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Wolfgang E. Elston

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VOLCANO-TECTONIC CONTROL OF ORE DEPOSITS, SOUTHWESTERN NEW MEXICO

by

WOLFGANG E. ELSTON

The University of New Mexico

INTRODUCTION

The article will attempt to defend the view that hypogene mineral deposits are related to volcano-tectonic structures and that methods of identifying volcano-tectonic structures would be a powerful exploration tool. For the sake of brevity, bibliographic references are kept to a minimum; the reader can refer to the index on the geologic map of New Mexico (Dane and Bachman, 1965). Most of the work shown as unpublished has now been published by the New Mexico Bureau of Mines and Mineral Resources and the U.S. Geological Survey. I would like to pay special tribute to the late Robert A. Zeller, who was always ready to give advice to the perplexed and whose views are reflected in the writings of many other workers.

A guidebook article can hardly do justice to so large (50,000 km^2 or 15,000 $miles^2$) and complicated an area. Only a few highlights (or author's prejudices, if you prefer) can be treated. The illustrations should be regarded as geologic caricatures, not accurate maps. Similarly, the text merely represents some broad-brush ideas, the result of work done since 1950. A factual summary of the mineral deposits of Hidalgo County was published in the Guidebook of the Society's 16th Field Conference (Elston, 1965); the detailed documentation still awaits publication. The speculative aspects of this article reflect the vast areas of ignorance on the nature of pre-Basin and Range volcano-tectonic structures throughout western North America.

MAJOR STRUCTURES

Southwestern New Mexico consists of two broad provinces, divided roughly by Interstate 10 (or, if you prefer, the Texas Lineament). To the south, during the Paleozoic and Mesozoic, were the Sonoran and Mexican gcosynclines, to the north, platform. To the south, there is Basin and Range structure, to the north is the transition between Basin and Range and Colorado Plateau, where mid-Tertiary volcano-tectonic structures are still largely preserved (see Elston, Coney, and Rhodes, this Guidebook). The two regions are separated by a persistent structural high: the Pennsylvanian Florida Islands of Kottlowski (1960) and the Early Cretaceous structure christened the Burro Uplift (Elston, 1958a) . Significantly, all major known mineralized Laramide porphyries in southwestern New Mexico are clustered around the edge of this high (Fig. 1). That porphyry-type ore deposits should be related to broad structures, which by their very size probably affect the mantle as well as the crust, is not surprising. Recent strontium isotope determinations point to a mantle source for at least a large part of the magma that formed mineralized porphyries (Moorbath, Hurley, and Fairbairn, 1967; Laughlin, Rehrig, and Mauger, 1969) .

The zone of intense Laramide folding and faulting (including thrust faults and strike-slip faults) that crosses southern Hidalgo County transversely from southeast to northwest seems to have little effect on distribution of porphyry bodies. Individual ore shoots, in contrast with mining districts, are of course controlled by local structures. In general, Laramide porphyry bodies were emplaced after the major northwest-trending folds and faults had formed. Mineralized post-porphyry fractures tend to have northeasterly trends. Northeasterly trends of mineralized fractures are especially apparent in the Central and Lordsburg mining districts.

Within the Basin and Range province it has been difficult to make generalizations about mid-Tertiary structural trends older than the main stage of block faulting, about 20 m.y. ago. The reason lies in lack of information on interactions between rejuvenated Laramide structures, mid-Tertiary volcano-tectonic structures, and late Tertiary Basin and Range structures. Information of this type is now being compiled on areas like the Mogollon Plateau, which are marginal to the Basin and Range province and less fragmented. A pattern of structural control of ore deposits by major volcano-tectonic frameworks and local eruptive centers is now emerging. Eventually, similar patterns may be found in the Basin and Range Province.

North- to northwest-trending Basin and Range fault zones, less than 20 m.y. old, control much of the present topography and also control the youngest mineral deposits. These include veins of manganese oxides and fluorspar, associated with black and white calcite, that have been mined intermittently on the east side of the Animas Valley.

