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GEOLOGY OF NEVADA

A Discussion to Accompany the *Geologic Map of Nevada*

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(Kleinhampl and others, 1975), and rhyolite domes occur in Storey and southern Washoe Counties (Thompson, 1956; Thompson and White, 1964). One of the most extensive areas of latest Cenozoic volcanic activity in Nevada is in the Lunar Crater area of northern Nye County (Scott and Trask, 1971) which contains many virtually uneroded basalt lava flows and cinder cones and two maar deposits.

Volcanic ash derived from the 6,600-year-old Mazama eruption at Crater Lake, Oregon, has been found in alluvium at a few localities in northern Nevada (Powers and Wilcox, 1964, fig. 2; Wilcox, 1965, fig. 3; Smith and Ketner, 1976). Ash from eruptions at Mono Craters in California may also be a constituent of the post-Pleistocene alluvium in southwestern Nevada (Gilbert and others, 1968; F. J. Kleinhampl, oral commun., 1978).

Black Mountain, a 6- to 7-m.y.-old volcanic center, southern Nye County. Labyrinth Canyon Member of Miocene Thirsty Canyon Tuff forms low mesas in lower right-hand part of photograph. This tuff pinches out eastward (away from observer) onto trachyte of Hidden Cliff that forms the main part of mountain. Two major episodes of caldera collapse are recognized in the Black Mountain volcanic center.

CENOZOIC TECTONICS

The most important Cenozoic tectonism in Nevada consisted of crustal extension that produced the present-day block-faulted basins and ranges. Most of the block faulting occurred in the late Cenozoic, and some is historic. The tectonic history of the early and middle Cenozoic is poorly known, but faulting and compressional folding have been documented locally.

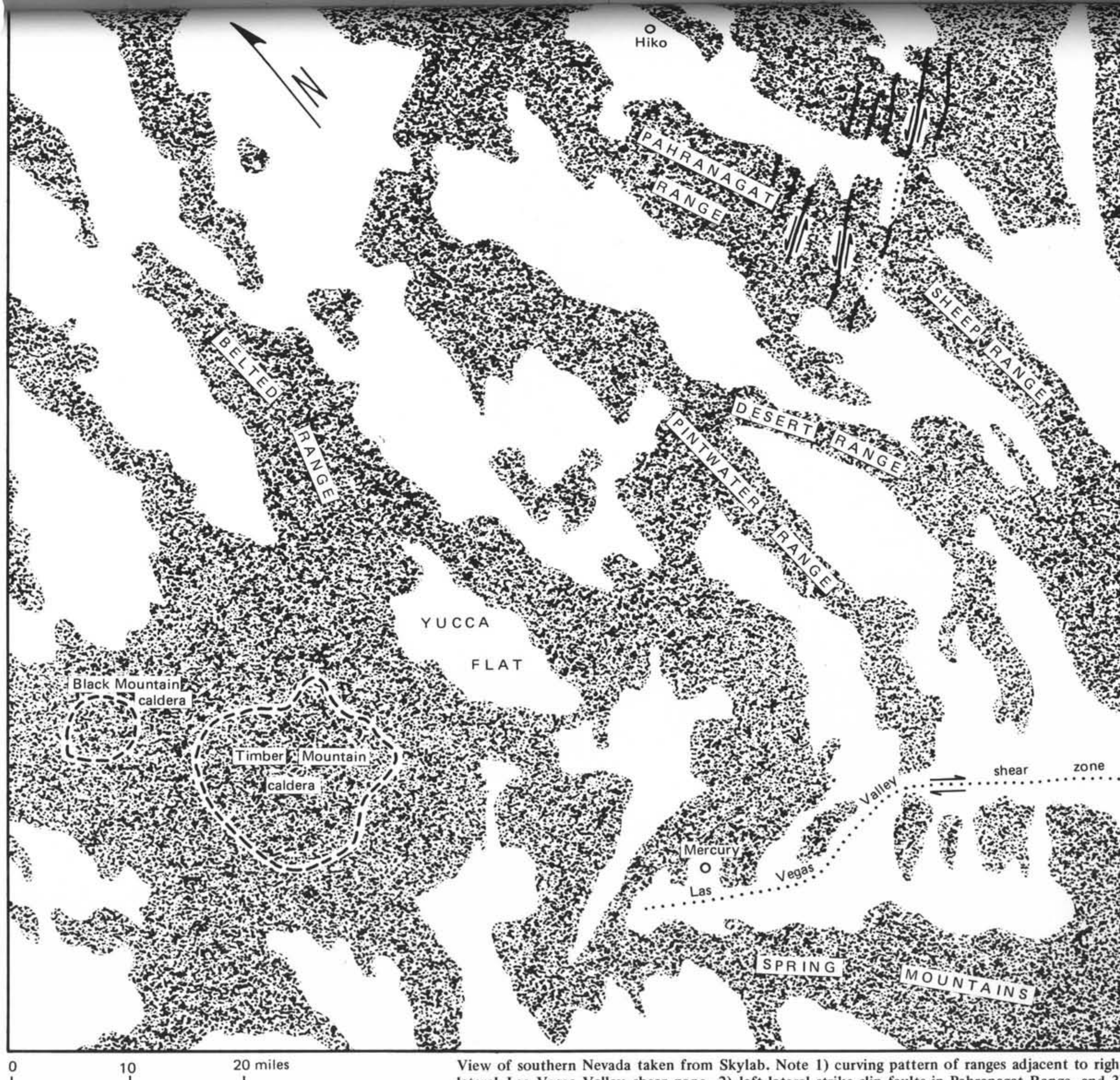
The Paleocene to middle Eocene history of Nevada is obscure because rocks of this age are sparse. Except for a few uncertainly dated plutonic rocks, the oldest igneous rocks in Nevada are about 43 m.y. old (late Eocene). Sparsity of sedimentary rocks of this age shows that Nevada was elevated and undergoing erosion during much of the early Tertiary.

