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Rate and Direction of Spreading in Dixie Valley, Basin and Range Province, Nevada

Note: This paper is dedicated to Aaron and Elizabeth Waters on the occasion of Dr. Waters' retirement.

ABSTRACT

The subsurface geometry of Dixie Valley indicates that for the last 15 m.y. the basin has been spreading at an average rate of at least 0.4 mm/yr. Offset Pleistocene shorelines indicate that for the last 12,000 yrs the basin has been spreading at an average rate of about 1 mm/yr. These rates are roughly consistent with geodetic measurements of historic faulting. The spreading direction obtained from large slickenside grooves on fault planes is approximately N. 55° W.—S. 55° E.

INTRODUCTION

According to plate tectonic concepts, the Pacific plate is moving northwestward relative to the North American plate. The boundary between these plates is a wide, broken zone in which one major element is the San Andreas fault system, connecting the East Pacific Rise with the Gorda Rise. Another important element in the zone is the system of faults which largely define the Basin and Range province; faulting within this province is a product of relative Pacific–North American plate movements. In contrast to the San Andreas system, however, Basin and Range faulting results from extension—or spreading—of the crust, and this faulting creates new crustal area.

We have shown (Thompson and others, 1967) that displacement on a fault segment of given strike in the Basin and Range province can be understood in terms of its components of horizontal extension and right- or left-lateral strike slip. The relation of the strike of a fault segment to the direction of spreading controls the lateral component of movement on that segment. (The vertical component is a necessary result of horizontal extension on a nonvertical fault.)

In order to understand the mechanics of the Pacific–North American plate boundary, it is important to establish both the direction and rate of spreading in the Basin and Range province. We have attempted to do this for one region which we believe to be representative of the province as a whole. Dixie Valley (Fig. 1) is one of about 20 major block-faulted basins between the Sierra Nevada to the west and the Wasatch Mountains to the east. Earthquakes and associated faulting occurred in this basin in 1903, 1915, and 1954. Three measures of fault offset for different intervals of time in Dixie Valley are available, giving three approximations of spreading rate: (1) Geodetic measurements made before and after the 1954 faulting give a measure of direction and amount of extension associated with a single earthquake. (2) Displacements of the shoreline of a late Pleistocene lake supply a measure of the extension during the last 12,000 yrs. (3) Fault displacements determined from our geophysical studies in Dixie Valley give the total amount of extension for late Cenozoic time (about 15 m.y.). The long-term direction of this extension can be determined from the average azimuth of large slickenside grooves on fault surfaces.

MEASURES OF RATE

Geodetic Measurements

The 1954 faulting showed an abrupt elastic rebound, with an extension component normal to the regional strike of the faulting, of 1.5 m (Whitten, 1957). The extent to which scarps in the alluvium of Dixie Valley have been effaced by erosion, before reactivation, suggests that displacements of this magnitude are repeated at any one place less often than every 100 yrs, but more often than every 10,000 yrs. If they occur every 1,000 yrs, the average spreading rate would be 1.5 mm/yr.

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Pleistocene Shoreline

A late Pleistocene lake occupied Dixie Valley, isolated by surrounding mountains from the nearby basin of Lake Lahontan. Gravel beach ridges clearly record where high lake stands impinged on the alluvium of the basin. Shorelines on the bedrock of adjacent ranges are evidenced by a "bathtub ring" of calcareous tufa. The highest readily recognizable shoreline stands at about 3,585 ft above sea level but it has been tectonically tilted and faulted (Burke, 1967). The degree of preservation of the shoreline complex indicates that the highest lake stand was contemporaneous with the high stand of Lake Lahontan.

We collected two samples of calcareous tufa for carbon-14 analysis from the east front of the Stillwater Range, lat 39°54′20″N., long. 117°59′45″W., elevation approximately 3,565 ft. The ages obtained by Isotopes, Inc. are:

Sample I-3269 11,560 ± 180 yrs B.P.
Sample I-3270 11,700 ± 180 yrs B.P.

