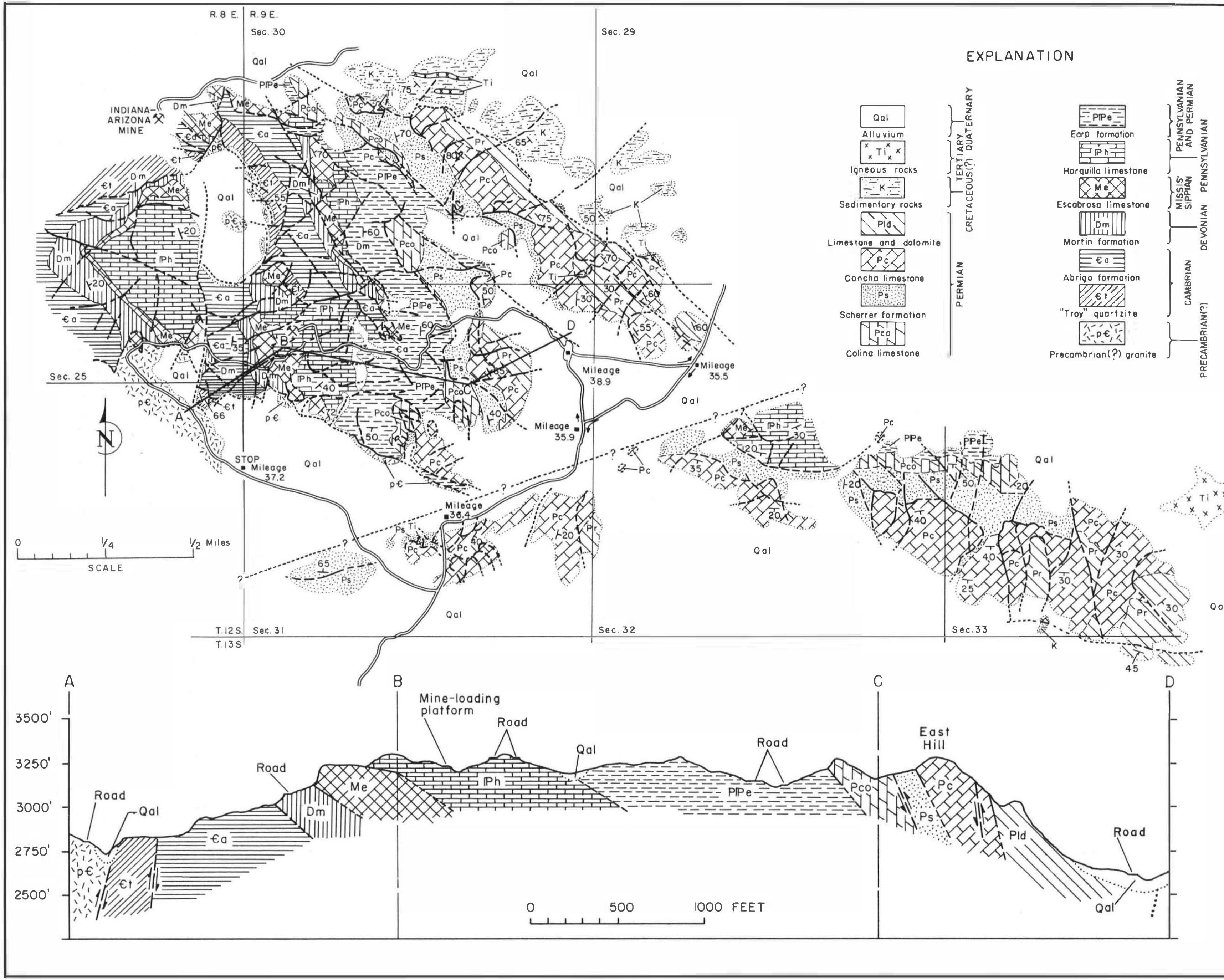

FIGURE 7. Geologic map of the central and eastern parts of the Waterman Mountains, Pima County, Arizona, and cross section approximately along route of traverse across Paleozoic formations.