The main evidence of tectonic activity during the early Tertiary is seen in the Sheep Pass Formation of east-central Nevada, which represents fluvial and lacustrine deposition in a broad internal drainage system. This formation has been considered to be Eocene in age (Winfrey, 1960) but more recent data (Fouch, 1977; T. D. Fouch, oral commun., 1978) indicate a Paleocene and Eocene, and possibly Cretaceous, age. The Sheep Pass rests unconformably on faulted and broadly folded Paleozoic strata (Kellogg, 1964; Moores and others, 1968), presumably deformed in the middle and late Mesozoic, and contains boulder conglomerate with clasts several feet across (Kellogg, 1964). Although much of this pre-Sheep Pass structure may be related to Mesozoic deformation, some may be related to deformation during deposition of the Sheep Pass Formation, as small faults cut conglomerate in the lower part of the Sheep Pass but do not affect overlying limestone and mudstone (Kellogg, 1964). Newman (1979) suggests that large scale normal faulting occurred during deposition of the Sheep Pass Formation.

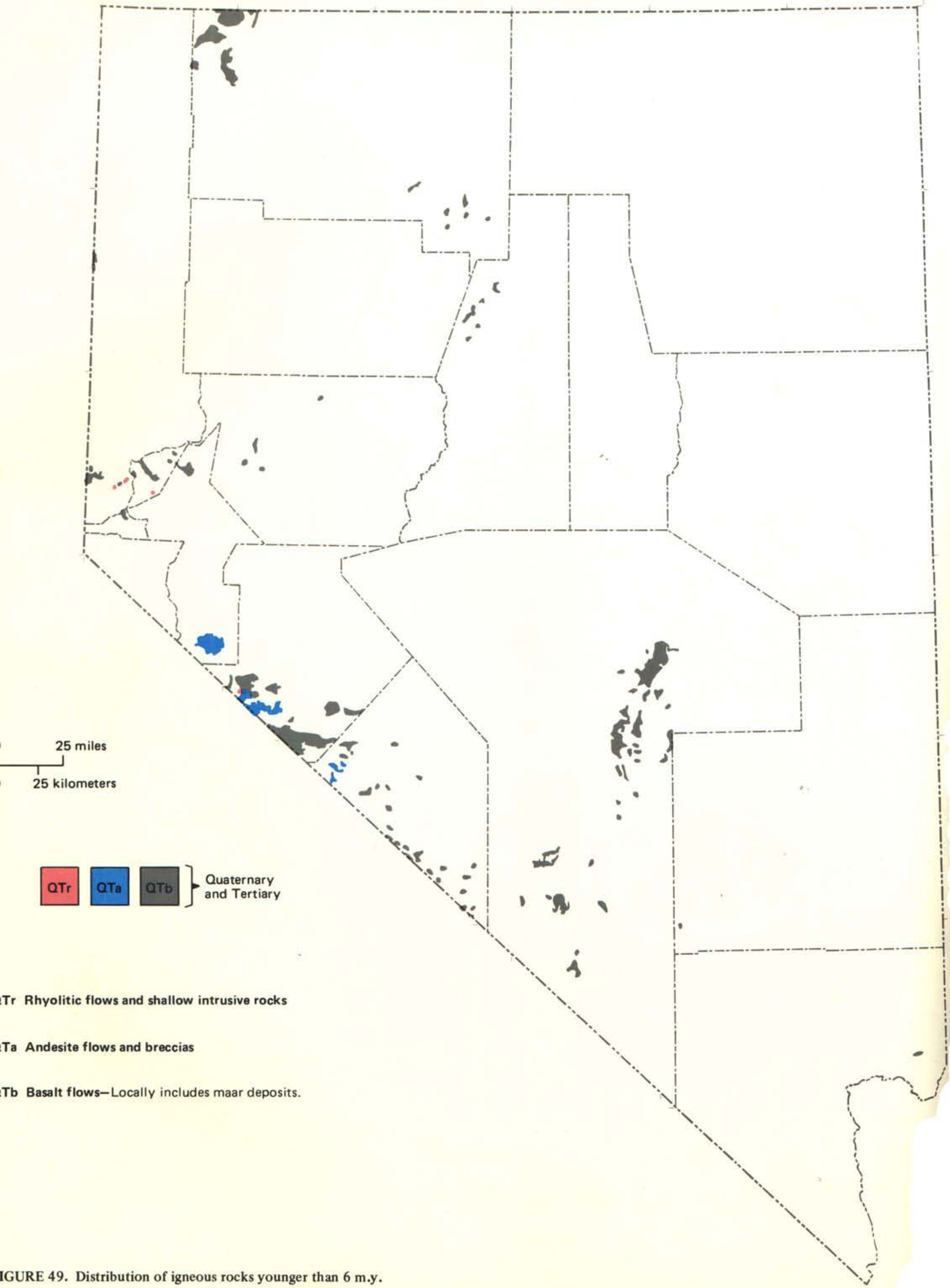
Clearly demonstrable middle Tertiary deformation has been described in western Elko County, where the Eocene and Oligocene(?) Elko Formation is strongly folded (Smith and Ketner, 1976). The formation commonly dips about 45° and in one place is folded into a partially overturned syncline. The folding is younger than 37- to 38-m.y.-old tuff in the Elko Formation, but older than 33- to 35-m.y.-old tuff in the unconformably overlying Indian Well Formation. The folds are approximately the same age as nearby exposed intrusive bodies. Middle Tertiary deformation has also been described in northern Elko County where faults that cut Eocene rocks apparently do not deform middle Miocene rocks (Coats, 1964).

Possible middle Tertiary deformation is indicated indirectly by the presence of coarse conglomerate at or near the base of Tertiary sequences at several places in Nevada. In southern Nye County, the early Oligocene Titus Canyon Formation contains coarse boulder conglomerate and in places is underlain by or includes monolithologic breccias composed of Paleozoic rock. These breccias, in places as thick as 200 feet (60 m), are believed by Cornwall and Kleinhampl (1964) to have formed mainly by landslides from the front of thrust faults, or the scarps produced by normal faults. In northern Elko County, the large size of boulders and abrupt changes in thickness

Thirsty Canyon Tuff (6 to 7 m.y. old), an ash-flow tuff with huge flattened pumice fragments. Near Black Mountain, southern Nye County. *Photograph by H. R. Cornwall.*



View of southern Nevada taken from Skylab. Note 1) curving pattern of ranges adjacent to right lateral Las Vegas Valley shear zone, 2) left lateral strike-slip faults in Pahranagat Range, and 3) Timber Mountain (9.5 to 11.5 m.y. old) and Black Mountain (6 to 7 m.y. old) calderas.

