Structural and Geologic Evolution of the Pioneer Mining District including Resolution, Pinal County, AZ

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Abstract

The Pioneer Mining District, including the Resolution ore body, resides in a region with a long tectonic history. Ground preparation controlling Laramide plutonic emplacement geometries and related copper porphyry-style mineralization began as early as 1740-1720 Ma with northwest-vergent subduction beneath the North American craton. At least one other Proterozoic, northwest-southeast-oriented compressive event, the 1675-1625 Ma Mazatzal Orogeny, helped further to develop strong northwest- and northeast-trending structural fabric in basement rocks. These structures were reactivated during two phases of the Laramide Orogeny as thrust, reverse, and strike-slip faults. Phase 1 consisted of northeast-vergent compression accommodated by northwest-trending thrust and reverse faults and fold axes, followed by Phase 2 northwest-vergent compression accommodated by strike-slip faulting. Acting in concert, these two phases reactivated preexisting Proterozoic structures to create localized, discreet, fault-block uplift and attenuation to complete removal of the Paleozoic section. Uplifted blocks were then down-dropped through regional right-lateral strike-slip faulting to create localized rhombochasm-style, structurally-bound basins into which Late Cretaceous crystal tuffs and volcaniclastic sediments were deposited. Northeast-vergent compression was compartmentalized within at least two lobes, separated by northeast-oriented tear structures. Resolution porphyry dikes and regional plutonic bodies, bracketed between 62-60 Ma, show preferred northeast-trending orientations, interpreted as taking advantage of preexisting weaknesses created during Proterozoic and Mesozoic compressional events. Cenozoic Basin and Range extension reactivated Proterozoic and Laramide structures, offsetting blocks of the Resolution ore body via down-to-the-west block and listric style faulting and right-lateral northwest-trending strike-slip faulting.

Introduction

The scope of this work is to provide a brief overview and chronology of events shaping the geology as it exists today within the Pioneer Mining District including Resolution, Pinal County, Arizona. A comprehensive body of work by previous authors exists, and for detailed investigations from which this work emanates, the author recommends their reference. Upon brief discussion of the local and regional geologic settings, this work will provide a brief chronologic description of geologic events that shaped this area.

Geologic Setting

The Pioneer Mining District, including the Resolution ore body (herein collectively "PMD"), lies on the eastern margin of the Basin and Range province of southeastern Arizona (Figure 1), a region typified by northeast-southwest crustal extension and thinning through block-, listric-, and strike-slip faulting that further modified earlier deformational structures (Spencer and Reynolds, 1987; Stavast, 2006). Located within a northwest-trending belt of complex geologic deformation in east central Arizona, rock units record a complex tectonic history affecting Precambrian through Tertiary rocks of repeated compressional and extensional tectonic events.

Locally, PMD lies within a zone of at least 3 sub parallel, northwest-striking, down-to-the-west listric normal faults of significant vertical offset, and significant right-lateral kinematic indicators (Devils Canyon, Concentrator, and Conley Spring Faults) (Figure 2). These Basin and Range structures are sub- to parallel with Mesozoic and older compressional structures, tilting stratigraphy and structures to the east-northeast.

Many high-angle faults within this region of the Basin and Range are truncated downward by, or flatten downward and merge with major detachment faults (Spencer and Reynolds, 1987). Such listric geometry results in up to several tens of kilometers of displacement within this portion of the Basin and Range (Spencer and Reynolds, 1987). Evidence for listric-style faulting in the PMD include arcuate surface expressions of major faults, e.g. Concentrator, Conley Spring faults, and Robles Canyon, steeper hanging-wall dips than footwall dips, and eastward-thickening of the Tertiary White Tail Conglomerate into down-to-the-west normal faults (refer to Figure 2).

Structural and Geologic History

Detailed geologic investigations have been ongoing throughout this area for more than one hundred years. Following is a brief summary outlining the geologic history of the area. Though a large and comprehensive body of work exists, only a select few authors are herein drawn upon to reconstruct this history.