These dates are in close correspondence with tufa dates from the high shorelines in the Lahontan basin (Broecker and Kaufman, 1965) and the Searles Lake basin (G. I. Smith, 1968). Although the validity of this dating method is open to some question (Morrison, 1968), the consistency of these dates indicates that a high shoreline age of about 12,000 yrs is a reasonable assumption for present purposes.

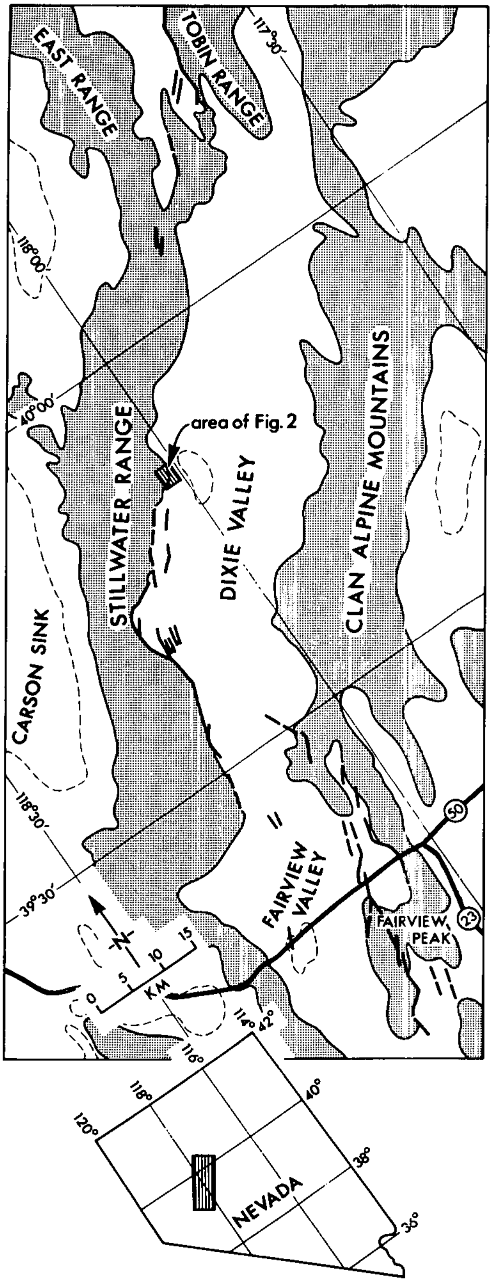

Figure 1. Location map of the Dixie Valley region. Fault scarps formed or reactivated in 1903, 1915, and 1954 are shown. Modified from Slemmons (1957) and Burke (1967).

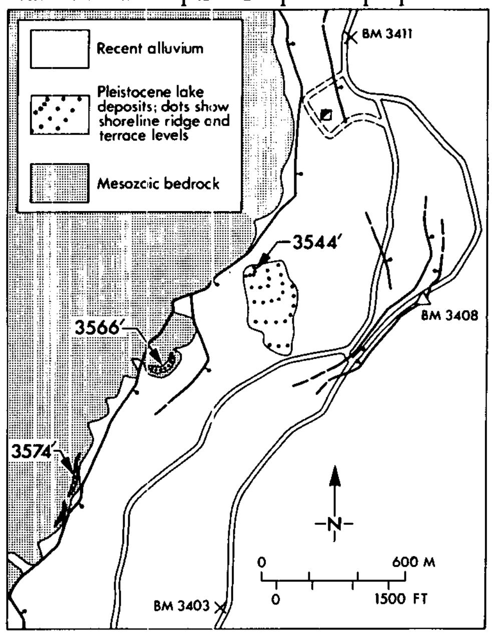

Figure 2. Map of offset lake shorelines in west-central Dixie Valley. The relative vertical spacing of beach ridges around the valley demonstrates that the highest beach ridge preserved in this area (3,544 ft) marks—like the tufa-cemented terrace deposits on bedrock—the highest lake stand.

