SOME CHARACTERISTICS OF THE EASTERN PENINSULAR RANGES MYLONITE ZONE

by

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A major regional belt of pervasively sheared cataclastic rocks, here termed the eastern Peninsular Ranges mylonite zone, is the subject of this paper. The regional characteristics of these mylonitic rocks, as well as a set of younger thrust faults that are spatially and temporally associated with them are briefly described. This discussion is preliminary with regard to the detailed structure of the cataclastic zone; most of the zone has been studied only in rough reconnaissance. Detailed petrofabric studies of the mylonitic rocks have been made only at Coyote Mountain, north of Borrego Valley, by Theodore (1966, 1970). Brief descriptions of the regional distribution and some tectonic implications of the cataclastic rocks have been made by Sharp (1966, 1967, 1968). Work on this zone by the author is continuing.

In the discussion to follow, the locations of named geographic landmarks and geologic features are shown in the map of Figure 1, or explained in its caption.

GEOGRAPHY AND GEOMETRY OF THE EASTERN PENINSULAR MYLONITE ZONE

As depicted in Figure 1, the cataclastic rocks of the mylonite zone extend from the latitude of Palm Springs southward about 80 km to the North Pinyon Mountains. The planar structure or foliation of the rocks dips generally in the range 30° to 60° toward the east or northeast, but locally and to a minor extent in other directions. What is most remarkable about the orientation of this zone is its approximately north-northwest average strike, coinciding with the trend of the eastern margin of the Peninsular Ranges through its linear 1500 km extent from Palm Springs to the tip of Baja California. Although the existence of the mylonite belt is only known as far south as shown on Figure 1, it is conceivable that the zone continues much farther southward, concealed by late Cenozoic sediments, alluvium and water of the Gulf of California.

Active faults of the San Andreas system, particularly two strands of the San Jacinto fault zone dextrally offset the mylonite belt, producing local anomalies in the average trend. The difference in the trends of the mylonite belt and the currently active faults emphasizes the difference in tectonic regimes and age of the two families of fault zones, the movements within the mylonitic rock probably having ceased long before beginning of movement on the fault of the San Andreas system (Sharp, 1968).

Thrust faults that generally dip at relatively lower angle are spatially associated with the mylonitic belt throughout the latter's length of exposure. Throughout the mylonite zone, truncation of cataclastic structure occurs at the thrust faults. Southward termination of surface exposure of the mylonite belt is in fact achieved mainly by truncation by one of the thrusts. The thrust belt is traceable for approximately an additional 15 km farther south where Quaternary deposits conceal it.

In contrast to the generally eastward- or northeastward-dipping structure of the cataclastic rocks of the mylonite zone, the geometry of the thrust faults is considerably more complex. Although the net regional trend of the thrust belt is the same as the mylonite zone, dip of the thrusts is typically shallower than the associated mylonitic rocks, and thus there is generally downdip truncation of the mylonitic structure as well. In addition to shallower dip, the thrusts define complex corrugated and locally imbricate surfaces. At least three major trough-like corrugations whose axes trend nearly east-west occur south of the Vallecito Mountains, in and north of the Pinyon Mountains, and in the central Santa Rosa Mountains (NE of the word "Rosa" in Figure 1). A nearly north-south-trending trough corrugation includes the north end of the Santa Rosa Mountains.

Both the belt of mylonitic rocks and the thrust faults appear to be unique within the eastern Peninsular Ranges topographic province of southern California and Baja California. As such they constitute an important "marker" zone which aids in the estimation of the displacement of the younger and presently active faults of the San Andreas system within the eastern Peninsular Ranges (Sharp, 1966, 1967).

MATERIALS OF THE MYLONITE BELT

The cataclastically deformed rocks of the mylonite belt include coherent, pervasively sheared granitic rocks of mid-Cretaceous age and older amphibolite-grade metasedimentary and possibly metavolcanic rocks of generally unknown but pre-mid-Cretaceous age. The rocks represent deformation under ductile conditions. Theodore (1970) estimates the depth of burial at the time of deformation to be on the order of 11 to 23 km at Coyote Mountain, and temperatures probably approached the minimum melting temperature of granite (650o - 7000 C). The geometry of granitic bodies displaced by faults of the San Jacinto fault zone suggests that Coyote Mountain may be one of the most deep-seated exposures within the mylonite belt; exposures of the same rocks in the Santa Rosa Mountains and in mountains west of Borrego Valley probably are shallower by about 6 km and 3 km respectively.

