



Major geologic structures between Lordsburg, New Mexico, and Tucson, Arizona

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MAJOR GEOLOGIC STRUCTURES BETWEEN LORDSBURG, NEW MEXICO AND DOUGLAS AND TUCSON, ARIZONA

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INTRODUCTION

The region of southwestern New Mexico and southeastern Arizona traversed by the joint field trip of the New Mexico and Arizona Geological Societies in 1978 is noted for its abundant and varied structural features. Gilluly's (1956) description of part of the Dragoon and Mule mountains shows many of these features and clearly implies a complicated tectonic history. In recent decades numerous field studies have been made of local areas or of selected structural features of southeastern Arizona and adjacent areas; from these studies varied and seemingly conflicting interpretations have been offered. Field review of past mapping and much new mapping during the last 16 years have provided the basis for a tectonic synthesis of southeastern Arizona (Drewes, 1976, 1978a, 1978b). This synthesis is being extended by us into New Mexico, where Corbitt and Woodward (1970) have also presented tectonic interpretations of Laramide deformation.

In this article we will summarize the main geologic features along the excursion route. Emphasis will be on description or field interpretation of age, geometry and direction of movement of faults and folds. This emphasis is in keeping with the main objectives of the trip: to illustrate representative features of a broad variety of geologic topics rather than presenting evidence in support of one or another hypothesis covering a single regional topic. With this background, the trip participants may be better prepared to participate in such informal discussions on regional geologic interpretations as may arise.

The structural complexities of the region reflect the following conditions: (a) Deformation has occurred repeatedly, first during the Precambrian Mazatzal revolution, and again in the Triassic, the Late Jurassic or Early Cretaceous, the Late Cretaceous to Paleocene Cordilleran orogeny, and the mid-Tertiary; some activity has continued to historic time. (b) Some structures were formed in response to regional stresses; others developed under local conditions. (c) Segments of many faults were reactivated, some of them repeatedly and with diverse directions of movement. Hereafter, such faults will be referred to as complex faults. Under these conditions it is no wonder that some seemingly conflicting interpretations occur. Indeed, the only structural generalization that may be valid is that it is unlikely that the rocks were ever structurally isotropic in the time span represented by the geologic record, except on a very local scale.

A brief review of the geologic setting of the region indicates the probable significance of the major kinds of structures. About 1,600 m.y. ago the region was covered by sedimentary and some volcanic rocks. Later these rocks were deeply buried; many of them were metamorphosed and massively invaded by granite stocks and batholiths before being uplifted and peneplaned. During late Precambrian and Paleozoic time the region bordered a craton and fluctuated between gentle uplifts and downwarps. Crustal disturbances and magmatic activity were renewed during the Triassic and extended into the Early Cretaceous, followed by a quiescent time during which an arm of the sea briefly invaded the region from the south. During Late

Cretaceous and Paleocene time the region was subjected to compressive stress like that occurring throughout the Cordilleran orogenic belt, resulting in folds and faults. Finally, from Oligocene time onward the extensional conditions of the Basin and Range province created the characteristic landscape of fault-block mountains separated by sediment-filled basins.

NORTHWEST-TRENDING FAULT SYSTEM

Northwest-trending complex faults are the most significant structures of the region. In the past they were commonly viewed as unimportant, owing to the local nature of many studies. This happened because, from one fault segment to another, the evidence of the age and direction of faulting varies, thereby obscuring their continuity and genetic association. The fault system is believed to have developed from sub-parallel flaws in basement rocks. Branch faults splay northerly or westerly from the complex master faults, merging with other nearby parallel master faults.

Movement on the basement flaws was mainly left-lateral and on at least one of them displacement was probably many kilometers. Some segments of the faults were reactivated w normal faults, and locally thrust faulting occurred up and across a broad northwest-trending fault zone. At least some of the faults were active during Precambrian time. Movement also occurred many times during the Mesozoic Era and several times during the Cenozoic Era. Episodes of left-lateral movement during the Precambrian and the Paleocene may have affected all or most of the faults of the system; the other movements may have been more localized.

