

Tertiary Igneous Chronology of the Great Basin of Western United States—Implications for Tectonic Models

ABSTRACT

The chronology of igneous activity in the Great Basin of western United States is used as a time framework for a simple plate model. This chronology suggests that a plate (Farallon plate) became underthrust to sufficient depth by the middle Tertiary to trigger the eruption of volcanic rocks of andesitic to rhyolitic composition in the central part of the Great Basin, 40 m.y. ago. This plate continued to be underthrust until about 19 m.y. ago, at which time it was completely consumed and volcanic activity ceased. When the oceanic ridge reached a certain point under the Great Basin about 16 m.y. ago, this resulted in the widespread eruption of olivine basalt and the main initial phase of Basin and Range faulting.

INTRODUCTION

Plate tectonic models which project or extrapolate from oceanic data to continental regions must be consistent with data collected on land. In the Great Basin of western United States the ages of igneous rocks are probably the best-documented part of the Cenozoic record. A sufficient number of the Tertiary rocks in this region have been dated by radiometric methods to establish a time framework for igneous activity. A summary of all known dates (McKee and others, 1970) shows two significant ages: one between 35 and 40 m.y. ago marks the start of Tertiary igneous activity; the other, a period about 17 to 19 m.y. ago, is a time of little or no volcanism. Volcanic activity resumed about 16 m.y. ago, and has continued until the present.

The age pattern outlined above can be integrated with the distribution of rocks of various compositions (Christiansen and Lipman, 1970; Lipman and others, 1970). It is also possible, in a general way, to analyze the tectonic development of the Great Basin during the Tertiary, and within the time framework of the igneous

activity. These geologic features must be accounted for in any model, including those based on plate tectonics.

AGE FRAMEWORK

Radiometric dates of Cenozoic igneous rocks in the Great Basin are summarized graphically in Figure 1.

Igneous activity started abruptly between 35 and 40 m.y. ago, after a long period of quiescence that extended back through the early half of the Tertiary into the Mesozoic. This abrupt start of igneous activity is documented by dates on more than 10 quartz monzonite to granodiorite plutons (Silberman and McKee, 1971; Armstrong, 1970; Willden and others, 1967), and numerous dates on andesite to dacite lava flows (McKee and Silberman, 1970; Blake and others, 1969). Rhyolite rocks which became the dominant part of the Tertiary column and are, for the most part, slightly younger than the plutons and andesite flows (starting about 34 m.y. ago) are represented by more than 200 dates (Armstrong, 1970; McKee and Silberman, 1970; McKee and Stewart, 1971; Marvin and others, 1970; and others; for a summary of references see Armstrong and others, 1969). Igneous activity continued through the Oligocene and first half of the Miocene, mostly as rhyolite to quartz-latite ash-flow tuffs, along with some andesite or dacite lava flows. At about 19 m.y. ago, volcanic activity ceased in most parts of the Great Basin (McKee and others, 1970).

A second phase of volcanism occurred after a several-million-year hiatus and is represented by voluminous outpourings of basalt and olivine basalt and a smaller amount of rhyolite and a little andesite. This volcanism started about 16 m.y. ago and has lasted until the present. The number of radiometric dates on rocks of these types is not representative of the volume of eruptive material, but numerous studies in local areas (Gilbert and others, 1968; McKee

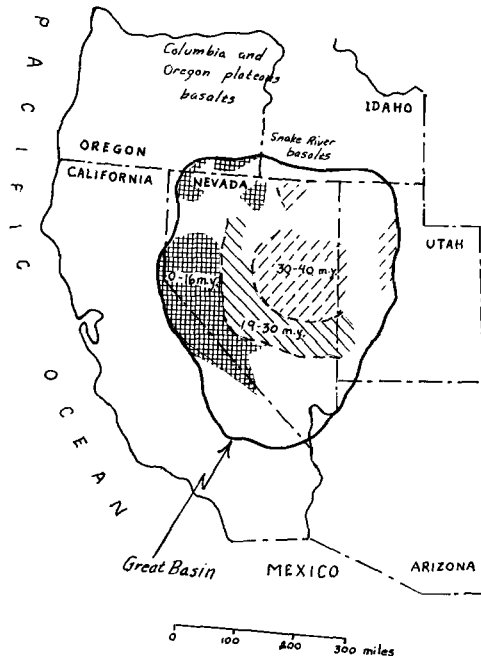


Figure 1. Age of igneous rocks in the Great Basin of western United States and approximate proportions of petrologic types. Histogram modified from McKee and others (1970), a summary of more than 500 K-Ar age determinations.

and Silberman, 1970; Noble and others, 1971; Armstrong, 1970; and others) clearly define the age limits of these rocks.

