Geologic map of the Tortolita Mountains, Pinal and Pima Counties, Arizona

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INTRODUCTION

The geologic map of the Tortolita Mountains encompasses the Tortolita Mountains 7.5' quadrangle plus parts of 3 adjoining 7.5' quadrangles; Desert Peak and Marana to the west and southwest, and Ruelas Canyon to the south. The Tortolita Mountains mark the northwestern extent of the Catalina metamorphic core complex (Davis, 1980; Banks, 1980; Keith et al., 1980; Dickinson, 1991; Force, 1997). Metamorphic and plutonic rocks of the complex were exhumed along a low-angle detachment fault of Mid-Tertiary age that is exposed along the southern edge of the Rincon and Santa Catalina Mountains and is inferred to lie buried beneath piedmont deposits along the southern edge of the Tortolita Mountains. A single small exposure of Middle Proterozoic Dripping Spring Quartzite on the southern piedmont of the Tortolita Mountains is interpreted to lie in the hanging wall of the Catalina detachment fault.

This study documents a ductile shear zone in the northern part of the range, herein named the Carpas Wash shear zone, and a system of brittle normal faults that are interpreted as the northern continuation of the Catalina detachment fault system. Other important conclusions based on our mapping include: 1) recognition of a major, east-dipping normal fault bounding the western edge of a west-tilted sequence of volcanic rocks at Owl Head Buttes, 2) reinterpretation of a sequence of metasedimentary rocks near the head of Parker Canyon as Paleoproterozoic Pinal Schist instead of Mesoproterozoic Apache Group, 3) recognition of a north-dipping, top-to-the-west low-angle normal fault with an exceptionally wide and well-developed chloritic breccia ledge in its footwall along the western edge, 4) reinterpretation of the Cochie Canyon shear zone as a septum of Pinal Schist separating two major plutonic complexes, and 5) reinterpretation of a part of an easterly strand of the Guild Wash fault zone as a series of south-dipping reverse faults that cut the lower part of the Tertiary supracrustal stratigraphic sequence and that are overlain by Tertiary conglomeratic units.

PREVIOUS WORK

Iles (1966) studied mineralization and structure in the Chief Butte area, and Budden (1975) mapped most of the Tortolita Mountains with a strong focus on the plutonic rocks in the footwall block. Banks et al. (1977) produced a reconnaissance map of the central and northern Tortolita Mountains incorporating some of Budden's (1975) mapping. Results of this mapping are discussed by Banks (1980), Davis (1980), and Keith et al. (1980). Skotnicki (2000) did detailed mapping of areas east of 111° 2.5' W and north of 32° 30' N in the Oracle Junction quadrangle. Some areas of Banks et al. (1977) bedrock mapping in the northern piedmont were incorporated into our map along with mapping of surficial deposits (Demsey et al., 1993) on the southern piedmont.

PLUTONIC AND STRATIGRAPHIC FRAMEWORK

Strict definition of hanging wall and footwall in the Tortolita Mountains is complicated by the fact that the boundary (as chosen by Ferguson) between the two blocks, the Carpas Wash shear zone, is cut by a complex system of brittle normal faults. The principle brittle structure is the Guild Wash fault, a north-dipping normal fault with a well developed chloritic breccia and locally preserved microbreccia ledge which lies directly to the north of and nearly parallel to the Carpas Wash shear zone in the north-central part of the range. To the east and west, normal faults truncate the Carpas Wash shear zone and offset it to the south several kilometers.

From a purely structural standpoint it can be argued that the northernmost strands of the Guild Wash fault should represent the northern boundary of the footwall. The Guild Wash fault has long been considered the northern boundary of the footwall in the Tortolita Mountains (Banks et al., 1977; Dickinson, 1991). Discrete mylonite zones kinematically linked to the Carpas Wash shear zone are present in a 2 km wide block preserved in the hanging wall of the Carpas Wash shear zone in the Parker Canyon area east of Guild Wash canyon. However, the Proterozoic crystalline rocks that host these ductile fabrics in this block are more akin in terms of stratigraphy, metamorphic grade, and texture to the crystalline rocks throughout the rest of the hanging wall.

From a stratigraphic and plutonic framework standpoint, the Carpas Wash shear zone represents a better choice for the northern boundary of the footwall block. The Carpas Wash shear zone transects the range from east to west as a single, discrete structure, and it represents the northern limit of a complex suite of Late Cretaceous through Mid-Tertiary plutonic rocks which constitute most of the footwall block.

Hanging wall Stratigraphic Framework

Proterozoic

Proterozoic rocks in the hanging wall of the Tortolita Mountains consist of medium- to coarse-grained, potassium feldspar porphyritic granite that intrudes three isolated blocks of greenschist facies pelitic schist. The granite is interpreted as the Mesoproterozoic Oracle Granite (Yo and Yom), and the schist as the Paleoproterozoic Pinal Schist (Xp). Swarms and pods of mafic dikes intrude the granite and the schist. Diabase dikes (Yd) are interpreted as Mesoproterozoic in age, and in general these strike northerly or northwesterly. Other mafic dikes are interpreted as Tertiary in age (Tm), and these tend to strike northerly or northeasterly.

The Pinal Schist is strongly metamorphosed in contact aureoles adjacent to the Oracle Granite, but elsewhere the lower greenschist facies regional metamorphic grade preserves delicate sedimentary structures and commonly 2 cleavages; a slatey cleavage axial planar to mesoscopic folds, and at least one generation of crenulation cleavage. Sedimentologically, the Pinal Schist is dominated by massive mudstone successions interbedded with laminated to thin-bedded siltstone, thin- to medium-bedded sandstone, and sparse medium-bedded volcaniclastic granule sandstone to pebble conglomerate. The strata as a whole are interpreted as a turbidite succession.

The Pinal Schist of southeastern Arizona represents one of the widest expanses of Paleoproterozoic supracrustal rocks in western North America previously reported to be void of volcanic rocks (Condie and Demalas, 1985; Copeland and Condie, 1986, and Eisle and Isachsen, 2001). Therefore, our discovery of a thin unit of phenocryst-poor rhyolite lava and a 1m thick dacitic tuff interbedded with the turbidites just west of Chief Butte is significant. Along strike to the south from these volcanic rocks, a discontinuous yet distinctive, medium-bedded volcaniclastic pebble conglomerate is interbedded with pelitic rocks attesting to the volcanic origin and Paleoproterozoic age of the igneous rocks mapped near Chief Butte. Samples of the pebble conglomerate, the dacitic tuff, and the phenocryst-poor rhyolite lava have been collected and submitted to Clark Isachsen at the University of Arizona for U-Pb zircon dating.

Cenozoic

A sequence greater than 1km thick of basalt to trachyte lava flows with sparse volcaniclastic sandstone, conglomerate, and silicic ash-flow tuff directly overlies crystalline basement in the northern Tortolita Mountains. Locally, a thin sequence of schist-clast conglomerate occurs along the depositional contact. Supracrustal rocks crop out in three areas; the Owl Head Buttes area on the west where strata dip steeply to the west, the Chief Butte area on the east where strata dip to the east, and a narrow, north-trending, fault-bounded strip in between where strata dip to the north. The top of the sequence is preserved only in the Chief Butte area where the volcanic succession is overlain by a tripartite sequence of conglomerate; volcaniclastic at the base (Tcv), polymict volcanic-, plutonic-, and metamorphic-clast in the middle (Tc), and monomict granite-clast at the top (Tcg).

In general, lava flows in the northern Tortolita Mountains are less than 50m thick and intervening sedimentary strata, if present, are thin and discontinuous. Flow breaks in amalgamated sequences are defined by zones of reddish autobreccia typically, but not always, infiltrated with red volcaniclastic sandstone. A wide variety of flow textures and phenocryst assemblages are displayed in the flows. Four map units were defined and given field names based on phenocryst mineralogy: aphyric mafic flows were mapped as aphyric basalt (Tb0), mafic flows in which plagioclase phenocrysts are the dominant phase were mapped as andesitic lavas (Ta), mafic flows in which mafic phenocrysts are the dominant phase were mapped as basaltic lava (Tb), and flows containing plagioclase and hydrous mafic phenocrysts (principally biotite) were mapped as dacitic flows (Td). Hypabyssal varieties of the andesite (Tai) and dacite (Tdi) were also recognized, along with monomict lava breccia associated with the dacitic flows (Tcd).

Geochemically, the basaltic flows range from true basalt to basaltic trachyandesite in composition, whereas the andesitic flows are trachyandesite, and the dacitic flows are trachyte according to the Le Bas (1986) classification scheme (Figure 1). Table 1 shows analyses of representative units from the study area along with a distinctive pyroxene-porphyritic basalt lava flow unit that occurs within the overlying conglomeratic succession in the northerly adjacent Chief Butte quadrangle (Spencer et al., 2002), and a phenocryst-rich dacitic lava that overlies basaltic lavas in a series of isolated inselbergs in the northwesterly adjacent Durham Hills quadrangle (Richard et al., 2002). The analyses are comparable to analyses from an extensive Miocene lava field that extends to the west and south of the map area into the Picacho, Sawtooth, Silverbell, Waterman, Tucson, and Roskruge mountains (Eastwood, 1970; Banks et al., 1978; Ferguson et al., 1999; and Ferguson et al., 2000). Although comparable in composition, the volcanic rocks in the Tortolita Mountains are interpreted as part of a distinct and significantly older volcanic field. This is based on a late Oligocene (26.39 $\pm$ 0.07Ma) $^{40}Ar/^{39}Ar$ single-crystal, laser-fusion sanidine date of a key rhyolite ash-flow tuff in the sequence (Peters et al., 2003).

Potassium metasomatic alteration, which strongly affects nearly all the volcanic rocks in the hanging wall block of the nearby Picacho Mountains (Brooks, 1986) was only detected in two of the analyses from the Tortolita Mountains, the phenocryst-rich dacitic lava from the Durham Hills quadrangle, and the oldest dacitic flow at Owl Head Buttes. K-metasomatism seems to be restricted to isolated occurrences in the Tortolita Mountains and to areas in the Durham Hills quadrangle which may have been overlain by thick basinal deposits.

A single, thin, poorly to moderately welded rhyolitic ash-flow tuff (Tt) is interbedded with mafic lava flows in the upper part of the volcanic sequence at Chief Butte and in the lower part of the sequence at Owl Head Butte. The tuff contains phenocrysts of plagioclase, sanidine, biotite, and sparse quartz, and has a distinctive peach-colored matrix with less than 5% volcanic lithic lapilli clasts. This tuff is petrographically identical to a tuff mapped in the Cloudburst volcanics of the Fortified Peak area (Orr et al., 2002). The tuff is interpreted as the same unit in both areas and serves as a marker unit within these isolated volcanic successions.

Hanging wall geochronology

Conventional K/Ar whole rock and biotite ages of the volcanic rocks of the Chief Butte and Owl Head Buttes areas range from 21 to 27 Ma (Jennison, 1976; Banks et al., 1978; Dickinson and Shafiqullah, 1989). $^{40}Ar/^{39}Ar$ single-crystal, laser-fusion sanidine dates of a thin rhyolite ash-flow tuff (Tt) in the Chief Butte area and a petrographically identical tuff in the Fortified Peak area are identical at 26.39 $\pm$ 0.07 and 26.33 $\pm$ 0.10 Ma respectively (Peters, 2003). This date is also in close agreement with the K/Ar biotite date of 26.7 $\pm$ 0.5 Ma reported by Banks et al. (1978). Since the same rhyolite ash-flow tuff is present in the Owl Head Buttes area, these rocks are interpreted as being coeval with the sequence at Chief Butte. The upper Miocene

(21-24Ma) whole rock and feldspar concentrate K/Ar dates of Jennison (1976) and Dickinson and Shafiqullah (1989) are considered spurious.

$^{40}Ar/^{39}Ar$ single-crystal, laser-fusion sanidine analyses of two distinctly different nonwelded tuffs interbedded with sandstone and conglomeratic sandstone sequences that overlie the Chief Butte and Owl Head Butte volcanics yielded ages of 19.68 $\pm$ 0.30 Ma, and 17.69 $\pm$ 0.17 Ma (Peters, 2003). The older date is from a phenocryst-rich nonwelded tuff in the northerly adjacent Chief Butte map area (Spencer et al., 2002), and the younger is from a phenocryst-poor, white nonwelded tuff (map unit Tty) located just west of Owl Head Buttes. These middle Miocene dates are atypical of known ages of Mid-Tertiary volcanic rocks in the Tucson area but correlate well with known ages from the Superstition volcanic field 60 km to the north (McIntosh and Ferguson, 1998).

Footwall Plutonic Framework

The footwall block of the Tortolita Mountains is composed chiefly of plutonic rocks of Late Cretaceous to Cenozoic age that intrude two relatively narrow, east- to northeast-striking belts of Proterozoic and Paleozoic rocks. A northern belt of Pinal Schist is intruded locally by the Oracle Granite, and bounded on the north by the Carpas Wash shear zone. In the southern part of the map a belt of complexly deformed Pinal Schist, Mesoproterozoic Apache Group and Paleozoic metasedimentary rocks forms a septum between two areas of plutonic rock that makes up most of the footwall block.

Plutonic rocks are divided into four suites, two lying to the north and two to the south of the metasedimentary septum. In the north, the 70Ma pluton of Chirreon Wash (Kgd) consists of medium-grained equigranular monzogranite to granodiorite with between 10% and 30% biotite and hornblende. The granite of Fresnal Canyon (Tf) is a medium-grained monzogranite to syenogranite with between 5% and 50% pegmatite, and contains less than 10% garnet, muscovite, and sparse biotite. In the northwest, the granite of Fresnal Canyon occurs as a discrete stock with a central core containing little pegmatite (Tfs), but to the east and south the granite occurs as a complex swarm of dikes intruding the pluton of Chirreon Wash. Two composite map units were defined with the unit Tf-Kgd containing greater than 35% dikes and the unit Kgd-Tf containing less than 35% dikes.

The pluton of Wild Burro Canyon lies to the south of the septum, and consists of three phases. The main phase (Tw) is a potassium feldspar porphyritic, medium- to coarse-grained quartz monzonite to quartz syenite containing between 15% and 25% biotite and hornblende. A mafic phase (Twm) consists of fine- to medium-grained equigranular quartz monzodiorite, monzodiorite, and diorite containing between 25% and 60% mafic minerals. A leucocratic western phase (Tww) consists of medium- to coarse-grained , equigranular to potassium feldspar porphyritic granite with less than 10% biotite. The main phase of the pluton of Wild Burro Canyon hosts a pervasive, steeply southeast-dipping weak to moderate protomylonitic foliation which is roughly parallel to foliation in metasedimentary rocks within and to the south of the septum.

The youngest plutonic suite occurs in the southeast, and is a fine- to medium-grained, equigranular granite containing between 5% and 15% biotite referred to as the Tortolita Mountains Granite (Ttm). In some areas, coeval intrusive relationships are suggested within the pluton of Wild Burro Canyon, but numerous dikes of the Tortolita Mountains Granite clearly cut the pluton of Wild Burro Canyon.

Intrusive relationships along the septum near the head of Wild Burro Canyon indicate that both of the southern plutonic suites are younger than plutonic rocks to the north. In both areas, strong protomylonitic to mylonitic fabrics within the dikes of the granites of Fresnal Canyon and Tortolita Mountains do not affect the older host rocks indicating that deformation probably occurred during and/or just after emplacement, while the dikes were significantly more ductile than their host.

Footwall thermochronology and geochronology

Conventional biotite K/Ar dates of plutonic rocks in the footwall block indicate Miocene (28 to 23 Ma) cooling ages (Mauger et al., 1968; Creasy et al., 1977; Banks et al., 1978). A series of four $^{40}Ar/^{39}Ar$ mica ages from the Tortolita Mountains (Spell et al., 2003), indicate progressive cooling from the northeast to the southwest from 25.5 to 21.5Ma.

Crystallization ages of plutonic rocks in the Tortolita Mountains were unkown prior to this study. The oldest of these, the pluton of Chirreon Wash, yielded a U-Pb, zircon age of 70 Ma (Clark Isachsen, written communication, 2003).

Units present in hanging wall and footwall

Rock units that predate and postdate the detachment fault system are present in both the hanging wall and footwall. The Paleoproterozoic Pinal Schist (Xp), and Mesoproterozoic Oracle Granite (Yo, and Yom) are found throughout the Tortolita Mountains, as are a suite diabase dikes (Yd) that, in the hanging wall, are interpreted as Mesoproterozoic because of their texture and orientation. Correlative dikes in the footwall, preserved as strongly deformed and metamorphosed amphibolite schist lenses within enclaves of metasedimentary rocks in the Cochie Canyon – Wild Burro Canyon areas, are interpreted as Mesoproterozoic because they are found only within the metasedimentary rocks. The amphibolite schist lenses in this area were not mapped separately, but their presence or absence was used to help differentiate metasedimentary rocks of probable Apache Group protolith (₽s-Ya) from those consisting only of probable Paleozoic protolith metasedimentary rocks (₽s).

A suite of texturally variable, undeformed, generally fine-grained, and consistently north northwest-striking mafic dikes and sparse small stocks (Tm) are present throughout the Tortolita Mountains. At one locality along Guild Wash Canyon one of these stocks, a fine- to medium-grained monzodiorite, intrudes a northwest-striking strand of the Guild Wash fault. A suite of north to northwest-striking, light-gray, phenocryst-poor, quartz and feldspar-phyric rhyolite porphyry dikes (Trp) occur in the northeastern Tortolita Mountains. The rhyolite porphyry dikes occur on both sides of the Carpas Wash shear zone, and even though they cut across discrete mylonitic shear zones just to the north and south of the shear zone, there is a good example of one of these dikes strongly sheared into and nearly parallel to the Carpas Wash shear zone along the eastern edge of the map area. Finally, a suite of undeformed, north-striking, coarse-grained, plagioclase-porphyritic dacite dikes (Tdd) are present on the northeastern piedmont, one of which intrudes the Carpas Wash shear zone at a high angle.

STRUCTURAL EVOLUTION

The structural boundary between the footwall and hanging wall blocks differs slightly from the stratigraphic and plutonic framework boundary. An incised block approximately 2km wide is preserved in the hanging wall of the Carpas Wash shear zone and the footwall of the northeasternmost strand of the Guild Wash fault. Ductile fabrics in this block are kinematically compatible with the Carpas Wash shear zone and are treated as footwall structures in our structural analysis of the range. The myriad of mostly ductile structural elements in the footwall block as depicted on our map (Sheet 1) represent only a small percentage of those recorded during our study. The data set includes several thousand measurements of mylonitic foliation, stretching lineation, schistosity, and various other linear and planar elements. In much of the footwall, composite plutonic units preserve completely different orientations and intensities of ductile fabrics at the same location (field station). Our data set is designed so that structural analysis can be done based on several criteria including type of measurement, which map unit(s) display the measurement(s), and where the measurement occurs on the map (principally footwall vs hanging wall). Statistical information gleaned from our stereonet plots (Figures 2-13), prepared using the Stereonet for Windows v. 1.1 software of Allmendinger © 2002 is summarized in Table 2.