Along the excursion route between Lordsburg and Douglas examples of the northwest-trending complex faults occur only at arm-waving distance or as inferrable concealed features. The more informative of these are described below and are keyed by number to Figure 1.

(1) *Peloncillo Mountains*

A major fault zone north of an Oligocene stock at Granite Gap trends northwest, dips steeply and has a group of echelon faults branching off to the north-northwest. The only locally recorded movement is early Tertiary, post-thrust faulting and pre-stock emplacement. Intrusive bodies of mid-Oligocene, Oligocene-Miocene and Pliocene ages occur along the fault zone, and in several places there is some mineralization. Local geology is presented by Gillerman (1958), Armstrong and Silberman (1974) and maps in preparation by Drewes and Thorman.

(2) *Chiricahua Mountains*

The Apache Pass complex fault is most readily interpreted near Marble Canyon at site 2. Splay faults branch from the master fault where it changes strike slightly, and fault horses lie along the master fault and some of the splay faults northwest of Marble Canyon. Major Precambrian features are

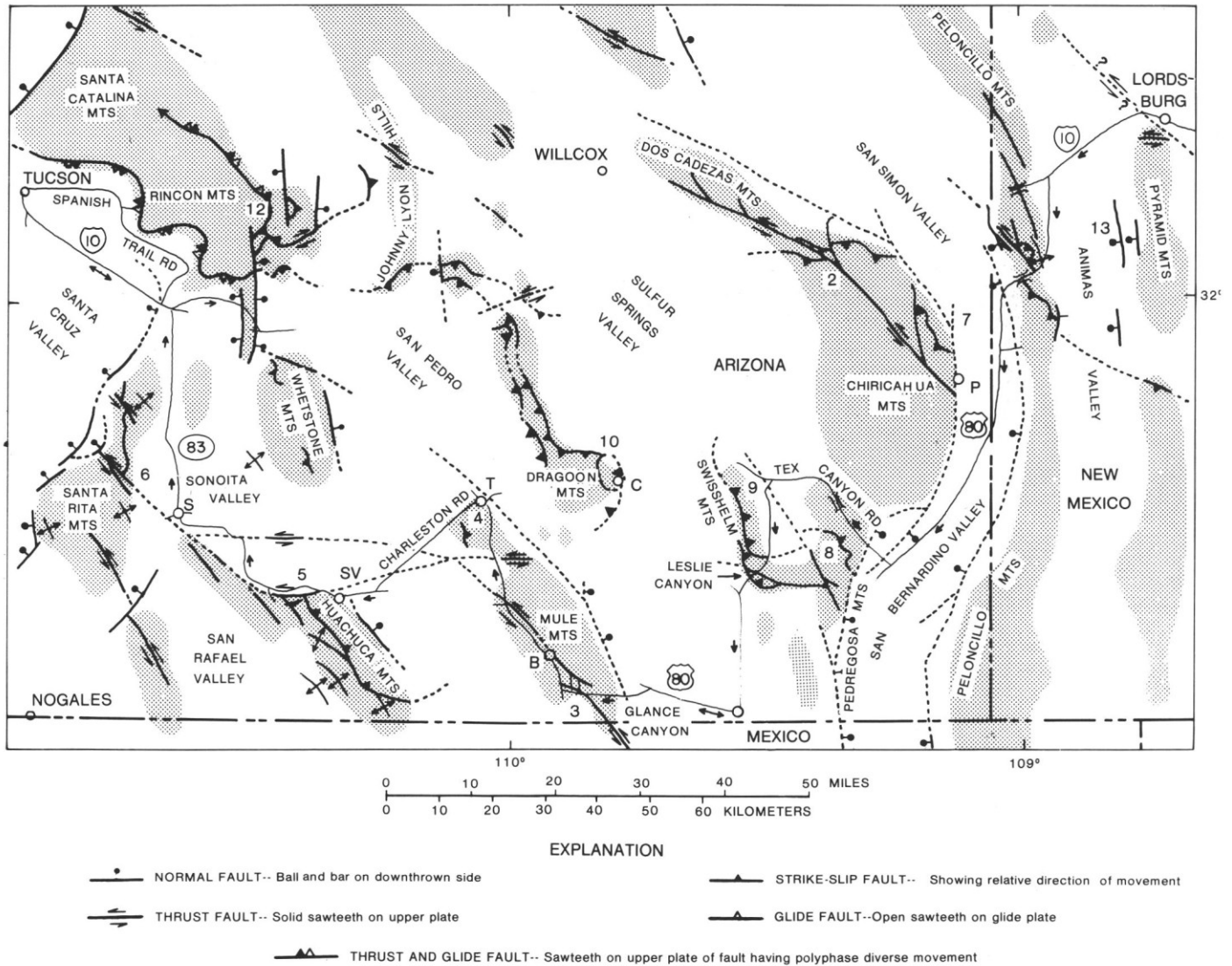


Figure 1. Sketch map of southeastern Arizona and southwestern New Mexico, showing examples of the three major kinds of structural features near the field trip route. Towns: (P) Portal; (T) Tombstone; (C) Courtland; (B) Bisbee; (SV) Sierra Vista; and (S) Sonoita. Locations keyed to text sections: 1, Peloncillo Mountains (Granite Gap area); 2, Chiricahua Mountains (Marble Canyon area); 3, Mule Mountains (Glance Creek area); 4, Tombstone Hills; 5, Huachuca Mountains (Kino Spring area); 6, Santa Rita Mountains (Sawmill Canyon area); 7, Chiricahua Mountains (Round Valley area); 8, Pedregosa Mountains (Limestone Mountain area); 9, Swisshelm Mountains; 10, Dragoon Mountains (southern part); 11, Santa Rita Mountains (northern part); 12, Rincon Mountains (Happy Valley area).