Precambrian

Oldest basement rocks within this area, the 1720-1700 Ma Pinal Schist, is a thick sequence of moderately metamorphosed marine, near-shore, terrestrial sedimentary, and subduction-related mélange facies (Anderson, 1989). Northwest-oriented Proterozoic subduction created a northeast-oriented crustal weakness of great significance throughout ensuing tectonic events. Northeastward strike and northwestern dip of steeply to vertically dipping foliation are described by previous workers. While no major folds have been described in the Pinal Schist, bedding and foliation relations imply major isoclinal folding (Conway and Silver, 1987). By 1675 Ma, sedimentation within the Pinal basin terminated with the onset of the Mazatzal Orogeny (Conway and Silver, 1987). This northwest-southeast-oriented compressive event was accommodated by northwest-directed thrusting and folding (Conway and Silver, 1987).

Overlying the Pinal Schist are, from oldest to youngest, the Pioneer Formation, Dripping Spring Quartzite, Mescal Limestone, and basalt (locally absent). Together, these units comprise the ~1625-1100 Ma Apache Group. Regional lithologic consistency within these units indicates cyclical sedimentation within a shallow marine basin (Wrucke, 1986). The Troy Quartzite, overlying the Apache Group, is the youngest Middle Proterozoic unit exposed in the PMD.

Throughout PMD, wherever the Pinal Schist, Apache Group, and Troy Quartzite are exposed, they are intruded by ~1100—1020 Ma diabase. Though regionally insignificant volumetrically, locally diabase may exceed the volume of intruded country rock, inflating the Proterozoic section by as much as 100% (Figure 3). Typically, sills are tens of meters thick, though multiple "stacked" sills may account for much thicker measurements. Multiple diabase intrusions are recognized by chilled margins at diabase-country rock boundaries, and by tabular septa of host rock that remain adjacent and (sub)parallel to the contact with previous intrusions (Wrucke, 1986). Diamond drilling at Resolution reveals that Proterozoic sedimentary units may form such large "rafts" or lozenges within the diabase. Typically, sills are slightly discordant to bedding, and may "step" across beds via thin vertical segments, but generally emplacement took advantage of bedding planes, facies changes within single units, and unconformities (Wrucke, 1986).

Paleozoic

Paleozoic platform sedimentary units overlying the Precambrian are, from oldest to youngest, the Bolsa Quartzite, Martin Formation, Escabrosa Limestone, and Naco Limestone. Basal conglomerates in the Bolsa Quartzite incorporate clasts of diabase, indicating deposition on an erosional surface where truncated Proterozoic diabase dikes and sills were exposed.

Though no detailed sedimentologic analyses of the Bolsa Quartzite have been conducted, cross bedding and trace fossils, including *Skolithos*, suggest an intertidal to shallow subtidal environment (Middleton, L.T., 1987; pp.279-280).

The Martin Formation, Escabrosa Limestone, and Naco Limestone are widely distributed throughout Arizona. Collectively, they represent a relatively stable period of deposition and brief regressions within a shallow marine basin that deepens to the north-northwest. The units are important hosts to manto replacement massive sulfide ore bodies originally mined in PMD.

Mesozoic

Mesozoic accumulation of back arc or foreland basin sedimentary and volcanic facies was succeeded by the development of Laramide volcanic-plutonic arcs (Manske and Paul, 2002; Dickinson, 1989), emplacement of granitic plutons, batholiths, and intrusion of porphyry dikes and sills. Laramide igneous activity coincided with east-northeast-west-southwest compression that featured northwest-trending, basement-cored uplifts flanked by reverse and thrust faults (Manske and Paul, 2002). Laramide compression "thickened" units through the Precambrian and Paleozoic sections through a combination of recumbent folding, thrust- and reverse faulting.

Late Laramide, localized, structurally-bounded basins received volcaniclastic sediment and volcanic ash from adjacent structurally controlled highlands and local volcanic activity. Collectively, these facies are referred to in the PMD as Kvs. Efforts are ongoing to recognize and correlate internal stratigraphy and facies within this unit. Within the PMD, this unit has no surface exposure, and is known only through underground mining and from recent diamond core drilling (Ballantyne, and others, 2003). Analogous facies of similar age are exposed in the Christmas District, 40 km to the south of Resolution.

