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PERMIAN SEDIMENTARY ENVIRONMENTS IN SOUTHEASTERN ARIZONA[1]/

by

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INTRODUCTION

This paper synthesizes work on Permian depositional environments of southeastern Arizona and is an outgrowth of the author's Master of Science thesis (Butler, 1969) that describes a 2,500-foot Permian stratigraphic section in the Empire Mountains of Pima County, Arizona. Permian outcrops of the Basin and Range Physiographic Province in southeastern Arizona are commonly faulted, intruded, and incomplete. Though outcrops are unknown in the portions of Maricopa, Pinal, Graham, Gila, and Greenlee counties shown in the following maps, data are interpolated into them from information available to the north and south.

DISCUSSION

The Permian stratigraphic section in southeastern Arizona (Bryant, 1968, p. 38-42) from bottom to top is as follows: the Earp Formation (Virgil to Wolfcamp); the Colina Limestone (Late Wolfcamp? to Early Leonard?); the Epitaph Dolomite (probable lower Leonard); the Scherrer Formation (Early to Middle Leonard); the Concha Limestone; and the Rainvalley Formation. Species of Parafusulina, indicative of Leonardian or early Guadalupian age (Sabins and Ross, 1963, p. 363; Ross and Tyrrell, 1965, p. 618), are commonly found a few tens of feet below the Concha-Rainvalley contact. A lithistid sponge, Actinocoelia meandrina Finks, is recognized in the lower part of the Concha Limestone in southeastern Arizona (Bryant, 1968, p. 41; Butler, 1969, p. 47). According to Finks (1960, p. 17), this sponge occurs in higher beds of Leonard age. Therefore, based upon sponge and fusulinid studies and stratigraphic position, the author would concur with Bryant and McClymonds' previous interpretation (1961, p. 1330) that the Concha Limestone warrants an age assignment of Leonard and Guadalupe (?).

All formational contacts are apparently conformable except the top of the Rainvalley which may represent an upper Permian, Triassic (?), and Jurassic lacuna in the sedimentary record. Although the Permian stage boundaries in southeastern Arizona are not yet firmly established, it is hoped that the abundant conodont fauna recovered by the author from the Colina, Epitaph, Scherrer, Concha, and Rainvalley formations will lead to better biostratigraphic control.

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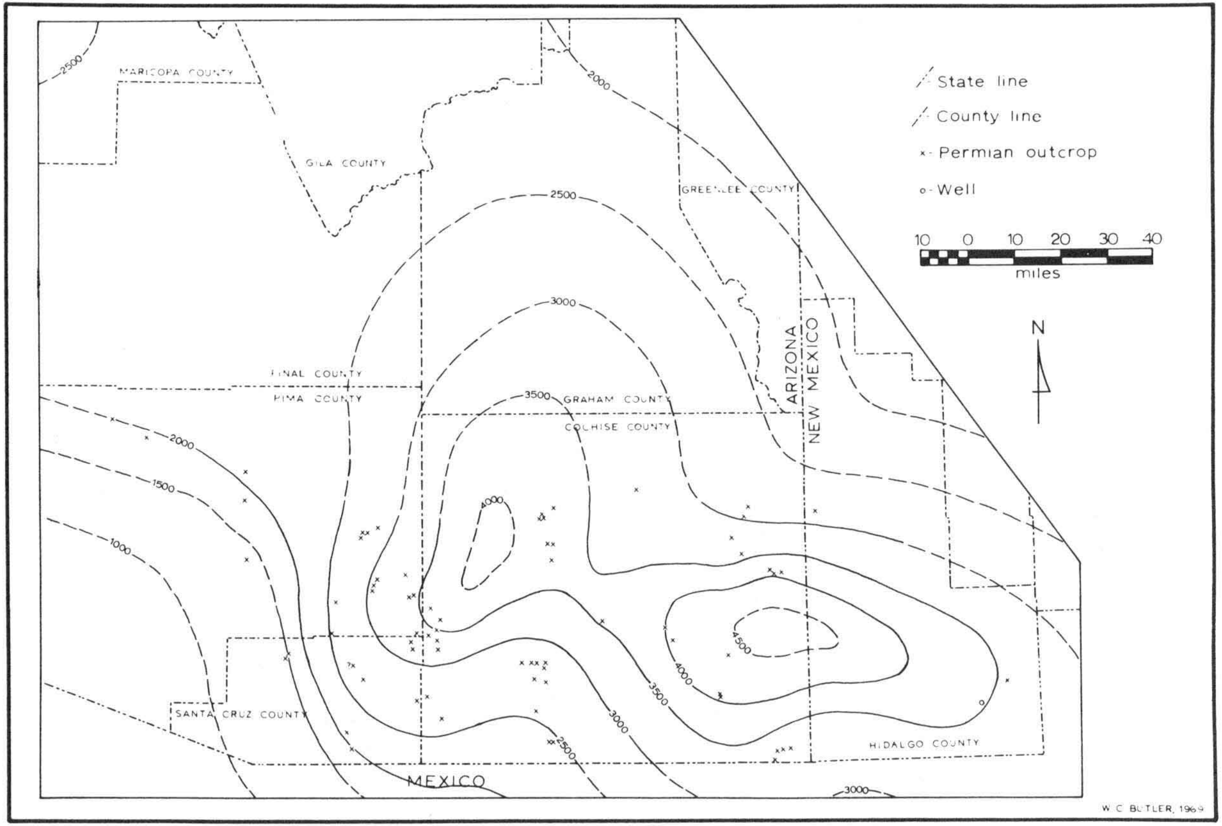

Figure 1.--Restored Permian Isopach Map. Contour Interval 500 feet. Contour Lines Dashed Where Inferred.