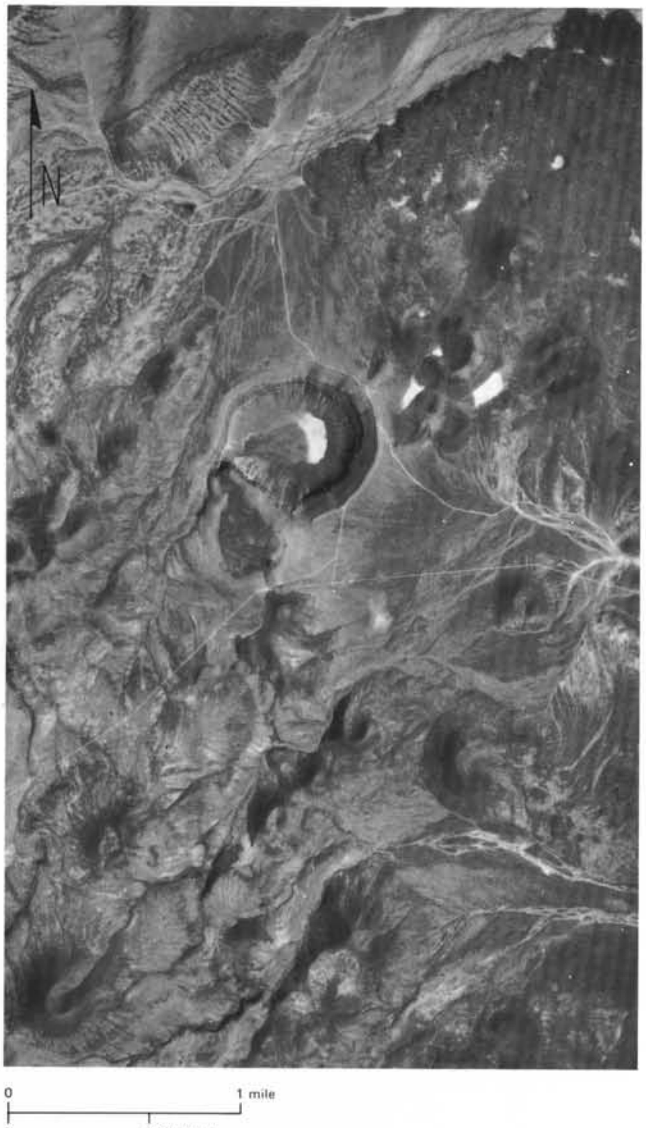


IGURE 49. Distribution of igneous rocks younger than 6 m.y.

0 1 mile
0 1 kilometer

Aurora crater (250,000 years old) on left, and younger but undated Mud Spring volcano on right, western Mineral County. *U.S. Geological Survey photograph.*

Late Quaternary Mud Spring volcano with Wassuk Range in background, western Mineral County.



Lunar Crater volcanic field, northern Nye County. Lunar Crater, a maar, in center. Small cinder cones occur in much of area. Margin of young lava flow distinguishable in upper right. *U.S. Geological Survey photograph.*

in the Eocene Meadow Fork Formation suggest that it was deposited in a narrow trough with steep walls (Coats, 1964).

Subsequent to initiation of widespread igneous activity in the late Eocene and early Oligocene and prior to late Cenozoic extensional tectonics, few structural events are recorded in Nevada except for events related to the igneous activity itself (fig. 50). Angular discordance between ash-flow sheets is not common, and most erosional unconformities are of only local extent. The lack of relief during the middle Tertiary is best demonstrated by the widespread distribution of individual ash-flow sheets and by the uniform stratigraphic sequence of ash-flow units from area to area in central and eastern Nevada (E. F. Cook, 1965; Grommé and others, 1972). Such ash-flows fill low areas much as water does, and only a slight topographic relief would cause great regional variations in the extent and thickness of individual flows and in the sequence of flows from area to area. The lack of such variability indicates that little regional tectonic distortion took place in Nevada in the middle Tertiary. Most structures of middle Tertiary age in Nevada are related to caldron subsidence or volcano-tectonic depressions and explain local disruption in the ash-flow stratigraphy.

The concept of little regional tectonic activity during the middle Tertiary in Nevada, as described in the above paragraph, does not mesh with concepts presented by Coney (1974, 1979) who has suggested that movement on low-angle (denudational or décollement) faults associated with metamorphic core complexes in eastern Nevada may be of this age. Workers in eastern Nevada, however, do not agree on the age of this faulting (see discussion under Mesozoic tectonics). Hose and Blake (1976) and R. K. Hose (oral commun., 1978) indicate that the faulting can be dated no closer than post-Middle Jurassic to pre-Oligocene, whereas other geologists (Armstrong, 1972; Coney, 1974; Snoke, 1979) consider the movement to be at least in part, if not entirely, middle or late Tertiary in age.