Ages of east-northeast-oriented quartz monzonite porphyry dikes are bracketed between 62 Ma (from K-Ar dates on dikes of similar composition from the Christmas District, 40 km south of PMD, and 61.2 Ma (from K-Ar dates on various intrusive phases of the Schultze Granite 15 km east of PMD, and 67-61 Ma Schultze Granite (Stavast, 2006). Stavast states that, "*Cu-bearing porphyry dikes of the Superior East and Resolution may have come from the Schultze or another intrusion of similar age. The amount of Schultze under the Apache Leap Tuff is unknown, and this could account for the copper in those two deposits* (Stavast, 2006, p. 160-161)." Porphyry dikes are hosted in Precambrian through Cretaceous rocks within the district.

Cenozoic

Cenozoic activity is characterized by caldera-style magmatism and crustal extension. From approximately 29 Ma through 7 Ma, numerous caldera-style eruptions affected a zone from northern Mexico northwestward through southwestern Nevada (Nealey and Sheridan, 1989; Ryder and Fridrich, 1997; Ryder, 1999). Extension as regional brittle-ductile low-angle detachment faulting and metamorphic core complex development ensued ~25 Ma (Spencer and Reynolds, 1987, p. 543), and is presently accomplished through regional brittle large scale block, listric, and normal-oblique faulting within portions of the Basin and Range (Spencer and Reynolds, 1987; Ryder and Fridrich, 1997).

Incipient Basin and Range style faulting created localized basins throughout much of central Arizona. The Oligocene White Tail Conglomerate, sporadically exposed throughout much of north central Maricopa through northern Pinal counties, Arizona, preserves in its stratigraphy fanning dips and thickening of sediments to the east, indicating coeval deposition and eastward tilting of half grabens on down-to-the-west normal faults (see Devils Canyon Fault, Figure 2). Further, fanning dips are indicative of listric-style faulting. This suggests that at least locally, pre-Basin and Range extension was in progress at 38 Ma. Within the PMD, White Tail Conglomerate is deposited on an erosional surface established on the Kvs, against which late Cretaceous-early Tertiary porphyry dikes are truncated.

Capping the White Tail Conglomerate is the 18.5 Ma Apache Leap Tuff, a dacitic, moderately welded, crystal-lithic tuff. The Apache Leap Tuff is the prominent cliff former to the east above the town of Superior, Arizona. It has been proposed that this tuff emanated from sources in the Superstition Caldera Complex, 20 km to the northwest, though its source has yet to be clearly identified (pers. comm., 2005). Minor exposures of post-White Tail "older rhyolitic tuff" are present in the vicinity of Queen Creek Canyon at the base of the Apache Leap Tuff. A complete geologic section is presented in Figure 4 (modified from Marsh and Hart, 2003).

Discussion

Northwest and northeast-trending faults are present within the Resolution deposit (Figure 5). Northwest-trending faults, from west to east, are the West Boundary, Gant, Peterson West and Peterson East Faults. Kinematic indicators on these fault surfaces record the latest movement of these structures as stepping down to the west-northwest, and display a strong right-lateral component. Northeast-trending faults, from south to north, are the South Boundary, Resolution, N30E, Shaft, and North Boundary Faults (Figure 5). Kinematic indicators on northeast-trending fault surfaces demonstrate down-to-the-northwest down dropping, with some degree of left-lateral shear (Figure 6). It is likely that these presently normal faults are reactivated Laramide reverse and strike-slip faults that correspond with older basement weaknesses (Resolution Model, 2006).

The North Boundary and South Boundary faults bound a northeast-trending graben (Resolution Model, 2006). Possibly significant strike-slip displacement is suggested by kinematic indicators on fault surfaces retrieved in drilled core from Res-008/008A. This graben and bounding structures are parallel to sub parallel to Proterozoic subduction zone axes, and parallel AND perpendicular to Laramide compression axes, and are interpreted as reactivated, preexisting compressional structures.