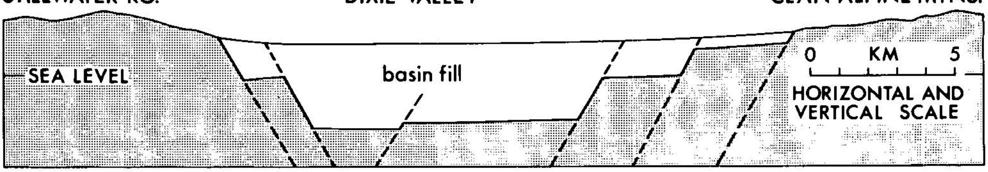

Figure 3. Generalized cross section of central Dixie Valley. Major offsets in bedrock at depth, as determined by geophysical means, are also evidenced by small recent scarps at the surface. After Burke (1967).

The shoreline deposits are offset by faults at many places; a particularly clear and measurable example is on the west side of central Dixie Valley (Fig. 2). There the vertical displacement is 9 m, and it may have occurred in two or more episodes of faulting. The fault surfaces are not exposed, and we must assume that their dip is similar to that of the many exposed faults—about 60°. Numerous scarps in the alluvium demonstrate that this offset is matched by opposing faults on the other side of the basin, and this inferred geometry is supported by seismic evidence (discussed in the next section) that shows the bedrock floor of the basin was not tilted by Basin and Range faulting. This geometry gives a vertical displacement of 9 m in the last 12,000 yrs, and a corresponding horizontal extension of 10 m in the basin during the same length of time. The average rate of extension is slightly less than 1 mm/yr.

Geophysical Exploration

A variety of geophysical techniques, including refraction seismology, gravity measurements, and magnetic depth estimates were used to determine the bedrock geometry of the valley and the subsurface dip of faults (Thompson and others, 1967; T. E. Smith, 1968). The results are summarized in Figure 3. With pre-fault topography restored, the total vertical displacement has been at least 5 km, and the horizontal extension has been 6 km or more. The time of inception of faulting is not known accurately, but Miocene-Pliocene sediments were deposited in the region in a subdued ver-

Figure 4. Grooves on a slickensided fault surface in Dixie Valley. The length of the hammer head is along the strike of the fault plane and the hammer handle is along the dip.

sion of present fault-block topography (Deffeyes, 1959), and we estimate the time to be about 15 m.y. The spreading rate, based on a minimum of 6 km of extension in 15 m.y., is at least 0.4 mm/yr.

SPREADING DIRECTION

1954 Faulting

Geodetic work, covering only the southern part of the 1954 faults, showed a general northwest-southeast extension direction on faults that have an average strike of about N. 15° E. (Whitten, 1957; Meister and others, 1968). Displacements of surface features (Slemmons, 1957) and the seismic first-motion solution (Romney, 1957) are generally consistent with the geodetic data.

Fault Grooves

Farther north in Dixie Valley itself, no consistent horizontal component of displacement was recognized in the 1954 fault breaks (Slemmons, 1957). Many older fault surfaces in bedrock are well exposed by erosion however, and grooves on these surfaces (Fig. 4) give a reliable measure of relative motion over a longer time period. A remarkable characteristic of the grooves is that their direction is generally independent of the strike of the fault segment on which they occur. The fault pattern is zigzag in plan, and when two blocks separated by a zigzag fault move apart, some fault segments would be expected to show lateral components of slip. This is exactly what is observed. For example, fault segments that strike north-south nearly always show a component of right-lateral slip. Those that strike northeast-southwest most commonly show a component of left-lateral slip.

Measurements on all grooved surfaces that could be found on the west side of Dixie Valley are compiled in Figure 5. The top histogram shows the azimuth (horizontal direction) of grooves. The mean azimuth, a little west of northwest-southeast, indicates the spreading direction. The scatter is probably caused in part by detachment and gravity sliding of small individual blocks. The bottom histogram shows the variability in fault directions (plotted as azimuth of dip direction for ease of comparison with groove direction).

