GEOLOGY AND THRUST FAULT TECTONICS OF PARTS OF THE ARGUS AND SLATE RANGES, INYO COUNTY, CALIFORNIA -- Stephen Carlisle Moore, PhD

GEOLOGY AND THRUST FAULT TECTONICS OF PARTS OF THE ARGUS AND SLATE RANGES, INYO COUNTY, CALIFORNIA

by

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Abstract

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by Stephen Carlisle Moore

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The Argus and Slate Ranges, located at the margin of the southern Sierra Nevada batholith, are traversed by the northwest trending Argus Sterling thrust fault, part of a regional system of thrust faults that are rooted in the batholithic complex. The thrust fault juxtaposes two plutonic terranes that underlie the Argus Range: a western terrane of coalescing quartz monzonite intrusions, and an eastern terrane in which roof pendants of Paleozoic and Mesozoic sedimentary and volcanic strata are intruded by epizonal plutons.

Paleozoic strata of the eastern terrane include miogeosynclinal, carbonate rocks of Devonian through Permian age. Permo-Pennsylvanian units, thicker and siltier than underlying limestones, indicate greater influx of terrigenous clastic material, increased subsidence, and local deeper water environments. Permian submarine debris-flow deposits of coarse limestone conglomerate record local tectonic instability within the geosyncline.

Mesozoic deposits include metamorphic equivalents of impure limestone and shale, interbedded with feldspathic and tuffaceous sandstones of plutonic and volcanic provenance. A Triassic age is probable for these strata, which document initiation of a Mesozoic plutonic-volcanic arc, oblique to

the trend of the miogeosyncline. Overlying andesite flows and sedimentary interbeds rich in volcanic detritus indicate emergence and continued volcanism in Triassic to Jurassic time.

Potassium-argon dates of plutonic rocks in the Argus Range indicate periods of intrusion at 165-170 m.y. and 140 m.y. (respectively Middle and latest Jurassic). Concordant dates from the pre-tectonic Hunter Mountain quartz monzonite, exposed in the autochthonous terrane, together with the latest Jurassic ages of plutons which cut the thrust, bracket the age of thrust faulting in the Late Jurassic. This faulting event contrasts with Late Triassic to Early Jurassic regional folding and thrust faulting episodes which preceded the initiation of widespread plutonism. The location, deformational style, trend and timing of thrust faults of the Argus and Slate Ranges suggest a genetic structural relation to the eastern margin of the Sierra Nevada Batholith.

The Argus Sterling thrust resulted from compressional failure of the crust near the batholithic margin, with relative uplift and eastward transport of the western granitic terrane. Slabs of Paleozoic limestone and Mesozoic volcanic rocks were sliced from subjacent roof pendants during emplacement of the overriding granitic plate, and were dynamically metamorphosed to tectonite marble and phyllitic mylonite. Variations in thrust zone lithologies, in the attitudes of thrust surfaces, and in the thickness of deformed zones occur along strike. Syntectonic plutons locally intrude the thrust plane.

The Cenozoic record is limited to Miocene(?) and younger strata. Fluvial gravels, landslide deposits from an ancestral Panamint Range, and basaltic, andesitic and silicic volcanic deposits accumulated on a surface of gentle relief. Late Pliocene and Pleistocene faulting, and eastward tilting of the fault-bounded blocks gave rise to the present Basin and

Range topography. The northwest-trending Mesozoic thrust fault system was broken into segments during development of the north-south trending Basin ranges.

Thrust faults in other ranges, on strike with the Argus Sterling thrust, occur from the Mojave Desert to the Inyo Mountains, and display a common structural setting and deformational style with Argus Range thrusts. These structures form a co-linear system of moderate-angle thrust faults, termed the Coso thrust system, with a strike length of at least 150 km. The system may have originated in a single major deformation in the Late Jurassic, possibly coincident with Nevadan events in the western Sierra, although additional data from the Slate and Inyo Ranges may reveal a more complex history.

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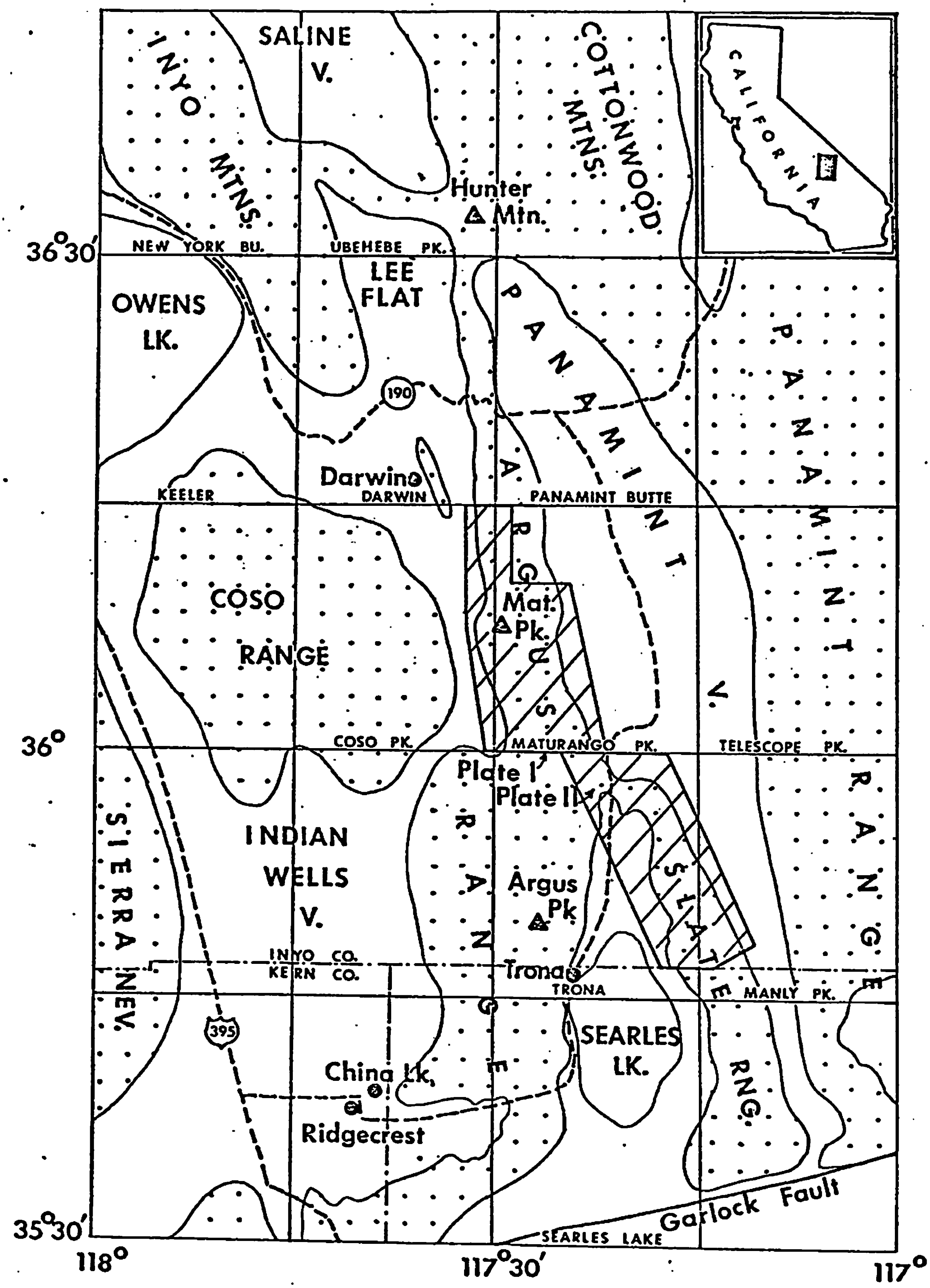
GEOLOGY AND THRUST FAULT TECTONICS OF PARTS OF THE ARGUS AND SLATE RANGES, INYO COUNTY, CALIFORNIA

Introduction

Geologic mapping of the central Argus Range was undertaken in 1972 to establish the geology and structure of an area which had had prior reconnaissance-level examination only. The early stages of mapping revealed a northwest-trending thrust system, which became the focus for study during the remainder of the project. Thrust faults in the area form an apparent link between previously mapped thrusts in other areas, and define a thrust system of regional extent. To document this relation, an area in the Slate Range was also mapped. Plates I and II present results of mapping of the Central Argus and northern Slate Ranges. Descriptions of the Argus Sterling thrust fault, the depositional and intrusive rock units, results of radiometric dating of four granitic intrusions, and an analysis of some Tertiary structural features are presented in this report.

The Argus and Slate Ranges are approximately half way between the Sierra Nevada and Death Valley, in the southwestern part of the Great Basin physiographic province, Inyo County, California (Figure 1). Geographic and geologic features referred to in the text are identified on Figures 2 and 3. The ranges join at Slate Range crossing, the divide between Panamint and Searles Valleys, and diverge southward. Panamint Valley bounds both ranges on the east, and the Argus Range is bounded on the west by granitic mountains and alluviated high valleys of the Coso Range.

FIGURE 1: INDEX MAP



North of Trona, a county highway crosses Searles and Panamint Valleys, and gives access via side roads to most of the area. Access to the western slope of the Argus Range is restricted and clearance must be obtained through the Naval Weapons Center (NWC), China Lake, California.

Approximately 120 days in the Fall, 1972, Spring, 1973, and Winter and Spring, 1974 were spent in the field and in regional reconnaissance. Parts of the Maturango Peak, Coso Peak, Trona and Manly Peak 15-minute quadrangles were mapped, using enlarged base maps (scale 1:24,000) and U.S.G.S. aerial photographs (series CQ). Thin sections and slabs of approximately 250 rock samples were examined. Modal determinations of granitic rocks were made by 500-point counts of stained sections and polished, stained slabs. Potassium-argon dates on seven mineral separates from four samples of intrusive rock from the Argus Range were determined in the geochronology laboratories of the University of British Columbia in 1974, with the aid of R. L. Armstrong and J. E. Harakal (Moore and Harakal, 1976).

Conventional boundaries of Mesozoic periods, particularly the Triassic and Jurassic, require modification, according to studies by Armstrong and others (see Armstrong and Suppe, 1973). The base of the Jurassic recognized here is 210 m.y., rather than 180-192 m.y. (e.g., Harland and others, 1964). Consequently, the "Late Triassic" and "Early Jurassic" of several referenced publications are respectively Early and Middle Jurassic in this report.

Previous bedrock mapping studies of surrounding areas include: Darwin and Panamint Butte quadrangles (Hall and MacKevett, 1962; Hall, 1971); reconnaissance geology of the Slate Range (Smith and others, 1968); and the structure of part of the southern Argus Range (von Heune, 1960). Much of the area of Plate II was mapped in reconnaissance by Smith and others

FIGURE 2: Geographic features, Argus Range

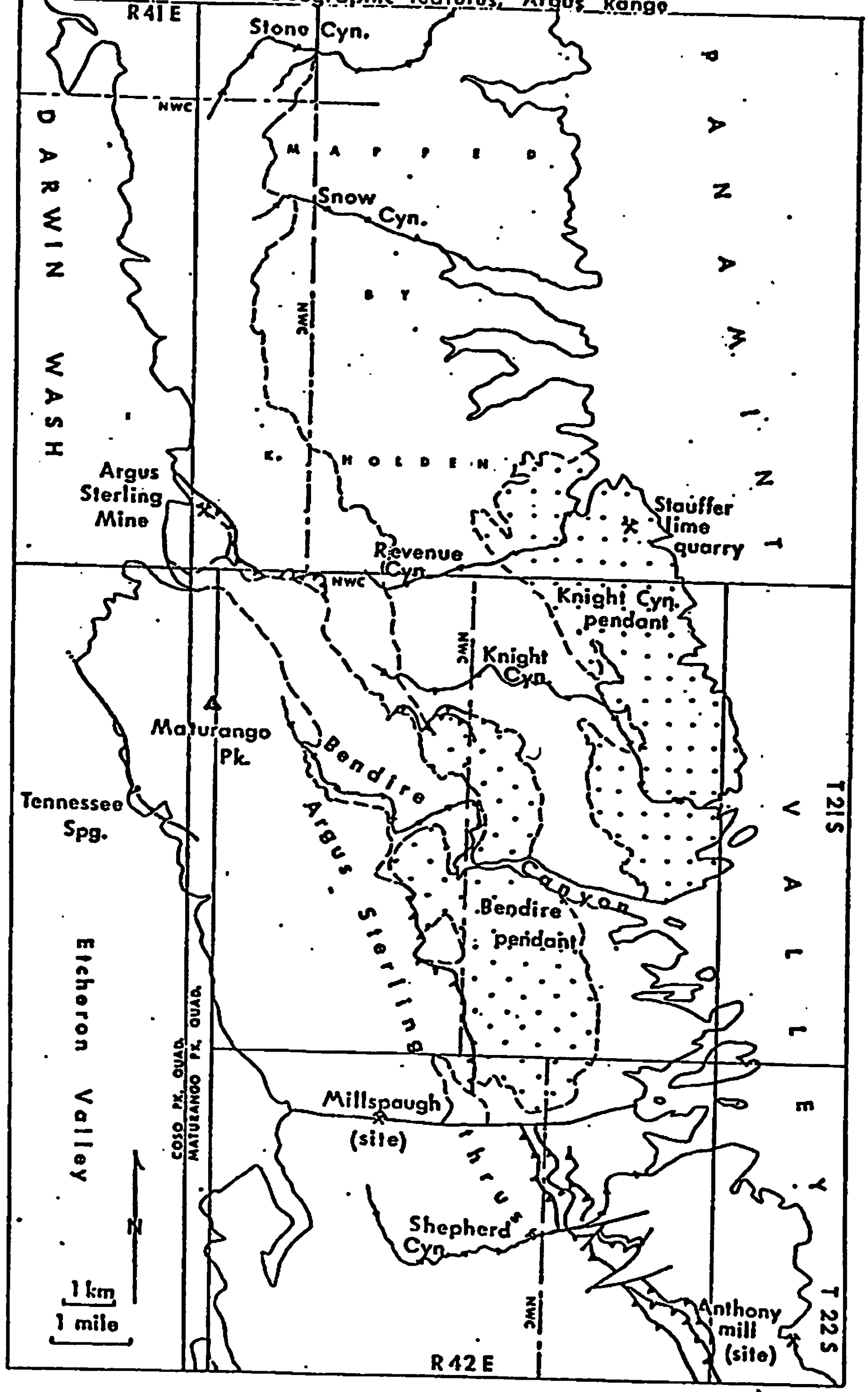
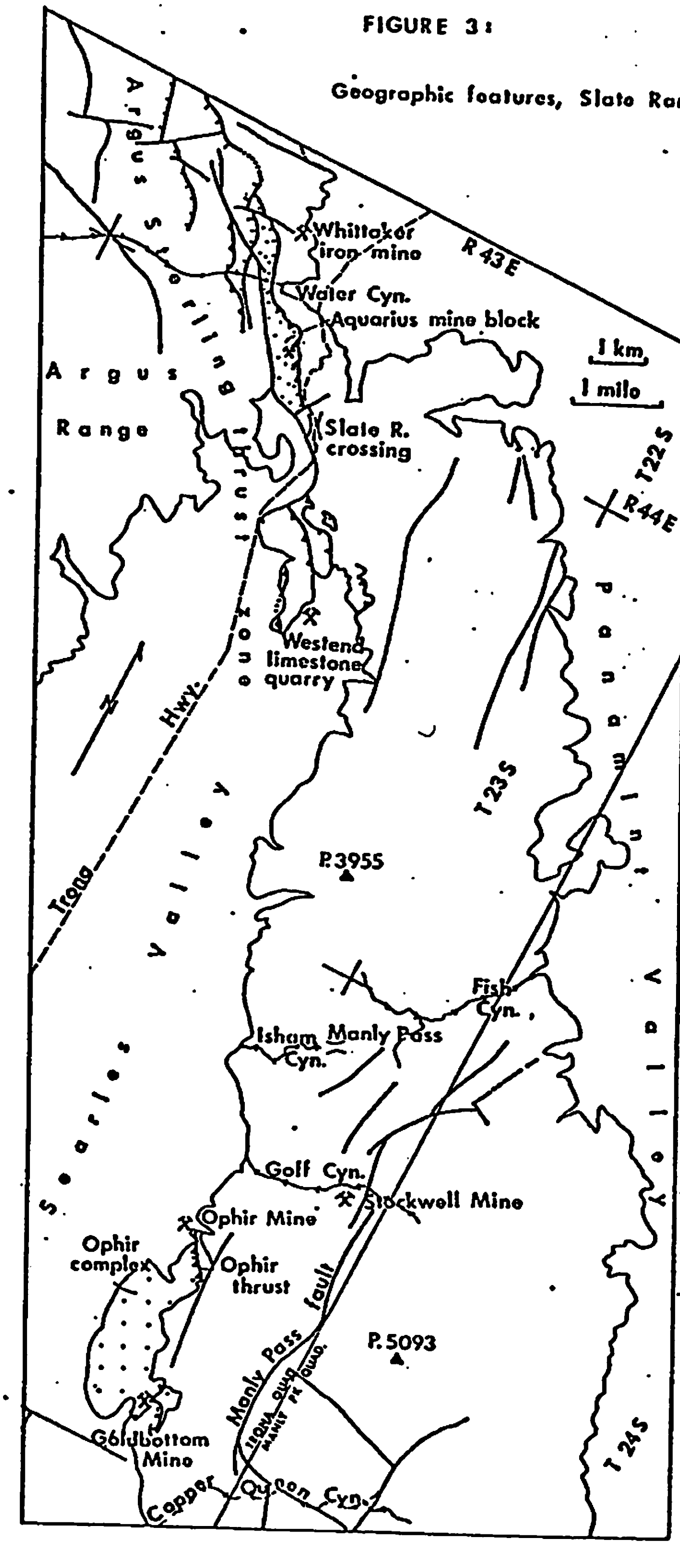


FIGURE 3:

Geographic features, Slate Range



(1968). The northern Argus Range between Bendire and Stone Canyons, including part of the area of Plate I, was mapped by K. Holden, California State University, San Jose, concurrently with this project.

Published reports based on this study are: Moore, 1974; and Moore and Harakal, 1976.

Geologic Framework

The mapped area is located in the southern part of the Cordilleran miogeosyncline, and was a site of thick accumulation of shallow marine, carbonate sediments during the Paleozoic. Volumetrically minor terrigenous clastic material was mostly from the craton to the southeast. To the northwest, deeper water deposition occurred at intervals during Paleozoic time. The subsident miogeosynclinal shelf became emergent in the Middle Triassic with the initiation of volcanism throughout the area from western Nevada to the Mojave Desert.

Triassic-Jurassic volcanism reflects the onset of batholithic intrusion, which altered the crustal structure of eastern California in the Mesozoic. Regional deformation began as early as Late Triassic and was active through much of the Mesozoic. Late Triassic to Early Jurassic folds and thrust faults developed in the sedimentary pile within the area of Figure 1, mostly preceding the intrusion of batholithic masses exposed between the Inyo and Slate Ranges. The Argus and Slate Ranges are located at the eastern margin of the Sierra Nevada batholith, near the eastern limit of the occurrence of Mesozoic volcanic rocks, and at the western edge of Precambrian basement exposure.

These ranges are composed of roof pendants of Paleozoic carbonate rocks and minor early Mesozoic sedimentary and volcanic rocks. The Argus

Sterling thrust fault, part of a northwest-trending system of thrust faults, is exposed in the Argus Range, where it juxtaposes contrasting plutonic terranes.

A Cretaceous and early Tertiary record is regionally lacking. Late Tertiary volcanism on a topography of gentle relief was interrupted in the latest Tertiary by Basin-and-Range fault block development, which in this area is reflected by eastward tilting of uplifted ranges and of downwarped valley floors.

Acknowledgments

I thank the members of my supervisory committee, Joseph A. Vance, Chairman, Eric S. Cheney, V. Standish Mallory, and Peter Misch, for their instruction, advice, guidance and friendship over the past years. For ideas and information generated by discussions, correspondence, and field excursions, I am grateful to these geologists: R. L. Armstrong, B. C. Burchfiel, G. Dunne, R. Gulliver, P. Ehlig, K. Holden, and C. H. Stevens.

Radiometric dating at the University of British Columbia was made possible by the generosity of R. L. Armstrong and J. E. Harakal. C. H. Stevens identified collections of fusulinids from the Argus Range. Clearance for geologic mapping within the Naval Weapons Center was obtained through Carl Austin and Ken Pringle. P. Fallert, University of Washington, assisted with thin-section preparation. A grant in 1972-73 from the University of Washington Department of Geological Sciences helped defray field expenses.

The warm hospitality of Ed Camus and Mrs. E. Camus (Trona), J. Nelson and L. Pigage (Vancouver), and Fletcher and Delia Tweed (Onyx Mine) is greatly appreciated. I am indebted to my wife Patti for her interest and encouragement.

I. STRATIGRAPHY

A. Paleozoic Rock Units

Paleozoic sedimentary rocks, predominantly carbonates, are exposed in the central Argus Range in faulted, homoclinal, and folded blocks intruded by Mesozoic granitic rocks. Late Paleozoic strata crop out along the range crest north of Maturango Peak. Devonian through Permian beds are present in two roof pendants east and southeast of Maturango Peak, referred to here as the Knight Canyon and Bendire pendants (Figure 2). Late Paleozoic rocks, partly mantled by Tertiary volcanic rocks, are also present at Water Canyon, at Slate Range crossing, along the western front of the northern Slate Range, and as foundered blocks in diorite south of Fish Canyon in the Slate Range.

The Paleozoic section resembles that described from the Panamint Butte Quadrangle (Hall, 1971). Early Devonian strata are dolomitic; Middle Devonian through Early Pennsylvanian units are predominantly limestone; and Middle Pennsylvanian to Permian rocks are mostly silty and clastic limestones. In the central Argus Range, the total thickness of exposed Paleozoic strata is about 2750 m (9000 ft). The units and their approximate thicknesses are summarized in Figure 4. Contact metamorphism has affected most of the Paleozoic rocks in the area causing marmorization and local dolomitization of limestones, as well as widespread formation of fine-grained calc-silicate hornfels from silty limestone.

Devonian through Middle Pennsylvanian carbonates were formed in a shallow marine environment on a broad, slowly subsiding shelf. Terrigenous material, other than thin beds of multicycle quartz sand, is scarce. A

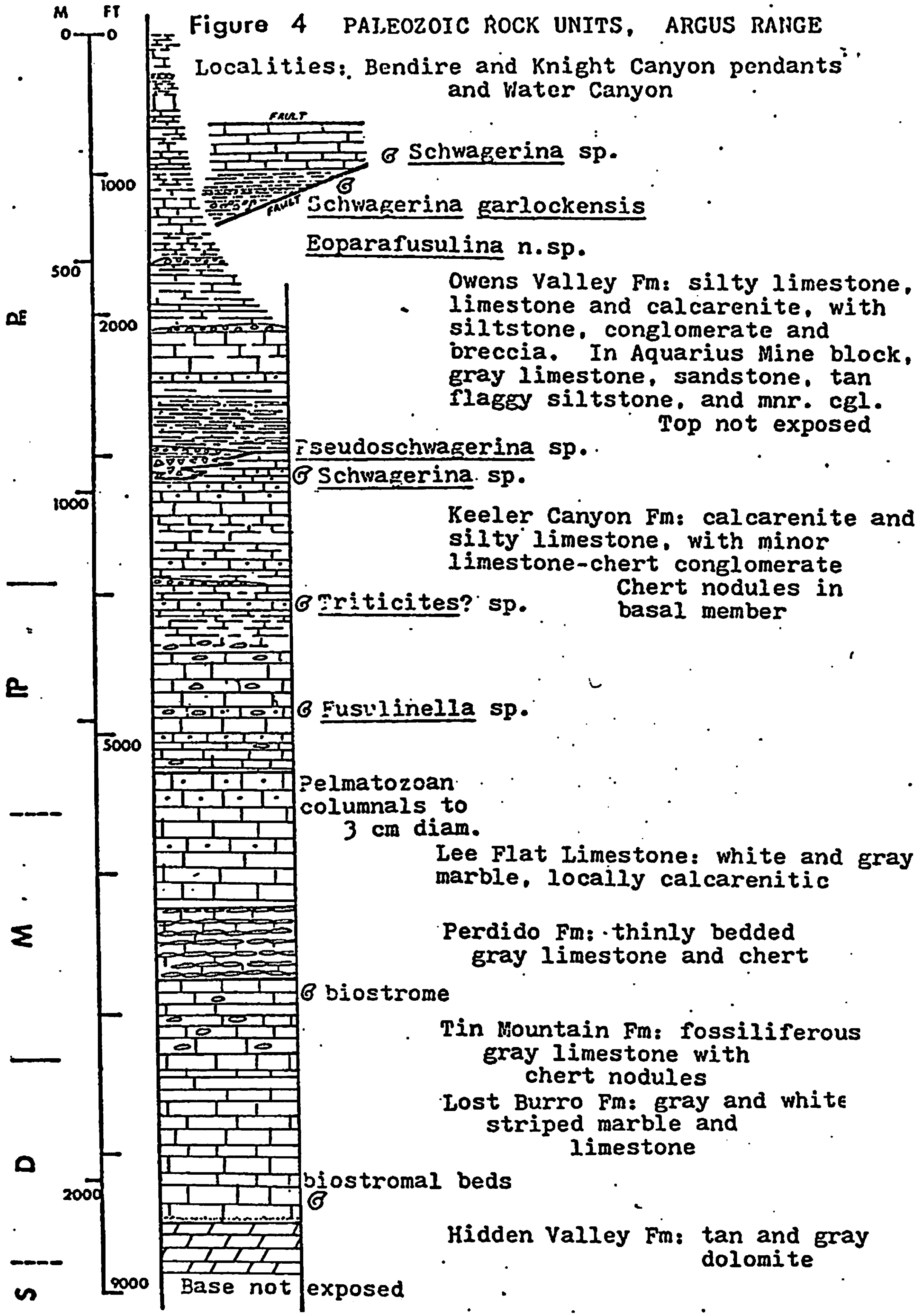


Figure 4 PALEOZOIC ROCK UNITS, ARGUS RANGE

change in the sedimentation pattern occurred in the Middle Pennsylvanian, as recorded by an influx of quartz silt in Permo-Pennsylvanian beds, lenses of coarse conglomerate and sandstone, and more pronounced lateral changes in lithology. Local areas of deeper water, moderate currents, and inclined and uplifted shelf areas contributed to the variability of sediments in the late Paleozoic.

Devonian System

Hidden Valley Dolomite

The Hidden Valley Dolomite was named by McAllister (1952) for exposures of light colored dolomite in the Quartz Spring area, northern Panamint Range, where the unit ranges in age from Silurian to Early Devonian. In the central Argus Range, only the upper 150 m (500 ft) of this unit are exposed beneath the Devonian Lost Burro Formation at the eastern edge of the Knight Canyon Pendant.

The unit consists of light gray and tan dolomite, commonly fetid, with a few meter-thick beds of medium or dark gray dolomite. Alternation of intergradational light gray and tan beds occurs at meter-thick intervals. Locally, beds of dark, fetid or tan dolomite contain large angular dolomitic clasts and sand sized grains, indicative of sediment reworking in a shallow to marginal marine environment.

Lost Burro Formation

A conspicuously striped dolomite unit was named the Lost Burro Formation by McAllister (1952) in the northern Panamint Range. In the Argus Range, the formation, exposed in the Knight Canyon pendant, consists largely of alternating beds of white and light to dark gray limestone, with local coarse-grained, light-colored marble. The unit has a pronounced striped appearance when viewed from a distance. Bedding thickness is commonly 0.5 to 2 m. The Lost Burro Formation is roughly 370 m (1200 ft) thick. The base is gradational and placed at the inception of alternating light and dark limestone beds interbedded with subordinate dolomite. The upper limit of dolomite interbeds resembling the Hidden Valley Formation is irregular. Dolomite locally transecting bedding is probably related to fluids introduced during intrusive episodes.

Beds of calcareous quartz sandstone 5 cm to 0.6 m thick are interbedded in gray and white limestone 15 to 30 m above the base of the formation. They weather brown and contain vitreous quartz sand and angular, flat chips of white limestone. These beds represent the Lippincott quartzite member of McAllister (1955), which thins and becomes less sandy south

Figure 5. Paleozoic strata of the Knight Canyon pendant, eastern flank of Argus Range. Rock units visible are the Lost Burro Formation (far right), dark gray Tin Mtn. Limestone, brown-weathering Perdido Formation, white and gray Lee Flat marble, and dark basal Keeler Canyon beds capping ridge at left.

and east of the type area in the Ubehebe Peak quadrangle. The corresponding horizon is represented by 20 m of sandy and quartzitic rocks in the Darwin quadrangle (Hall and MacKevett, 1962) but only 1 m of quartzite in the Panamint Butte quadrangle (Hall, 1971). Quartzite and sandy limestone near the top of the formation in other areas (McAllister, 1955; Hall and MacKevett, 1962; Hunt and Mabey, 1966) are apparently absent in the Argus Range.

Fossiliferous beds 2-4 m thick occur from 30 to 60 m above the base of the unit and contain silicified or calcitic remains of solitary and syringoporoid corals, stromatoporoids, gastropods, bryozoa(?), and pelmatozoa. Similar biostromes indicate a Middle Devonian age for lower Lost Burro strata in the Panamint Range (Hunt and Mabey, 1966).