PERIODS OF MINERALIZATION

Precambrian migmatites, granites, and schists record a complex history but no commercial ore bodies of Precambrian age have been found. Minor magnesite and ornamental serpentine ("ricolite") have come from the Big Burro Mountains. A few pcgmatites in the Gold Hills have traces of rare earths and uranium. The gold bearing quartz veins of the area cut not only the pegmatites but also post-pegmatite diabase dikes of unknown age. They may be as young as Tertiary.

In spite of lack of known mineralization, the Precambrian may yet hold a few surprises. Some of the rocks near

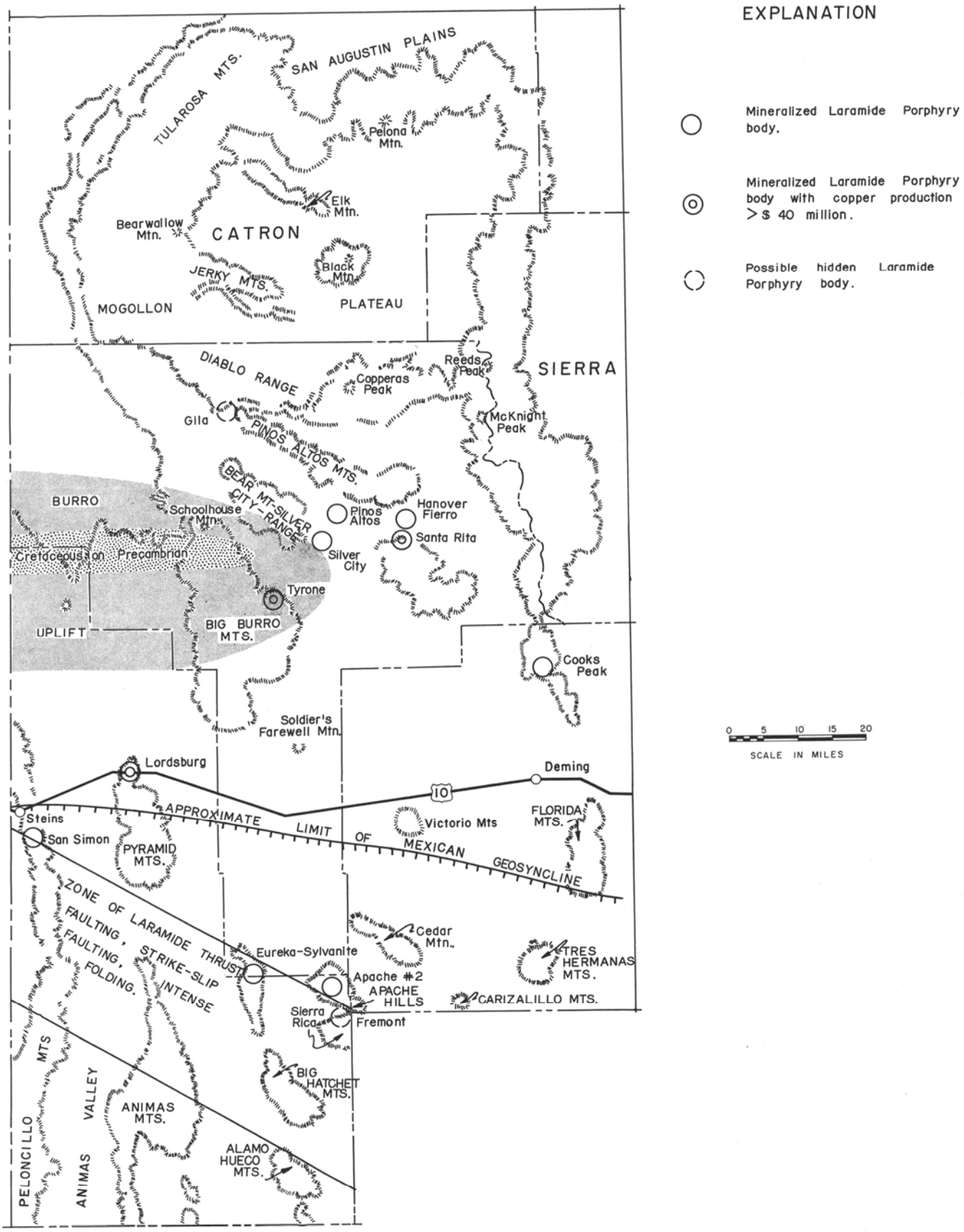

FIGURE 1.
Major tectonic provinces of southwestern New Mexico.