strongly offset in a manner not reflected in the Paleozoic rocks. Traces of Late Cretaceous thrust faults had 10-15 km of left separation before the emplacement of Oligocene stocks. A segment of the fault southeast of Marble Canyon was reactivated as a normal fault during the late Tertiary. Intrusive bodies and several mineralized areas occur along or near the fault (Sabins, 1975; Copper, 1960; and Drewes, 1978b).

Other examples of the northwest-trending faults occur along the route of the excursion between Douglas and Tucson, and two of them will be visited.

(3) Mule Mountain

The Gold Hill, Dividend and Mule Canyon faults are probably parts of one major fault zone that are separated from one another by the Jurassic Juniper Flat stock (dotted fault symbol northwest of Bisbee) and by an en echelon overlap.

Splay faults branch from the Gold Hill fault, and fault horses lie along it. At least two phases of movement occurred during the Mesozoic. Stocks intrude the faults, and mineralization occurs near them and was directed away from the Dividend fault near Bisbee (Ransome, 1904; Hayes and Landis, 1964, 1965).

(4) Tombstone Hills

A concealed fault is inferred to underlie gravels about 1 km east of Tombstone, separating diverse geologic terranes. A Late Cretaceous stock and Pliocene or Pleistocene basalt probably intruded rocks along or near the fault, and mineralization at Tombstone occurs near the fault (Gilluly, 1956). Temperature of mineralization decreases toward the southwest (Butler and others, 1938), away from the inferred northwest-trending fault.

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(5) *Huachuca Mountains*

The Kino Spring fault separates a sequence of Oligocene and Miocene gravels overlying Triassic and Jurassic volcanic rocks to the north, from another sequence of Upper Cretaceous, Lower Cretaceous and Paleozoic sedimentary rocks to the south. Splay faults and fault horses are present. Drag on up-ended beds near the fault indicates left-lateral movement occurred after Early Cretaceous deposition and Late Cretaceous(?) thrust faulting but before the Oligocene. The Oligocene and Miocene deposits are probably faulted down along the structure (Hayes and Raup, 1968).

