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LATE CENOZOIC TECTONISM IN ARIZONA AND ITS IMPACT ON REGIONAL LANDSCAPE EVOLUTION

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ABSTRACT

A distinctive suite of volcanic, sedimentary, structural, and physiographic characteristics permits differentiation of the post-12- to 15-Ma Basin-Range disturbance from earlier mid-Tertiary extensional tectonism in Arizona. Basin-Range volcanism comprises basalts or bimodal basalt-rhyolite suites that are concentrated in several fields in central and northern Arizona; the age of volcanism generally decreases northeast and east onto the Colorado Plateau margin. Structural and physiographic basins were filled with wedges of clastic sediments in the Basin and Range province. Basin-Range faults in the upper crust define irregular, segmented basins 10-30 km wide, 50-150 km long, and less than 2,500 m deep. These basins vary from symmetric, fault-bounded grabens to asymmetric troughs with gently basinward-sloping bedrock ramps that are downfaulted against major boundary-fault zones on one side of the basin. Most late Miocene and younger normal faults are probably fairly planar, with moderate to steep dips, although faults may flatten at mid-crustal depths near the brittle-ductile transition. Upper crustal deformation suggests about 10 to 20 percent extension during the late Miocene, directed east-west or west-northwest-east-southeast. Northwest-trending basin orientations in southwestern Arizona probably predominantly reflect southwest-northeast extension associated with mid-Tertiary deformation. The Basin-Range disturbance apparently propagated across southern and western Arizona from 15 to 10 Ma. Since 10 Ma, Basin-Range tectonism may have encroached onto the Colorado Plateau margin in northern Arizona.

Plio-Quaternary deposits and present landforms document the waning of tectonism in the Basin and Range province. Undeformed Plio-Quaternary upper basin fill and 1- to 10-km-wide bedrock pediments imply tectonic quiescence. Deposition of thin, coarse-grained pediment fans in the late Pliocene to early Quaternary and multiple lower to upper Quaternary fans or terraces reflects fluvial responses to climatic fluctations superimposed on basin dissection attendant with regional drainage integration. The Colorado Plateau contains sparse alluvial and eolian surficial deposits; regional bedrock erosion surfaces are broken by lithologically controlled cliffs formed during and since the late Miocene.

A 150- to 300-km-wide belt of Plio-Quaternary normal faulting, regional uplift, and historical seismicity extends diagonally northwest to southeast across Arizona. The greatest neotectonic fault concentration and largest Quaternary fault displacements occur along the Colorado Plateau margin of northwestern and north-central Arizona; this deformation may mark the southern terminus of the Intermountain seismic belt of Utah. Sparse piedmont fault scarps along reactivated Basin-Range structures, with small cumulative Quaternary displacements (<15 m), typify faulting in central and southern Arizona. The neotectonic belt may serve as a deformational corridor absorbing horizontal or vertical strain between tectonically stable blocks. Regional dissection coincident with this neotectonic belt suggests Plio-Quaternary uplift or arching, although nontectonic factors such as inherited relief, climatic changes, and denudation-induced isostatic uplift are likely important factors as well. Neotectonic faulting in southern and central Arizona may represent either a restricted, small-magnitude pulse within the waning Basin-Range disturbance or the development of minor extensional tectonism after the cessation of the Basin-Range disturbance.

INTRODUCTION

Recent geologic studies have greatly revised and expanded our understanding of late Cenozoic (post-15-Ma) tectonic events in Arizona and their impact on the physiographic evolution of the state. The goal of this paper is to summarize the current state of knowledge of late Cenozoic tectonism and regional stratigraphy, and the development of the physiography of Arizona. We draw upon a large body of published data and interpretations, as well as the results of several recently completed studies that are unpublished or in limited distribution.

This paper focuses on: (1) the late Miocene Basin-Range disturbance, the principal late Cenozoic tectonic event in Arizona; (2) neotectonic (Plio-Quaternary) deformation and volcanism; and (3) the influence of tectonism upon the late Cenozoic evolution of the landscape. Our tectonic margin is a southwest-tilted bedrock ramp. The Tucson basin of southeastern Arizona is fairly symmetric in cross-section (fig. 7B; Eberly and Stanley, 1978). A deep central graben is flanked on both sides by sets of homothetic faults; these faults are in turn flanked by fairly smooth bedrock ramps that slope upward to the surrounding range blocks. The Sonoita Creek basin of southeastern Arizona is a hybrid basin, with elements of symmetry and asymmetry (fig. 7C; also Anderson, 1978, and Eberly and Stanley, 1978). A similar variety of basin forms exists in the Great Basin, based on available seismic reflection data (Anderson and others, 1983).

Regional Variations in Basin Characteristics. Significant regional variations in basin geometries, patterns, and depths are observed in Arizona (fig. 6). Southeastern and northwestern Arizona contain large, deep, well-defined basins that have fairly consistent north-northwest to north-northeast orientations and fairly regular interbasin spacings of approximately 25 to 50 km. These patterns contrast with the generally shallower, less continuous, more variably oriented post-mid-Miocene basins of southwestern and south-central Arizona.

The style and degree of basin development also varies greatly within the Transition Zone (fig. 6). Only the Central Basin subsection contains reasonably well defined basins that resemble those formed in the Basin and Range province. Extensional deformation in the Tonto and Western subsections occurred along widely distributed sets of normal faults that form isolated escarpments; large, sediment-filled basins did not form there.

The causes of these structural variations are not currently understood. It appears, however, that late Miocene extensional deformation was concentrated in southeastern, central, and northwestern Arizona. Southwestern Arizona probably experienced relatively minor extensional deformation after the cessation or diminution of middle Miocene and older extension. The total amount of Cenozoic upper crustal extension in portions of the Transition Zone may be much less than that experienced by the Basin and Range province.

Geometry of Extension at Depth. Several hypotheses have been advanced regarding the geometries of Basin-Range extension in the middle and lower crust in Arizona. Earlier studies (e.g., Eberly and Stanley, 1978; Oppenheimer and Sumner, 1981) emphasized normal faults with moderate to steep dips into the middle crust.