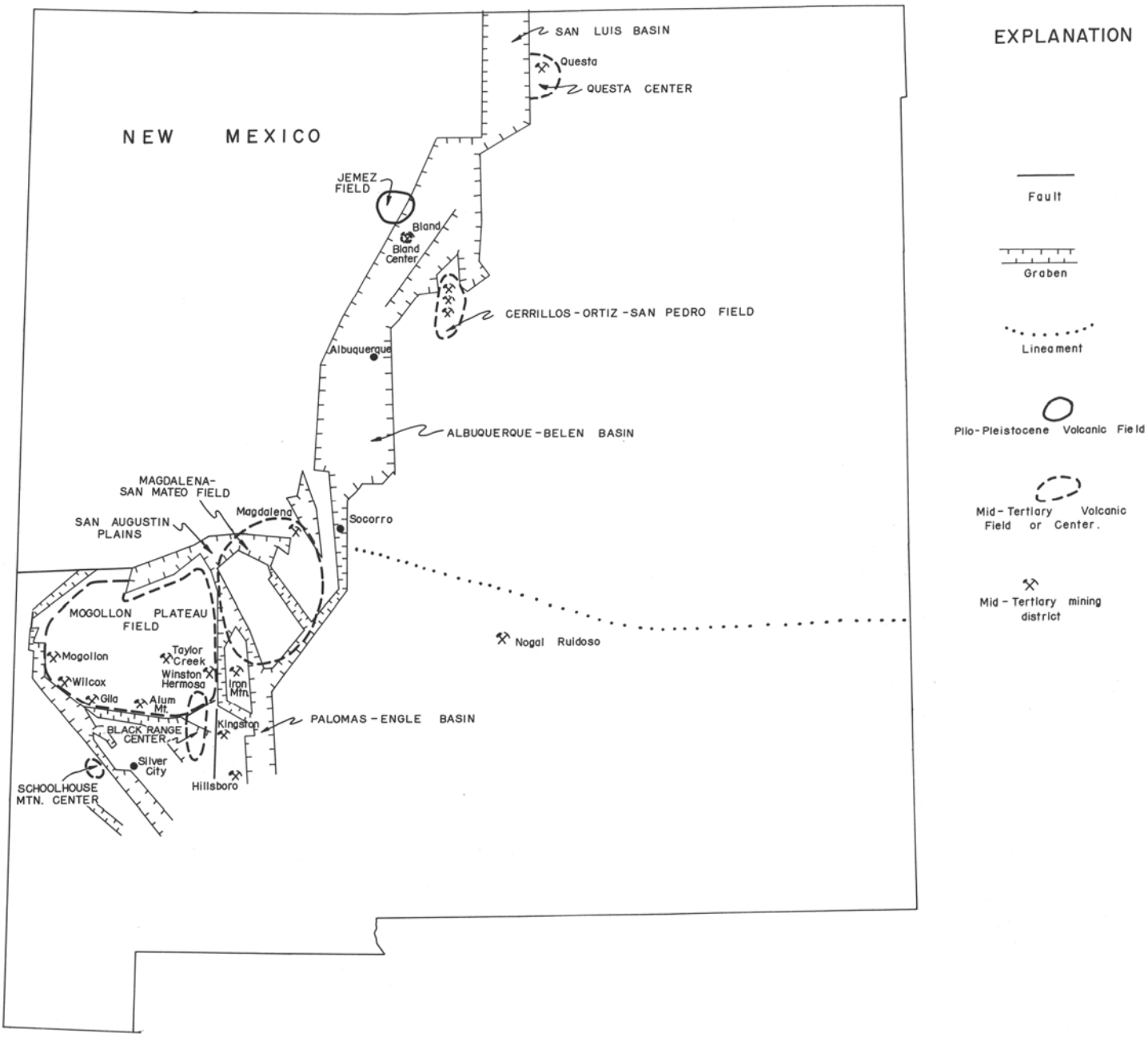

FIGURE 2.
Relationship of Neogene graben structures, volcanic centers, and mining districts.