PETROLOGIC FRAMEWORK

Older Volcanic Rocks

Three petrochemical groups of rocks—basalt, andesite-dacite, and rhyolite, in approximate relative proportion and according to age—are shown in Figure 1. The older rocks (20 to 40 m.y. old) consist of andesites and rhyolites; the latter type are larger and more widespread. The andesites are relatively silicic high-K andesites, similar to high-K andesite described by Taylor (1969). The rhyolitic rocks, which were erupted as ash-flow sheets, are relatively low-silica (68 to 74 weight percent SiO_2) undifferentiated types and may be the eruptive products of intermediate magmas similar in composition to the andesites. Oligocene plutonic rocks (granodiorites to quartz monzonites), chemically similar to the andesites, occur in the region.

Younger Volcanic Rocks

Basalt is the most abundant rock 16 m.y. old and younger. Rhyolite forms a second large group of rocks of this age, and intermediate types (andesites and dacites) are relatively rare. This bimodal assemblage contains both alkali-olivine and tholeiitic basalts, and high-silica subalkaline and peralkaline rhyolites. Many of the rhyolitic rocks are highly differentiated (Noble and others, 1968).

DISTRIBUTION

The general distribution of Cenozoic igneous rocks according to age is shown in Figure 2. This figure, which is a modification of a series of figures in Armstrong and others (1969), shows that initial volcanic activity was concentrated in the central part of the Great Basin and that the foci of volcanism moved progressively westward from this region. Volcanic rocks (the bimodal basalt-rhyolite assemblage) younger than 16 m.y. old occur mostly near the margins of the Great Basin.

TECTONIC SETTING

The older igneous rocks (high-K andesites and rhyolite ash-flow tuffs) were extruded on an erosion surface of low to moderate relief in a region that had been tectonically stable for many millions of years. Eruption was not accompanied by any marked increase in tectonism, except in local areas where caldera collapse resulted from ash-flow eruption. The region remained stable throughout the Oligocene and early Miocene, with lavas and ash-flows spreading as thin equidimensional sheets over large areas. When volcanic activity ceased about 19 m.y. ago, the volcanic rocks were generally unfaulted, overlapping sequences of flows.

The resumption of volcanism 16 m.y. ago was accompanied by widespread high-angle normal faulting—typical Basin and Range structure. This tectonism formed the present physiographic configuration of the region and resulted in over-all crustal extension of the Great Basin. The widespread basaltic volcanism is associated with, and probably related to, this unique tectonic “break up” of the region.

DISCUSSION

Cenozoic rocks of the Great Basin offer a unique opportunity for correlating type and age of igneous rock with distribution and tec-

