STRUCTURAL RECONNAISSANCE OF THE SOUTHWEST PORPHYRY COPPER PROVINCE

by

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Abstract

Faults have been recently mapped on a number of quadrangles of various sizes in Arizona and New Mexico, using photogeologic techniques applied to high-altitude and hyperaltitude imagery. The results suggest that faults are much more numerous and interconnected and more commonly recurrent than indicated by most published maps and that fault systems are more variable than generally recognized, strikes being variously sinuous, arcuate, circular, and irregular as well as relatively straight.

Mapping Techniques and Data Display

The reconnaissance mapping being reported essentially involves mapping of faults from synoptic views presented on available AMS high-altitude photographs (e.g., Fig. 1) and Landsat MSS Band-5, B&W imagery (e.g., Fig. 2). Both of these types of imagery were used on some quadrangles.

Observational techniques applied have evolved from geologic studies on high-altitude photography by the investigator over a period of two decades, based on ground-level mapping over a period of three decades. Apparently, the now-obvious geologic advantages of synoptic views were first recognized in an Arizona Geological Society paper (Mitcham, 1959). Fault observations are plotted by inspection onto USGS topographic base maps, variously 8.5-minute, 15-minute, and 1 x 2-degree quadrangles.

The reconnaissance has involved fault mapping of 27 quadrangles (24 within the Southwest porphyry copper province and 3 on adjoining portions of the Colorado Plateau) during the past five years, but only two quadrangles are reproduced for this paper because of proprietary considerations. As illustrated in Figures 1 and 2, an attempt is made to express order of magnitude of fault movement by weight of line. Solid lines designate indicated faults and dashed lines inferred faults. Both maps have been sample field checked; that is, field checking has been accomplished for only several selected key areas on each map.

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Fault Density

A perusal of the 27 newly mapped quadrangles suggests that, generally, fault density (in terms of miles of fault trace per square mile) greatly exceeds that indicated by published maps. This should be no surprise to those who have conducted detailed geologic mapping within mining districts where numerous faults not detected on the undisturbed surface are readily revealed by exposures in underground workings.

Measured average fault densities within selected quadrangles are listed in Table 1. These are considered to be minimum figures because more intensive mapping would probably increase mapped fault density for each quadrangle.

Some of the variations in fault density in the selected tabulation are due to quadrangle scale; that is, fault details are mapped with greater facility at larger scales. The Santa Rita quadrangle is a special case, as explained under a subsequent heading, and this accounts for the rather high fault density on the published map of this quadrangle.

Considering the quadrangles mapped during this reconnaissance as a sample and allowing for extrapolation into areas of thick valley fill, the density of fault trace for the portion of Arizona within the Southwest porphyry copper province would be at least 800 miles per 15-minute quadrangle and for the Colorado Plateau portion about 100 miles per 15-minute quadrangle. This suggests that the total length of fault trace in the state is at least 220,000 miles. Order of magnitude of the faults is not considered, of course, in arriv-