Hanging wall

Supracrustal rocks of the hanging wall are preserved in three isolated fault blocks that define a north-plunging antiform. Strata dip moderately to steeply to the east and west in the eastern and western blocks, respectively, and a narrow central strip is preserved in which strata dip moderately to the north. To the west, the hanging wall block is cut by moderately to gently dipping normal faults with surface traces that imply strongly concave-up geometries. The fault bounding the west side of the Owl Head Buttes block, herein named the Owl Head Buttes fault is invaded by extensive carbonate veins which were previously interpreted as slide blocks of Paleozoic limestone (Banks et al., 1977). This fault and another major fault that bounds the eastern edge of the central strip of supracrustal rocks appear to curve into the Guild Wash fault zone to the south, but poor exposure and the lack of supracrustal rocks in this area makes it impossible to confirm this.

At least two generations of normal faults cut the supracrustal rocks of the Chief Butte block. Based on our mapping and descriptions of fault geometry in a series of caved-in and/or currently inaccessible mine shafts in the middle of the block by Iles (1966), the volcanic rocks in this area are interpreted to lie in the hanging wall of a gently east-dipping, top-to-the west normal fault. This fault is exposed in a window in the middle of the block and as the fault that bounds the western edge of the block. This fault, tilted to the east past horizontal, is cut by younger, moderately west-dipping normal faults. Most of the mine workings in the Chief Butte mineral district are located along the most prominent of these younger faults where it intersects and brings to the surface the top-to-the west normal fault. Stratal tilts in the Chief Butte fault block decrease gradually, although possibly incrementally, up-section and to the east from greater than 60^{o} to less than 15^{o}. The duration of this tilting is constrained to be between the age of the main mass of volcanic rocks at approximately 27-26 Ma and 19.7 Ma, the age of a nonwelded tuff interbedded with gently tilted sedimentary rocks to the east.

Unlike supracrustal rocks to the west, strata in the Chief Butte block can be traced to the south where they are truncated by a strand of the north-dipping Guild Wash fault zone. In the area near the head of Parker Canyon, a thin sequence of andesitic lava that overlies Pinal Schist is truncated by a pair of south-dipping reverse faults that carry highly brecciated basement rocks (Pinal Schist (Xpx) and Oracle Granite (Yox) breccia units) in their hanging walls. These faults are interpreted to be erosionally truncated and overlapped by the conglomeratic sequence (Tc) that overlies the volcanic strata. Immediately to the south, the reverse faults are apparently truncated by a moderately to steeply north-dipping strand of the Guild Wash fault. Reverse motion along these faults is tentatively interpreted as brittle expression of local contractional strain within the hanging wall during top-to-the-west motion along the Carpas Wash shear zone.

Carpas Wash shear zone and the Guild Wash fault

The Carpas Wash shear zone is interpreted as a major zone of displacement between the hanging wall and footwall blocks in the Tortolita Mountains. The shear zone ranges between 25 and 100 meters wide and consistently dips about $45\text{-}60^{o}$ to the north. Mylonitic foliation in and near the zone is associated with a gently northeast-plunging stretching lineation, and kinematic indicators are consistently top-to-the west (Figure 2).

A series of north-dipping normal faults in the northern Tortolita Mountains display variable amounts of chloritic breccia and silicified microbreccia in their footwalls. The Guild Wash fault, the most prominent of these, is named for the west-flowing section of Guild Wash along the northern escarpment of the footwall block. In this area, the Guild Wash fault and the

Carpas Wash shear zone are nearly coincident, but to the east where Guild Wash turns sharply to the southeast, the fault splays into two widely divergent strands. The eastern strand truncates a pair of south-dipping reverse faults discussed in the previous section, where it cuts Mid-Tertiary supracrustal rocks, and is eventually buried by late Cenozoic piedmont deposits (QTs). North-side-down displacement of approximately 500m along the eastern strand of the Guild Wash fault, as illustrated on cross-section B-B', is based on the offset of a gently dipping intrusive contact between Oracle Granite and Pinal Schist. Pinal Schist on both sides of the fault includes a distinctive volcaniclastic pebble conglomerate suggesting that the intrusive contacts could be the same. Northeast-side-down displacement in excess of 2km is estimated for the southeastern strand of the Guild Wash fault based on approximately 1.5km of offset of the north-dipping Carpas Wash shear zone. A greater amount of displacement along the southeast strand is also implied by a significantly wider zone of brecciation and chloritic alteration along this strand in relation to the eastern strand.

Moderate north-side-down displacement along the eastern strand of the Guild Wash fault (as interpreted by Ferguson) is inconsistent with the juxtaposition of supracrustal rocks in its hanging wall with chloritic breccia and mylonitic fabrics in its immediate footwall. Typically, chloritic breccia and mylonitic fabrics in the footwall of a detachment fault system indicates exhumation on the order of several kilometers, and it seems unlikely that 500m of displacement could account for these relationships. Possible explanations for this are as follows: 1) the presence of supracrustal rocks in the hanging wall does not necessarily imply surface conditions. The area may have been buried by several kilometers of Tertiary sedimentary rocks during initial stages of fault development, 2) extreme geothermal gradients in the region related to Cenozoic magmatism may have elevated the brittle-ductile transition to relative shallow depths, 3) the chloritic breccia may have developed at depth along the north-side-down reverse faults that occur in the same area, and the chloritic breccia, which is sporadically preserved along the current trace of the eastern Guild Wash fault and apparently absent along its eastern trace, may be related to these older faults, and 4) the estimate of moderate offset is incorrect.

The interpretation of the Guild Wash fault as a major detachment fault (e.g. Davis, 1980; Dickinson, 1991) is supported by Jon Spencer and Steve Richard who interpret the relationship between Guild Wash fault and the Carpas Wash shear zone as follows:

> Quartz deforms by crystal plasticity at temperatures above about 300 degrees C. Mylonitic footwall rocks in core complexes invariably yield K-Ar and Ar/Ar biotite ages that reflect the time of cooling due to tectonic denudation. Biotite is thought to retain argon when temperature drops below about 325-300 degrees C. This is consistent with laboratory experiments that indicate a >300 degree C temperature for mylonitization (crystal plastic behavior of quartz). Rocks of the Carpas Wash shear zone are mylonitic, and quartz bearing rocks such as quartz veins and granite are mylonitized. The Carpas Wash shear zone deformed mylonitically, and includes plastically deformed quartz veins.
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> The hangingwall of the Guild Wash fault and its northern branch to the east includes Tertiary supracrustal rocks, including conglomerates with a fanning upward sequence that were deposited during faulting and extension. These rocks are now juxtaposed with the Carpas Wash shear zone. Many kilometers of displacement are necessary to juxtapose these contrasting rock types that were deformed under much different temperature regimes. The presence of chloritic breccia along the Guild Wash fault is consistent with brittle displacement through temperatures just below those necessary for mylonitization. Therefore we interpret the Guild Wash fault and its northeastern extension as a detachment fault with many kilometers of displacement. This displacement has juxtaposed supracrustal rocks, including Miocene conglomerate, with mylonitic crystalline rocks. An alternative interpretation of the Guild Wash fault is possible if the Carpas Wash shear zone is Laramide rather than middle Tertiary.

Divergence of the Guild Wash fault into two strands in the Guild Wash – Parker Canyon area preserves a 2km wide zone of Oracle Granite and Pinal Schist in the hanging wall of the Carpas Wash shear zone. In this area, two sets of discrete mylonitic shear zones, ranging between 30 and 200cm thick, cut the Oracle Granite. An older steeply northeast dipping set with dextral kinematic indicators are consistently cut by a steeply northwest dipping set with sinistral kinematic indicators. To the south, the density of the shear zones and their thickness increases towards the Carpas Wash shear zone. In the northern part of this block, shear zones represent less than 1% of the rock, but to the south the density of shear zones approaches 30%. The sinistral set also becomes more prominent to the south. The northern boundary of the Carpas Wash shear zone, which is almost always within the Oracle Granite, is gradational. The southern transition into highly sheared Pinal Schist is relatively sharp, although the Oracle Granite is so strongly sheared in places that it can be confused with Pinal Schist. In fact, large areas of Pinal Schist to the south of the Carpas Wash shear zone were mapped as highly sheared Oracle Granite by Banks et al. (1977). Ultramylonitic foliation of granite within the shear zone is locally folded into mesoscopic, asymmetric east and west verging folds with steeply north-plunging axes (Figure 2e).

Pinal Schist subjacent to the Carpas Wash shear zone is a fine-grained sericitic schist with ubiquitous quartz veins. The prominent schistosity shows abundant evidence of being axial planar to isoclinal folds with abundant transposed fold hinges displayed by the quartz veins. The orientation of schistosity and a fine crenulation lineation in the Pinal Schist converge towards parallelism with the Carpas Wash shear zone as the shear zone is approached from the south. Near the shear zone, a prominent, gently plunging lineation (Figure 2b,c,d) in the schist is approximately parallel to stretching lineation in the granitic rocks in the shear zone suggesting that the lineation is mylonitic, or that it has been rotated into parallelism by intense shearing in the zone. The origin and tectonic-metamorphic evolution of the lineation in the Pinal Schist near the Carpas Wash shear zone is poorly understood. In some areas, lineation in the schist is folded by the same mesoscopic, close to open, rounded to chevron style assymetric folds (both east and west verging) that occur in the mylonitic granite within the shear zone, but in other areas, the lineation appears to post-date folding. These relationships suggest a complex history of mylonitic fabric development, folding of the fabric and then continued shearing.

In the northwest-central Tortolita Mountains the Carpas Wash shear zone feathers into a zone of strongly chloritic-altered, interleaved Pinal Schist and pluton of Chirreon Wash granodiorite and monzogranite where it is truncated by the Guild Wash fault zone. About 5km to the southwest, the Carpas Wash shear zone appears again in the hanging wall of the inferred southwest continuation of the Guild Wash fault. Here, the Carpas Wash shear zone is defined by a series of small outcrops where complex interleaving of schist and granodiorite with an intense, north-dipping shear foliation identify this as part of the shear zone. The shear zone is also accompanied by a narrow zone of chloritic breccia and since hanging wall rocks show no sign of ductile deformation or chloritic alteration, the presence of a brittle fault zone nearly coincident with shear zone is indicated.

About 1.5km northeast of the Carpas Wash shear zone outcrops on the western piedmont, a major fault zone with a very wide (50 to 300m) silicified, chloritic breccia in its footwall apparently propagates out of an intrusive contact between granite of Fresnal Canyon and pluton of Chirreon Wash in lower Derrio Canyon. Named the lower Derrio Canyon fault, this structure is a remarkably well-exposed, very low-angle, northwest-dipping normal fault with consistent, top-to-the west brittle kinematic indicators (principally Riedel shears). The relationship of the lower Derrio Canyon fault to the Guild Wash fault and the Carpas Wash shear zone is poorly understood. However, the gently plunging, top-to-the-west kinematics along the lower Derrio Canyon fault are very similar to those along the Carpas Wash shear zone. Although no kinematic indicators have been observed along the Guild Wash fault, normal dip-slip kinematics are suggested by its map pattern and by the apparent offset of the Carpas Wash shear zone on both sides of the range. These observations suggest that the Lower Derrio Canyon fault and the western Carpas Wash shear zone are part of the same top-to-the-west detachment system.

Mimicking the trace of the Guild Wash fault in the north-central Tortolita Mountains, and lying in the footwall of the Carpas Wash shear zone is a north-dipping fault with unkown displacement that parallels upper Derrio Canyon. This fault, named the upper Derrio Canon fault is defined by a silicified chloritic microbreccia along much of its trace. To the west, the fault is truncated by the Guild Wash fault.

The age of the Carpas Wash shear zone is bracketed by the emplacement of two sets of dikes in the northeastern part of the range. A phenocryst-rich dacite dike (Tdd) cuts the shear zone at high angle, and in the same area a phenocryst-poor rhyolite porphyry dike (Trp) is strongly sheared into parallelism with the shear zone. Similar rhyolite porphyry dikes are also present on either side of the shear zone where they cut discrete shear zones with similar orientation and kinematics as the Carpas Wash shear zone. The rhyolite porphyry dikes, therefore appear to have been emplaced after top-to-the-west shearing in the zone was initiated, but before main displacement on the shear zone was complete. U/Pb zircon dating of these two dike units should constrain the age of the Carpas Wash shear zone.

The Guild Wash fault is constrained to be younger than the late Oligocene (27Ma) volcanic rocks in its hanging wall, and older than the QTs piedmont gravel unit it underlies.

Footwall

Ductile fabrics in the form of protomylonite, and mylonite with abundant stretching lineation are ubiquitous in the footwall block of the Tortolita Mountains. A series of stereonet plots (Figure 3-13) summarizes the data set.

The weak shape fabrics, weak to moderate protomylonitic foliations in the plutons of Chirreon Wash and Wild Burro Canyon (Figures 4, 5), and the schistosity in metasedimentary rocks of the septum (Figure 6) that separates them represent the oldest ductile fabrics in the range. Similar orientations and similar fabrics in the footwall block of the Durham Hills to the north (Richard et al., 2002) suggest that a regional tectonic event is responsible for these fabrics.

Mylonitic foliations in the granite of Fresnal Canyon and the Tortolita Mountains Granite (Figures 7, 8) are the most erratic in terms of average orientation, but this merely reflects the wide range of orientations of the myriad of dikes from these leucogranites that intrude the older melanocratic rocks (Figure 9). Within stocks of the granite of Fresnal Canyon, and the main pluton of the Tortolita Mountains Granite, gently dipping protomylonitic foliation dominates. In the north-central part of the range, dikes of the granite of Fresnal Canyon intruding the pluton of Chirreon Wash are dominantly north- and northwest-dipping and somewhat parallel to the weak foliation in the host rock. Farther south, these dikes pass through a stockworks zone with dike intersection lineations that tend to be gently plunging to the northeast or northwest and approximately parallel to stretching lineations within the dikes. In the southern part of the range, dikes of the Tortolita Mountains Granite tend to strike northwesterly with variable northeasterly or southwesterly dips.

Discrete, gently dipping mylonitic shear zones that cut all rock types are sparse and mostly confined to the southwestern part of the range. These fabrics are interpreted as the youngest in the range and their close spatial association with the southwestern edge of the range and the fact that they also tend to occur at high elevations along ridge crests suggests that they are related to formation of the southwest-dipping Catalina detachment fault that bounds the southern part of the range. In many areas, these shear zones are cut by dm- to m-scale synthetic and antithetic shear bands and/or folded by cm-scale crenulations (typically southwest-verging). As a whole these younger fabrics are interpreted as strain due to the relaxation of shear stresses related to unroofing of the footwall block (Reynolds and Lister, 1990; Wernicke and Axen, 1988; Wernicke, 1992). Discrete mylonitic shear zones are also sporadically present in the northern part of the range where kinematic indicators are both top-to-the northeast and top-to-the southwest.

Stretching lineation orientations throughout the range in all units are consistently gently plunging and northeast or southwest trending (Figures 3b, 4b, 5b, 7b, 8b). L-tectonite fabrics are common in the dikes of the granites and in many instances stretching lineations are oriented at high-angles to the dike walls. Kinematic indicators, shown as directional stretching lineations (Figure 3c) are evenly distributed between top-to-the northeast and top-to-the to southwest and are distributed somewhat evenly throughout the range. For example, many top-to-the northeast kinematic indicators are present in the southwest as are top-to-the southwest indicators in the northeast. The kinematic indicators are evenly distributed in terms of shear sense within the melanocratic older plutons (Figures 10), but not in the younger leucogranites. Kinematic indicators in the granite of Fresnal Canyon are dominantly top-to-the southwest, and top-to-the northeast in the Tortolita Mountains Granite (Figure 11).

Detailed study of Central Guild Wash footwall rocks

A detailed study by Jon Spencer was done of complex ductile fabrics in the footwall of the central Guild Wash fault wherein a sequence of 4 deformational events were tentatively recognized.

Proterozoic Pinal Schist, exposed over about 1 square mile adjacent to the Guild Wash fault in the central part of the northern Tortolita Mountains, was studied in an attempt to identify and characterize the structures and fabrics. This Pinal Schist is part of the Carpas Wash shear zone, and is intruded by granite near the Guild Wash fault. The following four deformations are tentatively identified, as follows: (1) The Pinal Schist is strongly deformed into a highly schistose rock with lithologic layering parallel to foliation. Syn-deformation metamorphism was not sufficient to produce visible mica within the foliation plane, but the strong schistosity is thought to be a product of oriented metamorphic phyllosilicates associated with this deformation phase. Foliation generally dips moderately to the north-northwest (Figure 12a). (2) The second deformation phase produced tight to isoclinal folds of lithologic layering, with axial planes subparallel to D1 schistosity. Fold axes were measured because axial planes were obscure and rarely clearly exposed. Fold axes are generally east-west trending and slightly to moderately west plunging (Figure 12b). (3) The third deformation phase is characterized by small kink folds of lithologic layering. Orientations of axes of kink folds are widely scattered, but they generally plunge westerly or northwesterly (Figure 12c). (4) Mylonitic foliation strongly affected granite near the Guild Wash fault. This granite was difficult to correlate with other granitoid units because of deformation and alteration, but is probably correlative with the nearby equigranular phase of the Oracle granite. Intruded Pinal Schist is also strongly mylonitic. The mylonitic foliation dips moderately northward and strikes east-west and is approximately parallel to the Guild Wash fault (Figure 13b). Mylonitic lineation clusters about a subhorizontal mean pole trending 076° (Figure 13a; Table 2). The mylonitic foliation dies out southward within the Pinal Schist and is rarely present in the intruding 70 Ma pluton of Chirreon Wash to the south.

The first (D1) and second (D2) deformations are possibly related, and as these deformations do not affect intruding Oracle granite, they are thought to be related to early Proterozoic tectonism. D3 kink folds are also possible of this age, but it is possible that they developed after Oracle granite intrusion but did not obviously affect the granite. Truncation of D3 by the Laramide pluton of Chirreon Wash is not clear, but given the general lack of deformation of the granodioritic plutonic rocks all along its intrusive contact, it seems unlikely that the kink folds developed after pluton intrusion. D4 mylonitic deformation affects the pluton of Chirreon Wash, but such deformation is rare in the area north of central Guild Wash, and does not affect the contact here. No sense-of-shear indicators were identified in this part of the Carpas Wash shear zone.

D4 mylonitic lineation, transposed into the southwestern quadrant, is oriented –6.5° 256°. This is not greatly discordant to the mean orientation of mylonitic lineation orientations in the range to the south. Most likely, the mylonitic deformation is part of the same period of mid-Tertiary extensional tectonics that exhumed the Catalina metamorphic core complex.

In terms of the broader structural analysis of the Carpas Wash shear zone presented in the previous sections, Spencer's D1 and D4 foliations are probably correlative with those represented in Figure 2a. D3 kink fold axes are similar to those represented in Figure 2e, and D2 fold axes are represented as a population within the older lineations of Figure 2c.

QUATERNARY MAP UNIT DESCRIPTIONS

Quaternary and late Tertiary deposits cover most of the piedmont areas west of the Tortolita Mountains and the area between Owl Head Buttes and Desert Peak. This alluvium was deposited primarily by larger streams that head in the mountains; smaller streams that head on the piedmont have eroded and reworked some of these deposits. Deposits range in age from modern to early Pleistocene or Pliocene. Approximate age estimates for the various units are given in parentheses after the unit name. Abbreviations are ka, thousands of years before present, and Ma, millions of years before present.

H **Mine dumps (recent)** – Disturbed areas in the vicinity of a marble quarry in the southwest corner of the map area.

Qy$_c$ **Modern river channel deposits (< ~1 ka**) --Active channel deposits composed of well-sorted sand and gravel to poorly-sorted sand, gravel and cobbles in the steeper channels. Channels are generally incised less than 1 m below adjacent terraces and bars, but locally incision may be as much as 2 m. Channel morphologies generally consist of a single-thread high flow channel or multi-threaded low flow channels with gravel bars. Channels are extremely flood prone and are subject to deep, high velocity in moderate to large flow events, and severe lateral bank erosion.