The same data are shown in another way in Figure 6. The azimuth of each groove set is plotted in relation to the fault plane on which

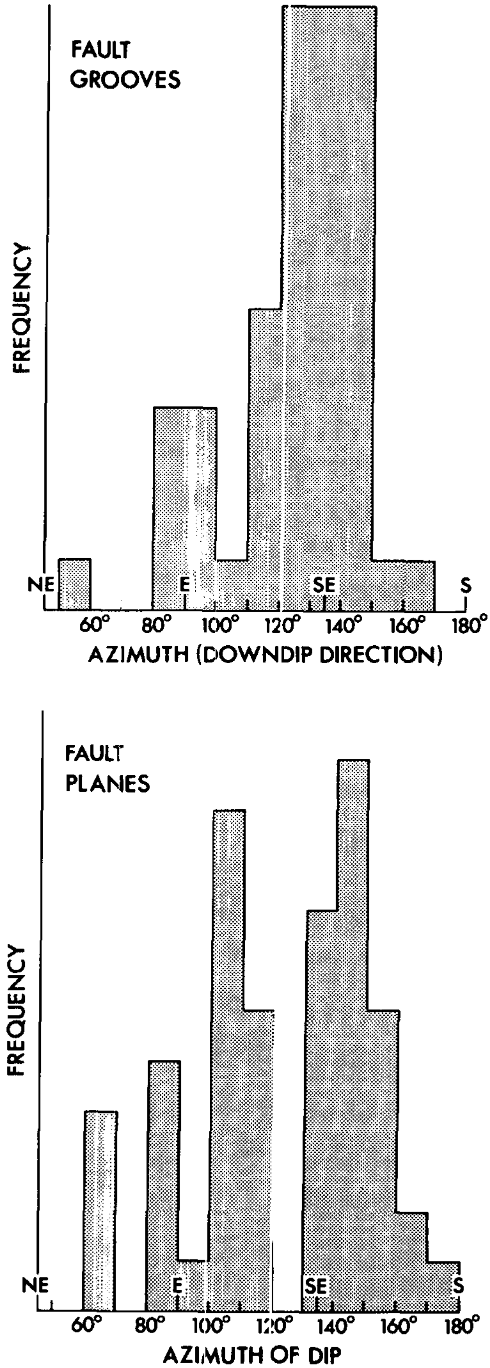

Figure 5. Histograms of the azimuths of fault plane grooves (above) and fault plane dips (below) on the western side of Dixie Valley. Fifty-four measurements for each are represented.