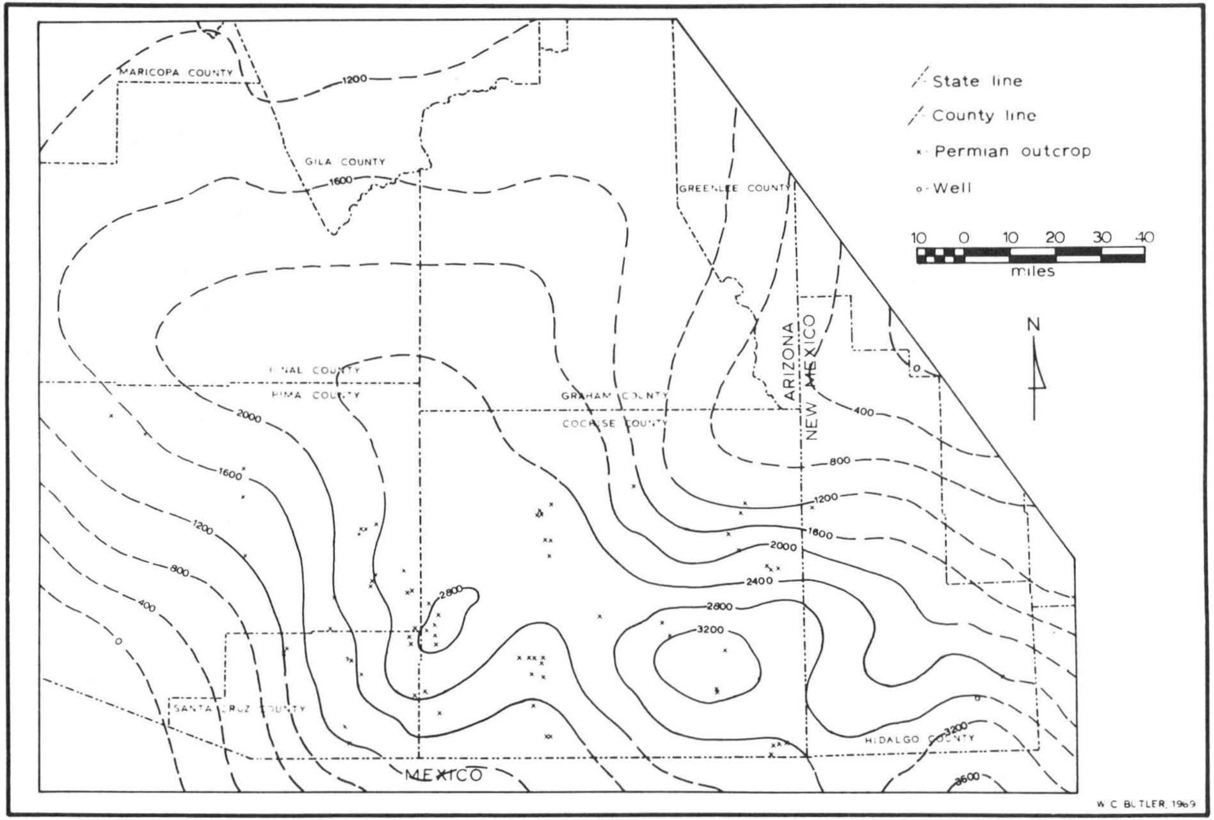

Figure 2.--Restored Leonard Isopach Map. Contour Interval 400 feet.

EARP FORMATION

Epeiric seas withdrawing intermittently during Virgilian and early Wolfcampian times coincide with increased continental erosion and the deposition of clastic sediments of the Earp Formation parallel to the Pedregosa Basin axis. Figure 3 is an isopach map of the Earp Formation and indicates that the thickest accumulation of Earp deposits is in east-central to northeast Cochise County. These deposits are mostly carbonates in contrast to a deltaic tongue (Lodewick, 1970, p. 8) composed of mostly silt-sized clastics extending from northern Pima to southern Cochise County (Figure 4). Streams transported terrigenous material down the paleoslope from the general vicinity of the Naco Highlands (Figure 5) in approximately southern Gila County (Rea and Bryant, 1968, p. 809) to the delta and associated tidal flats in the southeast. Bryant (oral communication) believes considerable erosion was taking place in approximately northern Pinal County and west of Winkelman and Superior and in central Graham County where Cenozoic rocks now unconformably overlie Precambrian rocks. The correctness of this idea is reinforced by Figures 3 and 4, which indicate that at least one conspicuous source of Earp clastics was near central Pinal County.

Detailed stratigraphic sections of the Earp Formation made by Lodewick (1970) and Micklin (1969) reveal the following mostly intertidal faunal association for the Virgil and Wolfcamp stages within the unrestricted basin: ostracods, algae, echinoids, foraminifera, crinoids, pelecypods, gastropods, brachiopods mostly of the spiriferid group, worms (?), ten genera of fusulinids, and five genera of conodonts. Rarer occurrences of syringoporid and rugose corals and bryozoans were also noted in this biofacies.

COLINA LIMESTONE AND EPITAPH DOLOMITE

Following Earp deposition, a marine transgression from the south resulted in the deposition of the Colina and Epitaph formations (Figure 6). Although the Colina-Epitaph interval is assigned to the thickest accumulation of basin fill, the embayment was shallow during the Colina-Epitaph transgression. The northern cratonic source areas were essentially eroded down to near base level, except perhaps in southern Maricopa County, and only very fine-grain detritus was being supplied. Mild tectonic activity is recognized in the area referred to as the Burro Uplift during this transgression. However, rather than acting as a significant source area, the uplift was merely a barrier to sedimentation. Paleomagnetic evidence strongly suggests that southern Arizona was geographically within ten degrees north or south of the equator during the Permian period (DuBois, 1964, p. 43; Nairn, 1964, p. 555 and 557; Dietz and Holden, 1970, p. 34). Perhaps both the Burro Uplift and the Florida Islands were similar to the mangrove islands, cays, or shoals observed today in tropical areas.

During Colina and Epitaph time, a seaway extended north to the Holbrook Basin, which is sometimes referred to as the East-Central Arizona Basin (McKee, 1967, p. 204). This seaway was constricted by 1) the Burro Uplift at the juxtaposition of Graham, Cochise, and Hidalgo (New Mexico) counties, and 2) by a shallow platform to the west. Intercalated dolomite and gypsum (Figure 7) formed in both the Holbrook and Pedregosa basins as a consequence of the shallow water, the high rate of evaporation, and the

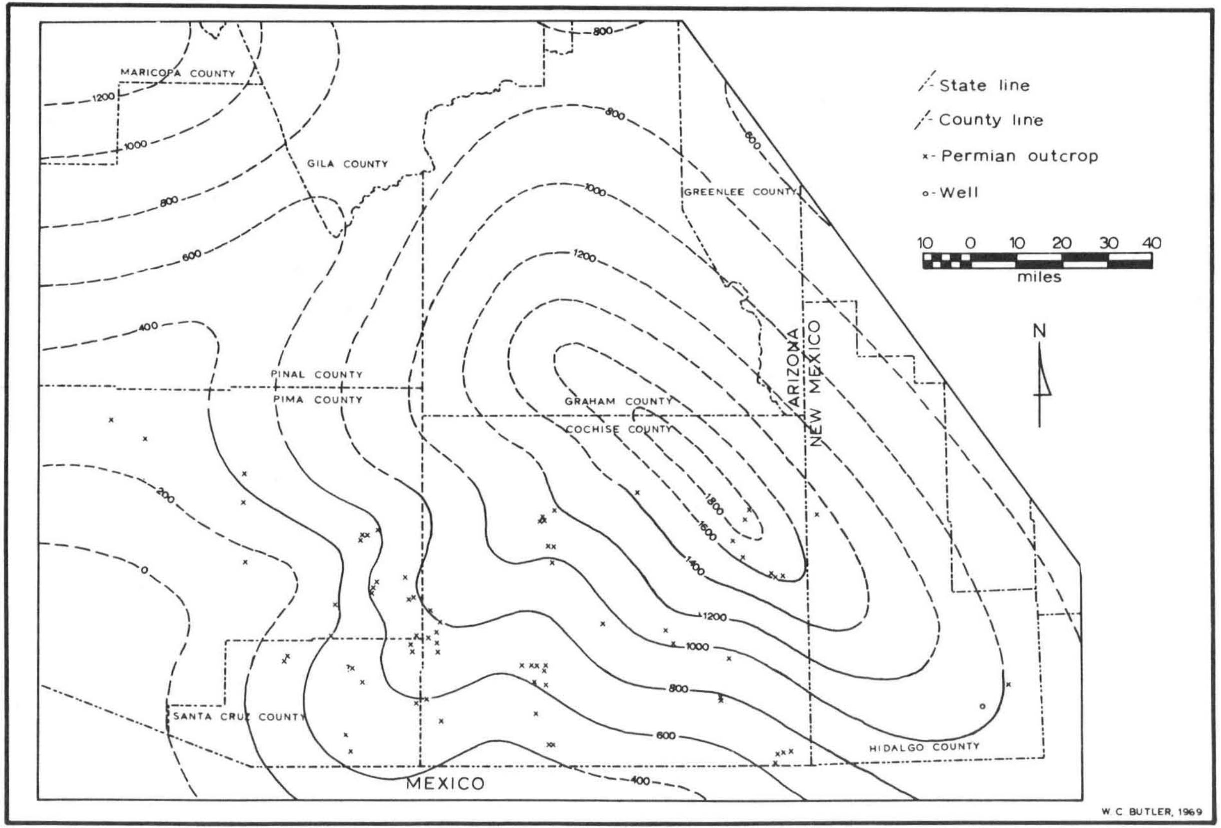

Figure 3.--Isopach Map of the Earp Formation. Contour Interval 200 feet.