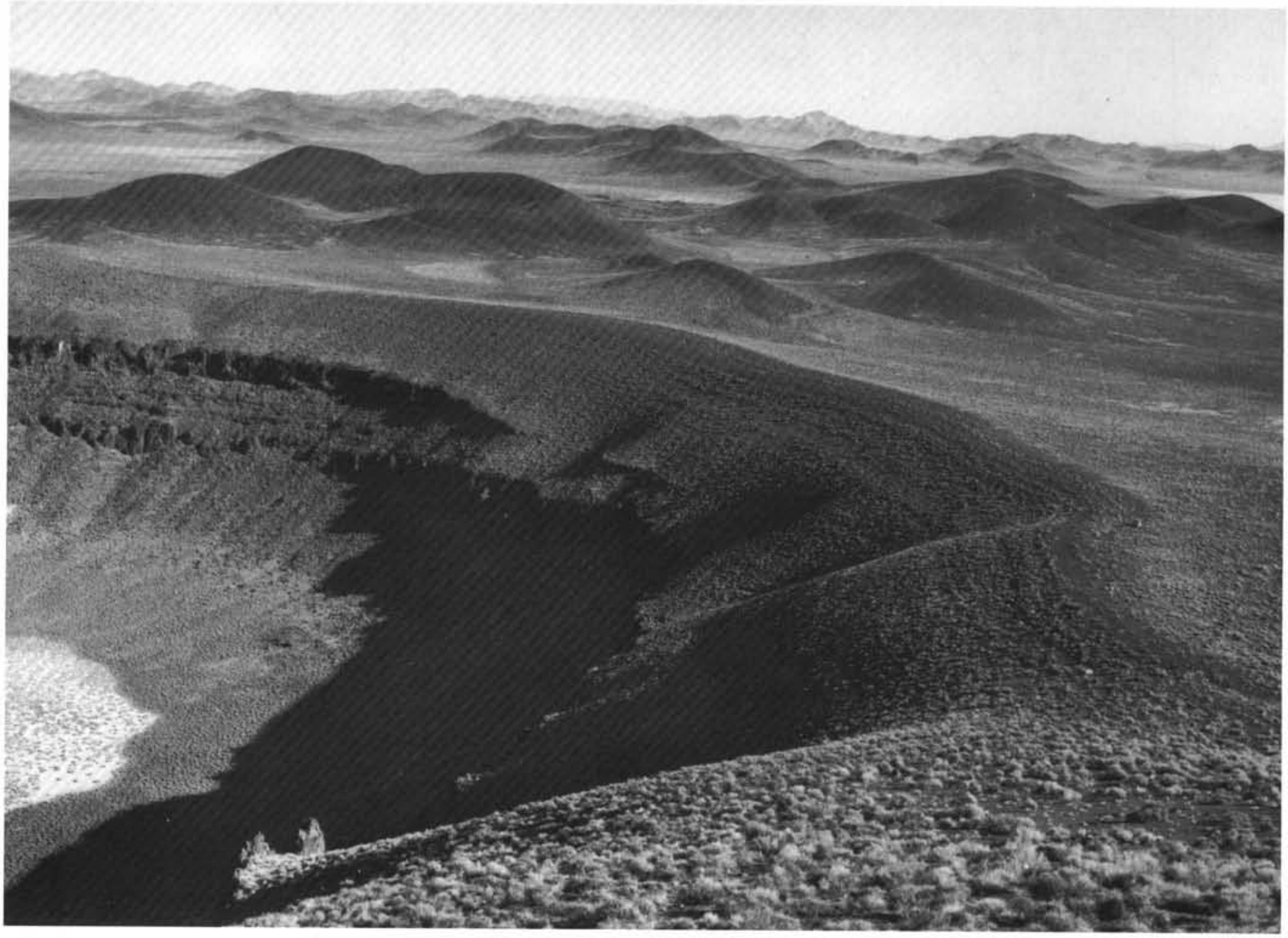
About 17 m.y. ago, a major change occurred in the tectonic setting of Nevada. Extensional faulting commenced, and the major basins and ranges that characterize the present-day topography were produced by extensional block faulting. Basalt or bimodal assemblages of basalt and rhyolite were erupted at this time, and continental sediments were entrapped in the fault-related basins.

The basins and ranges of Nevada were produced by a complex system of late Cenozoic normal faults (fig. 51) along which movement has resulted in the relative uplift of linear segments to form the mountains and the relative sinking of adjacent segments to form the valleys. The amount of valley fill in major valleys in Nevada is a few hundred feet (100 m) to more than 10,000 feet (3,000 m), and structural relief between the lowest part of bedrock areas under valleys to the highest parts of adjacent mountains is generally from 6,000 feet (2,000 m) to 15,000 feet (5,000 m).

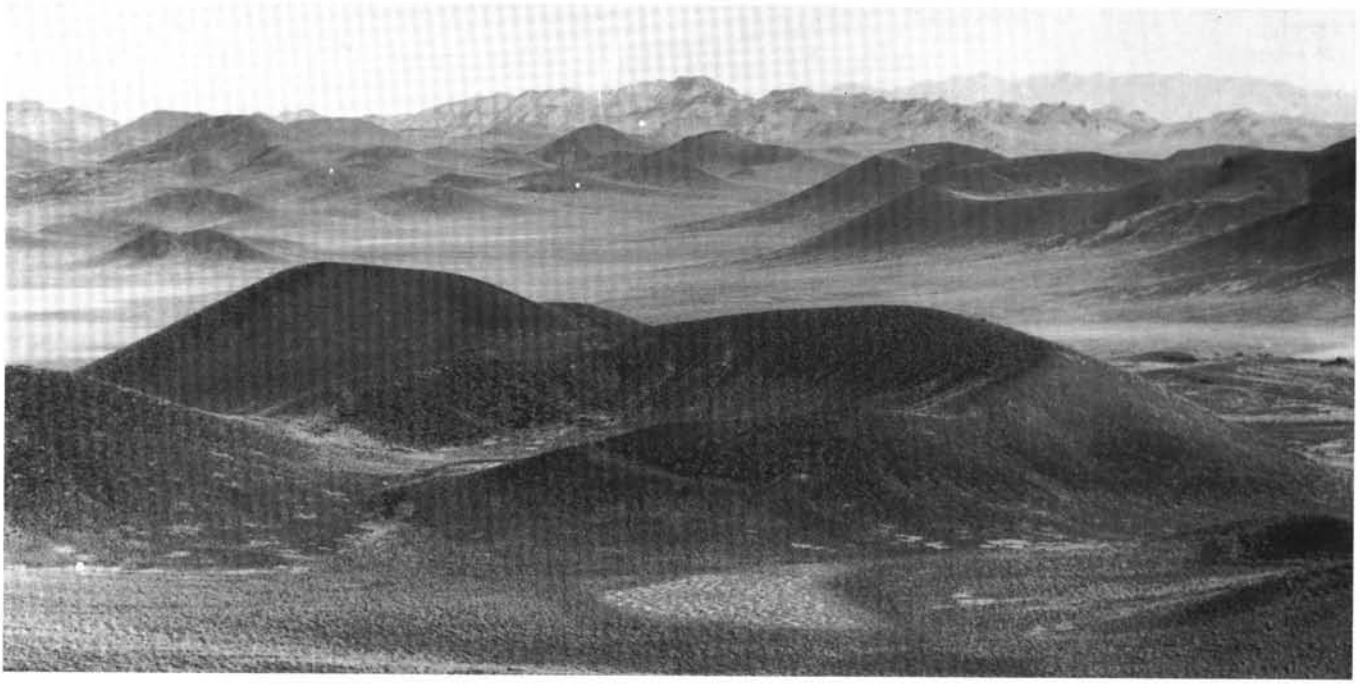
Three basic models of basin-range structure have been proposed (see Stewart, 1971 and 1978b for discussion). One model relates basin-range structure to a system of structural blocks rotated along curving, downward flattening (listric) faults. The uptilted part of an individual tilted block forms a mountain, the downslope part a valley. The second model relates basin-range structure to a system of horsts and grabens in which individual horsts form mountains and individual grabens valleys. The third model relates basin-range structure to a system of elongate rhombohedronal blocks formed by fragmentation of the upper crust by high angle faults. The uptilted part of a block forms a mountain and the downtilted part a valley. No unanimity of opinion has developed as to which of these three models is correct, and basin-range structure may involve elements of each. Other types of structures, such as low-angle denudational faults (Armstrong, 1972) and thin-skin distension (Anderson, 1971) are associated with basin-range structure locally.