Previous workers have long supported the Arizona overthrust model, in which local thrusting and regional overthrusting affected southeastern Arizona (Krantz, 1985). According to Drewes (1981), thrusting and overthrusting occurred in two large, northeast-vergent thrust lobes separated by a northeast-striking tear fault complex. Both lobes contain imbricate stacks of two or more major allocthonous plates, accounting for thrust slip that may have exceeded 100 km. Drewes (1981) describes a northeast-oriented "tear structure" approximately 120 km south of the PMD, accommodating compartmentalized movement between the two lobes. Significant brecciation at depth adjacent to the northeast-trending Resolution Fault could be an expression of a localized "tear structure," and subsequent reactivation of a fault controlled by such an older crustal weakness (Resolution Model, 2006). This feature is sub- to parallel to some of the major northeast-oriented major faults, porphyry dikes, and mineralization trends within the PMD (Figure 7). Krantz (1985) and Drewes (1981) demonstrate that in southeastern Arizona, northeast-vergent displacement of both lobes occurred in a first phase of northeast-southwest regional compression. Such compartmentalization within thrust sheets is well documented in the western Tucson Mountains (Figure 8, from Krantz, 1985), as well as in eastern Precambrian and Paleozoic fold and thrust belts in the eastern United States, and may well serve as a model of Laramide deformation within the PMD. Their work indicates that this northeast-oriented compression was followed by a second phase of localized northwest-oriented thrusting and strike-slip faulting.

Krantz's and Drewes' work has significant implications within the PMD. One of the unique features of the Resolution deposit is a marked attenuation to absence of the Paleozoic section within a northeast-trending graben, bounded to the north by the North Boundary Fault, and to the south by the South Boundary Fault (Figure 9). Ongoing diamond drilling results suggest a roughly rhombic geometry to this Paleozoic "window". If applied to the PMD, Krantz's and Drewes' two-phase Laramide compression model could account for this attenuation to absence of the Paleozoic section through fault-block uplift during the initial phase of thrusting, resulting in a beveling-off of the Paleozoic section, followed by second-phase northwest-oriented strike-slip development of a rhombochasm, down-dropping a beveled fault block. Furthermore, assuming Drewes' tear-structure concept is correct, northeast-oriented compartmentalization structures and associated brecciation would have provided excellent ground preparation and structural weakness for synchronous to later porphyry emplacement and related mineralization.

Coeval with this shortening was the development of regional prominent east-northeast-trending brittle structural fabric controlling subsequent fracture, fault, vein, and pluton and dike emplacement (Manske and Paul, 2002; Rehrig and Heidrick, 1972; Heidrick and Titley, 1982). It is presumed that this late to post Laramide (~62-60 Ma) plutonic activity provided the magma from which the Resolution porphyries are derived (Stavast, 2006).

Conclusions

1. Tectonic evolution of the region including the Pioneer Mining District dates back to at least 1740 Ma.
2. Lower Proterozoic subduction and accretion off of the western margin of the early craton established northeast-oriented basement weaknesses that were reactivated by later compressive and extensional events.

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3. The youngest compressive event, the Laramide, occurred in two phases, beginning with compartmentalized northeast folding and thrusting, followed by northwest-oriented shortening accommodated by strike-slip faulting.
4. Phase 1 Laramide folding and thrusting in present-day Arizona occurred as two discrete, northeast-vergent folding and thrust lobes, separated by a northeast-trending tear zone, probably occupying a preexisting Proterozoic basement weakness.
5. Phase 1 northeast-oriented Laramide deformation was further compartmentalized by principal-stress-parallel accommodating strike-slip, or "tear" structures, as demonstrated in other fold and thrust belts, e.g. southern Arizona, the Ouachita Mountains of south-central United States, and the Appalachian Mountains of the eastern United States. This event uplifted discreet fault blocks, resulting in partial to complete erosion of the Paleozoic section.
6. Northwest-oriented Phase 2 Laramide shortening was accommodated by strike-slip reactivation of preexisting northwest-oriented basement weaknesses, and resulted in rhombochasm development, locally down dropping previously eroded Phase 1 fault blocks.
7. Repeated northeast and northwest-oriented shortening from 1740-60 Ma produced a northeast-oriented structural fabric and brecciation at depth in country rock, creating weakness orientations taken advantage by late Laramide emplacement of granitic plutons and dikes.
8. Cenozoic Basin and Range extension further modified the section through northeast-southwest-oriented extension accommodated by northwest-oriented, down-to-the-west block and listric normal faults with a minor to major right-lateral component.

