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Cenozoic Crustal Movements in the Sierra Nevada: Reply

General Statement

The time of origin of the eastern escarpment of the Sierra Nevada in the vicinity of McGee Mountain, California, can be established only within broad limits. Several workers, having noted the old till on McGee Mountain (*see* Lovejoy, 1967, Fig. 2; Christensen, 1966, Fig. 5), concluded that the canyon of McGee Creek could not have existed when the till was deposited; hence the eastern escarpment probably developed after the "McGee stage" of glaciation (Blackwelder, 1931, p. 904; Matthes, 1933, p. 38; 1939, p. 1955; Putnam, 1962, p. 204). This inference does not negate the possibility that ice-falls of the McGee-stage glaciers spilled over the edge of an escarpment not yet scored by canyons. A study of the basalts underlying the McGee tills led Lovejoy (1964, 1965) to the conclusion that the escarpment existed before the basalts were erupted 2.6 m.y. ago (Dalrymple, 1963, p. 387), *i.e.* before the McGee glaciation. Having restudied relations in the field in 1966 and having reviewed Lovejoy's description, I can only restate my conclusion that, the evidence being insufficient for a critical choice, I prefer the interpretations of the earlier workers.

Recent work on the age of the oldest Pleistocene glaciations suggests that the difference between the alternative interpretations of the age of the escarpment need not be great because the McGee till could be nearly as old as the basalt on which it rests. Using paleomagnetic stratigraphy, Wensink (1964) inferred that the oldest glaciation in Iceland began just after the Mammoth polarity event, about 3 m.y. ago. Paleomagnetic stratigraphy in deep-sea cores shows that the first influx of glacial debris in the southern oceans occurred shortly after the Mammoth event (Opdyke and others, 1966). In the Sierra Nevada near McGee Mountain a till was discovered sandwiched between two lava flows dated respectively at 3.1 and 2.7 m.y. old (Curry, 1966). The Pliocene-Pleistocene boundary has been dated at 2–3 m.y. old in both France (Curtis, 1965) and New Zealand (Matthews and Curtis, 1966).

I should like to comment briefly on Lovejoy's discussion of the basalts on McGee Mountain, the glacial gradients, and the relation of faulting to the uplift of the Sierra.

The Basalts

I am inclined to agree with Lovejoy that the cinders that outcrop at 9200 feet on the escarpment north of McGee Mountain (Fig. 1; Lovejoy, 1967, Fig. 2) are probably not a remnant of a landslide mass, although that possibility is not beyond doubt. It is also

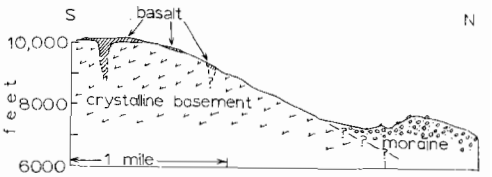

Figure 1. North-south profile of north slope of McGee Mountain (*constructed from* Rinehart, C. D., and Ross, D. C., 1964, Geology and mineral deposits of the Mount Morrison quadrangle, Sierra Nevada, California: U. S. Geol. Survey Prof. Paper 385, Pl. 1).

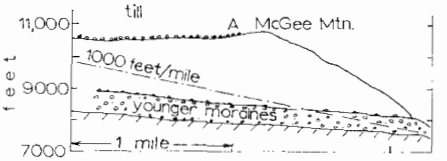

Figure 2. Profile of McGee Creek and McGee Mountain, looking northwest, projected onto a vertical plane striking N. 63° E., and showing point (A) where till was deposited (*constructed from* Rinehart, C. D., and Ross, D. C., 1964, Geology and mineral deposits of the Mount Morrison quadrangle, Sierra Nevada, California: U. S. Geol. Survey Prof. Paper 385, Pl. 1).

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improbable, but not impossible, that the cinders are part of (1) a slice in a fault along the escarpment or (2) a volcanic pipe exposed by erosion on the escarpment. Lovejoy's argument that the cinders are a remnant of material that cascaded down the escarpment implies the possibility that the escarpment was then only 600 feet high (Fig. 1), in which case the cinders might be a remnant of an extensive accumulation at the base of the slope. This seems more probable than does Lovejoy's inference that the escarpment stood nearly as high during the basalt eruption as it does now; it is unlikely that the cinders would have welded together on such a steep slope or that, having done so, a small patch would survive there for more than 2 m.y. The small amount of basalt debris lower on the slope casts doubt that any extensive mantle of basalt ever existed lower on the escarpment.

Although the Sierran escarpment need not have developed everywhere at the same time, a 1500-foot escarpment did develop on the east side of San Joaquin Mountain (about 20 miles northwest of McGee Mountain) after the eruption of a quartz latite 2.7 m.y. ago (Dalrymple, 1964; Rinehart and Huber, 1965; Curry, 1966).

Gradients of Glaciers

Lovejoy's arguments here are invalid because he does not consider the influence of the thickness of the glacial ice on the character of the flow. Shear stresses at the bases of glaciers depend on slope and on ice thickness and always range from 0.5 to 1.5 bars; if the ice thickens so that these stresses are exceeded, the glaciers become unstable and flow rapidly, thus reducing the thickness until the basal shear stresses return to normal range (Nye, 1960; Kamb, 1964). Lovejoy proposes a hypothetical glacier 760 feet thick on a gradient of 900 feet per mile; at the base of such a glacier the shear stresses would be near 5 bars. On the Mount Morrison quadrangle, two of the steeply sloping sets of moraines to which Lovejoy refers enclosed glaciers that were apparently not more than 200 feet thick (shear stress about 1 bar); the third feature is a rock glacier complex of undetermined thickness (R. R. Curry, personal commun.).

More convincing than arguments on mechanics, however, are the field relations. Figure 2 shows the distribution of till on McGee Mountain with respect to the present profile of McGee Creek. When the till was deposited (*see also* Lovejoy, 1967, Fig. 2), McGee Canyon, if it existed at all, could have been only a small fraction of its present depth. At the time the till was deposited, the escarpment was either not in existence or very low or too young to have been scored by canyons.

Faulting and Uplift

Lovejoy attributes to me the conclusion that the Sierra Nevada has been uplifted since McGee time. I have emphasized my belief that the available evidence supports Matthes' (1939) conclusion that the eastern escarpment developed by downfaulting of the east side rather than by uplift of the west.

Conclusions

It is clear that the evidence for the age of faulting at McGee Mountain is not conclusive. Lovejoy's comments on the significance of the basalts are a valuable contribution to the discussion. The major points in the interpretation that poses for me the fewest difficulties are the following:

(1) A low escarpment, less than 1000 feet, existed when the basalts were erupted on McGee Mountain.

(2) McGee glaciation occurred before any significant cutting of McGee canyon, possibly contemporaneously with the basalts.

(3) The oldest probable age for the major part of the relief, about 3000 feet, on the escarpment is the age of the McGee glaciation.

(4) The escarpment existed as it does today before the Wisconsin glaciations.

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