Quartzite of uncertain age

A 9 m (30 ft)-thick sliver of light gray quartzite underlies foliated carbonate rocks in the Argus Sterling thrust zone east of Maturango Peak in Sec. 9 (T21S, R42E). Spherical grains of quartz are undulose and were broken by penetrative deformation during thrusting. Clots of a carbonate mineral (dolomite?) occur in the matrix. It is uncertain whether the quartzite is entirely allocthonous in the enclosing marble or is interbedded with it.

Relatively pure orthoquartzite occurs regionally in the Eureka Quartzite (Ordovician), Hidden Valley Dolomite, and the Lost Burro Formation. In the Knight Canyon pendant, and in the Panamint Butte quadrangle (Hall, 1971), only very thin beds of quartzite are present in the two younger units. On this basis, an Ordovician age may be possible. Derivation from the Hidden Valley or Lost Burro Formations cannot be ruled out, however, as these units become sandier to the west and north. In the Darwin quadrangle, for example, these formations contain quartzite beds respectively 6 m and 7.5 m thick.

Mississippian System

Tin Mountain Limestone

The Tin Mtn. Limestone was named by McAllister (1952) for dark gray, fossiliferous limestone of Early Mississippian age in the northern Panamint Range. In the central Argus Range it is exposed along the length of the Knight Canyon pendant, and in the fault-bounded core of a southward-plunging anticline in the Bendire pendant. The formation sharply overlies the Lost Burro Formation and is overlain by interbedded chert and gray limestone of the Perdido Formation.

The unit consists of medium to dark gray fine-grained limestone and bioclastic calcarenitic limestone, commonly fossiliferous, with brown chert nodules and lenticles. Contact metamorphism has marmorized the limestone in the Knight Canyon pendant. The following section was measured north of the mouth of Knight Canyon.

Marble, medium to dark gray, including bioclastic calcarenite and beds with abundant brown chert nodules. Some beds with abundant silicified fossils, including solitary corals and pelmatozoan columnals. Wollastonite.	88 m

Marble, light to medium gray with a slight flow foliation parallel to bedding. Thick-bedded to massive with laminae that mark relict bedding. A few cherty interbeds with brown chert nodules. White calcitic ghosts of large solitary corals. Local scour structures filled with bioclastic trash.	79 m
Total	167 m (550 ft)

As this section has undergone folding and marmorization, this thickness is approximate.

A biostromal lens 12 m thick is present in Sec. 12 (T21S, R42E), about 50 m below the top of the formation. Assemblages of silicified large solitary corals, pelmatozoan fragments, colonial corals, Syringopora, and small gastropods occur in dark gray, cherty limestone.

Perdido Formation

The Perdido Formation was named by McAllister (1952) for a heterogeneous sequence of cherty limestone, sandy and silty limestone, siltstone and shale. In the Darwin area, Hall and MacKevett (1962) designated as Perdido Formation a sequence of interbedded chert and limestone that overlies the Tin Mountain Formation and is lithologically similar to the mostly non-clastic lower unit of the type Perdido.

The Perdido Formation in the central Argus Range is non-clastic, and similar to exposures in the Darwin and Panamint Butte quadrangles. The Perdido is exposed in the Bendire and Knight Canyon pendants. Brown-weathering chert beds and lenticles 1-10 cm thick are interbedded with medium gray limestone in 2-20 cm thick beds. The upper and lower contacts are gradational and apparently conformable. Crinoid fragments are sparingly present in the limestone interbeds. A section measured in NE 1/4, Sec. 13 (T21S, R42E) is approximately 160 m (525 ft) thick. From a distance, the formation has a brown appearance.

Contact metamorphism has caused the growth of wollastonite at interfaces between chert and limestone. Small folds are locally well developed in this formation, and tightly folded and broken beds occupy the core of the Bendire Canyon anticline.

No diagnostic fossils were found in the Perdido Formation. Its age is assumed to be Mississippian on the basis of stratigraphic position.

Lee Flat Limestone

The Lee Flat Limestone was named by Hall and MacKevett (1962) for exposures of gray limestone of Mississippian to Pennsylvanian age in the Darwin quadrangle. The unit is a non-clastic equivalent of the clastic upper Perdido Formation and/or Pennsylvanian Rest Spring Shale of the Ubehebe Peak quadrangle and Inyo Mountains area (Hall and MacKevett, 1962). It occurs in roof pendants in the central Argus Range and crops out in upper Stone Canyon at the northern end of the mapped area. At the Westend lime quarry in the northern Slate Range, Lee Flat marble overlies a west-dipping fault. The Lee Flat gradationally overlies the Perdido and is abruptly overlain by gray calcarenite of the Keeler Canyon Formation. A paced section north of Knight Canyon is 270 m (890 ft) thick.

White and light to medium gray marble make up the Lee Flat Limestone, which in the Argus Range has been recrystallized by Mesozoic intrusions. Bedding, though mostly obscured by marmorization, is reflected by color changes where bleaching has not obliterated the original compositional differences. A streaky foliation parallel to bedding is common. The light color of the marble in contrast to the gray limestone of the type area may be largely due to volatilization of carbon during metamorphism. In the Knight Canyon pendant, the Lee Flat is mostly white marble and tan, hydrothermally dolomitized marble. In the Bendire pendant, a lower gray marble and an upper light gray and white marble can be distinguished. Gray beds contain bioclastic calcarenite with abundant white calcitic crinoidal remains. Large crinoid columnals to 3 cm in diameter are common in some beds of the Lee Flat and seem to be characteristic of this unit. Thin chert stringers are present locally.

Light to dark gray Lee Flat marble, thick bedded and slightly to strongly foliated, are present at the Westend lime quarry in the Slate Range. Large crinoid columnals to 2 cm occur in bioclastic beds. Masses of silicified limestone, brown-weathering chert, and tan dolomite are common. Silica replaces carbonate along closely spaced bedding or foliation planes north of the quarry, yielding a cherty marble similar to the Perdido Formation, but siliceous lenses and layers are at least partly post-tectonic and therefore secondary.

No diagnostic fossils were observed in the Lee Flat Limestone. As it underlies Middle Pennsylvanian beds of the basal Keeler Canyon Formation and is in part equivalent to the clastic upper Perdido Formation of the Ubehebe Peak quadrangle, Hall and MacKevett (1962) assign it to the Mississippian and Early Pennsylvanian.

Pennsylvanian and Permian Systems

Keeler Canyon Formation

The Keeler Canyon Formation was named by Merriam and Hall (1957) for a prominently bedded, gray clastic limestone sequence in the southern Inyo Mountains. In the Argus Range it is best exposed in the Bendire pendant, where it overlies the Lee Flat Limestone with a sharp contact. At this locality, the formation top is placed at the base of a thick lenticular conglomerate, assigned to the Owens Valley Formation. As this distinctive bed is lacking elsewhere, the upper contact of the Keeler Canyon is gradational and its location is uncertain. In the central Argus Range the formation is 600-700 m thick.

The Keeler Canyon Formation consists of two main lithologies: gray limestone in thick beds, commonly calcarenitic with sand and pebble-sized calcitic fragments of biogenic origin; and laminated silty limestone, light gray or orange-weathering, with laminae spaced at a few millimeters that reflect varying silt content. Contact metamorphism of silty limestones yielded calc-silicate hornfelses in which the bedding and sedimentary structures are obliterated or altered. Marmorized, thick gray calcarenite and limestone beds stand out in relief as prominent gray ribs separating sequences of lighter-colored silty limestone or calc-hornfels.

The lower 180 m (600 ft) of the formation at Bendire Canyon comprise the "golfball horizon" member of Merriam and Hall (1957); it is thicker here than in the Inyo Mountains (60 m). Gray limestone beds of this lower member contain nodules of gray chert ("golfballs"), which are spherical and 1-3 cm in diameter. Irregularly shaped nodules and lenses are also common. While this association appears regionally characteristic of the lower Keeler Canyon Formation, scarce spherical chert nodules also occur in gray limestone of the Owens Valley Formation in Water Canyon.

Calcarenite and fairly pure gray limestone comprise about half of the formation south of Bendire Canyon where the section described below was measured. The former presence of small amounts of silt is manifested by variable amounts of tremolite needles in metamorphosed rocks. Dark gray limestones are locally very carbonaceous and fetid. Bioclastic beds contain fusulinids, bryozoa, crinoids, and pebble-sized limestone fragments. Thin, lenticular beds of conglomerate with rounded or angular carbonate and chert clasts of pebble to cobble size occur locally with calcarenite beds. Beds of calcarenite with a scoured base and internal grading occur rarely.

Silty limestones, making up the remainder of the unit, display closely spaced, planar and locally wavy laminae. Current ripple cross-lamination and low angle cross-lamination occur locally. A conspicuous feature of the silty limestones is the presence of oblate nodular structures composed of pure limestone in a silty limestone matrix. They are probably of algal origin. They range in size from a few centimeters to more than 0.5 m, and may occur singly, or in closely spaced clusters.

A measured section south of Bendire Canyon (Sections 22, 27, T21S, R42E) is approximately 700 m thick:

	Thickness (m)
Owens Valley Formation (hornfelsic silty limestone above the horizon of pinch-out of conglomerate in Section 27)	

Keeler Canyon Formation:

Limestone, medium gray, crinoidal, calcarenitic; massive bedding with a slight foliation. 1 m thick bed with abundant fusulinids contains *Pseudoschwagerina* sp. and *Schwagerina* sp., 56 m above base	133
Limestone, medium gray (section offset across small fault)	30 approx.
Silty limestone, hornfels and gray limestone, thin to medium-bedded	114
Limestone, calcarenitic, with pebble-sized, angular gray limestone clasts. Some rounded coarse calcite sand; crinoids and poorly preserved fusulinids	20
Silty limestone hornfels, laminated and thin-bedded, light gray or orange weathering	32
Pebble conglomerate, partly bioclastic, with clasts of limestone, crinoids, and minor dark gray chert	1.5
Silty limestone hornfels, laminated and thin-bedded, orange or light-gray weathering	20
Limestone, medium gray, irregularly bedded with crinoidal bioclastic lenses containing abundant silicified fusulinids including *Triticites*? sp.; flow folds in silty beds	11
Small fault in section	
Silty limestone hornfels, laminated and thin-bedded, orange or light gray weathering, with a few gray limestone beds. Chert nodules near base, decreasing in amount upward. Closely spaced laminae in silty beds, but some massive hornfels present. Light gray algal structures in silty limestone matrix.	163
Limestone, medium gray, slightly foliated massive bed, with chert stringers and a few golfball nodules	4.5
Limestone, medium gray, and light gray laminated silty limestone, partly hornfelsic	32
Calcarenite limestone, medium gray, finely foliated, with chert lenses and nodules. Dark gray limestone inclusions, marginally silicified, may be of algal origin. Spherical chert nodules from 0.5 cm to 3 cm. Well-rounded calcite sand present. Bioclastic lenses contain crinoid remains, solitary corals, bryozoa, brachiopods, and fusulinids, including *Fusulinella* sp.	18

Silty limestone, light and medium gray, thin-bedded and laminated, with variable silt content. Some chert beds and golfball nodules	15
Limestone, slight silty, medium to dark gray, with orange cherty nodules and irregular lenses. Golfball nodules 2 cm in diameter. Thin chert beds and lenses. A gray calcarenite bed contains fusulinids, bryozoa and bioclastic debris; Fusulinella sp.	14
Limestone, medium gray, and calcarenite, poorly bedded. Bioclastic lenses with black calcite crinoidal remains	29
Calcarenite limestone, dark gray (non-fetid) with crinoidal bioclastic lenses. Black and white calcitic crinoid material pebble-sized to 3 cm. Marmorized and slightly foliated. A few light gray chert nodules	61
Lee Flat Limestone (massive light gray and white coarse, bioclastic marble)	
Total thickness	698 m (2290 ft)

Sections of the Keeler Canyon Formation in the Knight Canyon pendant and upper Stone Canyon are complete, and similar to that above, but hornfelsic rocks are common and fossils have been destroyed by recrystallization. North of Knight Canyon, matrix-supported conglomeratic limestones up to 10 m thick, with angular clasts of marble and dark gray chert, are present near the top of the unit.

In the Slate Range, Keeler Canyon strata occur in two thrust lenses near Westend lime quarry. The structurally lower lens contains lithologically uniform, medium gray limestone and pervasively foliated tremolitic, silty limestone. Similar gray limestone in a small klippe northeast of the main lens contains crinoids and chert nodules 1-2 cm in diameter. The nodules suggest correlation of these rocks with the "golfball member" of the lower Keeler Canyon Formation. A structurally higher thrust lens contains a foliated and partially overturned section of Keeler Canyon beds overlying Lee Flat marble. Calcarenites, locally with graded beds, and golfball nodules are present in these strata. Pebble and cobble conglomerates occur 120 m above the formation base, and poorly preserved fusulinids 150 m above the base.

The age of the Keeler Canyon Formation in the Inyo Mountains is Middle Pennsylvanian (Atoka or Desmoines) to Early Permian (Wolfcamp) (Merriam and Hall, 1957). Five fusulinid collections from the central Argus Range were examined by C. H. Stevens. Fusulinella and Tricites? sp. in the lower and middle parts of the unit correspond to faunal zones established for the type section. Pseudoschwagerina, which occurs in upper Keeler Canyon strata in the Bendire pendant, first appears in the lower Owens Formation in the Inyo Range. In the latter area, an unconformity separates the two units. Therefore, either the Wolfcampian Pseudoschwagerina-bearing strata in uppermost Keeler Canyon beds were locally removed prior to Owens Valley deposition, or the formational contact is time-transgressive. Hall (1971) also noted that in the northern Argus Range, Pseudoschwagerina questionably occurs in upper Keeler Canyon strata. Schwagerina is common in upper Keeler Canyon strata and occurs with Eoparafusulina? sp. north of Bendire Canyon (Section 15, T21S, R42E).

Keeler Canyon deposition represents a change from the pre-Middle Pennsylvanian shallow carbonate shelf environments, although the latter persisted to the southeast, toward the craton. The presence of a terrigenous silt fraction and abundant allogenic bioclastic material in carbonate arenite sheets suggest a moderate-energy environment, offshore from a low-energy carbonate shelf. The carbonate sand was transported and winnowed by marine currents. Lenticular conglomerate beds with limestone and chert fragments may be storm lag deposits. The occurrence of coarse clastic material implies subaerial erosion of local uplifted areas. Shallow-water fauna in the lower part of the formation and algal nodules in the finer-grained interbeds put limits on water depth, but local moderate topographic relief of the sea floor is suggested by rare turbidite-like, graded calcarenite beds with a scoured base, and convolute loading structures. Elayer (1974) noted that the Keeler Canyon Formation in the southern Inyo Mountains contains a thick section of interbedded calcarenite turbidites and siliceous pelagic sediments, which may represent deep-water deposition. The Argus Range, and areas along depositional strike to the northeast, may therefore be transitional between near-shore and basinal deep-water facies.

Owens Valley Formation

A Permian sequence of silty limestone, calcarenite, limestone, shale and conglomerate in the southern Inyo Mountains was named the Owens Valley Formation by Merriam and Hall (1957). Rocks assigned to this unit, commonly metamorphosed, are widely exposed in roof pendants in the Argus and northern Slate Ranges. The formation is lithologically variable both vertically and laterally across this area. In contrast to the type area, where the Owens Valley rests locally on an unconformity, the formation is gradational and apparently conformable with the underlying Keeler Canyon Formation. The contact is thus arbitrary, but would not be placed any lower than shown in Figure 4. In the Bendire Canyon pendant, a lenticular conglomerate is chosen as a convenient basal stratum for the unit. The top of the formation is not exposed. Faulting and contact alteration near intrusions prevent an accurate estimate of thickness, which exceeds 900 m (3000').

In the northern Argus Range and areas farther north and west the Owens Formation can be distinguished from the Keeler Canyon by a basal 130 m-thick calcareous siltstone bed (Hall, 1971); a greater proportion of pure lenticular limestone beds, and laminated siltstone and silty limestone, and current-bedding structures. West of upper Stone Canyon and along the range crest north of Maturango Peak, the basal siltstone is absent and these lithologic changes are gradationally observable over a few hundred meters of section. The main rock types are calcarenite, limestone pebble conglomerate, and limestone interbedded with laminated silty limestone. Current ripple cross-lamination, low-angle cross-stratification and algal nodules occur in the silty carbonates, scour and loading features occur locally beneath pebbly calcarenites, and flame structure is present rarely in siltstone beds. Poorly preserved corals and fusulinids are present in bioclastic beds. In the Knight Canyon pendant, similar rock types are present, although metamorphic alteration is more intense. At these localities the base of the formation is placed above several rib-forming gray limestone or calcarenite beds, locally conglomeratic, that resemble a sequence of such beds near the top of the measured Keeler Canyon section in the Bendire pendant.

South of Bendire Canyon, distinctive beds of limestone conglomerate and breccia, and rusty-weathering siltstone, separated by silty limestone hornfels, are mapped separately on Plate I. The 100 m thick siltstone bed forms rounded, rubbly slopes, and is a noticeable dark band on aerial photos. It may be equivalent to the siltstone bed at the base of the Owens Valley in the northern Argus Range, but in the Bendire pendant, the formation base is placed beneath the underlying conglomerate. This lenticular rock body, with a maximum thickness of 180 m (600'), contains mostly angular, poorly sorted clasts of chert and limestone, commonly 2-25 cm in size (Figure 6). Moderately sorted pebble conglomerates, with interbedded laminated silty limestones, alternate with coarse, unbedded sedimentary breccias. Higher

Figure 6. Cliff-forming beds on ridge top are basal Owens Valley conglomerate and breccia, which thicken to 180 m in the valley at right rear. Hunter Mountain quartz monzonite is in the middle distance, and down-faulted Tertiary volcanic rocks occupy the foreground.

strata in the Bendire pendant include hornfelsic laminated silty limestone and beds of marble, including a thick white marble bed that caps prominent hills south of the Millspaugh fault. Metamorphic alteration increases toward the western exposed edge of the pendant. It is intense also in exposures of Owens Valley hornfels near the Onyx Mine.

Silty limestone, metamorphosed to fractured, monotonous fine-grained calc-hornfels, underlies the area north of Slate Range Crossing and is exposed beneath Tertiary volcanic rocks to the east. Bedding laminations and primary sedimentary features have been mostly obliterated. These rocks are assigned to the Owens Valley Formation, as other units lack thick sequences of silty limestone which could yield a metamorphic equivalent that is uniform throughout. Near the faulted top of the sequence, north of the mouth of Water Canyon, a 50 m-thick bed of conglomerate and an overlying 15 m gray marble bed are interbedded with hornfelsic silty limestone. The conglomerate contains angular clasts up to 0.5 m, but commonly 2-4 cm in diameter, of gray and white chert, silty limestone, and fine-grained sandstone and laminated quartzite. Lenticular interbeds of quartz sandstone are also present.

Fossiliferous Owens Valley strata occur in a fault-bounded thrust slice spanning Water Canyon, here referred to as the Aquarius Mine block (Figure 3). A rock type not present elsewhere is fissile, light yellow-brown to pinkish-brown siltstone, locally laminated. Interbeds of brown-weathering, mature quartz and chert-grain sandstone, with small-scale cross-lamination, are present. Conglomerate to 3 m thick, with well-rounded chert and limestone clasts 2-5 cm in diameter, occurs locally near the base of the sequence. Fusulinid limestone composed of packed Schwagerina skeletons occurs west of Slate Range Crossing in a lens 0.6 m thick, enclosed in tan flaggy siltstone. Siltstone strata in the Aquarius Mine block are overlain by medium gray, cherty, thick-bedded limestone, with common fusulinid-bearing bioclastic beds.

Altered and deformed carbonate rocks exposed in the northern Slate Range include gray marble, locally with chert stringers, brown-weathering tremolitic marble, gray laminated silty limestone and its hornfelsic equivalent, marmorized pebble conglomerate, and coarse limestone clast conglomerate. No diagnostic fossils were observed because of the advanced recrystallization of these rocks. Pebbly, bioclastic conglomerates are difficult to recognize, as the clasts have been stretched and smeared out into calcite streaks. These strata are assigned to the Owens Valley Formation, as they resemble no unit older than Permian. Blocks of tremolitic marble engulfed in intrusive rocks near Manly Pass are also questionably assigned to the Permian. The uniform gray color of the Slate Range exposure, and an apparent decrease in silt content of the carbonate strata, suggest a change in Permian lithofacies southeastward, toward the craton. Permian rocks southeast of the Argus Range, also including the "Anvil Spring Formation" of Johnson (1957) in the southern Panamint Range, appear to more closely resemble shallow-marine shelf limestones of the Permian upper Bird Spring Group than the Owens Valley Formation with its terrigenous silt fraction and variable facies.

Near Ophir Mine in the Slate Range, deformed strata of probable Permian age occur both above and below the Ophir thrust fault and are overlain by metamorphic rocks of Permian or Triassic age. Limestone with thin chert beds, interbedded with calc-silicate hornfels, is overlain along the thrust surface by a massive lens of tan marble, containing pentagonal pelmatozoan columnals, which are probably Permian in age (C. H. Stevens, personal communication).

The Owens Valley Formation is Wolfcampian and younger Permian in age. Fusulinids from the Aquarius Mine block were identified by C. H. Stevens. They include: Schwagerina sp., from gray bioclastic limestone; and Schwagerina garlockensis (Ross and Sabins) and Eoparafusulina n. sp. (lower Leonard? age) from fusulinid limestone. The position of these strata within the Owens Valley section is unknown.

Owens Valley depositional environments are in part a continuation of those of Keeler Canyon time. Carbonate arenites alternating with laminated silty limestone lacking bioturbation may reflect periodic moderate energy conditions in offshore areas. Low-energy shelf conditions are indicated by the abundant shallow water faunas and biostromes reported from other areas, and by massive lenses of relatively pure fossiliferous limestone.

Local abrupt topographic relief, and perhaps deeper water environments, are indicated by accumulations of coarse, intra-geosynclinal detritus. The occurrence of coarse marine conglomerates like that in the Bendire pendant is a prominent regional feature of Permian sedimentation. Pebble beds, crudely sorted by currents, and coarse, unsorted debris flow deposits interfinger laterally with fine-grained, silty carbonate sediments. The shape of the conglomerate body may be fan-like, and it was probably fed by a submarine channel.

Conglomerate and breccia exposed in the Bendire pendant is of Early Permian (Wolfcamp) age. Similar deposits have been reported in nearby areas. A conglomeratic sequence 900 m thick is exposed in Tucki Mountain in the Panamint Range (Hunt and Mabey, 1966) and appears from included fauna to be Late Pennsylvanian(?) to Early Permian in age; clasts of Mississippian and Pennsylvanian age are present in this deposit. Lenticular limestone breccias with clasts to 1 m also occur at the base of the Owens Valley Formation in the Inyo Range, where they overlie Keeler Canyon strata discordantly. Younger conglomerates occur in the southern Inyo Mountains, where chert, limestone and quartzite-clast conglomerates and interfingering sandstones are of Middle Permian age (Merriam and Hall, 1957).

The conglomerates reflect erosional stripping of local highs within the geosyncline. Strata as old as Early Mississippian were removed from the uplifted areas, transported laterally by marine currents, and channeled into adjacent areas of deeper water. Elayer (1974) interpreted a regional basin-to-shelf transition in the upper Owens Valley Formation in the southern Inyo Mountains. The lateral variability of the formation appears related to such regional bathymetric gradients and locally to pronounced relief of the sea floor. Vertical transitions in depositional environments and sediment types reflect the increased dynamism of uplift and subsidence in the geosyncline in the Permian.

Tectonite marble of mostly late Paleozoic age

Allocthonous lenses of foliated, isoclinally folded marble occur along the Argus Sterling thrust zone. The lenses are composed of relatively pure calcite marble, impure from Devonian through Permian formations. The major occurrences of marble lenses are: along the trace of the thrust zone from Argus Sterling Mine to 5 km east of Maturango Peak; a 4 km-long exposure in the Shepherd Canyon area; and small outcrops near the highway west of the Westend limestone quarry in the northern Slate Range.

Lenses near the Argus Sterling mine consist of gray and white fine-grained marble with a well-developed, and locally folded, flow foliation (Figure 32a). In color and purity the marble resembles Lee Flat Limestone, but it might include other Mississippian limestone. Dark gray marble with chert nodules may be either Mississippian or Pennsylvanian. Tan dolomite replaces streaky gray marble south of Argus Sterling Mine. Lenses north-east of Maturango Peak, from north to south, consist of medium gray and white flow-laminated marble (Lee Flat?); white to pale pink-weathering marble with gray flow laminations (Lost Burro?, or Lee Flat?); and gray marble with white laminations and chert lenses (Keeler Canyon?).

Tectonite marble occupies a trough-shaped depression in autochthonous rocks at the northern end of the Bendire pendant. From east to west, in ascending structural order, west-dipping slabs of light gray marble, massive tan and light gray coarse dolomite, and streaky white and gray marble overlie autochthonous granitic and Mississippian to Pennsylvanian carbonate rocks. Much of the marble appears to be isoclinally folded Lee Flat limestone, with infolded Perdido at the west end of the mass. Dolomitization of calcite marble occurred later, obliterating the foliation. Dolomite and gray marble east of recognizable Lee Flat marble have been mapped as questionable Lee Flat, although other late Paleozoic units may be represented.

A 4 km-wide marble lens near Shepherd Canyon contains medium gray, tan and white, fine-grained marble that is foliated and isoclinally folded. In contrast to purer marble lenses farther north, much of the marble appears to have been derived from silty limestone and may be Permian in age, assignable to the Keeler Canyon or Owens Valley Formations. The impure carbonate composition, presence of autochthonous Permian rocks north and south of the lens, and the presence of Triassic rocks tectonically emplaced above the lens make a Permian age plausible.

Light tan and light gray foliated marble forms three outcrops along the base of the hills west of the Westend quarry. Underlying Keeler Canyon beds lack the strong foliation of the marble, which is atypical of Keeler Canyon lithology and appears to be a highly deformed lens of middle or late Paleozoic limestone.

B. Mesozoic Sedimentary and Volcanic Rocks

Altered and deformed Triassic and Jurassic rocks, including carbonate, clastic and tuffaceous sediments and volcanic flows, occur as parautochthonous lenticular masses along the Argus Sterling thrust zone near Shepherd and Water Canyons. Similar metamorphic rocks crop out near the Ophir Mine, and include impure carbonate rocks interbedded with fine-grained clastic and tuffaceous rocks which were foliated during thrust faulting in the Slate Range. Mesozoic volcanic rocks which have not been transported along fault zones occur only near Shepherd Canyon, where an elongate roof pendant of tuffaceous volcanic rocks is present.

Rocks of these areas resemble sections of Mesozoic rocks in the Inyo Mtns. (Kelley, 1973; Elayer, 1974) and in the southern Panamint Range (Johnson, 1957), where volcanic rocks of presumed Triassic and Jurassic age overlie impure carbonate rocks of Early to Middle Triassic age. Elayer (1974) noted tuffaceous interbeds in Triassic limestone. Regional initiation of magmatic activity in the Triassic is supported both by stratigraphic evidence, and by the earliest determined ages on plutons (e.g., Armstrong and Suppe, 1973). Volcanic strata are absent in the Paleozoic section of this area and evidently indicate a Mesozoic age. The presence of volcanic clasts, plagioclase feldspar of plutonic or volcanic origin, or tuffaceous detritus in sedimentary strata similarly indicates a Mesozoic age. Where such strata are interbedded with carbonate rocks, a Triassic age is likely. Some uncertainty in age designation is due to the resemblance between metamorphosed impure carbonate rocks of late Paleozoic and presumed Triassic age.

Triassic carbonate and fine-grained clastic sedimentary rocks

Altered, epidote-rich metasedimentary rocks occupy tributary valleys north and south of Water Canyon (Figure 7). Rock types include metamorphosed silty limestone, calcareous quartz siltstone and sandstone, feldspathic sandstone, brown and purple shale, limestone, and tuffaceous sandstone and calcareous siltstone. These sediments occur in a tectonic lens

Figure 7. View south, toward Water Canyon. Altered, epidote-rich calc-hornfels and clastic sediments of Triassic age crop out in valley in foreground, overlying silicified Permian rocks at left. Dark outcrops at right are Mesozoic meta-andesite.

that pinches out southward, and is truncated northward by fine-grained intrusive diorite. A lens of epidote hornfels, with thin interbeds of mylonitic, feldspathic sandstone, is also present along the thrust zone between Water and Shepherd Canyons.

Silty limestone and fine calcareous sandstone are the most common premetamorphic rock types. The grain size of sandstones ranges from 0.1 mm to greater than 1.0 mm. Quartz grains are generally angular and locally poorly sorted. Sandstones also contain common plagioclase, and less commonly, grains of chert, albite, orthoclase, fine-grained diorite, and siltstone. A few sandstones also display phyllosilicate lenses or wisps that are relict pumice fragments, occurring with common white and pink feldspar grains.

The clastic material was deposited in a limy, shallow marine environment. A provenance in part plutonic or volcanic is apparent. The feldspathic component of sandstones may have been contributed by local volcanism or by unroofing of the earliest Mesozoic intrusions.

