A STRUCTURAL AND PETROLOGIC ANALYSIS OF A QUARTZITE--PEGMATITE TECTONITE, COYOTE MOUNTAINS, SOUTHERN ARIZONA

by

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Finally, I wish to give special thanks to my family for their unwavering support, encouragement, and love throughout my education.

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ABSTRACT

The Coyote Mountains southwest of Tucson, Arizona consist mainly of undeformed Mesozoic and Cenozoic intrusive rocks, but along the northern margin of the range is a thin shell of unusually deformed rock. There, a quartzite and marble tectonite sequence has been dilated profoundly by a system of thick pegmatite sills. Further north, these rocks are truncated by the Ajo Road decollement, a north-dipping normal fault separating the footwall of penetratively deformed rocks from overlying Mesozoic and Cenozoic volcanic and sedimentary rocks.

Discrete, northeast-dipping, curviplanar slip surfaces which are lineated dominate the internal deformation within the pegmatite. The expression of the internal deformation within the quartzite lenses is a penetrative, northeast-dipping foliation marked by north-northwest plunging lineation. The quartzite appears "plated" onto curved pegmatite surfaces in outcrop.

Strong, orthorhombic fabric symmetry with a monoclinic overprint is interpreted to indicate progressive deformation by rotation of normal shearing surfaces to parallelism with the overall plane of flattening. The quartzite tectonites were formed by plastic flow accompanying flattening and north-northwest extension and may be viewed as ductile shear zones controlled by the rheologic properties of the quartzite.

CHAPTER 1

INTRODUCTION

An unusual style of deformation has affected the rocks along the northern margin of the Coyote Mountains in southern Arizona. These rocks are highly strained and tectonized and form a thin, northeast-dipping sheath of deformed rock over the undisturbed rocks of the main mass of the range.

The Coyote Mountains are located about 45 km southwest of Tucson, Arizona (Figure 1) and lie at the northeastern end of the Baboquivari Range. The Roskruge Mountains lie to the north. The thesis area is contained entirely within the Papago Indian Reservation, and access is primarily through the tiny settlement of Nawt Vaya and from Route 86.

Mesozoic and Cenozoic intrusive rocks comprise the main portion of the Coyote Mountains, and these have intruded a Paleozoic sedimentary rock sequence of quartzite and carbonate. The Ajo Road decollement separates the rocks of the Coyote Range from Mesozoic through Tertiary volcanic and sedimentary rocks to the north. The rocks of the Roskruge Range are included in this lithologic package and consist predominantly of dacitic to rhyolitic flows, breccias, and tuffs.

The deformational style in the Coyote Mountains is of interest because it is, for the most part, of a ductile nature and is not characterized by the typical structural features of deformed rocks, such as

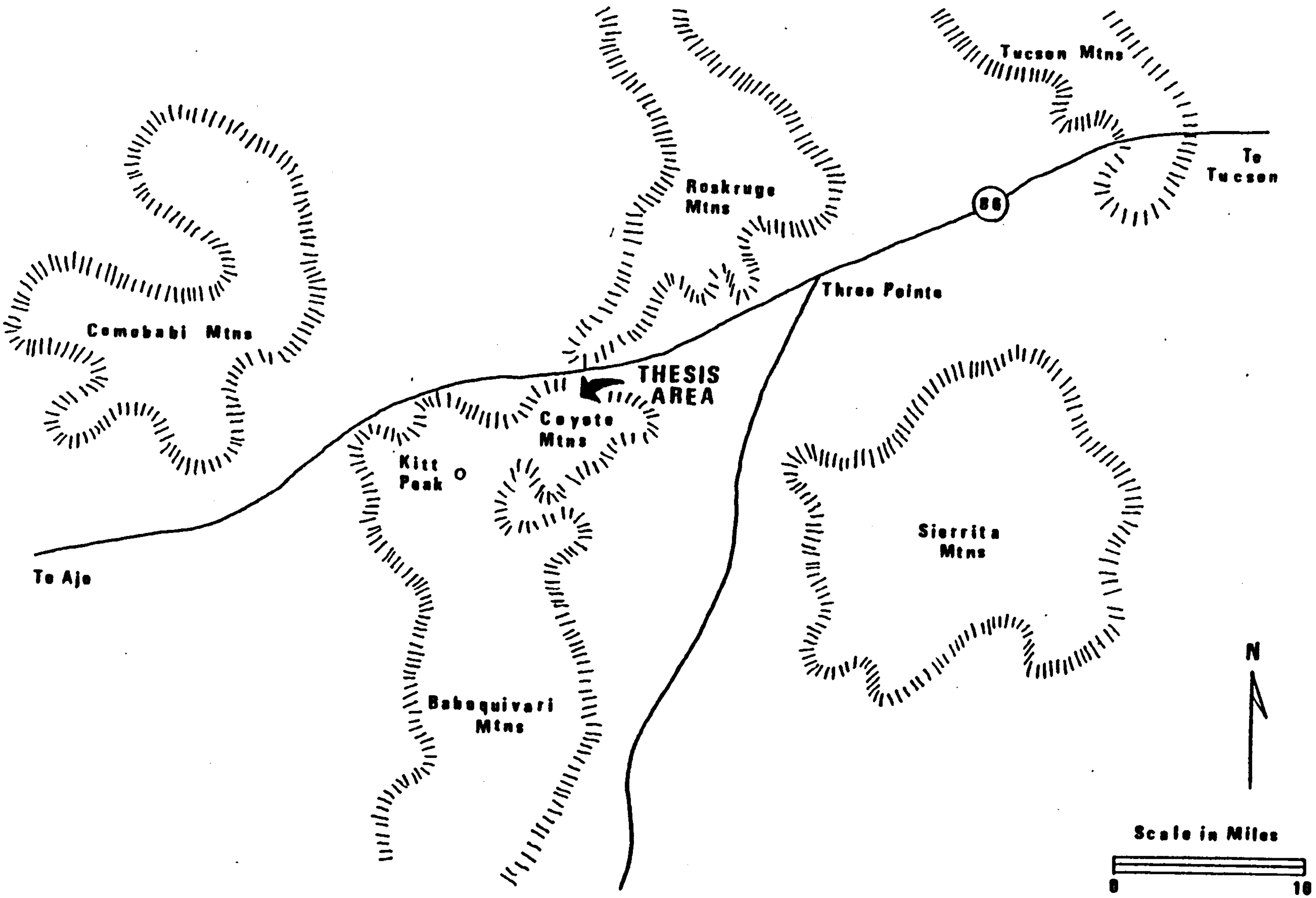

Figure 1. Location Map

faults and folds. Instead, the rocks have undergone great extension and flattening, manifested in northeast-dipping foliation and north-northwest plunging lineation. Perturbations in the style of these structural elements arise as a result of inherent mechanical differences among rock types. These rheological differences have also dictated the distribution and localization of strain through the veneer of deformed rock, so that the strain gradient is uneven and irregular in detail.

Almost no detailed mapping has been undertaken in the Coyote Mountains. Wargo (1954) and Kurtz (1955) mapped the Coyote-Quinlan complex; however, they did not deal with the deformational features in the ranges in any detail. Carrigan (1971) mapped a small area southeast of the area of this study with emphasis on the economic potential of the Paleozoic sedimentary rocks. The rocks in his thesis area do not show effects of the lineation-producing deformation; however, he notes evidence for an earlier event which resulted in folding and faulting of the Paleozoic rocks. Davis (in press) mapped the northern Coyote Mountains with particular attention to structure and the decollement surface. Currently, mapping of the Sells quadrangle and surrounding area, including the Coyote Mountains, is being carried out by members of the U. S. Geological Survey.

Purpose

The purpose of this study was to describe the unique deformational style in the northern Coyote Mountains and to fully analyze its expression in contrasting lithologies. It was hoped to gain an understanding of the interplay of the roles of intrusive and tectonic processes in this deformation and to qualify on all scales the effects of a single strain regime on contrasting rock types.

This study was divided into three parts, each of which contributed information on a different level. First, it was necessary to map the geology of the part of the Coyote Mountains of interest to this thesis. Mapping was carried out at a scale of 1" = 120 m on an aerial photograph base over an area of 8 sq km. About 40 days were spent in the field. Lithologic contacts and relationships were delineated and described at this stage.

The second stage was to describe and analyze the unusual deformational style in the rocks through detailed structural analysis. Substantial topographic and structural relief in Tohawaw Canyon in the Coyote Mountains have afforded an excellent opportunity to document in three dimensions some aspects of the effects of the lineation-forming deformation. The veneer of deformed rock in the northern Coyote Mountains occurs below a major decollement surface, and the kinematic significance of the petrofabrics in these rocks was examined through structural petrology. Universal stage study of 11 oriented samples was undertaken to analyze the fabrics in the quartzite and pegmatite to supplement and refine interpretations made from mesoscopic structures. The third and most focused aim of this thesis was to propose a scheme for internal movements in the rocks to satisfy field observations and symmetry requirements of the fabric diagrams.

CHAPTER 2

LITHOLOGIES

The distribution of the lithologic units in the northern Coyote Mountains is shown in Figure 2 (in pocket), the geologic map of the thesis area. This chapter describes the rock types from oldest to youngest. Descriptions of some of the complex contact relationships will be deferred until Chapters 3 and 4, where they will be presented in the context of structural geology.

Bolsa Quartzite

One of the lithologies which is structurally and mechanically most intriguing is the Bolsa Quartzite. It is mineralogically quite homogeneous and contains very minor feldspar, biotite, muscovite, and various heavy minerals. It appears white, grey, black, or more rarely, maroon in outcrop, and a light and dark layering parallels the foliation or cuts it at a low angle. The mineralogic difference between bands is slight, but the percentage of micas is slightly higher and the grain size is generally finer in darker layers.

No conglomeratic layers or lenses occur in the quartzite in the northern Coyote Mountains, and although its basal contact is not recognized there, the total exposed thickness is estimated at 30 m. The quartzite is presumed to be the Cambrian Bolsa Quartzite, as such a designation is compatible with its outcrop appearance, mineralogy, and structural position with respect to the overlying Abrigo and Martin Formations.

Abrigo and Martin Formations

Metamorphosed limestone, dolomite, and calcareous sandstone comprise a distinctive sedimentary rock sequence in the northern Coyote Mountains. These calcareous rocks are relatively nonresistant and weather to subdued shades of grey, green, tan, or brown.

The mineral assemblages observed in thin section include garnet + epidote, garnet + epidote + K-feldspar, garnet + K-feldspar + diopside, and dolomite + diopside + muscovite. Quartz is ubiquitous. Fossils are absent, perhaps destroyed during metamorphism and deformation. Locally, the rocks have been metamorphosed to massive skarns, but in general, the bedding, though tectonically modified, is still recognizable.

The calc-silicate lithologies correlate with the Cambrian Abrigo Formation and Devonian Martin Formation described by Carrigan (1971) in a nearby area. The disruption of the stratigraphic section by intrusion renders thickness estimates extremely difficult. Carrigan estimates the combined thicknesses of both formations to be 470 m in the eastern Coyote Mountains, but notes that repetition of units by faulting may have augmented the thickness. In the northern Coyote Mountains, a figure of 250 m is more likely, but no measurement of sections was undertaken.

Diorite

There are a number of intrusive rocks in the Coyote Mountains which qualify lithologically as diorite. Most phases are seen to intrude the Paleozoic metasedimentary rocks and are in turn intruded by pegmatite, but the precise age or age range of the diorite is unknown.

The biotite quartz diorite is characterized by a high biotite and plagioclase content with subordinate quartz. The texture is hypidiomorphic, and the outcrop expression of this rock type is quite subdued. It is not abundant in the thesis area, but small intrusions may be found throughout the northern part of the range.

Hornblende quartz diorite, hornblende diorite, and hornblendite essentially form a continuum, both mineralogically and texturally. Zoned plagioclase, hornblende, and sphene with small amounts of quartz constitute the mineralogy. The hornblende quartz diorite is hypidiomorphic granular in texture, but a distinctive glomeroporphyritic texture occurs in this rock as well as in the hornblende diorite and hornblendite. A highly chloritized glomeroporphyritic phase crops out in a few places in which relict cores of possibly pyroxene may be seen.

The relationships among these dioritic phases is not very clear, as they form fairly nonresistant outcrops which are deeply weathered. The large mass of mafic rock in the western part of the study area contains all of these phases, and it is possible that they represent differentiates from a cooling magma or are related intrusions, perhaps contemporaneous, from a common magma chamber. It is unlikely that they all would intrude coincidentally into the same area if they are unrelated, but much more detailed mapping and geochemical work would be required to solve this problem.

Roadside Formation

This unit consists of andesitic to latitic volcanic flows, breccias, and derivative sediments. Heindl (1965) has assigned a late Mesozoic age to this lithology. Both fresh and weathered rock surfaces are somber hues of purple, grey, brown, and black. Epidote and chlorite coat abundant fracture surfaces and occur as alteration minerals within breccia fragments. The Roadside Formation is best exposed in washes in the map area and forms low hills further north.

