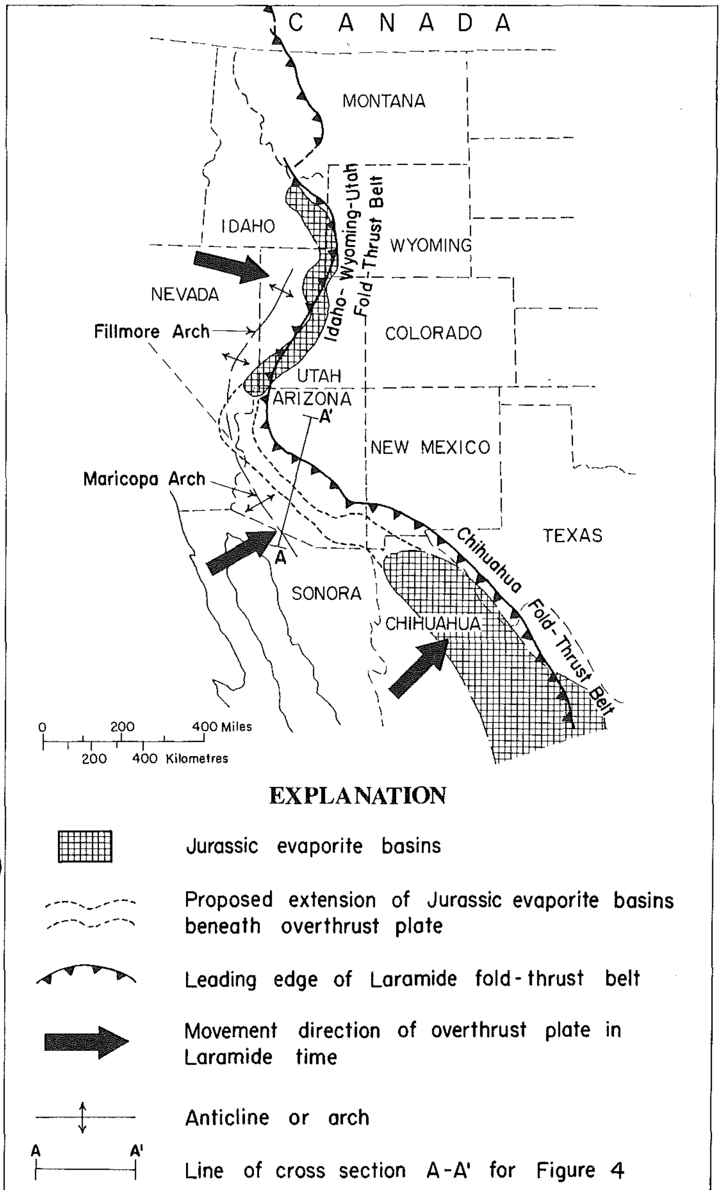


Figure 2, *oil and gas play*

discussed as potential reserves from a north-south trending belt in southeastern Idaho, western Wyoming and northern Utah. According to Moulton, a vice-president of Chevron was impressed enough to remark that these discoveries are the most significant since the Prudhoe Bay discovery on the Alaska north slope.

The impact of the overthrust natural gas discoveries on the nation's oil and gas picture is considerable. The U.S. Geological Survey estimate of undiscovered, recoverable natural gas resources (as of December 31, 1974) in the entire Idaho-western Wyoming-Nevada-Arizona-southwestern Colorado-western New Mexico region was 6 to 25 trillion cubic feet of natural gas (Miller et al., 1975). The potential natural gas reserves now being talked about from the southeast Idaho-western Wyoming-northern Utah portion alone is 1.75 to 10 times the U.S. Geological Survey estimate for the larger region. The U.S. Geological Survey estimate of undiscovered natural gas resources for the entire onshore and offshore conterminous United States was 286 to 529 trillion cubic feet. The southeast Idaho-western Wyoming-northern Utah discoveries alone constitute about 8 to 20% of the entire undiscovered potential natural gas reserve of the conterminous U.S!

