

# FIELDNOTES

## From The State Of Arizona Bureau Of Geology And Mineral Technology

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### THE DAY THE MOUNTAIN SMOKED

It was the spring of 1887 when the desert was dry and clear and cloudless, the earth began to shudder and tremblers lasted more than one hour. There was a sound of rattling and crashing rocks as loose little hills, splintering as they bounded down waterline from Miller Canyon into the old Charleston was smashed and ever ran in the same direction.

Ramsey Peak in the Huachuca Mountains and trees crashed down in Mustang Hills is a mountain peak. The defile through horseback simply. A freighter freight wagon opened and rocks fell.

Quake Jostles Prescott Region; Rain, Snow Pay Visit To State

Arizona Territory Shaken By Severe Earthquake; Bulletins From Various Towns Give Description Of Tremors

Bisbee and Benson Reporters Tell of Falling Rocks and Buildings

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Earth Tremor Felt In Arizona Cities

tremors from an earthquake in the Arizona Territory which measured 5 on the Richter scale were felt in Tucson and other cities.

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TOWNS OF GRANADOS, OPUTO, SONORA, HUASABAS, DEMOLISHED

Courier Carries the News to Nacozari: Agua Prieta to Send Aid to Region.

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# EARTHQUAKES

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

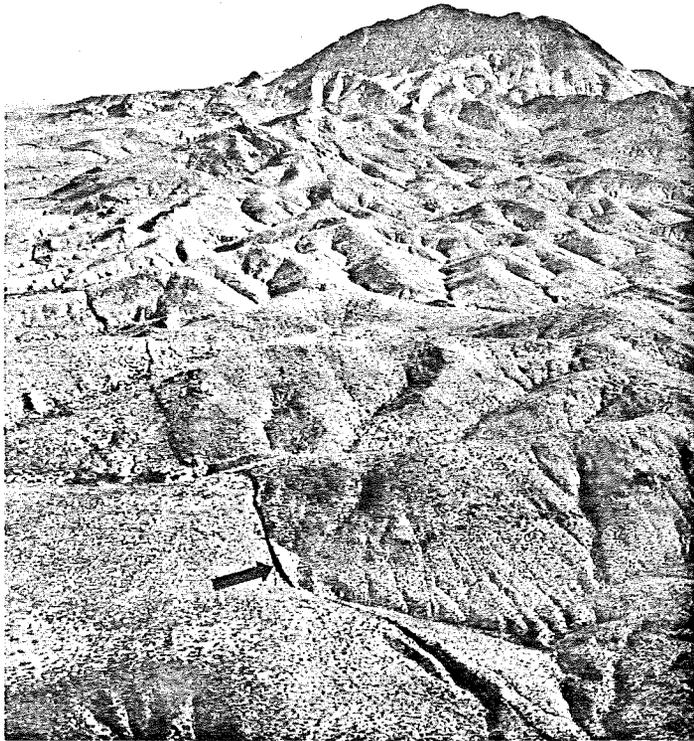


Fig. 1 Aerial view of 1887 fault scarp in Sonora. Fault begins roughly 5 miles south of Arizona border and continues 35 miles to Colonia Moreles in the San Bernardino Valley (photo courtesy of Pete Kresan).



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.