PALEOZOIC STRATIGRAPHY OF THE WATERMAN MOUNTAINS, PIMA COUNTY, ARIZONA

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INTRODUCTION

The Waterman Mountains are topographically typical of Basin and Range province mountains, but they are distinguished because they are composed predominantly of Paleozoic sedimentary rocks. In contrast, most nearby mountains and hills are composed principally of possible Precambrian rocks or of Cretaceous(?) and younger sedimentary, volcanic, and intrusive rocks. The interior structure of ranges in this area is known to be complex (Brown, 1939; Bromfield, 1950; Richard and Courtright, 1954). The structure in the Waterman Mountains is noteworthy because to a large extent it involves Paleozoic rocks whose stratigraphy is definable. These Paleozoic rocks are described briefly in this report.

The Waterman Mountains are about 35 miles west of Tucson, Ariz. (fig. 55), and about 5 miles southeast of the Silver Bell Mountains and the Silver Bell mining camp (fig. 45). South and southeast of the Watermans are the low hills of the Roskruge Mountains and to the east and west of the range are two broad alluvial valleys. The valleys on either side of the Waterman Mountains are about 2, 100 feet above sea level; the range rises to Waterman Peak, which is 3,820 feet in altitude (fig. 8A).

The Waterman Mountains were first mapped in 1924 for the Arizona State geologic map on a scale of 1:500,000 (Darton and others, 1924). Portions of the range were mapped by A. W. Ruff (1951) and by the writer (McClymonds, 1957) and a general mapping program by the U. S. Geological Survey is presently in progress on that part of the Waterman Mountains within the Papago Indian Reservation.

Internally the Waterman Mountains appear to be composed of the eroded remains of a crumpled recumbent fold, broken by three major sets of faults (fig. 7). The fold trends northwestward through the central part of the range and plunges to the southeast. The northeastern flank of the fold is well expressed by the ridges along the northeast front of the range. The southwestern flank is represented by both the ridges in the southwestern part of the range and the hills south of the Waterman Mountains. The rocks on the southwestern flank appear to be more thoroughly broken by faults than those on the northeastern flank, and the hills south and east of the main part of the Waterman Mountains are presumed to have been displaced eastward along a strike-slip fault (fig. 8C). Folding, other than expressed in the large, poorly defined recumbent fold, is minor and occurs within incompetent beds such as those of the Earp formation.

The major fold was broken by high-angle thrust faults that trend generally N. 45° W. The large wedge of older Paleozoic rocks in the central part of the range displaced, and is now bounded by, Pennsylvanian and Permian beds along this northwest trend (fig. 8B). This trend is roughly parallel to the probable fault contact between the Paleozoic rocks of the northeast flank of the fold and the topographically lower Cretaceous (?) rocks to the northeast. It is suggested that the Waterman Mountains were formed by the thrusting of Paleozoic and Precambrian(?) rocks through the Cretaceous(?) sedimentary rocks.

Subsequent faulting along N. 60°-75° E. and N. 85° W. trends displaced the N.

45° W. structures by amounts ranging from a few feet to about 1,000 feet. Displacement of about 1-1/2 miles appears to have occurred along the probable N. 75° E. -trending strike-slip fault south of the central part of the range.

Wilson (1949) stated that much of the thrusting in southern Arizona occurred during the Laramide orogeny along northwestward trends and that later Cenozoic orogenies had subparallel trends. The trend of the folding, the direction of movement, and the probable ages of the rocks involved in the Waterman Mountains conform to Wilson's hypothesis. L. A. Heindl of the Geological Survey (personal communication, 1957) reports that remnants of Paleozoic limestone south of the Waterman Mountains lie as klippe on Tertiary(?) intrusive rocks. The age of deformation in the Waterman Mountains is tentatively considered to be post-Cretaceous(?), and possibly as late as middle Tertiary.

STRATIGRAPHY

The entire sequence of Paleozoic rocks known in south-central Arizona lies in apparent conformity in the Waterman Mountains. Evidence of erosional intervals between periods of deposition is not marked, except for the red pebbly mudstone layer between the Mississippian Escabrosa limestone and the Pennsylvanian Horquilla limestone. The Paleozoic section in the Waterman Mountains is shown diagrammatically in its relationship to Paleozoic sections to the east and west in figure 9.

The older rock formations of the range are confined to the western part of the central portion, and progressively younger beds crop out eastward and northward, with a few repetitions due to fault displacements.