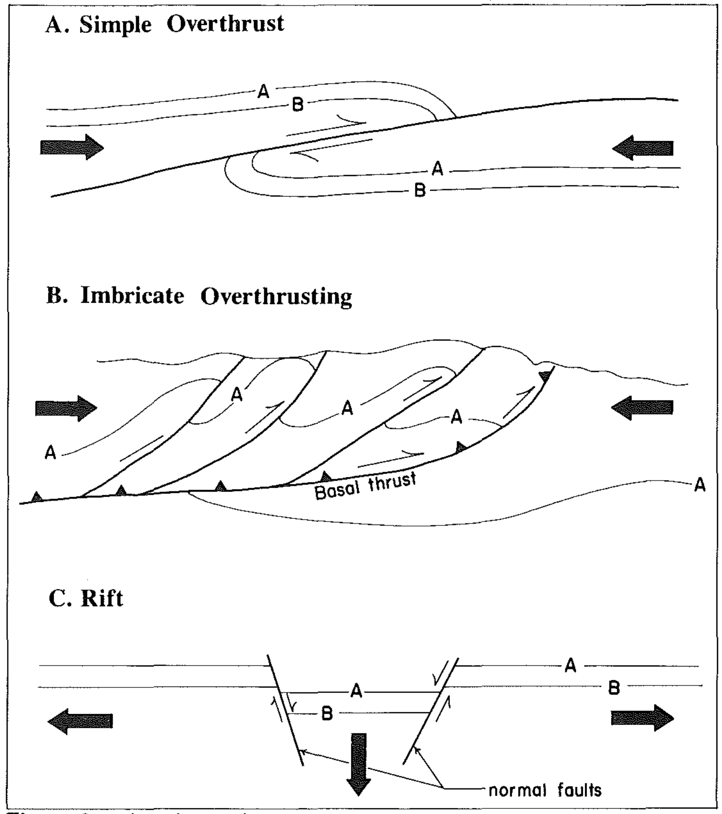


Figure 3, *oil and gas play*

In geological parlance, the newly discovered petroleum fields occur in sedimentary rocks of Jurassic age (see time scale in Figure 4) within the Idaho-Wyoming-Utah overthrust belt (Figure 2). The petroleum source is thought to have been organic matter associated with Triassic and Jurassic marine-shales. These source rocks may have resembled the well known younger oil shales of northeastern Utah and northwest Colorado. During Cretaceous time, 139 m.y. to 70 m.y. ago, the Idaho-Wyoming-Utah region was beset by overthrust faulting produced by end-on compression of the earth's outer crustal layer. Some idealized styles of overthrust faulting known to be present within the Cordilleran overthrust belt portrayed on Figure 2 are depicted in Figure 3. Figure 3A is a simple overthrust. In this structure, successively older marker beds labeled 'A' and 'B' have been shoved over themselves along a low-angle fault. Because older rocks have been shoved over younger rocks, the fault is termed a low-angle reverse or thrust fault. The aspect of having been shoved and pushed by crustal shortening gives rise to the term overthrust. The block or layer that was pushed over the underlying rocks is known as the upper plate. Figure 3B shows a more complicated system of plates thought to be common in overthrust belts. Shortening has taken place on several thrust fault slices which have stacked up one on another. These thrust faults commonly flatten downward into a basal or sole thrust. The piled-up aspect of the layers and thrusts above a basal thrust has a decidedly imbricated aspect; hence the term 'imbricate overthrusting".

