FIELDNOTES
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# SUBSIDENCE-FISSURES AND FAULTS
## In Arizona

By H. Wesley Peirce

### Introduction

Quietly, hundreds – perhaps thousands – of square miles of Arizona's land surface is being lowered by *subsidence.* Peripheral fracturing in the form of earth fissures and cracks is relatively widespread and common. These ongoing, somewhat insidious phenomena have an important influence not only on already-completed engineering structures but on planning for future land use. Implications for the future suggest an increasing entanglement between Arizona's population growth and areas susceptible to subsidence and related hazards.

The Picacho–Casa Grande region of Pinal County is the most intensively-investigated subsidence, fissure and "fault" area in Arizona. Laney, R. L. (U.S. Geological Survey), Raymond, R. H. (U.S. Bureau of Reclamation) and Winikka, C.C. (Arizona Department of Transportation) developed and compiled two important maps, with some text and survey profiles. These items, published in 1978 (see references), are available free of charge from the Arizona Water Commission*. This work impressively demonstrates the magnitude of the problem as evidenced in Maricopa, Pinal and Pima Counties (Figure 1).

The U.S. Geological Survey has undertaken special studies under the direction of geologist Tom L. Holzer. Tom is studying subsidence and fissuring throughout the southwest from Texas to California. He is especially interested in: (1) controls and causal factors that attend the nine-mile-long Picacho fissure zone which occurs between the Picacho Basin and the Picacho Mountains on the east, and (2) learning the extent to which the prediction of future fissuring in susceptible areas of the U.S. might be possible.

### General Geologic Setting

The Basin and Range Province, constituting the southwestern half of Arizona, is characterized by broad–to–narrow valleys that alternate with large–to–small mountain ranges. It is the geologic setting of this province (where over 90% of Arizona's population resides) that is conducive to the processes of subsidence, fissuring and "faulting" (Figure 1).

Beneath the valleys are thick sequences of relatively–young, soft sedimentary materials capable of storing large amounts of groundwater within a thousand feet of the surface. This water, combined with rich soils and a long growing season, is supportive of extensive agricultural development (about 95% of Arizona's irrigated acreage is in the southwestern half of the State). However, the valleys or basins terminate laterally against the hard rock ranges. This interface between valley and range constitutes a major geologic and land-use discontinuity that cannot be overemphasized (Vuich and Peirce, 1973).

Water can be viewed as a geologic material, a part of the overall foundation inherited from the geologic continuum that predates the coming of technological man. Under the surface, it is called groundwater, and it occupies pore spaces in sediments – soft sediments in the case of southern Arizona basins. If the water is removed there is a natural tendency for the finer-grained, soft sediment to become more compact, to occupy less space. The amount of compaction or shrinkage is controlled largely by the volume of sediment dewatered by pumping.

### Subsidence

*Subsidence* is a lowering of the earth's surface caused by processes acting below the land surface. Although subsidence is a result of the interaction of natural earth forces, it can also be man-induced by the large-scale removal of underground fluids, such as, petroleum or water.

Land level changes can be quantified only by repeated, high quality survey measurements at established points. Most likely much of the subsidence in Arizona remains undocumented due to the absence of a network of appropriately-placed survey stations that can be periodically monitored. Fortunately, there are a few adequately- surveyed and monitored regions in Arizona that can

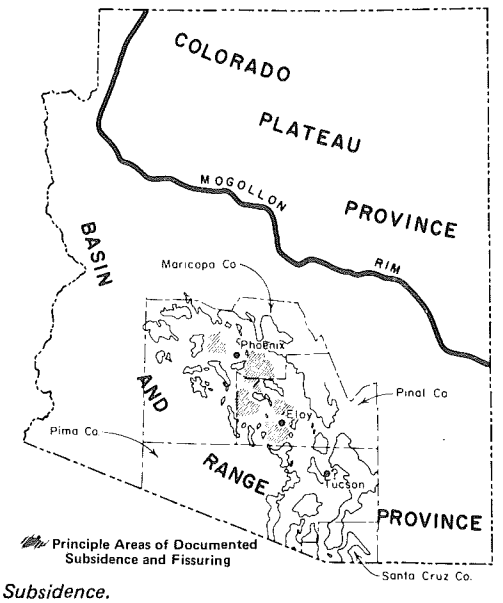



**Figure 1,** ***Subsidence.***

**Arizona Water Commission, 222 N. Central Avenue, Phoenix, Arizona.*

serve as important 'case histories', illustrating subsidence.