Rocks of the mylonite zone range from barely sheared cataclastic augen gneiss to ultramylonite. Generally, very great thicknesses of rock are involved in the shearing and there are few known abrupt gradients in degree of deformation within the zone. The greatest width of the mylonitic zone occurs southwest of the city of Indio, where at an average dip of about 400, the thickness of mylonitized rocks exceeds 8 km. This figure of thickness should be regarded as a minimum, because there is evidence in the same locality that crustal shortening normal to the strike of the zone has occurred on the associated thrust faults. At present, no upper limit can be placed on the entire thickness of the mylonitic zone because of the uncertainty of the amount of post-mylonite thrusting.

INTERNAL STRUCTURES OF MYLONITIC ROCKS

Cataclastically deformed rocks of the mylonite belt possess a foliation ranging from barely perceptable to pronounced. On the surfaces of this pervasive shear foliation, there is usually a strong linear structure produced by trains and concentrations of dark and light minerals. The lineation is usually oriented approximately eastward or northeastward, or approximately downdip for rocks with the typical strike.

Small-scale folds, as well as a few larger ones, exist within the mylonite belt and their axes tend to parallel the lineation in the rocks. At microscopic scale, axes of quartz grains in the mylonitic rocks are concentrated in the plane of the foliation but normal to fold axes and the lineation. A detailed study of the petrofabrics, noting in particular flattening normal to the foliation and elongation parallel to the lineation in these rocks, was made at Coyote Mountain by Theodore (1966).

Estimates of the amount of strain that has taken place within the deformational belt are difficult to make because marker lithologies that have been found to date are either concordant to the cataclastic fabric of the rocks or cannot be traced across boundaries of the zone into undeformed rock. Thus, the generally unknown amount of simple shear in small samples of the zone, taken with the additional complexities introduced by the thrust faults which prevent direct measurement of the entire width of the shear zone, makes an assessment of the total strain represented by the zone impossible to determine from fabric geometry along. In spite of this general situation, the degree of intensity of cataclasis is not uniform within some bodies of originally relatively homogeneous tonalite and granadiorite. At Pinyon Flat (near the small patch of stippled alluvium between the words "Santa" and "Rosa" in the Santa Rosa Mountains of Figure 1), a narrow subzone of strongly sheared granodiorite has been noted cutting across relatively less deformed but otherwise equivalent rock. The planar structure within the strongly sheared fabric *lay* at a very small angle to the boundary surface of the subzone, so small as to be nearly unmeasureable. Strain within this subzone thus is probably very large, perhaps 100 or even greater. The amount of strain in the more typical cataclastic rocks probably is substantially less as judged by the larger grain size and weaker development of cataclastic texture. In this example, the perpendicular relation between the lineation in the planar shear structure and the line of intersection of the boundary surface of the zone of large strain with the shear foliation outside of the zone was readily evident.

The structures observed in these rocks and their orientation with respect to the regional boundaries of the deformation zone (Escher and Watterson, 1973) suggest horizontal shortening of the crust, achieved by thrusting from the NE or ENE direction which raised crystalline rocks of the hanging wall (now largely concealed beneath alluvium of the Salton Trough) over similar rocks in the eastern Peninsular Ranges. The collapse of the Salton Trough to form the great topographic depression that extends into the Gulf of California is a much later tectonic event; its formation will be described briefly below.

AGE OF THE MYLONITIC DEFORMATION

The youngest rocks affected by the cataclastic deformation of the mylonite belt are granitic rocks, including gabbro, quartz diorite, granodiorite, and quartz monzonite, of the Cretaceous southern California batholith. The presence of sillimanite cutting cataclastic fabric of rocks exposed at Coyote Mountain led Theodore (1970) to the conclusion that high temperatures and pressures existed at the time of deformation, and unpublished K-Ar dates obtained from two transects across the cataclastic zone suggest that the shear zone existed and influenced the position of contours of equal apparent K-Ar ages of approximately 70 my (F.K. Miller, U.S. Geological Survey, personal communication). The crystalline rocks in this region show the typical characteristics of mesozonal emplacement, a conclusion that is consistent with contemporaneous high temperature and great depth of burial.