Clifton, Arizona shown as Precambrian granite by Lindgren (1905) are, in fact, part of a gabbro-anorthosite-granophyre complex and anorthosite was reported 70 miles (115 km) to the southeast as xenoliths in Precambrian granite of the Big Burro Mountains (Hewitt, 1959) . Nickel or chromite, anyone?

Unlike adjacent areas of Arizona, no evidence for post Permian-pre-Late Cretaceous ("Nevadan") mineralization has been found in New Mexico although angular unconformities between Paleozoic and Lower Cretaceous rocks in the Peloncillo, Animas, and Big Hatchet Mountains show that deformation extended into New Mexico. Perhaps future radiometric dates will supply more surprises.

Late Cretaceous to early Tertiary (Laramide, 45 m.y. — 75 m.y.) radiometric dates have been published for the Santa Rita, Pinos Altos, Tyrone, Morenci, and Eureka stocks. Petrographic and structural similarities indicate the same age for porphyries in the Lordsburg, Apache No. 2 and Cooks Peak districts. Many small mineralized intrusions, like the Copper Flat porphyry near Hillsboro, are undated. Laramide porphyries are, of course, a prime exploration target and more on their geologic setting follows. Two little

known possible targets for future exploration are shown on Figures 1 and 2: the intensely altered rocks and mafic to intermediate intrusions near the mouth of the Gila Canyon northeast of the village of Gila, and an area of felsic dikes, skarn, and widespread hornfels in the Sierra Rica.

Mid-Tertiary volcanic rocks are associated with mineral deposits all over southwestern New Mexico. In and near the Mogollon Plateau at least four Tertiary periods of mineralization can be dated, one for each "Datil" cycle and one contemporaneous with deposition of Gila Conglomerate on the flanks of newly-risen fault blocks. These include the 28 m.y. base-metal (mainly zinc) deposits of Magdalena and possibly coeval deposits of base and precious metals in the older volcanic rocks of the Black Range. Hydrothermal alteration around Alum Mountain associated with an eruptive center of the Alum Mountain Formation (27-28 m.y.) appears to be fumarolic type, at least on the surface.

Molybdenum, tin, and beryllium are metals generally associated with granite and rhyolite. The tin deposits of the Taylor Creek district in the Black Range are associated with a 24 m.y. porphyritic rhyolite. This makes them more or less contemporaneous with the much more important molybdenum deposits (containing significant traces of tin) near Questa in Taos County and also the molybdenum prospects between Nogal and Ruidoso, Lincoln County. The age of the porphyries associated with beryllium deposits around Iron Mountain and elsewhere in the Sierro Cuchillo is unknown, but probably mid-Tertiary. The gold-silver veins at Mogollon are younger than Deadwood Gulch Rhyolite and older than Bearwallow Mountain basaltic andesite, which brackets them at about 21 m.y. The age of the native tellurium deposits of the Wilcox district is unknown.

Veins containing psilomelane, fluorspar, meerschaum, and iceland spar have been worked along late Tertiary (< 20 m.y.) Basin and Range faults. At least one vein grades upward into travertine, indicating near-surface conditions. Although at present uneconomical to mine for manganese, some of these veins might be valuable for their trace elements. Hewett and Fleischer (1960) report up to 3 percent tungsten in one vein in the Animas Mountains. Other psilomelane veins are relatively high in rare metals like thallium.

Now that it is known that Tertiary volcanic rocks are mineralized, locally on a large scale as at Questa, the amount of ground favorable for prospecting has vastly increased.