An isolated outcrop of probable highly sheared Roadside Formation occurs anomalously far south on the Ajo Road decollement. Purple-grey, pasty material crops out immediately adjacent to the fault, and the color is diagnostic of this unit. At this outcrop, there is a block of unmetamorphosed, highly fractured, dolomitic limestone approximately 6 x 10 x 20 m. There are abundant microfossils present in this rock, but recrystallization has been quite intense. Only a tentative identification of these fossils as ostracodes can be made (K. Flessa, personal communication, 1980). This identification is too general to distinguish the age of the rock or to distinguish a marine or nonmarine affinity. The nature of the contact of the block with surrounding rocks has been obscured by intense shearing and faulting; thus, the limestone may be either a small, interbedded carbonate lens within the Roadside Formation or it may be an exotic block (Paleozoic?) incorporated into the sedimentary rock.

Cretaceous(?) Sand Wells Formation

The Roadside Formation is overlain by a lithology correlated with the Cretaceous(?) Sand Wells Formation (G. Haxel, personal communication, 1980). The contact is probably depositional, but the interface is poorly exposed. Facing directions visible in the red beds at a few localities near outcrops of the Roadside Formation are orderly and indicate a nontectonic contact between the two lithologies.

The red beds are a complicated sequence of conglomerate, sandstone, and siltstone. Sorting and grain size are both highly variable. The texture of the sedimentary rocks changes drastically both laterally and vertically over short distances, although there is an overall decrease in grain size stratigraphically upward. Compositionally, an overwhelming volcanic component remains constant. Fragments of Jurassic granitic rocks have been incorporated as well.

Bedding attitudes are enormously variable and do not appear to be systematic. Dip directions encompass a full 360°, and while beds are generally shallowly-dipping, near-vertical orientations are not uncommon. The best exposures of the red beds are in washes and on a low hill in the northern part of the area.

Pan Tak Granite

The Pan Tak granite includes four phases--an older equigranular granite and three younger phases. These younger phases include equigranular, coarse-grained granite; xenomorphic, medium-grained granite; and swarms of pegmatites, which comprise a large part of the northern

Coyote Mountains. The older granitic phase does not crop out in the study area, but forms a major portion of the southern half of the range.

It is convenient to group these phases, as they are nearly identical compositionally, and they are so intimately related spatially as to be virtually impossible to map as discrete units in most locations. The pegmatite and granite are commonly texturally gradational, and there are few examples of a clear intrusive relationship between the two lithologies.

The most spectacular pegmatite exposures are sills with undulatory upper and lower surfaces. These bodies usually dip to the northeast and are up to 60 m thick. In size the pegmatites range down to wispy pockets of slightly coarser-grained material in aplitic or granitic country rock of the same composition.

Mineralogically, the pegmatite and granite consist of quartz, microcline, albitic plagioclase, biotite, and locally-abundant muscovite and garnet. In some of the sills, a delicate zoning is developed which has the appearance of layering or pseudo-sedimentary stratification. It is a compositional phenomenon as evidenced by bands of garnets, but there is also a distinct foliation developed within mineralogically homogeneous feldspar layers. The orientation of this primary layering is a measurable structural element and, where present, it conforms to the general shape of the boundary of the pegmatite and country rock and dips to the northeast.

The granite varies in grain size from medium-fine to moderately coarse with an equigranular texture. A variant of the granite is a moderately fine-grained xenomorphic phase which lacks mica and garnet. This fine-grained phase occurs as plugs which are intruded by pegmatite. It is probably a phase of the granite-pegmatite complex, rather than an unrelated intrusion.

The granite correlates with the Pan Tak granite (G. Haxel, personal communication, 1980), and the younger granite phase has been dated at 58 m.y. (Wright and Haxel, 1980). South of the thesis area, the older phase of the Pan Tak granite occurs. An age distinction can be made texturally, as this older phase is a granite gneiss with a noncataclastic mineral foliation defined by biotite. The foliation dips westerly and is cut by pegmatite dikes which do not have this flow foliation. The whole Pan Tak complex intrudes a Jurassic pluton in the Coyote Mountains, and similar intrusions are located in several other ranges in southern Arizona.

The isotopic systematics of zircons in the Pan Tak granite demonstrate an anatectic origin for the intrusion. A Precambrian parent rock is indicated by an 1100 m.y. upper intercept on the chord specified by analysis of zircons (Wright and Haxel, 1980).

Lamprophyre Dikes

The youngest intrusive rocks in the northern Coyote Mountains are a series of dikes which generally trend north-south and are near vertical. Although they appear to lack the high potassium and/or sodium minerals characteristic of a true lamprophyre, this name has been attached to them in previous studies (Wargo, 1954; Kurtz, 1955; Carrigan, 1971). It is a reasonable field term. The dikes are usually about 1 m wide and are from 6 to 60 m in length. They occur most commonly as intrusions in the pegmatite and granite.

The mineralogy and texture are variable in these dikes, but they generally contain augite phenocrysts in a felty groundmass of plagioclase, quartz, opaque minerals, and chlorite. There are some non-porphyritic phases which lack augite, but in general there is little variation in the dikes within the study area.

One unusual dike crops out in the western part of the map area. It is characterized by magnetite phenocrysts in a matrix of a fibrous mineral which is probably chlorite. This dike may be more closely related to a phase of the diorite than to the lamprophyre intrusions.

Quaternary-Tertiary Gravels

A large alluvial fan issues from Tohawaw Canyon. The deposits comprising this fan range from fine-grained sandstone to room-size boulders in levees of debris flow material. The clast lithologies include all of the rock types in the Coyote Mountain mass, but pegmatite and granite constitute the major percentage.

This fan has unfortunately obscured some structural and contact relationships in the underlying bedrock. However, stream incision into the alluvial blanket has locally exposed the Roadside Formation and Cretaceous(?) Sand Wells Formation in the northern part of the map area.

Recent Alluvium

Unconsolidated gravels and finer-grained alluvial sediments may be found in the washes cutting the alluvial fan. These sediments consist predominantly of Pan Tak granitic rocks, but all lithologies are represented.

CHAPTER 3

STRUCTURAL GEOLOGY

The overall geometry of rock relations in the northern Coyote Mountains has been greatly influenced by the intrusion of the complex Pan Tak granitic system. This major intrusive event caused enormous dilation in three dimensions of the Paleozoic rocks. The sills of the Pan Tak granitic system have engulfed the quartzite and marble. Quartzite lenses are sandwiched between undulatory surfaces of the pegmatite sills (Figure 3). Sharp contacts are maintained in the Abrigo and Martin Formations with little encroachment of pegmatite into the interiors of these sedimentary rock pods.

The Paleozoic sedimentary rocks and the Pan Tak intrusion are truncated at the northern edge of the Coyote Mountains by the Ajo Road decollement, and the Tohawaw Canyon fault has produced displacement within the range itself in a direction perpendicular to the decollement.

Internal Deformation

The internal deformational features within the various lithologies are mainly northeast-dipping foliation, north-northwest plunging lineation (Figure 4), normal faults, and pinch and swell features. These structures are present on all scales and affect nearly all the lithologies.

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Figure 3. West Wall of Tohawaw Canyon. -- Note the pinch-and-swell morphology of the white pegmatite sills and the invervening grey Bolsa Quartzite. The saguaro cactus near the center of the picture is about 4 m tall.

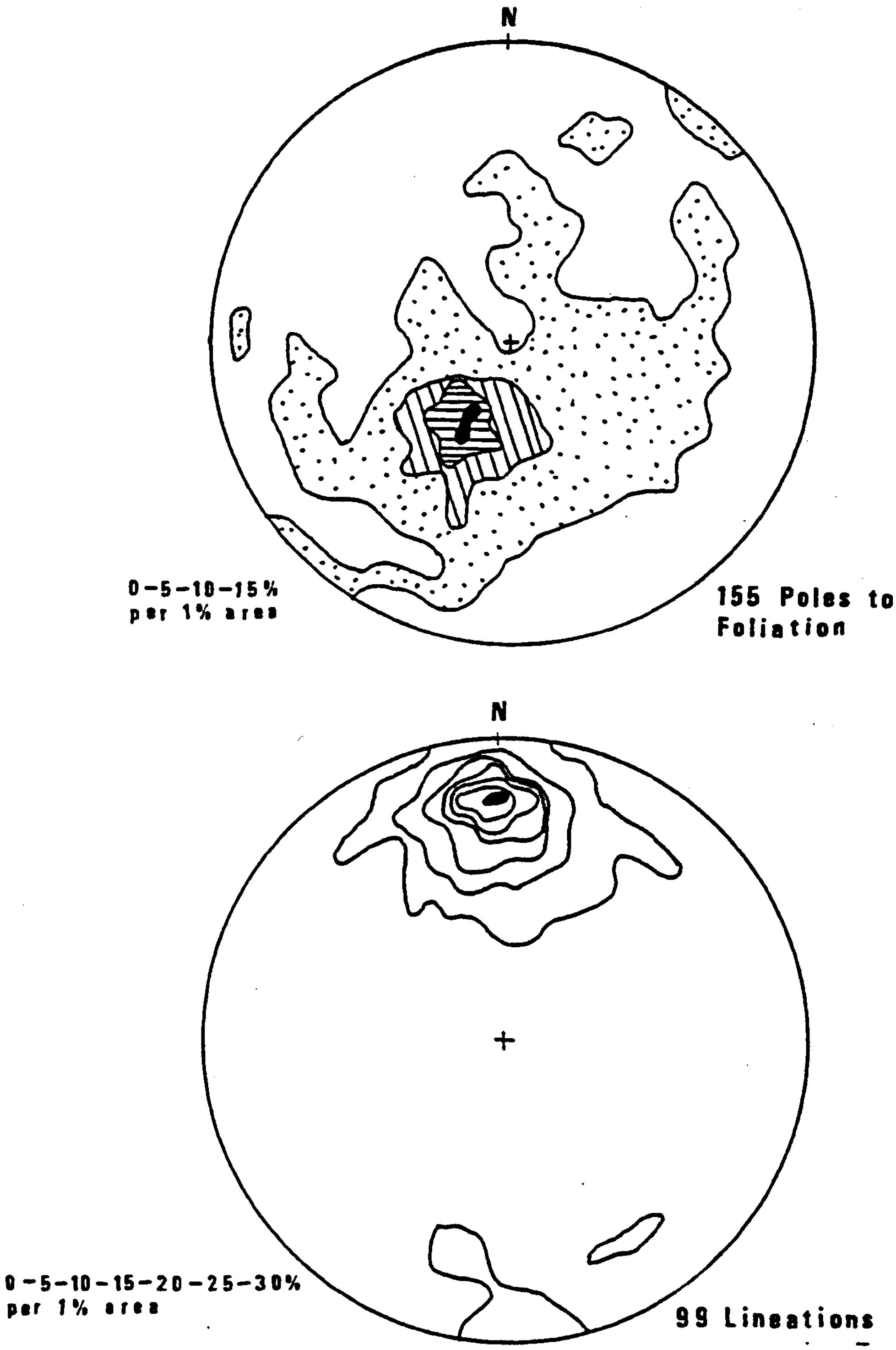


Figure 4. Foliation and Lineation Data.

Bolsa Quartzite

The quartzite is lineated tectonite wherever it crops out. A very strong mineral lineation and foliation penetrate the rock (Figure 5), and these elements are defined by the orientation of streaked plates of muscovite and biotite as well as by flattened, elongate quartz grains. The structural petrology of this lithology will be addressed in detail in a later section.

In thin section, the plastic deformation of the quartz is apparent. The grains are undulose and partially recrystallized, and flattening has been extreme. Both original and recrystallized grains are deformed, and original grain shape is not preserved. Within individual lenses of quartzite, a great variation in strain is evident in thin section. The average long dimension of grains is at least an order of magnitude smaller in the tail of a lens than in the center. This average size includes measurements of both recrystallized and unrecrystallized grains, and some of the latter may be up to 5 mm long.

Sample Q1Y from the tail of a lens (Figure 6) is highly recrystallized. Grain size is small (0.02 mm), and subgrain boundaries are few. The grains are fairly equidimensional, and all are undulose. In sample Q4Y, from the center of a lens (Figure 7), subgrain boundaries and selvages of recrystallized grains are present in large original quartz grains. Elongation parallel to lineation is quite pronounced, although recrystallized grains are generally more equidimensional. The average long dimension for old and new grains is 0.1 mm, and undulatory extinction is ubiquitous.

Figure 5. Lineated Bolsa Quartzite.

