Basin and Range rifting in northern Nevada: Clues from a mid-Miocene rift and its subsequent offsets

Mary Lou Zoback
George A. Thompson
Department of Geophysics
Stanford University
Stanford, California 94305

ABSTRACT

A linear rift composed of dike swarms and graben-filling volcanic rocks marks the inception of Basin and Range rifting in northern Nevada 17 to 14 m.y. ago. This mid-Miocene rift, with its associated aeromagnetic anomaly, indicates S68°W-N68°E (±5°) extension. A small strike-slip (transform) fault at Sawtooth dike, one short element of the rift, confirms the mid-Miocene extension direction. The present extension, based on data throughout the Basin and Range province, is N65°W-S65°E (±20°), which is consistent with younger fault offsets of the rift. In the Sawtooth dike region this 45° change in direction of extension took place between 15 and 6 m.y. B.P.

The Nevada rift is thought to be part of a linear rift zone roughly 700 km long, which includes feeder dikes of Columbia River basalts and the mid-Miocene location of the Yellowstone hot spot. Extension in this zone was probably perpendicular to a then-active trench along the western plate margin. The clockwise change in extension direction is consistent with a superposition of right-lateral shear along the plate margin when the San Andreas fault was activated.

INTRODUCTION

At least tens of kilometres of crustal extension accompanied late Cenozoic block faulting in the Basin and Range province of the Western United States (see Thompson and Burke, 1974, for references). Evidence from earthquakes, geodetic strain, chains of volcanic vents, and slip lines on fault planes indicate that the present extension direction (east-west to southeast-northwest) in Nevada and Utah is much more nearly uniform than the geometric complexity of fault blocks would suggest. This paper describes an attempt to determine the extension direction in north-central Nevada in mid-Miocene time, when widespread Basin and Range faulting began (see Noble, 1972, for references), and to relate this direction and its later changes to changes in the plate tectonic regime.

MID-MIOCENE EXTENSION DIRECTION

Dikes and chains of volcanic vents are sensitive indicators of extension direction (Nakamura, 1977). We will also describe transform faulting between offset segments of Sawtooth dike to re-enforce an extension direction obtained from dikes alone.

Dikes of mid-Miocene diabase and rhyolite are abundant in the southern half of the Oregon-Nevada lineament (Stewart and others, 1975). The southern segment of the lineament—the northern Nevada rift—is marked by an unusual positive aeromagnetic anomaly that trends north-northwest (see Fig. 3 of Stewart and others, 1975; first discussed by Mabey, 1966). The anomaly coincides with a narrow belt of volcanic rocks (Fig. 1), but the amplitude and extent of the anomaly require additional deep-seated magnetic rocks (Robinson, 1970). We are currently reinterpreting the anomaly based upon an intensive study of the magnetic properties of the dikes and flows. K-Ar ages of the volcanic rocks are mid-Miocene, between 13.8 and 16.5 m.y. old (Fig. 1; also McKee and others, 1971).

Diabase dikes, in swarms 5 to 7 km wide, are exposed in the Cortez and Roberts Ranges (locs. Y and Z, Fig. 1) (Muffler, 1964; Gilluly and Masursky, 1965; Christiansen and McKee, 1978; E. H. McKee, unpub. map). The dikes are similar in composition to the basaltic andesite flows. Rhyolite dikes, including Sawtooth dike (Fig. 1), are exposed in the northern part of the rift. Most dikes and swarms are aligned parallel to the magnetic anomaly.

Normal faulting of the same north-northwest trend as the dikes and magnetic anomaly was partly contemporaneous with volcanism, as evidenced by a flow-filled fault trough overlain by unfaulted younger flows (Gilluly and Masursky, 1965; Zoback, 1978).

The age span of the volcanic rocks points to a time interval approximately 17 to 14 m.y. ago for the formation of the northern Nevada rift. The direction normal to the rift and its individual elements (extension direction) is N68°E-S68°W (±5°), the Miocene extension of this paper. Miocene extension in the Basin and Range area of southern Nevada and western Utah was also approximately in the same direction, according to a study by Anderson and Ekren (1977).

EVIDENCE AT SAWTOOTH DIKE

Sawtooth dike is magnificently exposed along Owyhee Bluffs, about 60 km north of Battle Mountain (Figs. 1, 2, 3). The dike is vertical, 25 m wide, and has a distinctive petrography that allows correlation of offset dike segments. It is porphyritic rhyolite with as much as 50% quartz and K-feldspar, and it is reversely magnetized. Offsets of the dike are interpreted by us as an analogue of a leaky transform fault with right-lateral slip equal to the dike thickness, 25 m (Fig. 4A). The curved end of the northern segment and the orientation of the small central segment (Figs. 2 and 3) result from a local departure from the regional stress field, caused by superposition of right-lateral shear along the transform fault (Fig. 4B).

The transform fault trends N70°E and is orthogonal to the dike as nearly as can be determined, which shows that the dike walls opened perpendicular to its trend. The fault orientation is consistent with the mid-Miocene extension determined from the northern Nevada rift.