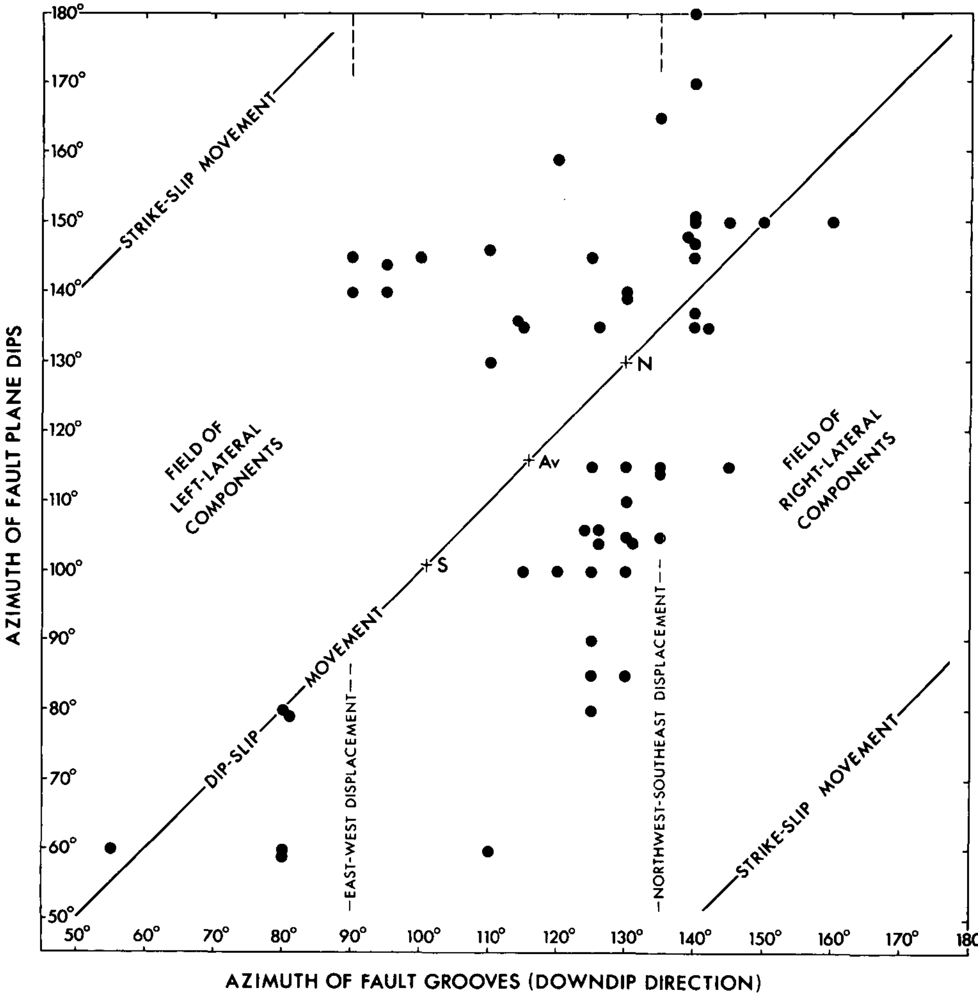

Figure 6. Plot of the azimuths of dips on fault plane segments in Dixie Valley versus the azimuth of fault grooves on those segments.

it occurs. To avoid ambiguity, the azimuth of a groove set (in the down-dip direction) is plotted against the corresponding azimuth of fault plane dip. The field is almost evenly divided between normal faults with left-lateral and those with right-lateral components of slip. Pure dip slip is rare, and no faults with pure strike slip were found.

The point "N" on Figure 6 represents the mean topographic trend of the northern half of the Dixie-Fairview basin and a hypothetical spreading direction normal to that trend. "S" is the corresponding point for the southern half, and "Av" is the point for the basin as a whole. The mean groove direction and the median groove direction both lie between 125° and 130°, to the right of "Av." This plot suggests that the basin as a whole has a slight right-lateral component of motion within it. From the average groove direction, we interpret the spreading direction to be approximately 125° or, in more conventional terms, N. 55° W.–S. 55° E. In Figure 1, this inferred spreading direction is oriented left to right on the page.

Comparative Data

We made similar groove studies in the Comstock Lode district and near Genoa, Nevada—150 to 200 km southwest of Dixie Valley. The indicated spreading direction in the Comstock district is N. 60° W.–S. 60° E.; near Genoa the direction is east-west.

Earthquakes triggered by the Benham nuclear explosion, 300 km to the southeast of Dixie Valley, released tectonic tension in a west-northwest–south-southeast direction (Hamilton and Healy, 1969). These results are surprisingly consistent with ours, and it appears that within the expected local variations—and within the uncertainties of measurement—the spreading direction is nearly constant over a wide region of the Basin and Range province.

CONCLUSIONS

For the last 15 m.y., Dixie Valley has been spreading at an average rate of at least 0.4 mm/yr; and for the last 12,000 yrs, it has been spreading at an average rate of about 1 mm/yr. The spreading direction is N. 55° W.–S. 55° E. Normal faults bounding the valley are markedly crooked, and fault segments have right- or left-lateral components of slip depending upon their strike.

The spreading direction appears to be fairly consistent over a wide region of the Basin and Range province. This direction is in harmony with the relative Pacific–North American plate motions postulated by Atwater (1970).

The 5 km of spreading in Dixie Valley, if extrapolated to the whole breadth of the Basin and Range province, suggests a total spreading of about 100 km, a 10 percent increase in crustal area.

ACKNOWLEDGMENTS

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Basin and Range structure has been a source of geologic debate since the earliest explorations of the American West, and citation of all the literature which serves as foundation for this small report would increase our bibliography by an order of magnitude. We happily acknowledge that a paper by Fuller and Waters (1929) is an otherwise unrecorded part of our legacy. This lucid and objective report, and discussions with Aaron Waters beginning more than 25 years ago, are greatly appreciated.

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