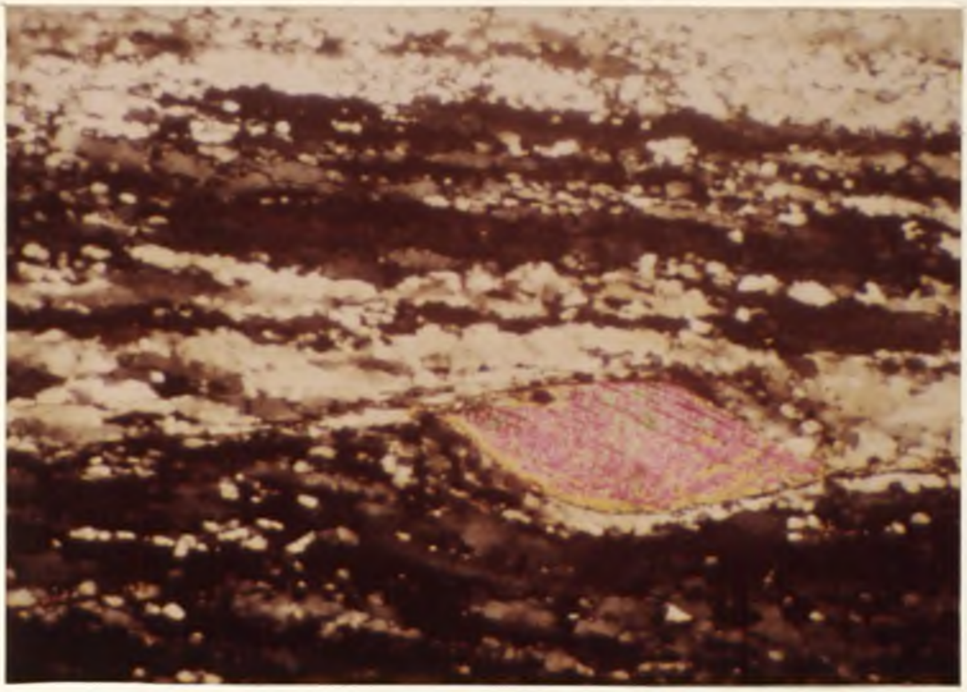


Figure 6. Quartzite Sample Q1Y. -- Sample from tail of a quartzite lens. Magnification X56.

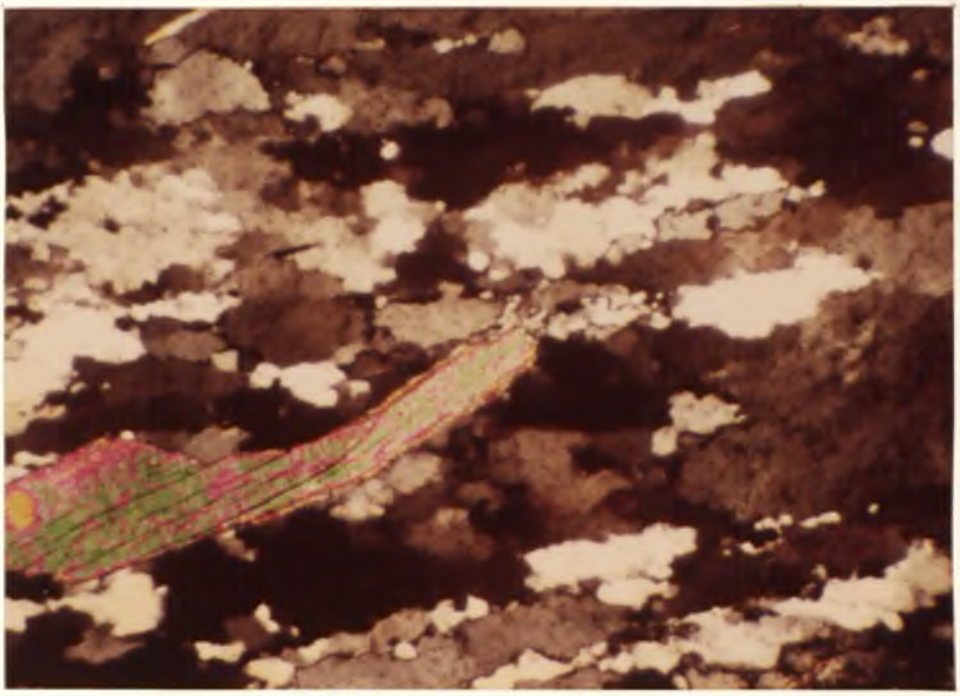


Figure 7. Quartzite Sample Q4Y. -- Sample from center of a quartzite lens. Magnification X56.

Small pinch and swell features with wavelengths of 1-10 cm occur locally in the quartzite, and the foliation and lineation have been warped by these small structures (Figure 8). Where quartzite layers are quite thin (0.5 cm) and alternating with thin concordant veins of pegmatite, this pinch-and-swell feature more closely resembles mullion structures whose presence is due to the contrasting ductilities of the two media (Figure 9). The long axis of the "ripple" features is oriented perpendicular to the trend of the lineation.

Small normal faults occur locally in the quartzite, and slip ranges from 1 mm to 20 cm in the direction of plunge of the lineation. Faults with very small displacements occur within and parallel to the troughs of the pinch-and-swell features (Figure 10). Normal faults with larger amounts of slip (up to 20 cm) are rare, but affect both quartzite and pegmatite (Figure 11). All normal faults offset foliation and lineation.

Thin section examination reveals the ductile nature of the small normal faults. In the necked regions of the pinch-and-swell structure, north-dipping steep surfaces of shear have developed, but there is no structural discontinuity across many of them. Figure 12 illustrates a delicate shear zone cutting through the necked region of such a structure. It steps down, across, and through the layers, but no open fracture occurs. Thinning in this region is about 30%, and grain size is smaller compared to the bulging region.

The light and dark banding visible in quartzite outcrops may represent relict bedding. The foliation is generally subparallel to

Figure 8. Pinch-and-swell Feature in Bolsa Quartzite. -- Thin pegmatite veins have also been affected.

Figure 9. "Corrugated" Outcrop with Surface Parallel to Layering of Quartzite and Pegmatite.

Figure 10. Small Normal Faults in Quartzite.

Figure 11. Normal Fault. -- Offset is 20 cm.

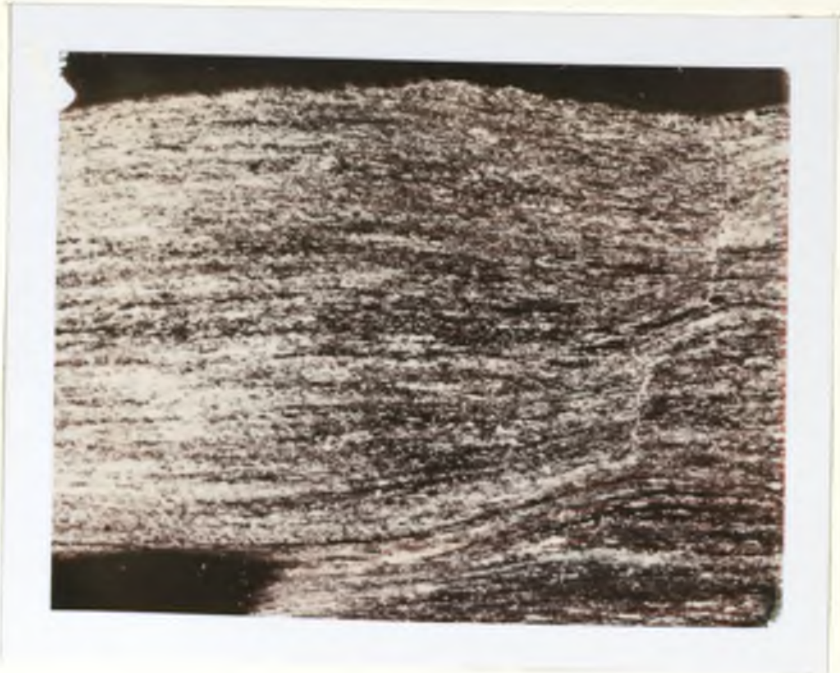


Figure 12. Shear Zone in Necked Quartzite. -- Magnification X1.8.

this layering, but the angle between the two may be as great as 30°. There is evidence that this relict bedding may have been isoclinally folded and transposed. The strong overprint of the foliation and lineation in this rock has obscured these structures, and the homogeneous nature of the quartzite makes relict bedding hard to discern.

Abrigo and Martin Formations

These calc-silicate lithologies behaved differently than the Bolsa Quartzite during the lineation-producing deformation. The foliation and lineation occur locally in these rocks, but they are not penetrative at the same scale as in the quartzite. In general, the calc-silicate rocks are recrystallized and metamorphosed, but are not everywhere tectonized. Folds are present in these rocks at some locations, and are abundant at the arroyo exposure pictured in Figure 13.

The stereographic projection of poles to foliation in all rock types (Figure 4) shows a strong concentration of measurements in the southwest quadrant. The projection includes measurements of surfaces in the Abrigo and Martin Formations which probably represent bedding that has been folded. These folded surfaces dip to the west and northwest and impart a distinct, but low-density scatter of poles into the southeast quadrant of the projection.

Thin section examination reveals that some apparently undeformed rocks are actually penetratively deformed, but the style of deformation is subtle as its expression depends on the quartz and feldspar content of the rocks. In rocks with a substantial quartzo-feldspathic

Figure 13. Folded Calc-silicate Rock.

fraction, streaked feldspar grains and a foliation defined by flattened quartz grains are visible in hand sample. In thin section, quartz and feldspar display undulatory extinction, fracturing, shearing, and recrystallization. The companion minerals--epidote, garnet, and diopside--remain unstrained. Thus, there are layers and pockets of deformed quartz and feldspar in otherwise relatively undeformed rock (Figure 14). Identification of the penetrative deformation in the calc-silicate rocks may be accomplished with certainty only through thin section examination.

Diorite

The diorite rocks are locally foliated. Lineation has not been recognized, although G. H. Davis observed lineation in biotite quartz diorite at the fold locality in Figure 13 (personal communication, 1980). The finer-grained varieties, particularly the biotite quartz diorite, appear most susceptible to deformation. There is, however, no systematic, widespread structural imprint imposed on the diorites by the lineation-producing deformation.

Roadside Formation

The internal deformation within this volcanic unit is intense, but has been limited to brittle fracturing, faulting, and shearing. Primary markers such as layering are rare in this massive rock, so structures are difficult to discern. Near the decollement, the rock appears shattered and almost unrecognizable except for the purple-grey color of the gouge which has been produced.

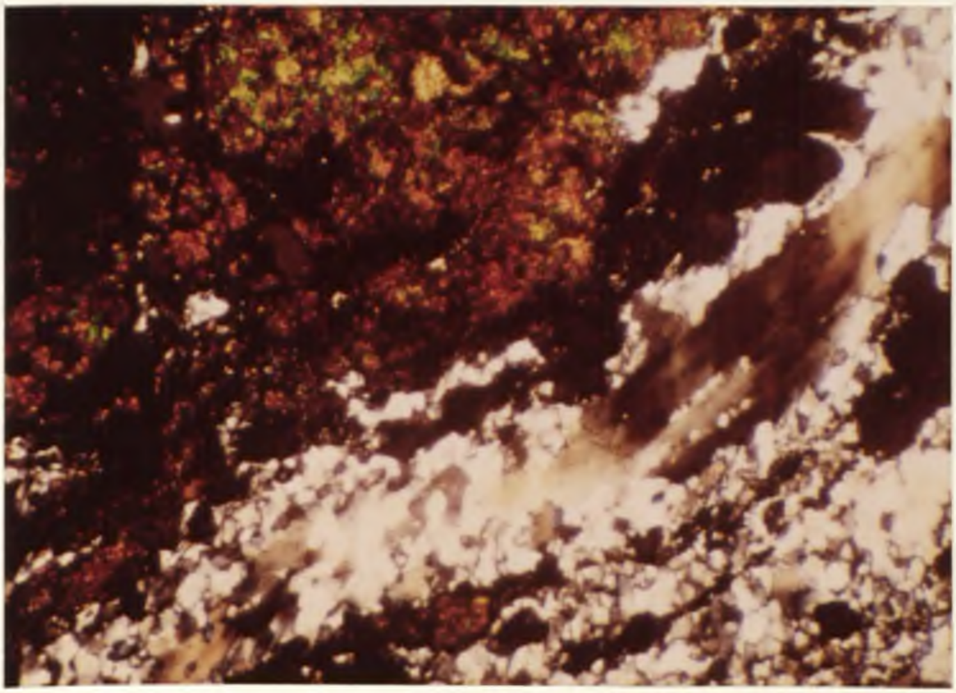


Figure 14. Typical Calc-silicate Metamorphic Assemblage. -- Mineralogy is quartz, feldspar, garnet, epidote, and diopside. Magnification X56.