Sawtooth dike cut basaltic andesite more than 350 m thick and rhyolitic ash-flow tuff units and then fed a massive rhyolite flow that overlies the ash-flow units (Figs. 2 and 5). All are reversely magnetized. Intertonguing of the basaltic andesite flows with water-laid rhyolite tuffs (Fig. 5) is consistent with small age differences between basalt and rhyolite in the Midas trough area (sanidine K-Ar age is 14.3 ± 0.8 m.y. for Sawtooth dike; whole-rock K-Ar age is 15.1 ± 1.6 m.y. for basaltic andesite; E. H. McKee, personal commun.) and all along the northern Nevada rift (Fig. 1).

The south end of Sawtooth dike is cut off (Figs. 1 and 5) by the northern bounding fault of the Midas trough (Rowan and Wetlaufer, 1973). A younger, olivine-rich basalt flowed along the floor of the trough (Fig. 5) and over alluvium in the valley west of the trough (Stewart and Carlson, 1976a). The basalt yielded a whole-rock K-Ar date of 6.3 ± 2.3 m.y. (E. H. McKee, personal commun.). The prominent northeastward-trending fault system that cuts Sawtooth dike was thus formed between 15 and about 6 m.y. ago.

PRESENT EXTENSION DIRECTION

Evidence from earthquake focal mechanisms, geodetic data, volcanic vents, and historical faulting is fairly consistent in defining the present extension direction in Nevada and Utah. Slip directions on faults younger than the northern Nevada rift are also in agreement.

Earthquake focal mechanisms compiled by Smith and Sbar (1974) show a consistent orientation of N70°W ± 25° for the horizontal tension axis. Scatter of the data about the mean is approximately the same as the accuracy of individual determina-

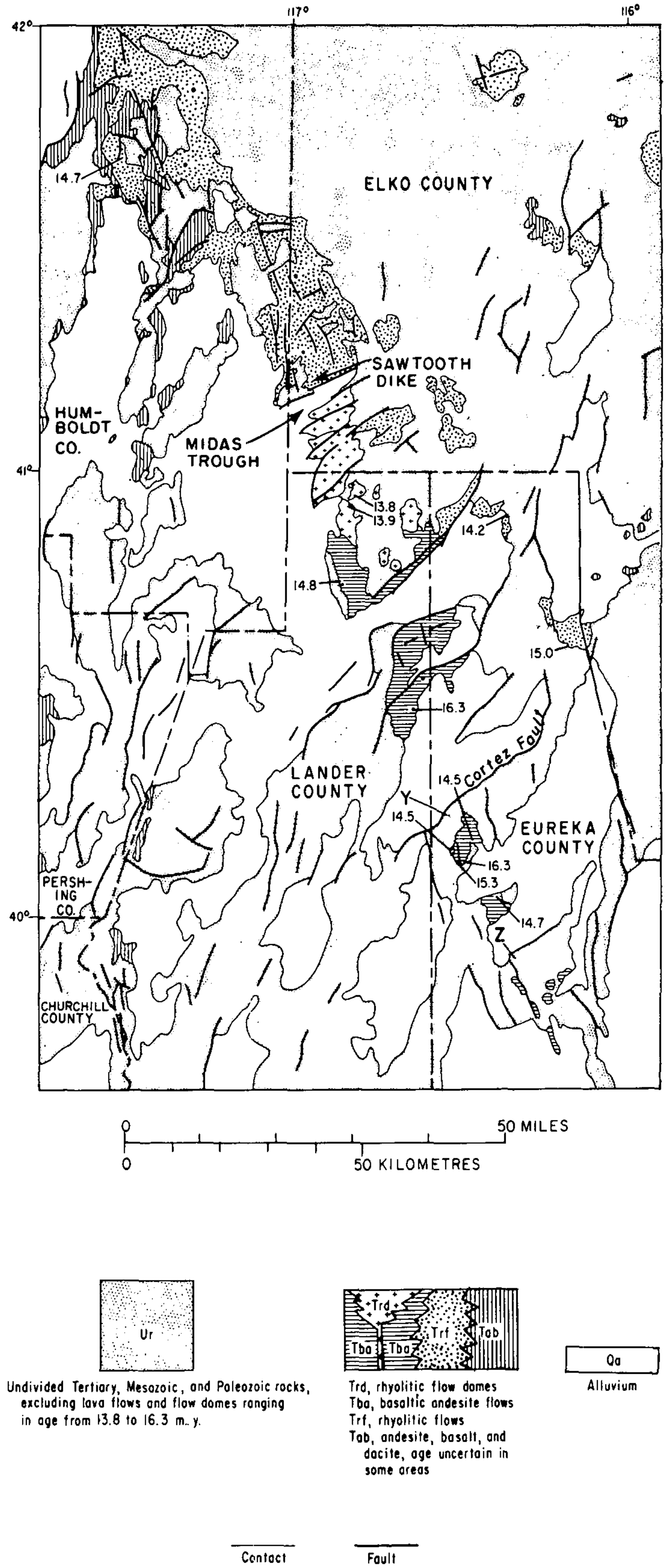

Figure 1. Geologic map showing distribution of 13.8- to 16.3-m.y.-old lava flows and flow domes in north-central Nevada (after Stewart and others, 1975). Numbers are K-Ar dates in m.y. B.P. Y and Z are locations of exposed diabase dike swarms.