VOLCANO-TECTONIC CONTROLS

The distribution of mid-Tertiary mineral deposits around the periphery of the Mogollon Plateau makes volcano-tectonic control likely. The same has long been known for ore deposits of the San Juan Mountains, Colorado. In another article in this Guidebook (Elston, Coney, and Rhodes) the Mogollon Plateau is interpreted as the surface expression of a ring-dike complex in a moderate state of erosion. Hydrothermal alteration is exceedingly widespread, especially along the southwestern flank from Mogollon to Alum Mountain and near the crest of the Black Range between Beaverhead and Winston, and, more locally, on some cauldron walls. Almost all basal andesites are altered, but it is difficult to distinguish deuteric, hydrothermal, and low-grade metamorphic alteration. Commercial mineralization, past and present, is known only from domal upwarps or culminations in the rim (Fig. 3).

THE BASIN AND RANGE PROVINCE PRIOR TO BASIN AND RANGE FAULTING

By analogy with the Mogollon Plateau and the San Juan Mountains, the mineral deposits associated with volcanic rocks of the Basin and Range Province may also be part of volcano-tectonic structures which have been so fragmented by faults that they are not easily recognized. The method of locating volcanic vents by determining flow direction of ash--flow tuffs from their fluidal texture in thin sections (Elston and Smith, in press) may prove to be a valuable exploration tool. The paper by Elston, Coney, and Rhodes tells how fluidal textures of the Datil Formation (restricted sense) indicate an eruptive center near Magdalena. Much of this work was done by Krimsky (1969), who can be said to have discovered the Magdalena mining district. Too bad an illiterate prospector discovered it a century ago.

The problem of the pre-Basin and Range structure of the Basin and Range Province is interesting to prospectors for oil as well as for metals. If the interpretation of the Mogollon Plateau as the surface expression of a pluton is correct, its interior basin would be a poor risk for an oil or gas well and the area beyond the outer rim would be much more favorable. To date, nobody knows how many volcano-tectonic complexes there are in the Basin and Range Province or how they could be recognized. A combination of detailed geologic mapping (look for flow-banded rhyolite!), measurements of fluidal textures, and gravity and aeromagnetic surveys may give the answer.

CONTROL OF VOLCANO-TECTONIC STRUCTURES

So far, this discussion has tried to show that Tertiary ore deposits are controlled by volcano-tectonic complexes, at least in some places. The association of mineralization and flow-banded rhyolite of the type that forms the framework of the Mogollon Plateau is characteristic of many areas of mid-Tertiary mineralization. The Kimball district just north of Steins is a good example. The next question is: What controls volcano-tectonic complexes?

One answer appears to be given by Figure 3: graben-type fault structures or rift valleys of the Rio Grande type. Unfortunately, this is an oversimplification. The beginning of rifting in the Rio Grande trough is usually placed at about 20 m.y. Plio-Pleistocene basalt volcanoes in the rift zone and the great Jemez Mountains volcanic complex are clearly controlled by older faults on the border of the Rio Grande trough. However, how does one explain the control of pre-20 m.y. volcanic centers, as at Questa, Magdalena, and the Mogollon Plateau? For more details see the abstract by Elston (this Guidebook). Structural rejuvenation may be part of the answer, but students of African rift valleys have long debated the chicken-and-egg question whether faulting