In Arizona, in the Basin and Range country, large quantities of water are pumped from the ground. As an example, in 1977 alone, enough water was pumped to cover a football field with a water column over 1,000 miles in height. Groundwater is an integral part of the natural foundation of the earth; when it is removed in large quantities, dewatered earth materials may shrink or compact, thereby lowering the earth's surface (Fig. 2B). How large might this effect be?

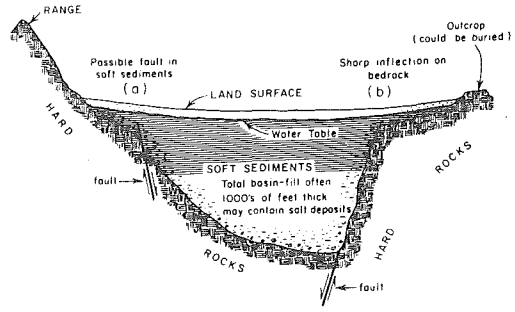
In the Picacho Basin, centered about the town of Eloy, an area of at least 120 square miles has subsided between 7.0 and 12.5 feet since 1952. The maximum average subsidence rate has been calculated at 0.5 feet per year. Importantly, the groundwater decline in this region ranges from about 200 to just over 300 feet for the period 1923-1977 (Laney and others, 1978). Near Stanfield, 12-15 miles west of Casa Grande, an area of about 7 square miles has subsided between 8.0 and 12.0 feet, with groundwater declines up to 450 feet.

These are the regions that represent the best *known* elevational lowering of the land surface in Arizona. Away from this area of relatively-intense monitoring, survey data rapidly decrease. Because there is a direct relationship between water decline and subsidence, decline data are essential for evaluating subsidence potential. Again, the actual demonstration of subsidence requires repeated land-level surveys.

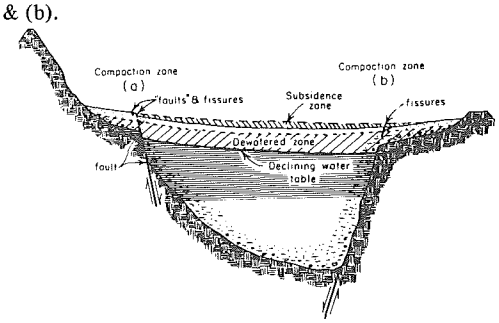
Information is skimpy for the larger Phoenix region. Schumann (1974) documents some subsidence and Laney and others (1978) show important water decline data and the positions of known fissures. Groundwater decline of up to 300 feet beneath portions of Scottsdale and the Arizona Canal suggest a subsidence potential for this region. A potential for fissuring also exists where the dewatered sediments are interrupted laterally along the east side of a north-south Camelback Mountain-Papago Buttes bedrock trend.

Recently, a lady from Pennsylvania, with a retirement house under construction in Arizona, contacted State officials about an item that was printed in a Pennsylvania newspaper. The emphasis of the article was that Arizona was "sinking". Quite naturally she wrote to learn more about what was going on that might affect her future here. Her new home is being constructed in the Sun City area of Phoenix. Utilizing the available data, we note that groundwater decline beneath Sun City and environs is between 200 and 300 feet. This alone is enough to invoke a probability of some subsidence. A close look at data suggestive of the subsurface condition indicates a major northwest-trending irregularity, probably a change from thick valley fill on the southwest to thin valley fill and shallow bedrock on the northeast. This change takes place approximately beneath State Highway 93 from south of Glendale northward to Sun City and beyond. A conservative interpretation would suggest that there is some potential for surface fissuring. Whether subsidence and/or fissuring will ever become a serious problem in the Sun City region cannot be presently determined.

Tucson's water supply is exclusively from groundwater, much of which is pumped from within the same valley as the city is located. Groundwater decline has passed 100 feet in some areas and is increasing with time. Officials concerned with this problem consider that the City may be on the threshold of subsidence. A cooperative program between the City of Tucson and the U.S. Geological Survey is being initiated. Emphasis will be placed on: (1) measuring water level trends, (2) placing compaction recorders in selected wells, (3) remeasuring points of elevation that were accurately established in the past, and (4) adding new leveling stations. Here is a chance to study the effects of groundwater removal in a basin before it has undergone the readjustment process. It has been suggested elsewhere that the potential longer-range subsidence problem in Tucson could be reduced by taking a larger percentage of water from an undeveloped basin to the west.