(6) *Santa Rita Mountains*

The Sawmill Canyon fault zone splays markedly to the southeast and contains aligned fault horses where it narrows to the northwest. From the stratigraphic sequences on opposite sides of the fault zone, movement is seen to have recurred from Triassic to early Tertiary time. Only vertical components of movement are inferrable from the geologic record for the Mesozoic. Late Cretaceous thrust faulting cut up and across the fault zone. Paleocene(?) movement was left-lateral, based on nearby evidence (Drewes, 1971 a, 1971b, 1972).

Thrust Faults and Related Structures

Thrust faults occur in many ranges of the region, and associated with them are some tear faults, disharmonic (plate-bounded) normal faults, and folds. Typically thrust faults are subhorizontal or gently inclined and subparallel to bedding, but in places they are steeply inclined along with the bedding or they cut across bedding. In some respects thrust faults resemble other low-angle faults, such as glide faults and low-angle or listric normal faults. The recognition and appreciation of bedding-plane faults appears to provide the greatest mapping difficulty, particularly where field evidence comes from geologic relations rather than exposed sheets of breccia. Segments of some thrust faults were reactivated as local glide faults, thus further hampering regional interpretations based solely on local field studies.

Most of the thrust faults were formed in one tectonic environment, at about one time, with one direction of transport. The faults were probably formed under a cover 2-6 km thick, with that thickness increasing to the southwest. Fault movement culminated about 75 m.y. ago to the west; to the east, where dating is not as closely controlled, the movement was probably slightly younger. Upper thrust plates moved east-northeast relative to lower thrust plates. These features are described by Drewes (1976, 1978b), and an interpretation of their genesis in the Cordilleran orogenic belt is given by Corbitt and Woodward (1970) and Drewes (1978a).

The amount of tectonic movement was probably large. Around the Rincon Mountains a stratigraphic sequence is duplicated in juxtaposed thrust plates. This duplication in the direction of tectonic transport is at least 16 km, thereby implying a plate transport of at least that distance (Drewes, 1973, 1974). In several ranges Precambrian crystalline rocks of different facies of one formation are juxtaposed, thus implying substantial amounts of movement on even some of the supposedly subordinate thrust faults. Data from a rootless stock and its possible continuation in a lower tectonic level provide a more speculative argument that tectonic transport may have been on the order of 200 km. 293

A few thrust faults were formed during times other than Late Cretaceous (Drewes, 1971a, 1972), and glide faults were formed both during other times and in a shallower tectonic environment than most of the thrust faults (Cooper, 1960, 1973; Davis, 1975; Drewes, 1972, 1974, 1977).

In the following paragraphs we will focus on descriptions of the main features of selected thrust faults. Most of those between Lordsburg, Douglas and Tucson will only be referred to briefly, as the excursion route only comes within arm-waving distance of them; however, near Courtland in the southern part of the Dragoon Mountains, there are extraordinary local complications that warrant further explanation (Gilluly, 1956; McRae, 1966). In addition, thrust faults will be visited east of Tucson.

(1) *Peloncillo Mountains*

Bedding plane disharmonic faults occur over a distance of 10 km near Granite Gap. Mostly younger Paleozoic rocks are thrust over older rocks, but locally Cretaceous rocks are faulted into Pennsylvanian rocks. Nearby Cretaceous formations are warped into folds of large amplitude and north-northwest-trending axes (Gillerman, 1958; Armstrong and Silberman, 1974; maps in preparation by Drewes and Thorman).

(7) *Chiricahua Mountains*

Near Round Valley, a few kilometers north of Portal, Paleozoic and Cretaceous rocks are abundantly thrust faulted. Typically, younger rocks are placed on older ones, and both bedding and faults dip south or west. Tear faults and disharmonic normal faults occur in individual plates or groups of plates.