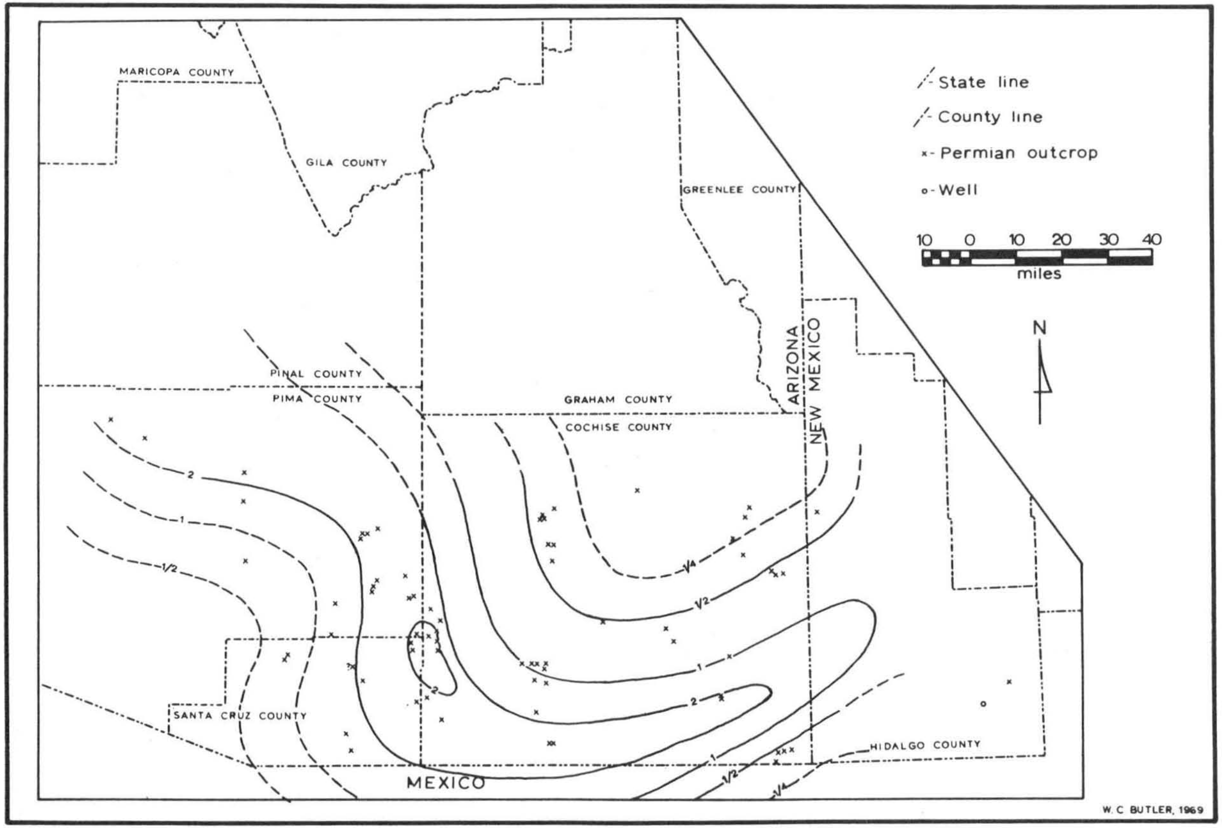

Figure 4.--Clastic Ratio Map of the Earp Formation.

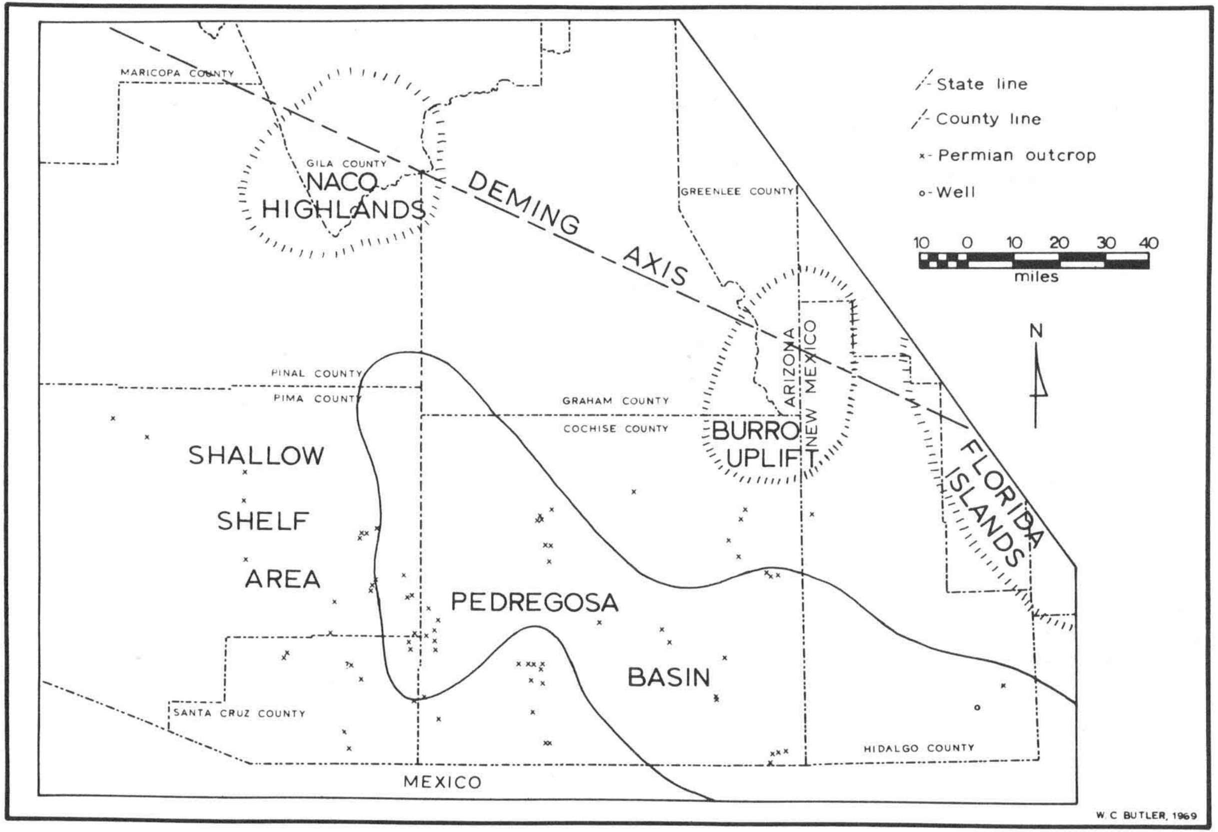

Figure 5.--Paleotectonic Map of the Lower Permian in Southeastern Arizona.