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Figure 1 Location map of Pinal County, AZ, including the Pioneer Mining District and Resolution ore body, in relation to geologic structural provinces (CP=Colorado Plateau, TZ=Transition Zone, BR=Basin and Range).

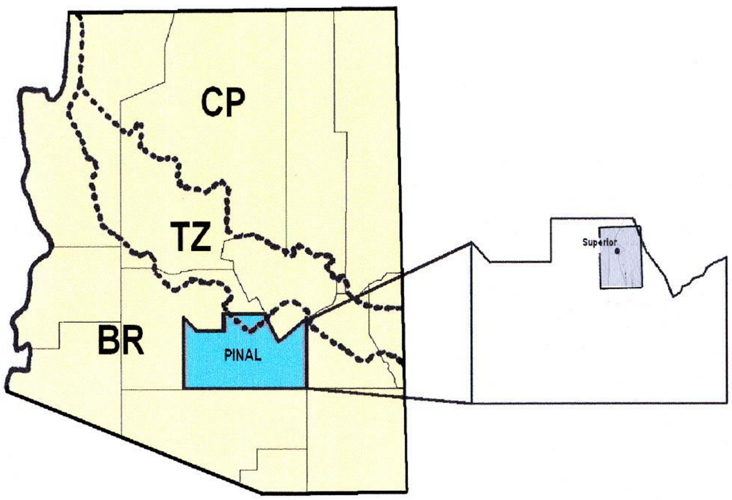

Figure 2 Generalized cross section of the Pioneer Mining District at ~33^{o}22’10”, view looking north. “Growth” within the Tw into the down-to-the-west Devils Canyon Fault is interpreted.

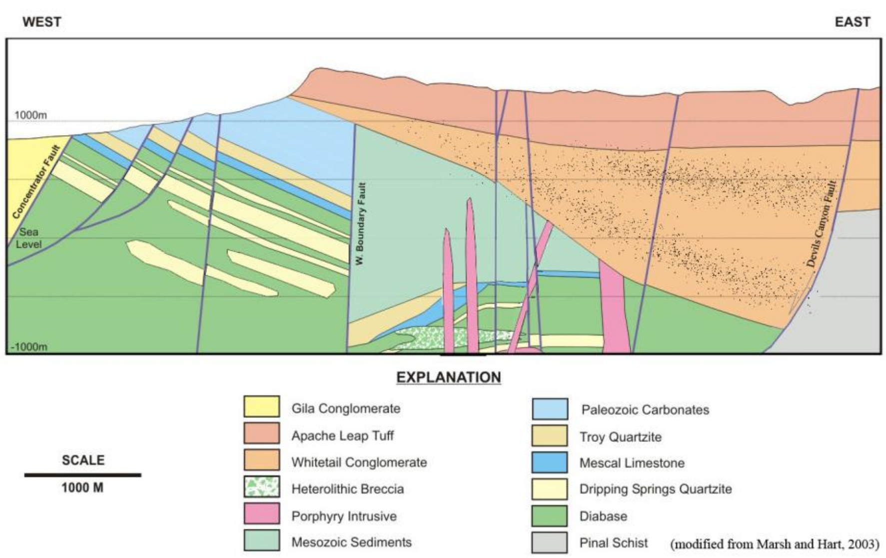

Figure 3 Schematic describing inflation of Precambrian section by intrusion of 1100 Ma diabase. Though volumetrically insignificant regionally, local inflation may approach 100% of original thickness of section. Note the "rafts" of units created during multiple intrusive events.