Qy$_2$ **Late Holocene alluvium (< ~2 ka**) -- Channels, low terraces, and small alluvial fans composed of cobbles, sand, silt, and boulders recently deposited by modern drainages. Includes Qyc where not mapped separately. Downstream-branching distributary channel patterns - small, discontinuous, well-defined channels alternating with broad expansion reaches where channels are very small and poorly defined - are typically on western piedmont. Local relief varies from fairly smooth channel bottoms to the undulating bar-and-swale topography that is characteristic of coarser deposits. Flood flows may significantly change channel morphology and flow paths. Terraces have planar surfaces, but small channels are common. Soil development associated with Qy2 deposits is minimal.

Qy$_1$ **Holocene alluvium (~2 to 10 ka)** -- Low terraces found at scattered locations along incised drainages and broad alluvial fans on the western edge of map area. Qy1 terraces are slightly higher and less subject to inundation than adjacent Qy2 terraces. Surfaces are generally planar but fans may be incised up to 2 m. Qy1 terraces are 1 to 2 m above adjacent active channels. Surfaces typically are sandy but locally have unvarnished, open, fine gravel lags. Soil development is minimal with weak subangular blocky structure and no to weak (stage 1) carbonate accumulation (see Machette, 1985, for description of stages of calcium carbonate accumulation in soils). Yellow brown (10YR) soil color is similar to original fluvial deposits.

Qy **Holocene alluvium, undifferentiated (<~10 ka)**-- Includes Qyc, Qy2, and/or Qy1 deposits. Used where not possible, at this scale, to map surfaces separately. Unit Qy consists of smaller incised drainages in the mountains and on the upper piedmonts.

Qly **Holocene to Late Pleistocene alluvium (~2 to 130 ka**) -- Terraces and broadly rounded alluvial fan surfaces approximately 2 m above active channels. Qly is composed of mixed late Pleistocene (Ql) and Holocene (Qy1and Qy2) alluvium. Qly areas are covered by a thin veneer of light brown, fine-grained Holocene alluvium and scattered fine gravel lag, with reddened Pleistocene alluvium exposed in patches on low ridges, in roads and wash cut banks. Drainage networks consist of a mix of distributary channel networks on the lower piedmonts and tributary channels on the upper piedmonts.

Ql **Late Pleistocene alluvium (~10 to 130 ka) --** Broadly rounded to rounded and moderately dissected relict alluvial fans and terraces. Surfaces are 1 to 2 m of active channels with relict bar and swale morphology preserved. Deposits consist of gravel, cobbles, and finer-grained sediments. Ql surfaces commonly have loose, open lags of pebbles and cobbles; surface clasts may exhibit weak rock varnish. Ql soils are brown to strong brown (7.5YR), weakly to moderately developed, small to moderate subangular blocky strucure and stage I-II calcium carbonate accumulation.

Qm **Middle Pleistocene alluvium (~130 to 750 ka)**
Qm_p **Middle Pleistocene alluvium over pediments**
Middle Pleistocene alluvium (~130 to 750 ka) -- Moderately dissected relict alluvial fans drained by well-developed, moderately to deeply incised tributary channel networks. Channels are incised 1-4 meters with channel dissection increasing towards the mountains. Well-preserved, planar Qm surfaces are smooth with moderately to strongly varnished, moderately packed cobble pavements. More eroded, rounded Qm surfaces are characterized by scattered cobble lags and broad ridge-like topography. Qm alluvium derived from granitic rocks tend to have smooth gravel surfaces with little to no varnish on surface clasts, and lesser amounts of carbonate accumulation through the soil profile. Soils contain reddened (7.5-5YR), argillic horizons, with obvious clay skins and subangular blocky structure, and stage III to IV soil carbonate development. Qmp is a thin, discontinuous veneer of middle Pleistocene alluvium over bedrock pediment. Outcrops of the underlying bedrock is common.

Qmo **Middle to Early Pleistocene alluvium (~500 ka to 1 Ma)**
Qmo_p **Middle Pleistocene alluvium over pediments**
Middle to early Pleistocene alluvium (~500 ka to 1 Ma) -- Moderately to deeply dissected relict alluvial fans. Qmo forms broadly rounded ridges that are higher than adjacent Qm surfaces but not as high or eroded as Qo surfaces. Tributary drainage networks are incised 3 to 6 m, increasing towards the mountains. Qmo soils are very well developed with a distinct dark red (5-2.5 YR), heavy clay argillic horizon and subangular blocky to prismatic structure. Carbonate accumulations range from stage III to IV. Qmop is a thin, discontinuous veneer of middle to early Pleistocene alluvium over bedrock pediment. Outcrops of the underlying bedrock is common.

Qo **Early Pleistocene alluvium (~750 ka to 2 Ma)**-- Early Pleistocene alluvium (~750 ka to 2 Ma) -- Moderately to deeply dissected relict alluvial fans remnants. Qo surfaces are highly eroded, rounded ridges with up to 10 m of active channel incision. Qo deposits consist of cobbles, boulders, and sand and finer clasts with soil development similar to Qmo soils. Qo surfaces vary from red where the argillic horizon is preserved, to light colored where carbonate-rich fragments derived from the underlying petrocalcic horizon litter the surface. Unit Qop is a thin veneer of well-preserved Qo alluvium over bedrock pediment. Qo surfaces record the highest levels of aggradation in the area surround the Tortolita Mountains, and are probably correlative with other high, remnant surfaces found at various locations throughout southern Arizona (Menges and McFadden, 1981; Pearthree and Calvo, 1987).

QTs **Early Pleistocene to Pliocene alluvium (~1 to 5 Ma)**--Unit QTs is a basin fill deposit consisting of very old, deeply dissected and highly eroded alluvial fan deposits derived from nearby mountains. QTs surfaces are alternating eroded ridges and deep valleys, with deeply incised tributary channel networks. Pockets of red, well developed soil mantle some of the hillslopes. QTs deposits are composed of poorly sorted angular to subangular granule and cobble, sandy conglomerate and cobbly sandstone. Deposits are moderately indurated with carbonate sporadically exposed at the surface. The conglomerate and sandstone contain clasts of potassium feldspar porphyritic, coarse-grained granite (Yo), medium-grained equigranular granodiorite (Kgd), and schist (Xp) derived from the northern Tortolita Mountains. Sparse mylonitic granitoid clasts indicate that the unit postdates exhumation of ductile-deformed portions of the Tortolita Mountains. The unit overlies the granite-clast conglomerate (Tcg)along a gently east-dipping angular unconformity and overlaps at least one major west-striking, down-to-the-north normal fault. Strata are horizontal to very gently east-dipping. The unit correlates with the Tcy unit of Skotnicki (2000). (0-100 meters thick).

Qtc **Talus and colluvium (Holocene and Pleistocene).** Unit Qtc consists of talus and colluvial deposits on steep hillslopes where it is sufficiently thick to obscure underlying bedrock. Deposits consists of angular to subangular boulders to fine sediments.

BEDROCK UNIT DESCRIPTIONS

Bedrock unit descriptions include all units mapped on the Tortolita Mountains, Ruelas Canyon, and Marana 7.5' quadrangle, and the eastern half of the Desert Peak 7.5' quadrangle.

Tcy **Younger Conglomerate (Miocene) –** Thin- to thick-bedded, pebbly sandstone, pebble-cobble sandy conglomerate and sandstone, typically in tabular-planar sets. Clasts are rounded to sub-angular and dominated by schist and granite with between 0-20% mafic volcanics. (>50m thick)

Tty **Younger tuff (Miocene) –** Phenocryst-poor, white nonwelded tuff containing sparse lithic lapilli of granite and schist. A $^{40}Ar/^{39}Ar$ sanidine age of 17.69 ± 0.17 Ma was obtained from this unit (Peters et al., 2003). (0-5m thick)

Tcg **Granite-clast conglomerate (Oligocene-Miocene) –** Massive to very thick-bedded, but very poorly exposed, boulder-cobble, potassium feldspar porphyritic, coarse-grained granite-clast conglomerate that contains up to 10% clasts of mafic volcanics and or schist. Stratal tilts in this unit range between 35^o to less than 10^o. (0-600 meters thick)

Tc **Polymict conglomerate (Oligocene-Miocene) –** Thin- to thick-bedded, reddish sandy matrix, cobble-pebble, rarely boulder, clast-supported, conglomerate and pebbly sandstone. The conglomerate contains sub-angular to rounded clasts of schist and granite (typically greater than 75%) and subordinate clasts of mafic and intermediate volcanics. Locally, especially near the base, volcanic clasts may constitute more than 50% of the clasts. Stratal tilts in this unit range between 35^o and vertical. (0-200 meters thick)

Yox **Oracle Granite breccia (Oligocene-Miocene deformation of a Mesoproterozoic unit) –** Strongly fractured, medium- to coarse-grained, potassium feldspar porphyritic biotite granite forming massive outcrops of monomict, angular to sub-angular, pebble- to boulder-sized clast-supported, typically jig-saw fit breccia.

Xpx **Pinal Schist breccia (Oligocene-Miocene deformation of a Paleoproterozoic unit) -** Strongly fractured, fine- to medium-grained sericitic phyllite and schist forming massive outcrops of monomict, angular to sub-angular, pebble- to cobble-sized clast-supported breccia with red sandy to silty matrix. The unit appears to grade northward into polymict, conglomerate of unit Tc.

Tcv **Volcaniclastic conglomerate (Oligocene) –** Thin- to thick-bedded, reddish sandy matrix, cobble-pebble conglomerate and sandstone containing greater than 80% volcanic clasts, locally with subordinate clasts of granite and schist. Clasts are typically nonequant, and sub-angular to sub-rounded. Conglomerate beds are typically clast-supported. The unit occurs in relatively thin units interbedded with mafic to intermediate volcanic flows in the Chief Butte area. (0-30 meters thick)

Tcd **Dacite clast conglomerate – breccia (Oligocene) –** Dominantly monomict dacite clast conglomerate and breccia, typically thick-bedded to very thick-bedded or massive with poorly defined bedding. Clasts are angular to sub-rounded, very poorly-sorted and suspended in a sandy volcaniclastic matrix. Clast-supported and matrix-supported units are both present. The unit occurs in at least two sequences interbedded with mafic lava flows to the north of the Owl Head Buttes. The sequences become thinner and finer grained to the north where they grade into polymict conglomerate and sandy conglomerate units. The polymict varieties contain up to 30% clasts of andesitic lava, basaltic lava and coarse-grained, equigranular to potassium feldspar porphyritic granite. To the south, the sequences become thicker as they grade into monomict lava breccia associated with dacite lava flows. (0-120 meters thick)

Td **Dacite lava (Oligocene) –** 5-10% plagioclase-porphyritic, biotite-phyric dacite lava. The unit occurs as two massive to autobrecciated flows that make up the northern Owl Head Buttes, and which grade to the north into monomict dacite clast breccia and conglomerate. Compositionally, the dacite lava unit ranges from trachyte to rhyolite. (0-200 meters thick)

Tcs **Schist clast conglomerate (Oligocene) –** Monomict, medium- to thick-bedded, clast-supported, red sandy matrix, pebble-cobble conglomerate with sub-angular to sub-rounded nonequant clasts of fine- to medium-grained sericitic schist. The unit, less than 20m thick, is restricted to the northern Owl Head Buttes area where it directly overlies schist and is overlain by mafic lava. (0-30 meters thick)

Tdi **Hypabyssal dacite (Oligocene) –** Phenocryst-poor, plagioclase- and biotite-phyric dacitic hypabyssal bodies intrude Tertiary volcanic rocks in the northern part of the map area. The unit is petrographically, and geochemically identical to phenocryst-poor, dacitic lava flows that occur in the Owl Head Buttes area and within the Cloudburst volcanics in the Fortified Peak area (Orr et al., 2002). Compositionally, the hypabyssal dacite unit ranges from trachyte to rhyolite. A biotite K/Ar date of 26.7 + 0.5 Ma was obtained from this unit from the Chief Butte area (Banks et al., 1978).

Tai **Hypabyssal andesite (Oligocene) –** Small stocks of hypabyssal andesite similar in composition to the andesite lava unit (Ta).

Tt **Welded rhyolitic tuff (Oligocene) –** Moderately welded rhyolitic ash-flow tuff containing approximately 10% phenocrysts of plagioclase, sanidine, quartz, and biotite with up to

10% lithic fragments of mafic to intermediate volcanic rocks. Color ranges from light peach to red. In some areas, a thin-bedded nonwelded tuff interval less than a few meters thick occurs at the base of the unit. The unit is identical petrographically to a welded rhyolitic tuff in the Cloudburst volcanics of the Fortified Peak area (Orr et al., 2002). A $^{40}Ar/^{39}Ar$ sanidine age of 26.39 $\pm$ 0.07 Ma was obtained from this unit (Peters et al., 2003). (0-15 meters thick)

Ta **Andesitic lava (Oligocene) –** A composite unit of mafic to intermediate lava flows characterized by phenocryst assemblages dominated by plagioclase with subordinate mafic phenocrysts. Plagioclase phenocrysts, range in size from less than 1mm to 6mm. Flows of this unit are differentiated from the basaltic andesite lava unit (Tb) by phenocryst assemblage, and from the dacitic lava and hypabyssal dacite unit by the lack of biotite phenocrysts. Two main flow units are recognized in the Chief Butte area. Quartz xenocrysts up to 2cm are present near the base of the flows, and the upper flow is overlain in some areas by the welded rhyolitic tuff unit (Tt). Compositionally, the andesite lava unit ranges from trachyandesite to trachyte. A feldspar concentrate K/Ar date of 24.0 $\pm$ 0.6 Ma (Dickinson and Shafiqullah, 1989) was obtained for this unit from the southern part of the Owl Head Buttes area. (0-120 meters thick)

Tb **Basaltic andesite lava (Oligocene) –** A composite unit of amalgamated mafic lava flows characterized by phenocryst assemblages of 2-15% pyroxene, $\pm$ olivine (ranging in size from 0.3mm to 4mm), and subordinate plagioclase (typically less than 1.5mm). The unit is differentiated from the andesite lava unit (Ta) by the subordinate abundance and size of plagioclase phenocrysts relative to its ferromagnesian phases. The matrix of the lavas is typically microcrystalline, but locally aphanitic, and ranges from vesicular to massive. Individual flow units range between 2 to 20m thick. The flow tops are defined by reddish scoriaceous zones that are commonly infiltrated with red volcaniclastic sandstone, and many areas, thin intervals of volcaniclastic sandstone occur between the flows. Compositionally, the lavas range from true basalt to trachybasalt and basaltic trachyandesite. A whole rock K/Ar date of 21.0 + 0.5 Ma (Jennison, 1976) was obtained for this unit from a sample in the Owl Head Buttes area. (0-600 meters thick)

Tb0 **Aphyric basaltic andesite lava (Oligocene) --** Massive, crystalline matrix mafic lava. Sparsely vesicular and rarely autobrecciated. (0-100 meters thick)

Tdd **Dacite dikes (Mid-Tertiary)** – A swarm of north-striking, apparently near vertical dikes up to 4m wide intrude the Mesoproterozoic Oracle Granite (Yo, Yom), Paleoproterozoic Pinal Schist (Xp), and Tertiary (Kgd) pluton of Chirreon Wash in the northeast corner of the map area. One dike, in the easterly adjacent Oracle Junction quadrangle (Sheet 1), clearly intrudes the Carpas Wash shear zone.

Tm **Mafic dikes and small stocks (Mid-Tertiary) --** Fine- to medium-grained, but usually fine-grained mafic dikes and stocks containing variable amounts of plagioclase (10-60%), and mafic minerals, typically chloritic altered. Sparse quartz is present in some dikes. Composition probably ranges from monzonite and quartz monzodiorite to diorite. Diabase texture is notably absent, which is the chief diagnostic feature distinguishing this unit from the diabase dike unit (Yd) of probable Mesoproterozoic age. The largest and most significant outcrop of this unit occurs in the north-flowing canyon of Guild Wash where it clearly intrudes the Carpas Wash shear zone and a northwest-striking strand of the Guild Wash fault.

Tgp **Granite porphyry dikes (Mid-Tertiary) –** Medium-grained syenogranite to alkali feldspar granite with less than or equal to 5% biotite. Dikes ranging in thickness up to 50 meters but generally less than 15 meters thick. The dikes are consistently northwest-striking and nearly vertical. The dikes are also characteristically unaffected by the ductile deformation that is pervasive in all host rocks. Texturally, the dikes change from potassium feldspar porphyritic along margins to medium-grained, equigranular in the core. Graphic texture and myrmekitic texture is also very common in these dikes. A K/Ar biotite cooling age of 24.0 $\pm$ 0.5 Ma (Banks et al., 1978) and a $^{40}Ar/^{39}Ar$ biotite cooling age of 24.07 $\pm$ 0.13 Ma (Spell et al., 2003) was obtained from a dike of this unit near Bass Spring in the central Tortolita Mountains.

Trp **Rhyolite porphyry dikes (Mid-Tertiary) –** Phenocryst-poor rhyolite porphyry dikes containing less than 10% phenocrysts of feldspar (1-4mm), quartz (1-3mm), and sparse biotite. The northwest-striking dikes, up to 5m wide, occur in the northeast corner of the map area where they cut units on both sides of the Carpas Wash shear zone. Within the shear zone, rhyolite porphyry dikes are strongly sheared into parallelism with the Carpas Wash shear zone.

Tag **Aplite granite dikes (Tertiary) –** This unit is not shown on the map, but these dikes are abundant within the Tortolita Mountains Granite and are important units in the structural database. The dikes, typically northwest-striking and nearly vertical, may be related to the granite porphyry dikes (Tgp).

Ttm **Tortolita Mountains Granite (Tertiary) –** Medium-grained, equigranular granite containing 5-12% biotite. Point count of stained slab (CAF-02-3636) is as follows: 36% potassium feldspar, 30% quartz, 21% plagioclase, 12% biotite and opaques. The granite occurs as a pluton in the southeast corner of the map area, southeast of Wild Burro Canyon and as a swarm of dikes that invade the pluton of Wild Burro Canyon northwest of Wild Burro Canyon. Sparse dikes are also present to the west of Cochie Canyon at the southern edge of the Tortolita Mountains. In the south, the pluton is pervasively deformed displaying weak to moderate protomylonitic foliation and stretching lineation, but to the north this deformation is minor to absent. The dike swarm which intrudes the pluton of Wild Burro Canyon is characterized by fairly intense ductile deformation with strong protomylonitic to ultramylonitic fabrics confined to the dikes, particularly to the south. This unit was previously referred to as the quartz monzonite of Tortolita Mountains by Banks (1980), and it correlates with the Tgf unit of Skotnicki (2000). A K/Ar biotite cooling age of 22.7 $\pm$ 0.7 Ma was obtained from this unit near the center of its pluton in the southeastern Tortolita Mountains (Creasy et al., 1977). A $^{40}Ar/^{39}Ar$ biotite cooling age of 23.69 $\pm$ 0.15 Ma (Spell et al., 2003) was obtained from this unit.

Ttmm **Tortolita Mountains Granite, mafic phase (Tertiary) –** Rare dikes less than 3 meters wide of fine-grained, equigranular weakly protomylonitic granite with up to 35% biotite. The dikes occur only in the southwestern part of the map area where they intrude the pluton of Wild Burro Canyon.