The importance of low-angle normal faults has been considered in more recent work. Wernicke (1985) proposed that middle and late Cenozoic extension in western Arizona was accommodated by a crustal-scale low-angle normal detachment-fault system. The master low-angle normal fault dips northeastward from a breakaway zone near the Colorado River into the lower crust beneath the Transition Zone of central Arizona. Near-surface extension observed in western and central Arizona manifests deformation of the upper plate, and the master normal fault zone has accommodated extension between major lithospheric blocks.

Recently published COCORP seismic reflection data image low-angle reflectors that are likely detachment faults in the middle and upper crust of west-central Arizona; such reflectors are not obvious beneath the Mogollon Rim and the Colorado Plateau (Hauser and others, 1986, 1987; Oliver and others, 1986). CALCRUST seismic profiles also reveal the presence of many low-angle reflectors interpreted as detachment faults in southwestern and south-central Arizona (Pridmore and others, 1986; Okaya and others, 1986; Frost and Okaya, 1986). Many of these detachment faults likely reflect mid-Tertiary crustal extension, however, and their role in late Miocene or deformation in not clear. Some of the subsurface low-angle structures may have influenced the formation of superjacent high-angle normal faults in a manner similar to that inferred for parts of the Great Basin (e.g., Allmendinger and others, 1983; Anderson and others, 1983).

Regional Time-Space Patterns of Basin-Range Tectonism

Available data suggest possible regional variations in the onset and cessation of Basin-Range tectonism in Arizona (fig. 3). The Basin-Range disturbance may have occurred somewhat earlier in southwestern Arizona (onset between 15 and 10 Ma, cessation between 10 and 8 Ma) than in southeastern and northwestern Arizona (13-10 Ma to 8-5 Ma) (Anderson and others, 1972; Eberly and Stanley, 1978; Shafiqullah and others, 1980; Menges and McFadden, 1981; Seager and others, 1984). Timing constraints in the central Transition Zone suggest development of individual basins either contemporaneous with or slightly after Basin-Range tectonism in southeastern Arizona (10-8 Ma to 6-2 Ma; McKee and Anderson, 1971; Nations and others, 1982; Keith and Wilt, 1985). Typical basin-and-range topography is not present on the Colorado Plateau in Arizona, although latest Miocene to Quaternary normal faulting and volcanism along the southern and western Plateau margins may represent a more recent phase of the Basin-Range disturbance (see section on neotectonics).

At a gross scale, northward progression of Basin-Range tectonism from the southern Basin and Range province to the Great Basin is suggested by regional tectonic analyses (Best and Hamblin, 1978; Eaton and others, 1978; Dickinson and Snyder, 1979; and Zoback and others, 1981). Seager and others (1984) have proposed an eastward migration of Basin-Range tectonism from southwestern Arizona into southern New Mexico.

Some limitations can be placed on possible migration patterns of Basin-Range tectonism within Arizona. First, the available data suggest that any proposed migration of Basin-Range tectonism occurred not as a uniformly propagating disturbance, but rather initiated synchronously, at least within time intervals of several million years, across large regional zones. Further, the rates of possible migration vary dramatically. Large-magnitude tectonism

Most of the dissection is demonstrably Plio-Quaternary. The dramatic cutting of the Colorado river system in the Grand Canyon region, however, has been interpreted to have begun in Miocene (Hunt, 1983) or Plio-Quaternary time (Lucchitta, 1972; Young and Brennan, 1974; Cole and Mayer, 1982). The data summarized in figure 11 provide minimum estimates of the amounts and rates of Plio-Quaternary downcutting where well-constrained ages of incision can be established. Rates are consistently high in the tectonically active western Colorado Plateau region (370 to 90 m/m.y.), but drop to more moderate levels (100 to 30 m/m.y.) in the dissected belt of central and eastern Arizona. Landscape dissection is minimal in most of south-central and southwestern Arizona, except along the lower Colorado River north of Parker, Arizona.

Neotectonic Deformation

Detailed geologic and geomorphic studies of individual Quaternary faults scattered about the state (Bull, 1974; Huntoon, 1977; Soule, 1978; Shoemaker and others, 1978; Anderson and Mehnert, 1979; Druke, 1979; Mayer, 1982; Pearthree and Calvo, 1987; Bull and Pearthree, 1988) and regional reconnaissance studies that focused on temporal and spatial patterns of surface faulting, volcanism, and regional uplift (Menges, 1983; Menges and Pearthree, 1983; Pearthree and others, 1983; Scarborough and others, 1986; Machette and others, 1986) have defined the broad patterns of neotectonic activity in Arizona. Regional patterns of surface faulting and possible long-wavelength (>200-km-wide) belts of uplift are emphasized in this summary.

Faulting Patterns. Most neotectonic structures observed in surface exposures are steeply dipping (>45°), normal-separation faults that dip away from adjacent bedrock escarpments or range blocks. The scale of neotectonic faulting varies widely across the state, ranging from less than 5 m of vertical displacement on <5-km-long scarps in southwestern Arizona to 310-470 m cumulative vertical displacement along portions of the 260-km-long Hurricane fault in northwestern Arizona and southwestern Utah (Anderson and Mehnert, 1979; Menges and Pearthree, 1983).

Most Quaternary faults occur in a northwest-trending belt that extends diagonally across the state (fig. 12), between the tectonically quiescent southwestern and northeastern portions of Arizona. Marked concentrations of faults within the belt occur on the margin of the Colorado Plateau in northwestern Arizona, north of the San Francisco volcanic field in north-central Arizona, and in the Mexican Highland section of southeastern Arizona.

Historical felt reports and instrumentally recorded seismicity in Arizona are also concentrated in a broad and diffuse northwest-trending belt (fig. 12; Sumner, 1976; DuBois and others, 1982a, 1982b; Stover and others, 1986). There is little direct spatial coincidence between individual historic epicenters and mapped Quaternary faults, but seismicity is concentrated where Quaternary faults are most abundant.