A. Predevelopment setting with theoretical subsurface marginal conditions (a) & (b).




B. Post-development response to groundwater withdrawal & decline showing dewatering, subsidence & local differential compaction of soft sediments near basin margins (a) & (b).

**Figure 2,** ***Subsidence.***

## Fissures and "Faults"

*Earth fissures,* as used here refers to relatively-lengthy cracks that develop at the surface in soft soils or sediments. An initial crack, inconspicuous one day, may become a gaping fissure the next. It is reported that the first fissure in the Picacho region was observed on Sept. 12, 1927, after a heavy thunderstorm the previous night (Leonard, 1929). Initially, this fissure (not a part of the present Picacho fissure zone) was about 1,200 feet in length. At the time, this new phenomenon stimulated much discussion and speculation as to its origin.

Fissures, thought to be related to water withdrawal, occur in Cochise, Pinal and Maricopa counties. There are at least 15-fissure areas in the latter two counties, involving over 100 individual fissures.

The Picacho fissure zone, about 9 miles in length, has received the most attention and publicity. Holzer and others (1979) suggest that this zone is unique in Arizona because it consistently reflects vertical offset ranging up to 1.5 feet. The west or valley side is down relative to the east or mountain side. The sharp step or scarp reflects a different kind of failure than the more common pull-apart, or tension fissure. As a consequence of its fault-like appearance, they refer to this feature as the *Picacho fault.* However, Holzer and colleagues are quick to point out that this is not the kind of fault that produces earthquakes. Rather, the "fault" occurred after 1961, as a result of groundwater extraction combined with poorly-understood subsurface controls. The lack of documented earthquakes in this region since 1961 supports their contention. Any claims to local seismicity are believed to stem from mistaking atmospherically-induced shocks (Peirce, 1975; Shakel, 1977; see Dubois, this issue) for earth-generated vibrations (Yerkes and Castle, 1976).

A recent newspaper article, entitled, "Earthquake Fault Line at Picacho," included the statement: "Geologists have discovered a possibly-active *earthquake fault line* (italics ours) caused by groundwater pumping north of Tucson" (Tucson Citizen, Nov. 16, 1969). This terminology, while unfortunate, exemplifies the difficulty of conveying scientific ideas to the public.

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*Subsidence* continued

An interesting debate emerges: Because the Picacho feature looks like a fault, but is not a source of earthquakes, should it be called a fault? In this case it is the Bureau's intention to refrain from the unqualified use of *fault.* To the extent possible, we will not consider as faults the various land slippages that might leave scarps or steps attributed to processes not accompanied by earthquakes. In the case of the Picacho phenomena, it is very important to recognize the fact of vertical offset. It is important because the damage potential to man-made structures is greater than that associated with the more commonly-observed, "simple" tension or pull-apart fissures. Consequently, we will refer to the *Picacho fault* of Holzer and others as the *Picacho "fault".* The Picacho fissure or "fault" zone passes across I-10 and beneath the bed of the Southern Pacific Railroad. Because of this, periodic repairs are made to both transportation arteries. Recent resurfacing has, at least temporarily, subdued the visible (down-to-the-west) offset.

Additional work by Holzer (1978, subsequent to Holzer and others, 1979) was designed to investigate the nature of the subsurface controls. Holzer speculated that a buried fault might be cutting an older portion of the soft sediments – a fault that does not reach the surface. Holzer's model suggests that this preexistent fault influences groundwater–dewatering patterns, which in turn permit the stress build-up that is responsible for the Picacho surface "fault". This concept is depicted in Figure 2 B(a).

Fissures, in general, are believed to form above certain buried hardrock irregularities that control soft sediment thicknesses along basin margins (Fig 2 A(a). These irregularities frequently can be delineated by appropriate geophysical techniques. Various studies are underway in connection with alternative aqueduct alignments for the delivery of Central Arizona Project (CAP) water to the Tucson area.

Subsidence and related phenomena are examples of cause and effect in that an act of unbalancing begets an act of readjustment. In this case a great deal of geologic time was involved in establishing the original condition of balance, whereas the unbalancing and readjustment processes occurred in less than one generation of humankind. The act of unbalancing continues unabated; therefore a logical conclusion is that readjustment must follow.