Tww **Pluton of Wild Burro Canyon, western phase (Tertiary) –** A steeply southeast-dipping interdigitate sheet of medium- to coarse-grained, equigranular, <10% biotite granite that occurs along the western edge of the pluton of Wild Burro Canyon. The granite forms massive outcrops along the divide between Wild Burro and Cochie canyons. Farther east, the granite occurs as small west- to southwest-elongate bodies. Although typically the youngest phase of the pluton, this phase shows some overlap in age with the mafic phase (Twm), but not with the main (Tw) phase. A point counted slab (CAF-02-2569) is as follows: 48% potassium feldspar, 31% quartz, and 21% plagioclase with sparse biotite and opaque minerals.

Xp-Tww**Pinal Schist with between 5-35% western phase of the pluton of Wild Burro Canyon dikes (Paleoproterozoic and Tertiary) –** A composite unit consisting of fine- to medium-grained sericitic to psammitic schist cut by abundant leucogranite dikes interpreted as the western phase of the pluton of Wild Burro. This unit is similar to a composite unit of schist intruded by dikes of the granite of Fresnal Canyon, but dikes of this unit contain little or no pegmatite.

Twm **Pluton of Wild Burro Canyon, mafic phase (Tertiary) –** Irregular shaped bodies of fine- to medium-grained 30-60% biotite and hornblende, quartz monzodiorite to monzodiorite and diorite that are concentrated along the southeastern margin of the pluton of Wild Burro Canyon (Tw). The bodies are characteristically heterogeneous in terms of grain size and composition with swarms of mafic-rich, fine- to medium-grained diorite to monzodiorite intimately mixed with less mafic-rich, medium-grained monzodiorite to quartz monzodiorite and quartz monzonite. Some bodies are sparsely potassium feldspar porphyritic. Foliation is typically absent to weak and if present it is not oriented consistently (as it is in the main phase). In most areas where foliated rocks are present, the foliation parallels the walls of intrusive bodies into the main phase and is interpreted as primary or magmatic in origin. Although typically showing intrusive relationships into the main phase (Tw), the mafic phase is also cut in some areas by rocks of the main phase. Similarly, the mafic phase, although typically older than the western phase (Tww) also shows intrusive relationships into this rock in some areas. Correlates with the Tgm unit of Skotnicki (2000).

Tw **Pluton of Wild Burro Canyon (Tertiary) –** A northeast-southwest elongate composite pluton with three main phases. The main and oldest phase (Tw) consists of medium- to coarse-grained, potassium feldspar porphyritic quartz monzonite to quartz syenite with 15-30% biotite and hornblende. The main phase is pervasively foliated with a steep regional southeasterly dip, parallel to a swarm of metasedimentary enclaves located in the northwestern part of the pluton. The foliation is weak shape fabric described as weak foliation or weak to moderate protomylonitic foliation in most areas. The pluton contains up to 10% schlieren oriented parallel to the foliation, and these are most abundant near bodies of the mafic phase (Twm). A point counted slab (CAF-02-3711) cut normal to the folation at the southwest edge of the range is as follows: 41% potassium feldspar, 30% plagioclase, 17% quartz, 11% mafic minerals, chiefly biotite. Note that the apparent low percentage of biotite is due to the cut normal to the foliation. Correlates with the Tgc map unit of Skotnicki (2000). A K/Ar biotite cooling age of 28.0 $\pm$ 0.9Ma was obtained from this unit near the mouth of Wild Burro Canyon (Mauger et al., 1968). A $^{40}Ar/^{39}Ar$ biotite cooling age of 22.36 $\pm$ 0.15 Ma (Spell et al., 2003) was obtained from this unit along the southwestern edge of the range.

Tmd **Diorite dikes (Tertiary)** – Fine- to medium-grained diorite dikes and small elongate stocks intrude the Granite of Fresnal Canyon in the southwest corner of the map area. The diorite is variably foliated.

Tf **Granite of Fresnal Canyon, composite unit (Tertiary) –** A mixed body of medium- to coarse-grained leucogranite with abundant (>5%) pegmatite. The leucogranite ranges from muscovite-garnet bearing to muscovite-biotite and magnetite, $\pm$ garnet bearing. Pegmatite, which is typically an alkali feldspar granite with minor muscovite, garnet and rare biotite, occurs as irregular dikes and pods with overlapping cross-cutting relationships with the leucogranite. The unit occurs as discrete plutonic bodies in the northwestern part of the range and as an extensive dike swarm that extends into the central and eastern parts of the range where it intrudes two units; the Pinal Schist, and the pluton of Chirreon Wash. The dikes are almost always composite, typically consisting of a core of coarse-grained pegmatite with walls of fine- to medium-grained leucogranite. The unit was previously know as the quartz monzonite of Samaniego Ridge (Banks et al., 1977), and the pluton of Cottonwood Canyon (Banks, 1980).

Tfs **Granite of Fresnal Canyon (Tertiary) –** Medium-grained, protomylonitic, muscovite, garnet, ± biotite leucogranite distinguished from map unit Tf by a conspicuous absence of pegmatite dikes and pods (cutoff is 5%). This unit represents the core of a granite of Fresnal Canyon pluton in the northwestern Tortolita Moutains, and is represented by three stocks, the largest of which was previously referred to as granitic gneiss by Budden (1975). A $^{40}Ar/^{39}Ar$ muscovite cooling age of 25.29 ± 0.15 Ma (Spell et al., 2003) was obtained from this unit near the head of Fresnal Canyon in the northwestern part of the footwall block.

Tf-Kgd **Granite of Fresnal Canyon with less than 65% pluton of Chirreon Wash enclaves (Tertiary) –** A composite unit consisting of pluton of Chirreon Wash intruded by abundant dikes of the granite of Fresnal Canyon.

Tf-Xp **Granite of Fresnal Canyon with less than 65% Pinal Schist enclaves (Paleoproterozoic and Tertiary) –** A composite unit consisting of Pinal Schist intruded by abundant dikes of the granite of Fresnal Canyon.

Kgdl-Tf **Leucocratic phase of the pluton of Chirreon Wash with less than 35% Fresnal dikes (Tertiary) –** A composite unit consisting of the leucocratic phase of the pluton of Chirreon Wash intruded by abundant dikes of the granite of Fresnal Canyon.

Xp-Tf **Pinal Schist with between 5-35% granite of Fresnal Canyon dikes (Paleoproterozoic and Tertiary) –** A composite unit consisting of Pinal Schist intruded by abundant dikes of the granite of Fresnal Canyon.

Kgd **Pluton of Chirreon Wash (Tertiary) –** An extensive pluton consisting of a main phase of medium-grained, equigranular monzogranite, quartz monzonite and granodiorite containing 15-30% ferromagnesian minerals dominated by subequal amounts of biotite and hornblende, and minor clinopyroxene, and opaque minerals. The pluton is pervasively weakly foliated with a consistent moderate northwesterly dip. To the southeast, zones with minor potassium feldspar porphyritic texture are present. Subordinate mafic and leucocratic phases are present in the east in the vicinity of Derrio Canyon and near the head of Wild Burro and Cochie canyons. The unit has previously been referred to as the Granodiorite of Chirreon Wash (Banks, 1980) and the Granodiorite of Derrio Canyon by Skotnicki (2000). A K/Ar biotite cooling age of 25.1 ± 0.9 Ma was obtained from this unit on the eastern piedmont of the Tortolita Mountains (Banks et al., 1978). A U-Pb zircon crystallization age of 70 Ma was obtained from this unit in the central part of the range.

Kgd-Tf **Pluton of Chirreon Wash with between 5-35% granite of Fresnal Canyon dikes (Tertiary) -** A composite unit consisting of the pluton of Chirreon Wash intruded by abundant dikes of the granite of Fresnal Canyon.

Kgdm **Pluton of Chirreon Wash, mafic phase (Tertiary) –** A phase of the pluton of Chirreon Wash containing greater than 35% mafic minerals, and generally slightly finer grained than the main phase. Found as small pods in upper Derrio Canyon and also to the south as several small blebs near the heads of Wild Burro and Cochie canyons.

Kgdl **Pluton of Chirreon Wash, leucocratic phase (Tertiary) --** A minor phase of the pluton of Chirreon Wash consisting of medium-grained, equigranular monzogranite and containing less than 15% mafic minerals. The phase is restricted to a small area near the head of Derrio Canyon.

Tgdp **Granodiorite porphyry (Tertiary) –** One small mass of gray granodiorite porphyry mapped by Banks et al. (1977) intrudes Oracle Granite on the piedmont south of Owl Head Buttes in the northwest part of the map area.

₽q **Quartzite (Paleozoic) –** Thin- to thick-bedded or banded gray vitreous quartzite with sparse interbeds of calc silicate schist and rusty sericitic schist.

₽m **Marble (Paleozoic) –** Massive, light gray marble.

₽s **Metasedimentary rocks (Paleozoic) -** A map unit composed of complexly interfingered quartzite, calc silicate schist, sericitic schist, and marble. Rare primary sedimentary structures are preserved (such as tabular-planar cross-stratification), but in almost all instances, compositional banding is interpreted as transposed bedding.

₽s-Ya **Metasedimentary rocks (Mesoproterozoic to Paleozoic) -** A map unit composed of complexly interfingered quartzite, calc silicate schist, sericitic schist, and marble with ubiquitous lenses and pods of fine- to medium-grained amphibolite schist. The amphibolite schist lenses are interpreted as deformed diabase dikes of probable Mesoproterozoic age and distinguish this unit from the other metasedimentary rock units. The unit is interpreted as sheared and metamorphosed Apache Group ± various Paleozoic units.

Yd **Diabase (Mesoproterozoic) –** Mafic dikes and pods displaying diabase texture or interpreted to be associated with nearby mafic dike with diabase texture. This unit is recognized only north of the Carpas Wash shear zone.

Yds **Dripping Spring Quartzite (Mesoproterozoic) -** Thin- to thick-bedded, fine- to medium-grained, moderately sorted, pink, feldspathic quartz sandstone with some parallel laminated siltstone interbeds and sparse granule and pebble trains. The sandstone displays wedge-planar to trough cross-stratified bedforms. This unit is restricted to a pair of low inselbergs on the southwest piedmont of the Tortolita Mountains. (>25 meters thick)

Yo **Oracle Granite (Mesoproterozoic) –** Medium- to coarse-grained, potassium feldspar porphyritic, biotite granite. This map unit includes fairly extensive zones of medium- to coarse-grained, equigranular granite with biotite and muscovite in the vicinity of intrusive contacts with the Pinal Schist. The unit also includes abundant pegmatitic zones and pegmatite dike commonly containing abundant tourmaline.

Yom **Oracle Granite, medium-grained equigranular phase (Mesoproterozoic) -** Medium- to coarse-grained, equigranular to slightly quartz-porphyritic granite with biotite up to 15%. This phase is mapped only in the vicinity of the Falcon Divide.

Xpr **Pinal Schist, aphyric rhyolite lava (Paleoproterozoic) –** A thin autobrecciated aphyric rhyolite lava flow interbedded within a quartzose psammitic zone of the Pinal Schist in the north-central part of the map area.

Xp **Pinal Schist (Paleoproterozoic) –** To the north of the Carpas Wash shear zone, Pinal Schist consists in most areas of laminated to thin-bedded siltstone, and thin- to medium-bedded sandstone interbedded with mudstone. These rocks, interpreted as a turbidite succession, are regionally metamorphosed to lower greenschist facies slate and phyllite, but in proximity to intrusive contacts with the Oracle Granite, the Pinal Schist is strongly hornfelsed to medium- to coarse-grained, locally porphyroblastic sericitic schist and psammitic schist. Rectangular porphyroblasts up to 1cm are totally replaced by fine-grained aggregates of quartz, sericite, and chlorite. Slate and phyllite locally preserve primary sedimentary structures such as ripple cross-lamination, graded bedding and flute molds. To the south of Carpas Wash shear zone, Pinal Schist occurs in two east-west striking belts. The northern belt, along Derrio Canyon consists of medium- to coarse-grained, commonly quartz veined sericitic schist. To the south along Cochie Canyon, the Pinal Schist ranges from coarse-grained schist to thin-banded quartzofeldspathic sillimanite gneiss. In the Cochie Canyon area, Pinal Schist is distinguished from other metasedimentary rocks of probable Mesoproterozoic and Paleozoic age by its abundant quartz veins.

Table 1. Major element geochemistry of volcanic and hypabyssal rocks from the Owl Head – Chief Butte area of the northern Tortolita Mountains with one analysis from an intermediate composition plutonic rock (CAF-02-260) from the central Tortolita Mountains. Samples were crushed in a steel jaw crusher, and ground in a Tema mill using a WC grinding set. The samples were fused into glass discs and analyzed on a Phillips wavelength dispersive x-ray fluorescence spectrometer for major elements. A separate split of the samples was used to determine loss on ignition gravimetrically.

Sample	Map unit	K2O + Na2O	SiO2 wt. %	TiO2 wt. %	Al2O3 wt. %	Fe2O3-T wt. %	MnO wt. %	CaO wt. %	MgO wt. %	K2O wt. %	Na2O wt. %	P2O5 wt. %	LOI wt. %	Total wt. %	Ba ppm
CAF-02-223	Tb	7.35	57.61	0.73	14.68	5.73	0.08	5.83	4.83	4.29	3.06	0.39	2.71	99.94	1312
CAF-02-227	Ta	9.74	61.38	0.62	15.90	4.73	0.07	2.86	2.66	6.37	3.37	0.35	1.82	100.14	1814
CAF-02-232-CM1	Ta	11.27	59.28	0.99	17.30	5.36	0.09	1.82	1.76	6.62	4.65	0.43	1.71	100.02	1342
CAF-02-232-CM2	Ta	11.19	58.89	0.98	17.24	5.32	0.09	1.81	1.75	6.54	4.65	0.43	1.71	99.42	1331
CAF-02-234	Tb	7.69	54.07	1.00	16.26	6.65	0.07	6.60	4.43	4.02	3.67	0.71	2.39	99.87	1525
CAF-02-260	Twm	7.65	59.78	0.91	16.84	5.98	0.10	4.59	2.57	3.57	4.08	0.54	0.71	99.67	1239
CAF-02-1206	Tb	7.66	53.61	1.00	16.17	6.68	0.09	6.34	4.66	4.05	3.61	0.71	2.73	99.66	1558
CAF-02-1230	Tb	7.44	53.44	0.97	15.84	6.56	0.08	6.42	5.01	3.92	3.52	0.69	2.55	99.01	1563
CAF-02-1408	Ta	8.52	62.79	1.04	15.70	5.62	0.08	2.70	0.87	3.87	4.65	0.50	1.58	99.40	1312
CAF-02-1967	Tb	6.34	52.94	1.28	16.47	8.29	0.15	6.62	4.30	2.82	3.52	0.50	2.74	99.63	960
CAF-02-1979	Tdi	9.17	68.81	0.44	15.07	2.39	0.03	0.99	0.81	5.51	3.66	0.12	1.70	99.52	1488
CAF-02-2037	Td	12.54	67.28	0.44	15.34	2.47	0.02	0.28	0.30	11.10	1.44	0.10	0.65	99.43	1467
CAF-02-2101	Ta	7.54	62.09	1.08	15.54	5.25	0.06	2.74	1.94	2.80	4.74	0.52	2.88	99.64	1381
CAF-02-2114-CM1	Tb	5.96	50.80	1.25	15.59	8.58	0.08	6.56	6.07	2.80	3.16	0.52	4.32	99.73	1106
CAF-02-2114-CM2	Tb	5.96	50.50	1.24	15.52	8.53	0.08	6.52	6.05	2.78	3.18	0.52	4.32	99.24	1102
CAF-02-2114-CM3	Tb	5.96	50.36	1.23	15.51	8.50	0.08	6.51	6.04	2.78	3.18	0.52	4.32	99.04	1088
CAF-02-2144	Tb	6.83	55.38	0.91	16.49	6.48	0.11	5.90	4.16	3.19	3.64	0.49	2.70	99.45	1189

Table 1. continued

Sample	Map unit	K2O + Na2O	SiO2 wt. %	TiO2 wt. %	Al2O3 wt. %	Fe2O3-T wt. %	MnO wt. %	CaO wt. %	MgO wt. %	K2O wt. %	Na2O wt. %	P2O5 wt. %	LOI wt. %	Total wt. %	Ba ppm
CAF-02-2279-CM1	Tdx	11.68	65.25	0.59	14.25	3.59	0.05	1.78	0.87	10.68	1.00	0.25	1.51	99.82	1445
CAF-02-2279-CM2	Tdx	11.66	65.41	0.59	14.25	3.61	0.05	1.78	0.87	10.66	1.00	0.25	1.51	99.97	1443
CAF-02-2279-CM3	Tdx	11.61	65.49	0.59	14.25	3.61	0.05	1.78	0.87	10.61	1.00	0.25	1.51	100.01	1425
CAF-02-2322	Td	10.12	69.37	0.43	15.18	2.42	0.05	1.07	0.41	6.32	3.80	0.12	1.13	100.30	1474
CAF-02-2333	Tb	4.52	50.53	1.52	15.24	8.61	0.19	9.44	2.76	1.77	2.75	0.77	6.05	99.63	814
JES-11-19-01-4	Tbu	5.31	46.97	1.78	16.06	10.37	0.17	8.59	7.01	1.63	3.68	1.09	1.93	99.28	1512
JES-11-30-01-3	Tbu	5.15	48.05	1.58	15.73	10.21	0.16	8.64	7.61	1.80	3.35	0.92	1.12	99.17	1203
JES-12-3-01-4	Tdi	10.63	65.41	0.41	16.33	3.22	0.05	1.52	0.97	6.82	3.81	0.21	1.33	100.08	2077
JES-12-27-01-2	Tdi	10.45	65.04	0.40	15.70	3.30	0.04	1.44	1.60	7.33	3.12	0.22	1.82	100.01	1929

Fe2O3-T is total iron expressed as Fe2O3.
LOI is loss on ignition.
ND is below the lower limit of determination.