Interpretations of the timing and rates of fault displacements are based primarily on morphologic analyses of fault-scarp profiles, soil-stratigraphic estimates of ages of faulted deposits, and vertical-offset measurements. They generally have the best resolution over the past 150 k.y. Late Pleistocene and younger ruptures occur throughout the entire length of the primary belt of faulting described earlier and along all but one of the faults mapped in southwestern Arizona (fig. 13). The youngest ruptures (<20 ka) further define a relatively narrow zone extending discontinuously from the Hurricane and Toroweap fault zones southeastward into the central and southeastern parts of the state.

Estimated rates of late Quaternary faulting vary by at least an order of magnitude within this belt, however (fig. 14). The largest Quaternary displacements (100-400 m) and the shortest estimated recurrence intervals between displacement events (~10 k.y.) occur along a narrow zone centered on the Hurricane fault zone of northwestern Arizona and southwestern Utah (NW1, fig. 14). Offsets of Quaternary basalt flows (Holmes and others, 1978; Hamblin and others, 1981; Anderson and Mehnert, 1979), steep and linear fault escarpments, and large composite knickpoints along streams that flow across the Hurricane escarpment (Mayer, 1985) indicate that these relatively high rates of faulting have persisted throughout the Quaternary.

A transitional zone with longer estimated recurrence intervals between displacements (10-100 k.y.) continues along the southern ends of the Hurricane and Toroweap fault zones southeastward into a series of faults near the Colorado Plateau margin in north-central Arizona (NW2, fig. 14). These faults offset middle to upper Pleistocene alluvium by a maximum of 8-30 m. Recurrence intervals between displacements are on the order of 10^5 years along Quaternary faults in the rest of the state. The Algodones fault southeast of Yuma is an exception to this. The recurrence interval between displacements is about 10 to 20 k.y.; this indicates that faulting in this area is part of the Salton Trough tectonic province (Y, fig. 14).

Faults in central and southern Arizona offset lower to upper Pleistocene piedmont alluvium by less than 10 m. These fault scarps commonly coincide with the surface projections of the primary basin-bounding structures inferred from gravity or seismic sections. Both the Quaternary scarps and the basin-bounding faults define the basinward margins of broad, suballuvial bedrock pediment benches described earlier (figs. 5, 12). These facts suggest that much of the observed neotectonic faulting in southern and central Arizona represents low-level Quaternary reactivation of a few (<30 percent) late Miocene basin-bounding structures following a Pliocene

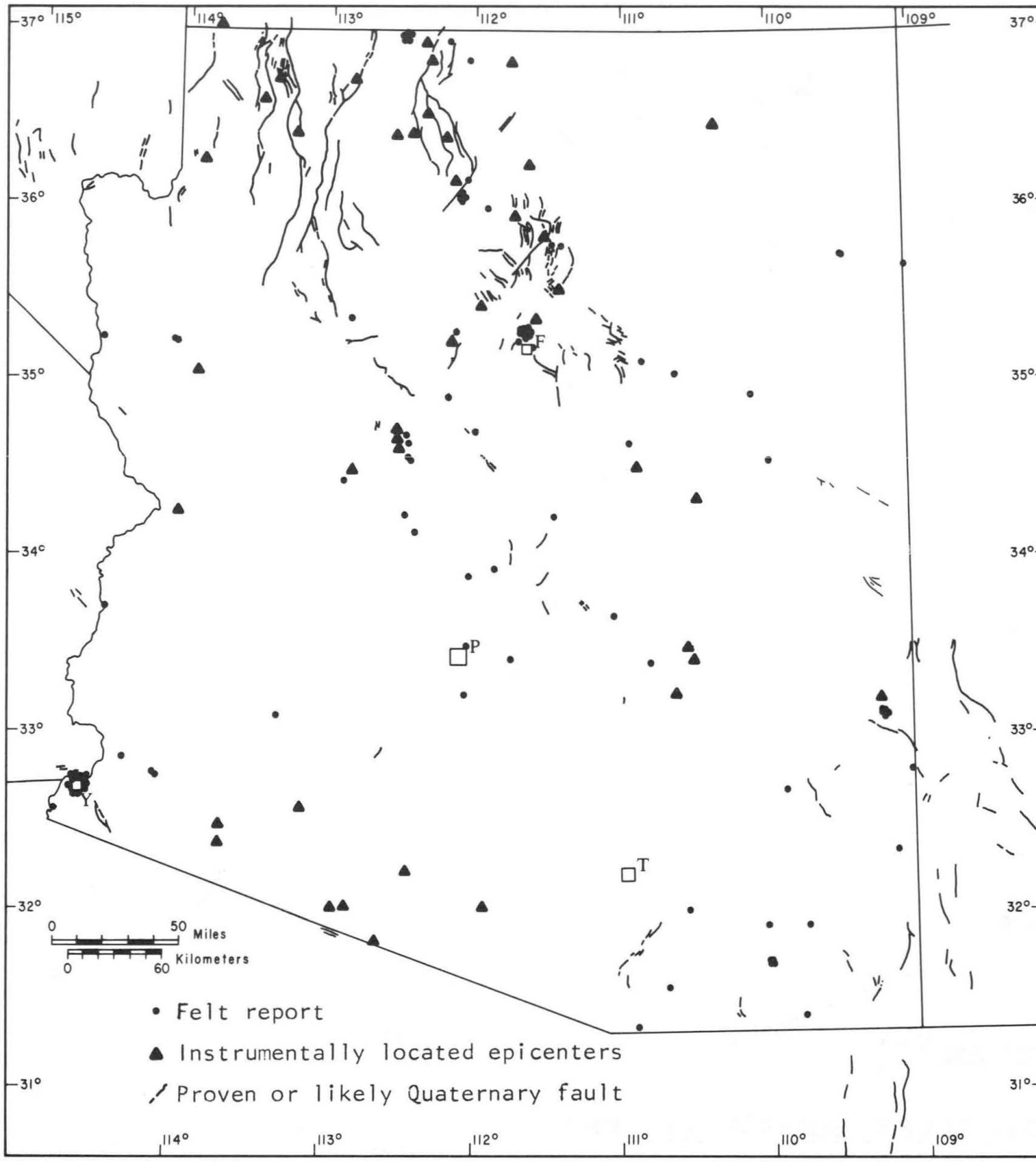

Figure 12. Locations of Quaternary faults and historical earthquake epicenters in Arizona. Map shows only faults with demonstrable Quaternary displacements or fault scarps with evidence for Quaternary surface rupture. Dots are epicenters located on the basis of felt reports; triangles are instrumentally located epicenters. The small number of seismographs in Arizona leads to location uncertainties in the latter category; most epicenters in southwestern Arizona may actually have occured farther to the southwest in the Gulf of California (M. Sbar, personal commun., 1982; T.C. Wallace, personal commun., 1987). Quaternary faults are generalized from Menges and Pearthree (1983), and earthquake data are from DuBois and others (1981, 1982).

tectonic lull in the Basin-Range disturbance (Menges and McFadden, 1981; Pearthree and others, 1983; Pearthree and Calvo, 1987).