(8) *Pedregosa Mountains*

At Limestone Mountain, Epis (1956) and Cooper (1959) show that an extensive plate of Paleozoic limestone dips gently eastward upon upended Upper Cretaceous rocks.

(9) *Swisshelm Mountains*

In the northern end of the mountains Paleozoic rocks are faulted in a younger-over-older style. In the central part, Pennsylvanian Horquilla Limestone is thrust over Lower Cretaceous Bisbee Formation along at least one horizon. To the south, much-faulted Paleozoic rocks are thrust mainly over Upper Cretaceous andesite (Epis, 1956; Cooper, 1959).

(10) *Southern Dragoon Mountains*

A few kilometers northwest of Courtland, the Jurassic Gleeson stock is thrust over a zone of Paleozoic and Cretaceous rocks (Gilluly, 1956; McRae, 1966; Drewes, 1978b). The Bisbee Formation beneath the thrust-fault zone is now seen to be a southwest-dipping, right-side-up sequence, rather than an overturned sequence as previously mapped.

(5) *Huachuca Mountains*

Thrust faults are shown by Hayes and Raup (1968) to follow the length of the range. On the west flank are folded Cretaceous rocks. The axial planes of the folds generally strike northwest and in plan are gently concave to the southwest. The axial planes of a few folds are faulted. At depth, these faulted folds probably flatten to the southwest, where they may merge with a concealed thrust fault. The zone

of mapped thrust-faulted lower Paleozoic sedimentary rocks and Precambrian granite rocks along the range crest cuts the axis of a large fold, suggesting that the folds are an earlier feature than the zone of mapped thrust faults, which probably extended to the southwest over the northeast vergent-folded terrane (Drewes, 1978b).

(11) *Santa Rita Mountains*

The northern part of the range contains many of the younger-over-older type of thrust faults, as well as some older-over-younger examples. Tear faults, disharmonic normal faults and folds are particularly common here. To the east-northeast, major fault movement is dated at about 75 m.y. Segments of thrust faults were reactivated about 53 m.y. ago, in response to a stress field that shifted sufficiently to have caused movement mainly on some northwest-trending complex faults (Drewes, 1972). Mineralization was localized along these structures near ore-porphry plugs.

All of the ranges around Tucson and east of Tucson contain bedding-plane faults and signs of compressive deformation. The chief objective of the third day of the excursion is the flank of the Rincon Mountains.

(12) *Rincon Mountains*

This area contains thrust faults, as well as a spectrum of younger gravity-propelled, low-angle structures, such as slump fields, landslide sheets, glide plates and low-angle normal faults, that commonly obscure the older thrust faults (Drewes, 1974, 1977; Thorman and others, 1978). Detailed studies of small areas were made by many students, with their results largely incorporated in a report by Davis (1975). The case for polyphase deformation in the Rincon Mountains is summarized by Drewes and Thorman (1978).

Where thrust faulting was the main type of movement on a low-angle fault, as is believed to be the case near Happy Valley east of the Rincon Mountains, many of the structural features associated with the faults are like those already described from the other areas. East of Happy Valley, thrust faults are continuous with a major strike-slip fault that trends east-northeast. In addition, in this area two major plates composed mainly of Paleozoic rocks are separated by a plate of Precambrian Rincon Valley Granodiorite. South and west of the mountains these three plates are more fragmentary, perhaps reflecting greater involvement of younger glide faulting.

The three major plates are faulted upon a suite of gneissic and mainly granitoid rocks in the core of a domal feature centered about the Rincon Mountains. Some, and perhaps many of the core rocks have a Precambrian parentage; all have been involved in remobilization, penetrative and pervasive protomylonitization and a thermal event that generally ended by early Miocene time. None of the core rocks is the source of the Rincon Valley Granodiorite. Further description of the challenging and enigmatic features of this area is left to the field trip itself.