These sedimentary rocks were deformed during movement along the Argus Sterling thrust zone, as manifested in the phyllitic foliation of fine-grained rocks, strained and stretched quartz grains in sandstones, disharmonic folds in thinly bedded, shaly limestone, and boudinage of thick carbonate beds and basaltic sills. Following deformation, the section was contact metamorphosed, yielding calc-hornfels from the silty limestones. An episode of hydrothermal alteration produced an abundance of epidote in most rocks. Garnet, actinolite, chlorite and sericite are also present in metacarbonates. The calc-hornfelses are locally friable, green-spotted rocks, with epidote-rimmed "eyes" of garnet, actinolite, quartz and calcite.

The metasedimentary rocks are overlain by Triassic-Jurassic lava flows. Although the contact is tectonic, it may be a faulted depositional contact, since fine-grained diorite of Mesozoic age (TrJi) intrudes both the metasediments and volcanic flows, suggesting pre-tectonic proximity of the two units.

The evidence for a Triassic age of these rocks is:

1. The presence of tuffaceous material and plutonic or volcanic feldspars;

2. Analogous stratigraphic relations in the Inyo Mtns. and Panamint Range, where Triassic carbonate, and locally tuffaceous, rocks underlie thick Triassic to Jurassic

volcanic sequences.

Permian(?) and Triassic rocks of the Ophir complex

Smith and others (1967) assigned metasedimentary and plutonic rocks near the Ophir Mine to the Precambrian. The present study does not support this assignation. Marble, calc-silicate hornfels, and schistone clastic and tuffaceous sediments (Figure 8) tectonically overlie strata of the Owens Valley Formation. Faulting, post-tectonic plutons, and alluvium have

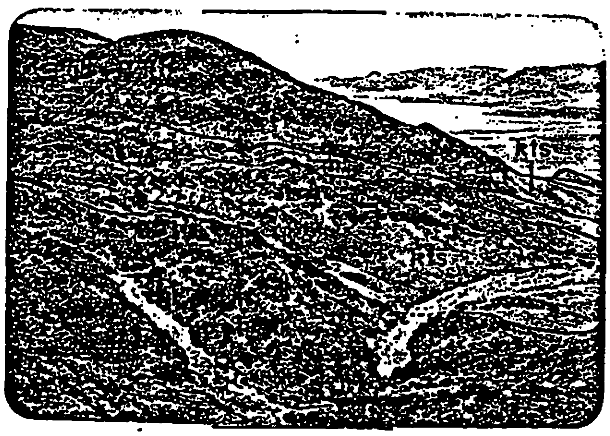


Figure 8. Southward view of metamorphic rocks of the Ophir complex. In foreground is blocky green and orange hornfels of Permian or Triassic age. It is overlain by micaceous metatuff with an intercalated marble band (tan color). Darker rocks at top of sequence include sheared alaskite of Goldbottom Mine. Searles Lake and Trona in background.

isolated this rock mass, here referred to as the Ophir complex, from correlative rock units. However, similarity to Triassic rocks of Water Canyon and to regional Mesozoic sections suggest that part of the complex is Triassic. Metamorphosed silty limestones of the Owens Valley Formation may also be present.

The following rock units near Ophir Mine have been differentiated on Plate II:

1. PmTrh: Dense green and orange-weathering hornfels with a southwest-dipping, blocky foliation overlies Owens Valley(?) tectonite marble. The unit is approximately 340 m (1100 ft) thick. The structurally lower two-thirds of the unit is dark green epidote and actinolite-rich calc-hornfels. These metamorphic rocks resemble metavolcanic greenstones owing to a high calcium, alumina and iron content, but are derived from impure carbonate rocks. The overlying orange-weathering hornfels is composed of quartz, diopside and garnet, replaced by calcite and fibrous amphibole. Bedding has been largely obliterated.

The hornfels is intruded by sheared alaskitic sills correlated with the alaskite of Goldbottom Mine, and by metabasaltic, slightly amygdaloidal sills which have been boudinaged during deformation.

2. Trts: Schistose clastic and tuffaceous sediments, with a 5 m thick bed of tectonite marble, sharply overlie the hornfels (Figure 8). The contact is probably a sheared sedimentary contact. Below the marble band, gray and green mylonitic tuffaceous rocks occur, with a well developed foliation defined by muscovite. Porphyroclastic grains of plagioclase, K-feldspar and quartz in a matrix of recrystallized mortar suggest a rhyodacite crystal tuff as a parent rock. Some clastic sediments may be intercalated with the tuffaceous volcanic rocks, and the interbedded marble suggests a lacustrine or marginal marine environment. Above and below the marble, pale green and white quartz-muscovite schists may have been derived from siliceous microcrystalline volcanic ash (Figure 9). Quartz lenticles may be relict clasts from a tuffaceous parent rock. Darker interbeds contain distinctive pale green, micaceous lenses, which are probably recrystallized lapillar clasts. The original textures of these rocks are mostly obliterated, but the mineralogy and composition indicate a volcanic parent.

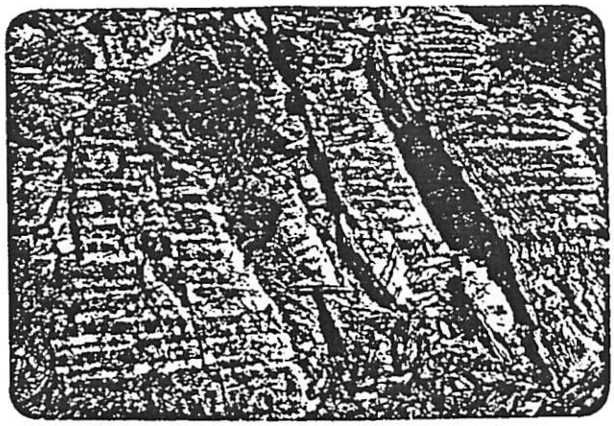


Figure 9. Metavolcanic mica schist outcrops near the right margin of Figure 8, Ophir complex. The west-dipping foliation is strikingly kinked.

3. Trh: Calc-hornfels, both foliated and blocky, crops out above the schists. Epidote-rich, orange-weathering hornfels resembles rocks of unit 1, but may be younger as it is apparently interbedded with the clastic rocks.

The interbedded carbonate and clastic rock sequence with included volcanic material is similar to regional sections of Triassic rocks. If it includes no major tectonic discontinuity, its position above probable Permian rocks suggests that it may be a Permian and Triassic section. The lowermost hornfels unit may include both Owens Valley and Triassic carbonate rocks, whereas units 2 and 3 are probably Triassic.

Calc-hornfels with a crude cleavage and interleaved white and gray tectonite marble near Goldbottom Mine are mapped as Permian or Triassic. The dark green hornfels is shattered and cut by numerous veinlets, and is similar to other hornfelses in the area. The cleavage is locally discordant to bedding, where the latter is preserved. The tectonite marble is strongly foliated and displays flow folds with eastward overturning.

Volcanic rocks of Triassic or Jurassic age

A continuous lens of Mesozoic volcanic rocks intruded by fine-grained diorite (see below) extends from the Millspaugh fault to Water Canyon. In the northern section of this lenticular mass, mostly andesitic rocks have been penetratively deformed, yielding slaty or phyllitic, dark green mylonites. Farther south the lens thickens and deformation has been non-penetrative, preserving some primary volcanic features.

Most of these rocks are uniformly dark green meta-andesites that appear aphanitic or finely crystalline in outcrop. In thin section, they show fine-grained, saussuritized plagioclase phenocrysts in an altered, plagioclase-lath matrix. Pyroxene or other mafic minerals have been altered to epidote, chlorite and other phyllosilicates. Two to five percent quartz occurs as small interstitial grains that are probably due to groundmass recrystallization. The matrix of a few rocks has been replaced by hematite.

These rocks are volcanic flows, although alteration is too extensive to recognize flow tops or bottoms. Volcanic breccia interbeds with meta-andesite clasts in a plagioclase-rich matrix occur locally. The lavas are overlain by tuffaceous and clastic rocks, and interbeds of tuff and quartz sandstone are present within the flow sequence. One basalt flow interbedded with andesite contains flattened, chlorite-filled amygdules. Such textures, and the presence of clastic interbeds, document a subaerial environment, but small intrusions of hypabyssal rock, such as monzonite porphyry, occur in the volcanic section, and are difficult to distinguish from flow rock in the field.

Quartz siltstone and sandstone interbeds are present south of Shepherd

Canyon and north of Water Canyon. The siltstone contains angular quartz grains 0.1-0.2 mm in diameter in a sericite matrix, with widely scattered, round 1 mm quartz grains. Tuffaceous interbeds just north of Shepherd Canyon are phyllitic mylonites with porphyroclasts of plagioclase and sutured quartz, and with quartz-feldspar lenses that are probably relict clasts.

Spanning Shepherd Canyon, an elongate roof pendant of hornfelsic siliceous tuff is intruded by quartz monzonite. Rock types within the pendant include metamorphosed vitrophyric airfall(?) tuff, pumiceous welded tuff, and local interbeds of tuff-breccia and volcanic breccia near Shepherd Canyon; and porphyritic andesite west of Anthony Mill. Relict textures in welded tuff are locally well preserved and include compacted pumice fragments, which consist of axiolitic and spherulitic quartz-feldspar intergrowths around quartz lenses in a devitrified matrix (Figure 10). Fragments of porphyritic volcanic rock to 5 cm are present in beds of breccia. The bedding and compaction foliation in these rocks dip gently.

These volcanic rocks have been baked to blocky, dense, light or brown-weathering hornfels, and are tourmalinized near Shepherd Canyon. In the southern end of the pendant, volcanic rocks have been bleached, pyritized and silicified, making differentiation from fine-grained granitic facies difficult.

The age of these volcanic rocks is bracketed by the underlying strata of probable Triassic age and the Middle Jurassic Hunter Mountain quartz monzonite, which intrudes the siliceous tuff.

Figure 10. Hornfelsic welded tuff of Triassic or Jurassic age near Shepherd Canyon, with compacted pumice fragments and volcanic clasts in a vitrophyric matrix.

Coarse-grained clastic sedimentary rocks and tuff of Triassic or Jurassic age

Sedimentary and tuffaceous rocks which overlie or are interbedded with andesitic volcanic rocks at Water Canyon include: volcanic and chert clast conglomerate; quartz and feldspathic sandstone; volcanic and chert sandstone; pumiceous sandstone; volcanic breccia, and phyllitic tuff.

Volcanic conglomerates contain poorly sorted, angular clasts commonly 2 cm to 25 cm in diameter. A few beds with rounded clasts are present. Pebbles of chert are abundant, as well as aphanitic or porphyritic volcanic clasts with pale green or violet coloration. The matrix consists of small angular pebbles and coarse sand. Coarse-grained sandstone and granule sandstone contain closely packed fragments of chert and volcanic rock, with plagioclase and potassium feldspar, and some smaller grains of plagioclase and quartz. One sample contained plutonic microcline. South of Water Canyon, conglomerate and granule sandstone have been mylonitized and possess a phyllitic foliation due to growth of muscovite along shear planes; stretched clasts are also present. Where preserved, bedding in the sedimentary rocks approximately parallels the foliation.

1. As it is more structurally isotropic, it is less penetratively deformed than the volcanics and less commonly foliated. Widely-spaced, west-dipping shear planes or blocky fracture are present locally;
2. Limonitic zones are present locally near intrusive contacts with volcanic and sedimentary rocks;
3. Texturally the diorite is more uniform than the volcanics, and it is moderately to slightly coarser in grain size;
4. It lacks amygdules and sedimentary interbeds.

The diorite body is apparently offset slightly by the reverse fault separating Triassic metasediments from overlying Triassic and Jurassic volcanic rocks north of Water Canyon. This fault appears to die out within the diorite, which cuts both pre-intrusive units. It is younger than the volcanic rocks and appears to truncate the rhyolite porphyry, and it is older than the Argus Sterling thrust.

C. Mesozoic Intrusive Rocks

In the Argus and Slate Ranges, roof pendants of Paleozoic and Mesozoic rocks are intruded by generally medium-grained, moderately silicic granitic rocks. The most common rock type is quartz monzonite, containing hornblende and biotite, with 10 to 30 percent quartz, and plagioclase (oligoclase to andesine) in slightly greater amount than potassium feldspar. Rocks with compositions from diorite to alaskite are also present. Alaskite, defined as leucocratic granite or quartz monzonite with a color index less than 5, makes up three intrusive masses and several smaller bodies.

Ages determined for granitic rocks in the Argus Range define two episodes of intrusion and cooling: 165-170 m.y. (Middle Jurassic) and 140 m.y. (latest Jurassic). Similar ages are reported by Ross (1969) for intrusive rocks of the southern Inyo Range. These dates span a period of time in the Jurassic during which fairly localized Early to Middle Jurassic intrusion of granitic magmas in the Inyo Mountains region was succeeded during the Late Jurassic by regional plutonism in the Sierra Nevada and Great Basin (Armstrong and Suppe, 1973). This intrusive event preceded the Late Cretaceous event that characterizes much of the Sierra Nevada, but which appears to be unrepresented in the Argus Range area.

The presence of the Argus Sterling thrust permits a division of Argus Range granitic rocks into pre- and post-tectonic. Two granitic complexes, those of Hunter Mountain and Maturango Peak, are juxtaposed by the thrust, which is in turn cut by post-tectonic plutons. K-Ar dating of these units brackets the age of the thrust within the Late Jurassic (Moore and Harakal, 1976). A cataclastic foliation in small alaskite bodies along the thrust implies syntectonic intrusion of small volumes of silicic magma.

TABLE 1: K-Ar AGES OF INTRUSIVE ROCKS, ARGUS RANGE

Constants: $K^{40}/K = 1.19 \times 10^{-4}$; $\lambda_{\epsilon} = 0.585 \times 10^{-10}$; $\lambda_{\beta} = 4.72 \times 10^{-10}$

Unit	Location	Mineral	K (%)	$*Ar^{40}$(mol/g)	$*Ar^{40}/Ar^{40}$tot.	Age (m.y.)
Hunter Mountain quartz monzonite	36°8'12"N; 117°26'15"W	hbl	0.39	1.209×10^{-10}	72.2%	169 ± 6
		biot	6.74	2.033×10^{-9}	80.9%	166 ± 6
Quartz monzonite of Maturango Peak	36°8'14"N; 117°30'15"W	hbl	1.00	2.989×10^{-10}	86.3%	165 ± 5
		biot	7.11	1.661×10^{-9}	85.6%	132 ± 5
Alaskite of Bendire Canyon	36°6'32"N; 117°27'17"	biot	6.89	1.739×10^{-9}	87.7%	140 ± 6
Quartz monzonite of the Argus Sterling Mine	36°8'56"N; 117°29'51"W	hbl	0.87	2.179×10^{-10}	76.2%	139 ± 5
		biot	6.68	1.291×10^{-9}	81.5%	108 ± 4

In the Slate Range, four main granitic units have been mapped. Three post-date the deformation at Ophir Mine, which may correlate with the Argus Sterling thrust (see Section II D). Further radiometric dating will be necessary to fully clarify the relationship of Slate Range structures and intrusions with those of the Argus.

The locations of granitic samples are shown in Figures 11 and 18. Table I shows the results of K-Ar determinations of four Argus Range units.

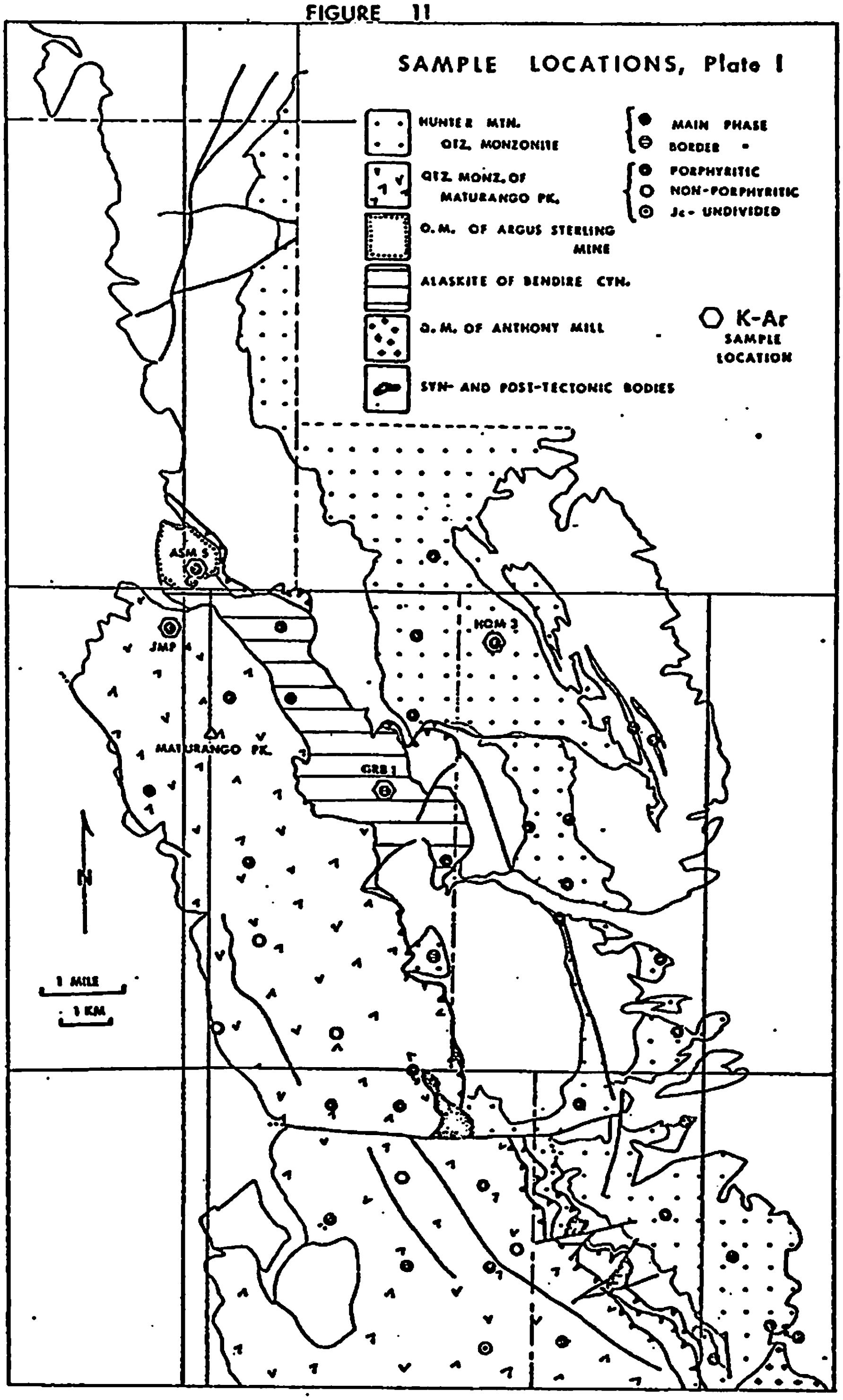
Pre-tectonic Intrusive Rocks

Hunter Mountain Quartz Monzonite

The Hunter Mountain quartz monzonite was named by McAllister (1956) for a complex of heterogeneous quartz monzonitic rocks that crop out on Hunter Mountain at the north end of Panamint Valley (Figures 1 and 37). Quartz monzonite correlative with the type area has been described in the Darwin and Panamint Butte Quadrangles (Hall and MacKevett, 1962; Hall, 1971) and in the southern Inyo Mountains (Ross, 1969; Dunne, 1971). In the Argus Range, rocks east of the Argus Sterling thrust that are correlative with the Hunter Mountain quartz monzonite extend from Stone Canyon to north of Water Canyon. A small sheared outcrop of granitic rock in the thrust zone near Westend lime quarry is questionably assigned to this unit. Sample HQM-3 from the Argus Range yielded concordant hornblende and biotite Middle Jurassic dates which agree well with other reported dates (e.g., 165 and 156 m.y.: Burchfiel and others, 1970; and 156, 163 and 178 m.y.: Ross, 1969).

The composition of sixteen samples of quartz monzonite from the Argus Range, plotted on Figure 12, averages 36.75% plagioclase, 28.75% K-feldspar,

FIGURE 11


SAMPLE LOCATIONS, Plate I
HUNTER MTN. QTZ. MONZONITE
QTZ. MONZ. OF MATURANGO PK.
Q.M. OF ARGUS STERLING MINE
ALASKITE OF BENDIRE CYN.
Q.M. OF ANTHONY MILL
SYN- AND POST-TECTONIC BODIES
MAIN PHASE
BORDER "
PORPHYRITIC
NON-PORPHYRITIC
Jc- UNDIVIDED
K-Ar SAMPLE LOCATION
ASM 5
JMP 4
HOM 2
GRB 1
MATURANGO PK.
N
1 MILE
1 KM

22.5% quartz, 7% hornblende, 4.25% biotite, with a color index of 12%. The zoned plagioclase ranges in composition from calcic andesine to calcic oligoclase (An_{50-26}). Accessory minerals include magnetite, sphene, apatite, zircon, epidote, orthite, and myremekite.

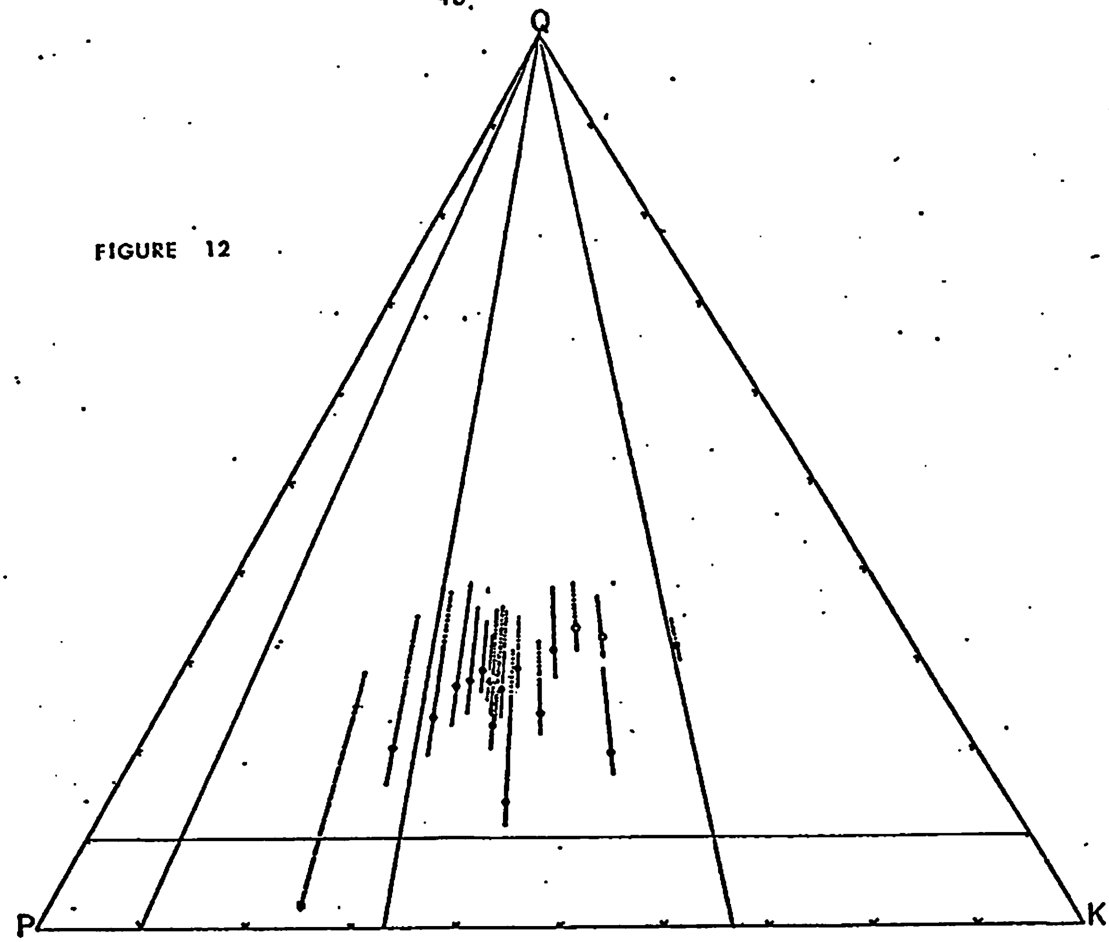
The main facies of this unit is homogeneous, equigranular, medium-grained quartz monzonite (Figure 13). Subhedral fine-grained plagioclase crystals are enclosed in an anhedral quartz-orthoclase matrix. The latter displays cuneiform granophyric intergrowths in border rocks and sills. Hornblende and biotite occur in clusters, or may be enclosed in poikilitic anhedral orthoclase. Large areas of quartz monzonite have been retrograded and mafic minerals are replaced by chlorite and epidote.

A dioritic or porphyritic border facies, commonly with a pyroxene syenodiorite composition, occurs south of Bendire Canyon. A continuous gradation from fine-grained quartz monzonite and granodiorite to porphyritic syenodiorite is observable north of Anthony Mill. Phenocrysts of plagioclase and augite, with interstitial perthite, occur in a fine matrix; hypersthene and biotite are locally present, the latter in part replacing pyroxene. Intrusive breccia is locally present in this unit.

Hunter Mountain quartz monzonite in the Argus Range is similar in composition to the Pat Keyes pluton, Inyo Mountains, as reported by Dunne (1971), but slightly richer in quartz than the average of rocks reported from the type area (McAllister, 1956; Hall, 1971). It is more homogeneous texturally than in the type area (where composite intrusion may have taken place), and differs from areas farther north in lacking porphyritic K-feldspar facies.

Structural adjustment of roof rocks took place during emplacement of Hunter Mountain magmas into the folded Paleozoic cover. The Knight Canyon

FIGURE 12

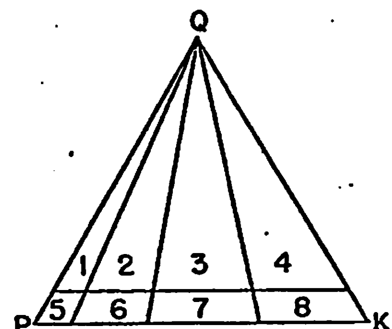


Hunter Mountain Quartz Monzonite

- • Jhqm
- ∘ ▪ sills in the Knight Cyn. pendant
- ▪ Jhd: syenodiorite border phase

——— hornblende + accessory minerals
······ biotite
- - - - augite + accessory
——— total mafics

NOTE: Measured on the vertical scale, the line through the point denotes the percentage of mafic minerals. The quartz content is given by the height of the bottom of the line above the P-K base, and the total feldspar content by the distance from the top of the line to the Q apex.



KEY

Q = quartz P = plagioclase
K = potash feldspar

1 quartz diorite	5 diorite
2 granodiorite	6 syenodiorite
3 quartz monzonite	7 monzonite
4 granite	8 syenite

pendant, rotated, steepened, and sharply truncated on the north, was intruded by sills along bedding, creating narrow septa which became separated from the parent block, and locally broke into stoped masses of calc-silicate hornfels. The Bendire pendant was uplifted several hundred meters with respect to the Knight Canyon pendant by the intruding magma. Many of the faults in these sedimentary blocks probably reflect differential stresses from underlying buoyant magmas, and were healed after cooling by zones of jasperoid and silicified carbonate rock. Lateral shouldering and upward raising of roof rocks appear to have been the dominant emplacement processes.

Zones of tactite and calc-hornfels occur marginal to many contacts. Late Paleozoic silty limestones favored the formation over large areas of impermeable fine-grained hornfels, consisting of intergrown grossularite, idocrase, wollastonite, diopside, actinolite, and epidote. More permeable, purer limestone favored formation of tactite and calc-silicate marbles adjacent to sills and small intrusions in the Knight Canyon Pendant. The following assemblages are common in tactites: id-gr-di, gr-wo-di, and gr-qtz-ca. Retrogression of grossularitic garnet to idocrase, diopside and calcite is common in most contact rocks. In calcitic and dolomitic marbles, the following assemblages were observed: ca-qtz-di, dol-ca-di, id-ca, and ol-ca (with olivine replaced by a serpentine mineral).

Quartz monzonite of Maturango Peak

Quartz monzonite, generally porphyritic, is present west of the Argus Sterling thrust and is named for the highest point in the Argus Range. The southern boundary of this unit occurs north of Water Canyon. The unit grades southward into diverse granitic rock types of the southern Argus Range. No clearly intrusive contacts with country rock occur within the

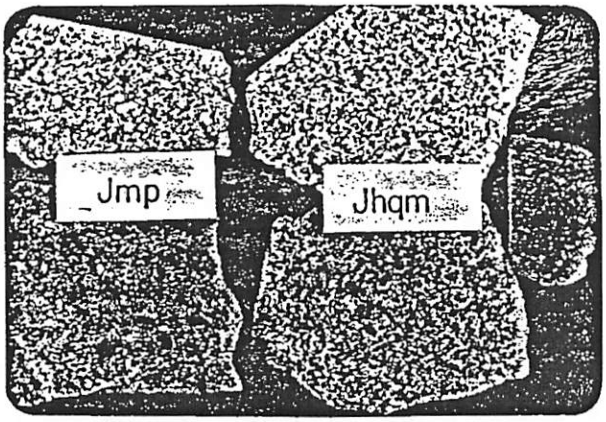


Figure 13. Natural and stained slabs of quartz monzonite of Maturango Peak (L) and Hunter Mountain quartz monzonite (R). At right is a cut slab of fine-grained diorite, a marginal facies of the Hunter Mountain unit.