SHEAR MATERIALS AT THE THRUST FAULTS

Shear products developed along the thrust faults are markedly different from the cataclastic and granitic rocks that the thrusts cut. Shear materials are highly localized and much more intensely mylonitized than the typical rocks of the mylonite zone, and the appearance of these shear products are quite uniform throughout the entire 100 km length of their exposure. Shearing that produced coherent cataclastic materials along the soles of the thrusts is usually 30 m or less in thickness. The shear materials consist of progressively comminuted country rock that becomes a microcrystalline ultramylonite and possibly pseudotachylite, typically 0.5 to 3 m in thickness, on the thrusts where the greatest displacements have occurred. The ultramylonitic rock almost always has a distinctive greenish brown color and has been shattered or jointed by slight movements since its formation. Internal linear structures in the ultramylonitic rock have not been recognized. Although above the coherent shear products localized along the soles of the thrust, crystalline rocks comnonly are intensely brecciated for distances of up to several hundred meters, similar brecciation in the footwalls is only rarely developed. Gradients of degree of brecciation are normal to the thrust surfaces and increase in intensity toward them.

MOVEMENTS ON THE THRUST FAULTS

Although there is no representation of topography in Figure 1, the traces of the thrust fault are nevertheless locally quite irregular. The irregularities and the changes in dip direction define the trough-like corrugations described above, and these geometric features are the chief clues to the directions of slip on the thrusts. Estimates of the magnitude of the slip depend on the distribution of rocks in the upper and lower plates and the absence of correlative rocks on opposite sides of the structure. Several especially significant segments of the thrust fault zone will be described in greater detail to present evidence for the amount and direction of movement.

NORTHERN SANTA ROSA MOUNTAINS THRUST

This structure is the northernmost and one of the largest within the belt of thrusting. From Palm Springs (where it is concealed by alluvium) the thrust extends southward (this segment has been called the Palm Canyon fault), then eastward and then north-northeastward. The barbs on the fault trace shown on Figure 1 indicate the direction of dip, usually less than 30° but rarely steeper. The distribution and contrasting kinds of cataclastic rocks above and below the thrust surface provides only evidence for a minimum amount of displacement. Southeast of this thrust fault there is a large imbricate sheet of cataclastic rocks that is terminated by the north-northeastern-trending segment of the fault. Rocks above the thrust contrast strongly in lithology with those below; a displacement with a south-southwestward horizontal component of at least 11 km is required to explain the present distribution of cataclastic rocks. It must be emphasized here that this is a minimum displacement because the imbricate plate of cataclastic rocks is terminated on the northeast, as well as on the northwest, by probably the same curving thrust fault; thus the full dimensions of this slice of cataclastic rock are unknown. Because the cataclastic rocks in the upper plate do not match the rocks to the southeast, no limit on displacement is provided by the upper plate exposures. Moreover, the lack of a constraint on the amount of erosional shrinkage of the upper plate adds to the possibility of substantially greater horizontal transport than 11 km.

The direction of tectonic transport is inferred to be south-southwestward for the upper plate because of the geometry of the sole of the thrust. The energy requirements for transport of the rocks above and below the slip surface are minimized by slip in this direction. This proposed direction of slip is nearly parallel to the lineation in the mylonitic rocks above and below the thrusts, suggesting that both the development of the mylonitic rocks and the younger thrusts that displace them are related to the same set of conditions of regional stress.

PINYON MOUNTAINS THRUST

South of Borrego Valley, a southward-dipping major thrust fault runs westward along the north edge of the Pinyon Mountains. Near the southwest side of these mountains the fault trace swings southward, and then eastward with dip to the north, producing an east-west elongate trough of overthrust rocks. The upper plate crystalline rocks contrast markedly with the underlying terrain, and no correlation between rocks above and below the thrust appears to be possible. As in the case of the northern Santa Rosa thrust, the data constrain only a minimum displacement on the thrust, in this case about 15 km of east-west crustal shortening.

AGE OF THE THRUST FAULTING

The thrust faults associated with the eastern Peninsular Ranges mylonite belt cut only crystalline rocks that make up the core of the ranges. Since the youngest part of the crystalline terrane consists of mid-Cretaceous plutonic rocks and the mylonitic rocks developed from them, the thrusts must be no older than mid-Cretaceous as well. The only constraint on their youth is stratigraphic in origin; in the Pinyon Mountains sedimentary rocks that are possibly correlative with the Eocene Poway Group of Kennedy and Moore (1971) rest on the overthrust plates, suggesting that the thrusted terrane was eroded to about its present level of exposure by Eocene time. The available data do not prohibit the thrusting from being restricted to a short interval of time, but these events could have taken place at any time between mid-Cretaceous and early Cenozoic.