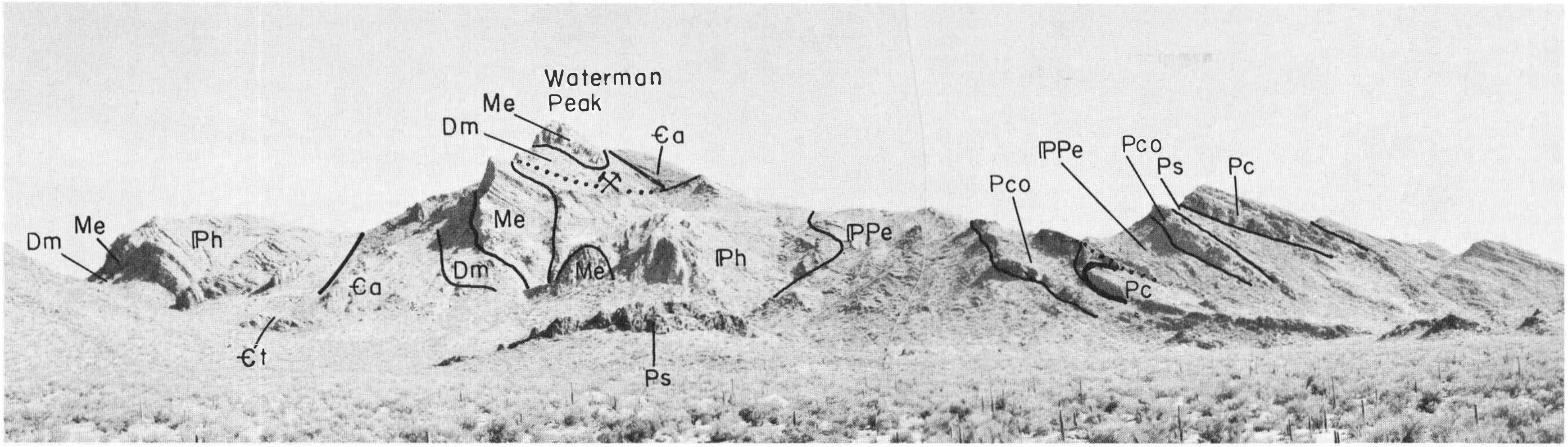
Cambrian System

Troy Quartzite

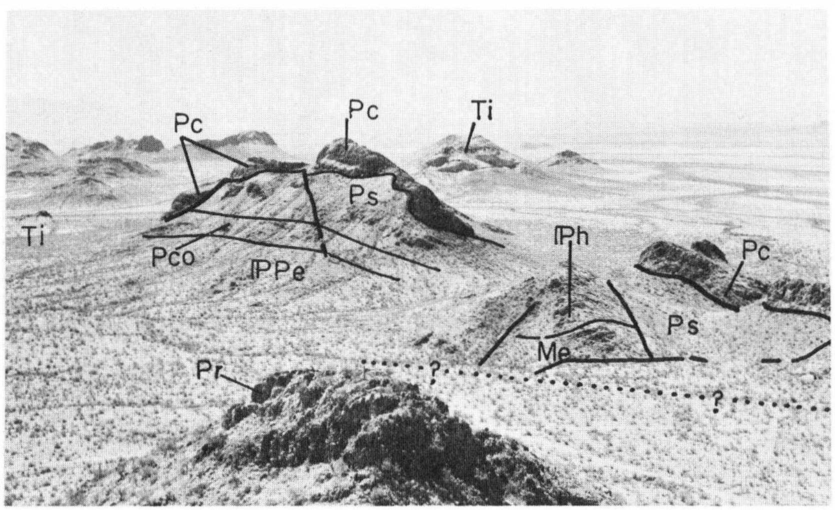
The Troy quartzite of Middle Cambrian age crops out in the western part of the Waterman Mountains. The Troy quartzite appears to lie on the greenish granite of Precambrian(?) age, but the contact is obscured by faulting wherever the writer observed it (McClymonds, 16). The Troy quartzite forms reddish-brown vertical or sloping cliffs and is easily recognizable by its prominence and stratigraphic position.

The formation is normally called the Troy quartzite in southern Arizona where the sedimentary rocks of the Apache group underlie the Cambrian quartzite; where the Apache group is missing and the Pinal schist or a Precambrian granite underlies the quartzite the term "Bolsa quartzite" is used. The writer, in working in south-central Arizona, has found no reason to designate the Cambrian quartzite by two terms, implying different strata, and thus carries the term "Troy" from the Vekol and Slate Mountains, where the Apache group is present, to the Waterman Mountains area.