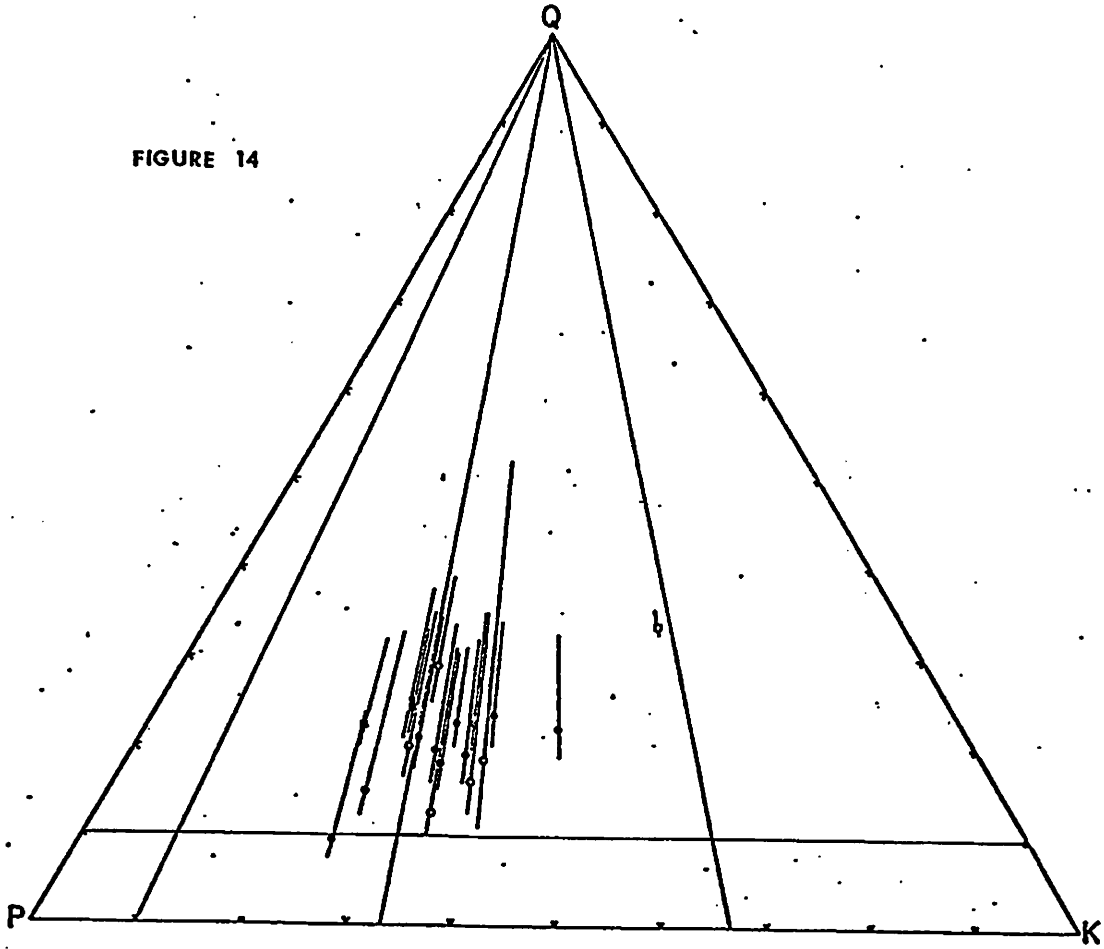
area mapped.

The Maturango Peak unit is part of the extensive granitic Coso terrane that includes the intrusive rocks of the Coso Range and southern Argus Range and extends westward to Owens Valley, with an undefined southern limit. Non-porphyritic quartz monzonite in the Argus Range, partly coeval with quartz monzonite of Maturango Peak, and in part probably younger, is mapped as undivided rocks of the Coso terrane.

A Middle Jurassic K-Ar age on hornblende from this unit suggests that it is roughly contemporaneous with the Hunter Mountain quartz monzonite (Table I). The discordance of the biotite is probably due to the proximity of the sample to younger intrusions.

The average of 11 porphyritic and 5 non-porphyritic samples, shown in Figure 14, is 41.5% plagioclase, 24% K-feldspar, 16% quartz, and 18.5% mafic minerals. Many samples fall within the granodiorite field. Associated with the relatively homogeneous quartz monzonite are small bodies of syenodiorite and aplite, and south of the Millspaugh Fault, numerous

FIGURE 14



Quartz Monzonite of Maturango Peak
and granitic rocks of Coso terrane

• Jmp: rocks with K-feldspar phenocrysts

° Jmp: non-porphyritic rocks

▪ Jc

▫ Jc or younger alaskite

—— total mafic minerals

northwest-trending dikes. The rock typically contains anhedral to subhedral, pale pink or purple perthite phenocrysts, 1-2 cm in length, in a matrix of finer plagioclase (Figure 13). The phenocrysts may contain small oriented crystals of plagioclase or biotite, and may be rimmed by oligoclase, yielding a rapakivi texture. Quartz occupies small pockets in the interstices of feldspar crystals. Plagioclase is subhedral and weakly zoned, consisting of sodic andesine locally rimmed by calcic oligoclase; compositions in the range An_{38-30} are typical. Matrix orthoclase is variably microclinic or wavy and twinned. Either biotite or hornblende may be dominant in given specimens. Accessory minerals include apatite, sphene, magnetite and zircon. Partial alteration of biotite to chlorite pervades much of the unit.

Two blocks of hornfelsed impure carbonate rock northwest of Maturango Peak comprise all that can be inferred of the wall rock of this intrusion. The rarity of stoped blocks, and the presence of flow foliations and stretched cognate inclusions imply that these rocks were emplaced at greater depth than those of the eastern granitic terrane. The unit was juxtaposed against the epizonal terrane of the Hunter Mountain quartz monzonite by later major reverse slip along the Argus Sterling thrust.

Similarity in age, composition, low quartz content, and porphyritic textures between the Maturango Peak quartz monzonite and the Hunter Mountain quartz monzonite (here including rocks of the type area) suggest that the two units may be equivalent, but are exposed at different intrusive levels across the thrust. Further study of the Coso terrane and its relation to the Hunter Mountain unit is needed before correlations across the thrust will be possible.

Alaskite of Goldbottom Mine

Medium-grained alaskitic rocks containing sub-equal amounts of quartz, orthoclase and plagioclase intrude schistose and hornfelsed rocks near Ophir and Goldbottom Mines in the Slate Range. The alaskite is strongly sheared and displays crude cataclastic foliation which dips west or defines broad open antiforms. In the southwestern part of the outcrop, however, deformation of the rock is largely limited to shearing of included mafic dikes. Sericitization has obliterated the original ferromagnesian minerals and has clouded the plagioclase. Strained quartz and mortar zones reflect penetrative deformation.

The alaskite intrudes rocks of inferred Triassic age. The sills and apophyses which cut the latter are still apparent after deformation and tectonic transport of the entire block of intrusive and country rock. If this deformation can be correlated with the Argus Sterling thrust, the age alaskite is pre-Late Jurassic.

Syntectonic Plutons

At three locations along the Argus Sterling thrust, small bodies of aplite or fine-grained alaskite have been cataclastically foliated by motion on the thrust, and were therefore introduced into the thrust zone during deformation in the Late Jurassic. Associated with the foliated rocks are small bodies of undeformed aplite and quartz monzonite, suggesting that intrusion took place during the waning stages of movement.

North of the Millspaugh fault, a pluton of mylonitic aplite truncates the trace of the thrust and intrudes discordantly into mylonitic and lineated quartz monzonite of the upper plate (Figure 23). Foliation in the aplite is marked by elongate stringers and mortar trails of fine-grained quartz and feldspar. Crystallization of the leucocratic magma was followed by cataclasis, producing 2 mm porphyroclasts of quartz, orthoclase and sodic plagioclase in a sutured matrix of orthoclase and quartz (Figure 15). Matrix quartz is broken into polygonal strained domains, and perthitic orthoclase is incipiently microclinized. Sericite has grown parallel to the foliation, and secondary yellow-brown biotite is present.

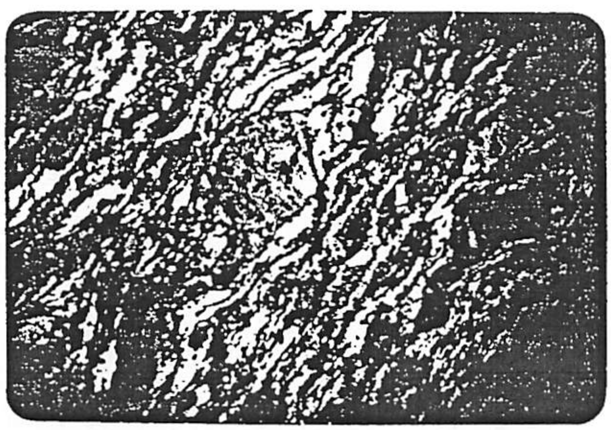


Figure 15. Photomicrograph of syntectonic alaskite, mylonitized by movement on the Argus Sterling thrust. Porphyroclasts of orthoclase (gray) are set in a matrix of quartz lenticles (white) and granulated feldspar. 10X.

Quartz-rich alaskite, locally displaying "chessboard" albitized orthoclase has intruded the thrust zone northeast of, and structurally below, the body referred to above. This mass has been microbrecciated by movement on the thrust and displays partially annealed cataclastic textures, bent albite lamellae, strained quartz, and sericitic mortar zones.

A third mass of alaskite spans Water Canyon. It intruded the fault surface separating upper plate quartz monzonite from underlying Mesozoic sedimentary and volcanic rocks. A steep foliation defined by elongate mineral grains and mortar zones in fine-grained mylonite is present north of the canyon. Westward from the east contact of this body, a crude fracture in the alaskite and shearing in dioritic dikes reflect decreasing deformation above the basal plane of movement.

Post-tectonic Intrusions of the Argus Range

Alaskite of Bendire Canyon

Coarse-grained alaskite occurs in an elongate pluton along the Argus Sterling thrust northeast of Maturango Peak. Guided by the west-dipping plane of the thrust, the buoyant magma forced apart the juxtaposed fault blocks. In the area where Bendire Canyon turns eastward (Figure 16), the alaskite intruded the lower plate sedimentary rocks discordantly.

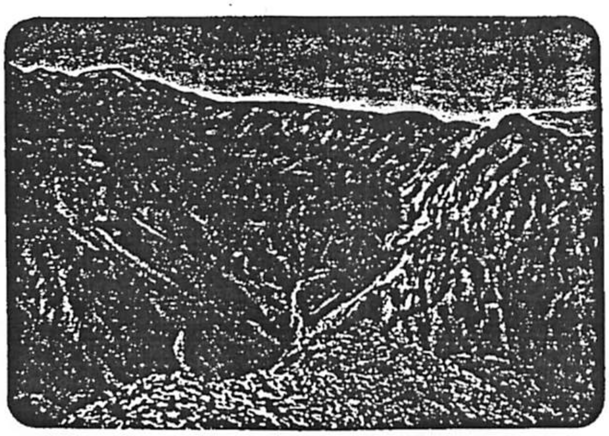


Figure 16. Alaskite of Bendire Canyon, looking north across the canyon. The pluton intrudes Lee Flat marble at right and beds of the Keeler Canyon Formation at left. Dark, garnet-rich skarn marks the intrusive contact at left.

Biotite from this pluton gave a K-Ar age of 140 m.y. (latest Jurassic). Apparently the major motion on the thrust had ceased by this time. Minor late movement, however, is indicated by cataclasis within the southern apophysis of the pluton, which intrudes the thrust plane. Quartz is pervasively strained throughout the body. Intrusion may therefore have closely followed the major movement along the thrust.

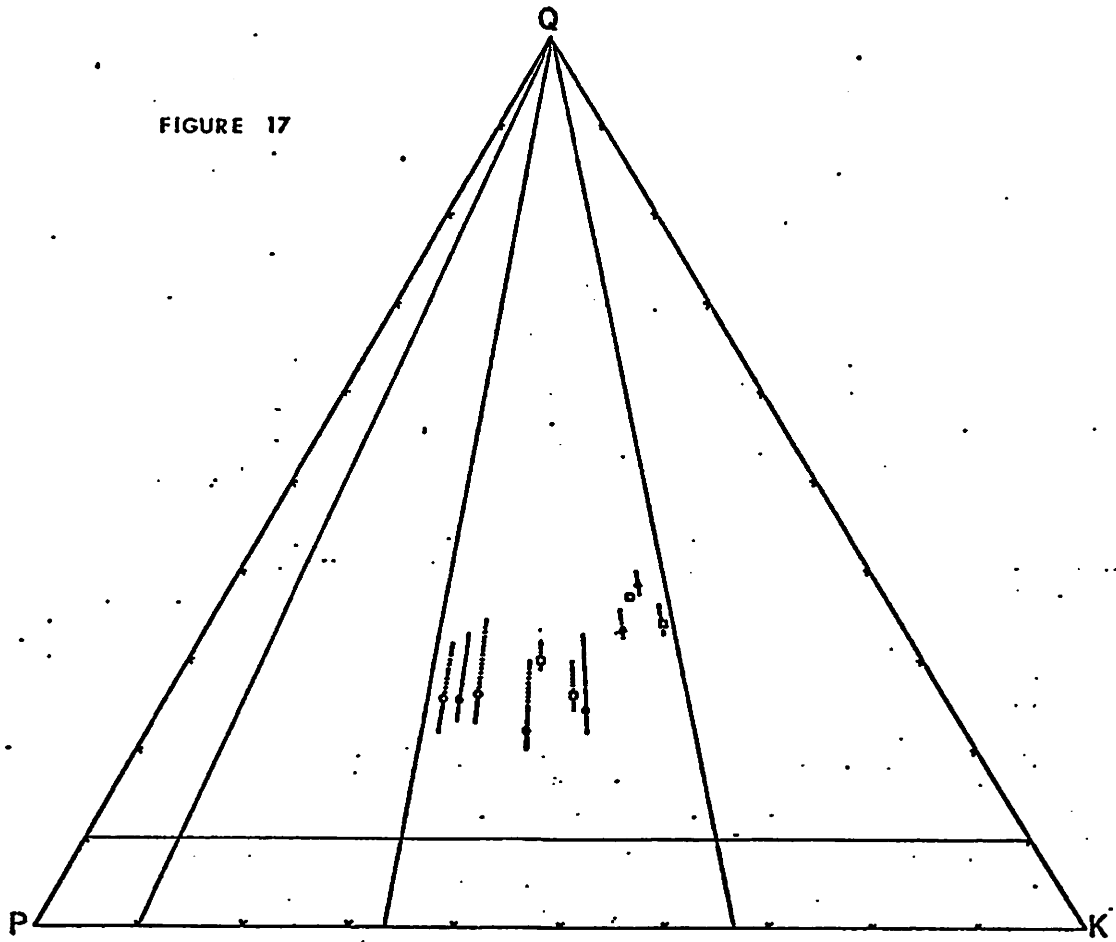
Intergrown coarse anhedral grains of sodic plagioclase, perthite and quartz occur in approximately equal proportion, and about 3 percent biotite in euhedral books 0.5 cm in diameter is present (Figure 17). Saussuritized and weathered plagioclase (oligoclase?) crystals 0.4 cm long display weak zoning and albite twinning. Deformation twins and bent crystals are common. Coarse perthitic orthoclase or microcline in 1 cm wide grains is purplish pink to salmon pink, and is locally altered to chessboard albite. Small euhedral plagioclase inclusions occur in the perthite.

A chilled border phase occurs at the southeast end of the pluton, where phenocrysts up to 0.5 cm in length include euhedral orthoclase, subhedral plagioclase, and embayed quartz in a fine matrix of K-feldspar and quartz. Thin tactite zones are developed where the pluton intruded the Lee Flat and Keeler Canyon limestones (Figure 16). These zones are 5-10 m thick with a sharp outer contact and contain green garnet or idocrase, brown grossularite, and dodecahedral hematite, pseudomorphic after magnetite.

Quartz monzonite of the Argus Sterling Mine

A small pluton which intrudes the thrust zone near the Argus Sterling Mine consists of fine to medium-grained equigranular quartz monzonite; biotite exceeds hornblende. The pluton is concentrically chloritized,

FIGURE 17



Post-tectonic Intrusive Rocks of the Argus Range

- JKb: alaskite of Bendire Cyn.
- JKas: quartz monzonite of Argus Sterling mine
- JKam: quartz monzonite of Anthony Mill
- Ja: syn- and post-tectonic alaskite

— hornblende
— biotite
— total mafics

the central, medium-grained rocks displaying the best preservation.

This pluton is younger than and intrudes the alaskite of Bendire Canyon, as shown by the concentric pattern of alteration and finer grain size along the contact with the latter. Coarse-grained blocks of alaskite are included near the margins of the quartz monzonite. Sample ASM-5 yielded hornblende and biotite ages of 139 m.y. (latest Jurassic) and 108 m.y., respectively. The hornblende age is probably near the true age and indicates intrusion closely following the Bendire pluton. The biotite discordance may be related to chloritization or a later thermal event along the thrust zone.

This rock is typical non-porphyritic quartz monzonite, with anhedral, locally microclinic perthite; subhedral, twinned andesine to oligoclase plagioclase; subhedral mafic minerals in clusters or as small euhedra in quartz or K-feldspar; and magnetite, zircon, apatite, sphene, and myrmekite.

Quartz monzonite of Anthony Mill

Parts of a post-tectonic pluton of quartz monzonite with pink potassium feldspar phenocrysts are exposed near Anthony Mill and north of the mouth of Water Canyon, where fresh quartz monzonite intrudes sheared and mineralized dioritic rocks of the border facies of the Hunter Mountain quartz monzonite. Similar rocks exposed beneath Tertiary volcanic cover in the northern Slate Range are correlated with this unit. Much of the area of the intrusion lies beneath alluvium north of Slate Range Crossing. The age of the pluton is probably Cretaceous.

The distinguishing feature of this unit is the abundance of anhedral, rounded perthite phenocrysts commonly 1 cm in length. Biotite and hornblende in roughly equal proportions are mostly enclosed by feldspar. The composition is similar to other quartz monzonite units of the area (Figure 17).

Post-tectonic Intrusions of the Slate Range

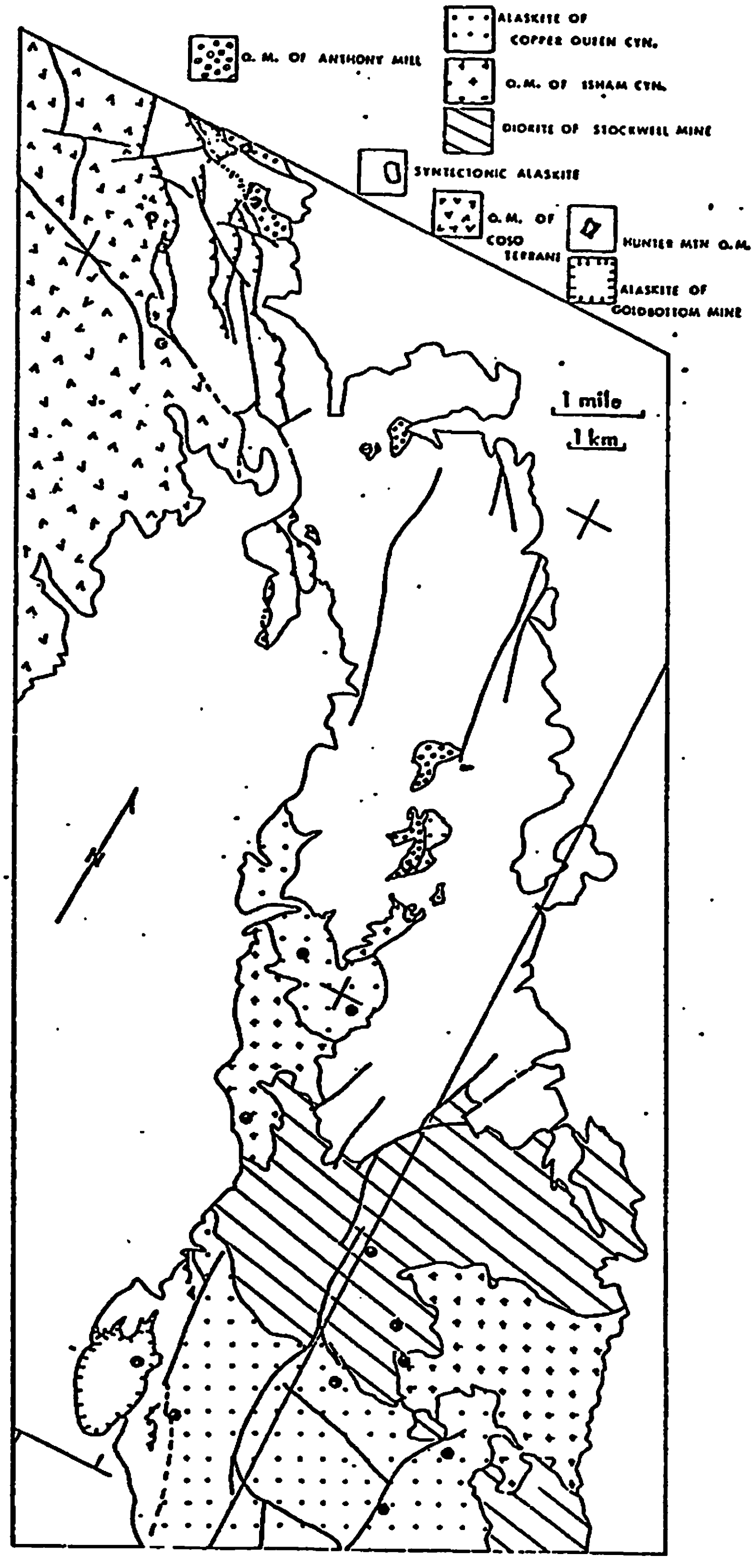
Diorite of Stockwell Mine

Hornblende diorite crops out at Stockwell Mine, south of Manly Pass, and makes up much of the uplifted block east of the Manly Pass fault. The wall rock of this intrusion is exposed only on the northeast flank of the range, where pendants and blocks of highly recrystallized Permian carbonate rocks have been intruded and dismembered by the diorite. Elsewhere, later intrusions of quartz monzonite and alaskite truncate the diorite.

The diorite has not been dated in the Slate Range. However, biotite-bearing hornblende diorite in Coyote Canyon, Panamint Range, 4 km east of diorite exposures in the Slate Range, yielded a 145 m.y. biotite age (Late Jurassic) (Armstrong and Suppe, 1973; Supplementary NAPS data). The unit appears to post-date the deformation at Ophir Mine, as small bodies of diorite intrude the deformed Owens Valley carbonate rocks north of Bundy Canyon mouth.

In contrast to most intrusive rocks of the area, this unit lacks potassium feldspar and contains very little quartz. The diorite is texturally and compositionally variable. Grain size varies from fine to medium, and coarse pockets are present locally. Darker varieties contain calcic plagioclase, elongate crystals of hornblende, and some biotite, with a color index commonly near 40 percent. Lighter segregations are plagioclase-rich diorites which contain minor quartz and only minor hornblende, and 10-15% biotite (Figure 19).

FIGURE 18: SAMPLE LOCATIONS, Plate II



Chlorite and epidote have commonly replaced the mafic minerals causing the dark green to gray appearance of outcrops as viewed from a distance.

Quartz monzonite of Isham Canyon

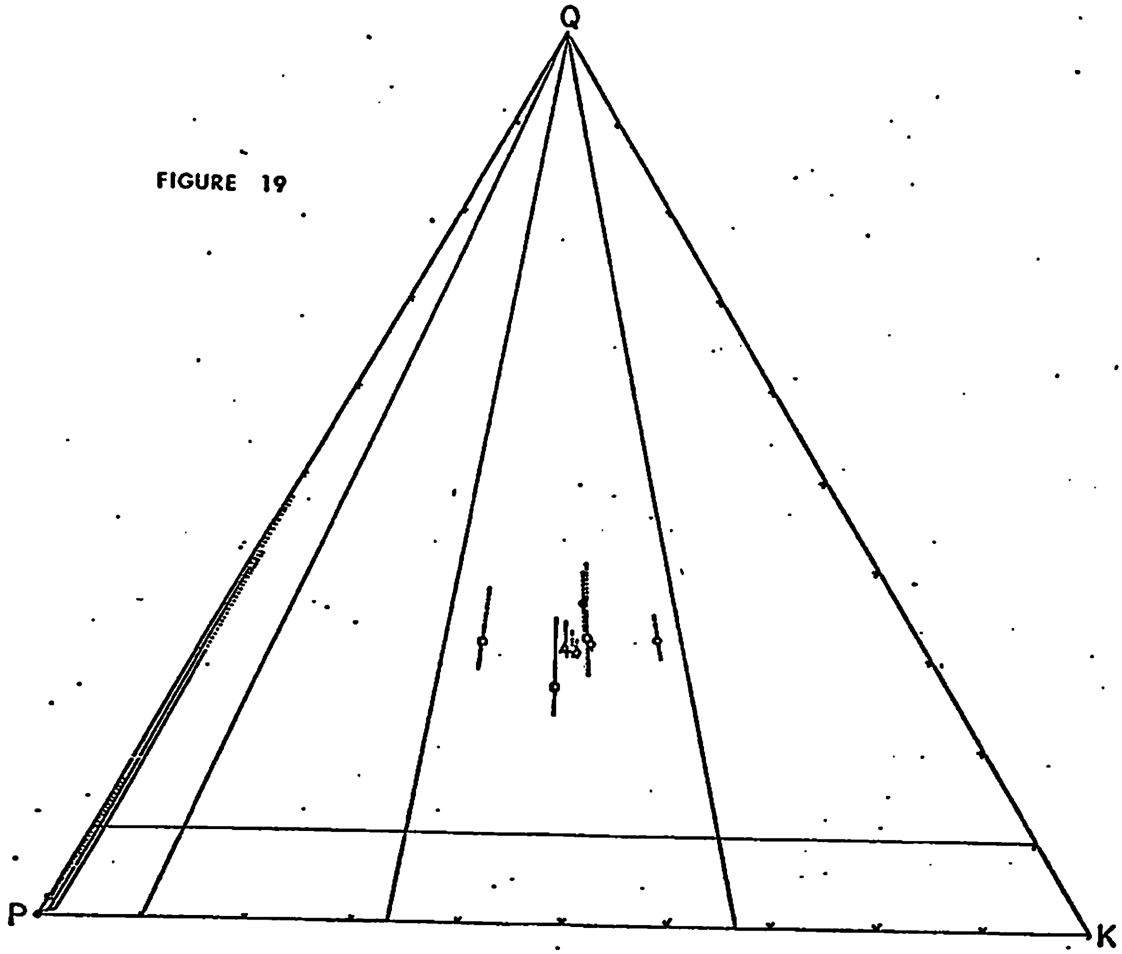
Light gray, medium-grained, equigranular quartz monzonite intrudes the diorite at Manly Pass and Isham Canyon, and near the January Jones Mine on the east side of the range. In some areas, diorite is intruded by numerous small bodies of the gray quartz monzonite and the mutual contacts are difficult to discern. West and southwest of Manly Pass, numerous stoped blocks of diorite and later intrusions of alaskite account for a large volume of the quartz monzonite. Equigranular rock exposed in an erosional window north of Manly Pass is included with this unit.

Petrographically and compositionally, the quartz monzonite resembles rocks of the Hunter Mountain or Argus Sterling Mine quartz monzonite units, with equigranular subhedral plagioclase, interstitial perthite and quartz, and variable amounts of hornblende and biotite (Figure 19). Its age is unknown, but Armstrong and Suppe (1973: NAPS data) obtained an age for hornblende-biotite quartz monzonite at Manly Peak in the Panamint Range, 6 km east of exposures in the Slate Range, of 137 m.y. (biotite). The unit post-dates deformation of rocks of the Ophir complex, and precedes intrusion of the alaskite of Copper Queen Canyon.

Alaskite of Copper Queen Canyon

Coarse-grained, pink alaskite, intruding all earlier units is present north of Manly Pass, east of Goldbottom Mine in Copper Queen Canyon, and on the crest of the range south of the diorite exposure. The alaskite is also

FIGURE 19



• Jds: diorite of Stockwell Mine

▫ Jic: quartz monzonite of Isham Cyn.

∘ JKcq: alaskite of Copper Queen Cyn.

• " quartz monzonitic phase

▲ Jgb: pre-tectonic alaskite of Goldbottom Mine

—— hornblende + magnetite

—— biotite

—— total mafics

Intrusive Rocks of the Northern Slate Range exposed in erosional windows north of Manly Pass, as irregular masses on the east flank of the range, and as small bodies in diorite or quartz monzonite south of Manly Pass.

As this unit is very similar texturally and compositionally to the alaskite of Bendire Canyon in the Argus Range, and to other leucocratic units in the Inyo Mountains, it is tempting to postulate a latest Jurassic to Early Cretaceous age. B. C. Burchfiel (personal communication, 1975) reports a Rb-Sr isochron date for alaskite near the Ophir Mine of 170 m.y., or Middle Jurassic. If correct, this date has important implications for the age of deformation of the Ophir complex. However, several lines of evidence make this age determination suspect. These include the similarity to the Argus Range alaskites, and the possibility of latest Jurassic ages for the earlier Stockwell Mine and Isham Canyon units. Furthermore, structures in the Slate Range along strike of the Late Jurassic Argus Sterling thrust are truncated by the alaskite (see Section II-D). I therefore favor an Early Cretaceous age for this unit.