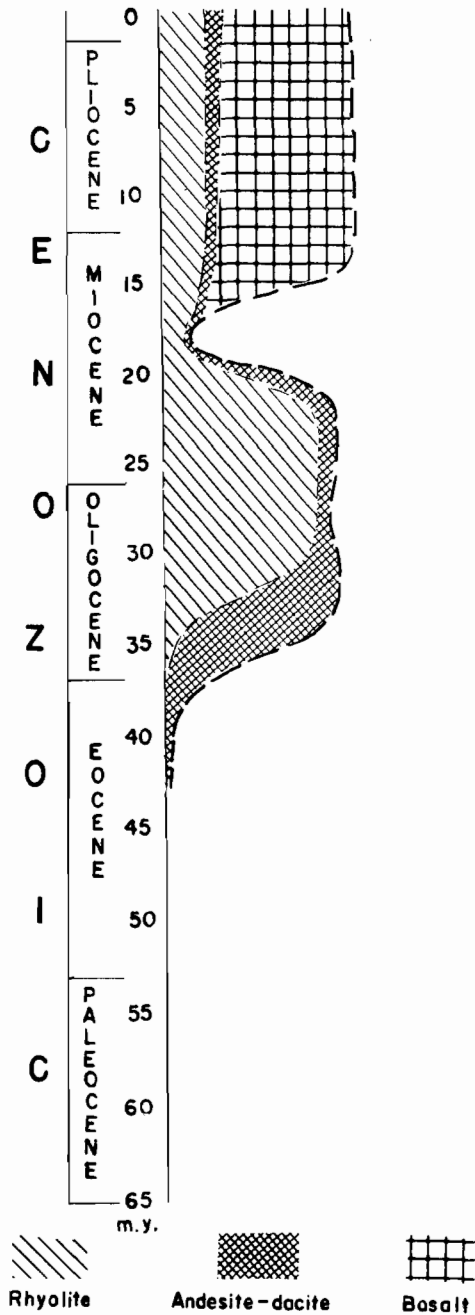


Figure 2. Distribution of silicic (andesite to rhyolite) volcanic rocks according to age in the Great Basin of western United States.

tonic setting. These measurable features are used in conjunction with sea-floor spreading theory as the framework for a plate tectonic model. The timing of events in this model is the best established parameter, and the critical ages must be considered in any viable model.

This model is summarized in Figures 3a, b, c, and d, and uses as its basis sea-floor spreading and continental drift ideas developed by McKenzie and Parker (1967), Morgan (1968), Atwater (1970), and others. Assuming that a ridge that was forming oceanic crust during the early Cenozoic existed in the east Pacific, and that the eastern plate (Farallon plate of McKenzie and Morgan, 1969) moved eastward and under the continental North American plate, then at about 60 m.y. ago the Farallon plate reached a certain depth on the subduction zone. There, temperatures were high enough for partial melting and generation of magma, which was erupted as high-K andesite and rhyolite differentiates in the central Great Basin. Continued subduction of the plate resulted in continuous eruption of volcanic material through the stable crust of the region. This type of volcanism and tectonic setting persisted for about 20 m.y., between 40 m.y. and 19 m.y. ago, as long as the Farallon plate existed. The shift in position with time of most intense volcanism across this region supports the idea of a dynamic model. By 18 m.y. ago, the plate was completely consumed, and the rise began to pass beneath the continental plate. Volcanic activity ceased in the Great Basin for a few million years until at 16 m.y. ago, the rise reached a position beneath the Great Basin (see Menard, 1960), causing crustal expansion (Basin and Range block faulting) and basaltic eruption. This condition has existed since 16 m.y. ago.

Some aspects of this simple two-dimensional model fit predictions based on analyses of different geophysical phenomena, while others do not. The initial volcanism about 40 m.y. ago corresponds well with that predicted by Atwater (1970), following the concept that the Farallon plate began to underthrust the North American plate at the latitude of San Francisco about 60 m.y. ago, and traveling at a rate of about 7 cm/yr, reached a point beneath the Great Basin in about 5 m.y., or 55 m.y. ago. If the magma generated by partial melting of this plate took about 20 m.y. to reach the surface, assuming fusion took place at a depth of 80 and 100 km and magma traveled upward at a rate between 0.03 and 0.06 cm/yr (Haesebe and others, 1971), the first volcanic activity would