One can see from the diagrams that the repetition of layers produced by overthrusting produces a thickening of the earth's crust in the overthrusted zone. This zone is commonly 100 to 200 km wide and parallels the mountain-belt which they undergird. Organic matter which may have been originally present in an overthrusted region could be converted into petroleum fluids by increased heat and pressure resulting from burial under the overthrusted plates. The oil people call this process

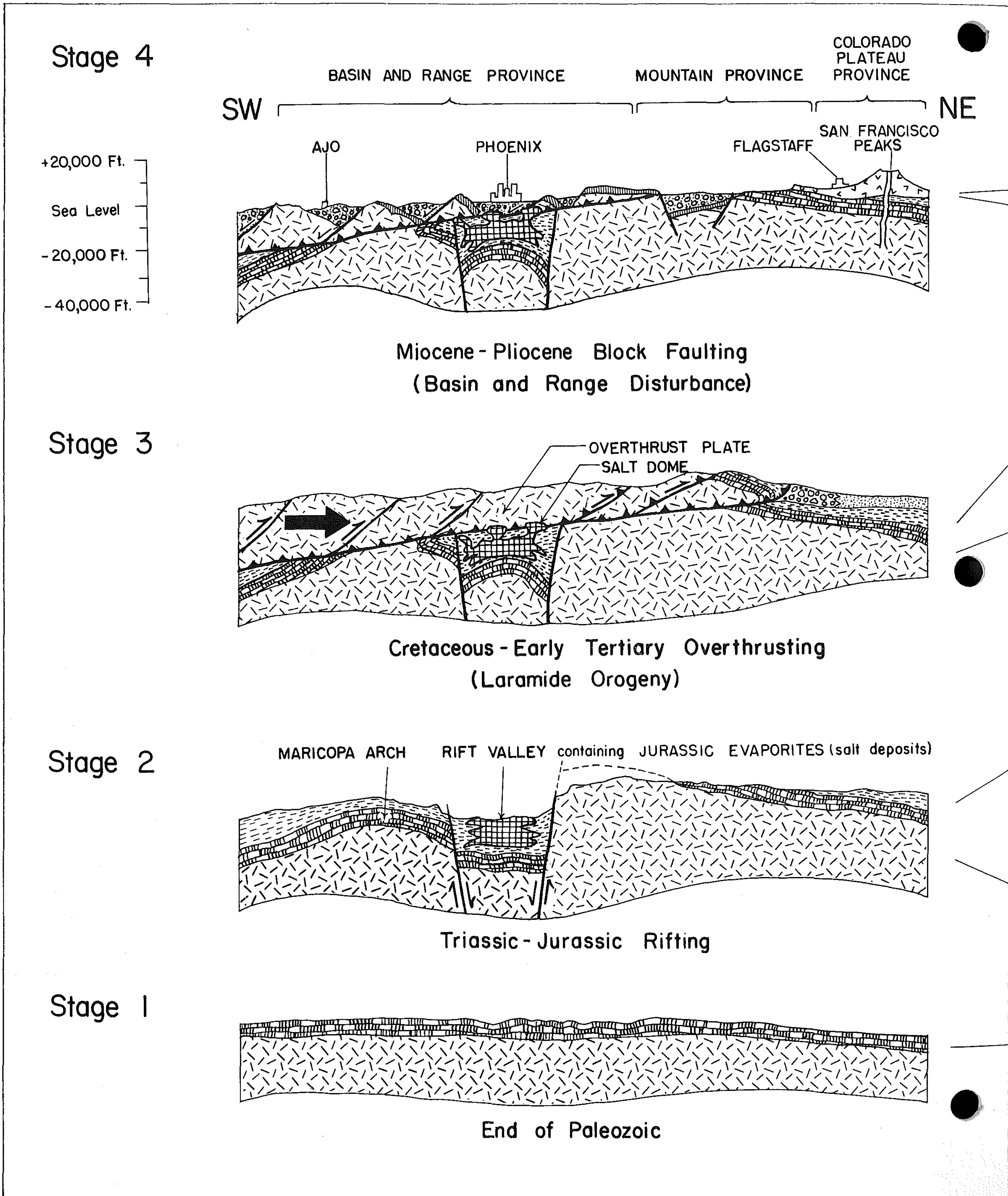
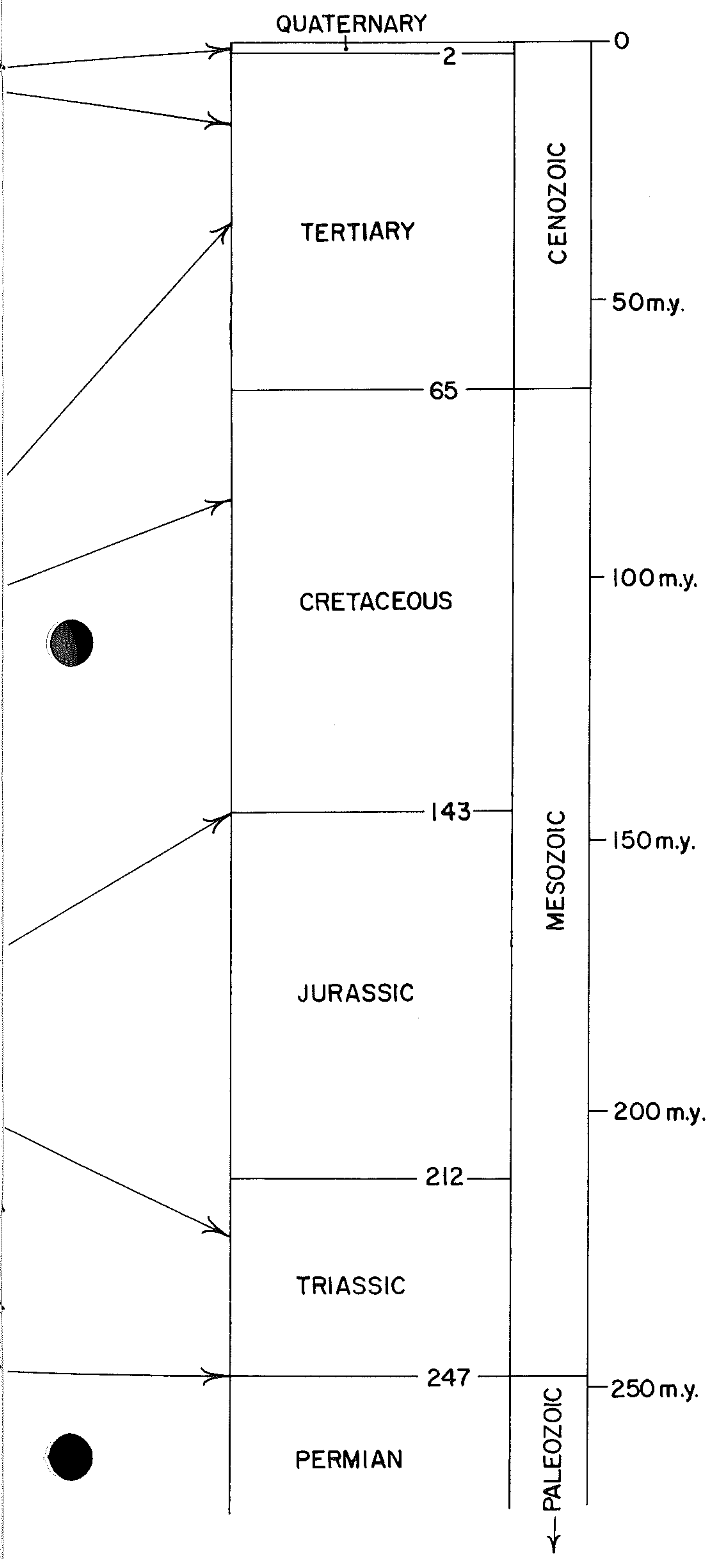