Basin-range structure is clearly the result of regional extension, because normal faults that bound major mountain or valley blocks dip about 60° and require 1 mile of extension for each 2 miles of dip slip.

Estimates of the amount of extension necessary to produce basin-range structure are generally of order of 10



Lunar Crater, a maar, northern Nye County. View northeast. Note car for scale on east (right) rim of crater. *Photograph courtesy of Nevada State Highway Department.*



Slightly eroded cinder cones about one-half mile (1 km) northeast of Lunar Crater, northern Nye County. *Photograph courtesy of Nevada State Highway Department.*

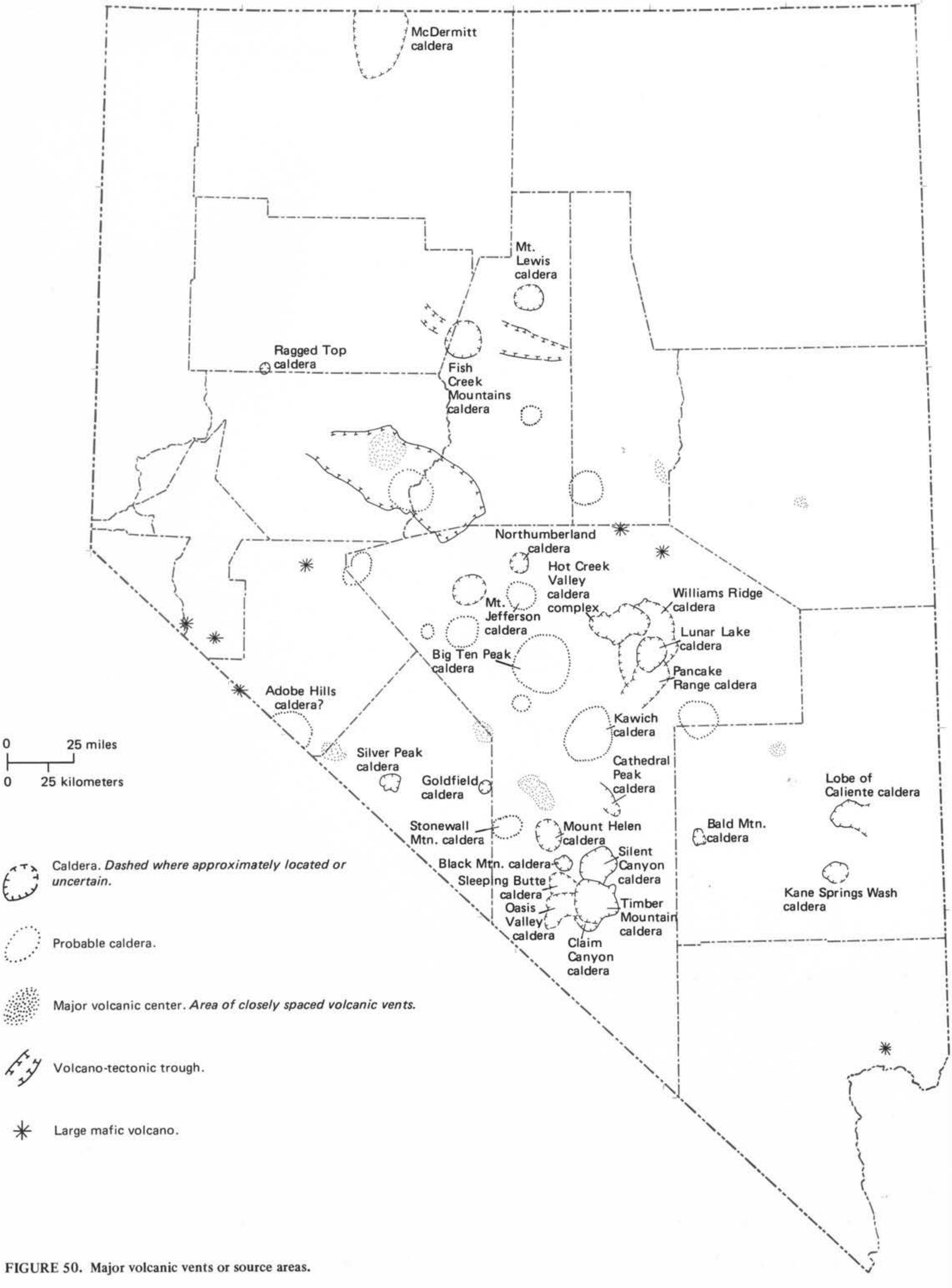


FIGURE 50. Major volcanic vents or source areas.