Possible Regional Uplift. The generalized topographic map of Arizona shows a northwest-trending band of relatively high-altitude, high-relief terrain separating areas of much flatter regional topography in the southwestern and northeastern corners of the state (fig. 15; Godson, 1980). The main band of elevated terrain coincides with the dominant region of Plio-Quaternary landscape dissection and encompasses most of the individual neotectonic structures and historic earthquake epicenters in the state (figs. 11, 12).

Regional topographic profiles were constructed across this band of anomalous topography, using the generalized contours of 1:250,000-scale subenvelope maps (fig. 16). The

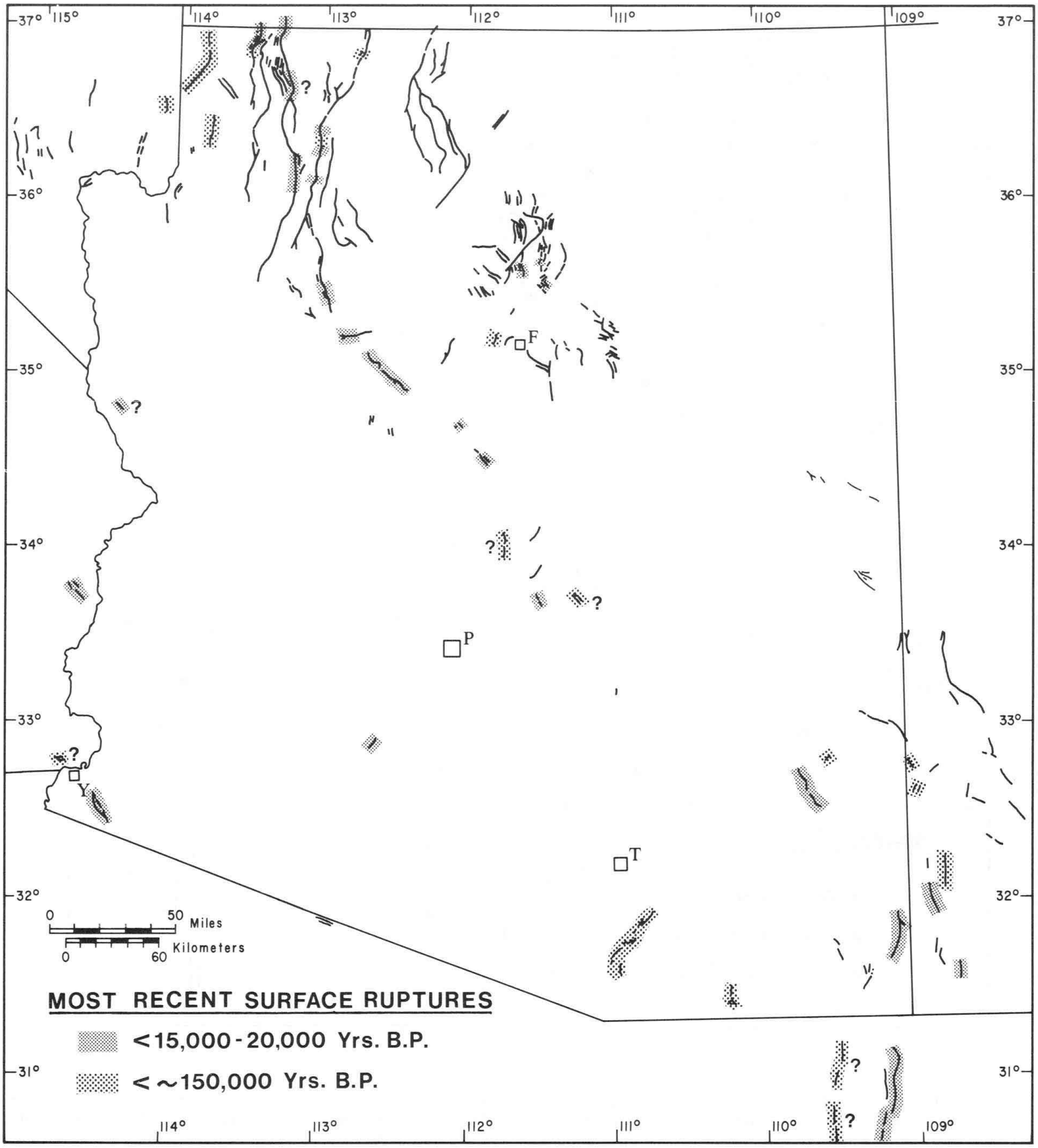

Figure 13. Location of faults with Holocene or late Pleistocene surface ruptures, based on combined offset and morphologic data of fault scarps summarized by Pearthree and others (1983). All faults active during these intervals may not have been identified, but the record is most complete for faults active in the past 15,000 years. Some unpatterned faults, particularly in north-central and northwestern Arizona, may have been active in the past 150,000 years, but many of these faults occur in bedrock areas that offer no clear means of documenting offset of Quaternary deposits.

most prominent feature evident in both cross-sections is a broad central arch of elevated topography, 200 to 350 km wide, which coincides with the rugged physiographic band identified in figure 15. In northwestern Arizona, the margins of the regional arch coincide with faults or monoclines with known or suspected Quaternary activity. In central Arizona, the arch straddles the Transition Zone and the Mogollon Slope section of the Colorado Plateau. The crest of the arch is centered over the zone of maximum regional dissection; the flanks of the arch coincide with