Sand Wells Formation

The conglomerate, sandstone, and siltstone of this unit display a brittle style of deformation expressed by abundant fractures, faults, and shear zones. Close to the Ajo Road decollement, these rocks are progressively shattered to the point that they constitute a pink-maroon paste along the fault proper. The variability in dip direction of the clastic rocks suggests folding and faulting in these sedimentary rocks, but exposures are too poor to permit positive identification of such structures.

Pan Tak Granite

The coarse-grained young phase of the Pan Tak granite has developed a strong foliation and lineation which may be considered penetrative within the constraints of its grain size and mineralogic heterogeneity. The quartz grains show features typical of plastic deformation--undulatory extinction, grain elongation, and recrystallization. A great deal of the strain in the granite is accommodated in the quartz component of the lithology, while the feldspar fraction has been merely fractured and sheared (Figure 15).

This style of deformation on the microscopic scale is also characteristic of the pegmatite phase. However, the planar element of foliation in the coarse-grained granite and in the quartzite is not exactly correlative with the planar element in the pegmatite. Discrete slip surfaces exist in the pegmatite, and these are not uniformly distributed through the sills. These surfaces are well-developed at the margins of the pegmatite bodies, but they are not strictly penetrative

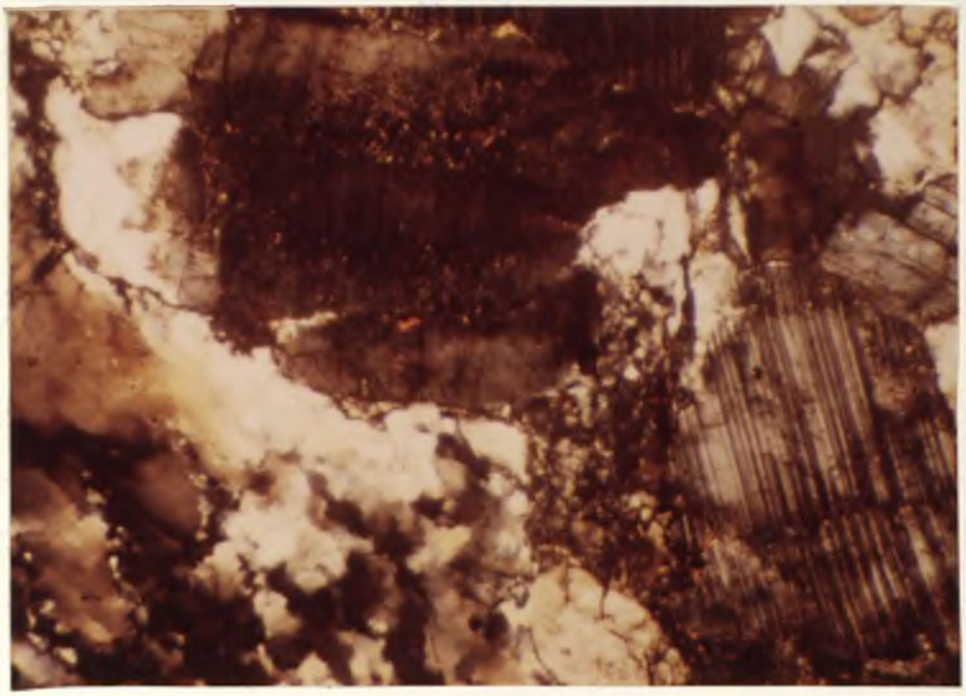


Figure 15. Deformation Texture in Granite. -- Plastically deformed quartz adjacent to brittlely fractured feldspar. Magnification X56.

(Figure 16). They become very closely spaced as the pegmatite boundaries with quartzite are approached and then become penetrative within the quartzite as a true foliation. They are curviplanar, strongly lineated, and parallel the form of the pegmatite contacts.

Where sedimentary rock packages are insignificant within large volumes of pegmatite, as in the southeastern part of the map area, fairly widely spaced slip surfaces are developed through zones as much as 100 m thick. The slip-surface zones are separated by undeformed rock, and these alternating bands of deformed and undeformed rock, although their boundaries are vague, may be traced east-west for hundreds of meters.

In addition to these shallowly-dipping slip surfaces, steeply northeast-dipping, curviplanar surfaces which are also lineated occur within the pegmatite. Their steep attitudes tend to become shallow down-dip with a sympathetic change in the plunge of the lineation (Figure 17). These steep slip surfaces are less prevalent in the interiors of the sills, but some poorly developed surfaces may be found there as well.

The shape of the pegmatite sills is that of large-scale pinch and swell (Figure 18). A discussion of the primary versus tectonic origin of the form of the sills is deferred to a later section.

Lamprophyre Dikes

The only structural feature present in the dikes is high-angle jointing. A north-south set of fractures is the most prevelant, but a

Figure 16. Lineated Slip Surfaces in Pegmatite.

Figure 17. Steep (70^{o}) Lineated Slip Surface.

Figure 18. Pinch and Swell in Pegmatite Sills. -- Thinning is up to 50%. The saguaro cactus below the center of the picture is about 3 m tall.

subordinate east-west set is present as well. No evidence for ductile deformation was found (Figure 19).

Ajo Road Decollement

The distinctively deformed terrane of the Coyote Mountains is tectonically juxtaposed against the Roadside Formation and Sand Wells red beds by the Ajo Road decollement. Slickensides plunge steeply at 40-60° to the north on the fault surface, and normal movement is indicated from the stratigraphic and lithologic relations. The decollement trends west-northwest and dips north at an average of 45° (Davis, in press). In detail it is curviplanar with a sinuous trace along the mountain-pediment interface (Figure 20).

The hanging wall rocks consist of the Roadside Formation overlain by the Sand Wells Formation. These rocks are everywhere moderately fractured, but in the vicinity of the decollement they are shattered and assume a pasty, gougy appearance. At one exceptionally fine exposure, a sliver of intensely sheared Roadside Formation crops out along the fault surface as the lowest member of the upper plate. It is overlain by similarly deformed red beds of the Sand Wells Formation. At all other exposures of the fault in the map area, the Roadside Formation is absent and the red beds occupy the lowest structural position in the hanging wall.

The footwall rocks cut by the Ajo Road decollement consist primarily of Pan Tak granite and pegmatite, and lamprophyre dikes. A brittle, mylonitic foliation spatially associated with the decollement overprints the earlier, more ductile, mylonitic foliation in the Pan Tak

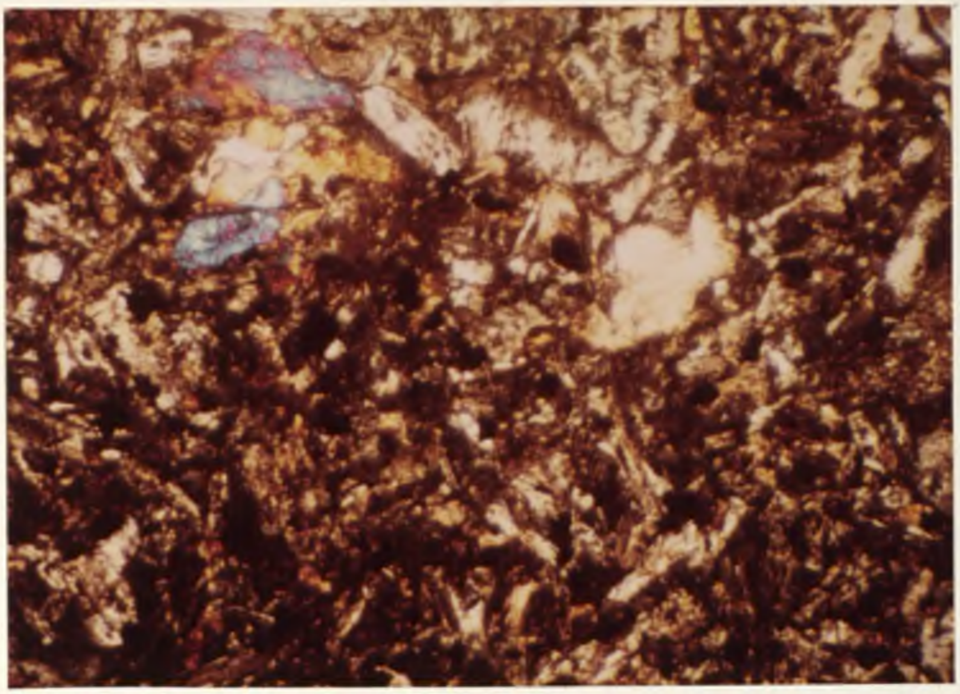


Figure 19. Undeformed Lamprophyre Dike. -- Magnification X56.

Figure 20. Plane of the Decollement (Dark Slope in Middle Ground).

phases. This decollement-related imprint is characterized by intense brecciation of the footwall rocks, and faint foliation associated with this faulting event is measurable in outcrop. The outcrop expression of the footwall near the decollement is that of a brown-to-green, chloritic, tabular mass of rock whose protolith may be determined only from field relations. The mineralogy in hand sample is indeterminable, and alteration and brecciation are so extreme that one of the most notable features of the rock is its fissile but shattered character (Figure 21).

The intensity of brittle mylonitization in these rocks decreases rapidly down and away from the decollement, although a clear cataclastic overprint is visible through at least 100 m of rock. This penetrative decollement-related fabric diminishes in pervasiveness structurally downward, where the zones of slip surfaces, described earlier, are the dominant style of deformation.

In thin section, the rocks of the decollement are true mylonites, and subangular to subrounded fragments floating in comminuted groundmass attest to intense movement on the fault (Figure 22). The nature of the mylonitic foliation is visible in outcrop. In thin section, brittle mylonitization and brecciation can be seen to overprint previously deformed granite and pegmatite. Locally, quartz veins lace the mylonite, and the quartz is unstrained and unrecrystallized.

Tohawaw Canyon Fault

The high-angle Tohawaw Canyon fault strikes nearly north-south, normal to the Ajo Road decollement. It postdates formation of the

Figure 21. Outcrop Appearance of Pegmatite(?) in the Ajo Road Decollement.

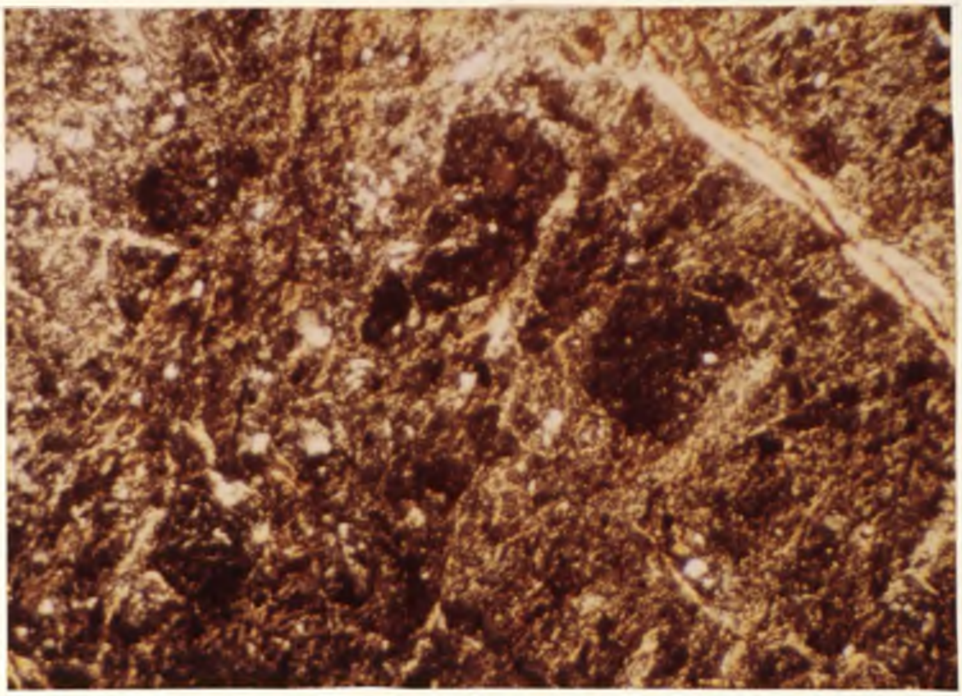


Figure 22. Mylonitized Pegmatite(?) in Thin Section. -- Magnification X56.

tectonite fabric in the Coyote Mountains, since there are blocks of lineated rocks which are rotated in the fault system. Calc-silicate rocks along the fault zone itself are quite altered, and solution movement is indicated by a near-vesicular texture exhibited by some rocks.

The Tohawaw Canyon fault parallels the Pan Tak fault, which lies about 2 km west of the study area. Both faults show right-slip movement, but the sense of rotational movement of the east and west blocks across each fault is different. Wargo (1954) noted that the block east of the Pan Tak fault was rotated so that the south end moved up. However, across the Tohawaw Canyon fault it appears that the south end of the block west of the fault moved up with respect to the east block. Both faults are similar in the dimension and nature of the fault zones and are probably related to the same deformation. The intersection of the Tohawaw Canyon and Pan Tak faults with the Ajo Road decollement is covered by alluvium, and their structural relationship is unknown.