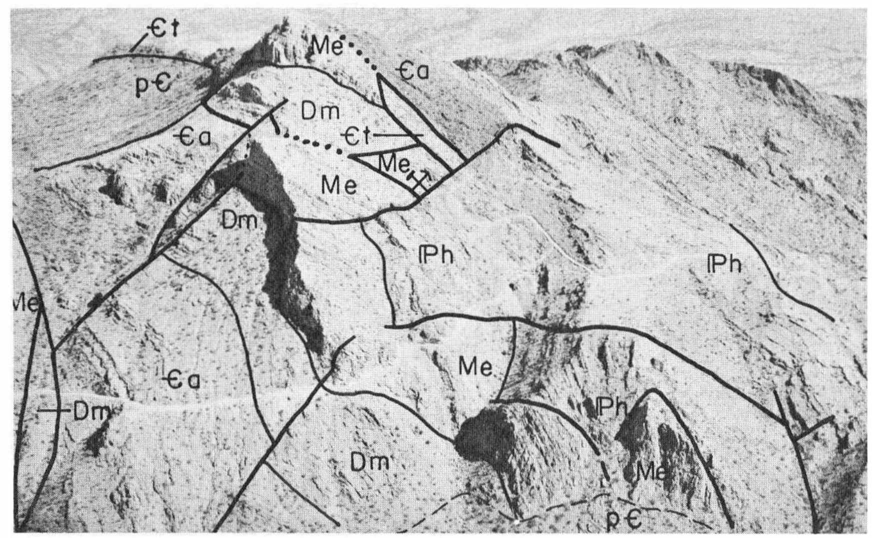
The Troy quartzite is made up of silt- to granule-sized poorly sorted, subrounded, clear to milky quartz grains, firmly cemented by silica. Iron stain, in the form of limonite and small pseudomorphs after pyrite, produces the reddish-brown color. The weathered surface of the quartzite is white to brown, glassy, and characteristically coated with black desert varnish. The lower 20 feet of the Troy contains a large concentration of granule- to medium pebble-sized quartz particles; no fragments of the underlying granite were recognized within the basal unit. Much of the



A. View north of south central part of the Waterman Mountains; Cambrian "Troy" quartzite (Ꞓt) and Abrigo formation (Ꞓa); Devonian Martin formation (Dm); Mississippian Escabrosa limestone (Me); Pennsylvanian Horquilla formation (ℙh); Pennsylvanian and Permian Earp formation (ℙPe); Permian Colina limestone (Pco); Scherrer formation (Ps); Concha limestone (Pc), and "Rainvalley formation" (Pr); Tertiary intrusive rhyolite (Ti). Dotted lines indicate contacts in defilade.



B. View southeast of hogbacks at east end of the Waterman Mountains.



C. South front of Waterman Peak.

FIGURE 8. Photographs of the south central and eastern parts of the Waterman Mountains, Pima County, Arizona. Photos by N. E. McClymonds.

formation has small-scale, low-angle crossbedding with cosets up to 4 feet thick.

The formation is about 220 feet thick in the central and southwestern parts of the Watermans. Ruff (1951) reported 95 to 185 feet of the Troy at the northwest end of the range. The thinning of the formation toward the northwest indicated by these measurements may be stratigraphic, or may be only apparent as a result of faulting. No fossils were found in the Troy quartzite of the Waterman Mountains, and the formation was identified by its stratigraphic position and lithologic character.

Abrigo Formation

The Abrigo formation crops out in its normal stratigraphic position in the western part of the Watermans, and in the central part of the range it is repeated three times in fault slivers. The Abrigo formation everywhere appears to overlie the Troy quartzite conformably; it forms a slope-cliff-slope topography reflecting its three members.

The strata between the Troy quartzite and the Martin formation can be correlated with other sections of the Middle and Upper Cambrian in southern Arizona in only a broad sense, except for the possible correlation with the Southern Belle quartzite of the Santa Catalina Mountains (Stoyanow, 1936). Because of the variation of lithology from area to area, these sediments are all grouped here into the Abrigo formation, much like the original description of the Abrigo by Ransome (1904).