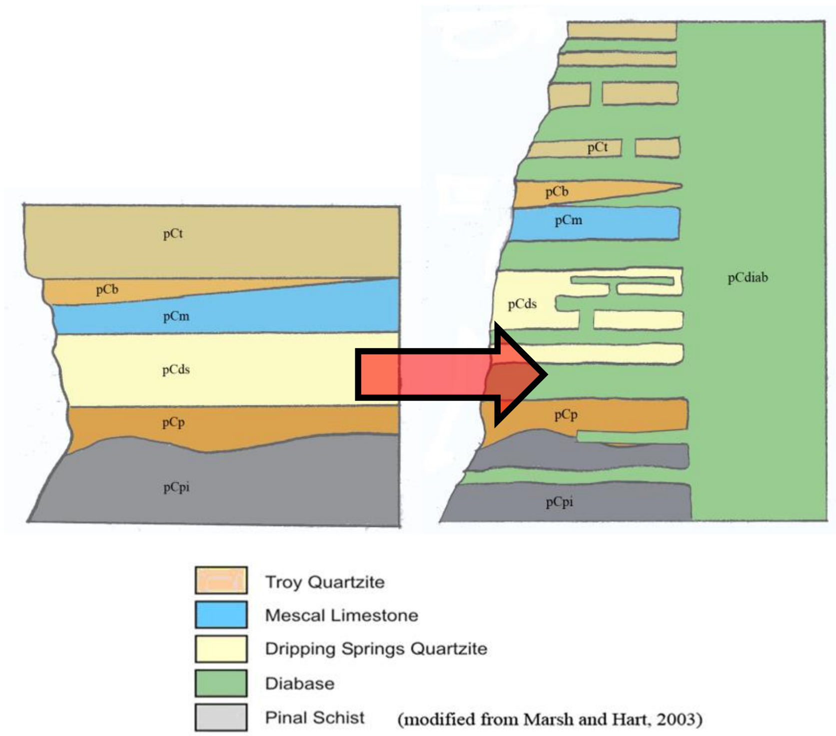

Figure 4 Complete geologic section of the Pioneer Mining District at ~33°22'10", view looking north (from Hammer, 1973; modified by Andrews and Hart, 2002).

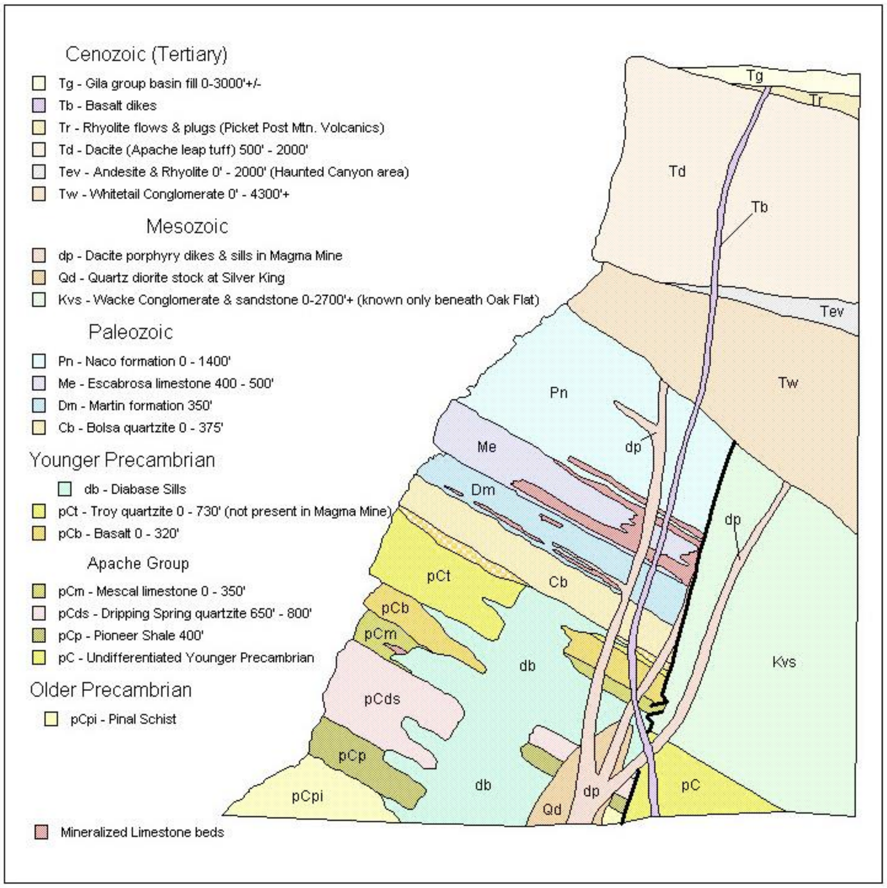

Figure 5 Plan view detail of faults, -700 m elevation, between Concentrator and Devils Canyon Faults. Modified from Resolution Model, 2006.