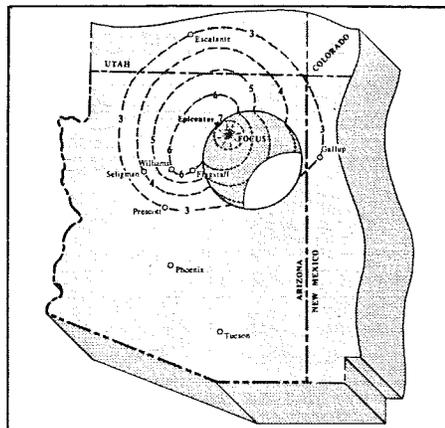
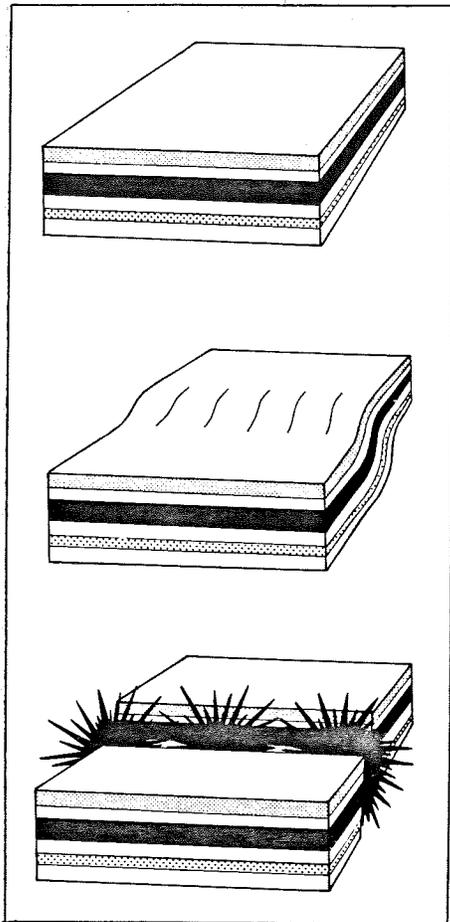
Seismologists have developed methods for measuring earthquake characteristics. Two scales are commonly used today: The Richter magnitude and the Modified Mercalli Intensity scales (Fig. 5). The former is a measurement of the quantity of energy released during an earthquake at the point of breakage. It 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
V	Felt by most people; some breakage of dishes, windows, and plaster; disturbance of tall objects	3.5
VI	Felt by all, many frightened and run outdoors; falling plaster and chimneys, damage small	4
VII	Everybody runs outdoors; damage to buildings varies depending on quality of construction; noticed by drivers of automobiles	4.5
VIII	Panel walls thrown out of frames; fall of walls, monuments, chimneys; sand and mud ejected; drivers of autos disturbed	5
IX	Buildings shifted off foundations, cracked, thrown out of plumb; ground cracked; underground pipes broken	5.5
X	Most masonry and frame structures destroyed; ground cracked, rails bent, landslides	6
XI	Few structures remain standing; bridges destroyed, fissures in ground, pipes broken, landslides, rails bent	6.5
XII	Damage total; waves seen on ground surface, lines of sight and level distorted, objects thrown up into air	7
		7.5
		8