Through FIELDNOTES, we will attempt to provide pertinent new information about subsidence-related matters in Arizona as it arises.

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*Symposium* continued

Heidrick suggested this phenomena implied fracture systems of local derivation which were radially or concentrically superimposed on those of more regional extent. The greater fracture abundance may represent the dynamic consequence of hydraulic fracturing in the vicinity of fluid-saturated plutons, where fluid pressure in the pluton exceeded the pressure exerted on the system by overlying rocks above the fluid-saturated pluton. The higher fracture density would correspondingly increase permeability and allow greater amounts of base metal deposition per unit volume.

The last talk by Stan Keith, of the Bureau of Geology and Mineral Technology, was perhaps the broadest in scope. In his view, porphyry copper deposits are part of a metallogenic spectrum that is sensitive to chemistry of time-related igneous rocks. This is supported by systematic variations of metal ratios in economic sulfide systems with alkalinity (sodium and potassium content) of time-related igneous rocks. Sulfide systems associated with time-related calcic magmas are zinc and copper-rich while those associated with more alkalic rocks (particularly potassic alkalic rocks) are more lead, molybdenum and gold rich (see Fieldnotes, v. 8, no. 1–2, p. 12, Figure 6). Similar variation of metal ratios in igneous rocks at trace metal concentration levels with the alkalinity of those igneous rocks also supports the above idea. Because alkalinity (specifically potassium content) of an igneous rock suite can be systematically related to subduction zone geometries, it follows that metals may be similarly related to subduction-derived magmas.

The occurrence of the porphyry copper cluster in southeast Arizona, according to Keith, was a fortunate coincidence involving a number of phenomena. The phenomena included: 1) pre-existing WNW to EW-trending, deep-seated basement flaws of the Texas zone, 2) subduction, 3) increased convergence rates nearly 80 m.y. ago which induced flattening of the underthrusting oceanic slab, 4) the shallowing slab produced calc-alkalic copper-bearing magmatism under the region from 70 to 50 m.y. ago, 5) the increased strain rates and a changing stress-field caused the Texas Zone flaws to move in left shear (see Fieldnotes vol. 8, no. 1–2, p. 12, Figure 5B), and 6) the left shear movement created deep-seated ENE-trending tensional zones that reached deep into the earth's upper crust and facilitated upward passage of magmas and volatiles, ultimately forming the porphyry copper deposits (Figure 4). Alone, each of the above phenomena were necessary but not sufficient for the occurrence of the prophyry copper cluster; in combination, however, they were sufficient. And, as a result, the region's inhabitants find themselves with a vital copper resource, the largest in the world.

Each of the introductory speakers emphasized different sets of working hypotheses to explain areas highlighted in John Guilbert's introduction. With respect to zoning, virtually all of the speakers stressed the emerging role of time in the alteration process. It is increasingly apparent that phyllic alteration (quartz-sericite-pyrite) consistently postdates earlier

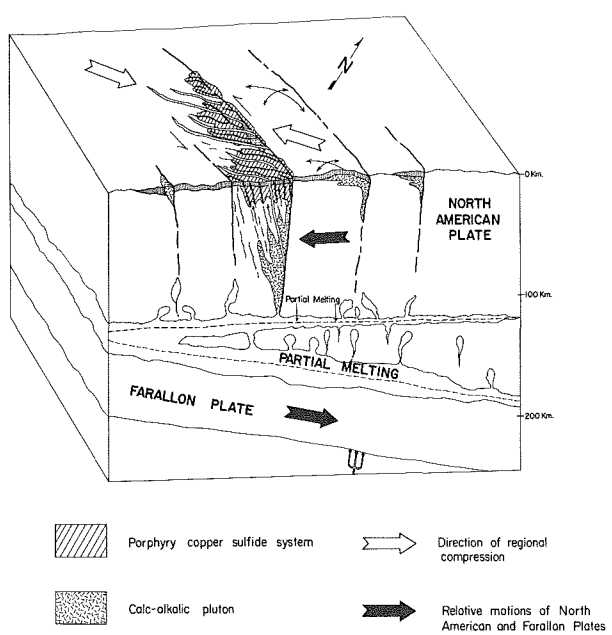


**Figure 3,** ***Symposium.*** Plate tectonic setting of SE Arizona prophyry copper deposits (75-50 m.y. ago).