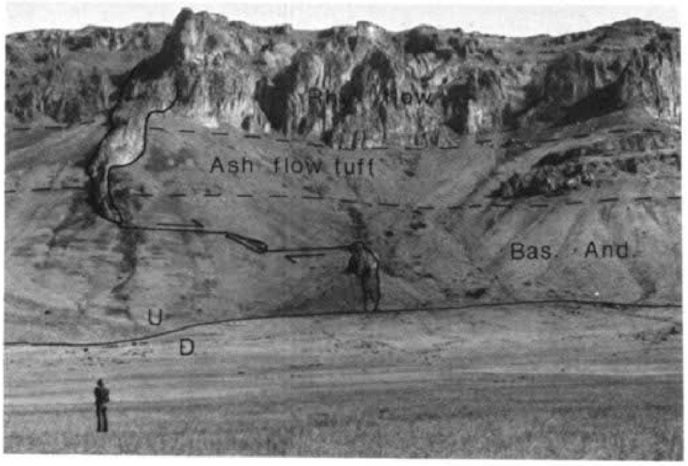

Figure 2. View of Sawtooth dike looking north. Dike and transform fault are outlined, and the basaltic andesite–ash-flow tuff–rhyolite flow contacts are indicated. Dike fed the rhyolite flow. Total length of transform fault is 375 m.

tions, so that regional variations, with the possible exception of the easternmost part of the Basin and Range province, may not be significant. Geodetic strain measurements in the Nevada Test Site area (Kinoshita and Savage, 1971) and Dixie Valley, Nevada (Meister and others, 1968), indicate a spreading direction between east-west and east-southeast–west-northwest. Chains of volcanic vents and cinder cones less than 6 m.y. old (Stewart and Carlson, 1976b) in two areas (40 km southwest of Battle Mountain and 95 km east of Tonopah) are consistent with east-southeast–west-northwest extension. From geologic data (Thompson and Burke, 1973; Thompson and others, 1967; Bateman, 1961; Russell, 1977; R. E. Wallace, 1977, personal commun.), the best estimate of the direction of opening is N60°W-S60°E (±15°). Thus, a consistent direction of east-southeast–west-northwest extension emerges.

Northeast-trending faults such as those of the Midas trough cut the northern Nevada rift nearly orthogonally and are responsible for most of the modern physiographic features along the trend, particularly south of the Midas trough (Fig. 1). These postrift faults segmented the aeromagnetic anomaly by both vertical and lateral offsets of highly magnetic blocks. In analyzing part of the aeromagnetic anomaly near the Roberts Mountains (loc. Z, Fig. 1), Mabey (1966) and Robinson (1970) concluded that there has been about 1.4 km of left-lateral slip along the N60°E-trending fault bounding the range. Combined with the vertical offset of about 2.2 km (from the topography plus the depth of valley fill determined by a gravity anomaly) and a reasonable assumption of 60° dip for the fault, this gives an extension direction of N72°W-S72°E. In the Cortez Mountains (loc. Y, Fig. 1), slickensides along the modern range-front Crescent fault indicate oblique motion with a left-lateral component of slip on that northeast-trending fault (Muffler, 1966). The extension direction inferred from the grooves is N50°W-S50°W.

In summary, the mid-Miocene extension direction was replaced by a new direction of about N65°W-S65°E (±20°), which we will call the present extension direction.

REGIONAL SYNTHESIS

The beginning of rifting around 17 to 14 m.y. B.P. in north-central Nevada apparently marks the inception of spreading in the northern Basin and Range (see Noble, 1972, for references).