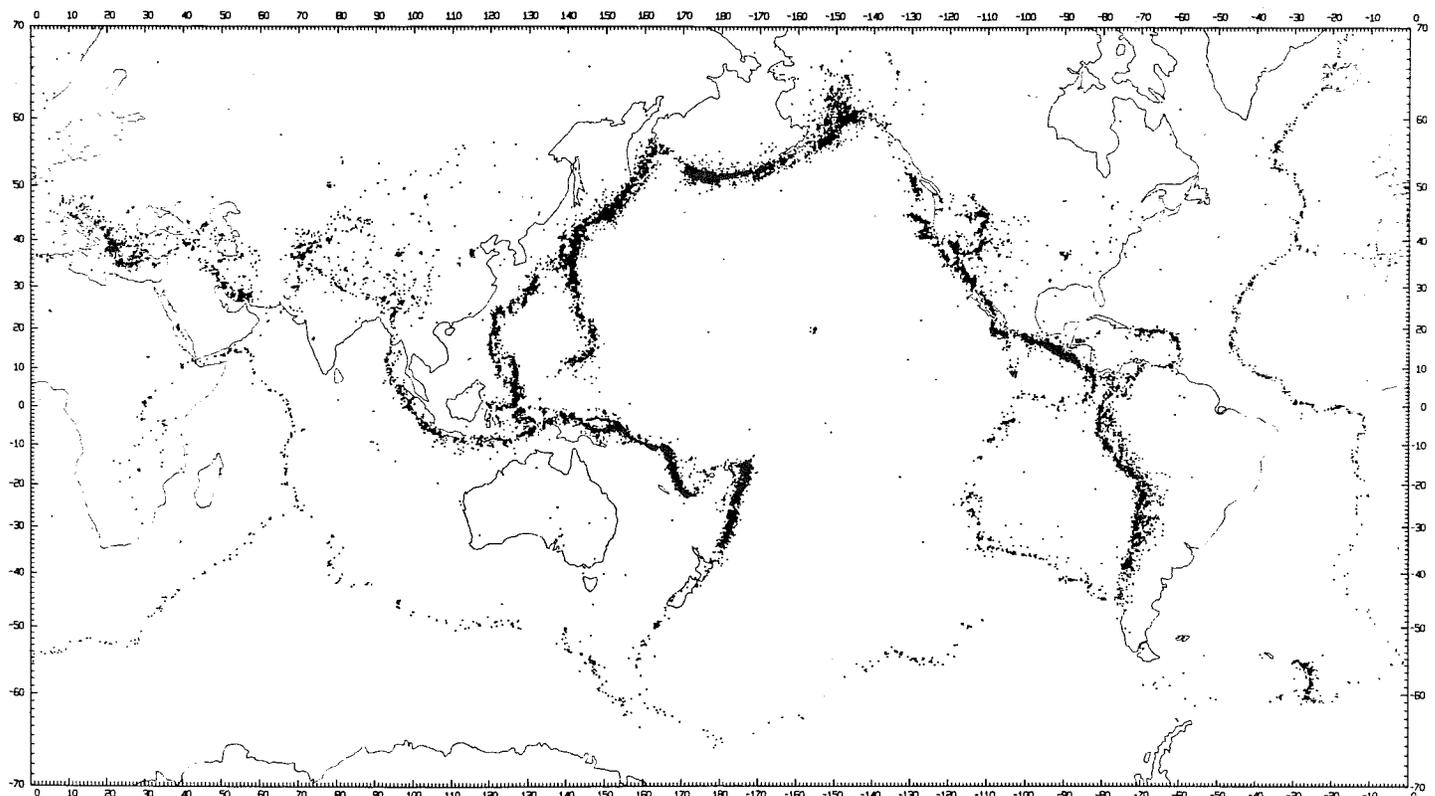


Fig. 6 World seismicity patterns. Earthquakes during the period 1960-1967 have been plotted (from Sbar, 1977).

## 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 volcanoes 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

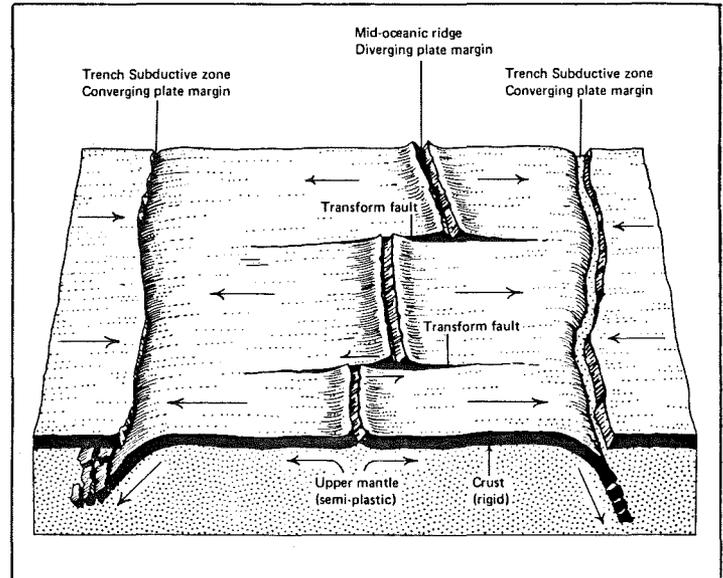


Fig. 7 Diagram showing converging, diverging and transform boundaries of the crustal plates (modified from Hamblin, 1975).

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.