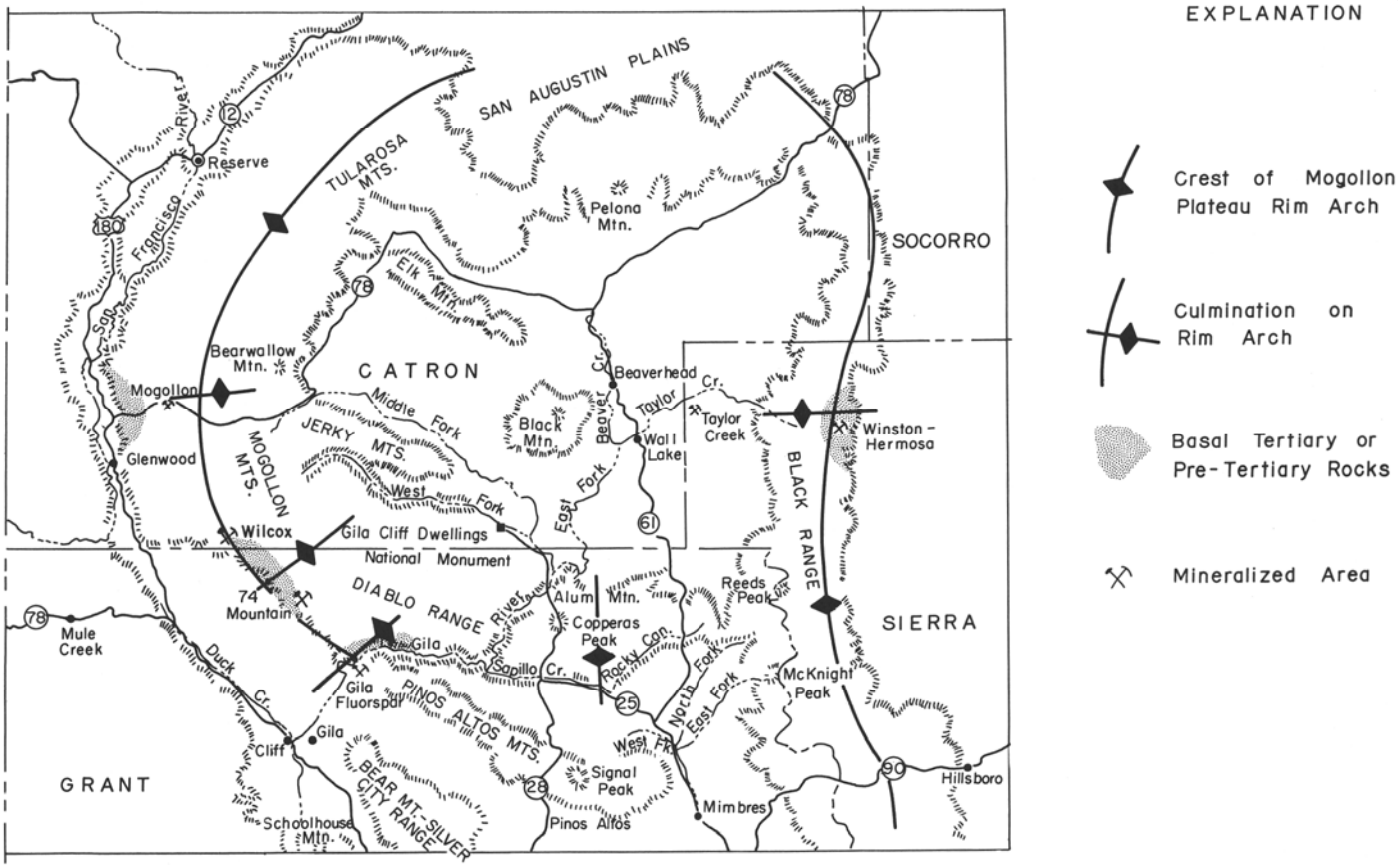

FIGURE 3.
Relationship of structure of Mogollon Plateau to mineralization.

causes volcanism or volcanism faulting. Finally, is there any evidence for rift related volcanism in the Basin and Range Province? So far, nobody has tried to locate centers systematically.

ARE LARAMIDE PORPHYRY BODIES RELATED TO VOLCANIC CENTERS?

At first glance, the absence of volcanic rocks around many Laramide porphyry bodies seems to preclude their interpretation as the roots of volcanoes. On the other hand, we know little about rates of erosion. When the White Mountain magma series of New Hampshire was believed to be Mississippian, nobody had much difficulty interpreting individual complexes as roots of volcanoes, even though only a few had associated volcanic rocks. Now that we know that they really are Late Jurassic to Early Cretaceous, no older than some western porphyries like Bisbee, Arizona, the matter appears in a different light.