Figure 4, *oil and gas play* Interpretative cross-sections illustrating the Anschutz concept for geologic development of south w

GEOLOGIC TIME SCALE



EXPLANATION

BASIN FILL GRAVEL AND VOLCANICS
(12 m.y. ago to today)

MID TO LATE TERTIARY VOLCANICS AND SEDIMENTARY
(26 m.y ago to 12 m.y. ago)

MID-CRETACEOUS CONGLOMERATES AND SANDSTONES
(90 to 70 m.y. ago)

MESOZOIC ROCKS
(220 to 145 m.y ago)

PALEOZOIC ROCKS
(550 to 250 m.y. ago)

OLDER PRECAMBRIAN CRYSTALLINE ROCKS
(1800 to 1400 m.y. ago)

western Arizona

maturation. Areas of matured rocks commonly occur buried under overthrusts or thick sedimentary piles. Most of the world's petroleum has been formed through some natural maturation process. It is interesting that our technology is still trying to economically duplicate the natural maturation process for the Utah-Colorado oil shale region.

During overthrusting, any petroleum fluids tend to migrate to reservoirs of lower pressure and temperature, which commonly are in the upper plate(s) of the overthrust. A good reservoir rock in the Utah-Wyoming region is the porous and permeable Jurassic Nugget Sandstone, an analog of the Navajo Sandstone which forms the spectacular cliffs in Zion National Park, southwestern Utah. Arizona's most productive petroleum reservoir rock is a Tertiary igneous rock on the Navajo Indian Reservation in the extreme northeastern part of the state. The oil is thought to have arrived there from nearby source rocks of Pennsylvanian age.

The basis of the Anschutz oil and gas play in Arizona is based on the idea that the Cordilleran overthrust belt extends southward from Utah into northwest Arizona and, thence, southeastward through Arizona into New Mexico to connect with the well-documented fold-thrust belt in Chihuahua, Mexico (figure 2). Large petroleum reserves have been known for years in the Veracrúz part of the overthrust belt south of Chihuahua. In fact, it is this part of Mexico which contains much of Mexico's newly found oil wealth and provides Mexico with increasing political muscle. Realization of enlarged oil potential in the overthrust belt has led Mexican oil explorationists northward to the Monterey and Monclovia area where PEMEX has recently (October, 1978) announced six trillion feet of gas from reservoirs in twelve structures in Jurassic rocks in the upper plate of an overthrust structural setting. They still have 78 more structures to drill! This gas was probably part of the Mexican/American natural gas transaction recently vetoed by the Department of Energy.

The Anschutz overthrust concept for southwestern Arizona is depicted in Figure 4. By the end of Paleozoic time, about 250 m.y. ago, a thin 3 km section of sedimentary rocks had accumulated on top of a thick mass of Precambrian continental crust which formed largely between 1800 and 1400 m.y. ago (Stage 1 on Figure 4). After Paleozoic time, a major Triassic-Jurassic rifting event linked evaporite basins in Utah with those in the Gulf of Mexico (Stage 2). The rift basin was formed as portions of the earth's crust pulled away from one another (Figure 3C). The intervening area subsided under gravitational forces along normal faults and was flooded by marine waters which poured from the newly formed Gulf of Mexico.

Organic materials in swampy backwater areas and algal mats in tidal areas provided hydrocarbon sources for later petroleum formation. Although such environments are locally represented in the thin, older Paleozoic sedimentary rocks they may have been more widely developed in the Jurassic-Triassic rocks, according to the Anschutz concept. The petroleum maturation event began nearly 90 m.y. ago with the onset of overthrusting during Laramide orogeny (Stage 3). From 90 m.y. to perhaps as recently as 20 m.y. ago, a great overthrust plate composed mainly of Older Precambrian crystalline rocks was emplaced over the position of the earlier Mesozoic age rift basin. Indeed, it completely covered the rift basin site and still conceals it today, according to the Anschutz model. The overthrust mass is thought to have been derived from perhaps 200 km or more to the southwest. Very possibly, it was of imbricate nature (Figure 3B). Heat and pressure from burial of the evaporite basin and associated organic rich sediments by the upper plate, converted low grade hydrocarbons into petroleum fluids that migrated to reservoir areas of low pressure. These might have been open spaces or fracture zones near salt domes or arched permeable reservoir rocks associated with the layered rock sequences which had become folded during the overthrusting.