The alaskite is composed of irregular coarse-grained mosaics of equal proportions of feldspars and quartz, and very minor biotite (average 3%) (Figure 19). Sodic plagioclase is subhedral to anhedral, and enclosed in anhedral pink K-feldspar and quartz. Pink feldspar imparts the light pink color to distant exposures. A quartz monzonitic phase with apparently gradational contacts is included in this unit. This light colored rock is fine-grained and contains up to 10 percent biotite.

The contact relations of the alaskite of Copper Queen Canyon are highly variable. The emplacement of numerous small discrete bodies of alaskite reflects control by numerous joints and fissures in the quartz monzonite and diorite country rock. The alaskite overlies its quartz monzonitic wall rock north of Manly Pass.

A different style of intrusion has taken place southeast of Stockwell Mine, where the alaskite contact dips northward beneath the dioritic country rock. Gently-dipping slabs and large blocks of diorite have been stoped off the roof of the alaskite magma chamber.

A peculiar marginal facies of fine-grained aplite occurs at the northern contact of the alaskite northwest of Manly Pass. In some areas, the aplite contains abundant rounded fragments, from 2.5 cm to 0.5 m in diameter, of diorite, porphyritic quartz monzonite, hornfelsed limestone, and of biotite alaskite. This aplitic phase, broadly coeval with the alaskite, was an earlier stage of intrusion at the exposed level, as large blocks of the distinctive aplite-enclosed breccia have been broken up and engulfed by the coarse alaskite.

Dikes

Several types and generations of dikes are present in the Argus and Slate Ranges. Main groupings noted in mapping include the following:

1. Granitic dikes present in Paleozoic roof pendants are related to emplacement of the Hunter Mountain quartz monzonite and later plutonic units. Aplite and alaskite dikes related to intrusion of leucocratic magmas are present in several areas of both ranges.

2. A swarm of quartz latite porphyry dikes trending WNW cuts across the Argus Range west of Revenue Canyon and post-dates the Hunter Mountain intrusion. The age of these dikes is not known. It may be Tertiary, however, as this trend is parallel to that of WNW-trending Tertiary fault zones, including the Wilson Canyon fault in the southern Argus Range (von Heune, 1960), the Millspaugh fault, central Argus, and the Snow Canyon fault in the

northern Argus Range (K. Holden, personal communication, 1974).

3. Altered green dikes of diorite or porphyritic andesite commonly trend northwest within the quartz monzonite of Maturango Peak and related rocks south of Millspaugh site. These dikes are probably related to NW-trending regional dike swarms present in the region from the southern Argus Range to the Inyo Mountains (Smith, 1962). As they parallel the Argus Sterling thrust and other reverse faults in this area, they may post-date the thrust (post-Late Jurassic), since they are controlled by a fracture system believed to have developed during this tectonic event. Several aplite dikes of unknown relative age trend east-west in this area.

D. Cenozoic Rocks

Volcanic rocks, fluvial gravels, and lake sediments were deposited on a late Tertiary pediment or erosional surface. Late Tertiary volcanism was preceded by a period of external drainage, during which streams carved a surface of low relief, remnants of which are preserved along the crests and east flanks of the Argus and Slate Ranges (Section II-E). Local relief was probably less than a few hundred meters. Low hills of resistant rock were inundated by volcanic flows, breccias and tuffs. Small playa lakes in the volcanic field were sites of carbonate deposition.

Basalts from the Argus and Panamint Ranges, preserved on remnants of this surface, have been dated at 4-5 m.y. (Hall, 1971). Similar basalts overlie volcanic, lacustrine and fluvial sediments in the central Argus and Slate Ranges. Thus the earliest sediments exposed, and the surface on which they are deposited, are late Miocene(?) to Pliocene in age. Regional Basin and Range faulting which led to the breakup of this surface, forming the present physiography of the ranges, followed basalt extrusion in the late Pliocene and Quaternary.

Significant topographic relief was locally present before the general initiation of Basin and Range faulting in the latest Tertiary. Early Pliocene faulting is indicated by fanglomerates derived from early Inyo and Panamint uplifts in the Darwin and Panamint Butte quadrangles (Hall and MacKevett, 1962; Hall, 1971). While thick fanglomerates are lacking in the Argus Range, landslide breccias, similar to those interbedded in alluvial fans in the Panamint Range, occur several kilometers west of their presumed source in the ancestral Panamint Range, and underlie the late Miocene(?) to

Pliocene volcanic rocks. Moderate topographic relief was also present in the southern Argus Range, where the mass of resistant, leucocratic quartz monzonite that makes up Argus Peak (west of Trona) stood as a monadnock above the bevelled surface.

Late Miocene(?) to Pliocene Deposits

Fluvial gravels

Uncemented alluvial gravels of diverse lithology (Tsa) mantle the prevolcanic surface and represent a lag deposit of stream-transported detritus from local and distant areas of higher elevation. In the Argus Range, deposits to 15 m thick contain pebbles, cobbles, and boulders, generally well rounded, of the following rock types: laminated, cross-bedded quartzites, quartz-pebble conglomerate; tan dolomite; gray, dolomitic oolite; gray and white marble; gray limestone and calcarenite, commonly crinoidal; silicified limestone breccia; diorite and porphyry; tan porous travertine; and andesite and basalt. In the Slate Range, the dominant constituent of these deposits is rounded boulders and cobbles of orange-weathering cross-laminated quartzite with chattermarked outer surfaces. Quartzite cobbles occur beneath volcanic rocks between Manly Pass and Goldbottom Mine. They reportedly also mantle the warped erosional surface of the southern Slate Range (Smith and others, 1968).

Quartzite and quartz-pebble conglomerate and dolomitic rocks are from late Precambrian and Cambrian formations that are exposed in the Panamint Range. These units are absent in the Argus and Slate Ranges. The high degree of rounding and the chattermarked surface of the cobbles indicates that they were transported by streams, probably from near the present Panamint

Range westward over the area of the present Argus and Slate Ranges. Calcarenite and limestone breccia, intermixed with cobbles of Panamint Range provenance, appear to be locally derived. These resistant rock types probably formed low hills on the Pliocene surface of the present Argus Range. Granitic clasts are generally lacking, except for fine-grained or dioritic rocks, probably because deep weathering created low relief areas on quartz monzonite exposures. However, granitic detritus is found in significant amounts east of Manly Pass, where thick grus derived locally from outcrops of alaskite underlies basalt.

Landslide breccias

Deposits of brecciated quartzite are found south of Knight Canyon mouth and south of Bendire Canyon (center, Section 25) in the Argus Range. Boulders of limestone and andesite breccia, and clasts of less common rock types, such as olive-green dolomite breccia, are associated with the quartzite, which is typically parallel or cross-laminated. The breccias were emplaced by landslides from the ancestral Panamint Range. Rock masses derived from oversteepened fault scarps were transported westward across a pediment slope that today dips eastward beneath Panamint Valley. The Panamint Valley fault zone, a possible source of these deposits, is 18 km to the east.

In two areas in the Argus Range, south of Bendire Canyon mouth (W 1/2, Section 25), and 2 km W. of the Onyx Mine, large boulders associated with basal lag gravels underlying andesite breccia are included in this unit. Boulders to 6 m in diameter of Paleozoic carbonate rock, andesite breccia, and Tertiary limestone or travertine are most common. Large blocks may have been deposited by several processes: landsliding, fluvial or sheetflood transport of landslide debris, or transport of large boulders from alluvial fan deposits and lake terraces by volcanic mudflows. Andesite lahars, particularly the basal units in a thick sequence, contain large blocks of travertine that were picked up from playa lake margins by the turbulent, high velocity mudflows and emplaced downslope from their site of origin.

Basalt, andesite, and silicic pyroclastic deposits

Volcanic rocks overlie the erosion surfaces exposed on the east flanks of both ranges. Basalt and andesite are commonly interbedded, and intertongue in the northern Slate Range, where a north-dipping andesite section is overlain and underlain by basalt. The thickest sections of volcanics are south of Bendire Canyon, where a minimum thickness of 180 m of diverse volcanic rock types is exposed, and the east side of the Slate Range, where a basaltic section to 100 m thick is present. Figure 20 schematically depicts the volcanic and sedimentary section south of Bendire Canyon, consisting of andesite (flows and lahars), with lacustrine, fluvial and tuffaceous interbeds. In general basalt is most common in the Slate Range, and in the Argus Range south of Water Canyon; and andesite predominates between Water and Bendire Canyons. Silicic pyroclastic deposits are present beneath volcanic flows near Slate Range Crossing, and locally elsewhere.

A dozen samples of basalt and eight of andesite were sampled for thin sectioning. The mineralogy of the basalts suggests an affinity to the alkali-olivine basalt suite. Two petrographic varieties of basalt can be distinguished. Augite-olivine basalts, common in the Slate Range, contain phenocrysts of augite in greater abundance than olivine. Augite phenocrysts are commonly subhedral, twinned, cumulophyric, and pale green in color. Olivines are generally euhedral with marginal or advanced alteration

SCHEMATIC COMPOSITE SECTION OF TERTIARY ROCKS

South of Bendire Cyn., Argus Range

Gray to pink, red-brown weathering autobrecciated andesite flow, mostly non-vesicular. Plagioclase, oxid. hornblende and biotite, and augite phenocrysts in a fine glassy matrix

Laharic andesite breccia distinct from lower lahars in: (a) dark-brown weathering; (b) more angular, smaller clasts; (c) more diverse clast types, including basalt and fine-grained pyroxene andesite. Also contains: clasts of quartzite and limestone, interbeds of fine lapilli, and boulders of underlying flows

Closely packed volcanic cobble conglomerate with well-rounded clasts, a conspicuous cliff-former with cavernous weathering. Matrix of coarse sand 1-5 mm with white coarsely crystalline calcite cement. Sand and cobbles 95% volcanic, with some quartz and epidote hornfels. A few boulders to 2 m, mostly from underlying flows

One or more flows of brown-weathering andesite, sparsely amygdaloidal in center, with dark red-weathering, vesicular, autobrecciated flow tops. Stubby phenocrysts of augite, with hypersthene and minor oxid. hornblende

Non-welded felsite air-fall tuff and tuff-breccia, white or light gray with lapilli and clasts 0.5-2 cm, locally larger with internal size-sorting; white pumice, gray perlite, obsidian, pink, white and red-brown flow-banded felsite in a fragmental perlitic or ashy matrix

Thick flows of andesite laharic breccia, commonly with cavernous weathering. Clasts generally light gray or pink, weathering gray or red-brown. Phenocrysts of plagioclase, pyroxenes, oxid. hornblende and biotite in a fine glassy matrix; generally non-vesicular. Clasts homogeneous in rock type; size varies from lapilli to blocks with little sorting; most show moderate rounding

Pink or tan thin-bedded lacustrine limestone, light gray-weathering, with lenticles of brown chert

Basal laharic breccia flows may contain clasts picked up from alluvial cover traversed during emplacement. These include rounded cobbles and boulders from fans or stream channels, and large angular blocks to 8 m diam. of Tertiary lacustrine limestone, and pC or Pz carbonate blocks of local or Panamint Range derivation

Locally derived clastic material and volcanic ash cemented by travertine, probably as lacustrine terraces. Clasts include calc-hornfels, granitic detritus, and volcanic material. Grain size varies from shaly or tuffaceous beds to poorly sorted conglomerate

Thin-bedded lacustrine limestone and travertine, precipitated from saline lakes. Commonly white, tan, or orange weathering, porous and coarsely crystalline; locally replaced by silica. Locally contains algal and plant remains and gastropod casts.

Andesite and/or basalt flows; andesite pink or gray with plagioclase and mafic phenocrysts; basalt finely crystalline, zeolitized and spheroidally weathering if overlain by a thick volcanic-lacustrine section

Landslide monolithologic breccia, composed of clasts of late pC or Є laminated, cross-bedded quartzite and quartz pebble conglomerate from Panamint Range area

Uncemented, mostly well-rounded basal gravels including pebble to boulder-sized clasts of Panamint Range provenance such as cross-bedded quartzite, gray and white calcite marble, tan dolomite, gray oolite; also more locally derived gray calcarenite, calc-hornfels, Tertiary travertine and andesite

Miocene(?) or Pliocene surface with a hundred or two meters of local relief

Pre-Tertiary basement of Hunter Mtn. Quartz Monzonite and roof pendants of late Paleozoic calc-silicate hornfels

FIGURE 20

to red-brown "iddingsite". Labradoritic plagioclase microphenocrysts are platy and pitted or corroded by glass. The matrix is gray or black glass with felty microlites. Rocks of this type grade into basaltic andesite with large plagioclase and augite phenocrysts in Fish Canyon. Rounded or flattened vesicles are common in most basalts.

Olivine basalts, lacking pyroxene, occur at several localities in the Argus Range. They range from older basalt at the base of the volcanic section, to youngest, probably late Pliocene basalts which are exposed east of Etcheron Valley. The latter basalts, which rest on a granitic surface, may have been deposited after the initial arching of the range, and the removal of previous volcanic deposits. Vesicular flow tops are easily identified, and distinctive vesicle cylinders occur in several flows. These flows are texturally distinct from other basalts, containing intersertal olivine, oxides and minor glass with intergrown coarse plagioclase plates. Older olivine basalts contain platy, pitted plagioclase (labradorite) phenocrysts, and euhedral olivine in a matrix rich in dark glass, opaque oxides and plagioclase microlites. Coarsely porphyritic basalt occurs in one flow northwest of Anthony Mill.

Pink, brown and gray andesites, occurring as lava flows or mudflow breccias, lack olivine and contain coarse pitted phenocrysts of labradorite and augite, and common euhedral grains of hornblende, biotite and hypersthene. Hornblende and biotite are invariably oxidized red-brown and rimmed by magnetite. Mudflows tend to have an aphanitic glassy matrix, while flows possess fine microlites in a gray glass matrix.

Laharic (mudflow) breccias are common south of Bendire Canyon (Figure 20). They are typically monolithologic with unsorted, rounded clasts of biotite-bearing andesite, but some breccias are distinctly polylithologic with angular clasts. Clasts picked up during turbulent emplacement are observed locally, and include blocks from underlying flows, alluvial clasts and travertine.

Columnar and platy-jointed to massive andesite lava flows are present from south of the Onyx Mine to Water Canyon. Similar flows occur interbedded with basalt at the northern end of the Slate Range. Remnants of andesite flows occur also near Manly Pass. Flows contain fine irregular vesicles or are poorly vesicular, in contrast to basalt flows.

White, pumiceous deposits of massive to bedded tuff (Tvp), resting on pre-Tertiary basement, and overlain by andesite and basalt flows, reach a maximum thickness of 90 m (300 ft.) east of Slate Range Crossing and occur within a radius of 5 km from the crossing. Localized interbeds of silicic lapilli-tuff are also common elsewhere in volcanic sections of the area. Clasts are commonly fine (0.5-2 cm), but may be as large as 5 cm. Clast types near Slate Range Crossing include white aphanitic or biotite-bearing rhyolite(?), pumice, and glass. Near Bendire Canyon, larger clasts of flow-laminated felsite occur in tuff beds (Figure 20). Beds of sorted pumice clasts suggest an airfall origin for tuff deposits. A possible source for the silicic tuff is a NE-trending rhyodacite dike (Tvr), surrounded by alluvium south of Bendire Canyon mouth. The dike is an elongate mass of vertically flow-foliated, chert-like rock, with phenocrysts of oxidized biotite. The locality may have been a vent for ash extrusion, later plugged by degassed silicic magme.

Lacustrine and terrace limestone and travertine

Playa lakes, which developed in small closed basins within the volcanic field in the Argus Range, were sites of bedded limestone deposition. Near-shore clastic material was incorporated in travertine in marginal lacustrine terraces. Two units (Tsl and Tst) are differentiated on Plate I, based on the content of clastic material.

Limestone occurs south of Bendire Canyon, at the Onyx Mine, south and east of Millspaugh, and south and east of Shepherd Canyon. Beds of porous limestone 5 cm to 0.5 m thick are white, tan, orange, or pink, and may contain thin orange or brown-weathering chert lenticles. The saccharoidal, porous texture of this limestone indicates some recrystallization by groundwater. Locally, as at the Onyx Mine, limestone has been replaced by silica from overlying volcanic flows. Limestone and terrace travertine south and east of Millspaugh site contain concentrically layered algal pisolites and tube-shaped impressions of algae or other plant material; the latter are 0.5 cm in diameter and perpendicular to bedding. Gastropod impressions are also common.

Alluvial detritus of mostly local provenance, deposited near lake shores, was cemented by travertine. Clasts in poorly stratified beds are commonly angular and include granitic material, calc-hornfels, pumice, and volcanic detritus.

Quaternary Deposits

Dissected fanglomerate of Pliocene to Pleistocene age near Manly Pass

Dissected, poorly sorted alluvial fan deposits (PQoa) derived from uplift along the Manly Pass fault occur in the Slate Range, mantling a pre-uplift surface of andesite, basalt and granitic rocks. Clasts are all of local derivation, and include alaskite, diorite and Permian marble.

At Manly Pass, fan gravels unconformably overlie a fault that cuts

Pliocene(?) volcanic rocks. East of the Ophir complex, basalt is interbedded with basal gravels of this unit. The unit is therefore mostly younger than Miocene(?) to Pliocene volcanic episodes. These strata have been elevated and tilted about 10° eastward during faulting west of the Ophir complex. Their age is Pliocene to Pleistocene.

Pleistocene lake gravels

Pleistocene lake levels are recorded by gravel deposits at several places along the margins of the Slate Range. A gravel deposit on Tertiary volcanics at the northern tip of the Slate Range is a remnant of deltaic deposits derived from Water Canyon. The deposit contains moderately rounded gravel and cobbles, mainly granitic. A compact pavement on the flat upper surface of the gravel records a 2000' elevation of fluvial Lake Panamint.

Shoreline gravels west of the Ophir complex and south of Goldbottom Mine record several levels of ancient Searles Lake. The locally derived, moderately rounded gravels were worked by wave action on the leeward shore of the lake. A wave-cut bench at 2240', marking the upper limit of gravels, occurs in outcrops of alaskite 1 km west of Goldbottom Mine. Several lower lake levels are recorded by gravel terraces partly overlain by sand and alluvium south of Goldbottom Mine, and by gravel terraces perched on steep west slopes of the Ophir complex.

II. STRUCTURAL GEOLOGY

At least five deformational events, ranging from Permian to latest Cenozoic, can be recognized or inferred in the Argus and northern Slate Ranges.

A. Local uplifts in the Permian are implied by lenticular beds of coarse clastic material in the Owens Valley Formation.

B. A Triassic or Early Jurassic folding event took place prior to intrusion of Jurassic granitic rocks.

C. Faulting within roof pendants, related to the emplacement of large masses of intrusive rock, occurred in the Middle Jurassic.

D. Development of the Argus Sterling thrust and related thrust faults along strike occurred in the Late Jurassic, largely following the emplacement of the Jurassic part of the southeastern Sierra Nevada batholith.

E. Basin-and-Range high-angle faulting, eastward tilting of fault blocks, and broad warping modified by faults, characterize the late Cenozoic.

A. Local Permian uplifts

Lenses of coarse conglomerate, consisting in part of unsorted, submarine debris-flow breccia, occur in the Argus Range and surrounding areas. Several conglomerate beds in the lower Owens Valley Formation are Early Permian, but other episodes of conglomerate deposition within the Late Pennsylvanian to Middle Permian range are known.

Clasts of chert and limestone derived from underlying units were deposited adjacent to local uplifted areas. The size, lack of sorting, and textural immaturity of clasts suggest a short distance of transport. It is possible that the coarse detritus was shed from fault scarps bounding uplifted blocks within the geosyncline. Although Permian faults have not been documented, local angular discordance is recorded by the sub-Owens Valley unconformity in the Inyo Mountains, and by an intra-formational unconformity in the Darwin area (Hall and MacKevett, 1963).

Marcantel (1975) noted that Upper Pennsylvanian to Lower Permian conglomerates in northeast Nevada, which texturally resemble those of the Owens Valley Formation, may have been derived from an unstable highland and deposited as marginal marine clastic wedges. The tectonic disturbance may be related to the Sonoma orogeny, which influenced sedimentation throughout the miogeosyncline in the Permian (cf. Bissell, 1974). The occurrence of these conglomerates along depositional strike from those of the Owens Valley Formation suggests a correlative tectonic episode and parallel depositional environments in distant parts of the miogeosyncline.

B. Triassic to Early Jurassic folding

An episode of folding in the Argus Range is bracketed by the Permian Owens Valley Formation and Middle Jurassic dates of the Hunter Mountain quartz monzonite, which truncates northwest-trending folds. By analogy with the Inyo Mountains area, folding in the Argus Range probably took place in the Late Triassic to Early Jurassic (Merriam, 1963; Ross, 1969). The record of this event is largely obliterated by intrusion and dismembering of folded roof rocks.

A major fold in the Argus Range is the Bendire anticline, exposed in the Bendire pendant. A broad, open fold to the south, the NNW-plunging anticline tightens, plunges more steeply, and becomes overturned to the east near its northernmost exposure. Overturning may be due to later tightening beneath the upper plate of the Argus Sterling thrust fault. The fold is truncated on the north by a high-angle fault.

Other folds present in Paleozoic rocks of various roof pendants trend N 15° W to N 25° W. Small N-trending open folds are exposed in the faulted section of Permian rocks north of Maturango Peak. No large folds demonstrably correlative with this event are present in the northern Slate Range.

C. Middle Jurassic faulting

Intrusion of the Hunter Mountain quartz monzonite in the Argus Range was accompanied by faulting of roof pendants and uplift of roof blocks. Faults and bedding planes became sites of continued intrusion between blocks, as in the Knight Canyon pendant, or served as channels for silica-rich fluids. The Bendire pendant includes several NNW and E-W trending faults. Fault zones are commonly healed with massive, brecciated, or slickensided, dark jasperoid.

D. Argus Sterling thrust fault, Late Jurassic

A northwest-striking thrust fault separating two distinct plutonic terranes is exposed in the Argus Range between Argus Sterling Mine and the Water Canyon area. This feature is named the Argus Sterling thrust fault. Maturango Peak quartz monzonite and related rocks of the Coso terrane were emplaced along a southwest-dipping surface over the epizonal Hunter Mountain quartz monzonite and its dismembered Paleozoic roof rock (Moore, 1974).

The granitic terranes juxtaposed by the thrust are of similar age but contrasting intrusive levels, recording substantial relative uplift of the upper thrust plate. Thrust surfaces dip southwest at attitudes ranging from 15° to 80°, and averaging 30-40°. The thrust zone is marked either by a single fracture, or by several imbricate shear surfaces which bound lenses of varying lithologies. Competent imbricate lenses or autochthonous rock buttress and steepen the fault surface. The thickness of the deformed zone varies from a few hundred meters to 1 km, generally increasing to the south.

Mylonitization of granular rocks and attenuation and flow of carbonates within the thrust zone characterize the deformational style. Lineations and fold axes in deformed rocks indicate an east-northeast direction of relative transport of the upper plate. A net slip of several kilometers is estimated along a moderately dipping plane that deeply penetrates the Sierra Nevada batholithic complex.

Quartz monzonite is consistently mylonitic or protomylonitic through a zone of at least 50 m above the base of the upper thrust plate. Beneath the upper plate, a variety of rock types have been dragged off of subjacent roof pendants and transported updip along the thrust zone, yielding diverse deformational phenomena (Plate III). These variations are described below.

Argus Sterling Mine

Thick zones of mylonitic upper plate quartz monzonite are separated from lower plate rocks by post-tectonic intrusions. Isoclinally folded, tectonite marble sliced from middle or late Paleozoic rocks was transported upward between the quartz monzonite and relatively undeformed, massive Permian calc-silicate hornfels (Figure 21). Downdip-plunging folds and a pervasive flow foliation with variable dips are typical of marble lenses in this area. The steep attitude of the marble lens near Argus Sterling Mine is probably due to intrusion of the later plutons.

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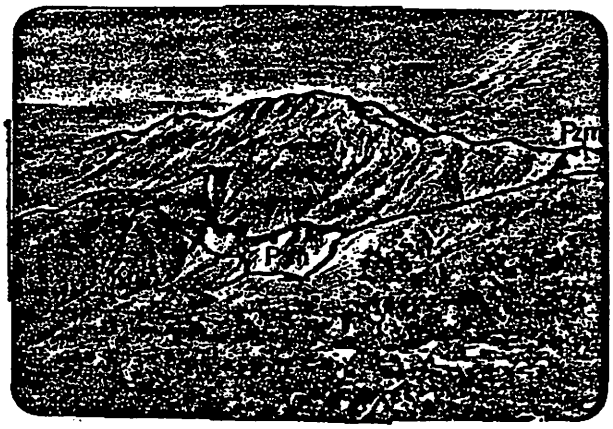

Figure 21. Northward view of thrust zone near Argus Sterling Mine from Maturango Peak. West-dipping gray and white tectonic marble slivers overlie Permian calc-hornfels at rear. The thrust zone is intruded by post-tectonic plutons in left foreground.

Northern Bendire pendant

Other marble lenses occur between Argus Sterling Mine and the north end of the Bendire pendant, where anticlinal middle Paleozoic formations have been overridden by the granitic thrust plate. The anticline was apparently tightened and overturned to the east, and overridden by tectonitic Lee Flat(?) marble dragged upward from the west limb of the anticline. This marble lens is roughly tongue-shaped, elongate eastward, and bounded on the northwest and east by inward dipping shear surfaces. This may indicate a general mullion-like shape for such marble lenses, which occupy trough-like corrugations parallel to dip beneath the sole of the thrust.

Beneath the tectonite marble lens, high-angle faults exhibit reverse displacement sympathetic with thrust movement. The northwest-trending fault which cuts the Bendire pendant in Section 15 probably originated during intrusion of the Hunter Mountain quartz monzonite. Near its northern end, however, the fault dips to the west, Tin Mountain limestone occupying the hanging wall, and then merges northward into the trough-like surface that bounds the tectonite marble lens. Tin Mountain limestone displays a 60° west-dipping foliation along which Syringopora masses have been stretched. Beneath the moderate to gently-dipping fault surface, bedded Keeler Canyon limestone has been contorted into tight folds, overturned to the east (Figure 22).

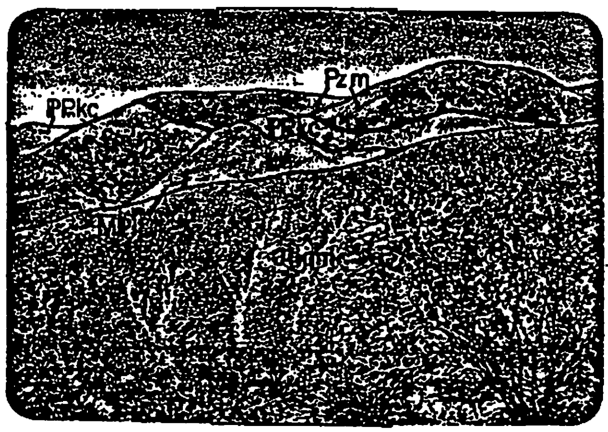

Figure 22. Tectonite marble, Lee Flat in part, occupying ridge crests, has been thrust over crumpled Keeler Canyon beds, left, and over Hunter Mountain quartz monzonite, exposed in foreground. View is to south.

North of Millspaugh fault

The thrust is marked by a single trace between the Millspaugh fault and the Bendire Canyon pluton. It dips 35° west, concordant with bedding in the underlying garnetized carbonate beds of the Owens Valley Formation.

Syntectonic and post-tectonic alaskite and aplite have intruded the thrust. The body in Section 34 is crudely sheared, whereas that in Sections 3 and 4 has a fine mylonitic foliation, concordant with that in the enveloping upper plate quartz monzonite (Figure 23). Mylonitic flow of the quartz monzonite around these bodies is reflected by highly variable attitudes of foliation and lineations.

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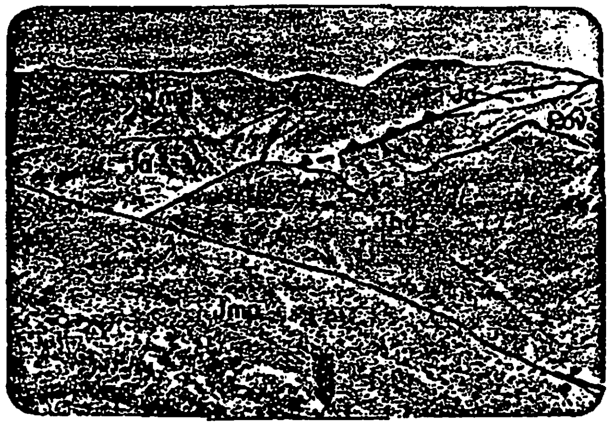

Figure 23. Northwest view of dioritic border facies of Hunter Mountain quartz monzonite (hematitic), overlain along thrust by Maturango Peak quartz monzonite. White masses near thrust are syntectonic alaskite intrusions. Hornfelsic Permian metasediments at far right. The Millspaugh fault occupies hidden valley in foreground.