Is there any evidence that can link Laramide porphyry bodies to volcanic centers? Many of them have differentiates of flow-banded rhyolite, resembling the flow-banded rhyolite of volcano-tectonic complexes. Lordsburg is a good example. A zoned deposit (see Clark, this Guidebook), pre-ore rhyolite is most abundant in the hottest zone, charac terized by chalcopyrite and sphalerite with appreciable traces of tin and tourmaline. On the west side of the San Simon district, in the Peloncillo Mountains south of Steins, the deposits are also zoned (copper, zinc-lead, lead-zinc, lead-silver), not around a porphyry body but around a fault. The fault controls felsite dikes, which appear to feed, and also to drain, a quartz monzonite porphyry sill. The ore is contact metasomatic, always associated with felsite dikes 1-2 m (3-6 feet) wide, never with porphyry.

In the Apache No. 2 district contact metasomatic ore is associated with a late rhyolitic differentiate of the porphyry. In the nearby Fremont district, rhyolite dikes are bordered by skarn and minor sulfides; thermal metamorphism is widespread, especially near rhyolite domes. If the rhyolite is a differentiate from a quartz monzonite porphyry, as it appears to be in the Apache Hills, there is no sign of porphyry in the Fremont district. Drilling alone could prove whether porphyry exists at depth. The association of ore with felsite, rather than coarse porphyry, was noted in many districts.

In 1958 I first published the notion that major Laramide porphyry bodies (i.e., those with cumulative production above $50 million) occupy structural highs between basins filled by basal andesites of Tertiary volcanic sections (Elston, 1958b) . Work since then has provided more evidence (Fig. 4) . In at least two places on Figure 4 boulders of rhyo-