The Abrigo formation of the Waterman Mountains is divided into three distinct members which may be traced throughout the area of outcrop. The lower member is composed mostly of siltstone and mudstone, with several thin sandstone beds. The mudstone is olive to brownish gray, micaceous, and silty, and the interbedded siltstone is brownish and greenish gray. Some of the sandstone beds are partly quartzitic. The lower member is slightly calcareous throughout, becoming more calcareous toward the top. This member is 275 to 332 feet thick.

One 30-foot sandstone unit in the lower member, composed of two sandstone beds separated by silty mudstone, occurs about 180 feet above the base. This unit is tentatively correlated with the Southern Belle quartzite (Stoyanow, 1936), and the underlying beds may correlate with the Santa Catalina formation (Stoyanow, 1936) in Peppersauce Canyon in the Santa Catalina Mountains. The middle and upper members of the Abrigo formation in the Waterman Mountains have no lithologic equivalents at Peppersauce Canyon.

The middle member of the Abrigo formation lies conformably, but with a sharp contact, on the lower member. This member is composed of dark-gray limestone with small brown muddy limestone pockets and, near the top, green shale partings. The beds are 1 to 15 feet thick and the middle portion forms a cliff, whereas the upper and lower portions of the middle member form a series of ledges. The middle member ranges in thickness from 239 to 276 feet.

Overlying the middle limestone member is the upper member of the Abrigo formation, composed of claystone and limestone. The claystone is olive gray to green, micaceous, and silty, in beds ranging from 3 to 10 feet in thickness. Interbedded with the claystone beds are 1- to 2-foot-thick beds of flat-pebble limestone conglomerate and silty limestone. An upper unit, about 50 feet thick, consists of a light-gray silty, marl-like material containing two prominent light-brown-weathering beds of resistant silty dolomite. The upper member is 110 to 171 feet thick.

The total thickness of the Abrigo formation in the Waterman Mountains ranges from 687 to 718 feet. Individual members vary in thickness, but no consistent thickening or thinning of the formation was recognized within the range.

Ruff (1951) found several indistinct trilobites about 45 feet above the base of the upper member in the northwestern part of the range, but elsewhere only worm-burrow casts and concretions were found. Although the age of the Abrigo formation cannot be ascertained in this area, the Abrigo or its equivalent has been described as Middle and Upper Cambrian (Stoyanow, 1936).

Devonian System

Martin Formation

The Martin formation overlies the upper member of the Abrigo formation with apparently perfect conformity. Although the time lapse between the deposition of the Abrigo and Martin represents the Ordovician, Silurian, and early part of the Devonian periods, the contact between the two formations appears to be almost gradational. The area of outcrop of the Martin formation is the same as that of the Abrigo. The Martin is 364 to 385 feet thick, and although individual units are not everywhere present, marker beds indicate no important thickening or thinning within the Waterman range.

The lower unit of the Martin formation is about 240 feet thick and is composed of interbedded resistant and nonresistant layers of gray, grayish-red, and brownish-gray finely crystalline silty dolomite, with a few beds of sandstone and silty limestone. This unit has no distinct fossils. A middle unit, about 100 feet thick, is lithologically similar to the lower unit but contains several beds with spiriferid and rhynchonellid brachiopods and, at the base, *Cladopora* sp. and *Aulopora* sp.

The upper unit is up to 42 feet thick and is composed of medium- to light-gray finely crystalline dolomitic limestone which weathers yellowish brown. The upper unit was considered by Ruff (1951) to be basal Escabrosa limestone, but it is here placed in the Devonian because, in the absence of fossils, the dolomitic nature of the unit makes it more similar to the Martin than to the Escabrosa, which is a rather pure limestone. Furthermore, in the southwestern part of the range, the contact between this unit and the Escabrosa limestone is an undulating surface having a relief of about 4 feet.

Spirifer orestes, *Tenticospirifer cyrtiniformis*, and other spiriferid brachiopods found about 60 feet above the base of the middle unit (about 300 feet above the base of the formation) restrict the upper portion of the Martin formation to Late Devonian age. The assemblage of fossils is similar to that described by Stoyanow (1936) in the Peppersauce Canyon section.

Mississippian System

Escabrosa Limestone

The Mississippian Escabrosa limestone overlies the Devonian Martin formation with apparent conformity, although an erosional surface is developed locally as mentioned above. Throughout the range, the Escabrosa forms a steep cliff, most prominently expressed as the capping ridges in the central and western parts of the range.