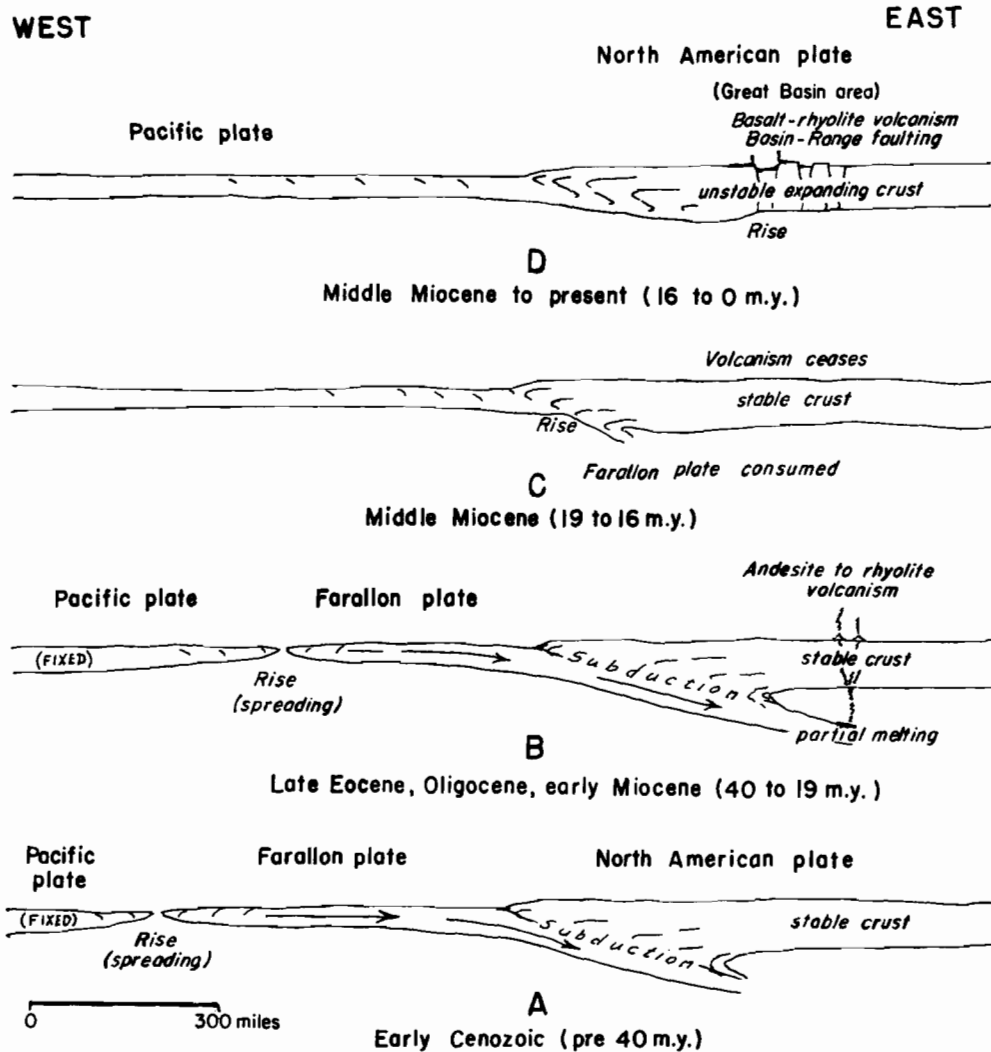


Figure 3. Schematic Tertiary plate-tectonic model of the eastern Pacific-western United States showing possible relationships between oceanic plates forming from a

Pacific rise and the North American plate. Type of volcanic rock and general tectonic setting of the Great Basin are in the correct time framework.

have started about 35 to 40 m.y. ago.

However, the first volcanic products on the North American plate are 400 to 600 km inland from the trench, a considerably greater distance than that predicted by Matsuda and Uyeda (1971) using heat-flow models, or by Atwater (1970) in analyzing the geometry and relative motions of the Farallon-North American plates. Even more difficult to understand is the apparent migration of volcanic activity toward the trench as subduction continued. No

explanation is offered for this, although models of deep-mantle convection of a vertical plume of hot material such as proposed by Morgan (1972) "fit" the distribution pattern well.

CONCLUSIONS

The two significant ages seen in the Cenozoic volcanic record of the Great Basin (about 35 to 40 m.y. ago and 16 m.y. ago) must be considered in any model of plate tectonics that in-

cludes this region. Discrepancies between timing of events predicted in models and actual K-Ar ages may be due to several reasons. Three possibilities include a variable spreading rate leading to an incorrect time scale (Heirtzler and others, 1968), an incorrect geometric and tectonic model, or the fact that the Tertiary volcanic rocks in the Great Basin may not be related to plate tectonics at all.

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