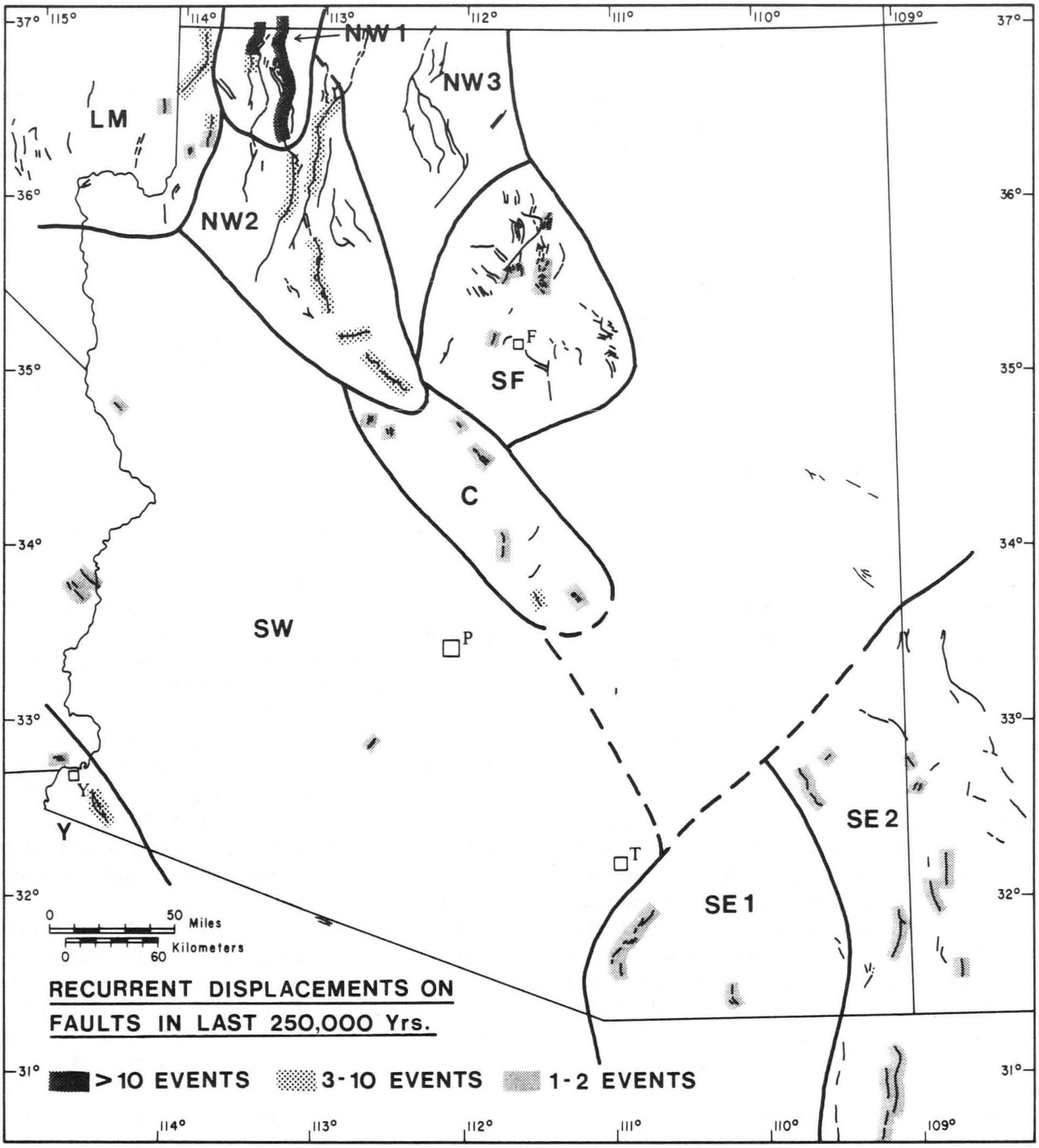

Figure 14. Estimates of late Quaternary vertical displacement rates on individual faults and domains of late Quaternary faulting. Displacement rates are estimated from amounts of vertical surface offsets of upper and middle Pleistocene alluvial geomorphic surfaces or basalt flows between 0.1 and 1 Ma. Domains are defined on basis of fault densities and fault displacement rates. Domains discussed in text are: Lake Mead (LM); three subdivisions of northwestern Arizona (NW1, NW2, NW3); the San Francisco volcanic field (SF); central Arizona (C); two subdivisions of southeastern Arizona (SE1, SE2); southwestern Arizona (SW); and Yuma (Y).

zones of diminished downcutting, recorded by sets of downstream-convergent bedrock canyons and regional terraces (fig. 11; Péwé, 1978; Menges, 1983).

These regional topographic anomalies and dissection patterns may reflect a broad, elongate zone of Plio-Quaternary uplift that closely corresponds to the main belt of Quaternary faulting and seismicity. The central and southern parts of this postulated zone of uplift coincide with regions of epeirogenic uplift proposed earlier (Cooley, 1968; Scarborough, 1975; Péwé, 1978). Lucchitta (1979) hypothesized Plio-Quaternary uplift in the Lake Mead area that decreases southward along the lower Colorado River