SUMMARY

Both the Peninsular Ranges mylonite zone and the series of thrust faults associated with it appear to represent the deep roots of an ancient shear zone within which crustal shortening normal to the axis of the Peninsular Ranges occurred. The parallelism of this zone with the Cretaceous coastline, the dip direction, and the direction of crustal shortening suggest that the mylonite zone may have been related to subduction at the (then) edge of the Pacific Plate but approximately 100 km east of the main subduction zone.

Stratigraphic evidence from the western part of the Peninsular Ranges indicates that unroofing of the southern California batholith was achieved by upper Cretaceous time. The nature of the cataclastic rocks in the Peninsular Ranges mylonite zone, as well as the temperature and pressure environment for these rocks discussed above, suggest that movement began in the late stages of batholithic emplacement before uplift and unroofing of the batholith had begun. Continuing thrust movements in the same zone during and subsequent to unroofing of the batholith probably led to the formation of the younger series of thrusts that displace the slightly older mylonitic rocks. The coherence of the ultramylonite developed along these thrusts suggest relatively great confining pressure and probably high temperatures localized at the thrust surface, but brecciation indicating brittle failure rather than ductile flowage in the rocks above and below the thrusts suggests depths at the time of movement of perhaps no more than a few kilometers.

The conclusion that relatively great confining pressure existed at the thrust fault surfaces is partly based on the fact that nowhere along the active faults of the nearby active San Jacinto fault zone are similar shear materials developed. Because geometry of plutonic bodies and of the belt of mylonitic rocks suggest that the vertical component of slip on the major strand of the San Jacinto fault zone may have totaled 6 km, the present level of exposure across this zone represents at least that much erosion of the crystalline terrane since the beginning of motion on this fault zone, possibly in Pliocene time (Sharp, 1967). Although stress and temperature conditions during the strike-slip faulting may have been substantially different than in the thrust faulting associated with the zone of mylonitic rocks, that strongly coherent cataclastic products are absent, even as fragments within the gouge and breccia zone of the active faults, suggests that the thrusting, at the present level of exposure, was a more deep-seated event.

The creation of the topographically and structurally depressed Salton Trough to the east of the Peninsular Range mylonite belt probably did not occur until much later, in mid- to late-Cenozoic time. Although some of the thrust fault slip surfaces were reactivated at the time of some of the uplifts of the Peninsular Ranges with respect to the trough, the sense of faulting at this time was opposite to the earlier events. Low angle normal faulting in the southern Santa Rosa Mountains on the pre-existing thrust fault surfaces played a significant role in the formation and east-west crustal extension of the Salton Trough.

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FIGURE 1:

Geologic map of the eastern Peninsular Ranges mylonite zone in southern California. Striped pattern represents the distribution and approximate strike of planar fabric in the cataclastic rocks. Granitic rocks of the southern California batholith, undifferentiated from prebatholithic crystalline rocks are unpatterned. Highly deformed late Cenozoic sediments and generally undeformed Quaternary alluvial deposits are collectively represented by areas whose margins are stippled. Thrust faults, in part associated with the belt of cataclastic rocks are shown with heavy barbed lines or heavy dotted lines. Young faults constituting parts of the active San Andreas system are shown with lighter weight lines.