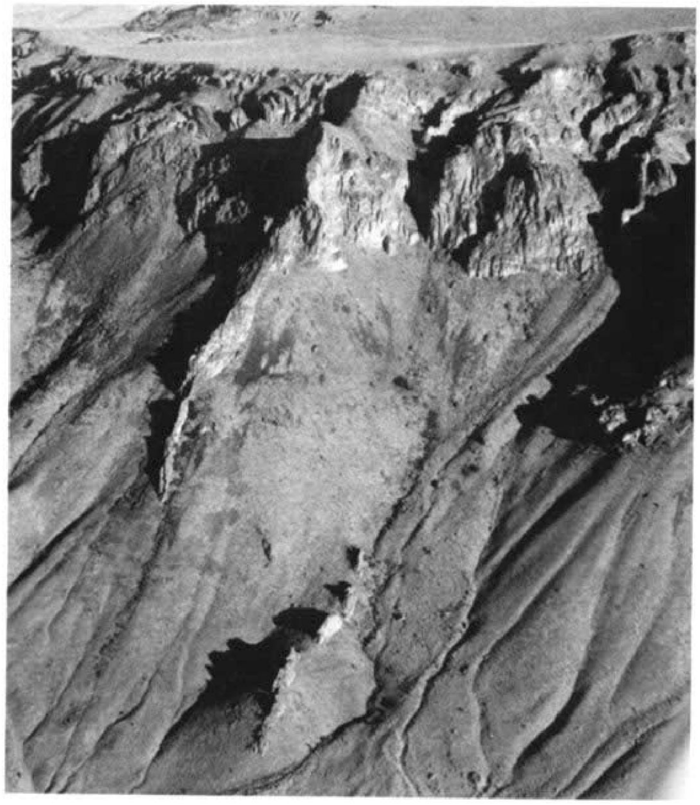

Figure 3. Aerial view of Sawtooth dike looking northwest.

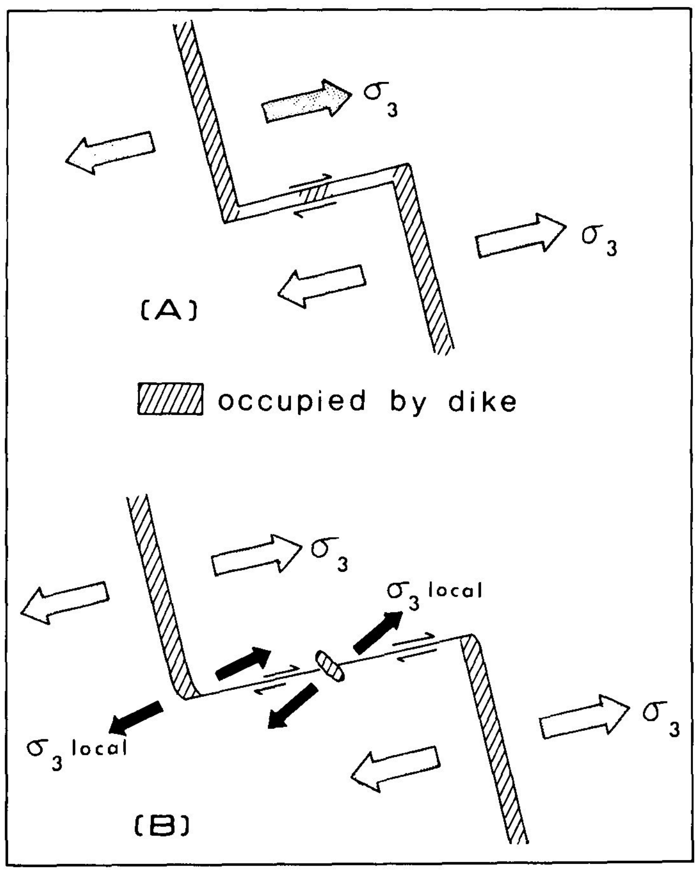

Figure 4. Diagrammatic maps showing postulated stress regime at the time of intrusion of Sawtooth dike. (A) "Leaky transform" origin. (B) Local re-orientation of stress field resulting from shear along the transform fault.