Joint Systems

Two prominent, near-vertical joint systems affect the Coyote Mountains. They trend orthogonally, east-west and north-south, and appear to be strictly extensional features. The trace of the north-south joint set is subparallel to the trend of the mineral lineation. Although aperture ranges from hairline cracks to at least 4 m, no offset was detected across the joint planes to indicate any shear component. A possible exception to this is small normal faults found in the quartzite which strike east-west. While the timing of these faults cannot be definitely established with respect to initiation of jointing, the style of the two planar elements is different, and it is likely that the jointing is a later overprint throughout the range.

Structural Petrology

A petrofabric analysis of the Bolsa Quartzite and Pan Tak pegmatite was undertaken in order to clarify and resolve some of the details of the lineation-producing deformation. Specifically, the nature and variation of the internal movements within the two lithologies were studied through conventional thin-section examination in conjunction with universal stage methods for oriented thin sections.

Eleven oriented samples were collected, and three mutually perpendicular thin sections were cut from each. The oriented sections were cut parallel and perpendicular to foliation and lineation at each locality. The samples include eight quartzite specimens from Tohawaw Canyon, six of which were taken along a single quartzite sigmoidal lens at about six meter intervals. The remaining three samples were of pegmatite, one from Tohawaw Canyon, one from immediately below the Ajo Road decollement, and one from a ridge about one kilometer east of Tohawaw Canyon.

The universal stage technique described by Knopf and Ingerson (1938) was employed for determining the orientations of c-axes of quartz in the samples, and approximately 250 measurements were made for each. The section cut normal to foliation and parallel to lineation was chosen for study because of the ease with which true extinction in the grains of these samples could be achieved. It is felt that measurements in this oriented section were sufficient to determine the true quartz subfabric in the rocks, as no grains were encountered in the widely spaced traverses which could not be brought to extinction. In addition, a total of 80 measurements of poles-to-cleavage in micas were made in the two sections oriented perpendicular to foliation for each sample. The pegmatite sample CM-40 contained only very fine-grained sericitic material, so only a quartz subfabric was determined in this specimen.

The data from this microscope study were converted to numerical form to be used in the unpublished computer program, USTA, of Dr. George H. Davis. The results were plotted on lower-hemisphere, equal-area stereonets by the Calcomp plotter at The University of Arizona as density distributions of percentage of measurements per one percent area.

The diagrams for all the samples exhibit a strong maximum or split maximum located at a high angle (60-90°) to the lineation and within or very near the plane of the foliation. The symmetry of these diagrams is near orthorhombic in several of the quartzites (e.g., Q1Y, Q3Y, Q4Y, Q6Y), but in detail they are strictly monoclinic to triclinic.

The symmetry of the mica subfabric for all the samples is axial, and thus will not affect the overall fabric symmetry. When the noncrystallographic fabric elements, the foliation and lineation, are considered, the overall symmetry is restricted to monoclinic for most samples. Triclinicity becomes apparent in the pegmatite sample, CM-40, from directly below the decollement (Figure 23) and also in sample CM-45.

A contrast in the c-axis distribution between the quartzites and pegmatites is evident. Although strong maxima are developed in both

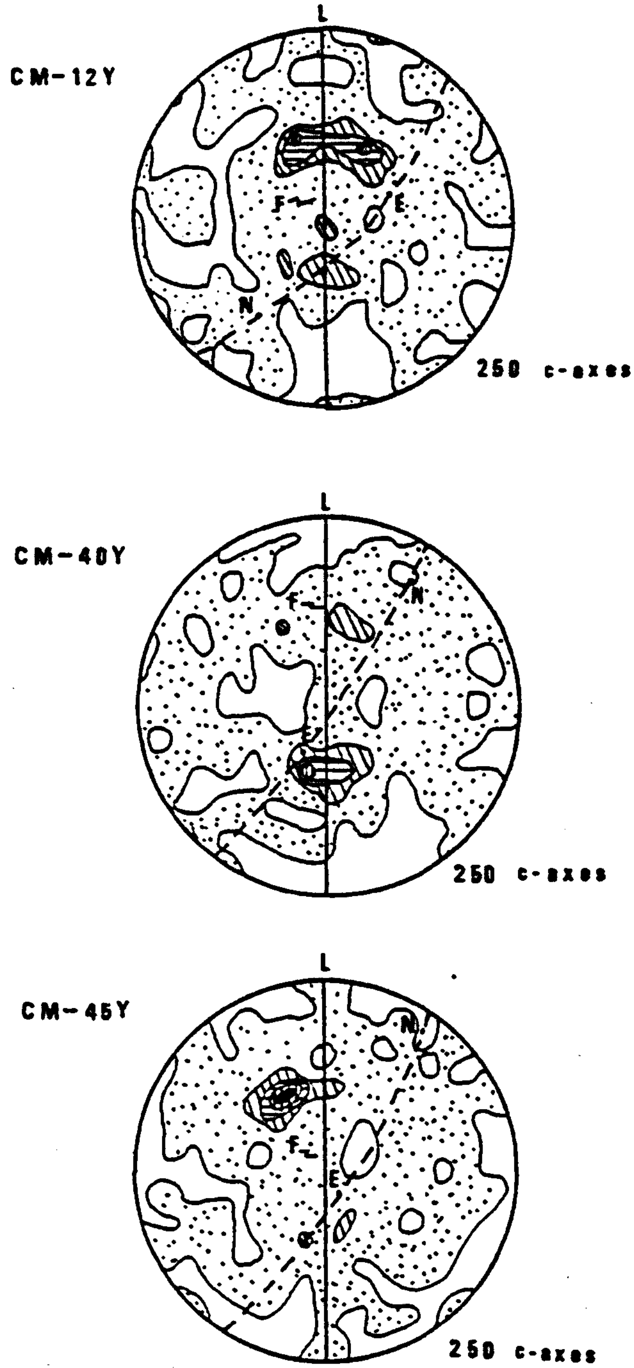


Figure 23. Quartz Fabric Diagrams for Pan Tak Pegmatites. -- Contour interval 0-4-6-8-10% per 1% area. F = foliation, L = lineation, N = north, E = east.

lithologies, there is a much greater scatter of low densities in the c-axis distribution in pegmatites (Figure 23). This is probably a function of the high feldspar content, which would produce perturbations in the manner in which neighboring quartz grains would deform. The attitudes of the maxima are generally concordant with those in the quartzite specimens.

The quartzite lens which was sampled in detail is located in the lower portion of Tohawaw Canyon. The six samples from the east wall exposure of the lens show a subtle progression in the quartz fabric from the tail to the interior of the sigmoid (Figure 24). In the most highly strained portion, the tail, the two maxima lie at a high angle to the lineation. In samples Q3Y and Q4Y the intensity of the maxima alternates until one predominates midway along the lens at Q5Y. This maximum shifts slightly in Q6Y, and Q7Y, which is located at the transition from the center of a lens to the tail, exhibits the initiation of a weak second maximum which may develop to repeat the pattern at Q1Y farther along the tail of the lens. Q1Y and Q7Y, at each end of the lens, both show c-axis girdles inclined at an acute angle to the foliation. The girdles in the intervening samples maintain parallelism and coincidence with the foliation.

Sample Q9Y (Figure 25) is also from this lens, but was taken about 70 m to the west. Its c-axis distribution does not indicate that there is any dramatic change laterally in quartz subfabric within a lens.

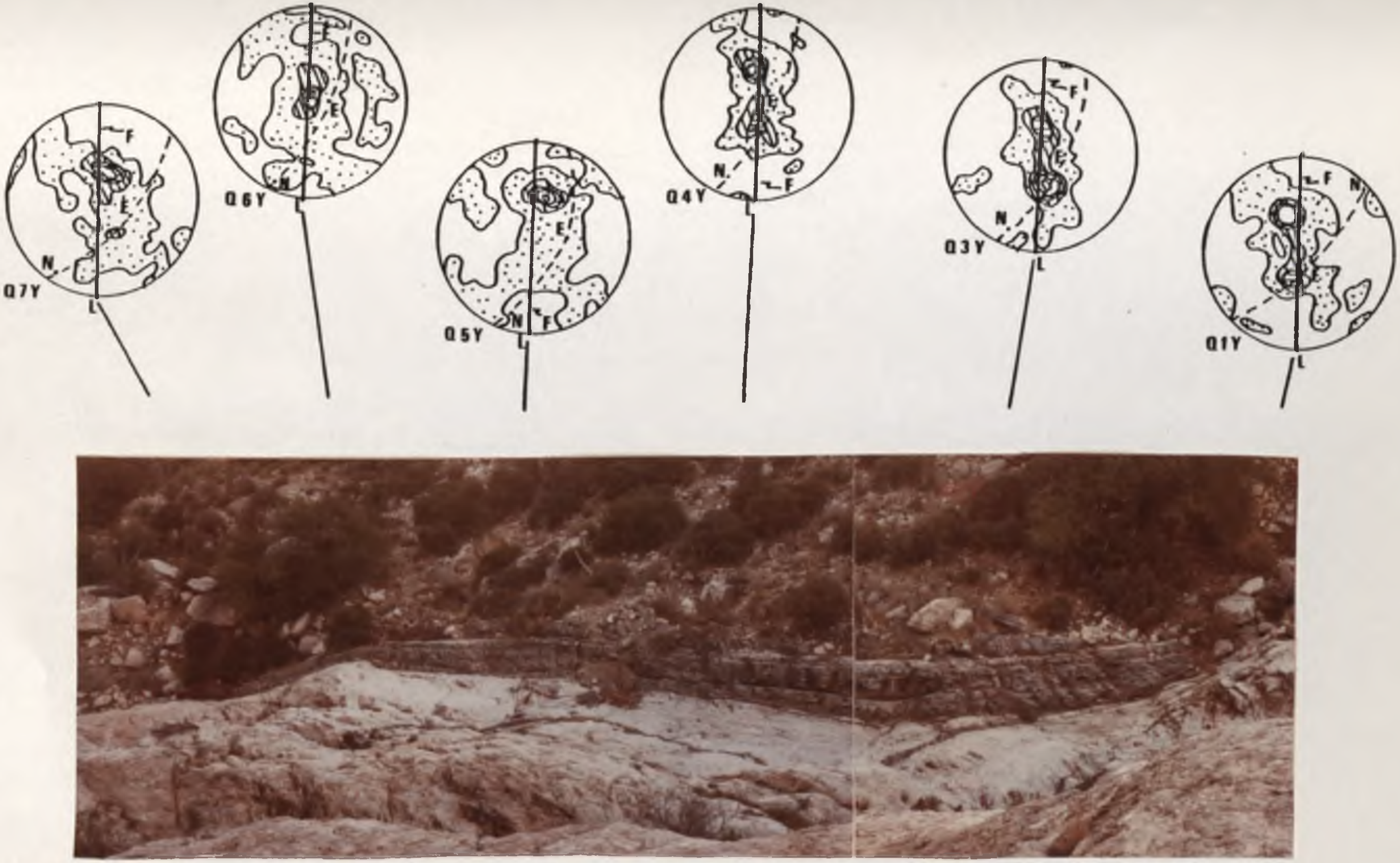
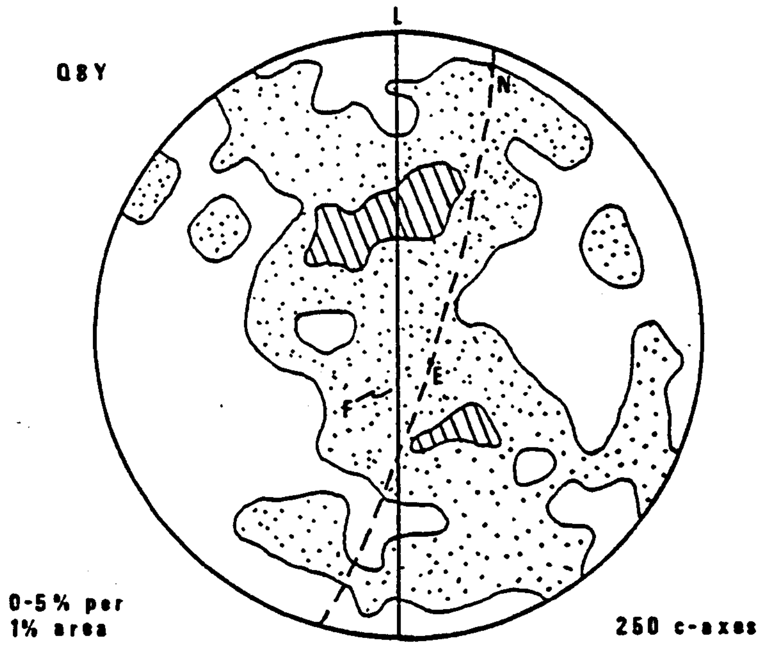


Figure 24. Quartz Fabric Diagrams for Lens in Tohawaw Canyon. -- 0-5-10-15-20% per 1% area, with 250 measurements for each sample. F = foliation, L = lineation, N = north, E = east.