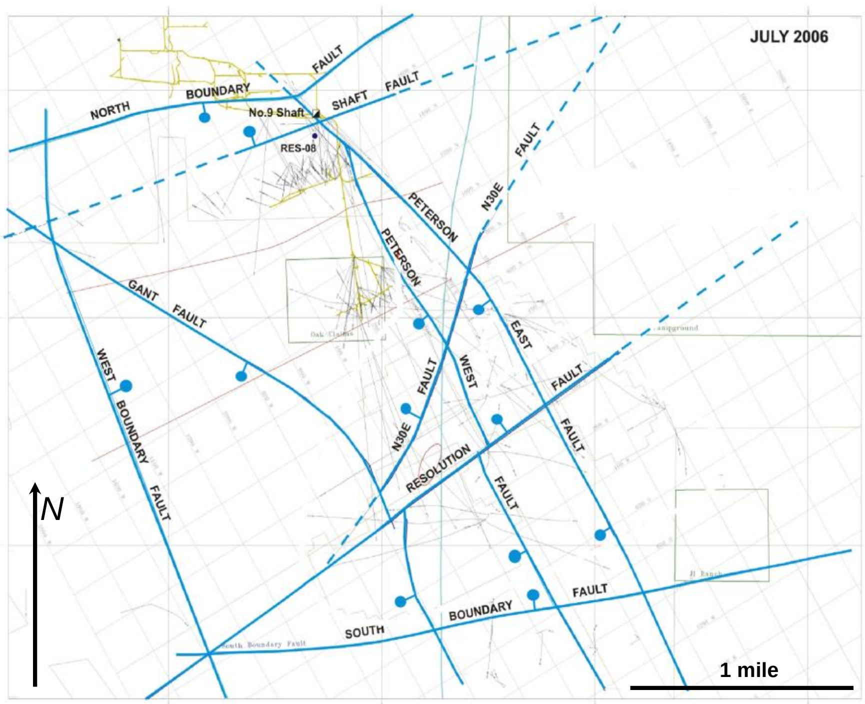

Figure 6 Plan view detail of faults, -700 m elevation, between Concentrator and Devils Canyon Faults. Right- and left-lateral displacement on faults interpreted from drill core data and from rhombochasm analogues in the western Basin and Range. Modified from Resolution Model, 2006.

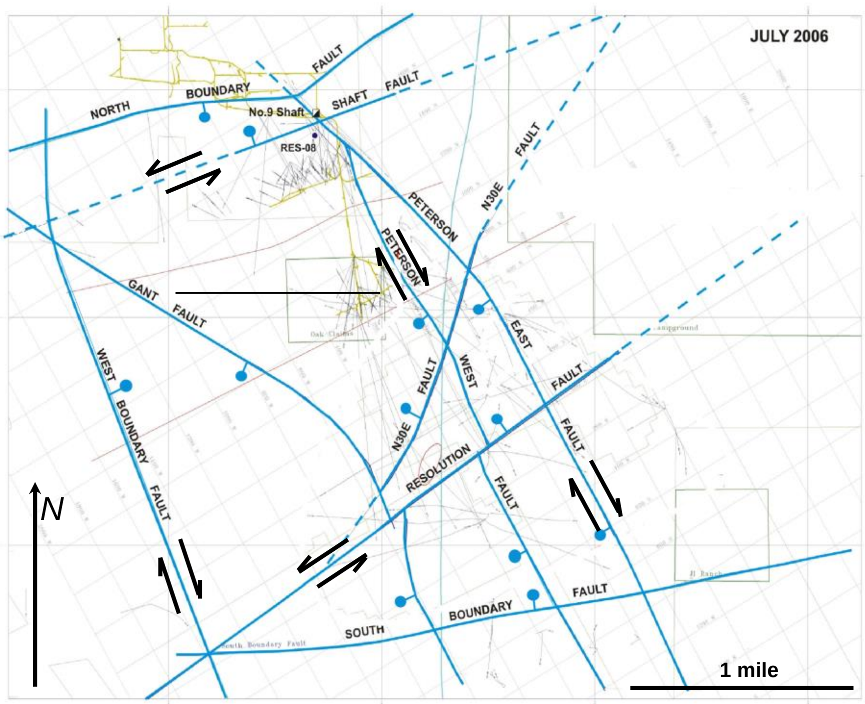

Figure 7 Interpreted regional distribution of Laramide northwest (red) and southeast (blue) major thrust sheets, or lobes, separated by northeast-trending tear structure, shown in red (from Drewes, 1981).