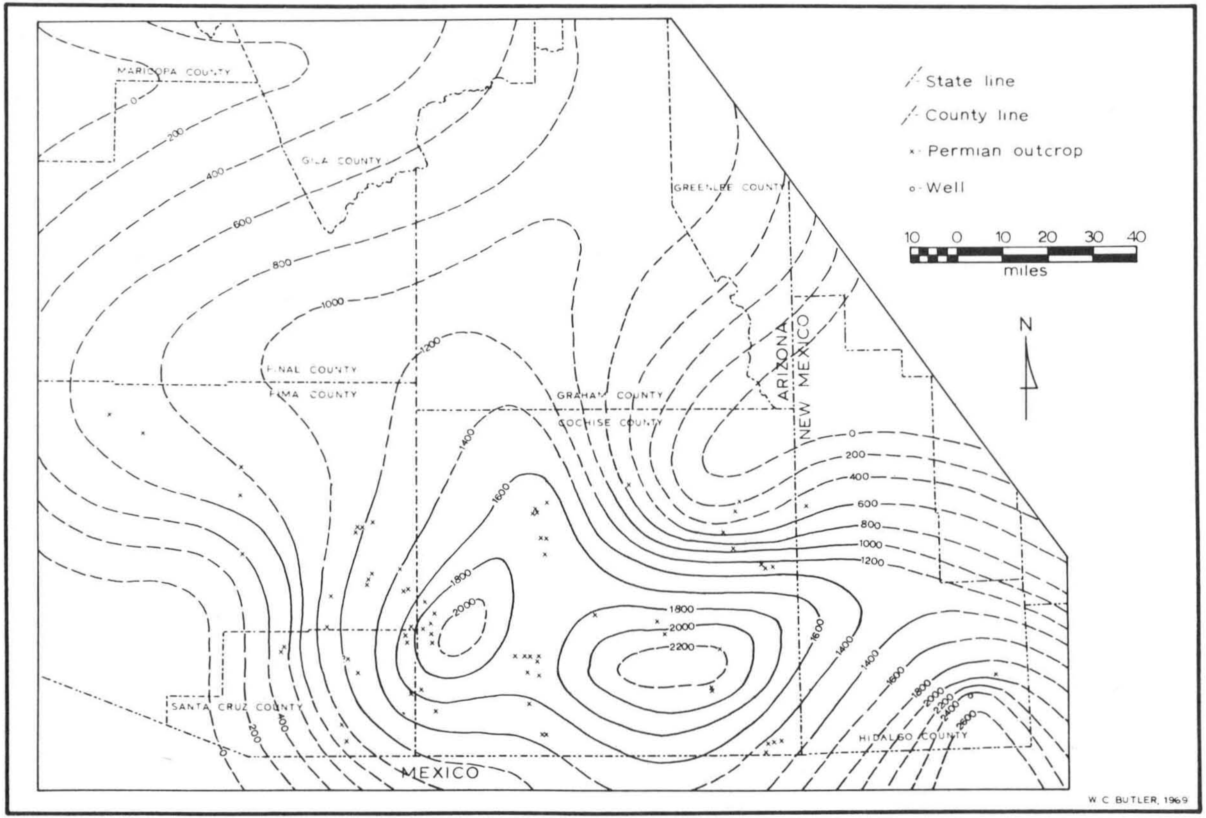

Figure 6.--Isopach Map of the Colina Limestone and the Epitaph Dolomite. Contour Interval 200 Feet.

frequent accumulation of dense brines. Chloritic marls, siltstones, argillaceous dolomites, carbonaceous dolomites, intraformational breccias, and thin beds (2 inches to 2 feet) are also characteristic of the Colina-Epitaph interval in eastern Pima County. Algal stromatolites, desiccation cracks, erosional channels, ripple and cross-laminations, and oolites are rare in this interval. All of the above features infer intertidal and subtidal and subtidal conditions within a shelf lagoon (Laporte, 1969, p. 105) existing at this time with clastic source areas remaining to the north as interpreted from Figure 8.

The Colina Limestone becomes progressively less fossiliferous from the subtidal type section in central Cochise County to the intertidal environment in Pima County. Wilt (1969, p. 77-79) concluded in her study of the Colina Limestone in the type locality that the combined occurrences of unabraded shell hash and the predominance of micrites and biomicrites in this formation are due to scavenger organisms breaking up the unwinnowed substratum. The transition from the subtidal to intertidal environment is also marked in the Colina Limestone by a slight thinning of the formation over the Earp delta in the Empire Mountains (Butler, 1969, Figure 27). Furthermore, there is a significant proportional increase in dolomite and clastics superjacent to the delta in this area (Figures 7 and 8).

A typical fossil suite from the Colina Limestone lagoonal biofacies suggests that bryozoans, echinoids, pelecypods, and gastropods were more or less evenly distributed throughout the lagoon. Brachiopods were best adapted to the central part and the six reported genera of fusulinids have been found near the inlet of this Permian lagoon. Porifera have not been reported in this particular biofacies and corals are rare. One criteria for recognizing a change from the unrestricted intertidal environment to the slightly restricted intertidal is manifested by a corresponding change from a community with common crinoids and fusulinids to one of common bryozoans replacing the crinoids and fusulinds. When conditions became more saline, as recorded by the gypsum deposits in the Epitaph Dolomite, the faunal diversity was reduced to only four genera of common brachiopods, five genera of common gastropods, one type of coral, and one echinoid genus (Gilluly, et al, 1954, p. 41). This reduction implies that gastropods have the widest tolerance of salinity.

SCHERRER FORMATION

Renewed uplift along the Deming Axis (Turner, 1962, p. 67) or perhaps less likely either tectonic activity in the Uncompahgre Uplift area of southwestern Colorado, or the Zuni-Defiance positive area of northeastern Arizona and east-central New Mexico (Baars, 1962, p. 161), initiated the rapid influx of two bimodally, but well-sorted quartz sand bodies to the south. These orthoquartzite bodies are separated vertically by a dolomicrite member which is slightly sandy in the shallower parts of the basin. The sand in the essentially low-energy carbonate-forming environment was possibly blown into the basin where penecontemporaneous (?) dolomite was forming. Some fossils collected and identified by Bryant (1951, p. 112) from this middle carbonate unit are referred to the somewhat deeper part of the intertidal facies in northeastern Santa Cruz County. Crinoid stems, Archaeocidaris sp., bryozoans, Dictyoclostus bassi (Peniculauris

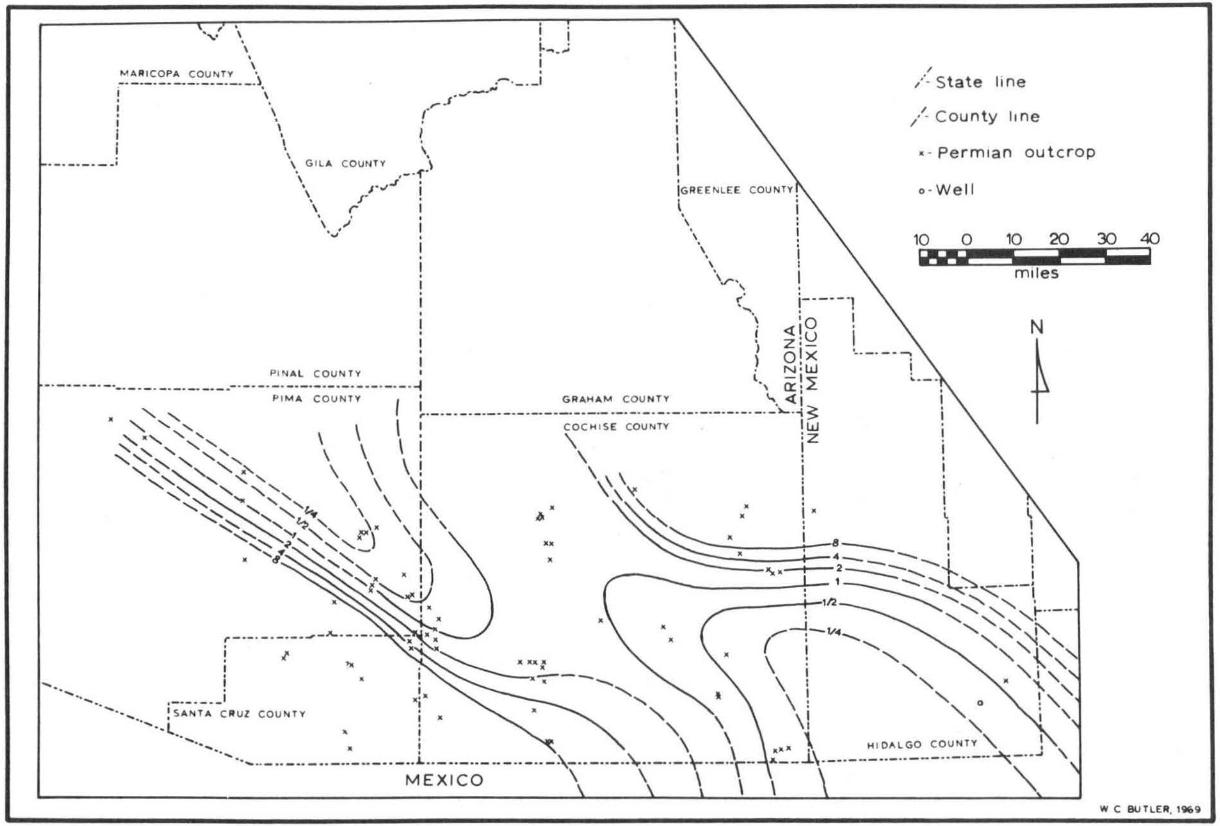

Figure 7.--Limestone to Dolomite Plus Gypsum Ratio Map of the Colina Limestone and Epitaph Dolomite.