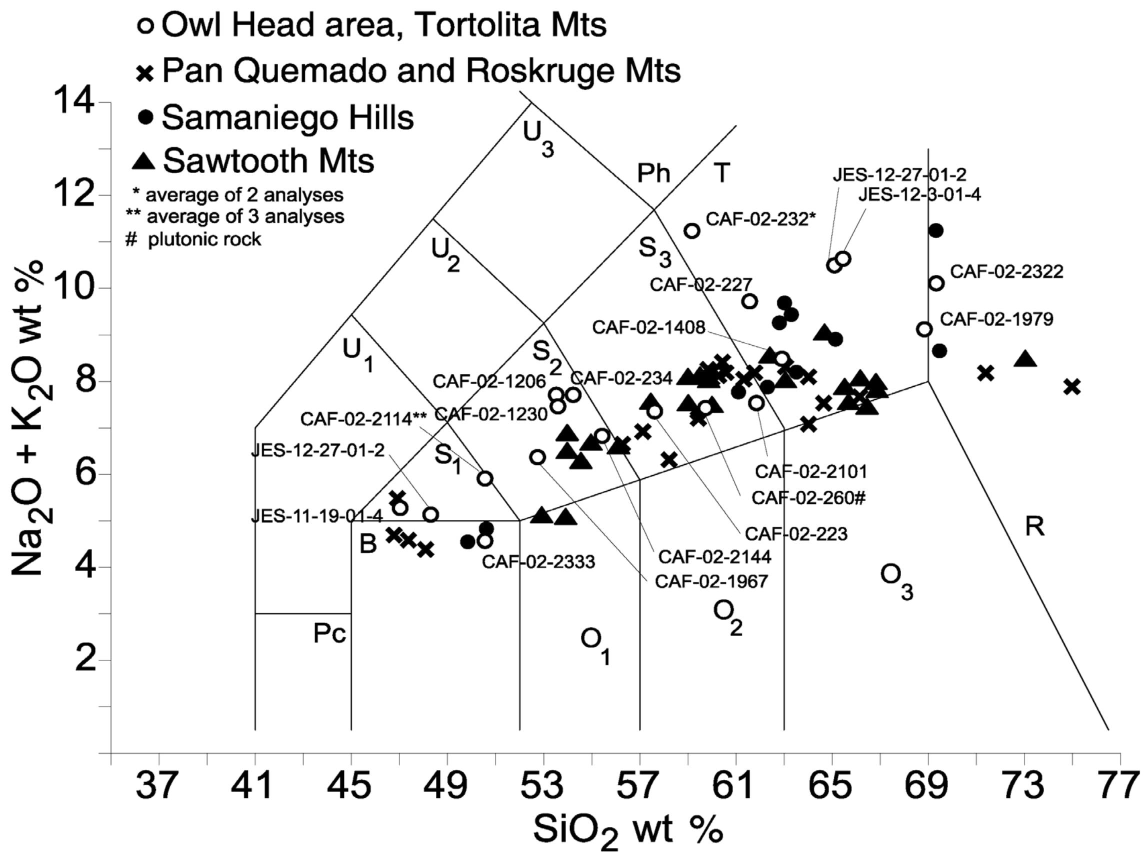


Figure 1 Total alkali versus silica diagram of Le Bas et al. (1986) showing analyses of Mid-Tertiary volcanic and hypabyssal rocks from the Owl Head – Chief Butte area of the northern Tortolita Mountains. Complete analyses of samples shown in Table 1. Also shown are data from Mid-Tertiary volcanic and hypabyssal rocks of the Pan Quemado and Roskruge Mountains (Ferguson et al., 2000; Eastwood, 1970), Samaniego Hills (Eastwood, 1970), and Sawtooth Mountains (Ferguson et al., 1999) which includes one analysis (sample E-2N) from Banks et al. (1978). Field name abbreviations are Pc: picrobasalt, B: basalt, O_1: basaltic andesite, O_2: Andesite, O_3: Dacite, R: rhyolite, S_1: trachybasalt, S_2: basaltic trachyandesite, S_3: trachyandesite, T: trachyte, U_1: tephrite basalt, U_2: phonotephrite, U_3: tephriphonolite, T: phonolite

Table 2 Criteria for selecting structural data sets shown in Figures 2-11 stereonets, and linked Bingham analyses values using the Stereonet for Windows v. 1.1 software of Allmendinger © 2002. Type IDs listed in Table 3.

Figure	Units	measurement	Type ID	n	Trend 1	Plunge 1	Eigen1	Trend 2	Plunge 2	Eigen2	Trend 3	Plunge 3	Eigen3
8b	Ttm, Ttmm	stretching lineation	574, 3387	179	**240.4**	**3.5**	0.8531	344.6	75.8	0.1165	149.5	13.7	0.0304
8a	Ttm, Ttmm	mylonitic foliation	560, 561	180	**33**	**81.7**	0.7584	246.1	7	0.1661	155.6	4.5	0.0756
11b	Ttm, Ttmm	directed stretch	3387	16	**63**	**26.1**	0.9266	238.6	63.8	0.0413	332.2	1.7	0.0321
9b	Ttm, Ttmm	dikes	656	100	**266.6**	**71.5**	0.7305	41.4	13.2	0.1491	134.4	12.6	0.1204
5b	Tw, Twm, Tww	stretching lineation	574, 3387	73	**237.4**	**0**	0.9455	327.5	78.7	0.043	147.4	11.3	0.0115
5a	Tw, Twm, Tww	mylonitic foliation	560, 561	89	**330**	**58.9**	0.8087	151.3	31.1	0.1452	241.8	0.8	0.0461
10b	Tw, Twm, Tww	directed stretch	3387	12	**57.9**	**0.7**	0.9208	275.4	89.2	0.0706	147.9	0.5	0.0086
7b	Tf, Tfs	stretching lineation	574, 3387	267	**64**	**1.6**	0.8948	324.3	80.7	0.0681	154.3	9.2	0.0371
7a	Tf, Tfs	mylonitic foliation	560, 561	143	**172**	**72.2**	0.7809	341	17.5	0.1547	72	3.2	0.0645
11a	Tf, Tfs	directed stretch	3387	22	**236.1**	**3.1**	0.8185	129.4	79.4	0.1472	236.7	10.2	0.0342
9a	Tf, Tfs	dikes	656	212	**165.7**	**60.8**	0.6231	350.6	29.1	0.2524	259.5	2.1	0.1245
4b	Kgd, Kgdl, Kgdm	stretching lineation	574, 3387	111	**247.1**	**0.6**	0.8652	345.1	85.4	0.0886	157	4.6	0.0463
4a	Kgd, Kgdl, Kgdm	mylonitic foliation	560, 561	67	**162.4**	**59.1**	0.6524	334.5	30.7	0.239	66.6	3.5	0.1086
10a	Kgd, Kgdl, Kgdm	directed stretch	3387	12	**246.4**	**3.8**	0.7134	142.6	74.4	0.2325	337.4	15.1	0.0541
6a	Septum*	planar elements	541, 554, 560, 561	143	**333**	**34.2**	0.761	182.5	52	0.2031	73.2	14.5	0.0359
6b	Septum*	tectonic lineation	429, 574, 577, 578	113	**239.6**	**4.5**	0.8495	108.4	83.2	0.1161	330	5.1	0.0344

* Septum defined as all metasedimentary rocks from map units Xp, Ᵽq, Ᵽm, Ᵽs, and Ᵽs-Ya in the footwall block, southern Tortolita Mountains (UTM Grid Zone 12 Northing >3592000 and <3599000).

Table 2 continued

Figure	Stereonet	measurement	Type ID	n	Trend 1	Plunge 1	Eigen1	Trend 2	Plunge 2	Eigen2	Trend 3	Plunge 3	Eigen3
3a	all footwall units**	tectonic foliation	320, 554, 559, 560, 561, 562	1116	**169.2**	**69.7**	0.5535	340.1	20.1	0.3499	71.2	3	0.0966
3b	all footwall units**	stretching lineation	574, 3387	922	**63.7**	**1**	0.8535	326.6	81.8	0.0987	153.9	8.2	0.0478
3c	all footwall units**	directed stretch	3387	95	**61.3**	**5.6**	0.7515	189.4	81	0.2004	330.6	7	0.0481
3e	all footwall units**	dikes	656	471	**202.7**	**75.9**	0.5909	347.9	11.6	0.2371	79.5	7.8	0.172
3d	all footwall units**	crenulation	564	30	**5.4**	**85.4**	0.6749	238.8	2.7	0.2864	148.6	3.7	0.0387
2a	CWSZ***	tectonic foliation	320, 554, 559, 560, 561, 562	201	**165.9**	**32.4**	0.8263	319.7	54.7	0.0881	67.9	12.5	0.0857
2c	CWSZ***	tectonic lineation	429, 572, 574, 577, 598, 3387	104	**249.5**	**3.8**	0.7305	343.9	48.7	0.1929	156.2	41.1	0.0766
2d	CWSZ***	stretching lineation	574, 3387	64	**248.8**	**4.6**	0.7356	344.8	52.4	0.1708	155.3	37.2	0.0936
2b	CWSZ***	directed stretch	3387	20	**249.4**	**20**	0.7387	113	63.3	0.1782	345.7	16.9	0.0831
2e	CWSZ***	younger lineation	578, 2935	30	**321.2**	**50.8**	0.6651	66.1	11.9	0.2575	165.2	36.7	0.0773
13a	Xp, Yom	mylonitic lineation		67	**75.6**	**6.5**	0.7955	223	82.2	0.1574	345.1	4.1	0.047
13b	Xp, Yom	mylonitic foliation		41	**174.9**	**33**	0.8332	67.3	25	0.1049	307.9	46.5	0.0619

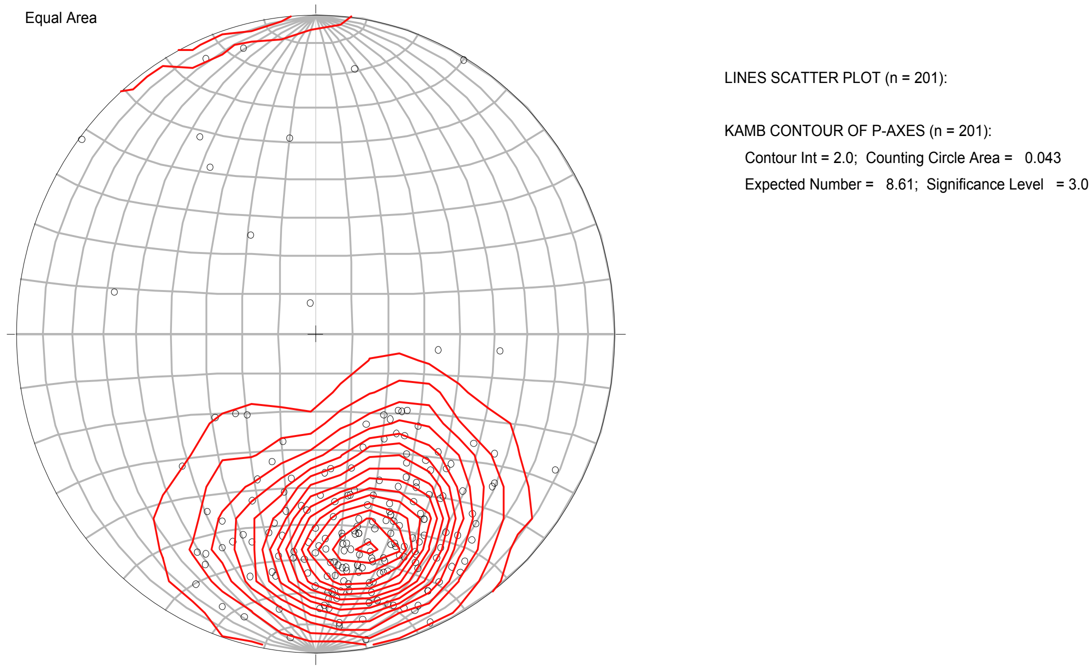
** all map units lying between UTM Grid zone 12 northing >3589000 and <3606200

*** Map units Xp, Yo, and Yom lying between UTM Grid zone 12 northing >3604000 and <3606200 and UTM easting >490000.

Table 3 Type ID structural elements

Type ID	Structure	Type ID	Structure
320	generic mylonitic foliation	562	ultramylonite
429	mineral lineation	574	stretching lineation
541	bedding	577	intersection lineation
554	schistosity	598	linear penetrative tectonic structure
559	mylonitic foliation, well-developed s-tectonite foliation	656	dike
560	protomylonite	2935	fold hinge
561	mylonite	3387	directional stretching lineation

A) Poles to foliation, Carpas Wash shear zone, northern Tortolita Mountains



B) Directed stretching lineations, Carpas Wash shear zone, northern Tortolita Mountains

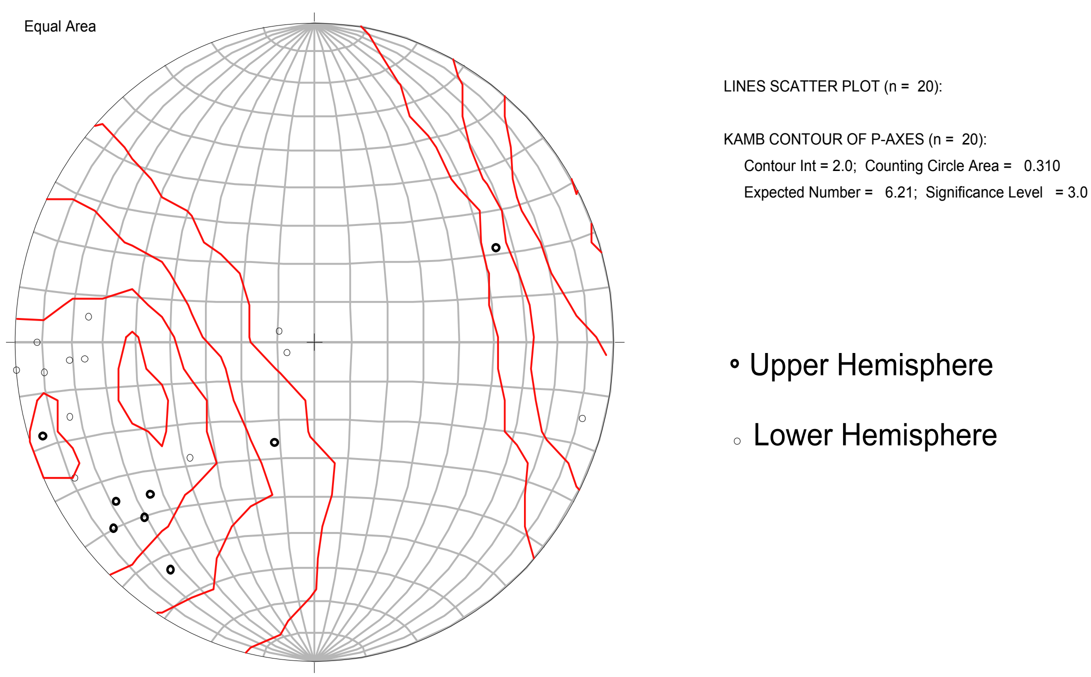
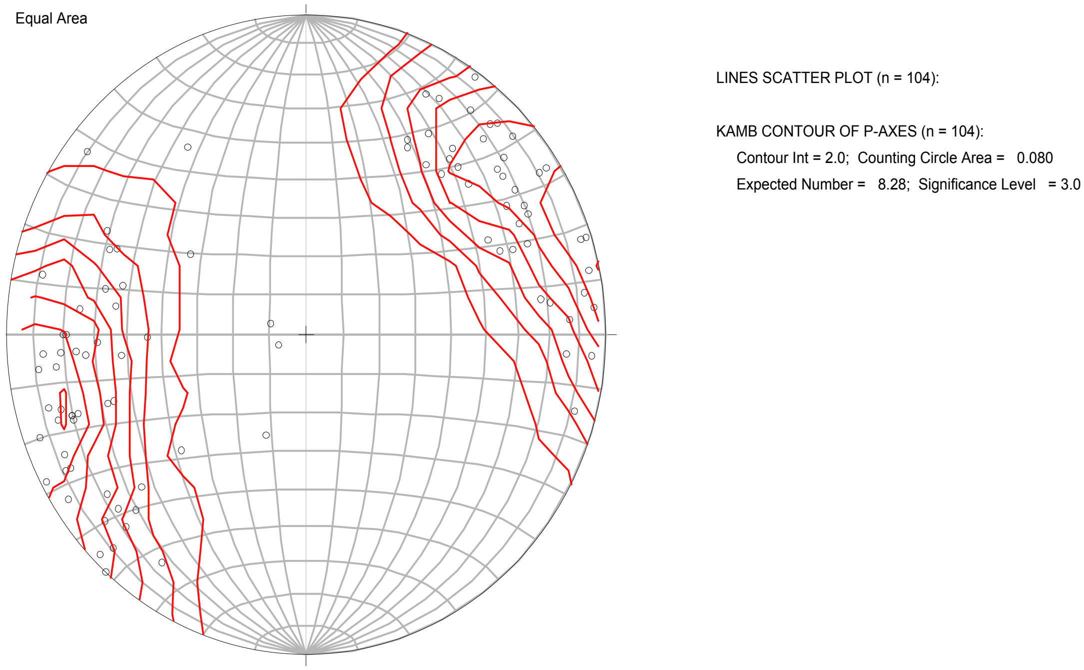


Figure 2a) Lower hemisphere stereonet plot of poles to schistosity, and mylonitic foliation, and 2b) directed stretching lineation in Proterozoic Pinal Schist and Oracle Granite within and near the Carpas Wash shear zone, northern Tortolita Mountains. Analysis from program SteroWin, v. 1.1, by R.W. Allmendinger (2002).

C) Older lineations (including stretching lineation), Carpas Wash Shear Zone, northern Tortolita Mountains



D) Stretching lineation, Carpas Wash Shear Zone, northern Tortolita Mountains

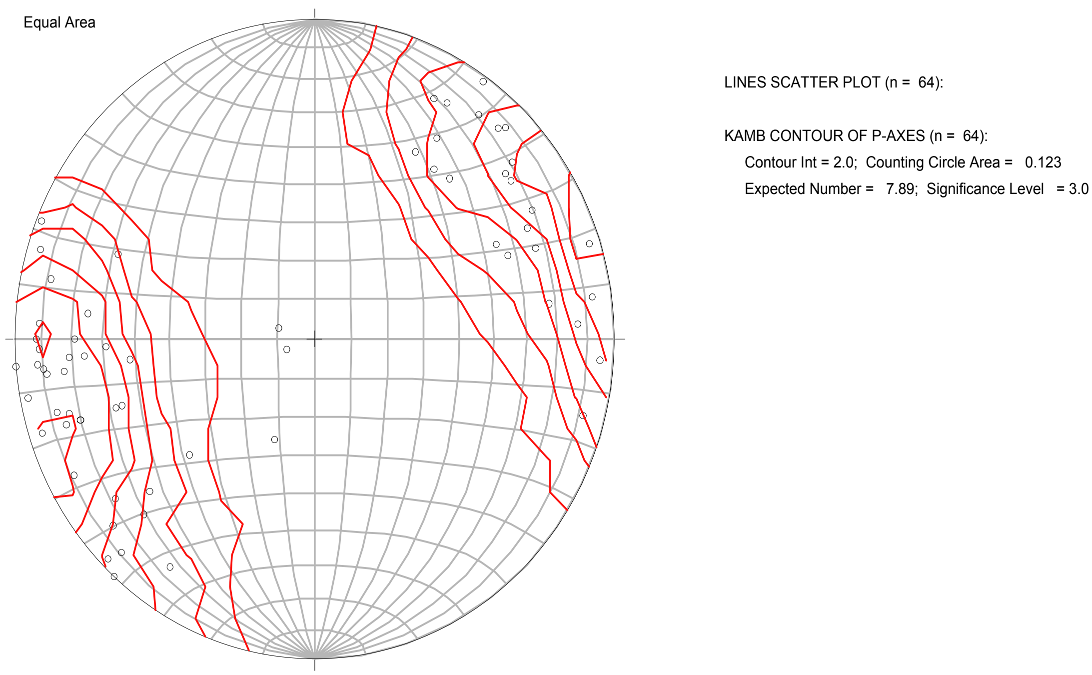


Figure 2c) Lower hemisphere stereonet plot of mineral lineation, crenulation lineation, stretching lineation, and hinge lines of isoclinal folds, and 2d) stretching lineation in Proterozoic Pinal Schist and Oracle Granite within and near the Carpas Wash shear zone, northern Tortolita Mountains. Analysis from program SteroWin, v. 1.1, by R.W. Allmendinger (2002).