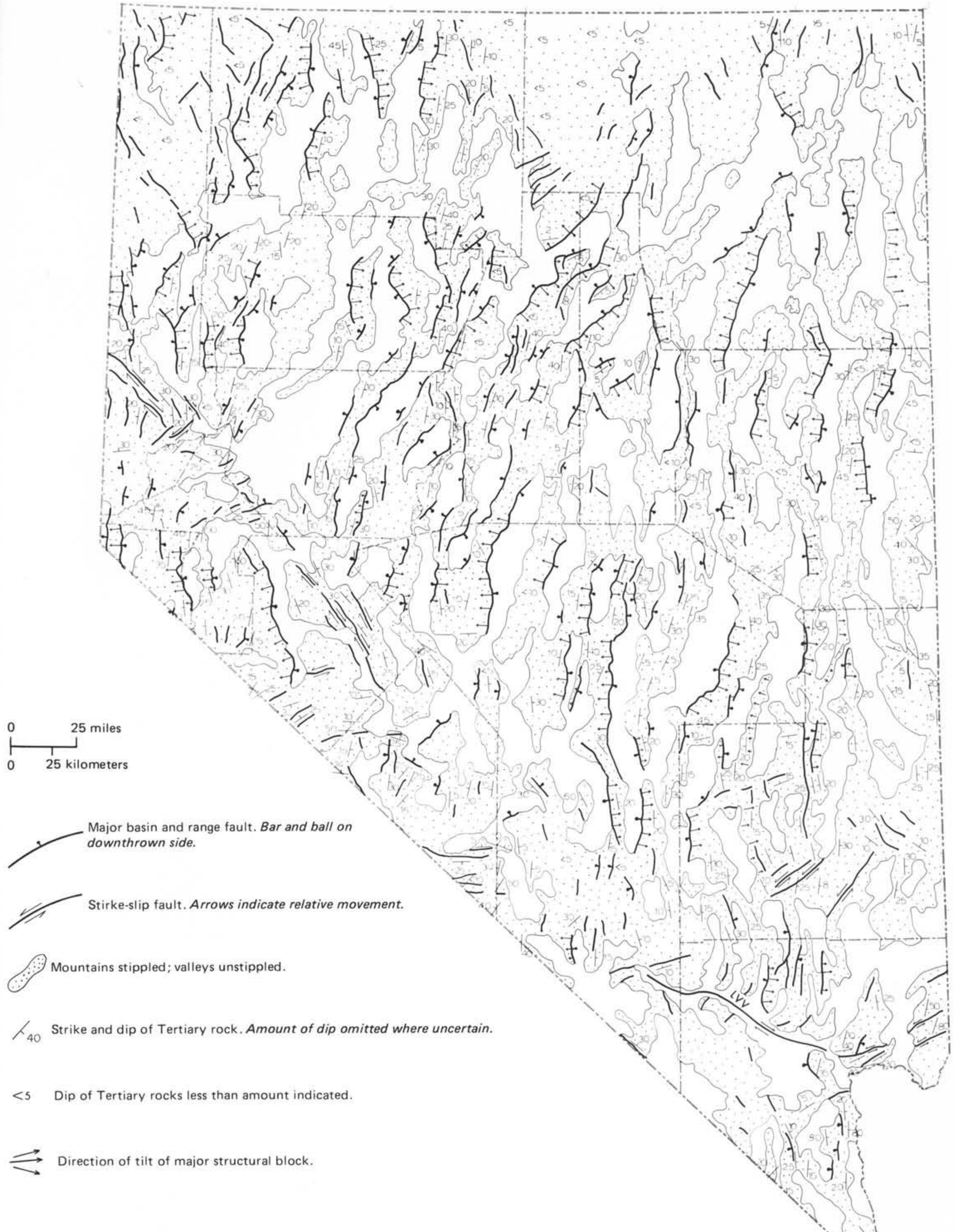
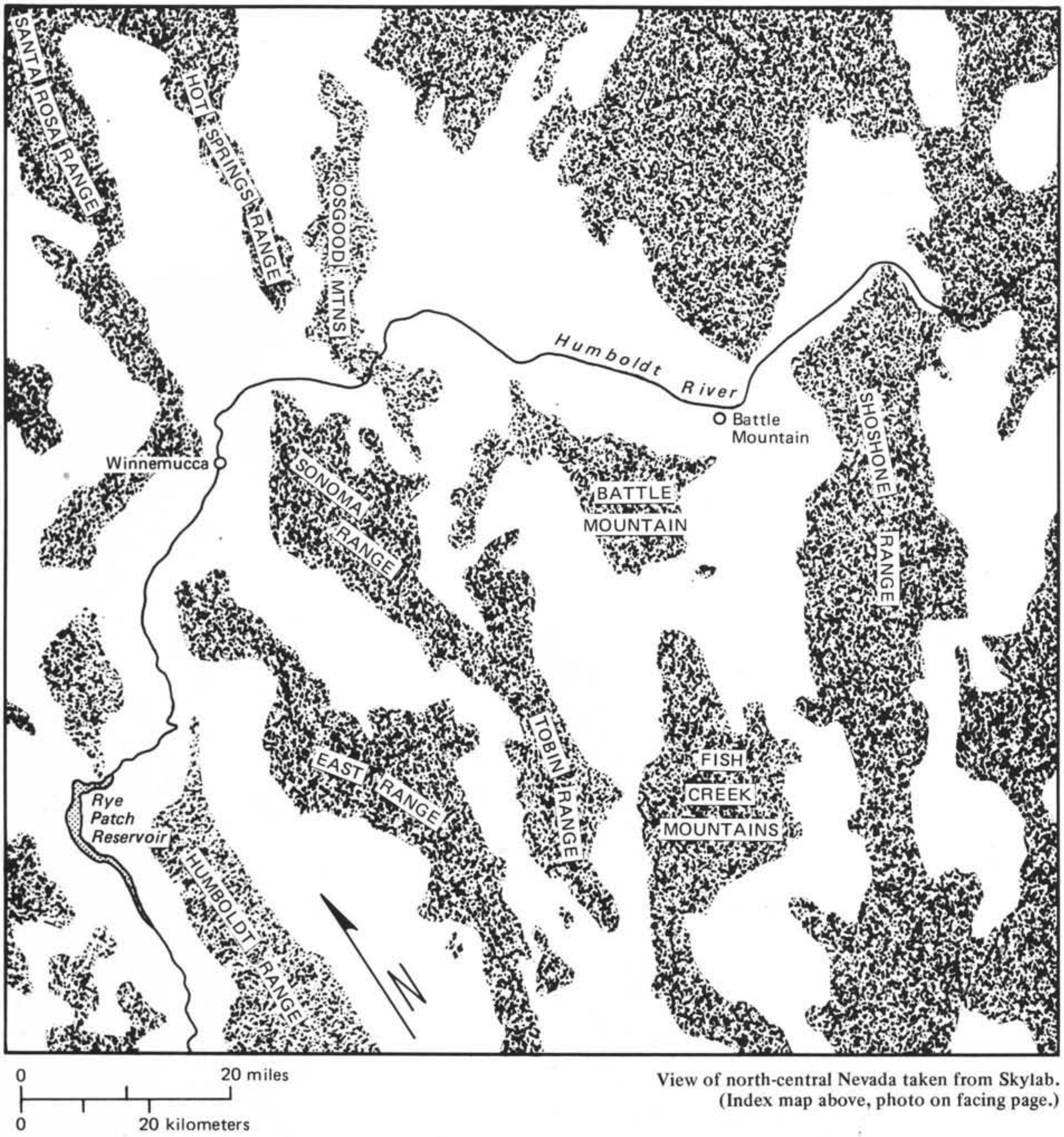


