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Cenozoic Crustal Movements in the Sierra Nevada: Discussion

Abstract: The position of McGee stage till on top of McGee Mountain, California, has long been considered as evidence of 4000 feet of post-McGee vertical displacement along the Sierran frontal fault. Evidence and analysis (Lovejoy, 1964) have shown that such faulting *preceded* the emplacement of a basalt volcano and associated flows 2.6 m.y. ago, thus precluding significant post-McGee faulting. McGee glacial gradients of 900–1000 feet per mile, similar to measurements for younger glaciers in the region, indicate that McGee Canyon was shallower and steeper during McGee time. The McGee till therefore was most probably emplaced as an alb moraine. Its present position is not evidence of later Sierran frontal uplift by faulting.

Introduction

Although the 1966 analysis of Cenozoic Sierran tectonics by Christensen is welcomed as a broad survey of the available theories and evidence, his refutation (Christensen, 1966, p. 175) of my interpretation of the geology at McGee Mountain, Mono County, California, warrants a reply. My specific concern is with Christensen's explanation of the field evidence pertaining to the early Pleistocene faulting of over 4000 feet, which was reported at McGee Mountain by Putnam (1962) and by Rinehart and Ross (1964) whose paper was not available prior to my submission of a manuscript in 1964.

A review of the evidence, which has been presented in detail elsewhere (Lovejoy, 1964, 1965), indicates that McGee Mountain had been bounded by its steep frontal scarp before the deposition of the basalt thereon 2.6 m.y. ago (Dalrymple, 1963). The basalt, formerly considered to be but a flow in an old valley remnant now atop McGee Mountain, is really a volcano with associated flows (Fig. 1). Indeed, Rinehart and Ross (1964, p. 57, and Pl. 1) wrote that "abundant bombs and scoriaceous brick-red agglomeratic materials on McGee Mountain indicate a nearby source," and they mapped but did not mention the small basalt flow remnant on the steep scarp front, 840 feet below the volcano at the crest. On the other hand, referring to that remnant, Putnam (1962, p. 191) stated, "Part of it [the basalt flow on McGee Mountain] has moved downslope by landsliding."

This mass, glued on top of granite bedrock on a resistant topographic nose, far below the volcano, was shown (Lovejoy, 1964, p. 155–157, 161) to be neither an intrusive nor a landslide mass, as Putnam thought, but definitely part of a basalt (andesite) flow in place, lying on an essentially straight (one cycle) slope with no geomorphic evidence of two separate periods of displacement. Flowage surfaces in the remnant of basalt dip 21 degrees, parallel to the present 28-degree slope, and indicate no great modification of the slope since the flow emplacement 2.6 m.y. ago.

Because the till to which Christensen refers is younger than the basalt, the till cannot have been greatly faulted, a conclusion reported earlier (Lovejoy, 1964, p. 163) as follows: "Of course, if there has been no significant post-basalt faulting at McGee Mountain, there can have been no faulting amounting to 4000 feet since McGee glacial time. Yet, several competent geologists have regarded the nature and position of this old till as evidence of a great post-McGee uplift."

Unfortunately, Christensen did not discuss the basalt and was apparently unaware of my published analysis. His conclusions (Christensen, 1966, p. 178) that the Sierra Nevada *had* been uplifted by faulting 4000 feet since McGee time is contrary to those drawn from field evidence. Admittedly, the McGee till represents an enigma and has been considered to be evidence of that faulting. The situation will be analyzed further therefore to show how the

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evidence of the till itself precludes considerable post-McGee uplift.

Christensen's Criticisms

Christensen (1966, p. 175) considered my explanation "improbable on two grounds, field relationships and mechanics." The field relationships in question are the presence of (1) morainal material, similar to that found on McGee Mountain on the eastern side of McGee Canyon, and (2) "alluvium" beneath the till on both sites. His mechanical bases for improbability are the slopes which the McGee glacier could have and could not have had. These points will be discussed in turn.