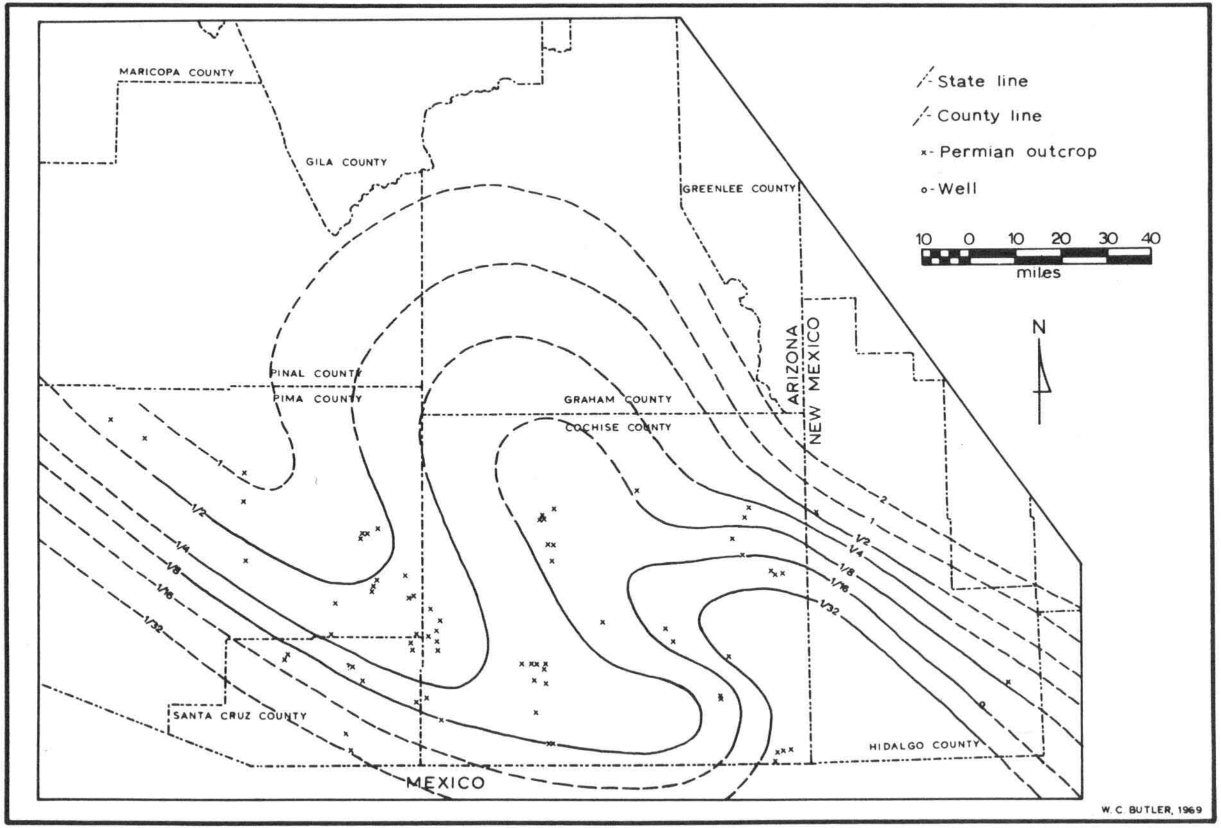

Figure 8.--Clastic Ratio Map of the Colina Limestone and the Epitaph Dolomite.

bassi of Muir-Wood and Cooper, 1960), Composita sp., and large and small gastropods are common in the fossil assemblage. Euomphalids, bellerophontids, and Chonetes sp. are less commonly found.

The orthoquartzite bodies also exhibit low-angle tabular-planar cross-bedding which in addition to the fan-shaped blanket geometry of the entire deposit, infer a high intertidal littoral environment for the Scherrer Formation. Longshore drift was virtually ineffective in dispersing the sand parallel to the shoreline. Regular echinoids, common in the Scherrer dolomicrite and the lower cherty Concha, lived on a relatively hard mud-free substratum (Cooke, 1957, p. 1191) that was subjected to moderate current action. The Scherrer, 300 to 500 feet thick in southern Cochise County, is projected to have been 700 feet thick in northern Cochise County (Figure 9) where it is thought to be transitional with continental beds to the north (Sabins, 1957, p. 500). At least some erosion of Scherrer source rocks presumably took place in central Graham County along the Deming Axis. All Paleozoic rocks have been stripped from this area and geologic cross sections show Cenozoic rocks resting unconformably on older Precambrian rocks.

At the time of this writing there has been no acknowledgement or formal description of a fossiliferous stratigraphic section of middle and upper Scherrer and lower and middle Concha one-quarter mile southeast of American Peak in the Patagonia Mountains, Santa Cruz County, Arizona. This section was recently recognized as being Scherrer and Concha by the author who gratefully acknowledges the help of graduate student, Richard Moores, who is presently conducting a field examination of the area. An interesting feature of this section is a brecciated zone with large siltstone and sandstone clasts in a carbonate matrix occurring within the middle Scherrer carbonate unit (Figure 13). This soft-sediment deformation is inferred to be a submarine landslide, perhaps triggered by tectonic adjustments along the Deming Axis to the north. A second significant feature at the American Peak section is the unusual gradational contact between the Scherrer Formation and the overlying Concha Limestone.

CONCHA LIMESTONE AND RAINVALLEY FORMATION

The Pedregosa Basin slowly subsided during the time of deposition of the Concha Limestone as evidenced by an undisturbed and diversified deeper-water shelf fauna above the near-shore deposition of the Scherrer. Many productid brachiopods etched from the Concha reveal delicate spines still attached and unbroken. The massive clean microsparites of the Concha are relatively widespread. These detritus-free sediments reflect deposition below effective wave base and represent the maximum inundation of the land area by the Concha sea.

Evidence for a relatively shallow but widespread extension of the Permian shelf in western United States is inferred by the previously noted occurrence of a time-stratigraphic, restricted actinocoelid sponge in western Wyoming, northern Arizona, southern Nevada, southern New Mexico, and western Texas (Finks, et. al., 1961, p. 564) in addition to the southeastern Arizona occurrence. Comparisons of time-equivalent brachiopods corroborate the existence of an arm of this inland sea between western Texas and northern Arizona through southeastern Arizona