FIGURE 51. Major basin-range faults, tilt of major structural blocks, and attitude of Tertiary rocks. Locality: LVV–Las Vegas Valley shear zone.



View of north-central Nevada taken from Skylab. (Index map above, photo on facing page.)

to 35 percent of the original width of the region, but vary considerably because of disagreements about the geometry of the normal faults at depth. If the structure is considered to be composed of relatively simple horsts and grabens, then, estimates of the amount of extension suggest about 10- to 20-percent increase in the width of the region (Thompson, 1959; Stewart, 1971), whereas if the structure is considered to be composed of blocks tilted along downward-flattening faults, estimates range from 30 to 50 percent (Wright and Troxel, 1973) to as much as 100 percent locally (Proffett, 1977).

Two types of evidence have been used to date the development of basin-range structure. The first is indirect and based on the assumption that the time of transition from calc-alkalic volcanic rocks in the early and middle Cenozoic to fundamentally basaltic volcanic rocks in the late Cenozoic marks the change from predominantly compressive tectonics (related to a subduction zone) to extensional tectonics (related to wrench faulting, back-arc spreading, or some other factor). This volcanic transition in most areas of Nevada appears to have taken place about 17 m.y. ago (McKee and others, 1970; McKee, 1971), and coincides with the initiation of extensional tectonics—but how much of the initial extension resulted in the shaping of present-day mountain and valley structural blocks is uncertain.

Direct evidence of the development of basins and ranges is based on the first appearance of fault-controlled sedimentary basins and topographic forms approximately resembling those seen today. In Nevada, such basins were well defined about 11 to 13 m.y. ago (late Barstovian to Clarendonian) (Axelrod, 1957; Robinson and others, 1968; Gilbert and Reynolds, 1973). In a study in western Nevada, Gilbert and Reynolds (1973) described one such basin that was in existence from about 12.5 to 8 m.y. ago, but noted

that it was unrelated to present basins in the area. Sedimentary basins related to those of today did not develop in that area until approximately 7.5 m.y. ago.

In southern Nevada, evidence of the late development of basin-range structure has also been described (Ekren and others, 1968). In this area, two systems of faulting have been recognized. The earlier system consists of two sets of faults, one striking northeast and the other northwest, and is developed only in rocks older than 17 m.y. The younger system, a single set, strikes north and cuts 14-m.y.-old tuff that is not cut by the older system of faults. The north-trending system then, started to develop sometime between 17 and 14 m.y. ago, but relief related to this faulting did not develop rapidly. That the area had low relief about 11 m.y. ago is indicated by a widespread tuff of that age that does not vary significantly in thickness between present-day valleys and mountains, a situation that would be impossible if present-day topographic relief had developed by then. By the time another tuff had erupted about 7 m.y. ago, however, the topographic grain was much as it is today. This younger tuff lapped up against some of the ranges and in places flowed into valleys that are the sites of present-day streams.

Strike-slip faults are locally a major feature of the late Cenozoic tectonic framework of Nevada. The most conspicuous group of these faults are northwest trending and occur in a northwest-trending belt (the Walker belt, fig. 3) in the western part of Nevada and adjacent parts of California. In southern Washoe County, these faults are well defined, cut Cenozoic volcanic and sedimentary rocks, and are considered to be related to right-lateral strike-slip displacements (Bonham, 1969). The amount of Cenozoic right-lateral displacement in southern Washoe County is uncertain, but Bonham (1969) suggests that it could be as much as 20 miles (32 km).

In eastern Mineral County, several well-defined, northwest-trending faults cut Cenozoic volcanic and sedimentary rocks, and offset of the margins of mid-Tertiary ash flows (Hardyman and others, 1975; Ekren and others, 1979) suggests a combined right-lateral fault displacement

High altitude oblique photograph, north-central Nevada, looking southwest. Cortez Range, Eureka County, in lower left. Note conspicuous fault bounded northwest (right) side of range and southeastward dip of late Cenozoic lava flows and sedimentary rocks on southeast (right) side, indicating a southeastward tilted fault block. Crescent Valley in lower right. Shoshone Range in middleground on right side. *U.S. Geological Survey–U.S. Air Force photograph.*