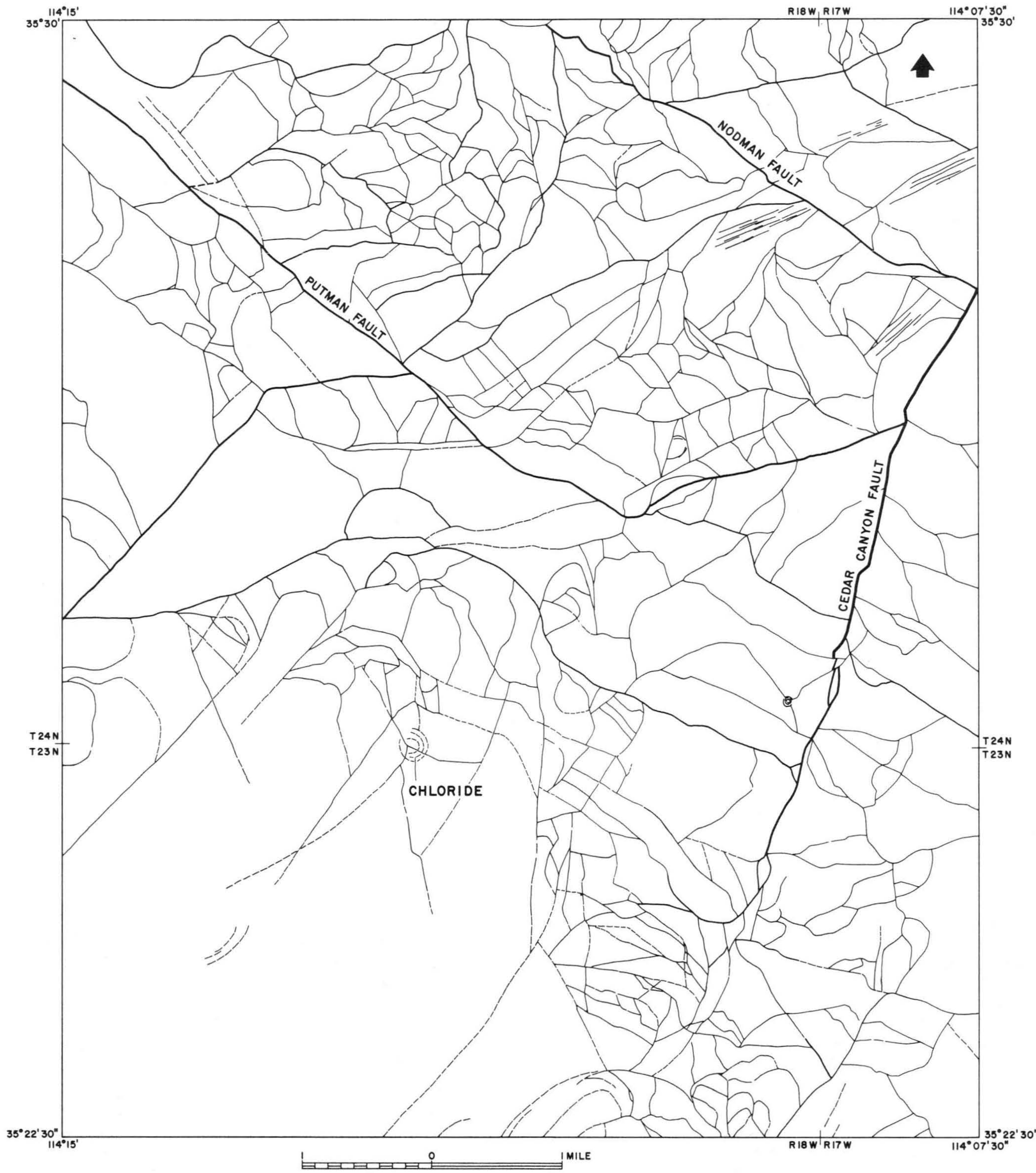

Fig. 1. Fault map, Chloride 7.5-minute quadrangle, Mohave County, Arizona. Mapping from AMS high-altitude photographs (Mitcham, 1974).