At the base of the Escabrosa limestone is an 85-foot unit of gray to pinkish aphanitic to finely crystalline fairly massive limestone. Within this 85-foot unit are two zones of nodular chert and a 2-foot-thick sandstone bed, respectively 40, 50, and 65 feet above the base. Overlying the massive beds is 25 feet of thin-bedded, color banded, aphanitic limestone which commonly forms a notch or shelf in the Escabrosa cliff. A second gray limestone unit lies above these less-resistant beds. This unit, which is as much as 110 feet thick, contains several types of horn corals, including Syringopora sp. and Michelinia sp., and brachiopod and gastropod outlines. The uppermost unit of the Escabrosa is light-gray or pink, medium to finely crystalline limestone that contains a few horn corals in the lower beds and abundant crinoid stems in the upper part. The uppermost unit is 40 feet thick in the central part of the Watermans and thickens to 55 feet toward the northwest.

The total thickness of the Escabrosa limestone ranges from 228 to 282 feet. Much of this difference appears to be due to erosion of the uppermost unit prior to the deposition of the younger deposits, but some westward thickening also is indicated.

Pennsylvanian System

Horquilla Limestone

The Horquilla limestone lies on the Escabrosa limestone unconformably, having a 7- to 20-foot basal conglomerate made up of red and gray chert nodules in a red mudstone matrix. The Horquilla limestone crops out widely throughout the Waterman Mountains and usually forms steplike or dip slopes. In the central part of the Waterman Mountains a section of 488 feet of the Horquilla was measured, and Ruff (1951) reported 671 feet of the Naco formation (Horquilla limestone of this report) in the northwestern part of the range. The differences in thickness probably resulted from either repetition or cutting out due to faulting.

The Horquilla limestone is composed of alternating beds of limestone, silty limestone, and siltstone. This alternation suggests either oscillation of the seas, or climatic changes or orogenic movement in the source areas. The limestone is light to medium gray, is aphanitic to finely crystalline, and usually weathers light gray. The silty limestone is brownish gray and weathers light brown to grayish orange; some beds appear conglomeratic, with stringers of silty limestone enveloping cobble-sized nodules of less silty limestone. The siltstone is brownish gray to light red, weathers light to dark brown, and is usually calcareous. The beds are commonly 8 to 30 feet thick, but some are 1 to 2 feet thick.

Although a few beds have abundant fossils, fossils are not common in the Horquilla limestone. Chaetetes milliporaceous, the type fossil of the Horquilla in southern Arizona, occurs in two horizons, about 160 and 410 feet above the base of the formation. Syringopora sp. was found only near the base, and other corals were identified in the interval from 115 to 160 feet above the base. Fusulinids are common in the lower 118 feet of the formation, and ostracods occur in a few beds in the lower 182 feet. Crinoid stems are common, but scattered, throughout. Brachiopods are usually broken into fragments or are represented only by outlines, but one bed, 280 feet above the base, contains Dictyoclotus sp., Neospirifer sp., Rhipidomella sp., and rhynchonellid brachiopods. This bed also contains pelecypod and crinoid stems up to three-quarters of an inch in diameter.

Pennsylvanian and Permian Systems

Earp Formation

The units lying between the Horquilla and Scherrer formations in the Tombstone Hills, 65 miles southeast of Tucson, were described by Gilluly and others (1954) as the Earp formation, Colina limestone, and Epitaph dolomite. In the Empire Mountains, 30 miles southeast of Tucson, D. L. Bryant (1955) found that the three formations were not distinguishable, and applied to the sequence the name Andrada formation, previously used by Wilson (1951). Farther west, in the Waterman Mountains, the units are quite similar to the Andrada formation; however, here there are two distinctly separable members, which are likely correlated with the Earp formation and Colina limestone of the Tombstone Hills section. Thus, although the Waterman Mountains section is not strictly lithologically similar to the Earp formation of the Tombstone Hills area, it is here considered equivalent -- representing, at most, a facies change. The Colina limestone is directly correlated with the Tombstone Hills section. The Epitaph dolomite is not recognized in the Waterman Mountains, but there is a possibility that the upper dolomite units in the Colina may be partly equivalent to the Epitaph.