Shepherd Canyon area

The crosscutting Millspaugh fault downdrops the thrust zone to the south. South of the fault, imbricate lenses of Hunter Mountain quartz monzonite, Mesozoic volcanic and sedimentary rocks, and Paleozoic marble occupy the thrust zone. A roof pendant of Mesozoic volcanic rocks in the autochthon suggests that these rocks have been detached from similar pendants in the downdip subsurface. Several cross-faults with small offsets, and small post-tectonic alaskite bodies occur in this area.

Immediately south of the Millspaugh fault a slab of sheared, parautochthonous Hunter Mountain quartz monzonite has been thrust over the volcanic roof pendant. It is overlain by metavolcanic rocks which display a well-developed phyllitic cleavage (Figure 29). Foliation planes are healed with post-tectonic muscovite.

South of Shepherd Canyon, tectonite marble crops out along the thrust for 4 km. Small marble slivers are also present in the same structural position between the metavolcanic and quartz monzonite sheets, north of Shepherd Canyon. The marble is similar to lenses northeast of Maturango Peak, and displays a well-developed mylonitic flow foliation, locally with small, downdip-plunging folds. A lens of early Mesozoic epidote calc-hornfels and siltstone is present between the Paleozoic marble and Mesozoic volcanics. Stratigraphic order is preserved within the sequence of rock layers, although all mutual contacts are surfaces of movement (Figure 24).

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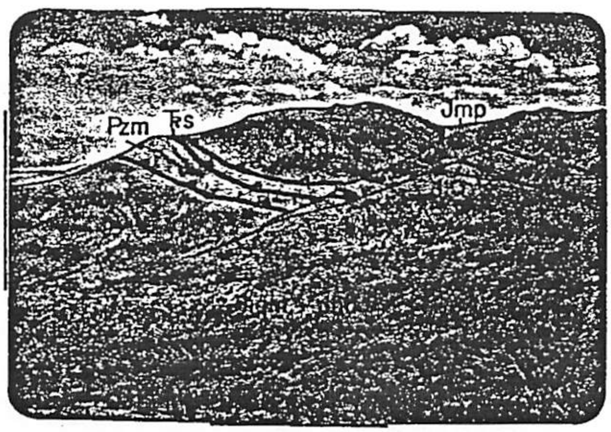

Figure 24. Tectonic rock slices in the Argus-Sterling thrust zone, south of Shepherd Canyon. Overridden granitic units at base are overlain by tectonite marble (light-colored, prominantly ribbed outcrops at left), sheared Mesozoic diorite (dark green), and the granitic upper plate, far right rear.

West of Anthony Mill, intrusive diorite porphyry is present in place of phyllitic Mesozoic volcanic rocks between upper plate quartz monzonite and tectonite marble. The diorite body, well-foliated on the margins but crudely sheared internally, is a competent mass of rock which steepened the basal contact of the granitic thrust sheet, and controlled the pinch-out of the underlying hornfels and marble lenses.

Water Canyon area

The thick deformed zone of structurally complex and highly altered rock in the Water Canyon area is among the most difficult to interpret in the mapped area (Plate II). Hornfelsic Permian metasedimentary rocks are overlain by: the parautochthonous Aquarius Mine block of Owens Valley limestone and siltstone; epidotized calc-hornfels and clastic sediments of probable Triassic age; a section of Mesozoic volcanic rocks and interbedded tuffaceous and conglomeratic metasediments; and granitic rocks of the upper plate, the base (eastern contact) of which is quite steep (60°) in this area (Figures 25 and 26). Later cross-faults, and high-angle faults parallel to thrust structures obscure the original geometry of the thrust.

Here, as to the north, parautochthonous blocks detached from overridden sedimentary and volcanic rocks at depth were transported upward along moderately west-dipping faults. The thick section of mostly undeformed volcanic rocks appears responsible for the buttressing of the upper plate. South of Water Canyon, the base of the quartz monzonite plate is intruded by syntectonic alaskite, and downdropped adjacent to the latter along a normal fault, so that estimation of the attitude of the thrust plane is difficult.

The Aquarius Mine block is bounded on the east by a moderately dipping surface that is probably a fault. Evidence that the block has been faulted into place is seen in the contrasting lithology, metamorphism, and bedding attitudes between it and the underlying featureless hornfels. The upper (western) surface of the Aquarius Mine block has been infiltrated by silica-rich fluids along a reverse fault, causing partial or

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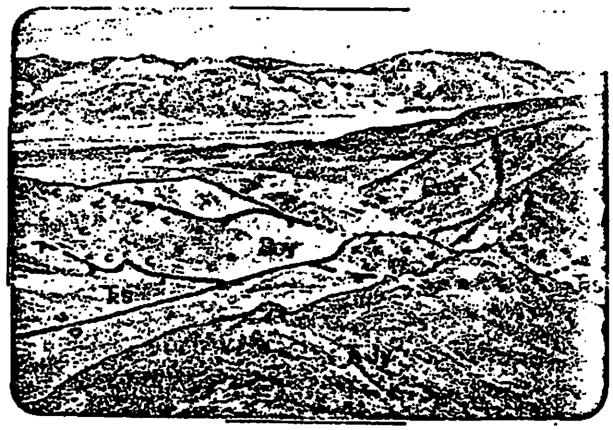


Figure 25. Lower structural levels of Argus Sterling thrust zone, Water Canyon, looking southeast. Autochthonous Permian calc-hornfels (light-colored rocks in middle distance) is overlain by Permian gray limestone and brown chert of the Aquarius Mine block. Brown patch at left is chert along exhumed fault surface beneath Triassic metasediments occupying valley at left. Thick Mesozoic volcanic section in foreground. Panamint Range in rear.

26

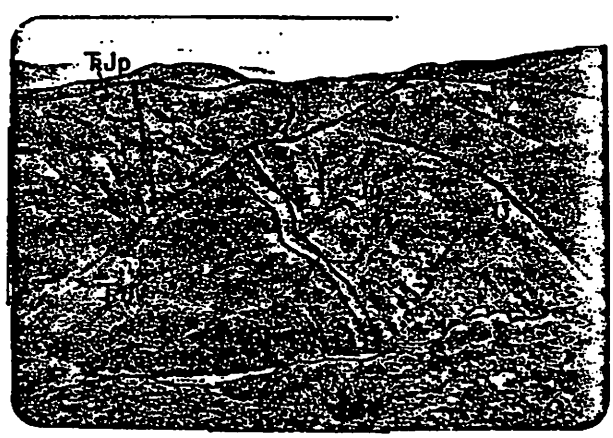


Figure 26. Upper levels of the thrust zone, Water Canyon, looking south. Mesozoic meta-andesite (TrJv), lower left, is overlain by phyllitic conglomerate and sandstone (TrJs) at left rear. Quartz monzonite at right and light-colored, late-tectonic alaskite overlie the former units along a steep fault surface, marked by whitish patches of sheared alaskite.

advanced replacement of gray limestone by dark gray and tan jasperoid. Siliceous, "cherty" rocks make up the north end of this block, which pinches out abruptly 1 km north of Water Canyon.

Triassic sedimentary rocks have been deformed by shear along the thrust system (boudinaged basaltic sills, and local tight folding), but are too altered to allow confident structural analysis. As stated earlier, they appear to be in faulted depositional contact below the volcanic rocks. Silica replacement of Permian limestone, and the abundant growth of epidote and chlorite in hornfelsic Triassic rocks were caused by entry of post-tectonic hydrothermal fluids into dilatant rock masses within the thrust zone.

Westend limestone quarry, northern Slate Range

South of Slate Range Crossing, the thrust system is concealed by Cenozoic deposits, and only the lower levels of the thrust zone are exposed along the western margin of the Slate Range. At the Westend lime quarry, imbricate plates of Paleozoic limestone crop out. The autochthon here, as at Water Canyon, is hornfelsic Owens Valley metacarbonate rocks. Gray Keeler Canyon limestone and calcarenite tectonically overlie the hornfels. A klippe of well-foliated gray limestone with spherical chert nodules is marked by a characteristic limonitic zone near its base. This basal thrust may connect, beneath Tertiary volcanic rocks, with the base of the Aquarius Mine block.

Lee Flat marble overlies the Keeler Canyon rocks in inferred thrust relationship. It is stratigraphically overlain by basal Keeler Canyon beds, which are foliated and locally overturned.

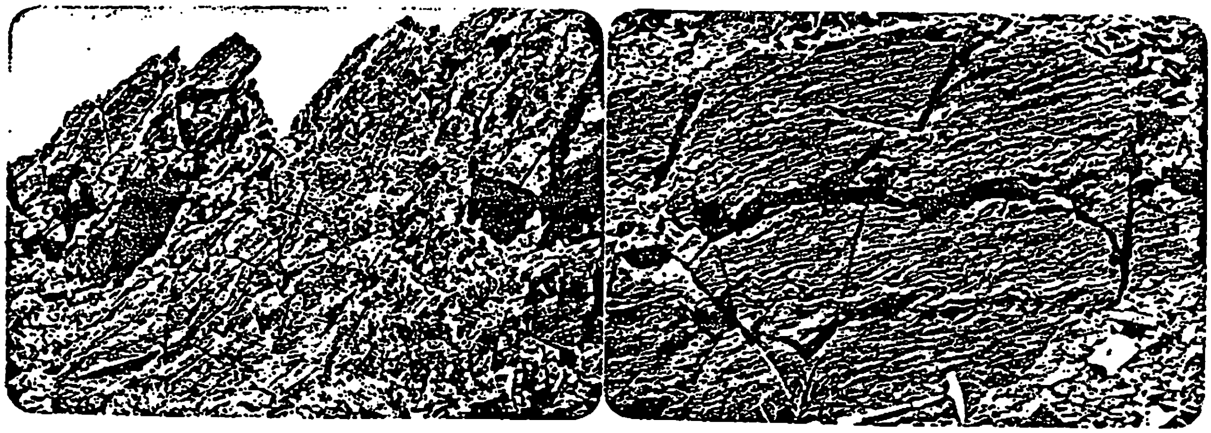
Tectonite marble outcrops thrust over Keeler Canyon strata comprise a third allochthonous lens. A small exposure of sheared granitic rock crops out in this area. A thrust surface underlying an upper granitic plate is inferred to lie west of the highway, striking southeast toward the western front of the Slate Range.

Western front of the Slate Range

No thrust faults are exposed in the northern Slate Range between the West-end lime quarry and the Ophir complex. A Tertiary range-front fault, inferred from the steep escarpment offsetting Tertiary basalts, downdrops the allochthonous terrane west of the range.

Structures in gray limestone, calcarenite and conglomerate exposed along the front of the range indicate movement along west-dipping surfaces. This is best seen in SE 1/4, Section 23. Prominent features include WSW-dipping beds which have been transposed by a steeper (60°) foliation, siliceous stringers folded isoclinally and intrafolially within a west-dipping foliation, and eastward overturning of folds developed in chert beds (Figure 27). In Section 26, conglomerate clasts have been stretched parallel to a west-dipping foliation, and in several other localities clasts in Permian calcarenites and pebble conglomerate have been intensely smeared out.

As this area is on strike with the southeastward-trending Argus Sterling thrust, it is likely that folds and foliation were imparted by differential movement beneath a thrust plate, whose present trace is concealed beneath alluvium.



(a) (b)

Figure 27. Relation of foliation to bedding in gray Permian limestone, western front of the northern Slate Range. (a) Steep west-dipping foliation cuts, folds and transforms bedding defined by 5 cm-thick brown chert layers. Overturned folds and rootless folds are visible. (b) West-dipping foliation and associated eastward-overturned folds in cherty limestone.

Ophir complex

Late Paleozoic and Mesozoic sedimentary rocks and alaskite near the Ophir Mine were deformed in an event that may be synchronous with the Argus Sterling thrust. A sequence of metamorphic rocks, somewhat thicker than is usual along the Argus Sterling thrust zone, comprises the Ophir complex. These rocks possess a pervasive foliation that dips west from 30° to 60° except where folded into antiformal structures.

The Ophir thrust, southeast of Ophir Mine, separates crinoid-bearing marble from underlying metamorphosed Owens Valley silty limestone (Figure 28). Rocks beneath the thrust contain thin cherty beds that have been deformed into southeast-overturned disharmonic, isoclinal folds. Many beds have been dismembered into lenses and boudins, and structures similar to those along the west front of the Slate Range are present.

28

Figure 28. Ophir thrust, looking southwest. Massive Permian marble tectonically overlies hornfels and cherty marble of the Owens Valley Formation with 90° discordance.

Orange and green Permian to Triassic hornfelses of the Ophir complex are crudely sheared, whereas the overlying tuffaceous sedimentary rocks are metamorphosed to strikingly foliated muscovite schists. Open antiforms and kinked crenulations in mica schists represent deformation within the complex that followed cleavage formation. Tectonite marble similar to lenses in the Argus Range occurs within shattered, altered hornfels near Goldbottom Mine. The lens dips 40° SW and is well foliated.

The Ophir complex was examined by Smith and others (1967), and appears from their reconnaissance to be related to the Sand Canyon thrust, exposed at the west margin of the southern Slate Range. The close-spaced, healed mylonitic foliations in Mesozoic volcanic and granitic rocks associated with a thrust fault in the Ophir complex also typify structural relations farther south in the Slate Range.

Age of thrust movement

K-Ar dating of granitic rocks in the Argus Range unambiguously brackets the age of movement on the Argus Sterling thrust within the Late

Jurassic, between 165 and 140 m.y. (Moore and Harakal, 1976; Table I). Because of the continuity of structures in the Argus Range, this age appears valid as far south as the Westend lime quarry.

The age of deformation at Ophir Mine is less certain. B. C. Burchfiel (personal communication) reports a Rb-Sr isochron date on the post-tectonic alaskite of Copper Queen Canyon of 170 m.y., implying an earlier age for this deformation. This age and the more advanced penetrative deformation above the Ophir thrust fault could mean that the Argus Sterling thrust was superposed on the earlier event, extending a zone of structural weakness northward at a later time.

The Middle Jurassic age of the alaskite can, however, be challenged on geologic grounds:

1. Structures along the western front of the Slate Range appear related to the concealed southward extension of the Argus Sterling thrust both in their geometry, and in that the thrust strikes directly along the west front of the range. Such structures are truncated in Section 26 by undeformed alaskite of Copper Queen Canyon. If these structures were caused by an earlier event, the "170 m.y." alaskite and older granitic units ought to show some deformation due to the southeastward continuation of a later, superposed Argus Sterling thrust. As they are completely undeformed along the western front of the range, they appear post-tectonic relative to the thrust.

2. Post-tectonic hornblende diorite (Stockwell Mine) and hornblende quartz monzonite (Isham Canyon) in the Slate Range may correlate with intrusions having similar compositions, exposed respectively 4 and 6 km to the east in the Panamint Range. Biotite K-Ar ages on the latter intrusions are latest Jurassic (Armstrong and Suppe, 1973). If the dates and correlation are valid, alaskite of Copper Queen Canyon must have a younger (latest Jurassic to Early Cretaceous) age.

3. Alaskite of Copper Queen Canyon is remarkably similar in composition and texture to the latest Jurassic Bendire Canyon pluton. It is tempting to correlate these intrusions based on their distinctive lithology.

Post-tectonic intrusive bodies with apparent latest Jurassic to Early

Cretaceous ages, and the apparent colinearity of structures that predate these plutons support a single Late Jurassic episode of thrusting in the Argus and Slate Ranges. Additional geochronologic data from the Slate Range will be required to verify this proposal.

Geometry at depth and displacement

The dip of the Argus Sterling thrust is partly controlled by the rocks overridden by the quartz monzonitic upper plate. Lenses of competent rock appear responsible for local steepening. Where the thrust plate overrides west-dipping sedimentary rocks, it is concordant with their bedding.

Estimating the average dip at depth is complicated by these features. Flattening at depth is unlikely, as granular, isotropic rocks are probably juxtaposed by the fault at depth as well as at the surface. High-angle reverse faults that cut the upper plate might indicate a steepening of the thrust plane at depth, but may also reflect upward adjustments to stresses within the granitic block, above a moderately inclined basal surface.

The structural style suggests a minimum displacement in excess of a few kilometers. If the attitude of the thrust surface is assumed to average 45°, the nature of the deep epizonal or mesozonal western granitic terrane probably limits the vertical component of movement to 10 km, with a maximum net slip of 15 km.

Foliation in deformed rocks

Several types of planar structures occur in foliated rocks in the thrust zone. These structures vary according to the type of rock deformed.

Most foliations in allochthonous lenses or overridden rock are roughly parallel to the overlying thrust surface. The west-dipping shear surfaces were created by differential tectonic transport beneath the upper plate. The following types are common.

1. Mylonitic rocks, whether cleavable or coherent, generally have a visible mylonitic flow structure, marked in two dimensions by flattening and crushing of component grains and crystals.

2. Fine-grained volcanic rocks, commonly deformed to phyllitic mylonites, possess a closely spaced cleavage, with abundant post-tectonic chlorite or muscovite (Figure 29), and are thus blastomylonitic. Tuffaceous metasedimentary rocks at the Ophir Mine contain abundant regenerated muscovite and are more properly termed schists.

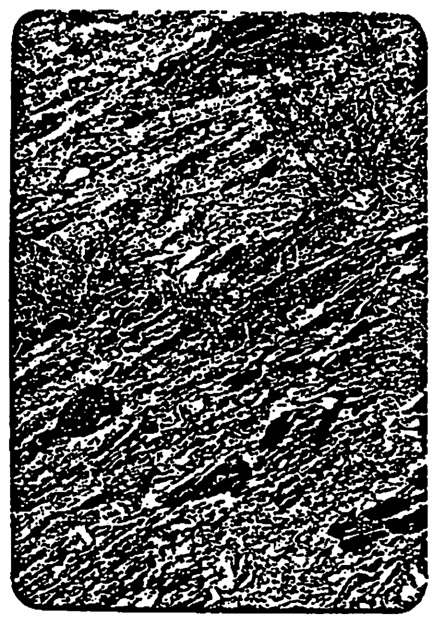


Figure 29. Phyllitic foliation in phyllosilicate-rich, mylonitic meta-andesite near Shepherd Canyon. Hammer gives scale.

3. Marbles deformed by metamorphic flow may be cleavable or coherent. Where cleavage is absent, the foliation is marked by streaky color layering, preferred orientation of calcite grains, and furrowed outcrops caused by variable resistance to weathering of the thin layers.

4. In granitic and volcanic rocks with incipient internal deformation, a widely spaced cleavage is present. Its west-dipping attitude indicates a genetic association with thrusting.

Petrographic features of mylonitic rocks

As much as 300 m of mylonitic rocks mark the eastern contact of the quartz monzonite of Maturango Peak at the base of the upper plate of the thrust. Most of these rocks are protomylonites, as the crushing of large grains in porphyritic rock is incomplete, yielding large, rounded porphyroclasts in a finely crushed matrix. Deformation in the upper parts of this zone are variably penetrative, phacoidal, or concentrated along discrete shears or within the less competent dikes.

Porphyroclasts of plagioclase and perthitic orthoclase are rounded and associated with trails of fine-grained, partly recrystallized mortar zones. Plagioclase grains show well-developed, bent glide twin lamellae, and orthoclase is commonly strained or fractured, and healed into mosaics of grains with slight orientation shifts.

Large subrounded quartz grains are commonly deformed into elongate lenticular porphyroclasts by shear along planes of strain that are oblique to the plane of foliation (Figure 30). These planes are diffuse, unhealed (undulatory) grain boundaries; they are length-slow and indicate translation in the [0001] zone. Mafic minerals in most mylonites have been obliterated by hydrothermal alteration. Sericite, chlorite, or secondary green biotite occur in strain shadows with quartz, or post-tectonically in the matrix.

The matrix of coarsely granular mylonitic rocks is a fine, sutured aggregate of crystals that indicates some recrystallization following cataclasis. The grains show a tendency toward fine polygonization. Other features of these rocks include: broken feldspar crystals, quartz- or calcite-filled tension fractures at right angles to the foliation,

Figure 30. Strained quartz lenticle from protomylonitic quartz monzonite near the base of the upper plate of the Argus Sterling thrust. Elongation of lenticle parallels mylonitic foliation; diffuse strain lamellae within the quartz are oblique to the foliation (36X).

sericitization of the matrix, and local albitization of potassium feldspar.

Finer-grained rocks than the above, such as andesite, equi-granular granitic rocks, and Mesozoic siltstone and tuffaceous clastic rocks were deformed to phyllitic blastomylonites (Figure 31). Large grains are strained, broken, or relatively undeformed, while the fine-grained matrix of these rocks has permitted post-kinematic, mimetic growth of fine sheets of phyllosilicates (muscovite or chlorite) parallel to the foliation, yielding a phyllitic or schistose, partially recrystallized mylonite. Annealing and neomineralization of mylonites may be related to latest Jurassic intrusion and thermal metamorphism along the thrust zone.

While visually ductile on the scale of an outcrop, tectonite marble commonly shows cataclastic effects in thin section, including rounded calcite porphyroclasts with deformation twinning and mortar trails. A lens of quartz occurs in the thrust zone east of Maturango Peak. The quartz has a well-defined foliation, and consists of very elongate grains which have been incipiently broken into polygonal domains in slightly different

Figure 31. Muscovite in the matrix of meta-andesite phyllitic mylonite near Shepherd Canyon. Larger plagioclase grains are rounded porphyroclasts, while smaller crystals retain euhedral shapes (36X).

orientations. Most grains are length-fast parallel to the foliation; their form is highly flattened normal to the c-axis and tabular parallel to the foliation. The lens is probably a quartz vein emplaced syntectonically along the thrust.

Schistose mylonites from Triassic tuffaceous sedimentary rocks in the Ophir complex possess a thinly-spaced foliation that allows these rocks to cleave cleanly into thin, mica-rich sheets. The conversion of clastic grains or phenocrysts to porphyroclasts indicates early mylonitization, followed by thermal recrystallization. Mica growth was in part post-kinematic, but ambient temperatures during deformation allowed some syn-kinematic growth of muscovite.

Folds and lineations

Folds a few centimeters to several meters in wavelength are associated with the thrust and occur chiefly in bedded limestones, marbles, and phyllitic or schistose rocks with a well-developed, closely spaced cleavage. The

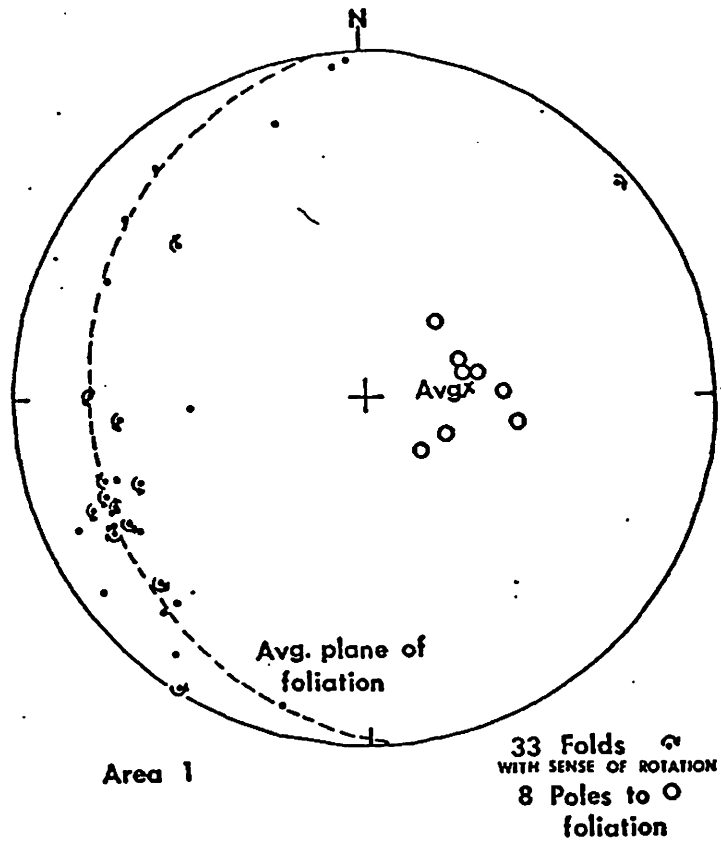
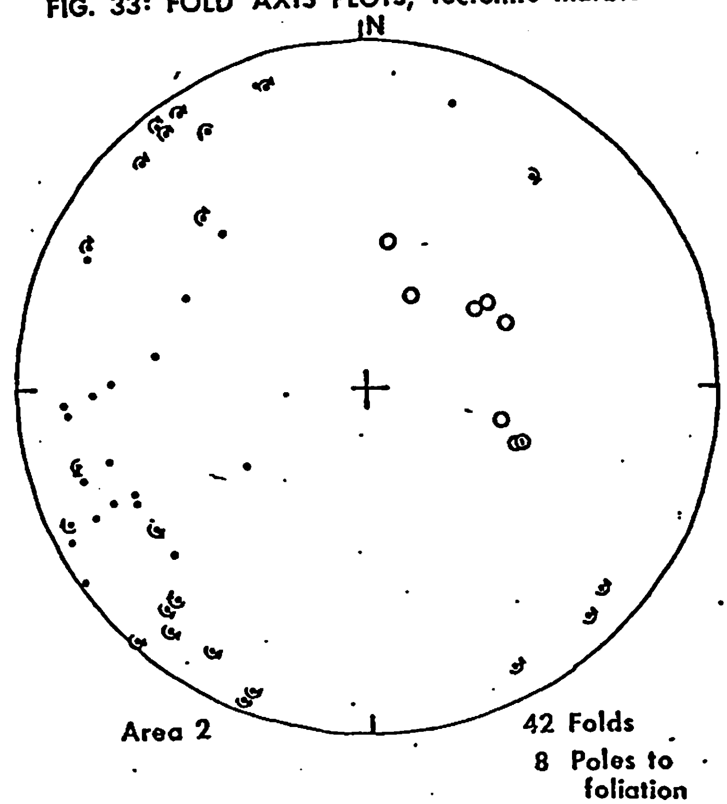
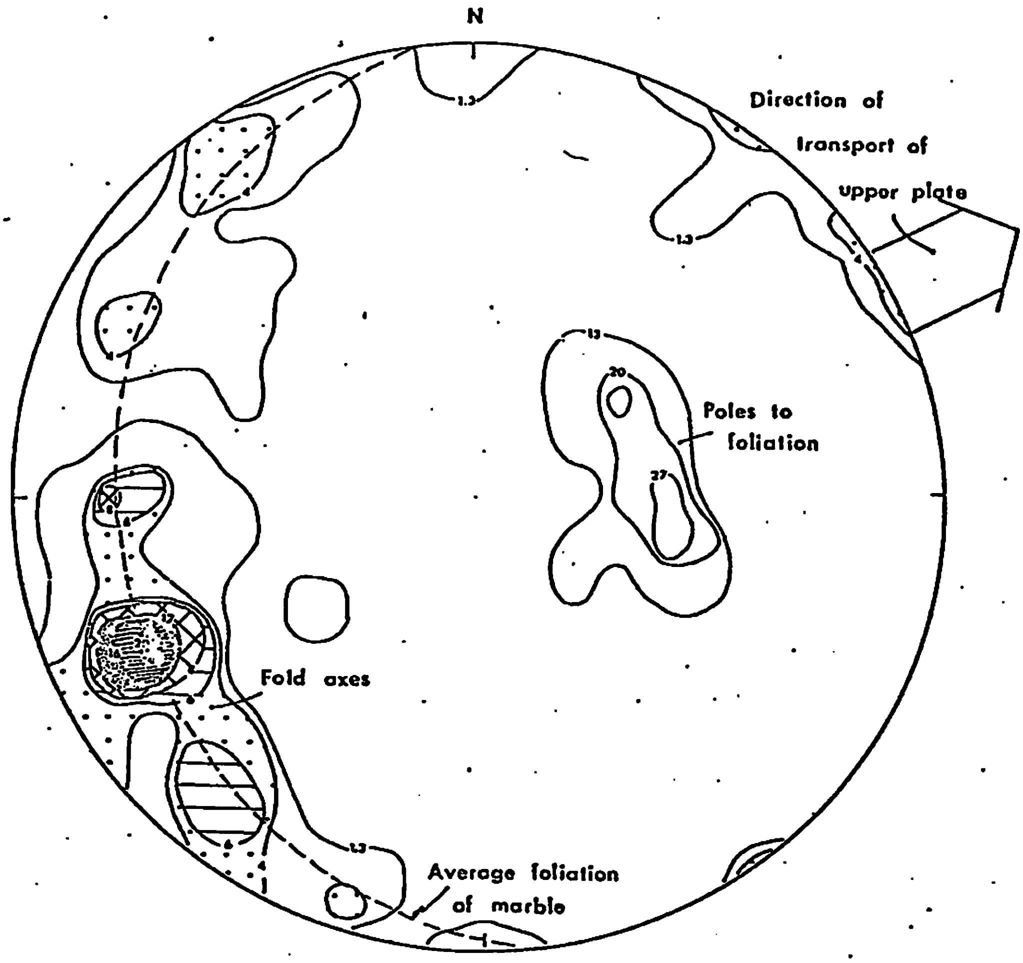


FIG. 33: FOLD AXIS PLOTS, Tectonite marble





Tectonite marble, Sec. 24

Contoured in %/1% area

15 POLES TO FOLIATION
74 FOLD AXES

FIGURE 34

east of Etcheron Valley) and those on its eastern flanks southwest of Slate Range Crossing, which rest directly on pre-Tertiary bedrock. Offset, tilting, and warping of these flows attests to the recent initiation of Basin and Range-style faulting.