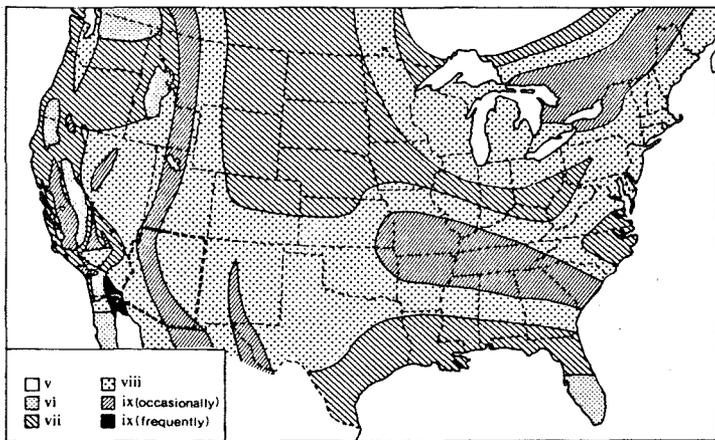
### Can Seismic Risk Be Determined?

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.

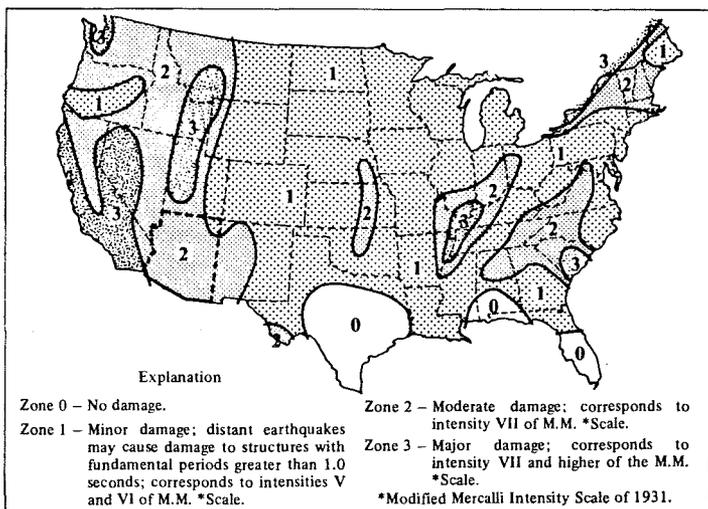
### Why Are Seismic Risk Studies Needed In Arizona?