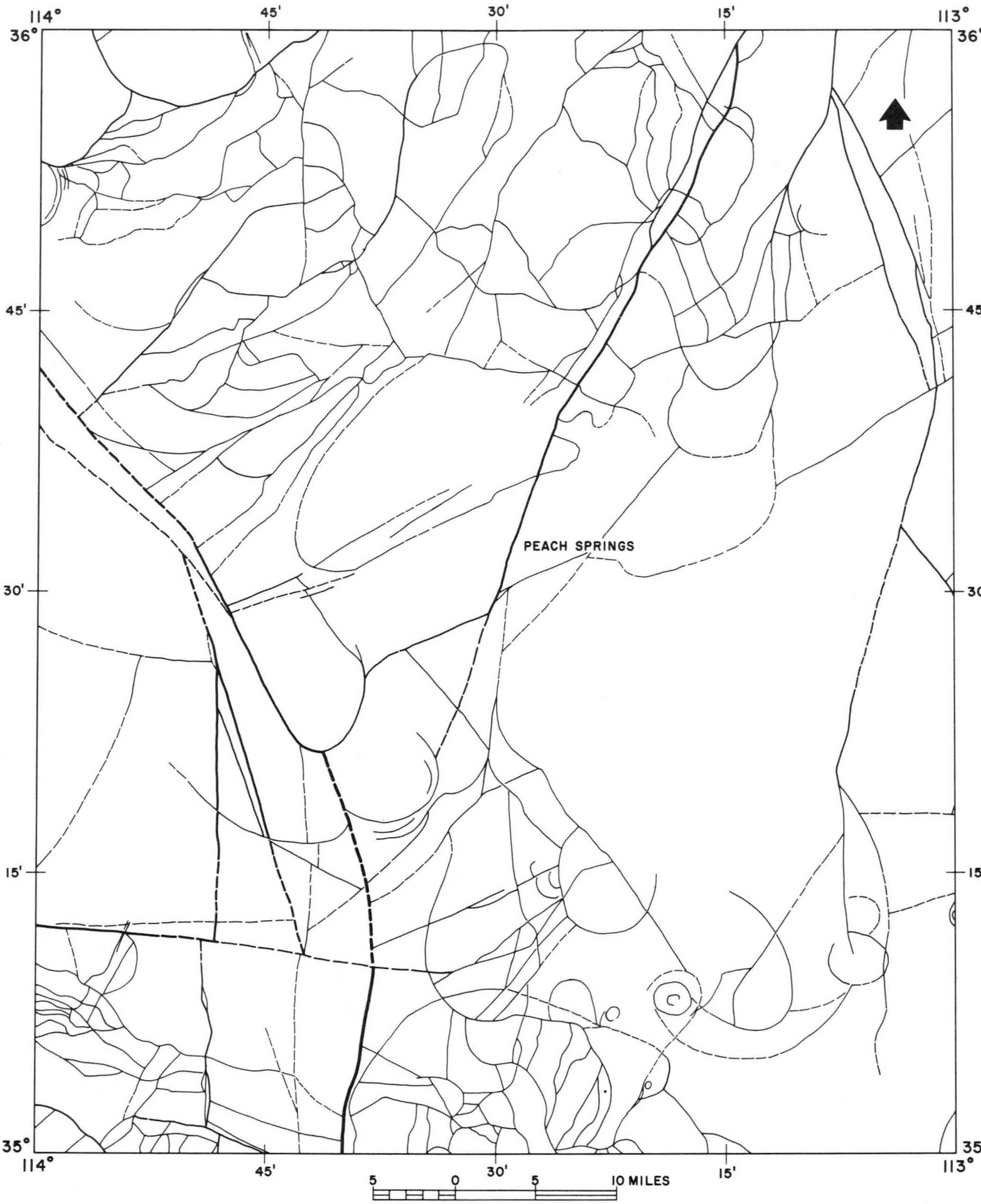

Fig. 2. Fault map, Peach Springs 1-degree quadrangle (west half Williams 1 x 2-degree quadrangle), Coconino, Mohave, and Yavapai Counties, Arizona. Reconnaissance mapping from Landsat MSS Band-5, B&W imagery (Mitcham, 1974).

Table 1. Fault densities for some quadrangles in the Southwest porphyry copper province

Quadrangle	Size	Fault Densities (miles of trace per square mile)	Source
Chloride, Arizona	7.5'	5.40	this reconnaissance
Clifton, Arizona	15'	3.31	this reconnaissance
Grand Canyon-Williams, Arizona	1x2°	0.38	this reconnaissance
Haunted Canyon, Arizona	7.5'	7.68	this reconnaissance
Haunted Canyon, Arizona	7.5'	1.90	Peterson (1960)
Santa Rita, New Mexico	7.5'	3.95	Jones and others (1967)

ing at this estimate. However, it may be of interest to note that the figure is about 100 times the total miles of fault trace displayed on a tectonic map of Arizona by Wilson and Moore (1959, Fig. 12).

Patterns in the Southwest Porphyry Copper Province Fault System

Faults in the Southwest porphyry copper province are intricately and almost completely interconnected (Figs. 1 and 2). Regardless of the strike length of a given fault (hundreds of feet or over 100 miles), at least one of its terminations intersects another fault. The entire province fault system can be described as one of hundreds of thousands of miles of strike length of intricately interconnected faults that form a pattern in which every compass bearing is represented and most are widely represented, even though strikes within certain sectors (e.g., north, northwest, or northeast) tend to be dominant in various portions of the province and over the entire province.

In pattern, strikes of faults in the province are variously sinuous, arcuate, circular, and irregular as well as relatively straight. The wide variation in strike patterns of faults is not particularly surprising. This investigator has observed the same phenomenon in other regions, for example, the Midcontinent region where he has mapped a number of quadrangles. Other investigators are reporting the same or a very similar phenomenon (e.g., Gedney and others (1976) in south-central Alaska, Peterson (1976) in Nebraska, Kansas, and Iowa, and Smith (1976) in Utah, Nevada, and southern California).

A number of explanations have been attempted for circular or arcuate fractures or faults, which are frequently concentric or overlapping. These vary from meteoric impact to collapse following doming as a result of igneous intrusion (Smith, 1976). True explanations probably vary from structure to structure. In any case, detailed field investigations are needed to better understand these types of structures.