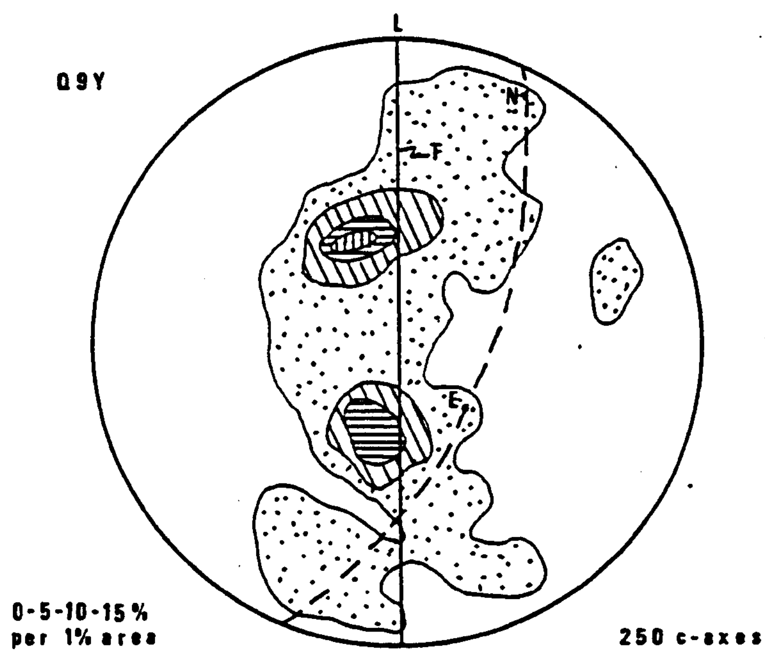


Figure 25. Quartz Fabric Diagrams for Samples Q8Y and Q9Y. -- F = foliation, L = lineation, N = north, E = east.

Sample Q8Y (Figure 25) is taken from the structurally lowest quartzite lens exposed in the shell of strained rock, and the degree of preferred orientation is substantially less than for the other quartzite samples. It is interesting to note that this sample appears as deformed in its outcrop expression as the quartzite from structurally higher levels. Its more diffuse c-axis distribution and low maximum concentration are evidence for an appreciable strain gradient with the degree of strain diminishing downward. The structural thickness separating the lens of Q8Y from the other quartzite lens sampled in detail is no more than 10 m.

The symmetry of all these orientation diagrams is orthorhombic, at a first approximation, but it is reduced to monoclinic when the unequal intensities of maxima or their asymmetric position with respect to foliation are considered.

An important feature of all the orientation diagrams is the pole-free areas perpendicular to foliation and parallel to lineation. Assuming that the normal to foliation represents an axis of shortening and that the lineation represents an extensional axis, the c-axes of quartz in these samples cluster about the intermediate axis, Y. Such distributions have been produced experimentally as discussed by Wilson (1975), and they arise when prismatic slip predominates over slip on the basal plane of quartz. Griggs and Blacic (1964) demonstrated that slip on $(10\bar{1}0)$ becomes more important than slip on (0001) at temperatures greater than 700°C at a strain rate of 10^{-5} sec^{-1}. Bouchez (1977) noted a c-axis maximum at the Y axis where prismatic slip in a basal direction was operative at relatively high temperatures. Tullis, Christie, and Griggs (1973) obtained similar results at high temperatures with slow strain rates and high strains. It must be noted, however, that the temperature at which prismatic slip becomes dominant in nature will be affected by many factors, including water content and slower strain rates. It is apparent from these diagrams that basal slip was essentially not operative by the time the quartz fabric was "frozen" in the rocks. There is clear indication that this shell of deformed rock was subjected to a respectable grade of metamorphism.

CHAPTER 4

INTERPRETATIONS

The contact relationships between the pegmatite and quartzite are enigmatic, and it is difficult to distinguish to what extent the intrusive nature of the contact has been modified tectonically (Figure 26). The style of deformation of a pegmatite sill as a whole is problematic, since mesoscopic evidence for such deformation is difficult to attribute unequivocally to a tectonic origin. The pinch-and-swell morphology of the sills may be the original shape of the intrusions, or they may have had generally planar boundaries with slight irregularities which were accentuated during deformation to produce the pinch-and-swell features (Figure 27). An actual increase in surface area may then have been involved, with the quartzite lenses essentially being stretched over the enlarging surface. In outcrop the quartzite appears tightly plated onto the curved pegmatite surfaces (Figure 28).

The fact that the pegmatites are deformed is unmistakable from thin section observations. It is equally clear that the quartzite in necked regions is more deformed than quartzite in bulging areas. Pegmatite intrusion alone cannot have produced the deformational features in the quartzite. At the time of intrusion, the axis of extension was oriented perpendicular to the pegmatite sheets; that is, it was normal to the plane which is now parallel to foliation. The lineation now penetrating the rocks, particularly the quartzite, is defined not only

Figure 26. Complex Contact of Pegmatite and Quartzite. -- This relationship occurs at the tail of a lens in Tohawaw Canyon.

Figure 27. Pegmatite Sill in Upper Tohawaw Canyon.

Figure 28. Quartzite Draped(?) over Pegmatite.

by the orientation of micas on foliation surfaces, but also by the elongation of the quartz grains themselves in both necked and swelled regions. This lineation, also defining an axis of extension, lies in the plane of the foliation, trending north-northwest. The occurrences of wide zones of lineated slip surfaces implies that deformation followed crystallization, since a liquid or even a partially crystallized magma could not sustain the shear stress needed to produce those surfaces. Additionally, the rocks at the west end of the Coyote Mountains have not been tectonized or deformed by the lineation-forming event, even though pegmatite swarms have intruded the country rock there.

The significance of the difference in character of the planar element from quartzite to pegmatite lies in the rheological properties of the two materials. It has been established that quartz deforms more plastically than feldspar (Lister, Paterson, and Hobbs, 1978). The Bolsa Quartzite, having been engulfed and dilated by pegmatites, provided ductile pockets of material within which slip and differential movement were more easily accommodated than in the surrounding pegmatite. A change in frequency of available slip surfaces occurs as the contact into pegmatite is passed, with the spacing of slip surfaces increasing dramatically away from the quartzite contact.

This relationship is strikingly displayed in the Tohawaw Canyon area where the Bolsa Quartzite is present. More commonly elsewhere in the northern Coyote Mountains, the pegmatite has yielded through broad slip surface zones, in contrast to the attenuated slip zones which develop where quartzite occurs. To a lesser extent, the calc-silicate lithologies perform the same structural function as quartzite.

Petrofabric Analysis

A great deal of controversy has been focused on the inferences of deducing simple shear versus pure shear from orientation diagrams. It is established that an orthorhombic fabric symmetry reflects orthorhombic symmetry of causal movements, but Paterson and Weiss (1961) stress the need for caution in such correlation of pure shear with orthorhombic movement (or of simple shear with monoclinic movement). Experimental work (Tullis, 1977) and computer-modeling studies (Lister, 1974) have shown that some relationship does exist between fabric symmetry and the nature of the causative shear. The results of such studies are important here.

The symmetry of the fabrics in the Coyote Mountains rocks is remarkably systematic within and between the Bolsa Quartzite and the Pan Tak granite, and it appears that the deformational textures and features in the rocks were produced during a single progressive event or phase. There is no indication of any relict fabric of an earlier deformation remaining in the quartzite subfabric, although folds and faults in the Abrigo and Martin Formations are clear evidence that progressive deformation took place.

The quartz has responded readily to the deformation, presumably under conditions which are approximated by the experimental results described by Bouchez (1977) and Wilson (1975). The temperature of 700°C found for the predominance of prismatic slip over basal slip is probably an upper limit. Factors such as water content and very slow strain rates may lower the activation temperature in nature (Wilson, 1975).

Nevertheless, a relatively high temperature is indicated for the Coyote Mountains by the extraordinary degree of preferred orientation in the quartzite samples. Maximum preferred orientation is commonly less than 12% in quartzites studied elsewhere (Bell and Etheridge, 1976), but in the Coyote Mountains concentration reaches 24.8%.

The symmetry of most of the fabric diagrams is monoclinic; however, there is a strong suggestion of an orthorhombic component. The unequal intensity of maxima is the main factor imparting monoclinicity to the fabrics. The development of asymmetry implies that the path of progressive deformation may have been complex. Considering the ease with which quartz reacts to deformation, it is probable that the effects of only the final stages of the deformation are preserved (Carreras, Estrada, and White, 1977; Lister and Price, 1978). The most significant aspect of these last stages is the initiation of movement to produce a monoclinic overprint on a previously well-developed orthorhombic fabric.

The nature of the orthorhombic movement cannot be determined from the diagrams, but the style of deformation of the pegmatite sills and quartzite bodies indicates that flattening with extension parallel to lineation occurred. The pinch-and-swell morphology of the sills has been noted. This pinch-and-swell structure is also present on the same scale in the quartzite. Locally, actual disconnection occurs in the necked regions in quartzite, giving rise to separated lenses. The lenses are severed from each other in a manner akin to "inverse boudinage" (Smith, 1975). That is, a ductile layer embedded in more competent material experiences necking and disconnection analogous to flow of layers of gelatin between layers of clay when the layered package is flattened and extended.

Such a scenario implies a movement plan whose symmetry is orthorhombic and, assuming no volume change for the pegmatite and quartzite as a whole, is pure shear. This part of the deformation produces an orthorhombic fabric symmetry characterized by single or double maxima of quartz c-axes, symmetrically disposed to the developing foliation and lineation (Figure 29).

Asymmetry of movement plan (i.e., rotational strain) is introduced at this stage of the evolving fabric, which leads to a strengthening of one of the maxima in each sample or shifts it slightly out of symmetry with the foliation and lineation. The maximum which intensifies in a sample is nearly always the one which plunges to the northeast. The only exceptions to this are Q3Y and Q6Y, and the maximum in the latter is plunging almost due east. In all samples except CM-40Y, the stronger maximum, when two modes are present, is the one oriented at a smaller angle to the lineation. The difference in angle(s) between the maxima and lineation is not great; the maximum nearer the lineation is usually inclined at 55-60°, while the one farther from the lineation is about 60-65° away (Figure 30). The asymmetry imparted to the maxima may reflect a change from pure shear to simple shear by slip in the plane of the foliation and parallel to the lineation. The intensifying mode nearer the lineation could result from rotation of preferred orientation development in response to asymmetric, internal movements induced by simple shear.

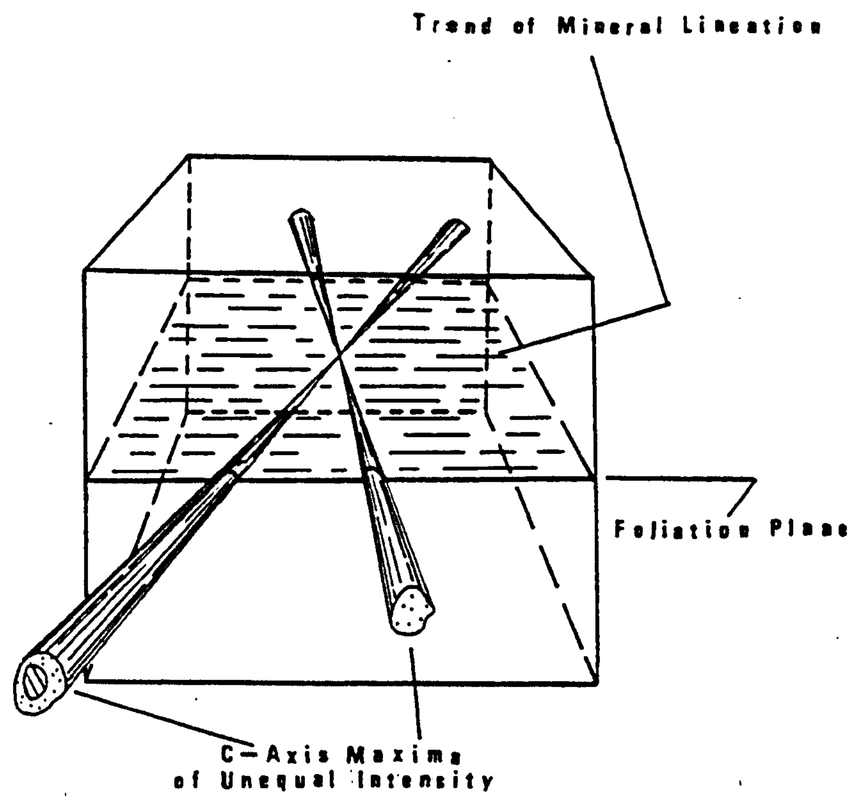


Figure 29. Geometric Relationship of Foliation, Lineation, and C-axis Maxima.