The great overthrust event was followed or accompanied in its late stages by uplift of the Colorado Plateau in northern Arizona. Erosion accompanying the uplift removed the upper plate of the overthrust from its former position along the southwestern part of the present Colorado Plateau. The uplift may have been achieved along high-angle reverse faults on which the Plateau was pushed up and to the southwest. Subsequent to or during the uplift event, southern Arizona, including the southwest margin of the Colorado Plateau Province, was buried to one kilometer or more by great sheets of volcanic rocks of explosive origin commonly referred to as ignimbrites. During this time local sedimentary basins formed and filled with non-marine conglomerates and sands which locally interfingered with the volcanics. The events just described preceded Stage 4, Figure 4.

Since 15 m.y. ago, and certainly after 12 m.y. ago, the contemporary Basin and Range Province started to form during a major episode of crustal break-up which was achieved by normal faulting. As for the Anschutz concept, the majority of these normal faults, which are high angle at the present-day physiographic surface, flatten with depth and merge with the basal thrust of the former overthrust (Stage 4 on Figure 4). Many of these faults formed along the older reverse faults which comprise the imbricate upper plate of the old thrust fault. Thus, faults, which once had reverse motion, later experienced normal motion. The Anschutz geometric hypothesis for Basin and Range faulting has important implications for oil exploration in that it means that depths to the basal thrust in the valleys are equal to those in the mountain blocks. Oil possibilities are expected to occur at approximately equal depths in both basins and ranges.

The Anschutz overthrust concept was presented to Arizona-based geologists during several meetings in the fall of 1978, and reactions were extremely "guarded," said Edgar McCullough, head of the Geosciences Department at the University of Arizona. Particularly vigorous controversy exists about structural geometries effected during Laramide orogeny. Virtually every geometric model has been proposed. Whether the Cordilleran overthrust belt can be in fact linked-up through Arizona is a topic of very lively debate.

Despite the controversy, no one can categorically deny the Anschutz overthrust model, which, like the exploration play, is unprecedented in its dimensions. The drill is the ultimate test of all models; and, certainly, the anticipated Anschutz drilling will test those models more than ever before. While the Anschutz play must be regarded as frontier exploration, the potential payoff is enormous and could dwarf the initial grubstake. Arizona geology has never been more exiciting.

Editorial Comment

It is interesting to note that local leaders in the Tucson area appear to be more interested in a future golf course than the possible development of new energy sources in the rapidly growing southwest. With today's technology, it is very easy to build a golf course above a petroleum field of great depths and thereby have one's cake and eat it too.

REFERENCE:

Miller, B.M., Thomsen, H.L., Dolton, G.L., Coury, A.B., Hendricks, T.A., Lennartz, F.E., Powers, R.B., Sable, E.G., and Varnes, K.L., 1975, Geological estimates of undiscovered recoverable oil and gas resources in the United States: Geological Survey Circular 725, 78 p.

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WRI 77-35: Maps Showing Ground-Water Conditions in the Northern Part of the Chinle Area, Apache County, Arizona-1976: by G.W. Levings and D.C. Farrar. (U.S.G.S. Federal Bldg., 301 West Congress St., Tucson, Arizona 85701.)

WRI 77-41: Maps Showing Ground-Water Conditions in the Southern Part of the Black Mesa Area, Navajo, Apache, and Coconino Counties, Arizona-1976: by G.W. Levings and C.D. Farrar. (U.S.G.S. Federal Bldg., 301 West Congress St., Tucson, Arizona 85701.)