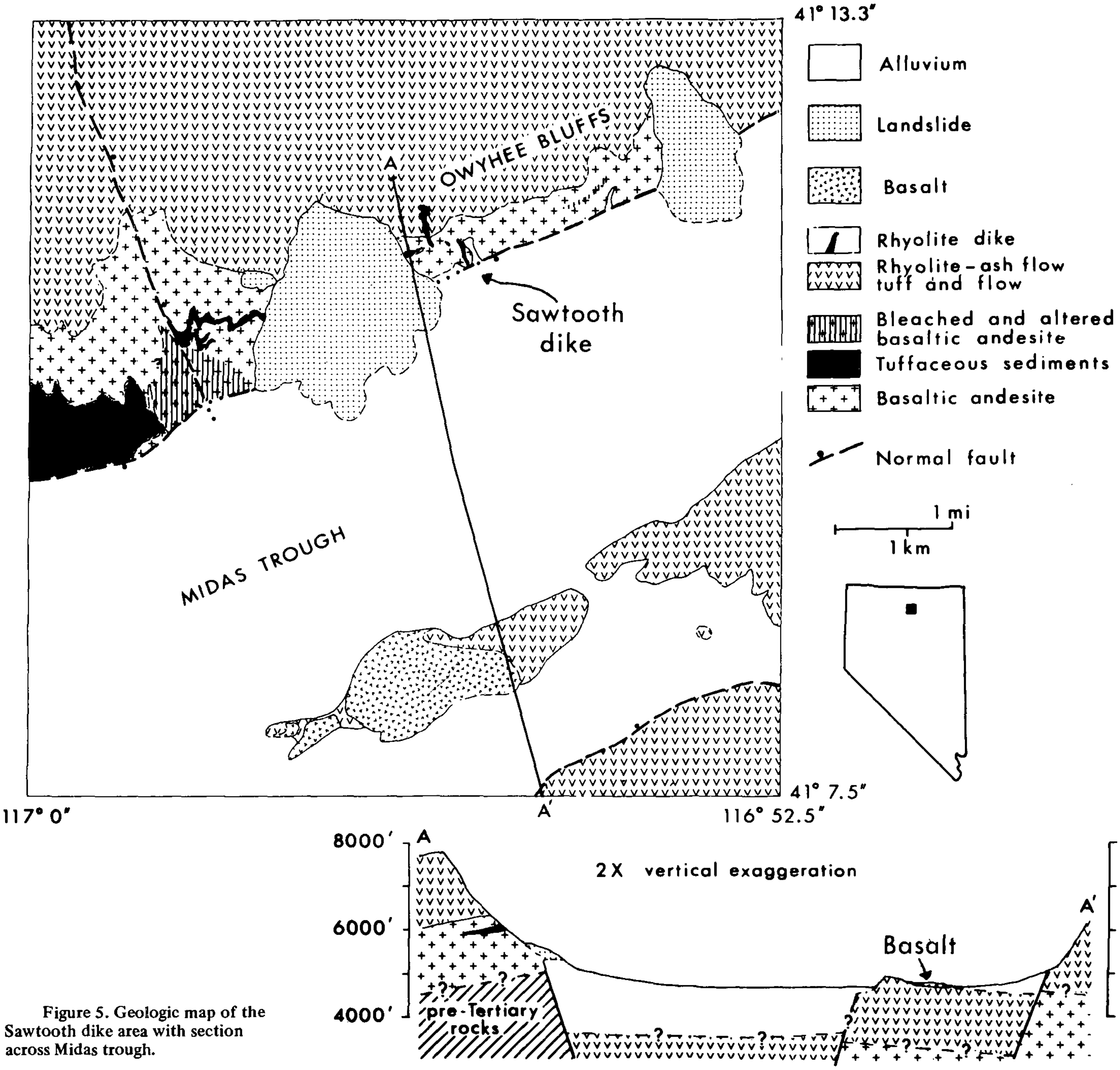

Figure 5. Geologic map of the Sawtooth dike area with section across Midas trough.

This same time interval brackets the eruption of more than 2×10^5 km^3 of basalt (Watkins and Baksai, 1974) from linear vents approximately perpendicular to the Miocene extension direction on the Columbia River Plateau. These feeder dikes have been identified over a broad region on the plateau by Waters (1961), Taubeneck (1970), and Swanson and others (1975). The major swarm on the plateau is the Chief Joseph swarm (Fig. 6).

Mabey (1976) interpreted various geophysical data in southwestern Idaho to indicate that the graben of the western Snake River Plain began forming contemporaneously with the eruption of the Columbia River basalts. This graben trends N30° to 35°W, nearly perpendicular to the Miocene extension direction. Moreover, the oldest silicic volcanic rocks inferred to be related to the eastward migration of volcanism along the eastern Snake River Plain (Yellowstone "hot spot" trend) are found along the south end of this graben; they have been dated at 15 to 16 m.y. B.P. by Armstrong and others (1975). Also initiated in this time interval was the abundant basaltic and silicic volcanism in southeastern Oregon west of the Snake River Plain. Silicic domes in southeastern Oregon younger than 11 m.y. show a monotonic decrease in age to the west-northwest toward Newberry caldera (MacLeod and others, 1976).

In summary, the aeromagnetic anomaly, the diabase dike swarms in Nevada, the feeder dikes on the Columbia River Plateau, and the general trend of the western graben of the Snake River Plain are all approximately perpendicular to the Miocene extension direction (N68°E-S68°W) and indicate a uniform extension direction throughout much of the Western United States in mid-Miocene time, as Taubeneck (1970) first suggested.