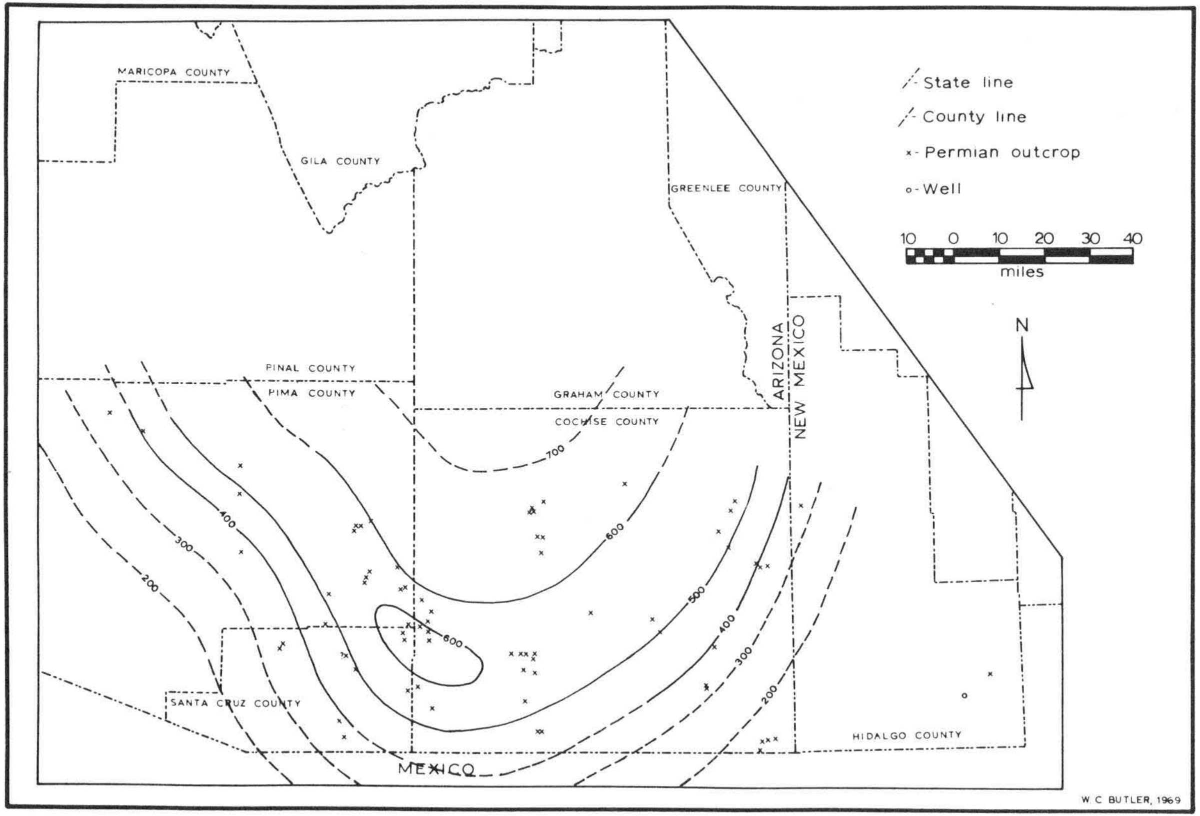

Figure 9.--Isopach Map of the Scherrer Formation. Contour Interval 100 Feet.

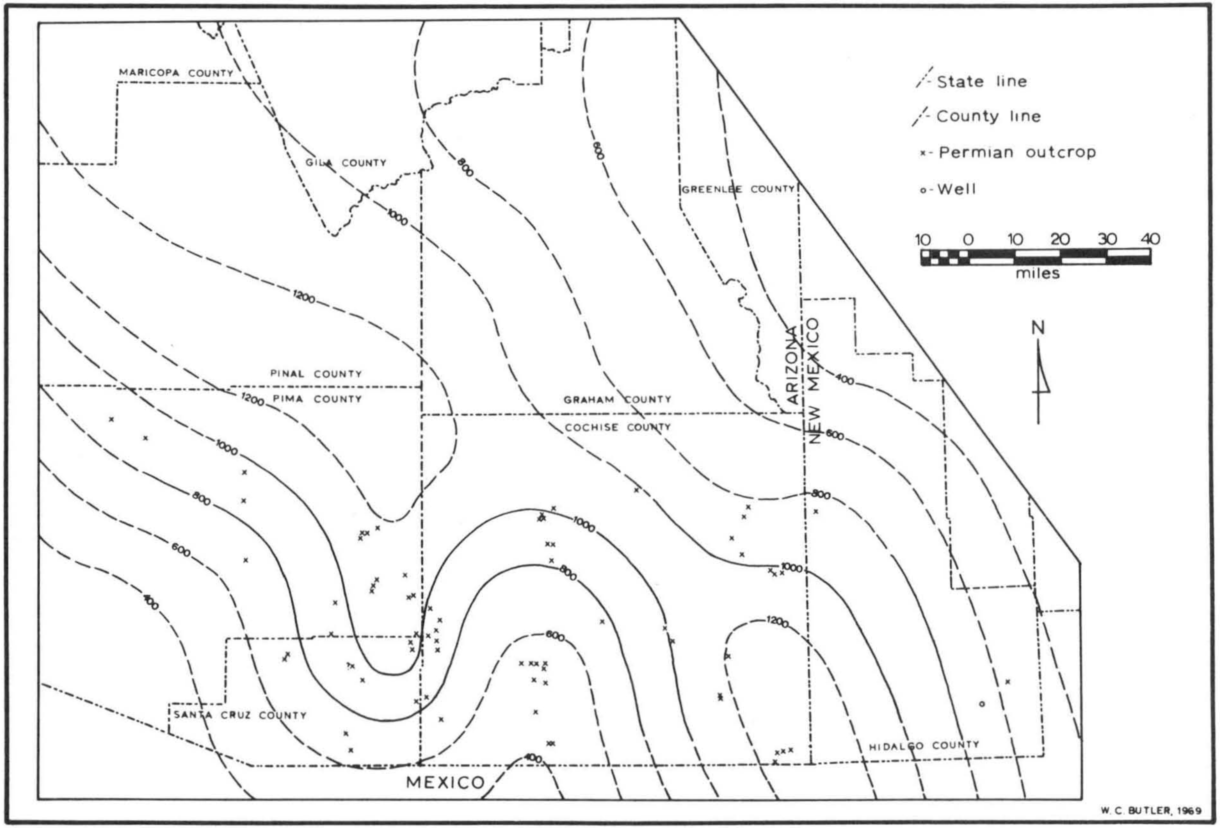

Figure 10.--Isopach Map of the Scherrer Formation and Concha Limestone. Contour Interval 200 Feet.

(Feth, 1948, p. 91). Another group of widely distributed fossils in western United States are the Permian fusulinids (Moore, 1964, Fig. 296). The zone of Parafusulina, which dominates the fusulinid faunas of the upper lower and lower upper Permian series, is found not only in southeastern Arizona, but also in Sonora Mexico (Cooper, et. al., 1953, p. 6), western Texas, southern New Mexico, Washington, California, Oregon, British Columbia, Canada, and Alaska (Moore, 1964, p. C393).

Arguments for and against a Permian seaway connecting the Leonard Sea of West Texas and Kaibab Sea of northern Arizona (Dunbar, 1941, Fig. 7) through western Arizona was discussed by Stoyanow (1942, p. 1278-1279). Stoyanow believed that the sea communicated between northern and southeastern Arizona through eastern Arizona and not through central Arizona (1942, p. 1275). McKee (1947, p. 291) inferred that the Kaibab seaway was continuous across western Arizona. Other opinions concerning the extent of the Permian seas are summarized by Bryant (1955, p. 114-116). Supportive evidence that some physical barriers to the migration of early Permian pelagic faunas were at least partially removed by late Permian time between southern and northern Arizona is based on reconnaissance work by Clark and Ethington (1962, p. 104) who have determined time-equivalent conodont faunas, mostly Wordian (Guadalupe stage), in western Texas, southeastern Arizona, west-central New Mexico, southeastern Idaho, and southern and western Wyoming. In addition, conodonts have recently been found by Fred H. Behnken (written communication, University of Wisconsin, Madison, Wisconsin) in eastern Nevada near Ely. These conodonts have also been assigned a Guadalupian age by Behnken.