E) Younger lineations, Carpas Wash shear zone, northern Tortolita Mountains

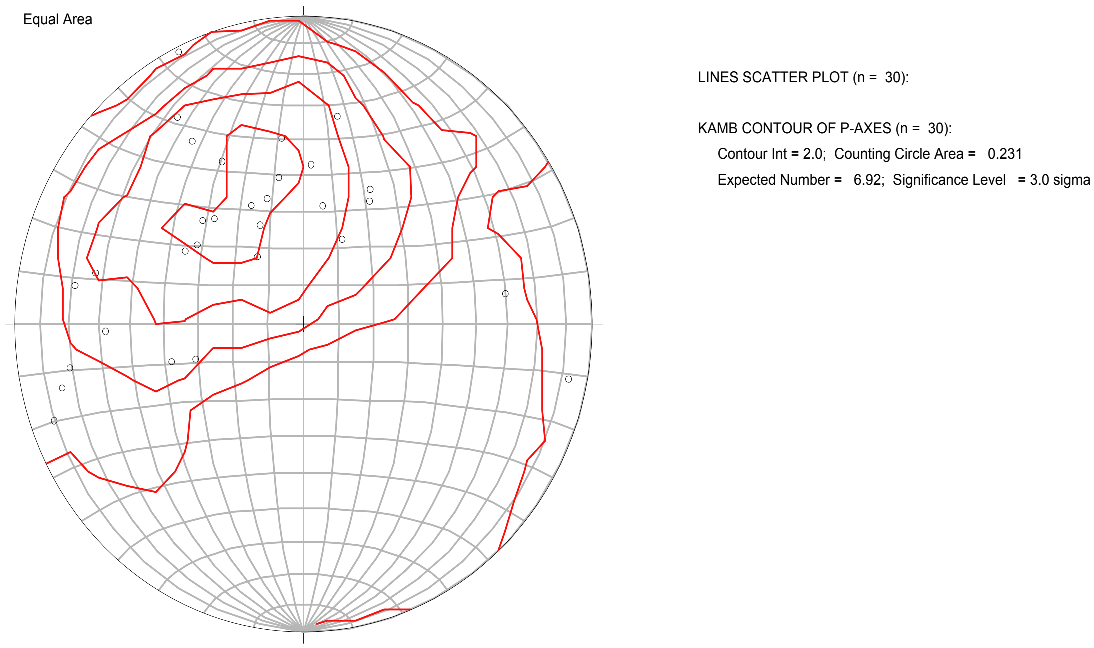
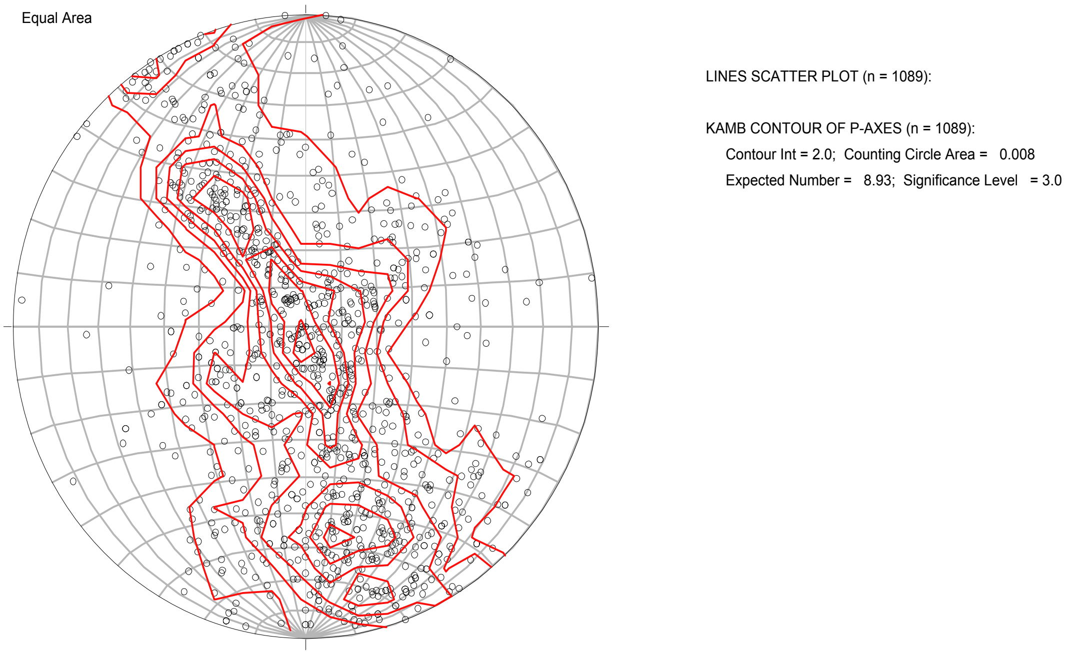


Figure 2e) Lower hemisphere stereonet plot of hinge lines of close to open mesocopic folds (commonly chevron forms) that deform mylonitic foliation and schistosity in Proterozoic Pinal Schist and Oracle Granite within and near the Carpas Wash shear zone, northern Tortolita Mountains. Analysis from program SteroWin, v. 1.1, by R.W. Allmendinger (2002).

A) Poles to foliation, footwall, Tortolita Mountains



B) Stretching lineation, footwall, Tortolita Mountains

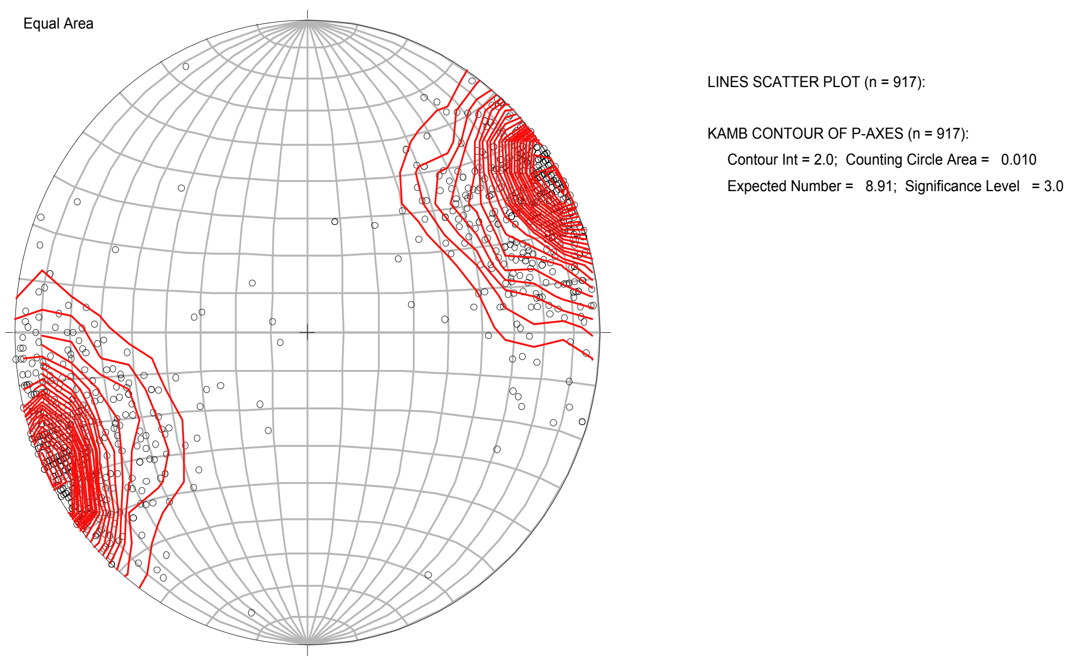
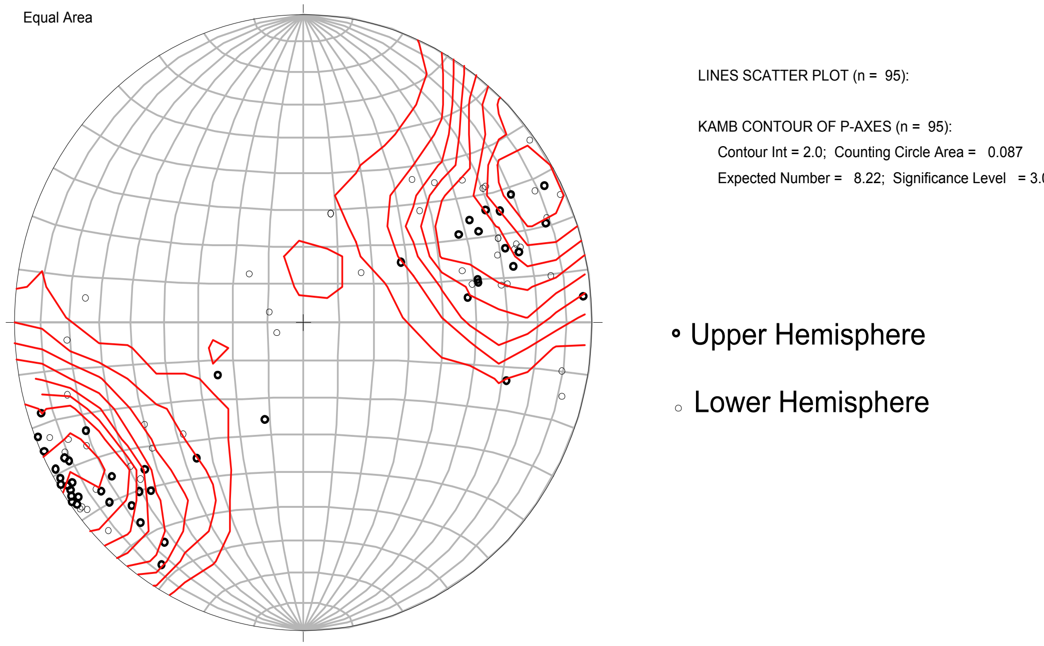


Figure 3a) Lower hemisphere stereonet plot of poles to schistosity, and mylonitic foliation, and 3b) stretching lineation in the footwall of the Tortolita Mountains. Analysis from program SteroWin, v. 1.1, by R.W. Allmendinger (2002).

C) Directed stretching lineation, footwall, Tortolita Mountains



D) Poles to crenulation cleavage and shear bands, footwall, Tortolita Mountains

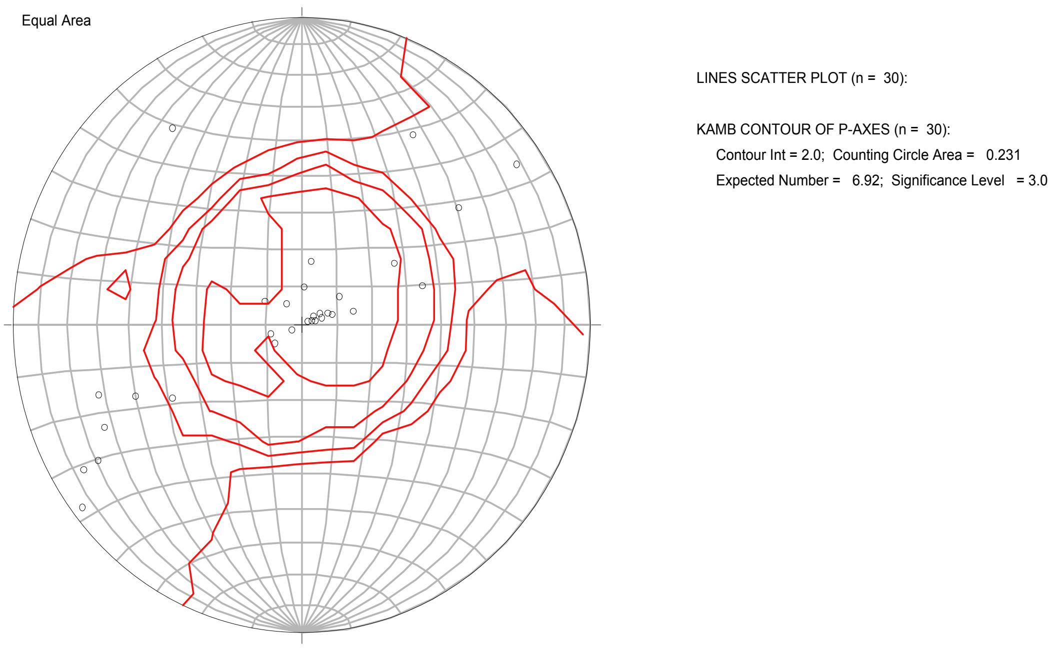
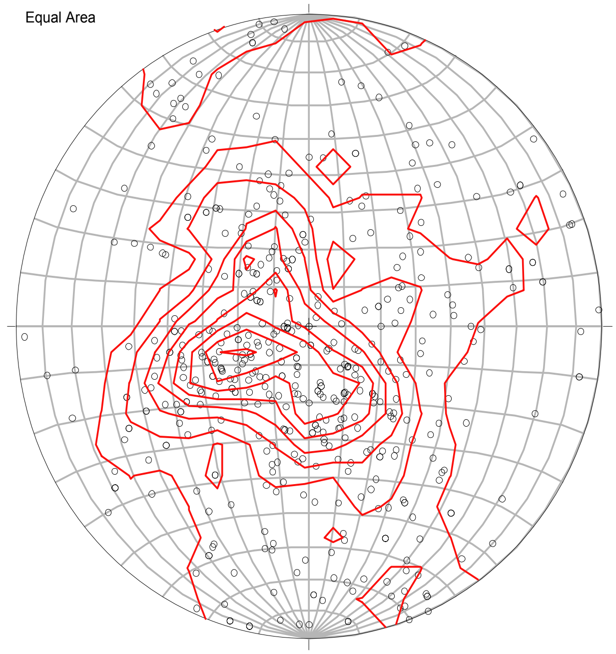


Figure 3c) Stereonet plot of directed stretching lineation, and 3d) lower hemisphere stereonet poles to crenulation cleavage and shear bands in the footwall of the Tortolita Mountains. Analysis from program SteroWin, v. 1.1, by R.W. Allmendinger (2002).

E) Poles to dikes, footwall, Tortolita Mountains

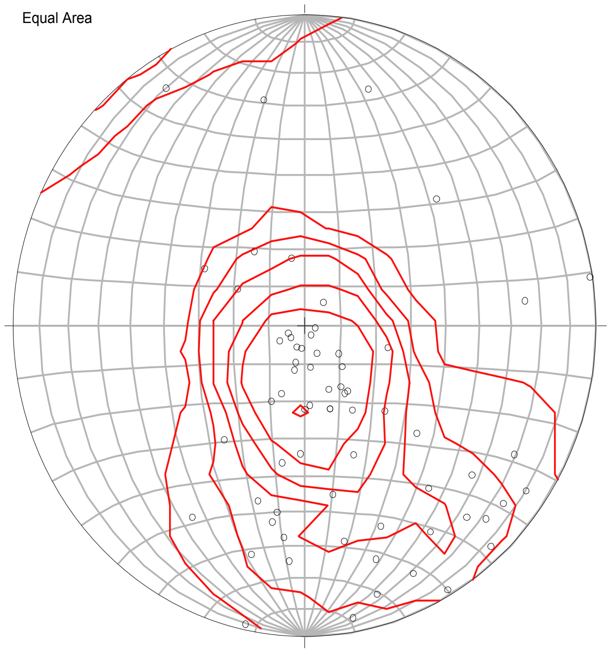


LINES SCATTER PLOT (n = 471):

KAMB CONTOUR OF P-AXES (n = 471):
Contour Int = 2.0; Counting Circle Area = 0.019
Expected Number = 8.83; Significance Level = 3.0

Figure 3e) Lower hemisphere stereonet plot of poles to dikes in the footwall of the Tortolita Mountains. Analysis from program SteroWin, v. 1.1, by R.W. Allmendinger (2002).

A) Poles to mylonitic foliation, pluton of Chirreon Wash, northern Tortolita Mountains



B) Stretching lineation, pluton of Chirreon Wash, northern Tortolita Mountains

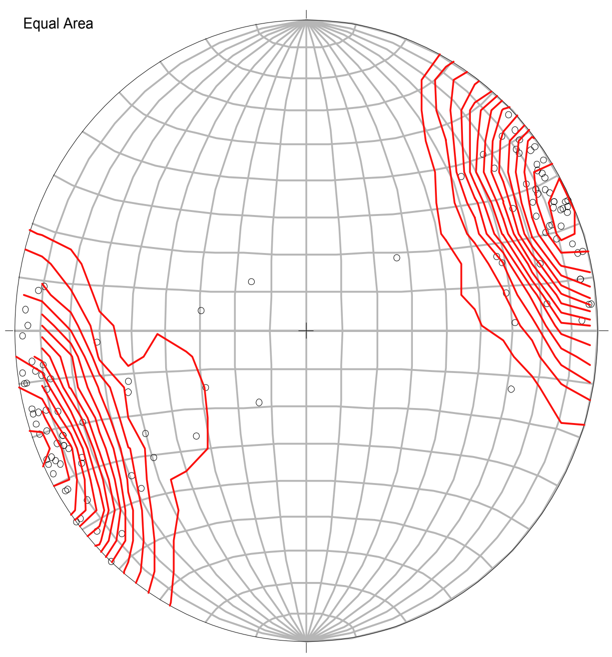
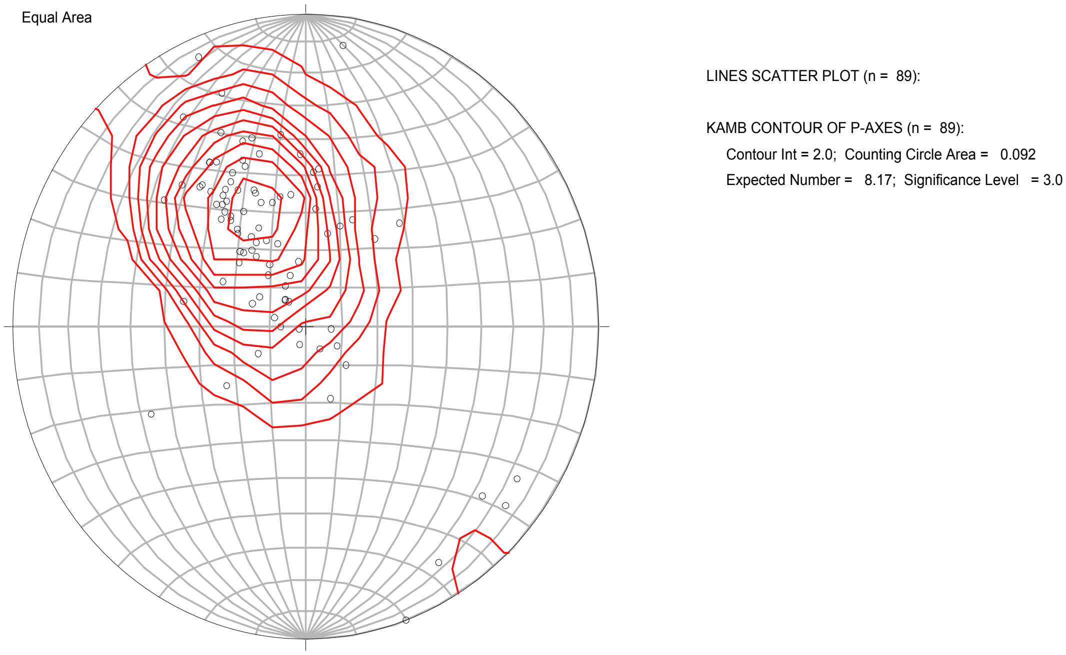


Figure 4a) Lower hemisphere stereonet plot of poles to mylonitic foliation, and 4b) stretching lineation in the pluton of Chirreon Wash, northern Tortolita Mountains. Analysis from program SteroWin, v. 1.1, by R.W. Allmendinger (2002).