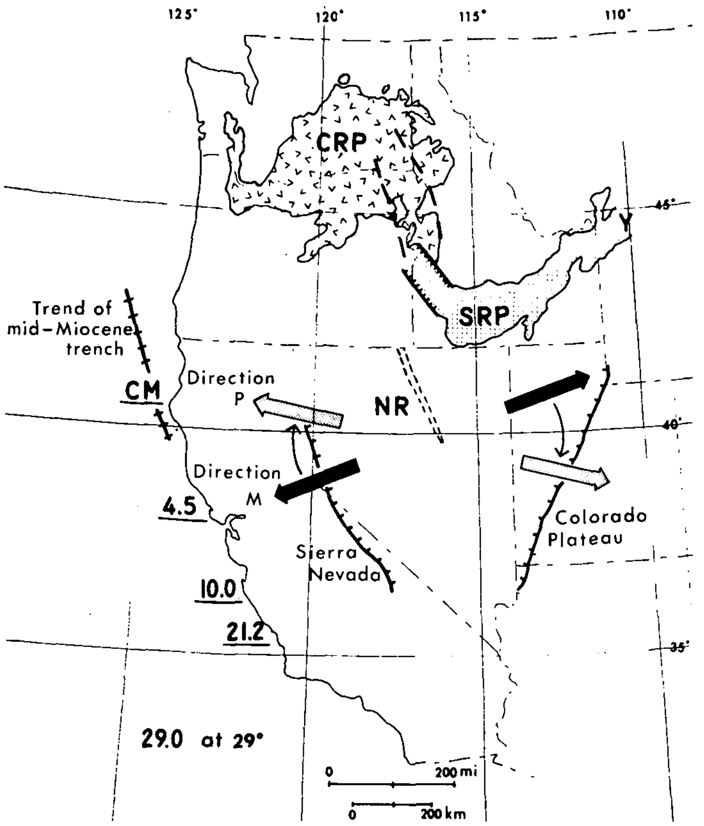

Figure 6. Map of the Western United States showing the mid-Miocene (M) and the present (P) extension direction. CRP = Columbia River flood basalt province, SRP = Snake River Plain, and Y = Yellowstone National Park. Northern Nevada rift (NR) is outlined by short dashes. Dates (in millions of years before present) off coast of California mark the locations of Mendocino triple junction (Atwater and Molnar, 1973). CM = Cape Mendocino, present location of the triple junction. Chief Joseph dike swarm is shown approximately by dashed lines.

It is interesting to note that all these features line up if Basin and Range extension is removed by assuming uniform spreading parallel to the mean of the present extension direction and the Miocene extension direction between the Colorado Plateau and the Sierra Nevada. As the major zone of dike intrusion on the Columbia River Plateau is quite broad, the realignment can only be made in a crude sense. A total extension of between 100 and 150 km (equivalent to eastward restoration of the northern Nevada rift by 70 to 100 km) gives the best alignment. Total uniform extension greater than 250 km produces a misalignment.

LATE TERTIARY PLATE MOTIONS

During mid-Miocene time, subduction of the Farallon plate was occurring under all of the Northwestern United States (see Fig. 6 for the location of the Mendocino triple junction at various times). However, the mid-Miocene trend of the subduction zone was probably north-northwest, about 20° clockwise from the present northwest trend of the Pacific–North American transform boundary that developed when the Farallon plate was consumed (Dickinson and Snyder, 1978). Thus, as in other regions of spreading behind an active arc, the direction of opening (that is, the Miocene direction) was apparently perpendicular to the trench.

Compilations of data on Cenozoic magmatism in the Western United States by Christiansen and Lipman (1972), Lipman and others (1972), and Snyder and others (1976) indicate that a broad (1,400 km wide) magmatic arc extended from the Front Range of the Rocky Mountains to the Sierra Nevada in the time interval 40 to 20 m.y. B.P. while the arc in the Pacific Northwest was narrow (300 km). By 20 m.y. B.P. the magmatic arc had abruptly narrowed to a zone only 400 km wide confined to the Sierra Nevada and the westernmost Basin and Range. The broad Oligocene–early Miocene arc apparently reflected a low-angle, shallow subducting slab while the narrow arc of 20 to 10 m.y. B.P. suggests a steeply dipping slab. Snyder and others (1976) pointed out that such a change in inclination would require rupture of the subducting lithosphere.

The postulated change in subduction regime was closely followed by formation of the north-northwest–trending, 700-km-long rift zone in the time interval 17 to 14 m.y. B.P. This suggests the following speculative sequence in the initiation of rifting: For some period prior to 17 m.y. B.P., basaltic melt accumulated near the base of the lithosphere, but rifting and eruption were inhibited by compression of the North American lithosphere, possibly due to basal traction exerted by the shallow subducting plate. By 20 m.y. B.P., the shallow slab had broken up, the active slab dipped steeply and produced a narrow magmatic arc, and compression in the crust was relaxed. The Yellowstone hot spot penetrated the American plate 16 to 17 m.y. ago, and the rift zone grew rapidly to the north-northwest and south-southeast from this locus.

DISCUSSIONS AND CONCLUSIONS

The northern Nevada rift appears to be part of a longer rift zone (700 km) that includes the graben of the western Snake River Plain and the feeder dikes of the Columbia River basalts, all formed about 17 to 14 m.y. ago. Localization of initial rifting to a narrow zone in the western Snake River Plain and northern Nevada suggests that the Yellowstone hot spot supplied the extra stress necessary to initiate rifting there, whereas on the Columbia River Plateau to the north, dike swarms broke through the lithosphere over a broad region, perhaps because a large volume of melt had already accumulated or because of a difference in the lithosphere.

Rifting perpendicular to the Miocene extension direction began in a back-arc setting, but the convergent plate boundary soon changed to a transform boundary, and spreading in the northern Basin and Range province changed to the present direction. In contrast, on the Columbia River Plateau, under which slow subduction is probably continuing (Silver, 1969), spreading ceased and anticlinal folds with approximately east-trending axes developed (Skehan, 1965).