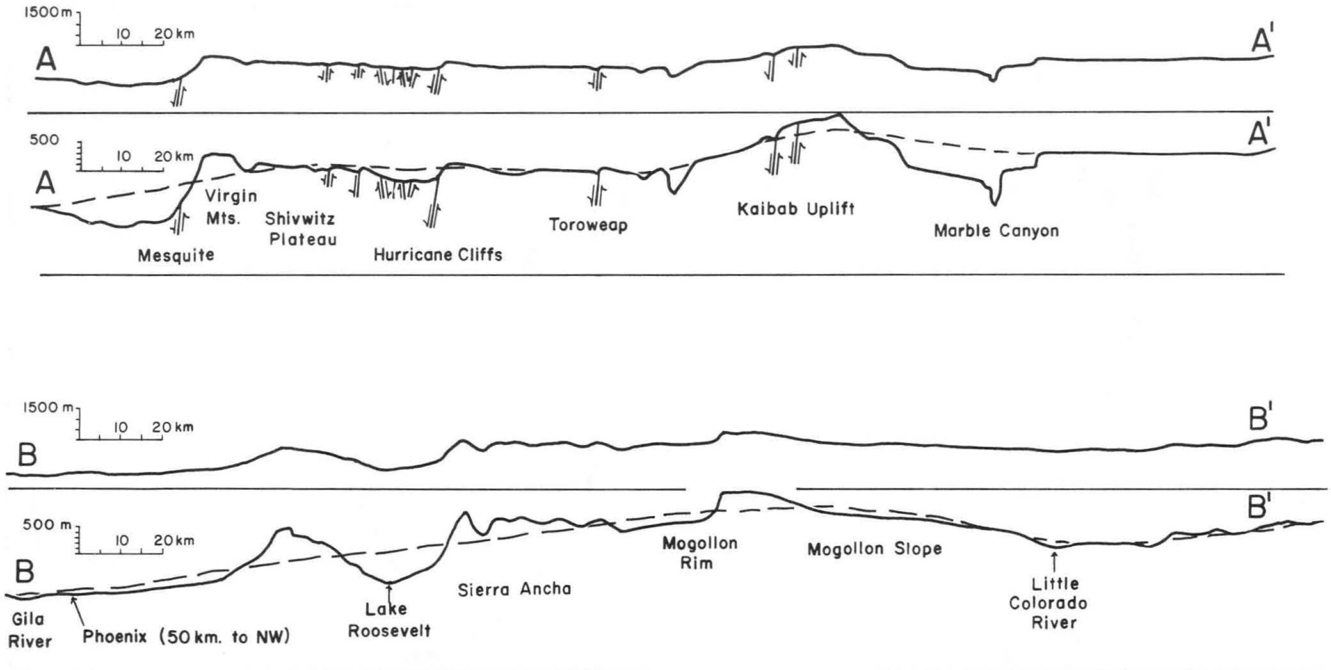

Figure 16. Profiles of generalized regional topography constructed from minimum altitudes depicted on 1° x 2° subenvelope maps, with contours defined by the altitudes of stream channels. Profiles are shown with both 8.3x and 15.5x vertical exaggeration. The locations of these profiles are shown in figure 15.

A. East-west profile of the western margin of the Colorado Plateau, north of the Grand Canyon. Note structurally defined central uplift.

B. Northeast-southwest profile across the Transition Zone, Mogollon Rim, and southern margin of Colorado Plateau, in central Arizona. A pronounced arch is centered over the Mogollon Rim.

interpretations postulate an initial phase driven by active mantle processes in the mid-Tertiary characterized by extension in an interarc or back-arc setting. At the initiation of the Basin-Range disturbance, passive rifting related to the evolving transform boundary was superimposed across this already extended terrane (Zoback and others, 1981; Eaton, 1982).

A critical factor in any satisfactory tectonic interpretation of the Basin-Range disturbance involves the nature and significance of the transition between Basin-Range and mid-Tertiary deformations. Important elements in this regard include variations in the rates, styles, and geometries of deformation, changes in magmatism and regional stress orientations, and any migration patterns evident in the tectonic timing data. Some type of composite interpretation may best satisfy the currently available information. Regional stratigraphic and structural data summarized earlier suggest several sequential and spatially superimposed extensional events in middle to late Cenozoic time in southern and western Arizona. The most recent event corresponds to the late Miocene and younger Basin-Range disturbance. It is not clear whether these deformations reflect discrete tectonic events, or are part of one post-Eocene tectonic disturbance with several distinct phases that may be related to varying thermal conditions in the lithosphere. However, some characteristics of the Basin-Range disturbance—the apparent clockwise rotation in the direction of regional extension, the abruptness in the transition in magmatic and deformational style, and a possible northward and eastward propagation of the disturbance—suggest a more discrete tectonic transition that is fundamentally controlled by the evolution of the San Andreas transform boundary.

Neotectonism

Neotectonic data summarized earlier suggest two fairly distinct tectonic patterns: (1) Basin-Range extension and volcanism have encroached onto the Colorado Plateau margin since the late Miocene; and (2) diffuse belts of middle to late Quaternary faulting are located between relatively more stable crustal blocks (fig. 17).

Tectonism at the eastern edge of the Basin and Range province may have migrated onto the Colorado Plateau in northwestern Arizona and southwestern Utah since 10 Ma (Best and Hamblin, 1978). However, available timing data for volcanism and faulting do not support a uniform eastward migration of neotectonic activity. There is a crudely defined eastward decrease in age of upper Miocene and younger volcanism, and perhaps normal faulting, across the Colorado Plateau margin, but detailed age constraints imply a spatially irregular initiation of activity at individual volcanic centers and faults within the broader zone of neotectonic deformation (Pearthree and others, 1983).