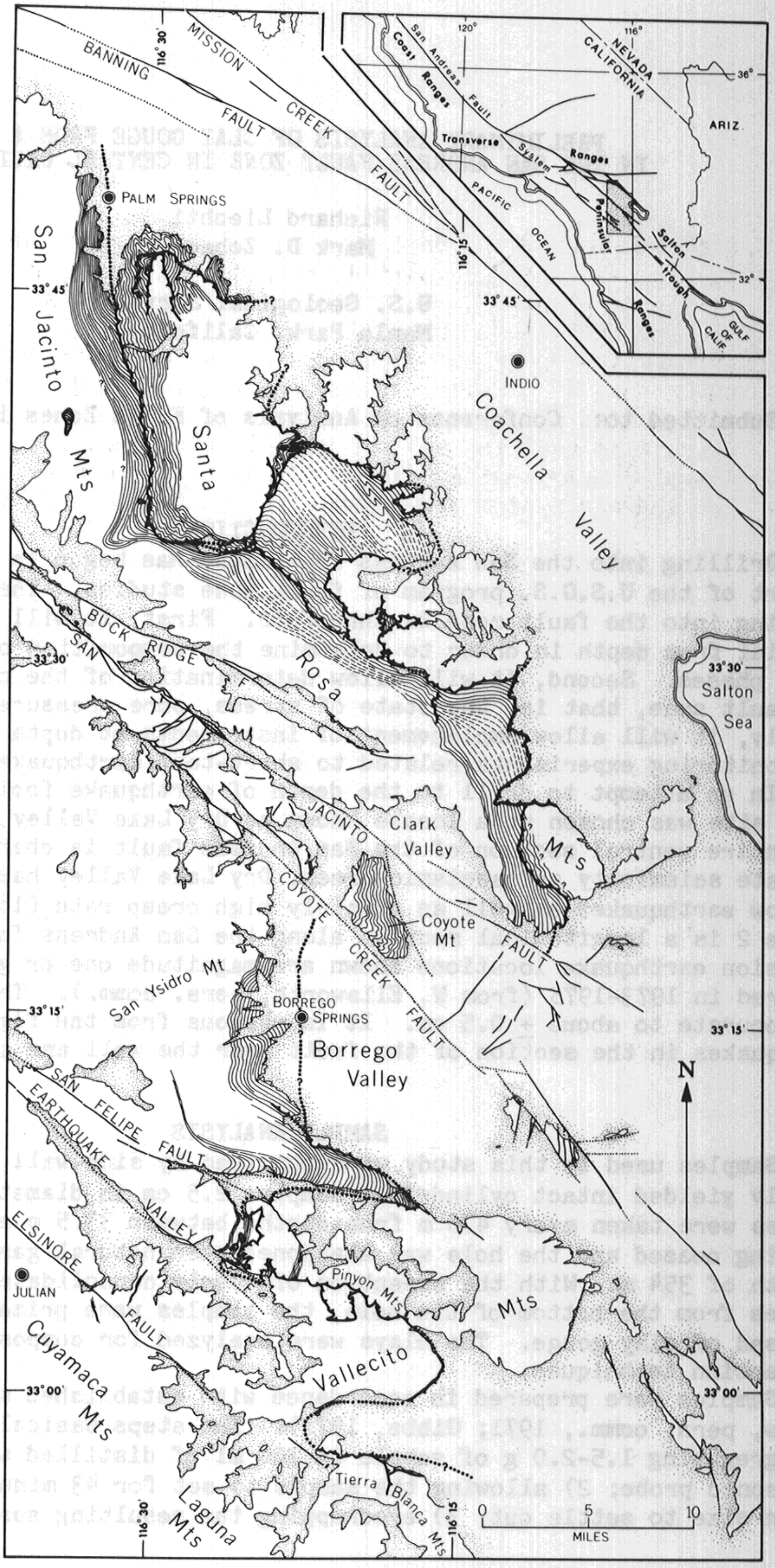
BANNING
MISSION
FAULT
CREEK
FAULT
116° 30'
116° 15'
PALM SPRINGS
San Jacinto Mts
Santa Rosa Mts
33° 45'
33° 45'
INDIO
Coachella Valley
BUCK RIDGE
SAN JACINTO FAULT
33° 30'
33° 30'
Salton Sea
Clark Valley
COYOTE CREEK FAULT
Coyote Mt
San Ysidro Mt
BORREGO SPRINGS
Borrego Valley
33° 15'
33° 15'
N
SAN FELIPE FAULT
EARTHQUAKE VALLEY FAULT
ELSINORE FAULT
JULIAN
Pinyon Mts
Mts
Vallecito
Cuyamaca Mts
33° 00'
33° 00'
Tierra Blanca Mts
Laguna Mts
116° 30'
116° 15'
0 5 10
MILES
120°
116°
36°
32°
NEVADA
CALIFORNIA
ARIZ.
Coast Ranges
San Andreas Fault System
Transverse Ranges
PACIFIC OCEAN
Peninsular Ranges
Salton trough
GULF OF CALIF

FIGURE 1