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

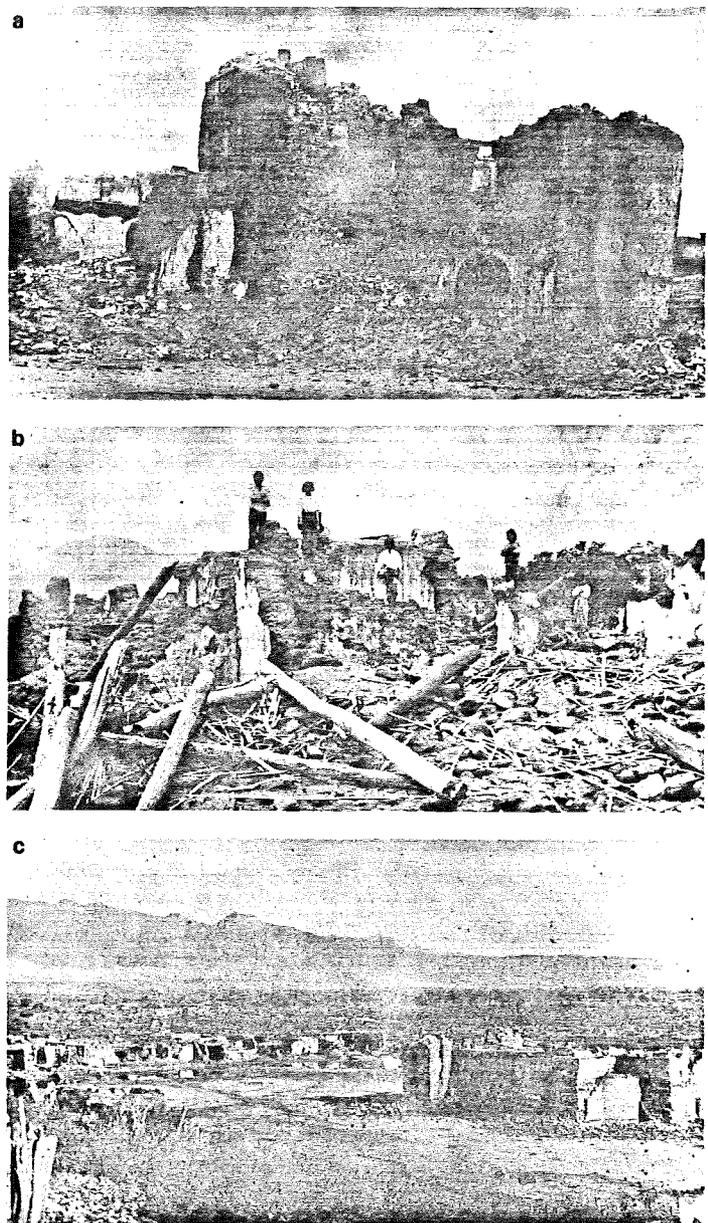


Fig. 9 Photos of building damage in Bavispe, Sonora during the May 3, 1887 earthquake: a) Church where 42 people were killed when the roof collapsed. Adobe walls were 24 inches thick. The building itself was 200 years old at the time of devastation; b) Destroyed home in Bavispe; c) View of village of 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).

(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

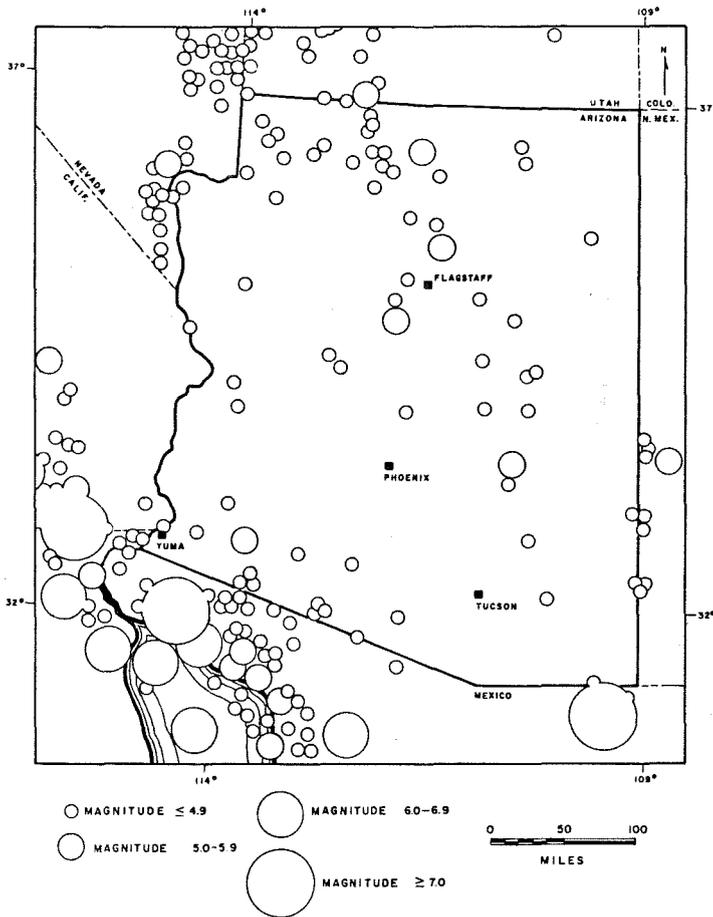


Fig. 10 Map of earthquake epicenters and sizes in or near Arizona (from Sumner, 1976).