The Earp formation crops out across the middle of the central part of the Waterman Mountains in a nearly north-south band and is composed of 893 feet of shale and siltstone interbedded with limestone and dolomite. The contact between the Earp and Horquilla formations is everywhere either covered or faulted. The two formations appear to be conformable at many localities, and along one road cut, although the contact itself was not exposed, it appears to be marked by a red shale and limestone unit.

Two beds of limestone-cobble conglomerate, 187 and 200 feet above the base, are excellent marker beds within the lower member. Overlying these beds are two massive grayish-red to green calcareous siltstone units about 160 and 165 feet thick, separated by thin layers of interbedded siltstone and dolomite. The gray to dark-gray dolomite is finely crystalline, contains only a little silt and scattered chert nodules, and weathers to a characteristic jagged surface. The uppermost part of the lower member contains 246 feet of interbedded siltstone, dolomite, and limestone in layers up to 20 feet thick, although individual carbonate beds are rarely more than 2 feet thick.

The Pennsylvanian-Permian time boundary was placed near the base of the Earp formation by Gilluly, Cooper, and Williams (1954) and Bryant (1955) in the Gunnison Hills and Tombstone Hills of southeastern Arizona. Fusulinids and bryozoa were the diagnostic fossils in the placement of the boundary. In the Waterman Mountains no fusulinids were identified in the Earp section; therefore, the Pennsylvanian-Permian boundary is only assumed to be near the base of the formation.

Permian System

Colina Limestone

The Colina limestone crops out from southeast to northwest across the central part of the Waterman Mountains and is pinched out by faulting at the east end of the northwestern part of the range. The limestone rests conformably on the Earp formation.

The Colina is about 200 feet thick and is composed of dark-gray very finely crystalline fossiliferous limestone with a few 10- to 20-foot-thick beds of dolomite at the top. Except for a thin-bedded unit at the base, the lower 115 feet of the formation is massive and forms a cliff. The upper part of the formation is bedded. One 20-foot unit, 80 feet above the base, contains scattered chert nodules, and calcite and quartz blebs occur in certain beds throughout the member. Near the top the upper part of the formation contains silt and weathers more readily than the underlying units.

Abundant fossils were found in the Colina limestone. Meekella sp. is restricted to a zone about 10 feet above the base of the upper member, but elsewhere there are brachiopods, including Dictyoclotus sp., Composita sp., and Phricodothyris(?) sp.; gastropods, including Worthenia sp., Glabrocingulum sp., Amphiscapha sp., euomphalids, bellerophontids, and trochoid and turreted types; and straight nautiloid cephalopods, small pelecypods, tabulate corals, echinoid spines, crinoid stems, and bryozoans.

Scherrer Formation

The Scherrer formation crops out in the central part of the Waterman Mountains and in the ridges immediately south of the range. Where the contact with the underlying Colina limestone has not been cut out by faulting, the Scherrer overlies the Colina conformably. In the Waterman Mountains, the Scherrer formation is divided into four units.

The lowest unit of the Scherrer formation is composed of red limy banded siltstone followed by greenish- to yellowish gray partly crossbedded sandy siltstone and sandstone interbedded with yellowish-weathering gray dolomite and limestone. The lowest unit is 89 feet thick.

The second unit is a massive light-red to yellow and white fine-grained sandstone with moderately well-sorted poorly rounded quartz grains, and is 204 feet thick. The lower part of the second unit weathers to reddish brown and forms cliffs; the upper part, which is calcareous and contains a few beds of dolomitic limestone, forms slopes.

The third unit is composed of thin-bedded gray to dark-gray finely crystalline silty dolomite that weathers light olive gray to gray and is 39 feet thick. Calcite blebs, scattered throughout the unit, may be recrystallized fossil remains. Spines of Permocidaris, typical of this unit east of the Waterman Mountains, were not found here.

The upper unit has a 72-foot-thick bed of grayish-orange to orange-yellow fine- to medium-grained slightly calcareous crossbedded sandstone at the base and 18 feet of thin-bedded dark-gray finely crystalline silty and calcareous dolomite at the top.