Remnants of the pre-uplift surface are preserved as (a) accordant east-sloping ridge tops east of Maturango Peak; (b) accordant range crest summits south of and including Maturango Peak; (c) erosional remnants of Tertiary volcanic rocks which dip 10-15° east near the Onyx Mine; (d) flat areas mantled by thick grus south of Millspaugh; (e) east-sloping, volcanic-mantled east flanks of the Argus and Slate Ranges (Figure 35).

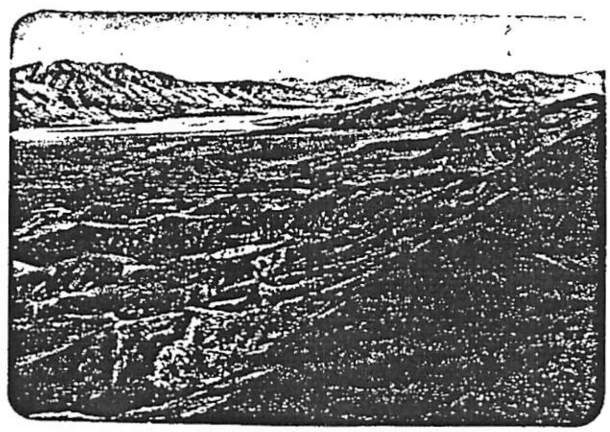


Figure 35. View SSE along the east flank of the Argus Range. East-dipping, volcanic-mantled remnants of a Miocene-Pliocene erosion surface are in the middle distant Argus Range (right) and in the Slate Range (right distance). Volcanic rocks in left foreground have been downdropped relative to the topographically and structurally highest part of the Argus Range at right (block 1 of Figure 36).

The late Tertiary fragmentation of this surface took place by faulting on the western fronts of ranges, eastward tilting of blocks, renewal of older NW-striking fractures, gentle warping, and E-W to NE-SW cross-faulting (Figure 36). Relative to the ranges to its west, Panamint Valley has been faulted down (as south of Bendire Canyon; Figure 35); up (as along the Ash

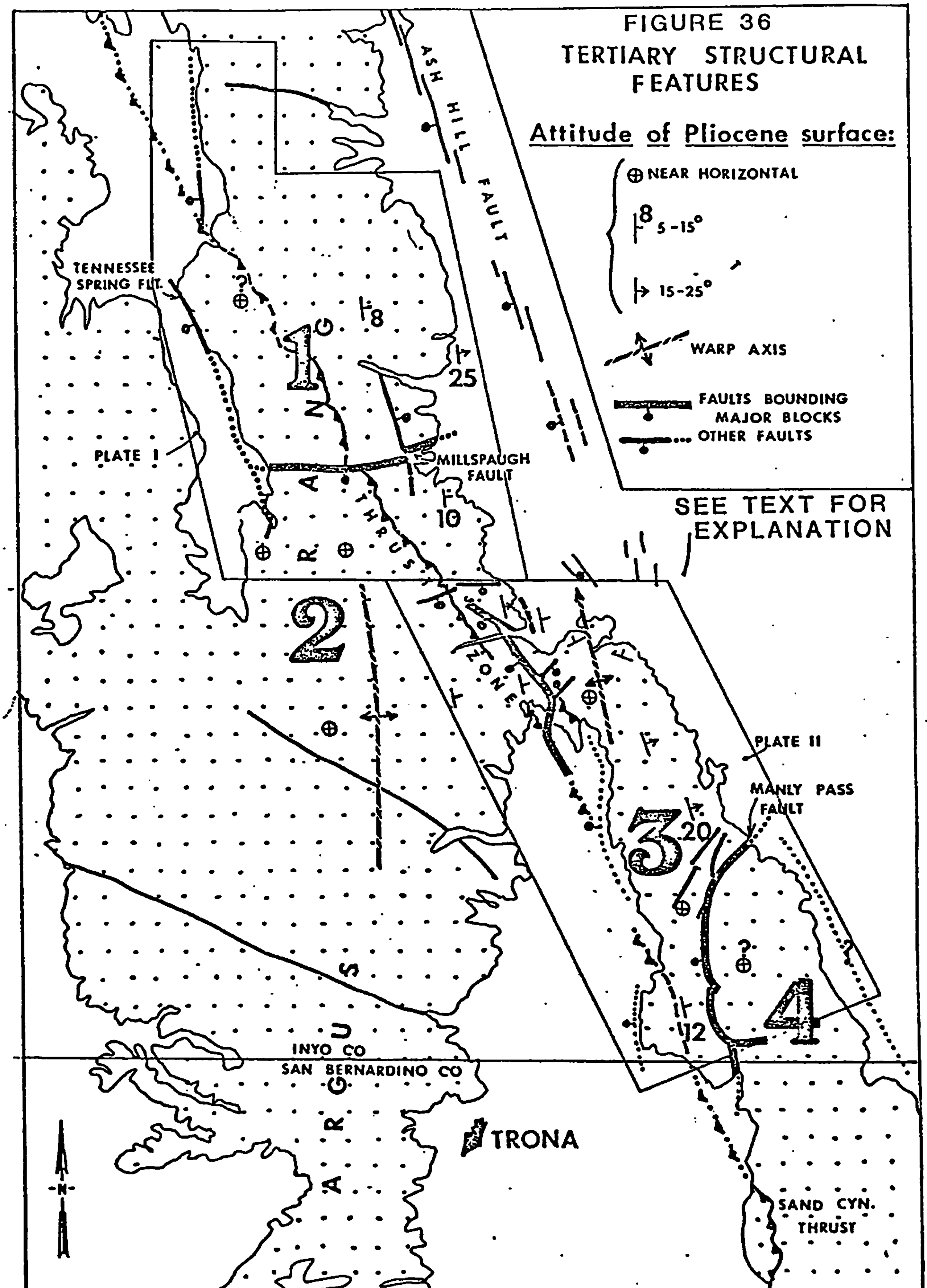


FIGURE 36
TERTIARY STRUCTURAL FEATURES
Attitude of Pliocene surface:
NEAR HORIZONTAL
8 5-15°
15-25°
WARP AXIS
FAULTS BOUNDING MAJOR BLOCKS
OTHER FAULTS
SEE TEXT FOR EXPLANATION
ASH HILL FAULT
TENNESSEE SPRING FLT.
PLATE I
MILLSPAUGH FAULT
ARGUS RANGE
THRUST ZONE
PLATE II
MANLY PASS FAULT
INYO CO
SAN BERNARDINO CO
TRONA
SAND CYN. THRUST
N
1
2
3
4
8
25
10
20
12

Hill Fault; Hall and Stephens, 1962); or it may remain a coherent part of the range block, as east of the northern part of the Slate Range.

The mapped area can be divided into four distinct, fault-bounded blocks (Figure 36):

1. The northern Argus block contains the highest point in the range and has been uplifted relative to block 2 along the Millspaugh fault, topographically expressed in the higher elevation of the northern block. Tertiary volcanic rocks have been erosionally stripped from this block almost everywhere except where downfaulted, east (Figure 35) and west of the range (west of Stone Canyon). The western front of the block is fault-bounded, with vertical displacement decreasing southward of Maturango Peak. Quaternary offsets occur in alluvium north of Maturango Peak. The pre-fault surface may be slightly convex due to warping, as it seems to steepen east of Maturango Peak.

2. The range-front fault of the northern Argus Range dies out in Etcheron Valley, the surface of block 2 being more accordant with the faulted granitic plateau of the Coso Range to the west. Warping of the pre-Basin and Range surface is well displayed south of Water Canyon along the crest and east flank of the range, where flat-lying basalt flows on the crest dip off eastward into northern Searles Valley. Erosional remnants of volcanic rocks are flat east of Etcheron Valley, but dip 10-15° east between the Onyx Mine and Water Canyon. Warping modified by minor renewed movements along the Argus Sterling thrust zone may account for the valleyward dips of the volcanics. Just north of the mouth of Water Canyon, moderately inclined volcanic rocks flatten out toward the valley, suggesting a fault or flexure along the eastern front of this block.

The boundary between the Argus and Slate Ranges (blocks 2 and 3) is a

NW-trending fault west of Slate Range Crossing, which uplifts the Slate Range and the Aquarius Mine block relative to the Argus Range. The divergence of the Slate Range from the Argus Range at this point clearly implies renewed movements on older, thrust-related fractures. A keystone block, lying in the pass at Slate Range Crossing and downdropped along NE-trending cross-faults, complicates the relations at the juncture of the two ranges (see below).

3. The northernmost Slate Range is an anticlinal nose that plunges north under the alluvium of Panamint Valley. South of the Westend Lime quarry, the western scarp of the range is bounded in the subsurface by the extension of the thrust zone, which seems to have controlled its uplift. The western front is faulted up, tilting Tertiary volcanic rocks on the east flank to as much as 20° east. Block 3 is bounded on the southeast by the Manly Pass fault. Volcanic rocks between Manly Pass and Goldbottom Mine are relatively flat-lying; however, faulting west of the Ophir complex has produced a frontal scarp and eastward tilting to 12° in latest Pliocene to Quaternary gravels derived from block 4. This uplift partly post-dated movement on the Manly Pass fault.

4. Uplift of the diorite-alaskite mass of block 4 along the Manly Pass fault was followed by erosion which removed all Tertiary deposits. It is not known if the steep eastern border of this block is faulted. South of the area of Plate II, warping, locally modified by renewed movement on pre-Tertiary faults, is dominant over range-front faulting (Smith and others, 1967).

Slate Range Crossing

The following features account for the peculiar juncture between the two ranges at Slate Range Crossing (see Figure 36).

1. The Argus and Slate Ranges are parallel anticlincal warps with the west limb of the smaller, eastern warp (Slate Range) up-faulted along renewed NW-trending fractures related to the Argus Sterling thrust zone.

2. A NW-trending fault is the structural boundary between the two ranges. This fault roughly follows the highway and is concealed by alluvium south of the pass; it trends northwest, occupying a strike valley in the Aquarius Mine block, and extends across Water Canyon. The Slate Range is structurally higher along this fault, which displaces basalt on its east side to as much as 150 m higher than volcanic rocks on the west. Other NW-trending faults north of Water Canyon relatively downdrop that part of the Argus Range lying southwest of the faults.

3. E to NE-trending cross-faults with south side down characterize the thrust zone from the Millspaugh fault to Slate Range Crossing. At the pass itself, this pattern ends where a keystone block with an andesite cover is downdropped into the low point between the two ranges.

4. The steep drainage head north of Slate Range Crossing appears to be erosional rather than structural, reflecting the lower base level of Panamint relative to Searles Valley.

Normal displacements on pre-Cenozoic reverse faults

West-dipping faults of the Argus Sterling thrust zone appear locally to have participated in localizing the late Tertiary regional pattern of west-side-down normal faulting and eastward tilting of fault blocks. As outlined above, for example, NW-trending faults within the thrust zone near Slate Range Crossing downdrop the Argus Range block. The western front of the northern Slate Range may also reflect Tertiary uplift along concealed thrust-related fractures.

The Tennessee Spring fault, west of Maturango Peak, is a well-exposed zone of mylonitic quartz monzonite with a pronounced west-dipping foliation. It coincides with the western scarp of the Argus Range for 3 km. The style of deformation is similar to that observed on reverse faults related to thrusting and does not suggest near-surface faulting. Uplift of the western front of the range was probably influenced by a pre-existing zone of phyllosilicate-rich mylonite.

North and south of the Millspaugh fault, similar west-dipping zones of phyllitic mylonite appear to have had large displacements during thrusting. The deformed rocks within these zones resemble those at the base of the upper plate, and probably reflect upward adjustments to stresses within the thick granitic slab. At least two such structures offset Tertiary limestone and volcanics.

Other Cenozoic faults

Major faults bounding the Argus Range on the west trend north to north-northwest. Late Tertiary basalt is offset by these faults east of Etcheron Valley, and by a 7 km long fault system south of upper Stone Canyon.

The Millspaugh Fault is an east-west trending structure that is similar in trend to the Wilson Canyon (von Heune, 1960) and Snow Canyon faults (K. Holden, personal communication). The northern block has been uplifted along this fault, and offset of several features indicates some oblique slip. Horizontal component separations of the following features are as follows:

West-dipping reverse faults near Millspaugh (dip 70° to 80° W): 1.2 km;
Base of Argus Sterling thrust plate (dip 30° to 35° W): 7.1 km
Contact between quartz monzonite and dioritic border facies (dip unknown): 1 km;
West-dipping, thick marble beds in Owens Valley Formation: 0.75 km;
Quartz veins north and south of fault, possibly faulted segments of

the same vein (vertical): 0.25 km.

Fault plane projections using the first two criteria suggest a net slip for the Millspaugh Fault of 1.4 km, with a vertical component of 0.9-1.3 km and a horizontal component of 1.0-0.5 km. Striations on fault plane slickensides plunge ESE at 60°. These data suggest a minor left-slip component of movement along the fault.

The Manly Pass Fault was named by Smith and others (1968). At least 730 m (2400') of vertical offset, measured between volcanic remnants west of the fault and flat accordant areas near the range crest, has occurred along the fault. At its northern end the fault veers northeast into southern Panamint Valley, with a decreasing amount of offset. Near the southern boundary of Plate II, a fault in Copper Queen Canyon left-laterally offsets the Manly Pass Fault and terminates at the head of the canyon in a flat-lying mylonite zone.

Other significant faults include: step faults and slumps in eastward-tilted volcanic rocks, and in oversteepened granitic slopes near the crest of the Slate Range, and valley-side-up faults north of the northern tip of the Slate Range, related to the Ash Hill en-echelon fault zone east of the Argus Range (K. Holden, personal communication).

III. REGIONAL IMPLICATIONS OF THE ARGUS STERLING THRUST

The Argus Sterling thrust is a northwest-trending, moderately inclined thrust fault, which dips west, deeply penetrating the plutonic complex of the southeastern Sierra Nevada batholith. It shares several characteristic features with other thrust faults that occur in a belt extending 150 km from the northern Mojave desert to the southern Inyo Mountains. Moderate westward dips, involvement of granitic rocks in thrusting, development of mylonites in granular rocks and closely spaced imbrication of overridden, ductile carbonate rocks, and intrusion of post-tectonic plutons into thrust zones define the structural style of this belt. These features, and the observation that the thrust faults are mutually on strike, strongly suggest that the faults may have developed as a single system. The term Coso thrust system is proposed for this structure, named from the granitic complex of the Coso Range, which includes plutonic rocks that occupy the hanging wall of the thrust system (Figure 37).

In contrast to earlier decollement-type thrust faults, which occur within the miogeosynclinal sedimentary wedge, the Coso thrusts are rooted in crystalline rocks. Rocks of the Precambrian basement occur within one thrust plate, and several thrusts have granitic upper plates, marking the eastern boundary of an extensive granitic terrane. Post-tectonic granitic rocks intrude this uniform western plutonic terrane, as well as the varied plutonic and sedimentary terrane east of the thrusts, and the thrust zone itself. Intrusive bodies within the zone of deformation suggest that thrust planes tapped deeper levels within the plutonic belt, serving as conduits which facilitated the rise of magmas. An intimate relation between the

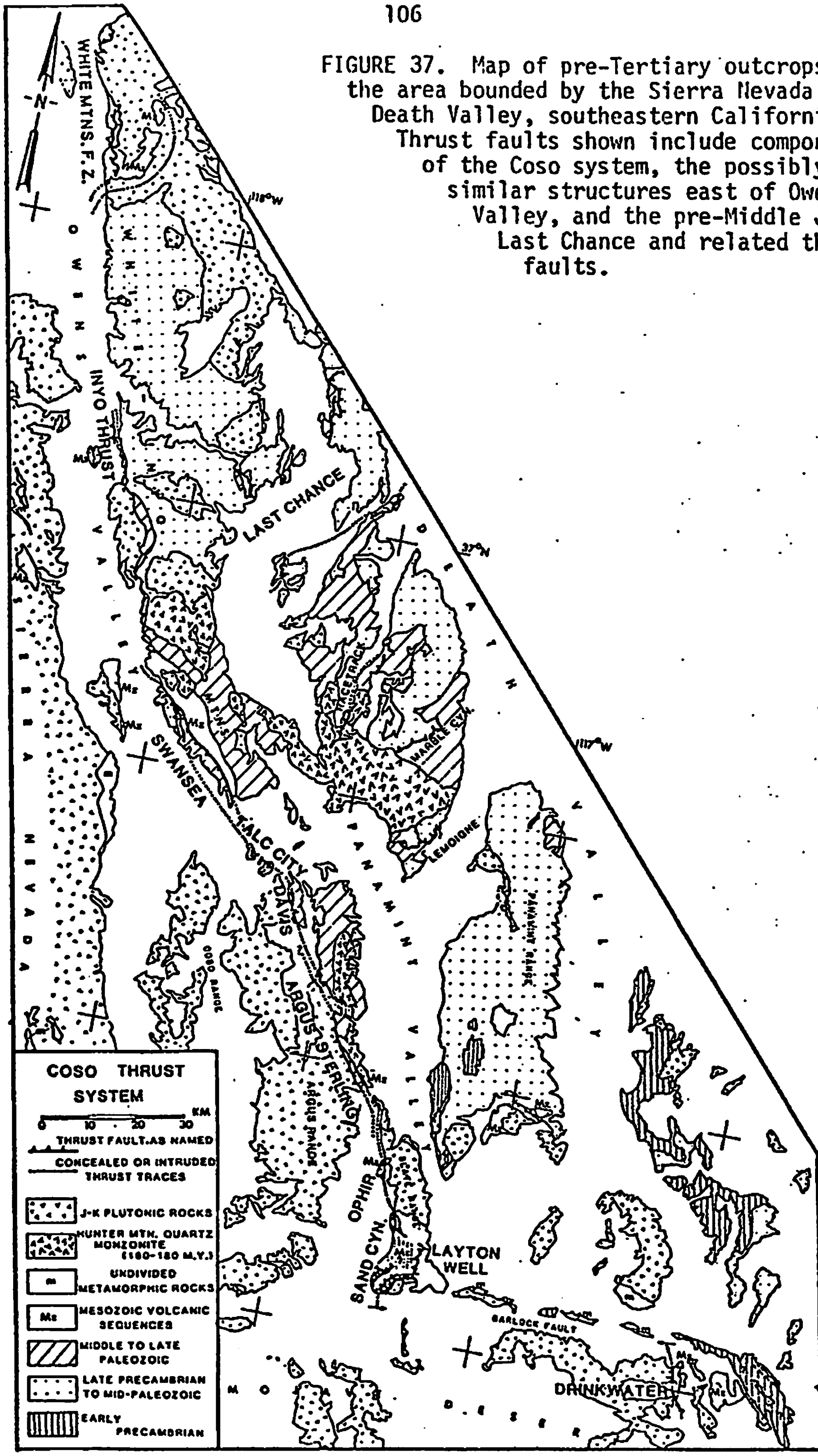


FIGURE 37. Map of pre-Tertiary outcrops of the area bounded by the Sierra Nevada and Death Valley, southeastern California. Thrust faults shown include components of the Coso system, the possibly similar structures east of Owens Valley, and the pre-Middle Jurassic Last Chance and related thrust faults.

Sierra Nevada plutonic complex and the thrust system is indicated.

The Coso thrust system underwent at least one movement event in the Late Jurassic, as determined by the ages of bracketing plutons, respectively 165 and 140 m.y., in the Argus Range. The 165 m.y. pre-tectonic age of the Hunter Mountain quartz monzonite in the Argus Range differentiates movement on the Coso system from emplacement of the Last Chance and other thrust plates, which preceded and are truncated by the Hunter Mountain unit. The pre-Middle Jurassic Last Chance thrust sheet, and underlying imbricate plates of the Racetrack, Marble Canyon, and Lemoigne thrusts (Burchfiel and others, 1970; Johnson, 1971), were emplaced eastward or southeastward by decollement in Cambrian and Mississippian rocks. The northwest strike of the Coso system intersects at a high angle the trend of the earlier decollement structures (Figure 37), which are related to the geometry of the geosynclinal wedge. The Coso system, by contrast, is related to the Jurassic development of the isotropic plutonic masses along a northwest axis.

Correlation of thrust faults along the thrust system, which has been fragmented by Cretaceous plutons and Tertiary faulting, is supported by the common structural features cited above. The Argus Sterling thrust fault is used below as a model for comparison with other segments of the postulated thrust system.

Coso Thrust System

Slate Range and Drinkwater Lake

The Argus Sterling thrust strikes parallel to the west front of the northern Slate Range, where, as indicated in Section II, structures in autochthonous Paleozoic carbonate strata suggest southward continuity of the thrust, beneath alluvium, with the Ophir complex. Although post-tectonic rocks have isolated the Ophir thrust from its northern and southern continuations, metaplutonic rocks within the Ophir thrust plate occupy a structural position analogous to similar rocks in the upper plate of the Sand Canyon thrust in the southern Slate Range.

Smith and others (1968) briefly described the Sand Canyon and Layton Well thrusts in the southern Slate Range. The Layton Well thrust brings Precambrian? schists over probable Mesozoic metasediments, which are strongly phyllitic and penetratively deformed. Deformation of rocks beneath the thrust is not restricted to the fault zone, but is of more regional extent. The Sand Canyon thrust, which structurally overlies the Layton Well thrust, juxtaposes a metaplutonic allochthon against the underlying Precambrian? schist. Smith and others interpreted the rocks of the plutonic allochthon as Precambrian, but noted the similarity of these rocks to those of the Ophir complex. Relations within the latter suggest that the plutonic rocks are in part, if not wholly, Mesozoic.

Mesozoic granitic rocks also occupy the upper plate of a west-dipping thrust at Drinkwater Lake in the northern Mojave desert described by Davis and Burchfiel (1973). They interpreted this thrust as an extension of the Slate Range thrust complex, offset to the east by the Garlock Fault. The plutonic rocks have been thrust over Mesozoic volcanic rocks along this thrust, whose southern extension has not yet been delineated in the complexly faulted north-central Mojave area.

The Slate Range thrust complex shares the following features with the Argus Sterling thrust:

1. An allochthon of Mesozoic plutonic rocks, in a structurally high position above imbricate thrusts, with a wholly granitic terrane lying west of the thrust zone;

2. Autochthonous or parautochthonous Mesozoic volcanic and sedimentary rock sequences;

3. Moderate westward dips and apparent eastward transport of thrust plates;

4. Formation of phyllitic mylonites and penetratively deformed crystalline rocks;

5. Colinear relation of trends of the Argus Sterling thrust, the Ophir complex and the Sand Canyon thrust.

The Argus Sterling thrust and thrusts of the Slate Range may therefore lie along a common linear zone of deformation, which is relatively narrow in the Argus Range and widens southward. Mylonites of this zone are a few hundred meters thick near Maturango Peak; the zone widens to a 2000 m thick, lensoidally sheared imbricate zone in Water Canyon; and in the southern Slate Range, the fault zone is represented by a regionally sheared terrane. The apparent involvement of Precambrian basement, and the wide areal extent of metamorphism of rocks in the Slate Range may indicate higher temperatures, more profound deformation, or greater uplift along this part of the thrust system.

Davis thrust

Hall and MacKevett (1962) mapped the Davis thrust in the Darwin Hills, northwest of the Argus Range, as a moderately west-dipping thrust of one to two thousand meters displacement. The thrust juxtaposes mid-Paleozoic rocks against late Paleozoic rocks and a pre-fault granitic stock. The authors believed the thrust was emplaced by forceful intrusion of the Coso batholith, the granitic terrane south and west of Darwin.

Between Darwin and the southern end of the Darwin Hills, a west-dipping fault surface, probably continuous with the Davis thrust, but not thus recognized by the above authors, brings finely foliated marble over late Paleozoic calc-hornfels. The tectonite marble is intruded on the west by post-tectonic granitic rocks. These relations are directly analogous to those at Argus Sterling Mine, 14 km to the southeast, and the faults are colinear. Closely-spaced imbrication and foliation of Paleozoic carbonate rocks, and truncation of pre-tectonic intrusive rocks by the Davis thrust, suggest further affinity with Argus Range structures. It is therefore likely that the Davis thrust, and the fault in the southern Darwin Hills, correspond to the lower imbricate surface of movement that is exposed at Argus Sterling Mine (Figure 38).

If the Davis thrust is a northern extension of the Argus Sterling thrust, its allochthon may have been emplaced beneath an upper plate of granitic rocks, i.e., the Coso terrane, corresponding to the Maturango Peak quartz monzonite in the Argus Range. Sheared quartz monzonite west of the Darwin Hills, containing zones of foliated rock dipping 60° W, recalls shear zones in the upper plate of the Argus Sterling thrust, and may represent this granitic allochthon. Radiometric dating of Coso rocks is needed to determine their age relative to the expected time of thrusting. The age of the Davis thrust, like the Argus Sterling thrust, is bracketed chronologically by plutons, and is also potentially determinable by radiometric dating.

The thrusts in the Argus Range and those near Darwin show the following relations in common:

1. Thrusts in both areas are mutually on strike and northeastward yielding;
2. Mid-Paleozoic carbonate rocks have been emplaced over late Paleozoic rocks;
3. Finely foliated and isoclinally folded tectonite marble occurs within thrust zones;

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Figure 38. Foliated, tectonite marble, in part silicified, south of Darwin. The marble overlies Permian hornfels and is intruded by a post-tectonic pluton. To the SSE, quartz monzonite of Maturango Peak is juxtaposed against light-colored hornfels of the northern Argus Range across a narrow band of white marble in the Argus Sterling thrust zone. The two faults are apparently correlative across 14 km of alluvium.

4. The thrusts dip 30-40° SW;

5. The allochthonous carbonate rocks are locally emplaced over prethrust granitic rocks;

6. Post-tectonic plutons intrude thrust zones;

7. Analogous to relations in the Argus Range, steep west-dipping shear zones characterize the allochthonous granitic plate, postulated to exist west of Darwin;

8. Large vertical displacement along the moderately west-dipping thrust, exposing the granitic terrane of the western Argus Range, may similarly account for the Coso terrane west of Darwin.

Talc City Thrust

The Talc City thrust is exposed in the Talc City Hills northwest of Darwin. It juxtaposes early Paleozoic dolomite and quartzite over tightly folded strata of the Keeler Canyon Formation. Structural analysis by Gulliver (1971) indicates that the allochthon was emplaced from the southwest.

The autochthon is characterized by well-developed NE-overturned folds and a SW-dipping cleavage. The deformed rocks have been intruded on the south by a post-tectonic pluton. The position of the thrust, and its sense of tectonic transport, suggest a relation to the Davis thrust, although the folded autochthon and later folding of the thrust surface at Talc City Hills suggest a more complex structural style than present at Darwin or in the Argus Range.

The nature of the source terrane of the Talc City thrust plate, as for the Davis thrust, is problematic. A conventional explanation is that thrust plates may have been emplaced from a terrane of sedimentary rocks to the southwest, subsequently obliterated by post-tectonic intrusive activity. It is possible, however, that allochthonous sheets were emplaced beneath an overriding upper plate composed of pre-tectonic granitic rocks. Later intrusive units south of the Talc City Hills make recognition of a postulated granitic upper thrust plate difficult.

Swansea thrust system

Northwest-trending, moderately SW-dipping thrust faults in the Paleozoic and Triassic section of the southern Inyo Mountains were mapped by McAllister (1956) and Merriam (1963). Studies by Kelley (1973) and Elayer (1974) provide a detailed view of their geometry. Numerous thrusts and reverse faults with low to high southwestern dips cut rocks ranging in age from Cambrian to Triassic. Successively older Paleozoic rocks in structurally higher imbricate slices overlie an autochthon of Mesozoic volcanics in the core of an asymmetric syncline. Displacement along individual thrusts is generally less than 1000 m. Small post-tectonic plutons intrude several thrust planes of the system. Several large and small overturned folds indicate tectonic transport to the northeast, but again, little can be said of the source terrane of these thrust plates, since the highly faulted zone appears to have influenced Tertiary subsidence of the Owens Lake basin to the southwest, concealing the upper structural levels of the thrust system.

Kelley and Stevens (1975) noted that these thrusts, comprising the Swansea system, are a likely continuation of the Talc City thrust. They interpreted these structures as ramp-like imbrications beneath a regionally extensive Inyo thrust sheet, thought to have been emplaced in Late Triassic to Early Jurassic time, before intrusion of the Hunter Mountain intrusive complex. The high-angle intersection of trends of the Coso thrusts and decollement-type thrusts like the Last Chance thrust fault (Figure 37) does not support this concept. The position, trend, and structural style of the Swansea thrusts suggest that they are a continuation of the thrust system that, as outlined above appears to link the Davis, Talc City, and Argus Sterling thrusts. A geochronological test of this correlation is whether the Swansea thrusts are cut by Hunter Mountain-age plutons, as proposed by Kelley and Stevens; this would demonstrate an earlier age for the Swansea thrusts. A leucocratic, post-tectonic pluton near the Swansea system yielded a 135 m.y. biotite date (Ross, 1969). It is therefore similar in apparent age and composition to post-tectonic plutons of the Argus Range, and does not invalidate the proposed correlation.