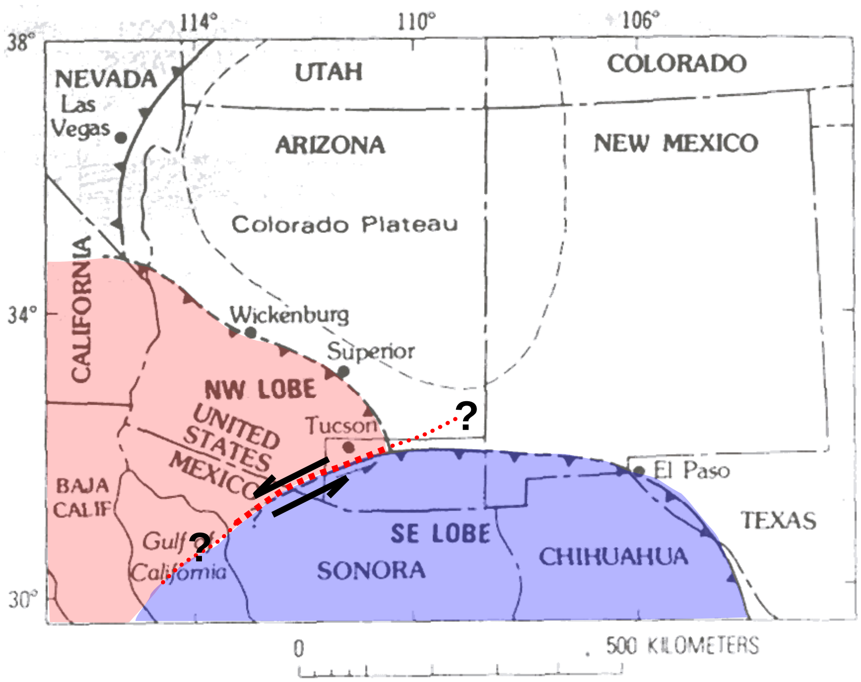

Figure 8 Compartmentalized northeast vergent compression with northeast-trending accommodating structures, western Tucson Mountains, Arizona, similar to the regional "tear structure" identified by Drewes, 1981 (from Krantz, 1985). Similar compartmentalization structures exist within other thrust belts, e.g. the Valley and Ridge province, Appalachian Mountains, eastern US and the Ouchita Mountains of south-central US. Structural trends within the PMD suggest that such compartmentalized folding and thrusting may have occurred within the PMD.

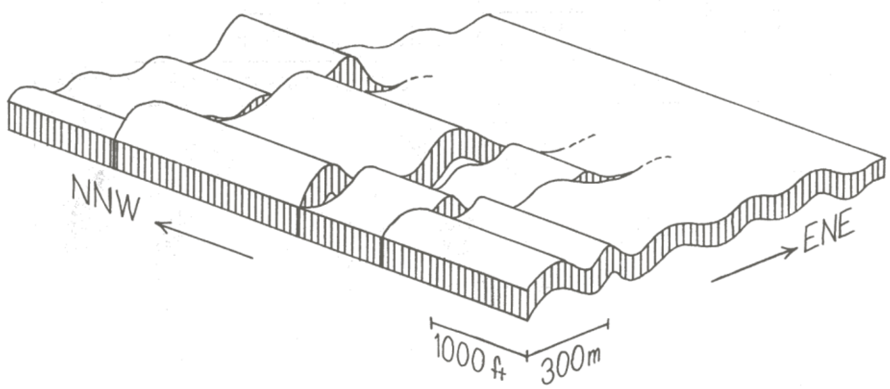

Figure 9 Approximate extent, in red, of attenuated to missing Paleozoic section and Kvs infill, -700 m elevation, vicinity of Resolution, approximately 2 miles east of the Concentrator Fault (modified from Resolution Model, 2006).