A) Poles to mylonitic foliation, pluton of Wild Burro Canyon, southern Tortolita Mountains



B) Stretching lineation, pluton of Wild Burro Canyon, southern Tortolita Mountains

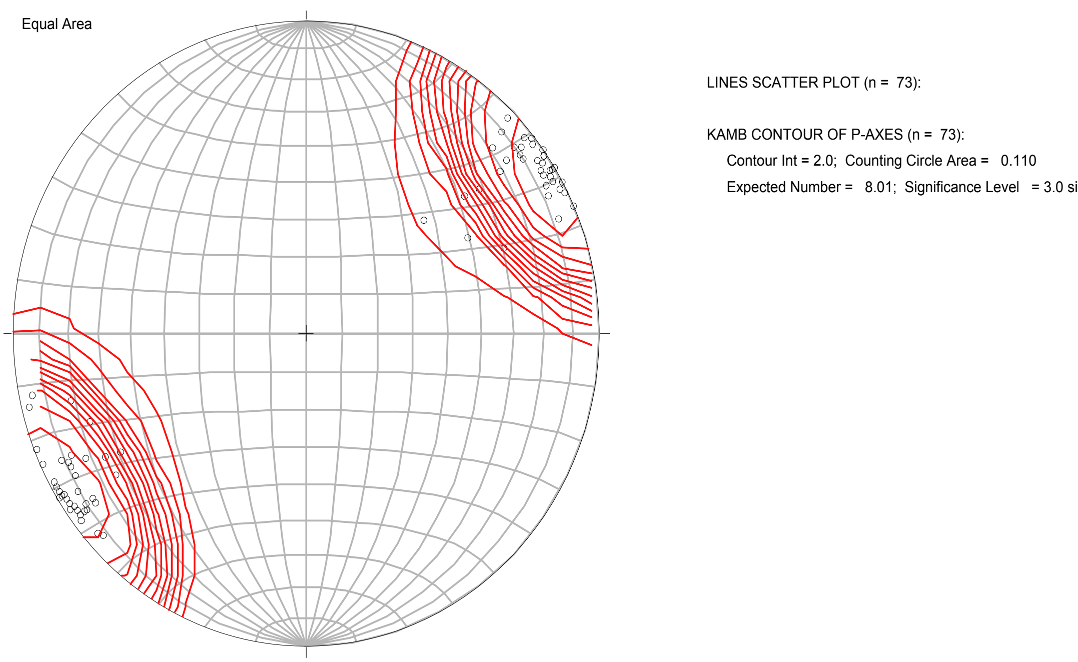
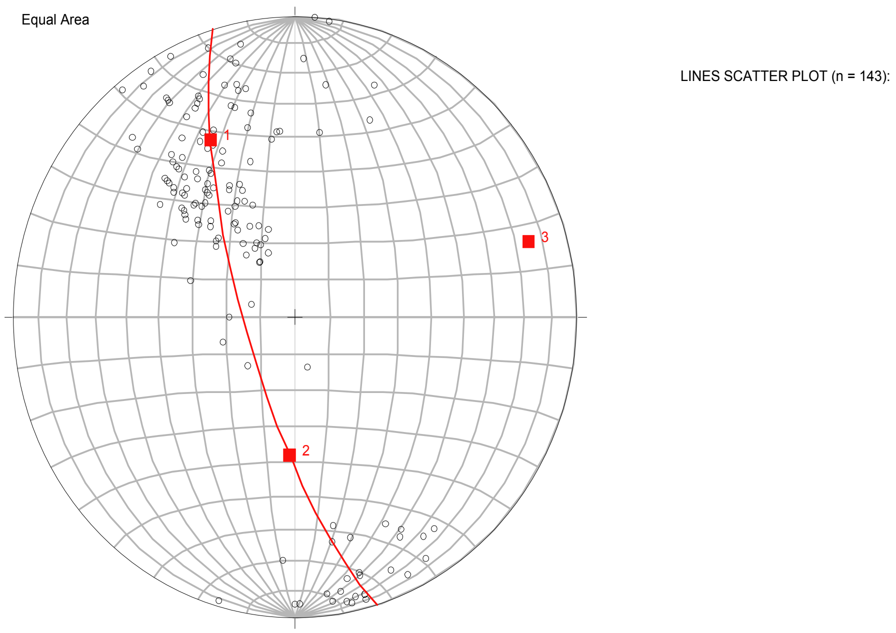


Figure 5a) Lower hemisphere stereonet plot of poles to mylonitic foliation, and 5b) stretching lineation in the pluton of Wild Burro Canyon, southern Tortolita Mountains. Analysis from program SteroWin, v. 1.1, by R.W. Allmendinger (2002).

A) Planar elements in metasedimentary rocks, central Tortolita Mountains septum



B) Lineation in metasedimentary rocks, central Tortolita Mountains septum

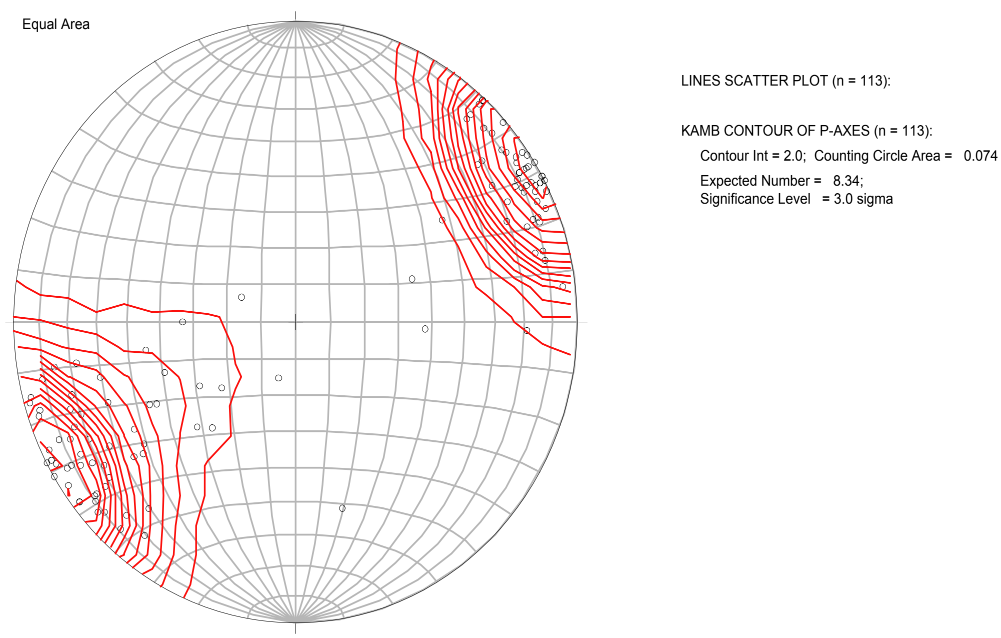
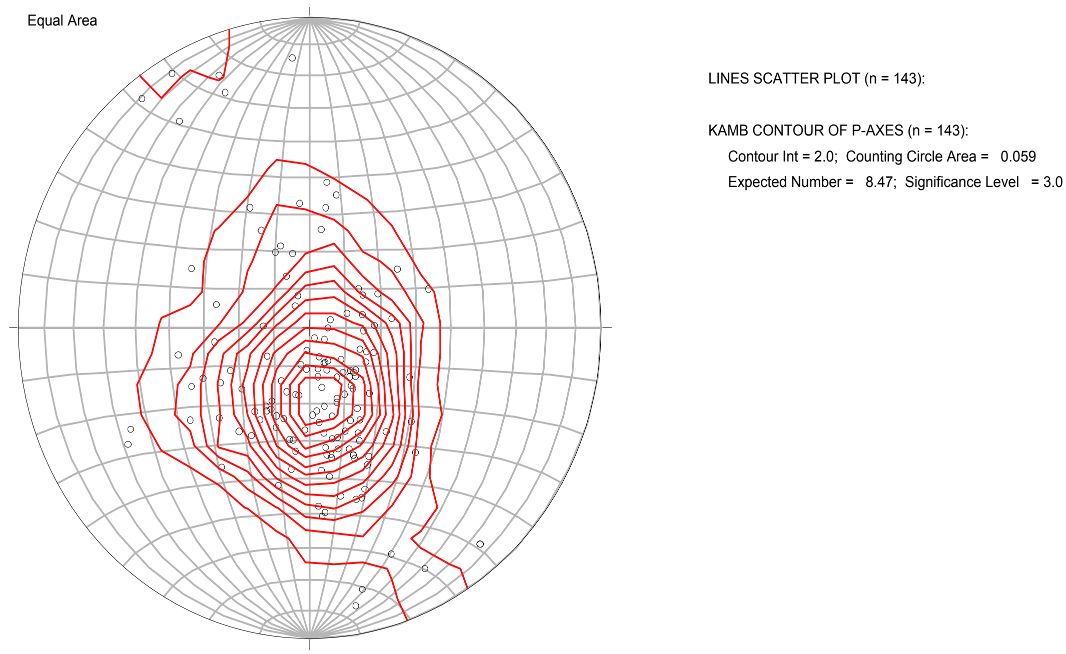


Figure 6. Lower hemisphere stereonet plots for schistosity, mylonitic foliation, and bedding (A) and stretching lineation, intersection lineation, hinge lines, and mineral lineation (B) in metasedimentary rocks within the septum, southern Tortolita Mountains. Analysis from program SteroWin, v. 1.1, by R.W. Allmendinger (2002).

A) Poles to mylonitic foliation, granite of Fresnal Canyon, northern Tortolita Mountains



B) Stretching lineation, granite of Fresnal Canyon, northern Tortolita Mountains

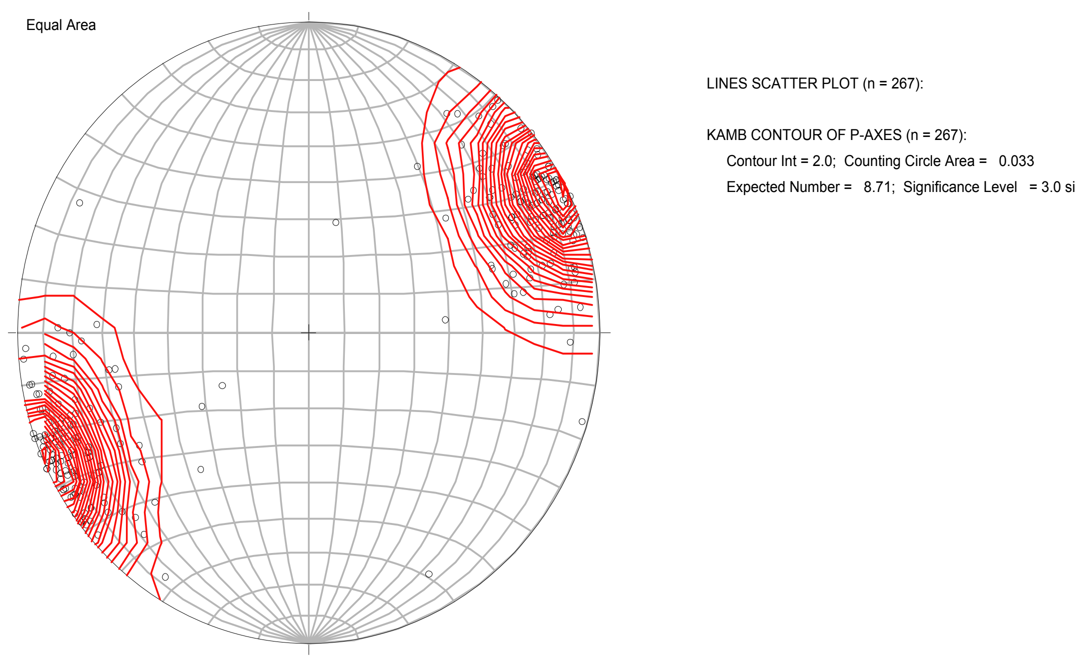
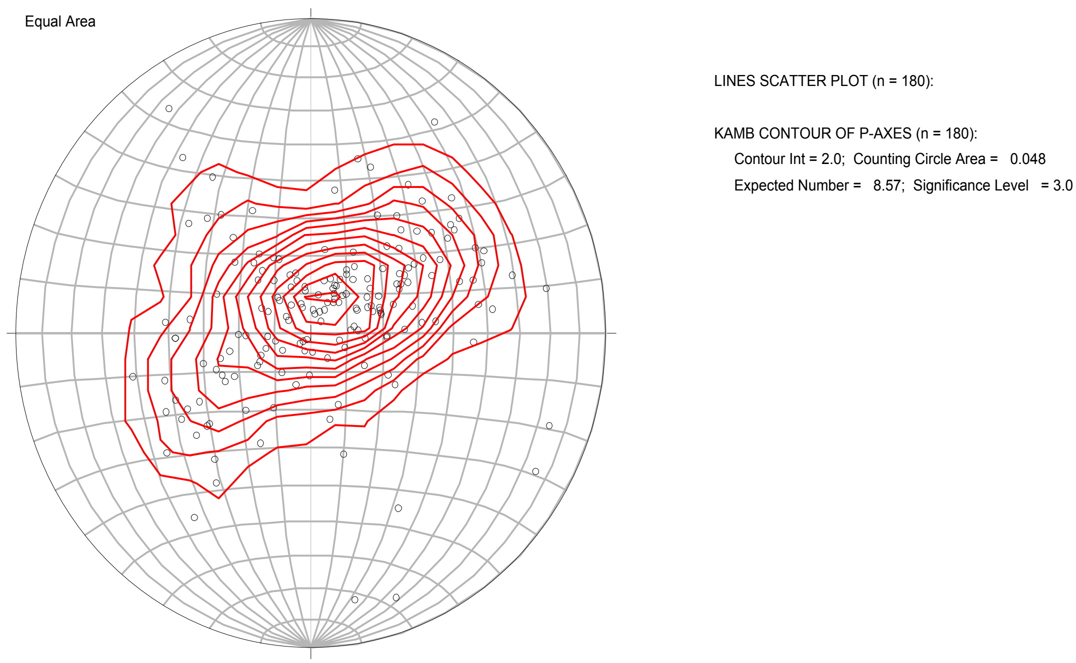


Figure 7a) Lower hemisphere stereonet plot of poles to mylonitic foliation, and 7b) stretching lineation in the granite of Fresnal Canyon, southern Tortolita Mountains. Analysis from program SteroWin, v. 1.1, by R.W. Allmendinger (2002).

A) Poles to mylonitic foliation, Tortolita Mountains Granite, northern Tortolita Mountains



B) Stretching lineation, Tortolita Mountains Granite, northern Tortolita Mountains

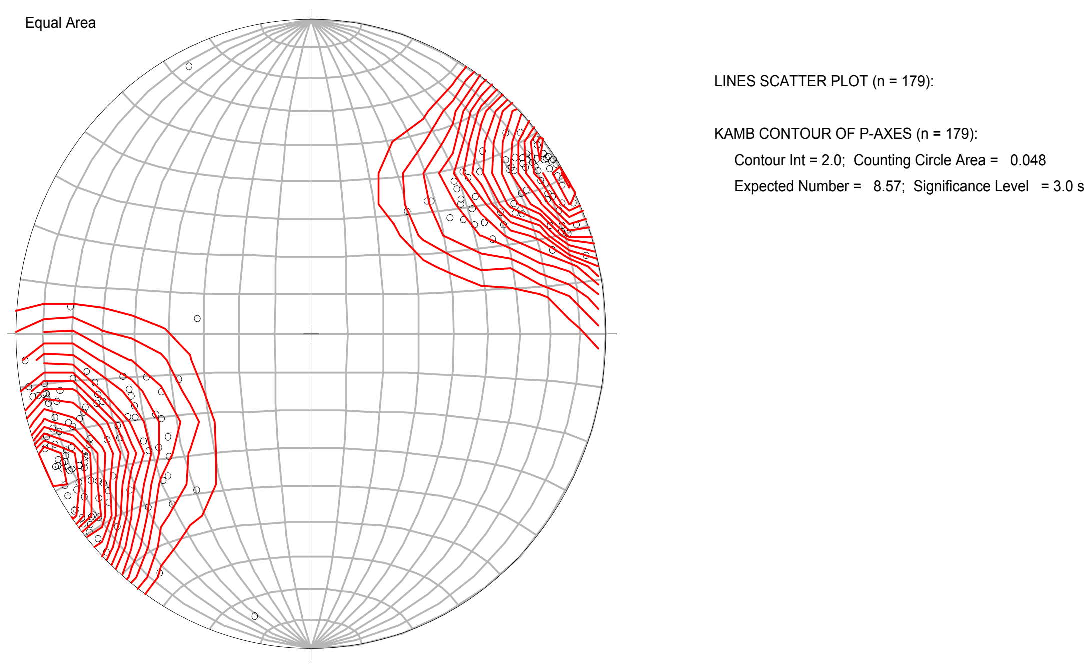


Figure 8a) Lower hemisphere stereonet plot of poles to mylonitic foliation, and 8b) stretching lineation in the Tortolita Mountains Granite, southern Tortolita Mountains. Analysis from program SteroWin, v. 1.1, by R.W. Allmendinger (2002).