MOUNT MORGAN TILL DEPOSIT: The < 5-acre till deposit on the west side of Mount Morgan (Rinehart and Ross, 1964, Pl. 1) to which Christensen refers is unfamiliar to me, and accordingly my analysis must be secondhand and nondefinitive. With reference to the McGee Mountain occurrence (Lovejoy, 1964, p. 168), I still think that the development of alb moraines on the outer side of the right-angle bend is significant. Christensen, however, apparently believes that the development of alb moraines in general must be limited to such loci, for he (1966, p. 175) considered it damaging to my theory that "Rinehart and Ross . . . mapped similar morainal material deposited on a rolling, alluviated ridgecrest on the opposite side of the canyon of McGee Creek on the *inside of the right-angle bend* [italics added]."

Sufficient for the formation of an alb moraine (Lovejoy, 1964, p. 168), I believe, is an overfilled valley. At the beginning of its first glaciation, the valley could readily become clogged with glacial ice which extends high up the valley sides, onto the pre-existing surface (*e.g.*, high-level berm, peneplain remnant, pediment slope, or resistant rock unit), and even beyond the main ice stream, where it

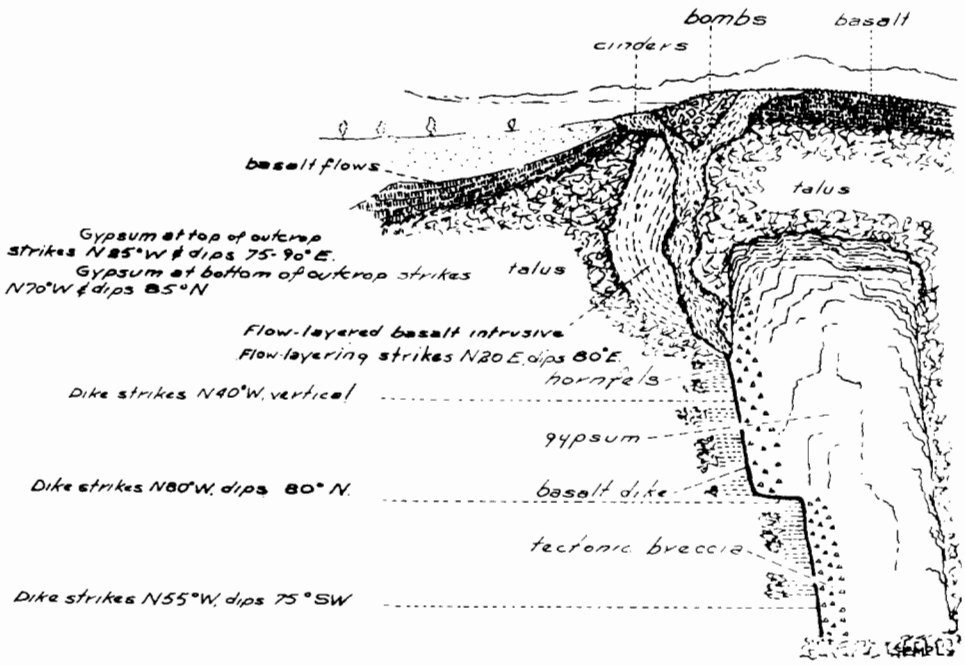

Figure 1. Schematic cross section of basalt plug on northeast face of McGee Mountain, California, viewed from the northeast. The hillside slopes about 30 degrees toward the observer and the talus, 35 degrees. The gypsum outcrop is an extremely steep cliff. Total height from bottom of gypsum to top of basalt is estimated at 600 feet. *Reproduced* by permission *from* Lovejoy, E. M. P., 1964, A critical study of the evidence of late Neogene faulting at McGee Mountain, Mono County, California: Arizona Geol. Soc. Digest, v. 7, p. 158.

stagnates. The ice leaves behind its debris which remains unaltered by subsequent glaciations that lower the valley floor as well as the topmost level reached by the ice.

A study of Rinehart and Ross' (1964, Pl. 1) map shows that the Mount Morgan till is located less than one-half mile upstream from the narrowest constriction in the entire length of McGee Canyon. It is not "inside the right-angle bend" but over one mile upstream from it. If it were inside the right-angle bend, it would also be, as Dr. E. B. Mayo (personal commun.) pointed out, outside the bend at Grass Lake, an apposition that may well be significant. The flow obstruction due to the tight constriction in McGee Canyon just below the Mount Morgan till would seem also to have had the desired effect; *i.e.*, the ice, having been partially dammed, would have risen higher here than below the dam, and if it had fortuitously extended onto the flat surface, the ice would have left evidence of its quondam occupancy. Similarly deposited remnants would not have lasted long on steep slopes. These are, I believe, adequate explanations for the presence of the Mount Morgan till exposure.