Megafauna diversity compiled from an investigation by Bryant in 1951 indicates that the subtidal environment of the Concha Limestone consisted of crinoids, two genera of bryozoans, fifteen genera and twenty-eight species of brachiopods, four genera of pelecypods, two genera of cephalopods, twenty-three genera and twenty-seven species of gastropods, horn corals, and echinoid spines. The most frequently occurring fossils of this assemblage were the horn corals, crinoids, Archaeocidaris, and brachiopod genera including Composita, productids, and Chonetes. The megafauna of the superjacent Rainvalley Formation includes the following community: one genus of pelecypod, several genera of gastropods, fourteen genera and seventeen species of brachiopods, one genus of coral, crinoids, Archaeocidaris sp., bryozoans, and one nautiloid. Chonetes sp., echinoids, euomphalids, and crinoids are found in greatest abundance. Imbrie, et. al., (1959), p. 72) would probably consider the latter assemblage equivalent to their shelly and Chonetes facies, which they attribute to an unrestricted, quiet, and deep water embayment environment. This author would refer the attributes of the Rainvalley to a slight shoaling of the Permian seas.

About 2,000 feet of Wordian (Guadalupe stage) rocks crop out near El Antimonio in western Sonora, Mexico (Cooper, et. al., 1953). Although this sequence of rocks is about twice as thick as the time-stratigraphic equivalent Concha and Rainvalley formations in southeastern Arizona, forty-four genera and sixty-four species of mega-fossils, mostly brachiopods, have been identified by Cooper and others. The high diversity, in addition to the deeper water, conceivably signifies a less restricted and more stable shelf away from terrigenous influxes.

Thicknesses of the Concha Limestone combined with those of the Scherrer Formation reveal a northwest-trending trough

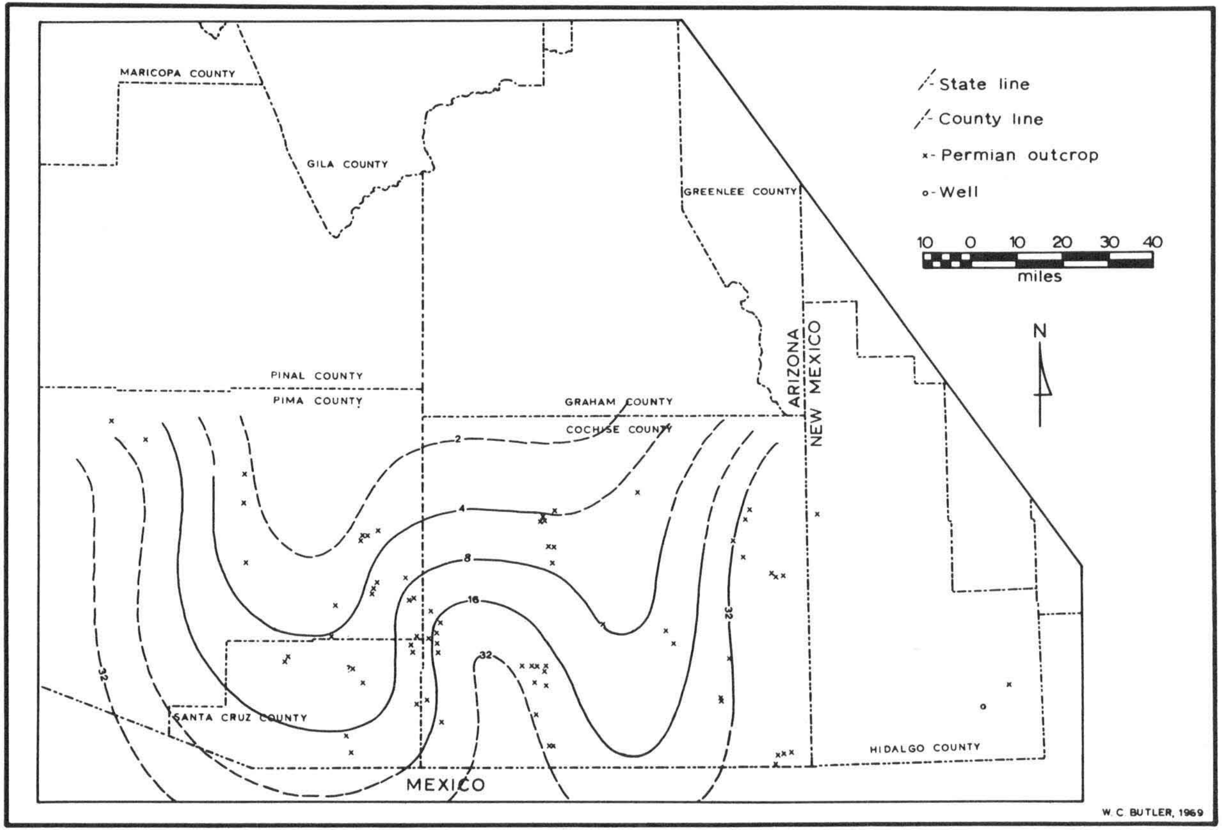

Figure 11.--Limestone to Dolomite Ratio Map of the Scherrer Formation and the Concha Limestone.

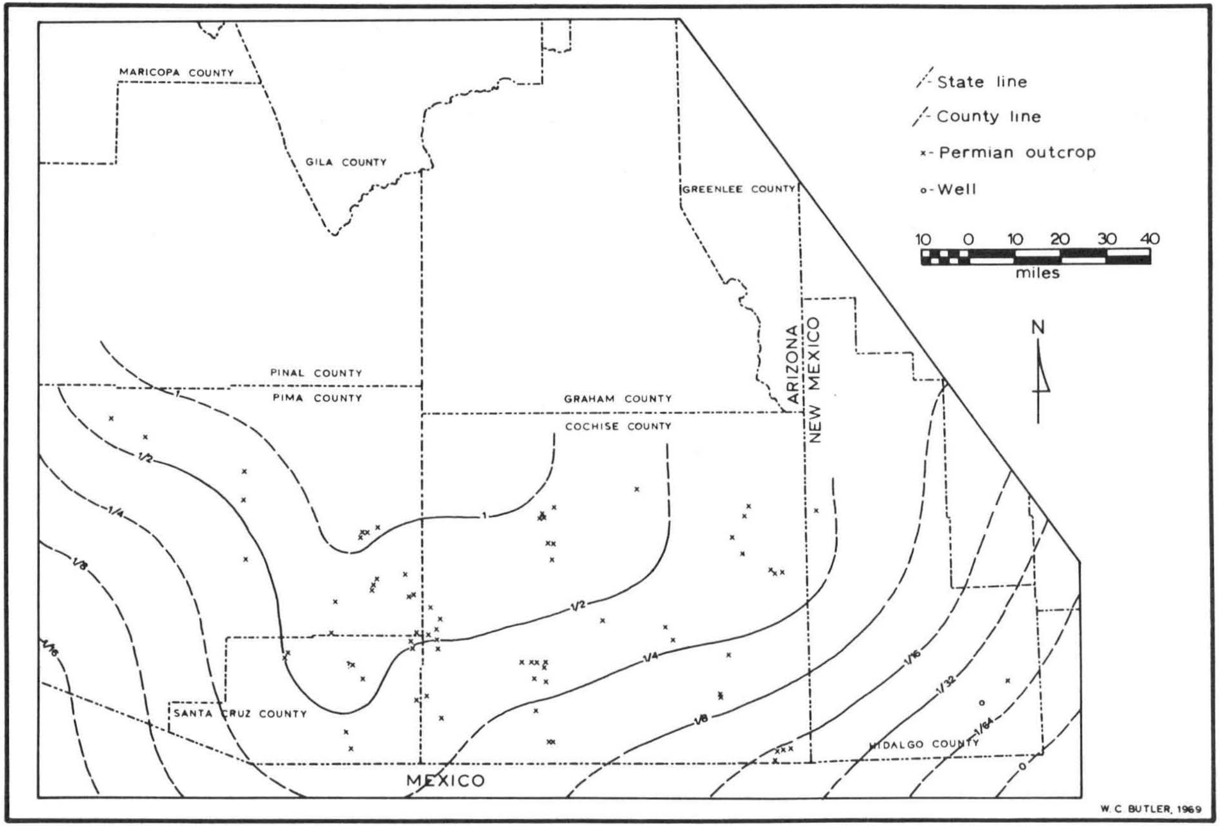

Figure 12.--Clastic Ratio Map of the Scherrer Formation and the Concha Limestone.