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WRI 77-113: Map Showing Ground-Water Conditions in the Lower Verde River Area, Maricopa, Yavapai, and Gila Counties, Arizona-1976: by P.P. Ross. (U.S.G.S. Federal Bldg., 301 West Congress St., Tucson, Arizona 85701; U.S.G.S. Library, 345 Middlefield Rd., Menlo Park, California 94025.)

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PB 250-377: Hydrothermal Convection Systems in the States of Alaska, Arizona, California, Colorado, Hawaii, Idaho, Montana, Nevada, New Mexico, Oregon, Utah, Washington, and Wyoming: by J.L. Renner and others. 1976 352 p. $10.50.

PB 259-326/AS-Water Resources Data for Arizona-Water Year 1975: 452 p. $12.

PB 274-306: Water Resources Data for Arizona-Water Year 1976. 1977. 689 p. $19.

BUREAU WELCOMES DR. LARRY D. FELLOWS AS STATE GEOLOGIST

The Bureau of Geology and Mineral Technology is pleased to welcome Dr. Larry D. Fellows as the first officially designated State Geologist of the State of Arizona and Assistant Director of the Bureau with the responsibility for the Geological Survey Branch. Dr. Fellows comes to Arizona from the position of Assistant State Geologist for the State of Missouri, Department of Natural Resources, Division of Geology and Land Survey, a position which he has held since 1971. Dr. Fellows is a graduate of Iowa State University (B.S., 1955), University of Michigan (A.M., 1957), and University of Wisconsin (Ph.D., 1963). Prior to joining the Missouri Survey, he was Assistant Professor of Geology at Southwest Missouri State University and a field geologist with Carter Oil Co.

Dr. Fellows comes to Arizona with a strong background in state geological survey organization and management. He is familiar with the operation of state governments and the role of a geological survey in serving these governments. Missouri, like Arizona, is a major hard rock mining state. As such, Dr. Fellows is experienced with the problems of mineral resource exploration, development and production, and has contributed greatly to his organization's role in assisting the Missouri mining industry. He is a Certified Professional Geologist and is a fellow of the Geological Society of America.

Dr. Fellows, his lovely wife, Jeanne, and three children, Brian, Graham and Kyle, will make their home in Tucson beginning in June.

Dr. Fellows

Ground Water Levels Studied

A report summarizing recent hydrologic data for the state has been prepared by the U.S. Geological Survey, in cooperation with the Arizona Water Commission. The report, "Annual Summary of Ground-Water Conditions in Arizona, Spring 1977 to Spring 1978", includes a map on potential well production, change in water levels of selected wells and boundaries of currently defined ground water levels in the state.

Copies of the annual study may be obtained without charge from the U.S. Geological Survey, 301 W. Congress, 5th Floor, Tucson, AZ 85701 (792-6671).

DID YOU KNOW?

According to the U.S.G.S. data, nearly 5.5 million acre feet of ground water was withdrawn from Arizona during 1977. This means that Arizonans used enough H_2O to cover a football field with a column of water 1,042 miles high!

Publication Announcement

In the December 1978 issue of Fieldnotes, we announced the availability of the first two maps (*Geology and Landforms*) in an environmental series of 10 maps, titled "Environmental Geology of the McDowell Mountains Area, Maricopa County, Arizona". Now, maps (3) *Land Slopes* and (4) *Caliche* may be ordered. Whereas the first two maps sold as a unit in one envelope for $2.50, remaining maps in the series will come in separate envelopes for $1.50 each. When this series of maps is completed this year, the set will be priced at $10.00. Mail order requests are to be accompanied by a $.25 postage and handling fee, and payment by check or money order.

The Bureau is currently filling orders for the first envelope, containing the *Geology* and *Landforms* maps, as well as envelopes #2 and #3, which contain the *Land Slopes* and *Caliche* maps, respectively. The map scale is 1:24,000.

FIELDNOTES
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