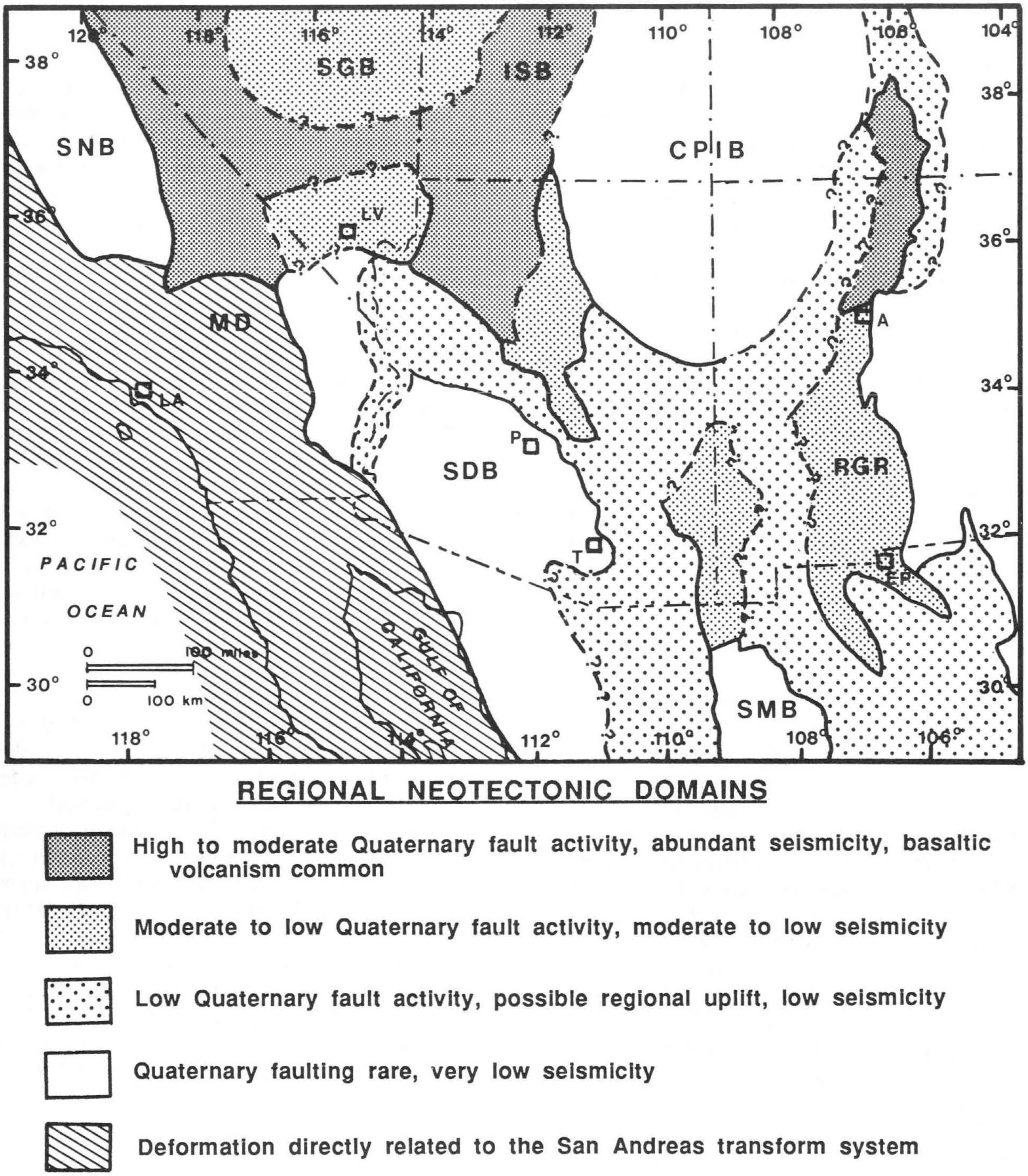

Figure 17. Interpretive map of the neotectonic setting of Arizona and adjacent areas. Deformation is distributed across the southern Great Basin (SGB), but is more concentrated and associated with volcanism along its eastern and western margins. The Intermountain seismic belt (ISB) on the eastern margin continues southward into the zone of deformation and volcanism in northwestern Arizona. This pattern may also include regions of more diffuse faulting and (or) volcanism along the southern and eastern margins of the Colorado Plateau in Arizona and New Mexico that, like the ISB, display some evidence for encroachment into the Colorado Plateau interior during the late Cenozoic. Generally north-trending zones or belts of faulting, with varying amounts of volcanism and possible uplift, are located in the southern Basin and Range province and the Rio Grande Rift (RGR) of Arizona, New Mexico, west Texas, and northern Mexico. These riftlike zones tend to occur between large regions of relative neotectonic stability, the Sonoran Desert (SDB), Sierra Madre (SMB), Colorado Plateau interior (CPIB), and Sierra Nevada (SNB) blocks. The degree and rates of faulting vary within and between these deformation belts, and internal variations define secondary narrow zones of more concentrated fault activity. Also included in figure are deformation zones closely related to the San Andreas transform system, including the Mojave Desert region (MD).

A better defined northeastward migration is evident in the time-space patterns of volcanism and faulting in north-central Arizona (figs. 2, 12, 14). Most of the Plio-Quaternary faulting in and about the San Francisco volcanic field occurs as variably oriented short faults that imply less a coherent regional extension than a brittle accommodation of localized uplift related to the volcanism. It is possible that the volcanism and faulting of the San Francisco field are related to a migrating zone of magma generation that is not directly linked to neotectonic deformation and volcanism in northwestern Arizona (e.g., Tanaka and others, 1986).

Tectonic encroachment onto the Colorado Plateau margin in east-central Arizona is not obvious, given the overlapping sequences of late Cenozoic volcanism and the lack of neotectonic faulting in the White Mountain volcanic field. In western New Mexico, Laughlin and others (1982) reported a pattern of northwestward migration of neotectonic faulting and volcanism onto the margin of the Colorado Plateau. Much of this activity is localized along the northeast-trending Jemez lineament, a proposed zone of crustal weakness and locus of Plio-Quaternary volcanism (Aldrich and Laughlin, 1984; Aldrich and others, 1986).

One or more elongate concentrations of surface faulting, commonly involving reactivated Basin-Range faults, occur within broader zones of possible uplift or arching (figs. 12, 15). The best-defined belt of this type extends from northwest to southeast across Arizona (fig. 12). There is an apparent gap in Quaternary faulting in east-central Arizona, but uplift may be continuous through this region. This belt likely merges in some manner with the zone of neotectonic faulting along the southeastern margin of the Colorado Plateau and the Rio Grande Rift in central New Mexico (fig. 17). A second possible belt of neotectonic deformation follows the lower Colorado River along the Arizona-California border. Deformational features in this zone include a region of possible Plio-Quaternary warping and uplift of the Bouse Formation (Lucchitta, 1979), a few late Quaternary fault scarps, and the eastern boundary of small-scale vertical crustal displacements detected by geodetic surveys in southern California (Gilmore and Castle, 1983).