Figure 13.--Submarine Landslide in Scherrer Formation.

as shown in Figure 10. This trough approximates the northwest-trending axis of the Pedregosa Basin. Both dolomite and quartz sand increase steadily in a general south to north direction. This agrees with the close proximity of the strand line to the north (Figs. 11 and 12). Beds of the Rainvalley Formation are more dolomitic, show more evidence of burrowing (?), and are thinner than beds below in the Concha. The Rainvalley features rare refluxion marks (?) and includes several quartzite beds. Both formations are fossiliferous and definitely subtidal in aspect. A typical megafauna of the Concha and Rainvalley includes: actinocoelid sponges; archaeocidarid echinoid spines and plates; diverse crinoid columnals; large gastropods of the bellerophonid and euomphalid groups; several genera of small turreted and fusiform gastropods; large brachiopods of the genera Meekella and Neospirifer, and large and small productids; small brachiopods of the Phricodothyris, Chonetes, and Composita genera; fistuliporid and polyporid bryozoans; and corals of the lophophyllid and dibunophyllid groups.

SUMMARY AND CONCLUSIONS

True wave-resistant biological structures or carbonate beachrocks have not been noted in Permian exposures of southern Arizona. Invariably limonite pseudomorphs after euhedral pyrite dominate the heavy mineral fraction of the insoluble residues from the carbonate. The environment is postulated to have been one of reduction in view of the pyrite and numerous dark carbonaceous carbonate rocks. The lack of reefs or banks and the common occurrence of chloritic marl beds also suggest quiet, non-turbulent, and semi-stagnant lagoonal conditions prior to Concha deposition in Arizona. The inland-sea shelf area of southeastern Arizona lacked environmental stability. Consequently, faunas did not greatly proliferate and develop the back reef, reef, and fore reef facies such as found peripheral to the Permian Delaware Basin in southeastern New Mexico (Malek-Aslandi, 1970, p. 2330) and western Texas. However, Greenwood (1969, p. 173) and Zellar (1965, p. 33) both mention reefs or banks existing in early Permian rocks of Hidalgo County, New Mexico. López-Ramos (1969, p. 2412) also cites the existence of similar biogenic structures in the early Permian rocks of Sonora, Mexico. Localized bryozoan reefs are reported by Feth (1948, p. 92, 95, and 99) in his stratigraphic description of Leonardian rocks that crop out in southern Santa Cruz County, Arizona. Although the author has not examined this outcrop, he believes that due to the bedded nature of the "reef"-bearing zones, these "reefs" are actually bryozoan biostromes.

Within the area studied, common bryozoans, common crinoids, and diverse and abundant brachiopods characterize the Permian subtidal environment in a tropical climate. Shoaling is hinted by a marked decrease in gastropod taxa, but with the retention of many individuals. Accompanying this latter change is a subtle decrease in brachiopod diversity. Several genera of gastropods, such as Omphalotrochus, Euomphalus, Goniasma, and Worthenia, endured a wide range of ecological conditions. Corals were found to inhabit a nutrient-rich niche predominantly in the subtidal environment. Brachiopods and crinoids are ubiquitous in the normal-salinity intertidal and subtidal depths. The echinoid Archaeocidaris sp. is least sensitive to depth changes.

From present data the most logical environmental synthesis would be to relate the regressive clastic portions of the Earp

Formation to a fluvial-deltaic-tidal flat complex and to consider the carbonate portion as supratidal to subtidal. The Colina-Epitaph sequence which gradually encroached upon the Earp delta and submerged coastal plain presumably represents shallow lagoonal to evaporating pan sedimentation, particularly in Pima County. The Scherrer reflects a near-beach environment. The deepest-water basinal rocks are correlated to either the cherty or the fusulinid-bearing Concha Limestone while the superjacent Rain-valley Formation inaugurated the final regressive phase. Maximum water depth in the Pedregosa Basin throughout the upper Leonard and lower Guadalupe stages was probably between one hundred and one hundred and fifty feet. This inference is in direct conflict with the interpretation of Imbrie, et al (1959, p. 73, 78) who relegate the Permian fusuline-bearing Beattie Limestone to shallow 30-foot depth water both in the shoal and shelf lagoon environments.

Figure 5 illustrates the irregular oblong geometry of the Permian Pedregosa Basin. Sedimentation decreased northeast toward the northern end of the Mexican Sonora Basin. The most active repository was centered in southeastern Cochise County with a subsidiary depocenter in west-central Cochise County. Based upon geometry, tectonic setting, arrangement of fill, the Pedregosa Basin tends to resemble the architecture of the "open-ended" basin model proposed by Potter and Pettijohn (1963, p. 235-237). "Open-ended" basin models are characterized by their symmetrical cross-sections and oblong shapes which widen and deepen down the axial plunge. Sandstones, shales, and carbonates predominate as the type of fill. The clastic sediments are fed to the basins by deltas at the up dip ends and are dispersed down the paleoslopes parallel to the basins' axes. Furthermore, the thickening of sediments occurs away from the source areas. Finally, these "open-ended" basins and their distal source areas are located in areas of mild to moderate subsidence and uplift respectively.

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EDITOR'S NOTE

Because of a delay on the part of the editor in the publication of this manuscript, the author wishes to add the following items.

Tectonics

Several major strike-slip faults have been postulated in southeastern Arizona. One such fault, the Sawmill Canyon fault (Lutton, 1958, p. 26), trends northwest through the southwestern portion of the Pedregosa Basin. The fault trend approximates that of the Deming Axis and the Mogollon Rim in central Arizona. Interpretations as to the fault movement vary. Poole and others (1967, p. 880, 893) state with respect to the Devonian System, "Evidence for the inferred right-lateral fault zones in southern Arizona is permissive rather than compelling." In contrast to this right-lateral movement, Professor Spencer R. Titley (University of Arizona, manuscript in preparation) finds left-lateral movement to be the case. Titley's preliminary work with the Mississippian Escabrosa Limestone argues for a left-lateral interpretation of the Sawmill Canyon fault and for an offset in post-Triassic to pre-Cretaceous times. The Permian stratigraphic maps in this paper were compiled without presupposing any lateral offset of the Pedregosa Basin. If re-evaluation of the Permian data is in order, this author would concur with Titley's interpretation. Restoration of a 100-mile left-lateral offset in Figures 1, 2, 6, 10, and 11 from northeastern Santa Cruz County (south side of the fault) to southeastern Cochise County (north side of the fault), would match nearly equal thicknesses of rock and effectively minimize the depocenter in west-central Cochise County. But, at the same time, such a restoration would certainly make interpretation of Figures 7, 9, and 12 more difficult.

To Muehlberger and Wiley (1970) the Texas Lineament in Trans-Pecos, Texas, is viewed as being a repeatedly re-activated zone of right-lateral faulting with a displacement of about 200 miles. To Sales (1968, Figs. 1 and 9) the Texas Lineament is left-lateral and contemporaneous with other Laramide lineaments. The Deming Axis in Arizona could be a local expression of this lineament. Muehlberger and Wiley, in their review of the Texas Lineament, state, "For many reason, but chiefly because of the distribution of Permian and later rocks in Trans-Pecos Texas, it is improbable that major strike-slip displacement occurred in the region after the beginning of the Permian Period. Thus, the evidence necessary to demonstrate wrench faulting along the Texas Lineament must be in rock older than Permian." Such is the evidence that Lutton (1958, p. 29) found when he stated, "The cataclasite and dragged foliation of the Precambrian rock near the Sawmill Canyon fault suggest that the flaw first developed at that time, as a right-lateral wrench."

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