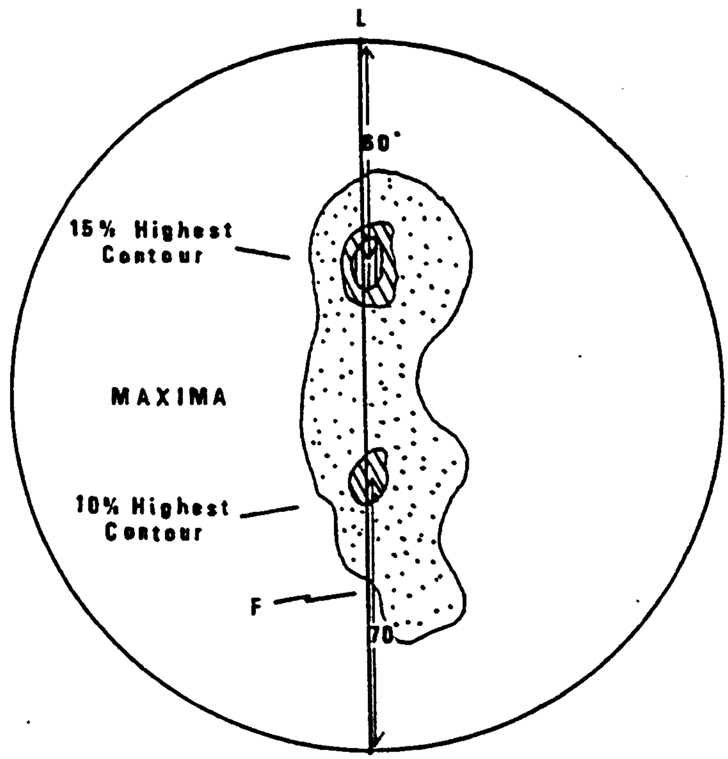


Figure 30. Angular Relationship between Lineation and Maxima. -- F = foliation, L = lineation, N = north, E = east.

Samples from the quartzite lens in lower Tohawaw Canyon (Figure 24) illustrate relatively constant angles between the maxima and the lineation for both the tail and the center of the sigmoid. The maxima in sample Q1Y maintain the same orientation with respect to foliation as those in Q4Y. However, the foliation in the tail is dipping 15 to 20° more steeply than the foliation in the center. This implies rotation or bending of the foliation in the late stages of deformation.

The kinematic scheme (Figure 31) envisioned for the lineation-forming deformation involves an initial pure shear which imparts a strong orthorhombic symmetry to quartz subfabrics in both quartzite and pegmatite. Flattening produces a penetrative foliation in hot, ductile quartzite layers, which also slip and flow parallel to lineation, and pinch-and-swell structures develop in pegmatite and quartzite. Slip surfaces form in the pegmatite sills adjacent to quartzite layers or through broad zones where ductile sedimentary rock is absent. Quartzite layers neck and may become disconnected.

Initiation of a ductile normal fault structure occurs after appreciable flattening. Locally, this slippage may dismember the quartzite lenses, and the result is to produce an evolving sigmoidal shape in the quartzite bodies. The shear zones would form at 45° to the axis of flattening, but continued flattening rotates the zones to a shallower angle.

The orientation of the finite strain ellipse thus becomes scale-depending, as indicated in Figure 31. Within tail sections, the ellipse is oriented at up to 45° to that for the quartzite-pegmatite complex as

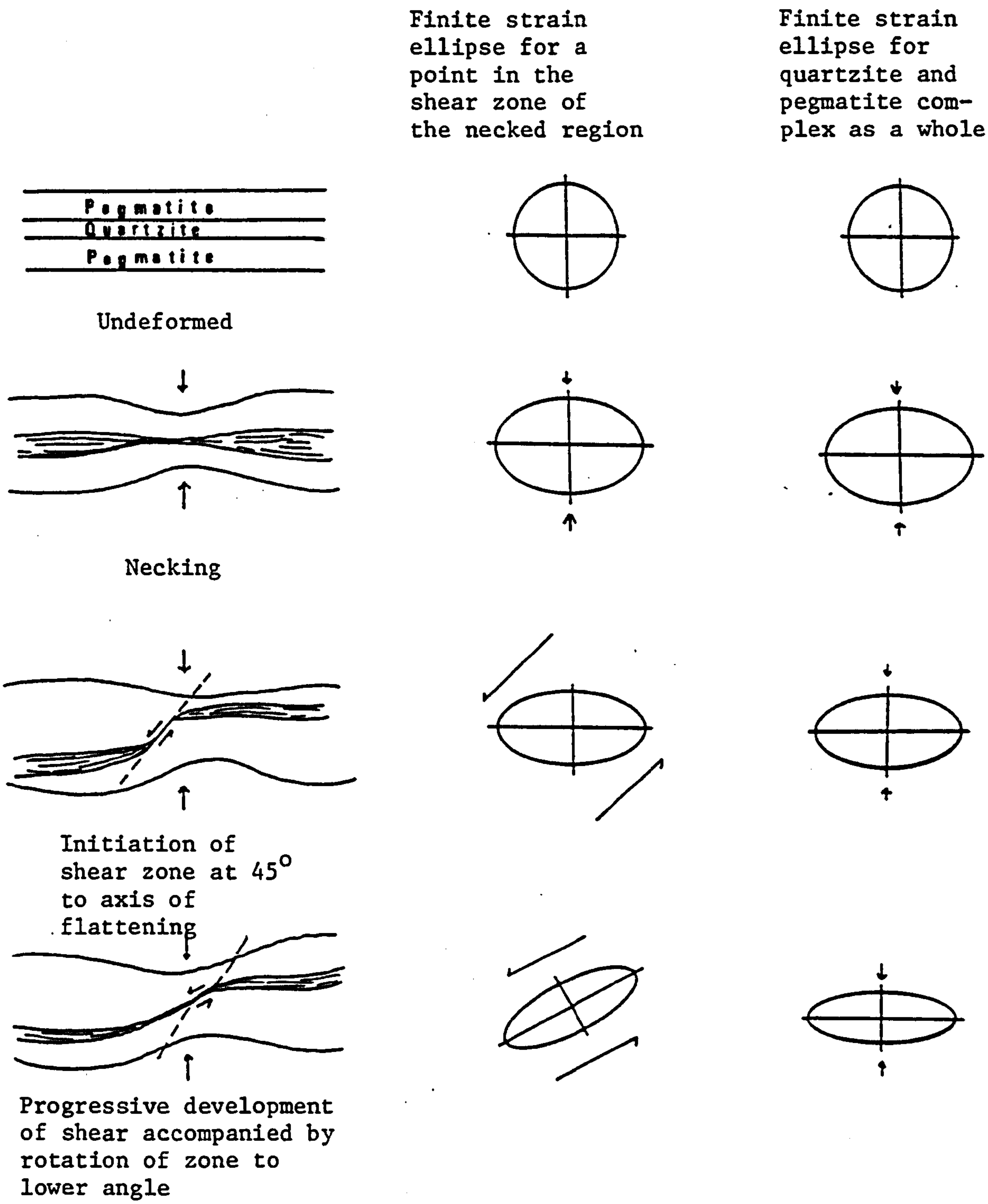


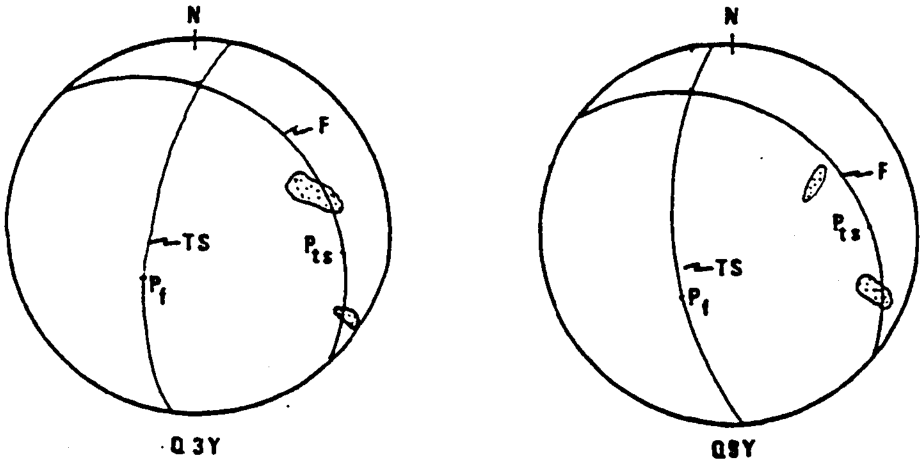
Figure 31. Scheme for Progressive Deformation in Pegmatite and Quartzite.

a whole. With continued flattening, the strain ellipse at any point is rotating toward parallelism with the overall strain ellipse.

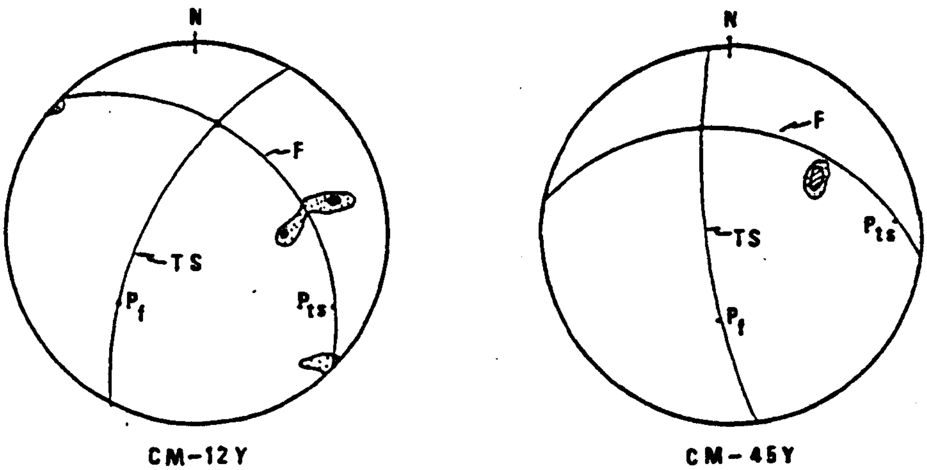
The orientation diagrams of Q1Y and Q7Y from the tails of the sigmoid support this interpretation (Figure 24). There is a slight inclination of the girdle to the foliation. The strain ellipse for these samples would be rotated into near parallelism with that for the samples in the center of the lens. The analog of this progressive deformation in pegmatite may be the formation of steep, lineated surfaces which merge down-dip with shallowly-dipping surfaces.

A quantitative description of the strain gradient through the shell of deformed rock is not easily constructed. The strongest field indication of the presence of such a gradient is the transition from strongly foliated, coarse-grained Pan Tak granite to the undeformed state, and of a similar change in style, very sporadically exposed, in the calc-silicate rocks. The inhomogeneous nature of all the lithologies except the quartzite has precluded a smooth strain gradient from developing. Instead, deformed rock occurs in diffuse zones below the decollement. Unfortunately, the quartzite was not found in an undeformed state to assess a smooth transition from strained to unstrained rock. Nonetheless, a definite decrease in preferred orientation and amount of strain is apparent in a sample at a low structural level.

In spite of a ragged strain gradient, it is interesting that orientation diagrams for quartz in pegmatites at various localities are quite similar in the positions of maxima. Figure 32 illustrates the



Quartzite



Pegmatite

Figure 32. Orientation Diagrams of Four Samples Shown in Geographic Space. -- F = foliation, P = pole to foliation, L = lineation, TS = thin section, P_{ts} = pole to thin section, N = north.

consistency in the quartz subfabric for several samples with data rotated into absolute geographic space.

Compton (in press) has analyzed quartz fabrics of the Elba Quartzite in the Raft River Mountains, Utah. This range has been subjected to a lineation-forming deformation, similar in style to that affecting the Coyote Mountains. Structural relationships in the Raft River Mountains are quite complex, and this is reflected in the three symmetry modes in the quartzite--orthorhombic, monoclinie, and triclinic. The c-axis distributions are unlike those for quartzite in the Coyote Mountains. Plane strain is indicated, although axial flattening and locally simple shear have affected the distributions. C-axis girdles are located about the axis of elongation in the samples that have orthorhombic symmetry, and basal and rhombohedral slip are interpreted as the orienting mechanisms in the quartz.

Asymmetry is present in some samples, producing monoclinic and triclinic patterns. Compton correlates the three symmetry modes with movements resulting in a progression from unfolded through folded rocks, even though extension was occurring simultaneously with folding.

Ajo Road Decollement

Although the Ajo Road decollement is an extensional feature, its relationship to the extensional, lineation-forming event is not clear. An undeformed lamprophyre dike intruding deformed pegmatite is truncated at the decollement, thus a deformational hiatus must have occurred between the lineation-forming episode and activation of the decollement.