Although the Scherrer has a total thickness of 422 feet in the Waterman Mountains, it appears equivalent, unit by unit, to the 687-foot type section in the Gunnison Hills, 55 miles east of Tucson (Gilluly and others, 1954, p. 29). Gilluly and others (1954) place the top of the Scherrer at the top of a sequence of sandstone beds. The 18 feet of dolomitic beds at the top of the uppermost member of the Scherrer formation in the Waterman Mountains are included in the Scherrer because these dolomitic beds are similar to the dolomitic beds in the third unit and contrast with the limestone composition of the overlying Concha.

Concha Limestone

The Concha limestone crops out in the eastern and southern parts of the Waterman Mountains and conformably overlies the Scherrer formation. The section of the Concha in the Watermans if 510 feet thick.

The Concha limestone is dark gray, is finely crystalline, and ranges from massive in the lower part to thickly bedded in the upper part. Fossils and chert nodules are numerous throughout the section and are abundant in some zones. A lower zone of chert, 50 feet above the base, is 60 feet thick and is composed of connected nodules which make up about 60 percent of the unit. Other chert zones are thinner and contain 20 to 40 percent of chert nodules. One 14-foot unit, 246 feet above the base of the formation, contains tan- and light-brown-weathering chert nodules and forms a distinct marker bed, as it does in many localities to the east.

Remains of fossil brachiopods, gastropods, pelecypods, corals, bryozoans, and fusulinids are common. *Dictyoclostus bassi*, *D. occidentalis*, rhynchonellid brachiopods, bellerophontid gastropods, crinoid stems, echinoid spines and plates, and bryozoa occur throughout the Concha. *Fenestrellina* sp. and trepostome bryozoa were found only in the lower part of the formation; *Neospirifer* sp., *Buxtonia* sp., *Derbya* sp., *Meekella* sp., and fusulinids in the middle part; and *Composita* sp., *Dielasma* sp., small brachiopods, turreted gastropods, and *Malonophyllum* sp. and other horn corals in the upper third. *Marginifera* sp., *Amphiscapha* sp., and Aviculopecten sp. were identified only in the uppermost 65 feet of the Concha limestone.

Limestone and Dolomite of Permian Age

Thinner bedded partly dolomitic limestone and dolomite beds lie conformably above the Concha limestone in the Mustang Mountains, which are 45 miles southeast of Tucson. The unit was recognized and mapped by Bryant (1955). The limestone and dolomite crop out in the eastern part of the Waterman Mountains and overlie the Concha limestone with no apparent break in deposition. Although the upper contact of these Permian rocks is everywhere either eroded or faulted, the unit is 321 feet thick in the Watermans, one of the thickest sections in southern Arizona.

The unit is composed of interbedded limestone and dolomite. The limestone is mainly dark gray, aphanitic to finely crystalline, and partly dolomitic, weathering light gray to light olive gray. The dolomite is dark gray, aphanitic, and usually calcareous, weathering to a lighter gray than the limestone and to a rough or jagged surface. Small chert nodules are scattered throughout the unit, and larger nodules make up about one-half of an 8-foot bed about 115 feet above the base. Calcite and quartz blebs are more common in the dolomite or dolomitic beds.

Dictyoclostus sp., *Rhipidomella* sp., *Composita* sp., spiriferid brachiopods, *Astartella* sp., *Amphiscapha* sp., turreted gastropods, scaphopods, echinoid spines, and bryozoans occur near the base of the unit. *Dictyoclostus bassi*, *D. occidentalis*, productid spines, *Marginifera* sp., *Avonia* sp., *Composita* sp., *Phricodothyris* sp., spiriferid and rhynchonellid brachiopods, unidentified pelecypods, *Euphemites* sp., *Amphiscapha* sp., several types of turreted gastropods, horn corals, echinoid spines and plates, crinoid stems, and several genera of Bryozoa were found in the chert zone 115 feet from the base. Most of the upper part of the unit has few fossils or fossil fragments.

Cretaceous(?) System

More than 1,600 feet of clastic sedimentary rocks consisting of shale, arkose, sandstone, and pebble conglomerate crop out along the lower slopes on the north side of the central part of the range. In part, these clastic rocks superficially resemble the Cretaceous Amole arkose of Brown (1939) in the Tucson Mountains and are tentatively considered on the basis of the lithologic similarity to be of Cretaceous age. No fossils were found to substantiate this designation. Similar deposits and, in addition, purple volcanic conglomerates crop out on the southern slopes of the Waterman Mountains and also are tentatively assigned a Cretaceous age, although they may be younger.