

Isotopic evidence for nonuniform thinning of lithospheric mantle during continental extension

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The mantle lithosphere underlying continental crust has isotopic and geochemical characteristics that distinguish it from the subjacent asthenospheric mantle. These differences are evident in the isotopic and trace element compositions of many basalt lavas erupted in continental settings. During continental extension, the lithosphere thins, and in some cases this is reflected in a temporal change in the isotopic compositions of basalt lavas. To the extent that the depth of origin of basalts can be estimated, the isotopic transitions in erupted lavas monitor the thinning of the lithospheric mantle.

A fundamental question in continental tectonics concerns the relationships between extension of the upper part of the crust, and extension in the lower crust and the mantle lithosphere. Models that relate upper crustal stretching to the lower lithosphere behaviour include those referred to as pure shear, simple shear (Wernicke, 1985), and distributed shear (e.g. Block and Royden, 1990). In each case, there are different predictions about how much thinning of the lithosphere should occur in association with a given amount of upper crustal stretching, whether the thinning should be uniform over large areas or restricted to certain geographic zones, and whether the zones of maximum lithospheric thinning should be directly beneath, or offset from, the zones of maximum upper crustal stretching.

In an attempt to evaluate the use of basalt geochemical characteristics for monitoring lithospheric thinning during continental extension, an extensive sampling and analysis program was carried out on Miocene to Recent basalts of the Basin and Range province of the western U.S. The data were collected so as to augment other studies (e.g. Bradshaw *et al.*, 1993; Feuerbach *et al.*, 1993; Rogers *et al.*, 1995) and thereby achieve relatively complete coverage, geographically and in time, of a region extending from the Sierra Nevada to the Colorado Plateau between latitudes 34°N and 39°N. This area underwent extension mainly between about 16 and 10 million years ago; but extension continues

in the western part of the region near the Sierra Nevada.

Small volume basaltic eruptions accompanied much of the extension, and these provide probes of the underlying mantle. The basalt geochemical data is converted to information about the depth to the lithosphere - asthenosphere boundary by assuming that tholeiitic basalts sample the mantle at depths less than 50 km, and that alkalic basalts (up to 10% normative nepheline), sample the mantle at depths of 50 to 70 km. These depth ranges, based on phase equilibria data, have some uncertainty, but changing them by modest amounts does not change the conclusions significantly. It also assumed that the pre-extension lithospheric thickness was 100 km.

The data are grouped into 9 geographical area for analysis; each group covers 5 to 20% of the total area of about 150,000 km². There are two types of temporal patterns observed. One type is illustrated by the Las Vegas-Lake Mead region (Fig. 1), near the eastern limit of the extended area, where there is a gradual transition in basalt isotopic compositions represented by shifts in ϵ_{Nd} from (lithospheric) values near -10 to values in the range 0 to +6 (the asthenospheric value being about +8). The data indicate that the lithosphere thinned more than would be predicted by fully distributed shear, but less than predicted by pure shear. In the Death Valley region, the data show little isotopic evidence for lithospheric thinning, even though the extension factor (*c.* 5) of the upper crust is similar to that for the Las Vegas-Lake Mead area.

The data indicate that lithospheric thinning was non-uniform over this area, with the most thinning occurring near the eastern boundary. The observations suggest that the extension has components of all of the models. Simple shear-like deformation is suggested by the observation that certain regions of upper crustal extension are underlain by relatively unthinned lithosphere; other regions suggest pure shear, but with total thinning factors smaller than the

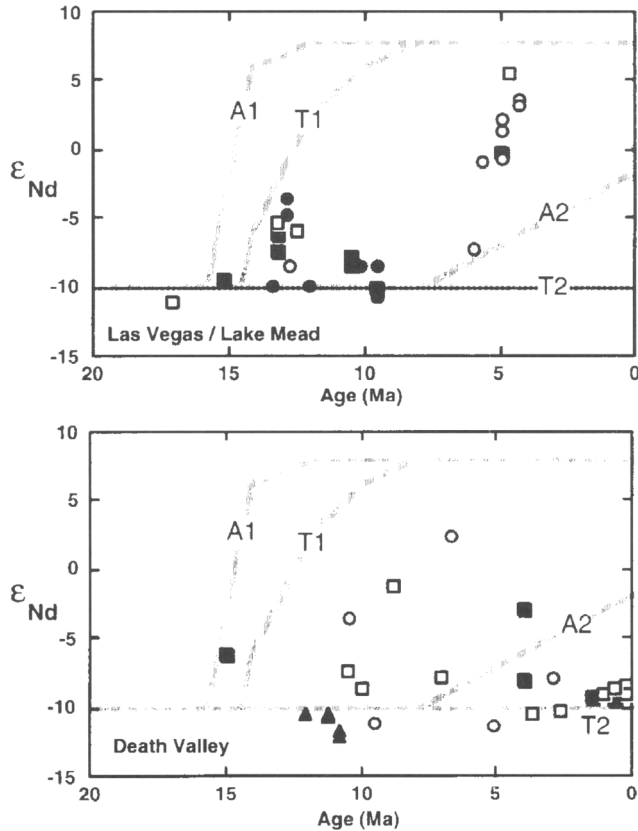


FIG. 1. Nd isotopic composition vs age for basalts from two sub-areas of the study region. Solid symbols are hypersthene normative lavas; open symbols are nepheline normative lavas. Trajectories A1 and T1 are for alkalic and tholeiitic basalts for the pure shear model; A2 and T2 are for fully distributed shear.

extension factors, possibly due to distribution of the thinning over an area larger than that represented by upper crustal extension. Regions where the lithosphere thinned by more than might be expected from the upper crustal extension factor, exist, but except in one case, have no basaltic volcanism. The lithospheric thinning history inferred from isotopic data is remarkably consistent with seismological estimates of present lithospheric thickness (Zandt *et al.*, 1995).

References

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