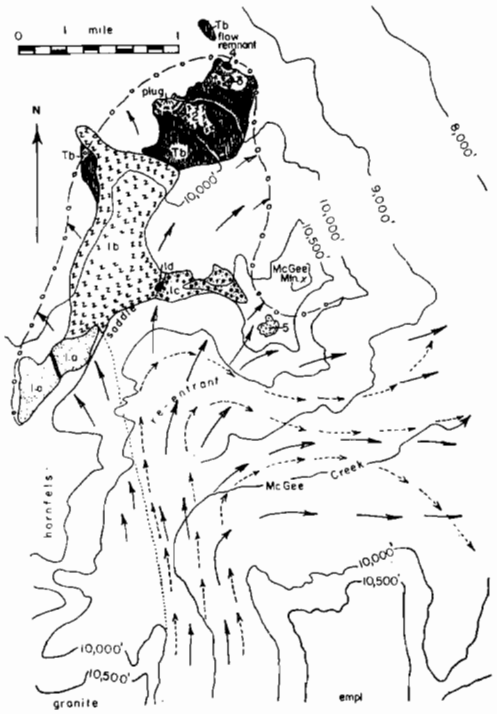

Figure 2. Map of McGee Mountain, California, showing till units (numbers and letters), basalt (Tb), direction of movement of glacial ice at surface (solid arrows) and at depth (broken arrows), estimated limit of alb moraine (dash-dot line), quartz monzonite dike in till unit 1a, and source areas of hornfels and granite. Figure (partial *tracing* of map *from* Putnam, 1962) *reproduced* by permission *from* Lovejoy, E. M. P., 1964, A critical study of the evidence of late Neogene faulting at McGee Mountain, Mono County, California: Arizona Geol. Soc. Digest, v. 7, p. 156.

"ALLUVIAL" MATERIAL BENEATH THE MORAINES: Apparently Christensen (1966, p. 175) believes that "the high level moraines were deposited in an ancient valley" and that the lowest units of unconsolidated material lying on bedrock on McGee Mountain (*see* Fig. 2, till units 1a, 1d, and possibly 3) are alluvium. Because the term "alluvium" is defined[1] as "stream deposits of comparatively recent time," this unconsolidated material would, according to Christensen, represent stream deposits in the ancient valley which extended to the right-angle bend in present McGee Canyon and then northward across the present upland subsummit surface of McGee Mountain. I do not question the existence of an ancient stream such as an ancestral McGee Creek. Furthermore, it is possible that the right-angle bend in the modern McGee Canyon resulted from the headward erosion of an east-trending canyon (on the frontal scarp of the Sierra) which beheaded that north-trending, structurally guided, ancestral McGee Creek in pre-McGee time.

I must disagree, however, with the date attributed by Christensen to this development. The evidence indicates that the first part of the McGee glacier carried with it an abundance of identifiable granitic boulders, which were at that time widely exposed in McGee Canyon south of McGee Mountain. That the alluvium in the immediately pre-McGee glacial, ancestral McGee Creek must have been rich in both grus and rounded gravels can be verified by a casual inspection of the modern streams leaving the Sierra. However, the utter lack of granite (Fig. 2) in the alleged alluvium on McGee Mountain was previously reported (Lovejoy, 1964, p. 165, 167) as follows:

> In unit 1b [which overlies unit 1a and contains the huge granite boulders] the fine material is grus,

[1] American Geological Institute, Glossary of Geology and Related Sciences, 1957, p. 8.

derived from the disintegration of the granite boulders. *Grus does not occur in unit 1a* [italics added].

. . . . . .

Unit 1c is very much like unit 1b, but it is separated from unit 1b by a very small (less than one-third acre) area of till remarkably like till unit 1a. This appears to underlie units 1b and 1c, although evidence of this is not convincing. This small bit of unit 1d is important to the subsequent analysis.