Remarkably consistent dike orientations all along this north-northwest–trending rift zone demonstrate that in mid-Miocene time, N68°E-S68°W (±5°) extension took place. Geologic and geophysical evidence indicates that at present, N65°W-S65°E (±20°) extension is taking place. This represents a clockwise change of about 45° in the direction of opening (Fig. 6) some time in the past 14 m.y. (Zoback and Thompson, 1976; Eaton and others, 1978). The clockwise change is consistent with superposition of right-lateral shear (corresponding to the activation of the San Andreas transform system) along the western margin of the plate boundary. The pronounced east-northeast–trending normal faults (Midas trough, for example) that cut the northern Nevada rift almost orthogonally may represent a conjugate set of faults required (with continuing movement on north-northwest-trending faults) to accommodate this change in spreading direction. Structural relations in the Sawtooth dike area indicate that this normal faulting (orthogonal to the initial rifting) was well underway by 6 m.y. ago and suggest that the change of the spreading direction had certainly begun by that time.

REFERENCES CITED

Anderson, R. E., and Ekren, E. B., 1977, Late Cenozoic fault patterns and stress fields in the Great Basin and westward displacement of the Sierra Nevada block: Comment: Geology, v. 5, p. 388-389.

Armstrong, R. L., Leeman, W. P., and Malde, H. E., 1975, K-Ar dating, Quaternary and Neogene volcanic rocks of the Snake River Plain, Idaho: Am. Jour. Sci., v. 275, p. 225-251.

Atwater, Tanya, and Molnar, Peter, 1973, Relative motion of the Pacific and North American plates deduced from sea-floor spreading in the Atlantic, Indian, and South Pacific Oceans, *in* Tectonic problems of the San Andreas fault system, Conf.: Stanford Univ. Pubs. Geol. Sci., v. 13, p. 136-148.

Bateman, P. C., 1961, Willard D. Johnson and the strike-slip component of fault movement in the Owens Valley, California, earthquake of 1872: Seismol. Soc. America Bull., v. 51, p. 483-493.

Christiansen, R. L., and Lipman, P. W., 1972, Cenozoic volcanism and plate-tectonic evolution of the western United States. II. Late Cenozoic: Royal Soc. London Philos. Trans., v. 271, p. 249-284.

Christiansen, R. L., and McKee, E. H., 1978, Late Cenozoic volcanic and tectonic evolution of the Great Basin and Columbia intermontane region, *in* Smith, R. B., and Eaton, G. P., eds., Cenozoic tectonics and regional geophysics of the western Cordillera: Geol. Soc. America Mem. 152 (in press).

Dickinson, W. R., and Snyder, W. S., 1978, Geometry of triple junctions and subducted slabs related to San Andreas transform: Jour. Geophys. Research (in prep.).

Eaton, G. P., Wahl, R. R., Prostka, H. J., Mabey, D. R., and Kleinkopf, M. D., 1978, Regional gravity and tectonic patterns: Their relation to late Cenozoic epirogeny and lateral spreading in the western Cordillera, *in* Smith, R. B., and Eaton, G. P., eds., Cenozoic tectonics and regional geophysics of the western Cordillera: Geol. Soc. America Mem. 152 (in press).

Gilluly, James, and Masursky, Harold, 1965, Geology of the Cortez quadrangle, Nevada, with a section on gravity and aeromagnetic surveys by D. R. Mabey: U.S. Geol. Survey Bull. 1175, 117 p.

Kinoshita, W. T., and Savage, J. C., 1971, Geodetic determination of strain from a nuclear explosion at the Nevada Test Site: Geol. Soc. America Abs. with Programs, v. 3, p. 143.

Lipman, P. W., Prostka, H. J., and Christiansen, R. L., 1972, Cenozoic volcanism and plate-tectonic evolution of the western United States. I. Early and middle Cenozoic: Royal Soc. London Philos. Trans., v. 271, p. 217-248.

Mabey, D. R., 1966, Regional gravity and magnetic anomalies in part of Eureka County, Nevada: Soc. Exploration Geophysicists Mining Geophysics Case Histories, v. 1, p. 77-83.

—— 1976, Interpretation of a gravity profile across the western Snake River Plain, Idaho: Geology, v. 4, p. 53-55.

McKee, E. H., Silberman, M. L., Marvin, R. E., and Obradovich, J. D., 1971, A summary of radiometric ages of Tertiary volcanic rocks in Nevada and eastern California. Pt. I: Central Nevada: Isochron West, no. 2, p. 21-42.

MacLeod, N. S., Walker, G. W., and McKee, E. H., 1976, Geothermal significance of eastward increase in age of upper Cenozoic rhyolitic domes in southeastern Oregon, *in* Proc. 2nd United Nations symposium on the development and use of geothermal resources, San Francisco, California, May 20-29, 1975, Vol. 1: Berkeley, Calif., Lawrence Berkeley Laboratory, Univ. California, p. 465-474.

Meister, L. J., Burford, R. O., Thompson, G. A., and Kovach, R. L., 1968, Surface strain changes and strain energy release in the Dixie Valley-Fairview Peak area, Nevada: Jour. Geophys. Research, v. 73, p. 5981-5994.