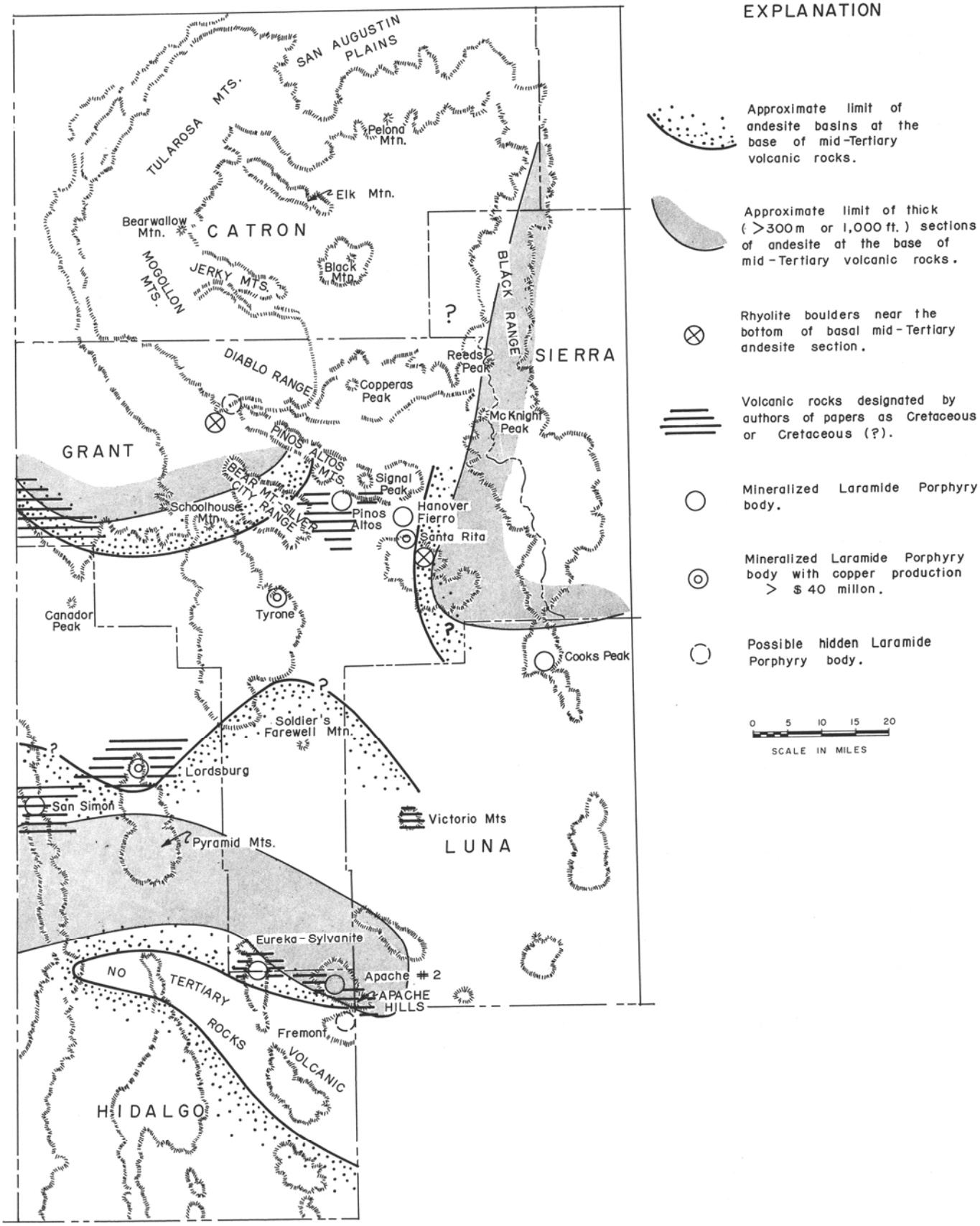

FIGURE 4.
Relationship of Laramide porphyry bodies to Cretaceous and basal mid-Tertiary andesites.

lite occur at or near the base of andesites supposedly older than rhyolites of the area. Their age and source are unknown, but in Arizona Cretaceous rhyolites are not unusual. In New Mexico most in situ Cretaceous volcanic rocks are andesite or basalt and there seems to be positive correlation between Cretaceous volcanic rocks and porphyry bodies (Fig. 4) . Near Pinos Altos the volcanic rocks can be bracketed between Turonian sediments and intrusive 74 m.y. porphyry; in the Peloncillo and Victorio Mountains and Apache Hills they are younger than Lower Cretaceous sediments and older than the mid-Tertiary volcanics. In the Little Hatchet Mountains the Early Cretaceous age assigned by Lasky (1947) has been questioned and I look forward to Bob Zeller's posthumous publication on the area (see article by Kottlowski in this Guidebook) . In the Lordsburg district the pre-porphyry basalt cannot be dated by field evidence; it is like the night clubs in San Francisco—topless and bottomless.

CONCLUSION

Enough has been said to show that in Tertiary rocks there is a connection between grabens and volcanic centers, and between volcanic centers and mineral deposits. An attempt to carry this principle from relatively unfaulted volcanic provinces on the edge of the Colorado Plateau into the Basin and Range Province will be difficult but not impossible. Our lack of knowledge of pre-Basin and Range structure of the present Basin and Range Province is one of the glaring gaps in the tectonic development of North America.

Finally, it was attempted to see whether Laramide porphyries are part of the root system of volcano-tectonic complexes. If the present is indeed the key to the past, it should be so. There are tantalizing hints that it may be so, but at present nothing is known about, say, the vent areas from which the andesites in basins surrounding porphyry bodies erupted. Are the basins calderas? Are the uplifts and their porphyries possible volcanic centers? Are crustal bulges like the Burro uplift in some way related to a horst and graben structure? How did rhyolite boulders come to rest within prc-rhyolite volcanic rocks?

Present techniques might suffice to find another Questa, a mineralized and structurally controlled mid-Tertiary center. How can one locate new Laramide porphyries? Careful field mapping and geophysical work may provide some answers, but the plotting of fluidal textures may lead us directly to the source of the Laramide volcanic rocks. If the sources are indeed related to porphyries, a powerful prospecting tool is now available.

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