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

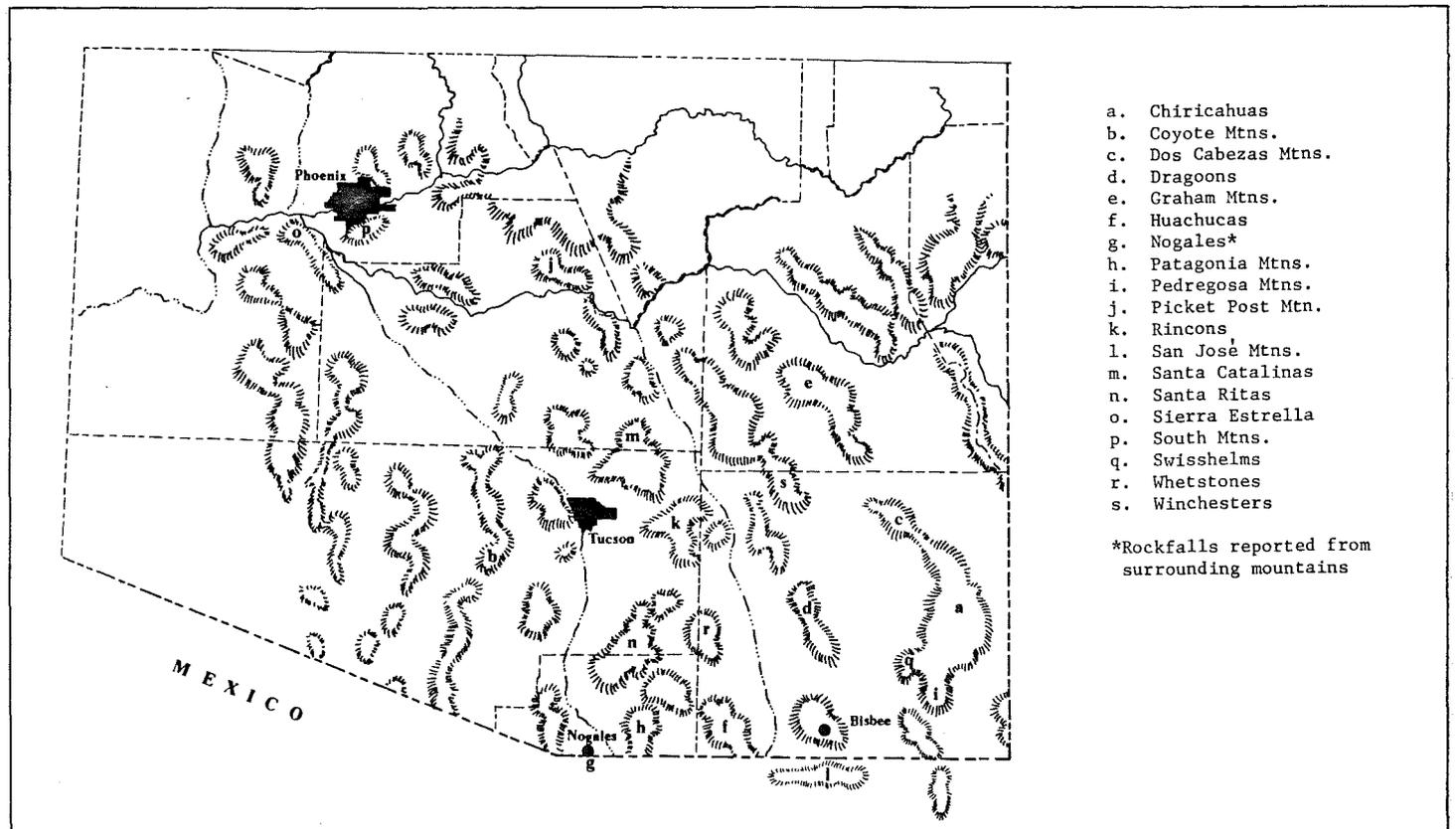
Damage from earthquakes generally results from secondary effects at the ground surface. Landslides, liquefaction, tsunamis and earth fissures all are examples of potentially-harmful phenomena triggered by the motion of seismic waves as they travel to or across the earth's surface. In Arizona, possible 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



- a. Chiricahuas
- b. Coyote Mtns.
- c. Dos Cabezas Mtns.
- d. Dragoons
- e. Graham Mtns.
- f. Huachuclas
- g. Nogales\*
- h. Patagonia Mtns.
- i. Pedregosa Mtns.
- j. Picket Post Mtn.
- k. Rincons
- l. San José Mtns.
- m. Santa Catalinas
- n. Santa Ritas
- o. Sierra Estrella
- p. South Mtns.
- q. Swisshelms
- r. Whetstones
- s. Winchesters