Unit 1d is identical to unit 1a, and contains neither grus nor well-rounded stream gravels. Nor is grus to be found in unit 3, which some workers also might consider to be alluvium. Unit 3 does contain a few greatly weathered granitic boulders very unlike those so abundant in units 1b, 1c, 2, and 5, but they appear to be locally derived from McGee Mountain granite.

Because the complete absence of grus in the lowest units renders it impossible to regard them as alluvium of an ancestral McGee Creek, Christensen's identification must be considered in error. I regard these lower units as part of the lateral moraine, formed in hornfelsic terrain; they were eventually overridden by loops of interior moraine as the glacial ice overwhelmed the upland surface on McGee Mountain (Lovejoy, 1964, p. 168–169). Although I have not seen and cannot explain the occurrence of "alluvium" beneath the Mount Morgan till, it would surprise me if that situation differed from the one just outlined.

ARGUMENTS BASED ON MECHANICAL THEORY: Christensen (1966, p. 175) wrote, "The hypothesis that the escarpment in front of McGee Mountain existed during the McGee glaciation requires that the glacier in the canyon of McGee Creek have an improbably steep slope. It would have fallen 4000 feet in less than 3 miles. . . ." In fact, however, McGee glacier need not have had such a steep slope. Since McGee glacial time, the mouth of McGee Canyon at the Hilton Creek fault scarp has probably not been appreciably lowered by glacial erosion, an assumption corroborated by the lack of modification of the Sherwin till, which precludes any great erosion of bedrock. The difference in the elevation (Table 1) of the mouth of McGee Canyon and of the present McGee till is about 2800 feet. Between these two points the distance is 2.5 miles, by way of McGee Canyon, giving a gradient of 1120 feet per mile.

More is involved, however, for Christensen (1966, p. 175) stated, "Even if there had been a piedmont glacier 1000 feet thick in Long Valley (for the existence of which there is no evidence), the slope would be 3000 feet in 3 miles." Such a gradient would be 1000 feet thick. In the lower reaches of McGee Canyon, on the north wall between the mouth and the right-angle bend, younger moraine lies about 760 feet above the canyon bottom, a reasonable estimate also for the thickness of the McGee glacier there and at the mouth of the canyon. Furthermore, the ice on top of McGee Mountain was probably just thick enough to flow. On the basis of the measurements given and those in Table 1, the gradient of the McGee glacier surface ice can be assumed to be 896 feet per mile.

TABLE 1. PROBABLE MEASUREMENTS AT MCGEE MOUNTAIN AND MCGEE CANYON

Location	(In feet)
McGee Mountain	
Till (elevation)	10,400
Ice (thickness)	200
Top of glacier (elevation)	10,600
McGee Canyon (at Hilton Creek fault)	
Mouth (elevation)	7600
Glacier at mouth (thickness)	760
Top of glacier (elevation)	8360
Difference at tops of glacier	2240

Morainal deposits (Rinehart and Ross, 1964, Pl. 1) occur (1) in Hilton Creek, (2) near Sherwin Lake, and (3) just south of the east end of Convict Lake. Their respective slopes are (1) 1060 feet per mile for 1.5 miles, (2) 1060 feet per mile for 1 mile, and (3) 1040 feet per mile for 1.5 miles. They parallel the slope of the underlying bedrock (*i.e.*, about 1000 feet per mile) and are as steep or steeper than those (900–1000 feet per mile) reconstructed for the McGee glacier.

In addition to Christensen's consideration of the internal stresses in a glacier is the need to consider the slope of the canyons down which the glaciers must have flowed. Christensen must have realized this when he wrote (1966, p. 175), "It can be argued that during the McGee stage of glaciation the canyon was much shallower than it now is." He dismissed the possibility, however, as he continued, "This argument, however, suggests that canyon-cutting, hence faulting, *started only slightly before the McGee stage* [italics added], thereby extending only

slightly the maximum age of faulting set by previous interpretations."

The question of faulting before or after McGee till deposition is thereby conceded by Christensen who has admitted that faulting could have been pre-till had McGee Canyon been shallower. This is the very point on which proof was offered in the previous paper (Lovejoy, 1964, p. 169). It seems to have been proved again in a different way here.

Acknowledgment

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