Two possibilities worthy of consideration are that the arcuate or circular structures are the result of collapse into openings resulting from differential movements at fault intersections or at points of strike change (Mitcham, 1974) or that they are the roots of old caldera structures. The latter explanation could provide a solution to the problem of locating Laramide volcanic centers, thus meeting the challenge of a way to find Laramide porphyry coppers as suggested by Elston (1970).

Recurrent Nature of Faults

The investigator is inclined toward the concept that a large percentage of faults in the province (and elsewhere) are recurrent over extensive periods of time. In an exaggerated way, this can be expressed as "once a fault, always a fault." This inclination is based on theory, the observational record, and the frequent notation during this reconnaissance of common fault patterns in adjoining, sharply contrasting terranes.

Theoretical Considerations

Once a region or area has been subjected to differential stress resulting in strain to the point of significant rupture (fracturing), further differential stresses at that point in time tend to be released by movement on the fractures (i.e., by faulting). This original faulting will develop some additional faulting, referred to as second-order faulting, third-order faulting, etc. To some extent, this original period of differential stress (orogeny) should determine the positions of faults and fault patterns "for all time" because in subsequent periods differential stresses will tend to be released by movement on existing faults, even though the principal stress axes may be of substantially different orientations. This is to say that after the first major tectonic disturbance or orogeny in a region the region or area has become so anisotropic on a major scale that strain buildup to the point of significant new rupture is attained with difficulty.

The Observational Record

The concept that faults are commonly recurrent is difficult to test observationally because the data critical to this test are only rarely available due mainly to paucity of exposure of faults. Perhaps in some areas the faults are exposed but mapping has not been done in sufficient detail to allow adequate gathering of the critical data. In at least certain localities where adequate data critical to testing for the recurrent nature of faulting are available and have been carefully gathered faults have been established as being recurrent.

For example, evidence of recurrent movements on inherited Precambrian fault zones is prolific in the outcrops of the Grand Canyon (Huntoon, 1974), where a thick stratigraphic section with good marker beds is well exposed and where careful, rather detailed mapping has been done.

Another example worthy of citing is the Ground Hog-Ivanhoe-Lovers Lane fault, which is the major fault and probably the master mineralizer in the Santa Rita district, New Mexico. A total of five periods of movement are established (proved) for this fault, two being preore and three being postore (Lasky, 1936; Lasky and Hoagland, 1949; Jones, Hernon and Moore, 1967). Two additional periods of movement are likely; that is, the total periods of movement on this master fault may be as many as seven. The total net slip on the fault is about 3,500 feet, and the total throw is as much as 1,600 feet locally (Lasky and Hoagland, 1949). Many other faults in the district are also demonstrably recurrent (Jones and others, 1967).

The body of critical data on the Ground Hog-Ivanhoe-Lovers Lane fault, at least on the Ground Hog segment of it, is so comprehensive that the fault may rank as the most thoroughly measured fault in the world because of a rather unique set of favorable circumstances, geologic and otherwise.

The stratigraphic section within the Santa Rita district, although involving many systems and series from Precambrian through Tertiary, is relatively thin and contains many excellent marker beds. This section is inflated by a number of sills, some of which also provide good markers. Furthermore, the sequence of dikes and other intrusions, which represent perhaps as many as 29 time-distinct intrusive events, also assists in the relative dating of fault movements.

Added to the geologic circumstances that are highly favorable to readings on faults is the fact that geologic exposures are numerous in the various mine workings and in very numerous core holes within the Santa Rita district, including those of the Ground Hog mine. The key data base of the district is also greatly enhanced by perhaps as many as 100 man-years of geologic observations especially considering that a large number of the observers involved have been highly competent men. This investigator would mention Sam Lasky in particular as the keenest geologic observer he has ever had the good fortune to know.

The recurrent nature of faulting is almost the rule in the Santa Rita district. Considering that the tectonic history here is essentially the same as that of the Southwest porphyry copper province, would not this rule also apply to the province if a set of circumstances as favorable to critical data assembly in this district applied to the entire province?

Faults and Contrasting Terranes

Observations in a number of quadrangles mapped during this reconnaissance demonstrate that the strikes of faults and fault patterns do not usually change from one terrane to an adjoining contrasting terrane, for example, where an area of isoclinally folded Precambrian schist adjoins an area of flat-lying Miocene ash flows. Also, the tracing of established premineral faults from areas of older, premineral rocks into younger, postmineral rocks is frequently possible. Both of these observations suggest recurrent faulting.

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