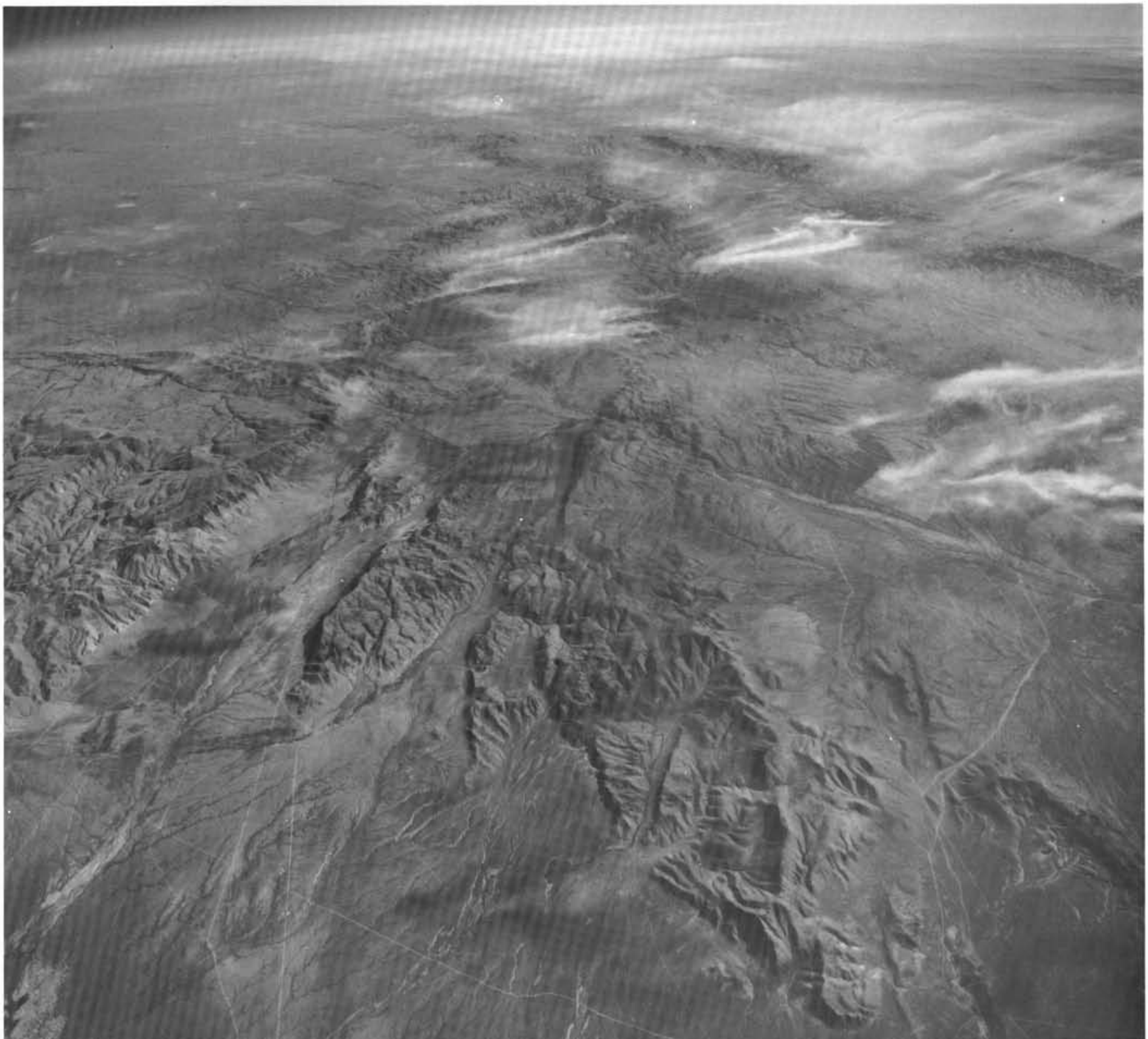
of at least 20 miles (32 km). In Clark County, a major northwest-trending right-lateral fault (the Las Vegas Valley shear zone) is presumed to underlie the alluvium of Las Vegas Valley (Longwell, 1960). Here, right-lateral displacement related to faulting and associated drag is estimated (see Stewart and others, 1968, for summary) to be from 25 to 40 miles (32 to 68 km). Fleck (1970b) and Anderson and others (1972) indicate that much of this displacement may have occurred from 15 to 11 m.y. ago, because 15-m.y.-old strata adjacent to the Las Vegas Valley shear zone are structurally disrupted in the same style as Paleozoic strata, whereas 11-m.y.-old volcanic rocks are undeformed. The Walker belt of Cenozoic right-lateral displacement in western Nevada is at least in part coextensive with an inferred belt of Mesozoic right-lateral distortion (Speed, 1978b), and Speed (1974) has suggested that the Cenozoic displacements in the Walker belt followed the trends of minimum fracture strength in this older belt of deformation.

Late Cenozoic left-lateral strike-slip faults occur in some parts of Nevada; the most conspicuous of these are in eastern Clark County (Anderson, 1973; Bohannon, 1979) and in southern Lincoln County (Tschanz and Pampeyan, 1970; Shawe, 1965).

Faulting occurred widely in Nevada in the late Quaternary, and surface faulting has occurred during several earthquakes in historic time (fig. 52). Historic surface faulting occurred near Olinghouse in 1869 (Slemmons, 1969), Wonder in 1903 (Slemmons and others, 1959), Pleasant Valley in 1915 (Page, 1935), Cedar Mountain in 1932 (Gianella and Callaghan, 1934), Excelsior Mountain in 1934 (Callaghan and Gianella, 1935), Rainbow Mountain and Dixie Valley-Fairview Peak in 1954 (Tocher, 1956; Slemmons, 1957). These young and historic faults indicate both extensional and strike-slip displacement and clearly indicate a present-day continuation of the tectonic activity that produced the basin-range topography of Nevada.

Theories of origin of late Cenozoic extensional and strike-slip faulting in Nevada and adjacent regions can be loosely grouped into four main categories: wrench faulting, back-arc spreading, subduction of the East Pacific Rise, and mantle plumes.

The wrench fault concept relates extension to oblique tensional fragmentation within a broad belt of right-lateral movement along the western side of the North American lithospheric plate (Carey, 1958; Wise, 1963; Shawe, 1965; Hamilton and Myers, 1966; Sales, 1966; Slemmons, 1967; Atwater, 1970). According to this view, western North America is within a broad belt of right-lateral movement related to differential motion between the North American and Pacific plates. Some of the right-lateral movement is taken up on the San Andreas fault and related zones of right-lateral shear, such as the Walker belt in the western Nevada and eastern California. The movement is also thought to produce distributed extension and tensional crustal fragmentation (including basin-range structure) along trends oriented obliquely to the trend of the San Andreas fault.



High altitude oblique photograph, western Elko County looking northeast. The Midas trough, a late Cenozoic northeast-trending graben extends from the lower left to the center of the photograph. Major escarpments are related to movement on high-angle faults. Faults cut mainly Miocene rhyolite flows. *U.S. Geological Survey–U.S. Air Force photograph.*