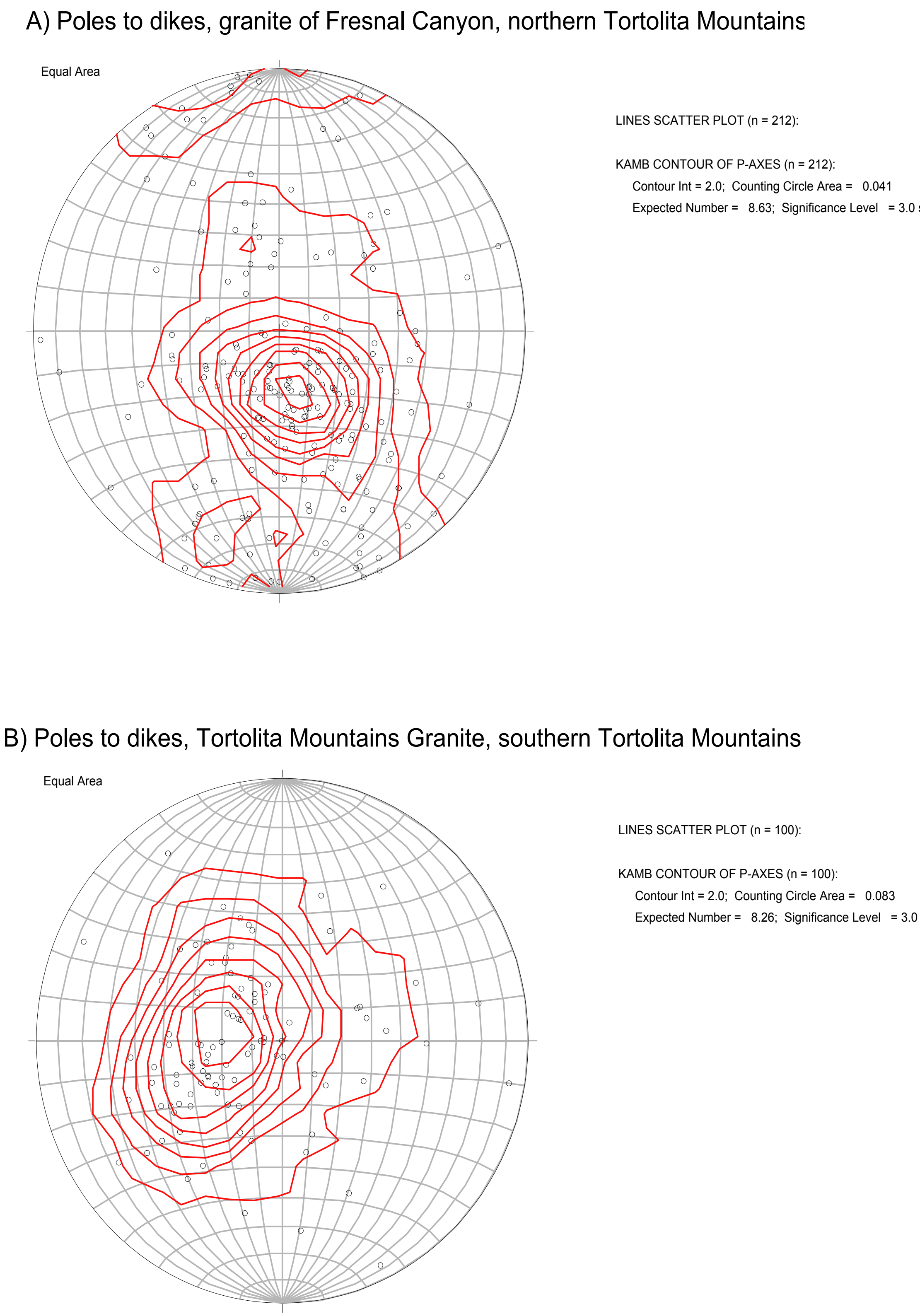
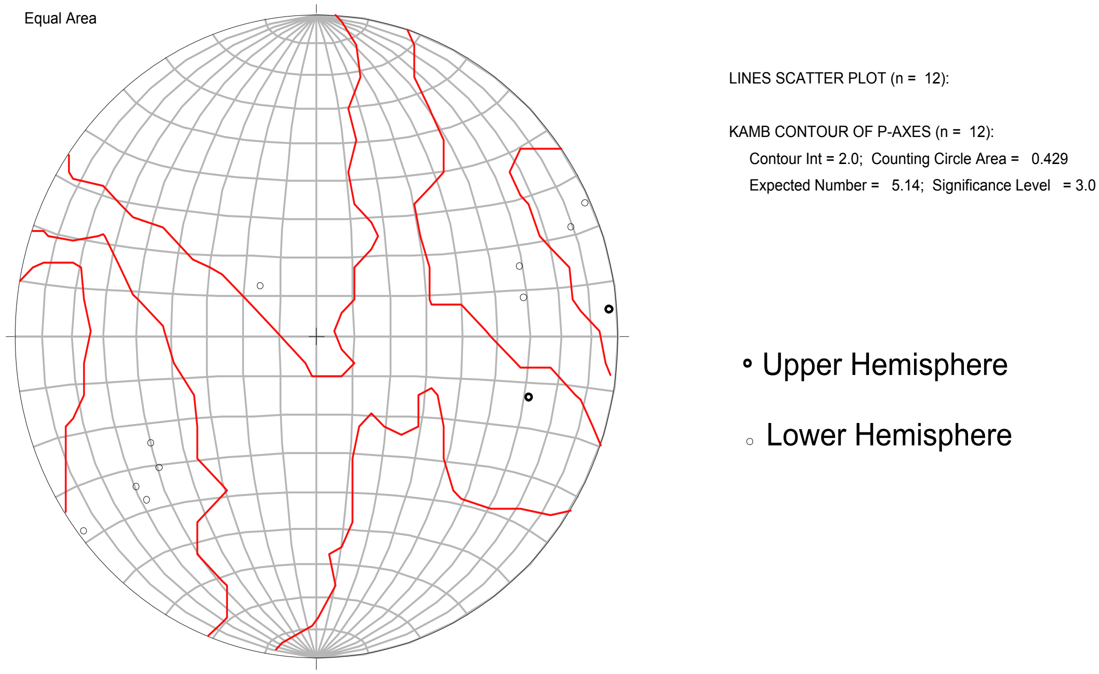


Figure 9) Lower hemisphere stereonet plot of poles to dikes in the granite of Fresnal Canyon (a), and the Tortolita Mountains Granite (b),Tortolita Mountains.
Analysis from program SteroWin, v. 1.1, by R.W. Allmendinger (2002).

A) Directed stretching lineations, pluton of Chirreon Wash, northern Tortolita Mountains



B) Directed stretching lineations, pluton of Wild Burro Canyon, southern Tortolita Mount

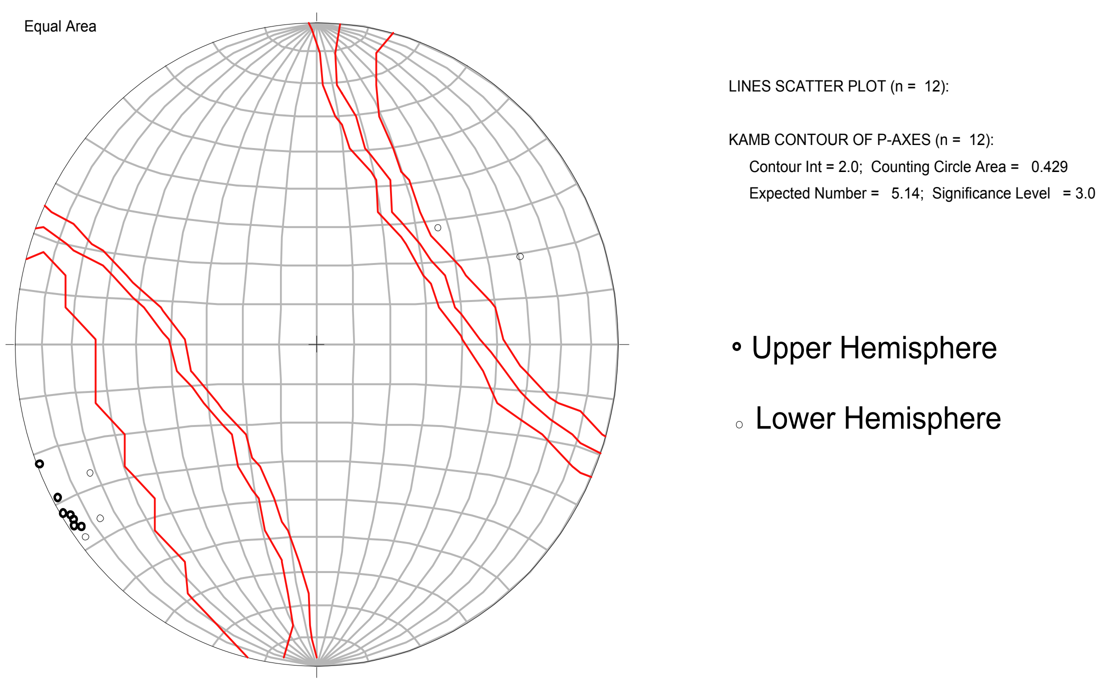
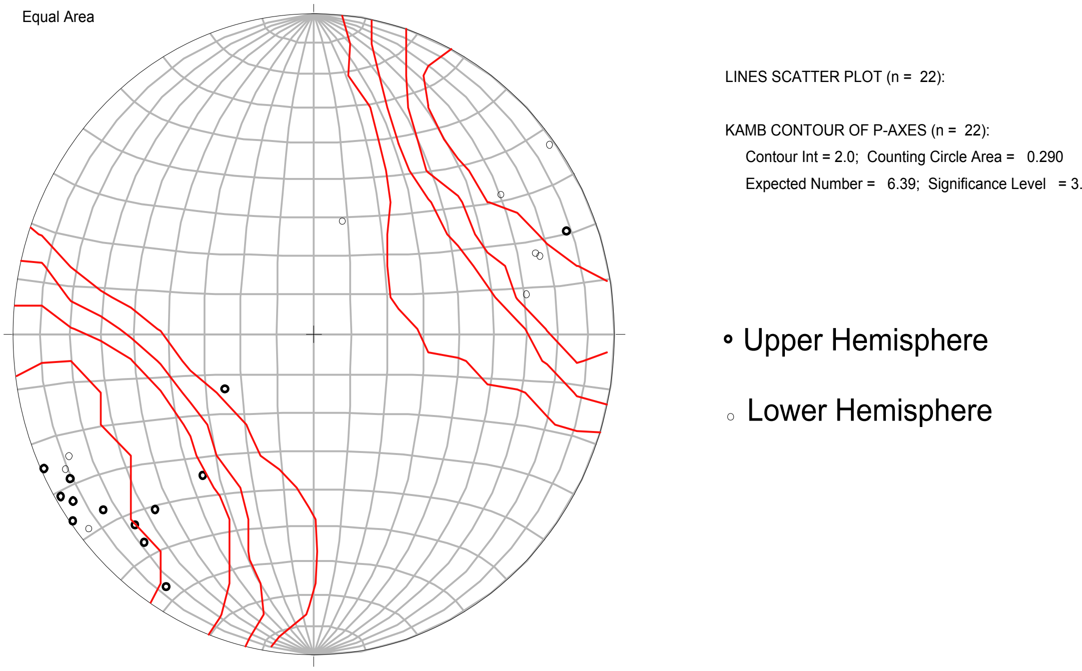


Figure 10) Stereonet plots of directed stretching lineation in the pluton of Chirreon Wash (a) and the pluton of Wild Burro Canyon, Tortolita Mountains. Analysis from program SteroWin, v. 1.1, by R.W. Allmendinger (2002).

A) Directed stretching lineations, granite of Fresnal Canyon, Tortolita Mountains



B) Directed stretching lineations, Tortolita Mountains Granite, Tortolita Mountains

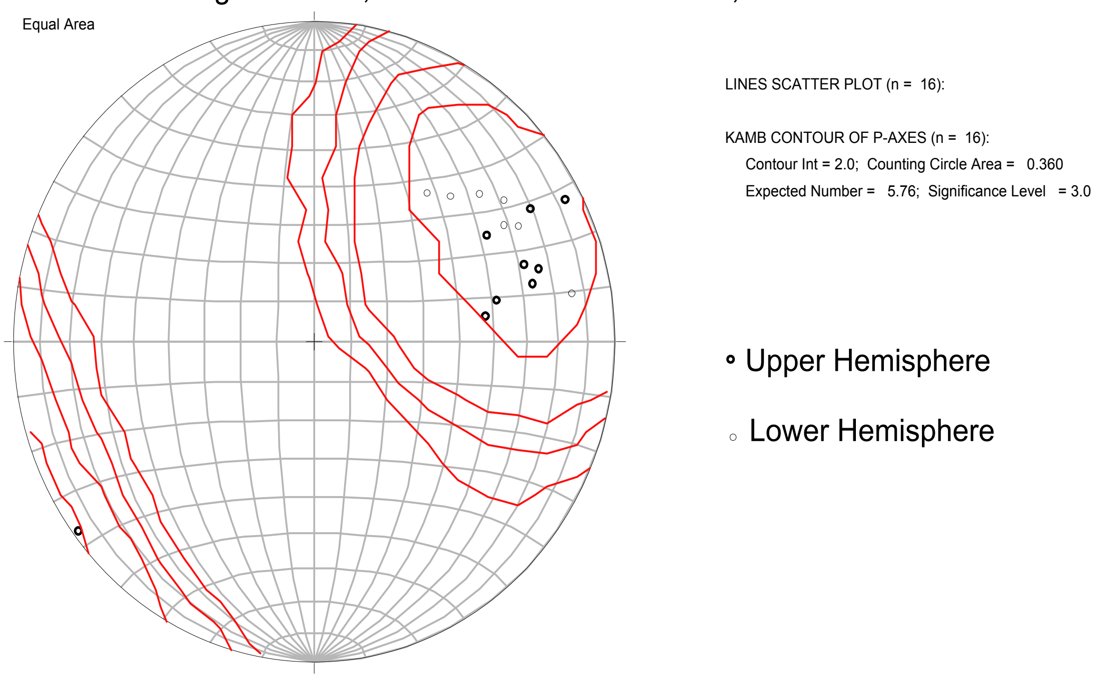
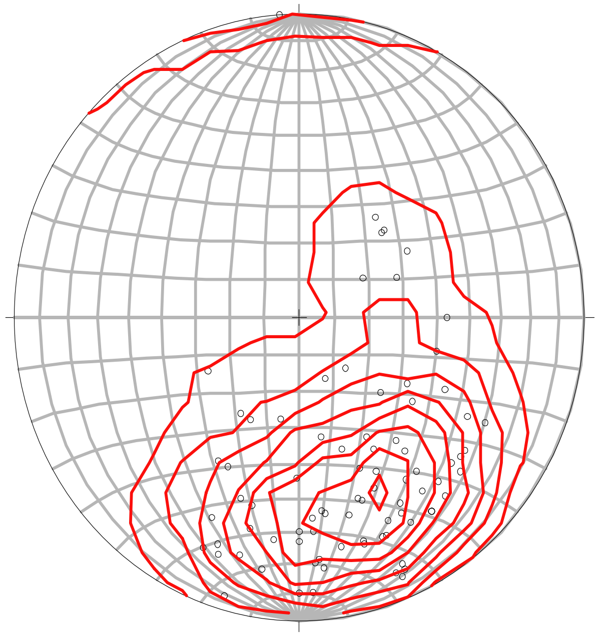


Figure 11) Stereonet plots of directed stretching lineation in the granite of Fresnal Canyon (a), and the Tortolita Mountains Granite (b),Tortolita Mountains. Analysis from program SteroWin, v. 1.1, by R.W. Allmendinger (2002).



a

Poles to D1 foliations

LINES SCATTER PLOT (n = 82):

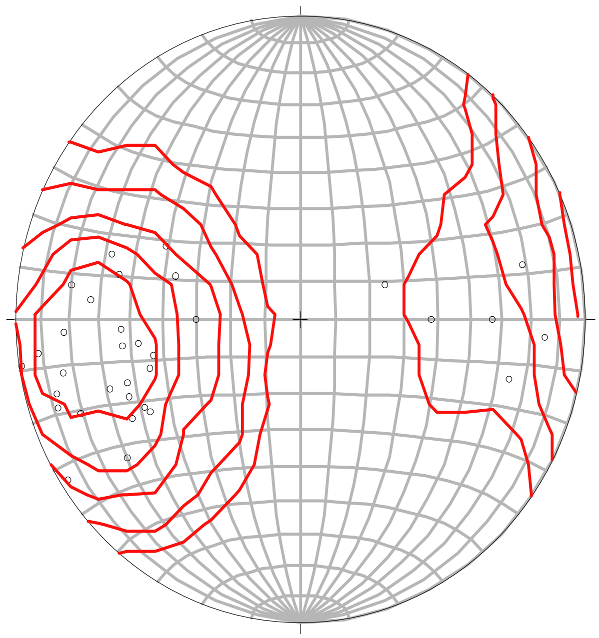
KAMB CONTOUR OF P-AXES (n = 82):
Contour Int = 2.0; Counting Circle Area = 0.099
Expected Number = 8.11;

Significance Level = 3.0 sigma

Equal Area Net

BINGHAM ANALYSIS POLE MEAN: 37 161

(eigenvalue 0757 out of 1)



b

D2 fold axes (folds of D1 foliation, axes lie within plane of foliation)

LINES SCATTER PLOT (n = 33):

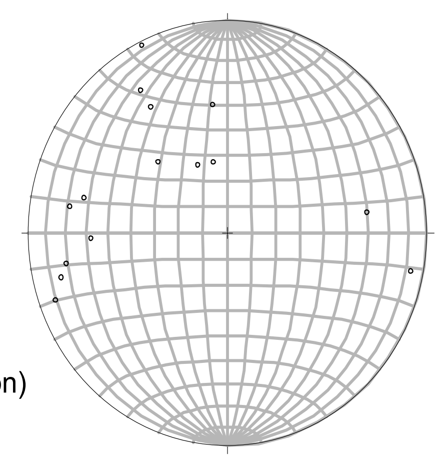
KAMB CONTOUR OF P-AXES (n = 33):
Contour Int = 2.0; Counting Circle Area = 0.214
Expected Number = 7.07;

Significance Level = 3.0 sigma

Equal Area Net

BINGHAM ANALYSIS POLE MEAN: 25 260

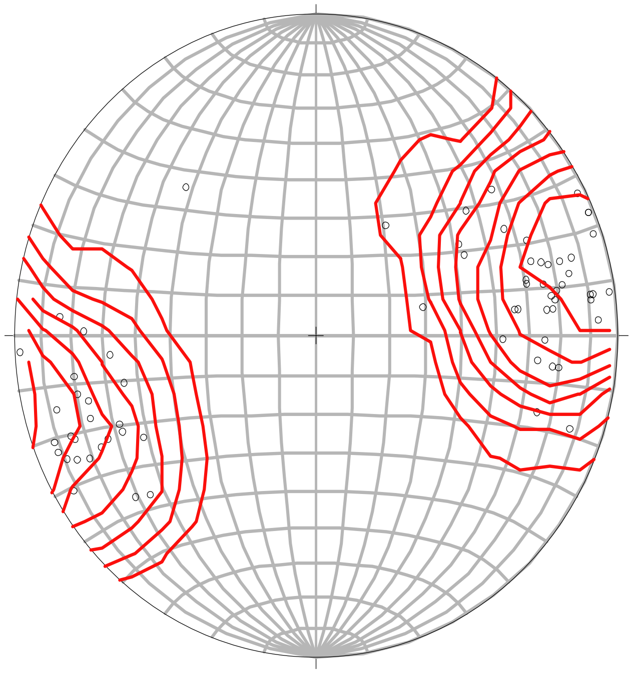
(eigenvalue 0.7672 out of 1)



c

D3 kink-fold axes (folds of D1 foliation, axes lie within plane of foliation)
Equal Area Scatter Plot of Lines (n = 15)

Figure 12. Stereonet plots for pre-mylonitic foliations and lineations in Pinal Schist in footwall of central part of Guild Wash fault, northern Tortolita Mountains. Data collected by J. Spencer. Analysis from program SteroWin, v. 1.1, by R.W. Allmendinger (2002).



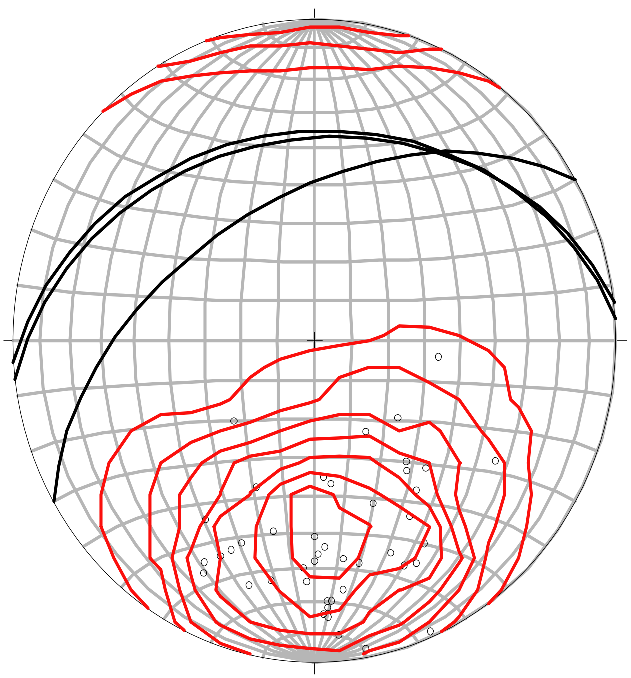


Figure 13. Stereonet plots for mylonitic foliation and lineation data from footwall of central part of Guild Wash fault, northern Tortolita Mountains. Most foliations in Pinal Schist but some are from granitoids. Data collected by J. Spencer. Analysis from program SteroWin, v. 1.1, by R.W. Allmendinger (2002).

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