The length of this hiatus is not known. The quartz subfabric of a pegmatite located about 3 m below the fault plane is similar to that for pegmatites elsewhere in the range (Figure 23, CM-40Y), which would indicate that at least some of the characteristics of the deformation were unchanged through the two events.

The decollement may have been activated as the culmination of the extensional plastic deformation imprinted on the northern Coyote Mountains rocks. Its character is somewhat intermediate between the ductile style of deformation exhibited in the Bolsa Quartzite and brittle faulting.

It is possible that the decollement is not a simple normal fault. Unstrained quartz in veins within the fault and variable development of mylonite in rocks below it hint that reactivation may have occurred at a later time.

A complete history of the decollement is not easily extracted from even thorough examination of exposures of the fault. The latest movement on the decollement is the only displacement that can be dealt with outside the realm of shear speculation. It is not known whether the effects of normal slip have masked earlier movements on the surface, and thus the total significance of the decollement in the scheme of Cenozoic tectonics cannot be established.

Roskruge Mountains

The relationship between the Coyote Mountains and the Roskruge Mountains is not clear, although they are only about 4 km apart at their closest points (Figure 33). The basin separating them is somewhat atypical of the Basin and Range Province. Instead of the usual thick sedimentary blanket filling the basin between the ranges, outcrops of Roadside Formation are present all across the valley.

The Roskruge Range has been sliced by innumerable, east-west trending faults. The nature of this faulting has not been well studied. Preliminary field examination indicates that they are probably high-angle faults and may have a component of normal movement across them. It is possible that the dacite to rhyolite volcanic rocks of the Roskruge Range (Bikerman, 1965) may be the extrusive equivalent of the Pan Tak granitic phases, and that the Roskruge rocks were originally structurally higher and possibly much closer to the Coyote Mountains. Normal faulting and tilting of structural blocks would have moved the Roskruge rocks overlying the Coyote Mountains down and northward, possibly with the Ajo Road decollement as the major surface of displacement. As previously noted, sheared Roadside Formation crops out at one locality at an anomalous structural level, and this could be explained as a smearing (plating) of the rock along the plane of slip.

The ages of the rocks do not contradict this hypothesis. The Roskruge rocks are from 8 to 16 million years older than the 58 m.y. Pan Tak granite (Roskruge dates from Bikerman, 1965), which is a fairly large age gap even when cooling of the pluton is considered. The relative ages of the rocks, however, do not preclude this hypothesis.

Figure 33. The Roskruge Mountains. -- Looking north from the Coyote Mountains to Bell Mountain.

Metamorphic Core Complex Model

The northern Coyote Mountains fits the model of a metamorphic core complex as outlined by Davis and Coney (1979). The Coyote Mountains lie within the "'Papago' domain" (Davis, in press), in which core complexes are characterized by north-south trending lineation.

The decollement in the Coyote Mountains is slightly steeper than is typical of core complexes and changes dip along its length. The zone of decollement-related mylonite below the fault varies in thickness along strike, but the upper contact with unmetamorphosed rock is sharp. The presence of lineated tectonite within a "core," a decollement zone, and the association of Tertiary volcanic rocks in the nearby Roskruge Range are concordant with the core complex model.

CHAPTER 5

SUMMARY

The lithologic and structural relationships in the northern Coyote Mountains are unconventional, but through careful mapping, supplemented by structural petrologic techniques, these relationships may be placed in a kinematic framework. Isolated shreds of sedimentary rock have localized strain whose gradient decreases with depth. The range abounds with extensionally-induced structures on all scales, and the rheological properties of each lithology has controlled the degree of development of the structures.

A brief synopsis of the geologic history of the Coyote Mountains contains some uncertainty in precise dates, but the relative timing is established with assurance.

A sequence of Paleozoic quartzite and carbonate was intruded by a series of diorites of varying textures and compositions. Folding and faulting within the Paleozoic rock sequence resulted when the older phase of the Pan Tak granite was intruded. The emplacement of the 58 m.y. Pan Tak granite phase with accompanying pegmatite sills enormously dilated and disrupted the existing lithologic package. In an aerial view of Tohawaw Canyon (Figure 34), the prominence of white pegmatite is clearly visible, and it is in this fortuitous deep incision that some of the fine details of the structural anatomy of the rind of deformed rock may be evaluated.

Figure 34. Aerial View of Tohawaw Canyon Looking South.

The ensuing Tertiary deformational event occurred post-58 m.y. and later than pegmatite injection. It was characterized by flattening and extension of the rocks on all scales. Profound heating and a large amount of strain have left a signature of ductile deformation, which has most strongly affected the Bolsa Quartzite.

Petrofabric analysis and field evidence indicate initial pure shear of the quartzite-pegmatite complex, producing flattening and pinch-and-swell structures, and an orthorhombic quartz c-axis distribution was established. Prismatic slip was the dominant mechanism of quartz deformation. Locally, simple shear was the deformational operator as indicated by the overprint of asymmetry on the quartz orientation diagrams, reducing their symmetry to monoclinic in most cases. During this part of the structural history, ductile normal faulting was initiated in a progressive deformational mode, which rotated tails of lenses to form sigmoids and formed steep, lineated slip surfaces in pegmatites. The veneer of deformed rock on the north side of the Coyote Mountains was completed as the deformation assumed a more brittle character, and displacement on the decollement was activated. The time span between cessation of the lineation-forming deformation and initiation of movement on the fault is unknown.

Mid-Miocene (listric?) denudational faulting, at least in part, accompanied formation of decollement surfaces. It is possible that the decollement represents a coalescence of listric normal faults. It has been shown in this study and in others (Davis, in press) that the decollement is a late feature in the deformational history of the Coyote

Mountains and in similarly deformed terranes such as the Santa Catalina-Rincon complex. It should be noted that slip-lines for denudation on decollement surfaces are subparallel to lineation (G. H. Davis, personal communication, 1980). Although formation of the lineated tectonite precedes decollement movement, the parallelism suggests that the two deformational phases may be related.

Figure 35 (in pocket) shows interpretive cross sections through the Coyote Mountains, and they illustrate the geometry of the sedimentary rock pods and the distribution and relationships of structural features.

The Cenozoic tectonics affecting the Coyote Mountains may have been a prolonged, multifaceted continuum or a series of extensional events punctuated by deformational quiescence. The thread of commonality in all the Tertiary and younger deformational events is their extensional nature, with a transition in the style of deformation from a ductile to a brittle response in the rocks, which may be a reflection of a regional cooling regime.

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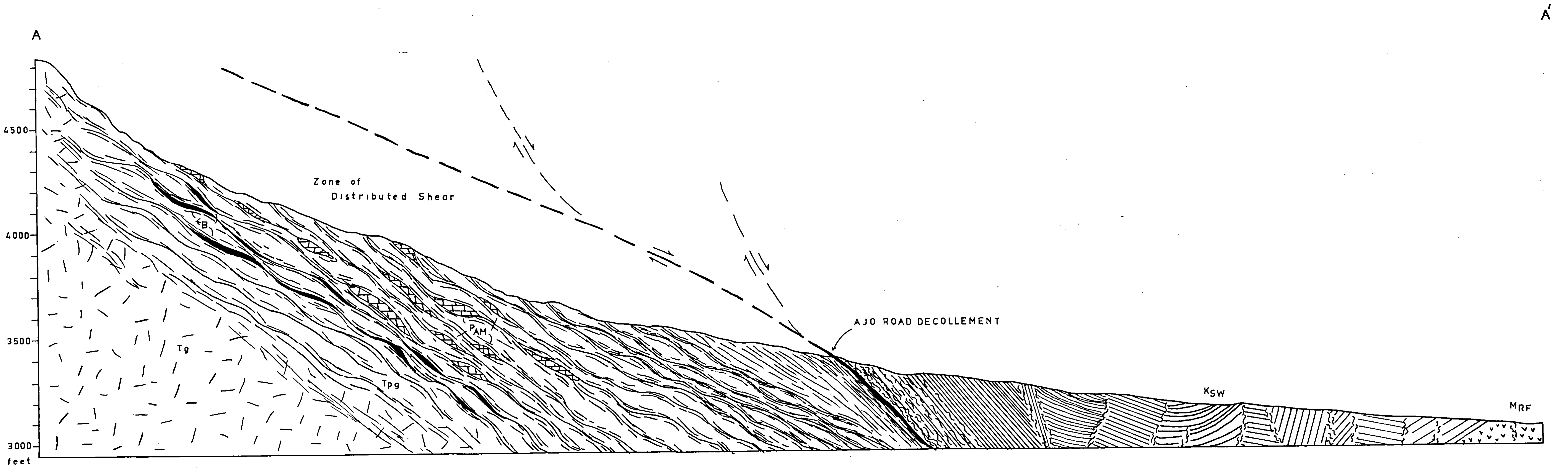

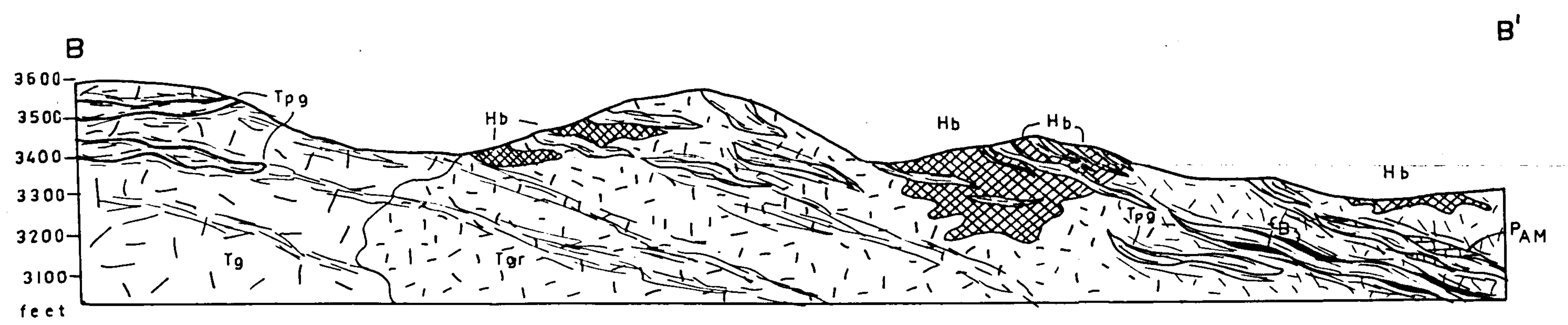

EXPLANATION

PAN TAK GRANITIC PHASES

Tpg Pegmatite

Tgr Medium Grained Granite

Tg Coarse Grained Granite

Slip Surfaces

Shear Zones

Lithologic Contact

Decollement Surface

Thinly to Thickly Bedded Rock

KSW Sand Wells Formation

MRF Roadside Formation

Hb Hornblendite

PAM Abrigo and Martin Formations

€B Bolsa Quartzite

SCALE

METERS 0 100 200 500 600 700

FEET 0 400 1200 2000

Fig. 35. INTERPRETIVE CROSS SECTIONS.

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1980
255

Fig. 2
Geologic Map of a portion of the Northern Coyote Mountains, Southern Arizona

EXPLANATION

CENOZOIC

- Qal — Quaternary Alluvium
- Qtg — Quaternary-Tertiary Gravels
- Tl — Tertiary Lamprophyre Dikes

Pan Tak Granite Phases (58 MY- Date By J.E. WRIGHT for USGS)

- Tpg — Pegmatite
- Tgr — Medium Grained Granite
- Tg — Coarse Grained Granite

MESOZOIC

- K_{SW} — Cretaceous (?) Sand Wells Formation
- M_{RF} — Mesozoic Roadside Formation
- L_S — Unmetamorphosed Limestone

Diorite Rocks - Age Unknown

- Bgd — Biotite Quartz Diorite
- Hdi — Hornblende Diorite
- Hb — Hornblendite

PALEOZOIC

- P_{AM} — Paleozoic Abrigo and Martin Formations Undifferentiated
- $€_B$ — Cambrian Bolsa Quartzite

Symbols:

- Mylonitized Rock
- 20 Lithologic contact, with dip where known
- 35 Bedding
- 40 Primary layering in pegmatite
- 21 Foliation
- 17 21 Penetrative foliation and lineation
- 34 29 Discrete slip surfaces or set of slip surfaces and lineation
- High angle fault
- 85 Joints in prominent pegmatite outcrops
- Decollement surface, with sawteeth on upper plate
- 18 Lineation
- Road
- X Prospect
- Adit
- 86 State Route

N
14°
APPROXIMATE MEAN DECLINATION, 1938

SCALE
METERS
0 100 200 300 400 500 600 700
0 400 800 1200 1600 2000
FEET

CONTOUR INTERVAL 100 FEET

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