Muffler, L.J.P., 1964, Geology of the Frenchie Creek quadrangle, north-central Nevada: U.S. Geol. Survey Bull. 1179.

Nakamura, K., 1977, Volcanoes as indicators of tectonic stress orientation—Principal and proposal: Jour. Volcanology and Geothermal Research, v. 2, p. 1-16.

Noble, D. C., 1972, Some observations on the Cenozoic volcano-tectonic evolution of the Great Basin, western United States: Earth and Planetary Sci. Letters, v. 17, p. 142-150.

Robinson, E. S., 1970, Relations between geological structure and aeromagnetic anomalies in central Nevada: Geol. Soc. America Bull., v. 81, p. 2045-2060.

Rowan, L. C., and Wetlaufer, P. H., 1973, Structural geologic analysis of Nevada using ERTS-1 images: A preliminary report, *in* Symposium on significant results obtained from the Earth Resources Technology Satelite-1, Vol. 1, Technical representations, Sec. A: Natl. Aeronautics and Space Adm. Paper G-20, p. 413-423.

Russell, Branch J., 1977, A structural break and kinematics of faulting in the White Mountains, California: Geol. Soc. America Abs. with Programs, v. 9, p. 491.

Silver, E. A., 1969, Late Cenozoic underthrusting of the continental margin off northernmost California: Science, v. 166, p. 1265-1266.

Skehan, J. W., 1965, A continental-oceanic crustal boundary in the Pacific Northwest: U.S. Air Force Cambridge Research Labs. Rept. AFCRL-65-904(3).

Smith, R. B., and Sbar, M., 1974, Contemporary tectonics and seismicity of the western United States with emphasis on the intermountain seismic belt: Geol. Soc. America Bull., v. 85, p. 1205-1218.

Snyder, W. S., Dickinson, W. R., and Silberman, M. L., 1976, Tectonic implications of space-time patterns of Cenozoic magmatism in the western United States: Earth and Planetary Sci. Letters, v. 32, p. 91-106.

Stewart, J. H., and Carlson, J. E., 1976a, Geologic map of north-central Nevada: Nevada Bur. Mines and Geology Map 60.

—— 1976b, Cenozoic rocks of Nevada: Nevada Bur. Mines and Geology Map 52.

Stewart, J. H., Walker, G. W., and Kleinhampl, F. J., 1975, Oregon-Nevada lineament: Geology, v. 3, p. 265-268.

Swanson, D. A., Wright, T. L., and Helz, R. T., 1975, Linear vent systems and estimated rates of magma production and eruption for the Yakima Basalt on the Columbia Plateau: Am. Jour. Sci., v. 275, p. 877-905.

Taubeneck, W. H., 1970, Dikes of Columbia River basalt in northeastern Oregon, western Idaho, and southeastern Washington: Columbia River Basalt Symposium, 2nd, Eastern Washington State College, March 1969, Proc.: Cheney, Eastern Washington State College Press, p. 73-96.

Thompson, G. A., and Burke, D. B., 1973, Rate and direction of spreading in Dixie Valley, Basin and Range province, Nevada: Geol. Soc. America Bull., v. 84, p. 627-632.

—— 1974, Regional geophysics of the Basin and Range province: Earth and Planetary Sci. Letters Ann. Rev., v. 2, p. 213-238.

Thompson, G. A., Meister, L. J., Herring, A. T., Smith, T. E., Burke, D. B., Kovach, R. L., Burford, R. O., Salehi, I. J., and Wood, M. D., 1967, Geophysical study of Basin-Range structure, Dixie Valley region, Nevada: U.S. Air Force Cambridge Research Labs. Final Sci. Rept. 66-848, 244 p.

Waters, A. C., 1961, Stratigraphic and lithologic variations in the Columbia River basalt: Am. Jour. Sci., v. 259, p. 583-611.

Watkins, N. D., and Baksi, A. K., 1974, Magnetostratigraphy and oroclinal folding of the Columbia River, Steens, and Owyhee basalts in Oregon, Washington, and Idaho: Am. Jour. Sci., v. 274, p. 148-189.

Zoback, M. L., 1978, A geologic and geophysical investigation of the Beowawe geothermal area, north-central Nevada: Stanford Univ. Pubs. Geol. Sci. (in press).

Zoback, M. L., and Thompson, G. A., 1976, Evidence of left-lateral slip on Basin and Range fault: Geol. Soc. America Abs. with Programs, v. 8, p. 1182.

ACKNOWLEDGMENTS

Reviewed by Kazu Nakamura, Robert Speed, and L. T. Grose. Stimulating discussions with John Stewart, E. H. McKee, Walter Snyder, and Allan Cox are gratefully acknowledged. E. H. McKee provided the K-Ar dates. Research was funded by National Science Foundation Grant EAR75-22505.

MANUSCRIPT RECEIVED AUGUST 15, 1977

MANUSCRIPT ACCEPTED OCTOBER 25, 1977