These deformational belts tend to border regions of relative tectonic stability (e.g., the Colorado Plateau interior, the Sonoran Desert province, the eastern Mojave Desert, and possibly the Sierra Madre Occidental of northern Mexico). The belts are aligned approximately northerly and trend perpendicular to the general direction of contemporary regional extension (Zoback and Zoback, 1980), but they bend around regions of tectonic stability. The belts may function as deformational corridors that absorb most of the regional horizontal or vertical strain between adjacent, more stable crustal blocks (fig. 17).

Relationship Between Neotectonic and Basin-Range Deformations

The neotectonic deformation in northwestern and north-central Arizona may be the contemporary manifestation of a migrating locus of Basin-Range tectonism along the western margin of the Colorado Plateau (fig. 17). The relationship between the main late Miocene phase of Basin-Range tectonism and the belts of neotectonic deformation in the Basin and Range and Transition Zone provinces is enigmatic, however. Quaternary fault scarps present in these areas have been considered as evidence for continuing Basin-Range tectonism (Shafiqullah and others, 1978, 1980; Drewes, 1981; Schell and Wilson, 1981). This intepretation is based on a general similarity in the orientations, geometries, and positions of neotectonic fault scarps and primary basin-bounding structures.

There are significant differences in the relative distributions and estimated rates of faulting in Quaternary and late Miocene time, however. Quaternary displacements have occurred on only a few faults of the primary set of Basin-Range structures, and Quaternary faults are concentrated in narrow zones within the broader region affected by the Basin-Range disturbance. Furthermore, offset data indicate very low displacement rates, and the occurrence of piedmont fault scarps at the outer edges of bedrock pediments implies reactivation of faulting following some (Pliocene?) interval of quiescence.

Neotectonic activity in Arizona may indeed be a late phase of the Basin-Range disturbance. If so, then the observed patterns suggest that this disturbance has declined via one or more stages characterized by decreasing rates of tectonic activity and more restricted areal extent. Alternatively, the Quaternary deformational belts may represent a separate tectonic regime, in part spatially superimposed on the Basin-Range disturbance. The general distribution, orientations, and physiographic expressions of belts of neotectonic faulting and possible uplift in southern Arizona resemble portions of the southern Rio Grande Rift. The neotectonic belts may represent separate, weakly developed riftlike features analogous to or related to the Rio Grande Rift (Seager and Morgan, 1979; Natali and Sbar, 1982; Machette and Colman, 1983).

SUMMARY

The Basin-Range disturbance is the dominant post-middle Miocene tectonic event that affected Arizona. The impact of this disturbance was most profound in western and southeastern Arizona, where range-valley physiography reflects patterns of deformation, sedimentation, and volcanism that are typically distinct from earlier mid-Tertiary tectonism. Dated volcanic rocks provide critical control on the timing of deformation. Their geochemistry and isotopic ratios are distinct from calc-alkalic mid-Tertiary magmatism and indicate rapid upward migration of mantle-derived magma. Basin-Range sedimentation consists mainly of clastic infilling of structural basins. Vertical variations in facies and sedimentation patterns imply transitions from syntectonic to posttectonic deposition in the latest Miocene and Pliocene.

Near-surface extension was accommodated primarily by moderately to steeply dipping normal fault zones, with varying scales of segmentation. Faults define grabens or tilted half-grabens containing up to 2,500 m of basin fill. Bedrock floors of tilted half-grabens have been rotated 10° to 20° by downfaulting against major fault zones on one side of the basin. Some basins contain inner grabens or horsts as well. High-angle normal faults probably flatten at or near the transition from brittle to ductile deformation in the middle crust. Estimates of cumulative regional post-15-Ma horizontal extension vary from 5 to 20 percent, depending on the fault geometries assumed.

Stratigraphic relationships bracket the main pulse of the Basin-Range disturbance between about 15 and 5 Ma throughout the Basin and Range province of Arizona. This timing contrasts with post-10-Ma Basin-Range tectonism along the western margin of the Colorado Plateau. These patterns suggest a fairly rapid propagation of the Basin-Range disturbance across southern and western Arizona between 15 and 10 Ma, followed by slower encroachment onto the Colorado Plateau since 10 Ma.

Waning or cessation of the Basin-Range tectonism in southern and western Arizona is recorded by intermittent aggradation of upper basin fill, which overlaps basin-boundary faults onto extensive bedrock pediments. Basin filling was terminated in most basins by the deposition of relatively thin, coarse-grained pediment alluvial fans above mildly discordant erosion surfaces. These fans may record fluvial responses to the initial climatic fluctuations in late Pliocene or early Quaternary time. Subsequent climatic changes are reflected by overlapping or inset sequences of terraces or fans. Sequentially inset terraces also reflect longer term Plio-Quaternary basin dissection related to integration with the regional drainage network. The Transition Zone displays similar patterns except for regionally more dramatic landscape dissection. Most of the Colorado Plateau is dominated by low-relief bedrock erosion surfaces broken by bedrock cliffs, in some areas positioned over faults or monoclines.

Bedrock surfaces along much of the western Colorado Plateau margin are disrupted by fault escarpments, volcanic fields, and canyons related to Plio-Quaternary tectonic activity. This area contains the largest Plio-Quaternary fault displacements (<300-400 m) in Arizona. This neotectonic activity may be a contemporary manifestation of Basin-Range tectonism that has migrated north and east onto the Colorado Plateau since 10 Ma.

Neotectonic features in southern, central, and western Arizona are restricted to three basalt fields and a relatively few fault scarps along Basin-Range fault zones. These scarps collectively define a diffuse deformational belt, with local zones of more concentrated faulting, trending diagonally from north-central to southeastern Arizona. Extensive Plio-Quaternary dissection along this deformation zone suggests an archlike belt of regional neotectonic uplift. The dissection may alternatively be interpreted as resulting from nontectonic factors such as inherited relief, climatic change, and isostatic rebound in response to regional denudation.

The relatively small Quaternary displacements (<15 m) along faults in central and southeastern Arizona imply that these deformational corridors absorb relatively small amounts of horizontal and vertical strain between adjacent tectonically stable crustal blocks such as the Colorado Plateau and Sonoran Desert regions. Neotectonic deformation in these belts may represent either a residual pulse of Basin-Range tectonism, or renewed smaller scale extension following a several-million-year tectonic lull.

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