\*Rockfalls reported from surrounding mountains

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

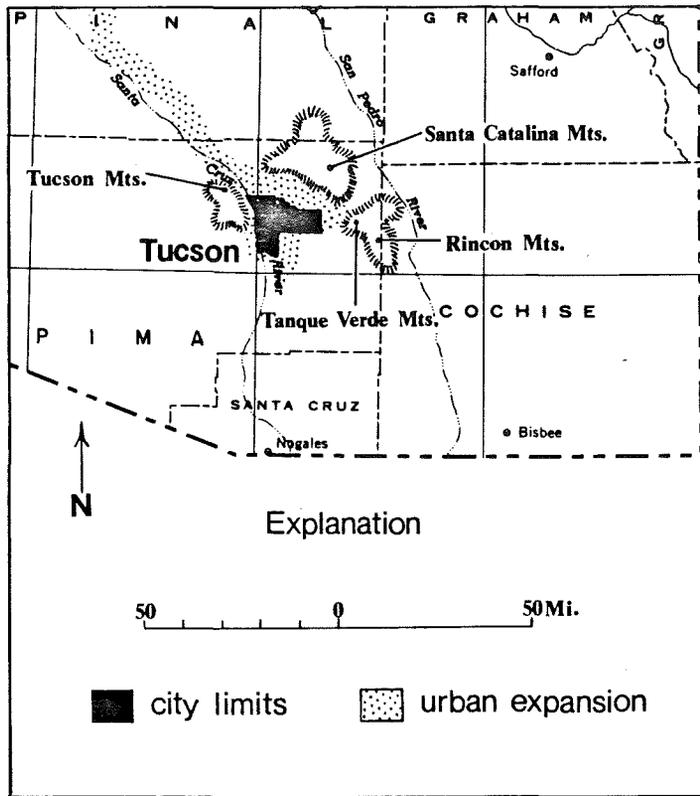


Fig. 2 Urban expansion encroaching upon the mountains surrounding Tucson.

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

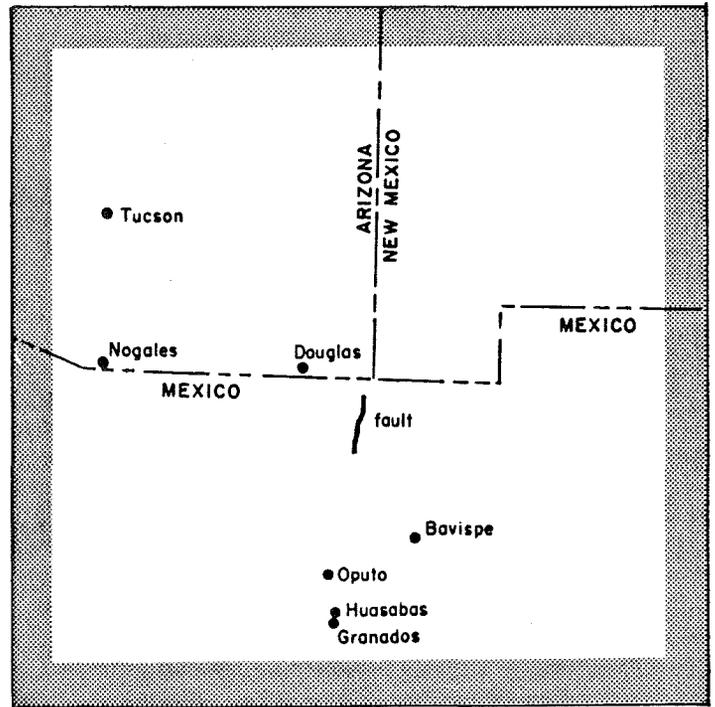


Fig. 1 Twelve people were reportedly killed in Huasabas and many homes destroyed in the village on December 19, 1923. Heavy building damage was also reported from Granados as a result of the earthquake.

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: sparsity 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 volcanoes, 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 Heylman (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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