FORUM

Stable isotope study of fluid inclusions in fluorite from Idaho: Implications for continental climates during the Eocene: Comment and Reply

COMMENT

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There at least four reasons to doubt the conclusion of Seal and Rye (1993) that their study "... provides compelling support for the climate modeling study of Sloan and Barron (1990)," which argued for cool and seasonal climates in the interior of North America during the Eocene. First, there is a large and internally consistent body of paleontological data that demonstrate warm (mean annual temperature >15 °C) and equable (mean annual range of temperature <15 °C) climates in the continental interior during the Eocene (e.g., Archibald, 1991; Hickey, 1977; Wing, 1991; Wing et al., 1991). Second, Seal and Rye did not give any Eocene temperature estimates, they only implied that the Eocene might have been similar to the modern day! If the isotopic data are so compelling, why not give estimates? Third, much of the debate about the Sloan and Barron model concerns seasonality, not mean annual temperature (MAT). MATs generated by the Eocene simulations are much warmer than modern MATs and are close to those inferred from paleobotanical data (Sloan and Barron, 1992; Wing and Greenwood, 1993). The controversial aspect of the Sloan and Barron (1990) simulations was the low cold-month temperatures, a climate parameter difficult to infer from isotopic data. Finally, paleobotanical and geological evidence indicates a substantial Eocene altitude for the sites studied by Seal and Rye (Fields et al., 1985; Axelrod, 1968). Axelrod (1990) estimated a paleoaltitude of 1555 m for the nearby Eocene Thunder Mountain flora, and much of the region from northeastern Washington State to northern Nevada has been considered an Eocene volcanic highland (Axelrod, 1966; Wolfe and Wehr, 1987, 1992). Thus, even if the isotopic data have been interpreted correctly, they may reflect the paleoaltitude of the site rather than a cool continental interior "decoupled" from the warm oceans.

Seal and Rye (1993) also stated that with regard to Eocene continental climate "... the paleobotanical data are largely restricted to continental margins" (p. 219). To the contrary, data for the continental interior were summarized in *Geology* (Archibald, 1991; Wing, 1991), and since 1990 there have been two additional articles in *Geology* that discuss the paleoclimatic implications of interior North American Eocene floras (Gregory and Chase, 1992; Wing et al., 1991). Paleoclimate inferences based on general climate model simulations or isotopic data must recognize and respond to the paleontological conclusions on the subject, or proper scientific debate will be stymied.

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REPLY

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We agree with Wing and Wolfe that "compelling" may be too strong a word to describe the support of our study for the modeling study of Sloan and Barron (1990) and that "tentative" might be more accurate. Our intention was to offer data as a paleoclimate reference point, and the data can be interpreted to support the conclusions of Sloan and Barron (1990). Regardless of the ultimate relation of our study to the climate modeling study, the comments of Wing and Wolfe do not challenge the fundamental conclusions of our work nor do they undermine the usefulness of fluid inclusions as paleoclimate indicators.

On the basis of climate modeling studies, Sloan and Barron (1990) concluded that the continental interior climates during the

Eocene were probably more similar to those today than to the warm marine climates recorded by the oxygen isotope signatures of deep-sea forams. They also made a plea for proxy data from continental interiors to aid in the calibration of their model calculations. Wing (1991) and Archibald (1991), among others, have answered this request with paleontological data that questioned some of the results of Sloan and Barron (1990).

The significance of our work centers on the fact that the fluid inclusions that we studied formed in a continental interior setting during the critical interval of Earth's history between 50 and 55 Ma when Cenozoic ocean temperatures are known to have been their highest. The fluid-inclusion record preserved by the Bayhorse fluorite deposits is of exceptional quality. With these observations in mind, our study resulted in three main conclusions: (1) The Eocene fluid inclusions are samples of ancient heated meteoric (ground) waters that did not undergo significant water-rock interactions to alter their isotopic compositions; (2) the oxygen and hydrogen isotope compositions of these ancient meteoric waters are identical to present-day meteoric waters; and (3) the equivalence of the Eocene and modern meteoric water stable isotope values implies that the general climatic conditions during the Eocene were similar to those today. The isotope data for the Bayhorse district most directly reflect the mean annual temperature of precipitation, which is one of the most important factors in determining meteoric water compositions. By analogy with the present, our data indicate Eocene mean annual temperatures at Bayhorse of approximately 10 °C.

In our paper, we did not elaborate upon the two main factors that control the present mean annual temperature of precipitation: latitude and elevation. The magnitude of these two factors in the Bayhorse district bears heavily on the significance of our fluorite inclusion fluid data. As pointed out by Wing and Wolfe, elevation was probably an important contributing factor in determining the temperature of precipitation at our locality, and thus indicates at least a local control on temperature. This observation is consistent with the approximately 670 m of subaerial volcanic cover which we reported from the literature (Ross, 1937) in our paper.

Regarding the other points of Wing and Wolfe, we did not intend to downplay the significance of the paleontological data available from the Cenozoic of western North America. The paleobotanical data that we chose to reference as most applicable were those from Ross (1937) from the Bayhorse area. Like Axelrod (1990), who reported data for the Thunder Mountain caldera, 90 km northwest of the Bayhorse district, Ross (1937) reported *Pinus*, *Sequoia*, *Alnus*, *Juglans*, *Quercus*, and *Salix*. Axelrod (1990) concluded that the mean annual temperature was 8.5 °C, favorably compared to our mean annual temperature of precipitation of 10 °C.

In summary, fluid inclusions hosted by minerals, such as fluorite, quartz, and adularia, among others, from epithermal mineral deposits provide important paleoclimate reference points in continental settings that are readily obtainable. However, these data and *all* other paleoclimate indicators must be evaluated in the proper context with respect to their temporal and spatial setting. Thus, Cenozoic epithermal mineral deposits in western North America hold great potential for providing a detailed picture of Cenozoic meteoric water compositions and climates, as first suggested by O'Neil and Silberman (1974).

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