Rooted thrust faults east of Owens Valley

The northern extension of the Swansea thrust system has been obscured by Cretaceous plutonism and by Tertiary faulting and sedimentation in Owens Valley. Thrust faults in two areas along the eastern margin of Owens Valley, though probably unrelated to the Coso thrust system, display a similar structural setting and analogous deformational features.

The White Mountains fault zone (Crowder and Ross, 1972; Crowder and others, 1972) is a thrust fault without structural counterpart in the northern Owens Valley area (Figure 37). Features in common with thrust faults of the Coso system include: imbricate thrusts that dip 30-40° west; penetrative west-dipping foliation in phyllitic volcanic rocks of Mesozoic(?) age; slices of foliated, isoclinally folded Paleozoic marble in the thrust zone; autochthonous granitic rocks overridden by thrusts; post-tectonic plutons near the thrust zone; and an age of movement possibly younger than Middle Jurassic, the minimum age of the Pellesier Flats quartz monzonite (Crowder and others, 1973).

The Inyo thrust (Olson, 1972; Stevens and Olson, 1972), exposed along the west margin of the Inyo Range, has been interpreted as an overthrust of regional extent along which allochthonous Precambrian and lower Paleozoic sedimentary rocks of the Inyo-White Mountains were emplaced from the west over upper Paleozoic rocks. This thrust fault developed earlier than the Santa Rita Flat pluton, which has yielded a K-Ar hornblende date of 156 m.y. (Ross, 1969). Stevens and Olson envision an east-dipping thrust surface which is continuous beneath the "Inyo-White Mtns allochthon" with the surface of the Last Chance thrust, east of the Inyo Mountains.

This interpretation of the Inyo thrust exposures, hinging on the presumed eastward dip of the fault, is open to debate. The following observations suggest, instead, that the younger, western rocks were thrust over the older rocks on the east along a moderately west-dipping thrust fault:

1. Cross-sections of the Inyo thrust are observed in three small canyons which cut through the fault surface. Mississippian and younger rocks, with black chert of presumed Ordovician age (Ely Springs Formation) lie west of a 50-60° W-dipping surface which abuts Ordovician rocks on the east. The interpretation of Stevens and Olson requires that this surface is a disturbed, but normal

stratigraphic contact, and that the black chert belongs with the Ordovician rocks east of this surface, but is complexly folded into the younger rocks it supposedly tectonically overlies.

2. Designation of the black chert as allochthonous Ordovician confuses the location and attitude of the main thrust surface. The chert actually occurs as massive, fault-bounded lenses, structurally a part of the late Paleozoic rocks west of the thrust, rather than part of an "allochthon" complexly infolded into these rocks. Its age is uncertain, as late Paleozoic formations in this area, e.g., Owens Valley Formation, contain chert. Planar structures in chert outcrops, probably relict bedding, are commonly observed to dip west, concordant with attitudes in much of the younger, western rocks.

3. The west-dipping surface of (1) is therefore probably the principal surface of movement. While it dips east in one area (Stevens and Olson, Figure 2, points 10-11), in most areas rocks of the eastern block actually lie beneath this surface, and therefore make up the autochthonous block.

4. Several W-dipping faults, with reverse displacement as determined from overturned folds beneath them, are reported by Stevens and Olson (1972) in hills west of the main Inyo thrust. Their presence in the "autochthon" beneath a tightly folded, east-dipping Inyo thrust requires a complex interpretation. They may be reinterpreted as imbrications in allochthonous rocks, west of and structurally above a main, west-dipping thrust surface.

5. Bedding and structures such as transposition foliations in the Ordovician rocks east of the main fault surface are commonly vertical or dip west at moderate to high angles, parallel to the observed W-dipping fault surface of (1) above. This geometry is difficult to reconcile with the east-dipping thrust model.

The Coso thrusts provide a conceptual precedent for west-dipping, deeply rooted thrust faults at the boundary between the Sierra Nevada plutonic complex and an eastern sedimentary and plutonic terrane. This style of faulting may have occurred at different points along the eastern margin of the batholith at various times in the Mesozoic, reflecting repeated episodes of compression localized at the batholithic margin. A granitic allochthon is apparently not important in the development of the White Mountains fault zone or the Inyo thrust, along which younger rocks (Late Paleozoic or Mesozoic volcanic rocks) were emplaced over older Paleozoic strata or plutonic rocks. This juxtaposition would be expected from faulting along the common limb between a structurally depressed trough coaxial with the batholith (the site of volcanic accumulation) and a structural high, such as the Inyo anticline (Stevens and Olson, 1972), east of the batholith.

Discussion

Rooted thrust faults comparable in tectonic style to the Coso thrust system are common in the Mojave desert region. Thrust faults involving plutonic rocks or crystalline basement in this region are listed in Table 3. The Chocolate Mountain-Vincent-Orocopia thrust system (Dillon and Haxel, 1975), for example, is a linear system of basement-rooted thrust faults similar in scale to the Coso system. Along these and other thrusts crystalline basement and plutonic rock were transported northeastward over greenschist-facies Mesozoic sedimentary and volcanic rocks. The Slate Range thrust faults of the Coso system juxtapose corresponding rock types.

Rooted thrust faults of the Mojave desert may be related to high crustal temperatures, as suggested by Armstrong and Dick (1974), and to the relative mechanical isotropy of the Mojave upper crust, part of which is a salient of ancient sialic crust at the continental margin, and lacks a thick, anisotropic geosynclinal cover. Diverse styles of thrusting in several areas of the Cordillera are linked to variations in these two parameters by Burchfiel and Davis (1975). Both isotropy and high heat flow were imparted to the previously cold, layered upper crust of the miogeosyncline by emplacement of Mesozoic batholithic rocks. As these factors are possible prerequisites for rooted thrust faults, the Coso system might therefore be regarded broadly as a distal response to the Mesozoic tectonic regime of the Mojave region. Its apparent close relation to the batholith itself, however, suggests a more specific genetic scheme.

The first of two major magmatic pulses which built the Sierra Nevada batholith occurred in Middle and Late Jurassic time. The Jurassic batholithic

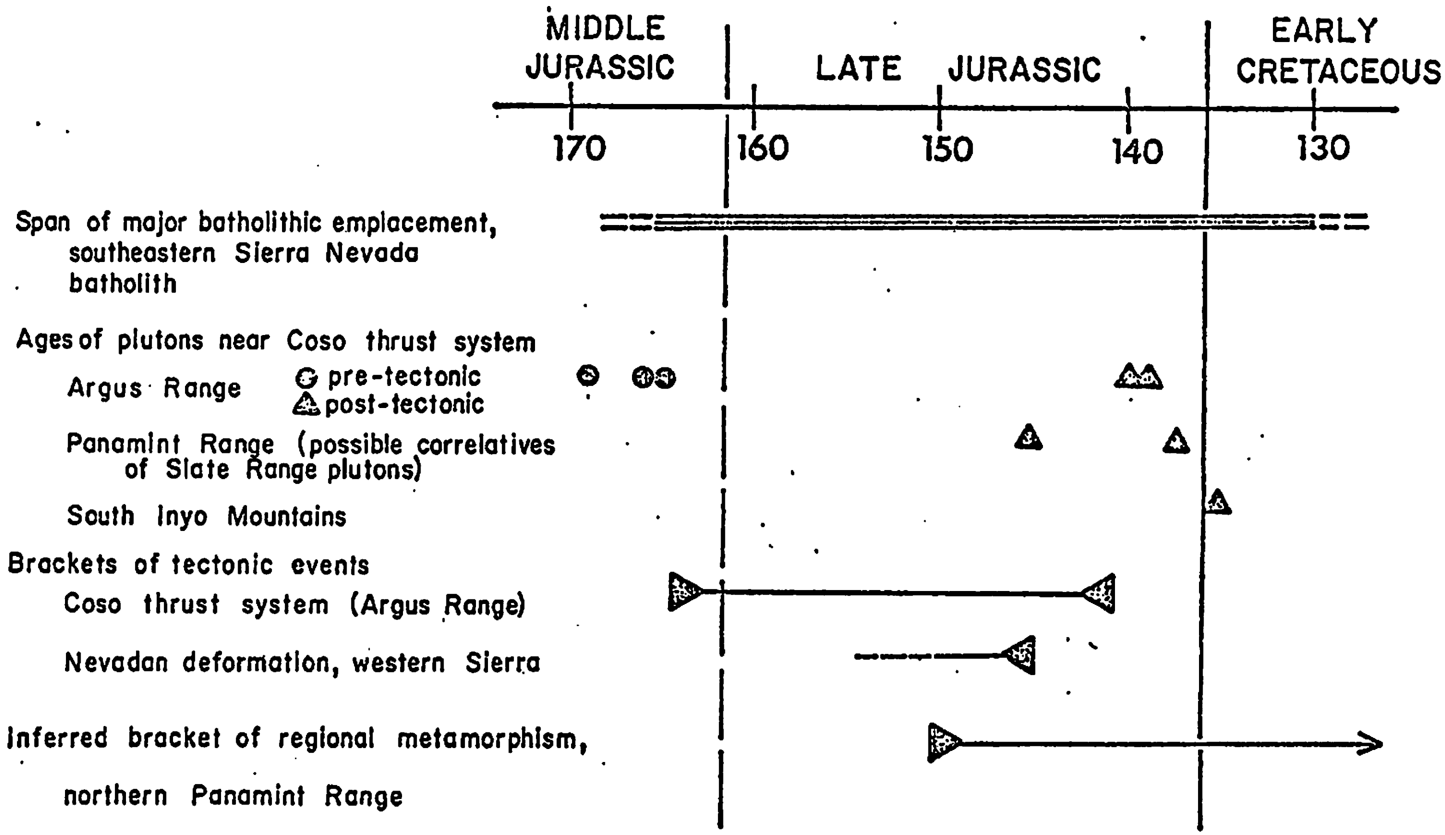

Table 2. Chronology of Late Jurassic intrusive, tectonic and thermal events. Sources: Armstrong and Suppe (1973), Moore and Harakal (1976) Ross (1969), Schweickert and Cowan (1975), Lanphere and others (1964). Epoch boundaries from Harland and others (1964).

TABLE 3: THRUST FAULTS INVOLVING PRECAMBRIAN BASEMENT OR PLUTONIC ROCKS IN THE MOJAVE REGION

System	Thrust and location	Average dip	Inferred direction of yielding	Allochthon	Autochthon	Age of movement	References	Remarks
COSO thrust system	Argus Sterling thrust, and related thrusts to N.	30° W	NE	Jurassic intrusive rocks	Pz sediments & Mz intrusive rocks	late Jurassic (160-135 m.y.)	This report; Moore, 1974	Moderate mylonite zone; granitic rocks intrude fault
COSO thrust system	Layton Well and Sand Cyn. thrusts, Slate Range, and Drinkwater Lake area	30° W	E	Mz intrusive rocks and pC(?) gneiss	Mz metavolcs. & metasediments	J?	Smith, et.al., 1968; Davis and Burchfiel, 1974	Widespread penetrative shear and diaphthoresis
COSO thrust system	South Park Cyn. fault and possible northern extension, Panamint Range	40° W	E	pC gneiss and late pC sediments	late pC sediments	J? (pre-145 m.y.)	Johnson, 1958; Armstrong and Suppe, 1973 (date)	Relatively small offset; granitic rocks intrude fault
	El Paso Mtns.	50° E	?	mostly Pz rocks	Mz metasediments (Mesquite schist) & intrusive rocks	Tr (?) (pre-218 m.y.)	Dibblee, 1967; Armstrong and Suppe, 1973 (date); R.L. Christiansen (pers.comm.)	Penetrative shear of all rocks
	Randsburg area	NE to flat; arched	N or W?	pC gneiss and Mz intrusive rocks	Mz metasediments (Rand Schist)	K?	Ehlig, 1968; Dibblee, 1967	Greenschist metamorphism of autochthonous rocks
Chocolate-Orocopia-Vincent thrust system	Vincent thrust, San Gabriel Mtns., with extensions in Sierra Pelona, & near Redlands	30-40° SW	NE	pC gneiss and Mz intrusive rocks	Mz metasediments (Pelona Schist)	K?	Ehlig, 1968; Crowell, 1968	Do.
Chocolate-Orocopia-Vincent thrust system	Chocolate Mtns. & Orocopia thrusts; & Picacho area	"moderate"	NE	pC gneiss and Mz intrusive rocks	Mz metasediments (Orocopia Schist)	K? (post-145 m.y.)	Dillon and Haxel, 1975	Do.
	McCoy Mtns. and N. Mule Mtns.	"gently S."	NE	pC gneiss	Mz metasediments	late K or later	Pelka, 1973; Crowell, 1968	Penetrative shear and slight metamorphism of autoch. rocks
	Winters Pass thrust, Clark Mtn.	30° W; flat at depth	E	pC gneiss	Pz sediments	Tr or J	Burchfiel and Davis, 1971	Inferred thin-skin geometry

rocks occupy a southeast trending belt. These rocks underlie the area east of the southern Sierra Nevada Range and extend into the central Mojave desert, and presumably include much of the western plutonic terrane of Figure 37 (Kistler and others, 1971; Armstrong and Suppe, 1973). The volume of Jurassic plutons relative to country rock is uncertain, and determination of the extent of these rocks west of the Coso thrust system is hampered by the present lack of geochronological data, and by overlap of Cretaceous and Jurassic intrusive loci. Figure 39 depicts a Jurassic batholith similar to that of the Cretaceous: a mass of coalescing, upper-crustal plutons, grading eastward into the terrane of discrete plutons that is exposed in the Inyo Range.

Formation of a linear belt of isotropic plutonic rocks affected the regional structure profoundly. The batholithic complex truncated the northeast trending miogeosynclinal wedge and thrust belts within the Paleozoic sedimentary prism. Pre-Cambrian basement rocks, which underlie miogeosynclinal strata throughout the area of Figure 37, were engulfed and downbuckled by magmas rising into the uppermost strata of the sedimentary section. During the peak of Jurassic intrusion, the plutonic belt was a zone of high heat flow. Crystalline basement and overlying Late Precambrian sedimentary rocks inferred to be present beneath the exposed batholith, were subjected to amphibolite-grade metamorphism at near-anatectic temperatures in the depths of the belt, and probably remained ductile throughout much of Late Jurassic time. Mid-Mesozoic metamorphic ages (100-150 m.y.) in basement rocks and overlying Precambrian strata east of the batholithic margin document high ambient crustal temperatures (Lanphere and others, 1964).

Kistler and others (1971) argue that much of the presently exposed

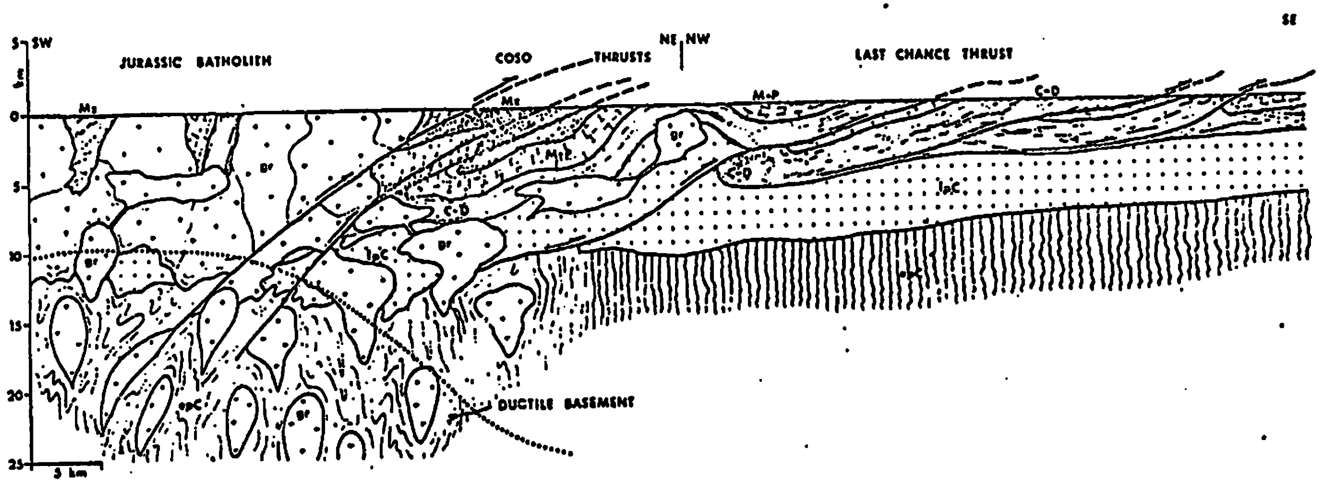

FIGURE 39. Schematic cross-section of the Coso thrust system at the latitude of the southern Inyo Mountains during Late Jurassic. Datum is the approximate present level of exposure; 1-5 km of overlying strata, presumably including thick accumulations of volcanic rocks, are omitted. The Last Chance and other northeast-trending decollement thrusts, that are oblique to the Coso system, are included by bending the section. Dotted line is a hypothetical isothermal surface separating stress-transmitting, rigid upper crust from high-temperature ductile lower crust.

Conclusions

A common deformational style and the near co-linearity of several moderate-angle thrust faults, marginal to the southeastern Sierra Nevada batholith, justify their recognition as a single structural entity. It is suggested that the thrust system originated in response to a single major movement event in the Late Jurassic, as determined from bracketing plutons in the Argus Range, although a multiple deformational history may be demonstrable with additional data. The thrust faults root deeply in the Sierra Nevada plutonic complex, and their development was influenced by the geometry of the Jurassic intrusive belt, and by the thermal characteristics of the batholithic crust. Structures east of Owens Valley may have had a similar origin.

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K-AR AGE BRACKET ON A LATE JURASSIC THRUST FAULT IN SOUTHEASTERN CALIFORNIA

Best Regards to Carl & Ken 1-3-76 /SCM

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Emplacement of the Argus Sterling thrust fault in the Death Valley region of southeastern California is chronologically bracketed by the ages of granitic rocks that cut, and are cut by, the fault surface (Moore, 1974). The relations permit an excellent opportunity for delimiting by potassium-argon the time span during which thrust faulting took place. Seven hornblende and biotite separates were prepared from four samples collected from two pretectonic intrusive masses and two post-thrust plutons. The separates were prepared by magnetic, heavy liquid and mechanical methods and checked for purity by X-ray diffraction. Argon determinations were made in the isotope laboratory of the Department of Geophysics and Astronomy, University of British Columbia, using an AEI MS-10 mass spectrometer. Potassium was analyzed by atomic absorption on a Model 303 Perkin-Elmer spectrophotometer by R. L. Armstrong, Department of Geological Sciences, University of British Columbia. Uncertainties presented are at 1σ. Constants used are: $\lambda_\epsilon = 0.575 \times 10^{-10}$; $\lambda_\beta = 4.905 \times 10^{-10}$; $K^{40}/K = 1.18 \times 10^{-4}$.

GEOLOGIC DISCUSSION

The Argus Sterling thrust is exposed in the Argus Range, Inyo Co., where it dips 15 to 40 degrees SW (Fig. 1). It juxtaposes distinct quartz monzonitic complexes and is further intruded by several younger plutons. Rocks correlative with the Hunter Mountain Quartz Monzonite (McAllister, 1956), intruding roof pendants of Paleozoic sediments, are overlain along the thrust by porphyritic quartz monzonite of Maturango Peak, part of a granitic terrane that extends several miles westward to the Sierra Nevada. North and east of Maturango Peak, plutons of alaskite and younger quartz monzonite have come up along the thrust plane separating the two blocks and spreading apart zones of mylonitic quartz monzonite and tectonite marble that characterize the thrust exposures further south.

Six of the seven apparent ages determined cluster at two time points, defining two episodes of intrusion and cooling (Fig. 2). The Hunter Mountain Quartz Monzonite yielded concordant hornblende-biotite ages which agree well with previously published dates on this intrusive complex (Burchfiel and others, 1970; Ross, 1969). The hornblende age of Maturango Peak gives a 165 m.y. minimum age for this unit and suggests that it is roughly contemporaneous with the Hunter Mountain unit.

The younger plutons yield ages that indicate an intrusive event at about 140 m.y. This event is probably responsible for the discordance in the Maturango Peak sample which was collected within one kilometer of the younger plutons. A young apparent age for biotite of the quartz monzonite of Argus Sterling mine may reflect late alteration in this extensively chloritized pluton.

Significant conclusions from these data are: (1) The Argus Sterling thrust was emplaced between 140 and 165 m.y. (Late Jurassic); (2) Radiometric ages from granitic rocks in this area are comparable with those from areas in the Inyo Mountains (Ross, 1969; Armstrong and Suppe, 1973); (3) Thrusting in the Argus Range postdated the onset of batholithic intrusion in this area comprising a tectonic event later than and distinct from the early Mesozoic deformation belt described by Burchfiel and others (1970), which is characterized by pre-mid-Jurassic thrust faulting (Fig. 2).

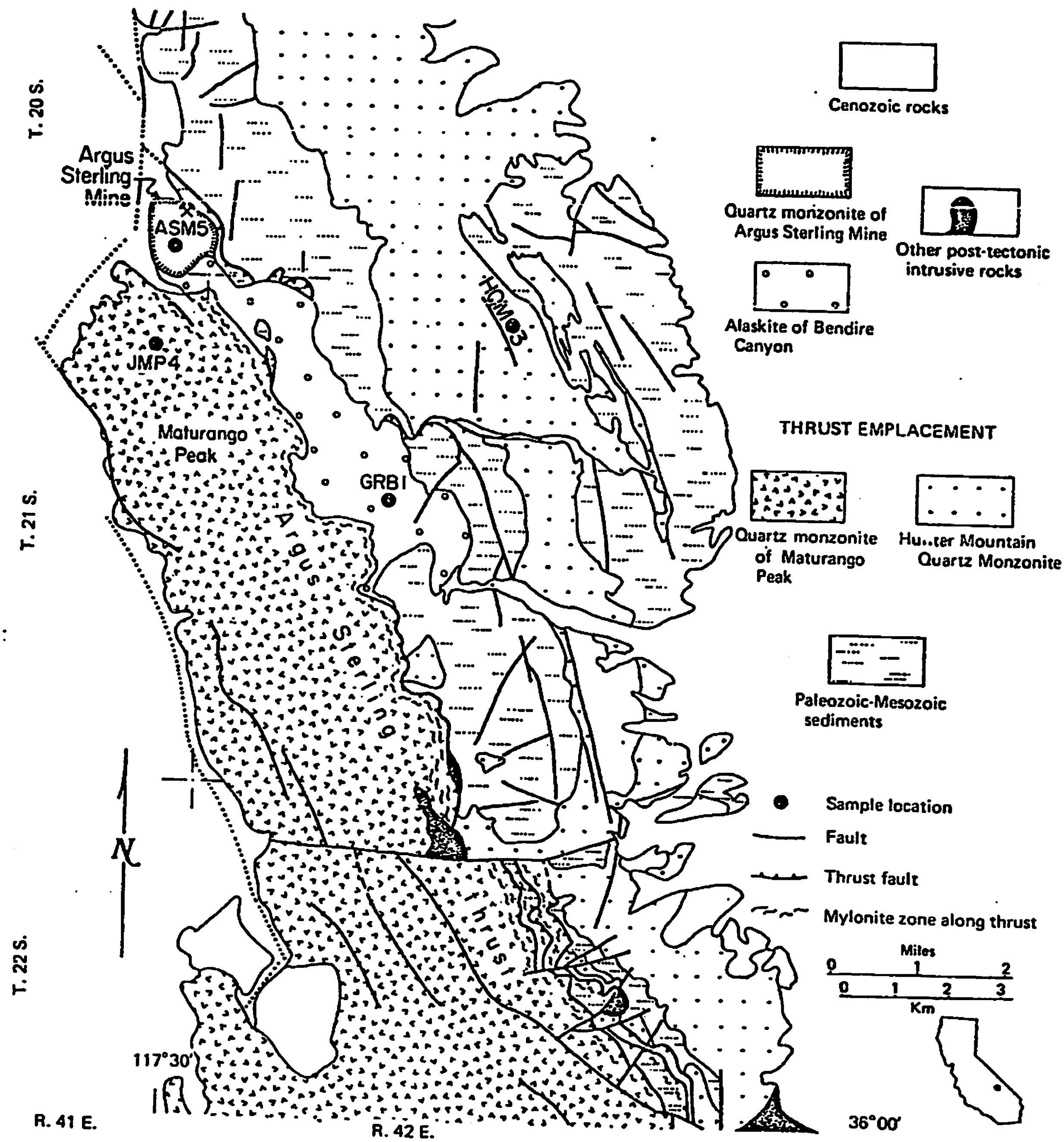

FIGURE 1. Geologic map of part of the Argus Range.

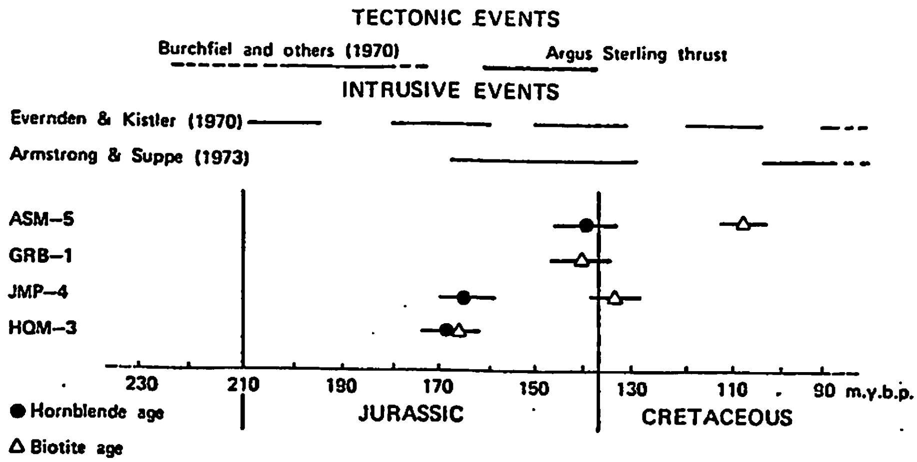

FIGURE 2. K-Ar ages of granitic rocks from the Argus Range compared with regional tectonic and intrusive events (period boundaries after Armstrong and Suppe, 1973).

SAMPLE DESCRIPTIONS

1. HQM-3 K-Ar <u>(hornblende) 169 ± 6 m.y.</u> <u>(biotite) 166 ± 6 m.y.</u>

Medium-grained, equigranular quartz monzonite is correlative with the Hunter Mountain Quartz Monzonite (36°8′12″N, 117°26′15″W; upper Knight Canyon, Argus Range, Inyo Co., CA). Several samples from the Argus Range average 37% calcic oligoclase to calcic andesine; 22.5% quartz; 29% potassium feldspar; 7% hornblende; and 4% biotite. Analytical data: (hornblende) K = 0.394%; $^*Ar^{40} = 1.209 \times 10^{-10}$ moles/g, $^*Ar^{40}$/total Ar^{40} = 72.2%; (biotite) K = 6.74%, $^*Ar^{40} = 2.033 \times 10^{-9}$ moles/g, $^*Ar^{40}$/total Ar^{40} = 80.9%.

2. JMP-4 K-Ar (hornblende) 165 ± 5 m.y. (biotite) 132 ± 5 m.y.

Quartz monzonite of Maturango Peak (36°8′14″N; 117°30′15″W; 2 km NW of Maturango Peak; Inyo Co., CA). Medium-grained, porphyritic quartz monzonite with potassium feldspar phenocrysts to 2 cm. Several samples average 41.5% sodic andesine, 16% quartz, 24% potassium feldspar, and 18.5% hornblende plus biotite. Analytical data: (hornblende) K = 0.997% $^*Ar^{40} = 2.989 \times 10^{-10}$ moles/g, $^*Ar^{40}$/total Ar^{40} = 86.3%; (biotite) K = 7.01% $^*Ar^{40} = 1.661 \times 10^{-9}$ moles/g, $^*Ar^{40}$/total Ar^{40} = 85.6%.

3. GRB-1 K-Ar (biotite) 140 ± 6 m.y.

Alaskite of Bendire Canyon (36°6′32″N, 117°27′17″W; near upper Bendire Canyon; Inyo Co., CA). Biotite alaskite containing roughly equal proportions of coarse-grained sodic plagioclase, quartz, and perthitic potassium feldspar; biotite averages 3%. Analytical data: (biotite) K = 6.89%; $^*Ar^{40}$ = 1.739×10^{-9} moles/g; $^*Ar^{40}$/total Ar^{40} = 87.7%.

4. ASM-5 K-Ar (hornblende) 139 ± 5 m.y. (biotite) 108 ± 4 m.y.

Quartz monzonite of Argus Sterling Mine (36°8′56″N, 117°29′51″W; Inyo Co., CA). Fine- to medium-grained quartz monzonite in a small pluton north of Maturango Peak. Analytical data: (hornblende) K = 0.872%; $^*Ar^{40} = 2.179 \times 10^{-10}$ moles/g; $^*Ar^{40}$/total Ar^{40} = 76.2%; (biotite) K = 6.68%; $^*Ar^{40}$ = 1.291×10^{-9} moles/g; $^*Ar^{40}$/total Ar^{40} = 81.5%.

All samples collected by S. C. Moore, 1974.

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