BASIN AND RANGE FAULT SYSTEM

Normal faults occur near many mountain fronts and trend parallel to the ranges; indeed, the physiography of conspicuously linear ranges and intervening valleys is commonly attributed to geologically young movement on these faults. In some parts of the region faults actually separate gravel deposits of the valleys from bedrock of the mountains. Elsewhere, nor-

mal faults occur in alluvial aprons flanking the ranges. In still other places the faults are concealed beneath the youngest units of alluvium.

Evidence of faulting is strong along the margins of the San Simon and San Bernardino valleys and the Santa Cruz Valley, but there is no evidence of faulting along the margins of the Sulfur Springs Valley and the San Rafael and Sonoita valleys. The strongly fault-bounded valleys are graben structures; those without apparent flanking faults may be broad synclinal sags between ranges whose bedding generally dips gently away from the fault-bounded valleys.

Oligocene rhyolitic volcanic rocks are most abundant in the ranges adjacent to the more conspicuous grabens. Miocene basaltic andesite and Pliocene-Pleistocene basalt are common on the flanks of ranges and in these grabens. The most recent volcanism is recorded in the Animas Valley 0.14 m.y. ago. This volcanic activity is probably genetically related to Basin and Range faulting.

Exceptionally, Basin and Range faults trend northwesterly or, more rarely still, northeasterly. The northwest-trending Basin and Range faults lie mostly in the northern part of the region and in adjacent parts of Sonora. Northeast-trending segments of faults occur along the Santa Cruz Valley. The northwest-trending normal faults are probably reactivated segments of old basement flaws. Some normal faults are long and apparently unbroken single straight strands. Others form a trellis-like system of shorter strands and cross faults, and still others form arcuate map patterns.

A few examples of Basin and Range faults are described below at sites seen only from afar.

(73) *Pyramid Mountains*

A short segment of reactivated range-front fault lies on the west side of the higher, southern part of the mountains. Fluorite mineralization along the fault may have occurred after an earlier episode of fault movement; young gravel deposits are offset by later faulting. Other faults cut the gravels at mid-slope and near the toes of the alluvial aprons. These occur near the site of a geothermal anomaly and hot-water well (Smith, this guidebook).

(7) *Chiricahua Mountains*

The east side of these mountains forms the boldest range front of the region. Although no fault has been located at the surface, both north- and northwest-trending faults are inferred to lie close to the mountain front to the north of site 7, where two wells that were drilled only a few kilometers from the front bottomed in Tertiary gravel or volcanic rocks at depths of about 2 km (Sabins, 1957).

(8) *Pedregosa Mountains*

Pliocene and Pleistocene basalt fills the graben east of these mountains. Some trains of cinder cones are aligned, particularly along the margins of the San Bernardino Valley, and their alignment is probably controlled by concealed normal faults. The fault scarp formed during the Sonoran earthquake lies along the east side of this valley, in Sonora, where an offset of as much as 2 m was reported by Aguilera (1920).

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(11) Santa Rita Mountains

A fault lies along the west side of the northern Santa Rita Mountains. Mostly it occurs in the flanking gravel deposits, but in places it occurs between gravels and bedrock. Surface offsets of 1-2 m occur on red soil that formed on gravel deposits perhaps as recently as the Sangamon Interglaciation (Drewes, 1972).

SUMMARY

The rocks of the region were deformed many times in response to a variety of stresses that had diverse orientations, and the deformation occurred beneath various thicknesses of cover. Some stresses were applied regionally, others locally. Many segments of faults were reactivated. As a consequence of such tectonic history, the structural features are very complicated at some localities, and their inferred development may seem to vary markedly from locality to locality. Such varied inferences need not conflict; most of them are probably partial answers to difficult questions. Although regional investigations are based on an accumulation of local field studies, the local studies should not ignore regional considerations.

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