17. This paper grew directly from studies in preparation for a symposium in "Paleontological implications of the Precambrian-Early Cambrian faunas of southeastern California," organized for the 1966 Annual Meetings of the Geological Society of America by A. R. Palmer. It has roots in NSF grant GP-1807, which enabled Cloud to obtain the critical reference materials, and the support by the U.S. Geological Survey of Nelson's areal studies in the White-Inyo Mountains.

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Glaciation about 3,000,000 Years Ago in the Sierra Nevada

Abstract. *Major glaciation in the Sierra Nevada of California resulted in the deposition of till which underlies latite 2.7 × 10⁶ years old and overlies andesite 3.1 × 10⁶ years old. This till, herein called the Deadman Pass till, is the oldest Pleistocene glacial deposit that has been found in temperate latitudes.*

In the Devils Postpile Quadrangle in Mono and Madera counties, California, along the main drainage divide of the Sierra Nevada between Agnew Pass and Minaret Summit, small patches of till have been mapped (*1*). These till bodies were believed to represent deposits of glaciers that spilled eastward from the Minaret ice field through isolated lower passes along the divide. More detailed study indicates that most of the mapped outcrops of till are actually part of a single extensive till sheet underlying the volcanic rocks that cap the summit of the ridge crest (Fig. 1). The till overlies an andesite flow that has been dated by the potassium-argon method at 3.1 × 10^6 years (*2*), as well as metasedimentary and granitic rocks of Paleozoic and Mesozoic age. The Two Teats quartz latite, which directly overlies the till, and in places actually incorporates it, has been dated by the same method at 3.0 × 10^6 years (*2*); this finding suggests that the till is 3.0 to 3.1 × 10^6 years old.

The till at Deadman Pass, and that exposed beneath the Two Teats quartz latite in the vicinity of Deadman Pass, are composed primarily of boulders up to 1.3 m in diameter. These are angular to subrounded, and consist of 40 percent metamorphic rocks, 30 percent granitic rocks, and 30 percent volcanic and unidentified rocks. The granitic and metamorphic rocks were derived mainly from the Ritter Range and adjacent headwaters of the Middle Fork of the San Joaquin River, whereas the bulk of the volcanic rocks were derived locally. The matrix of the till generally contains 2 to 5 percent fine volcanic ash and pumice, but in one locale the till grades laterally into a lahar with 30 to 50 percent volcanic ash matrix. The boulders in the till are quite fresh, and at a few places striae and polished surfaces are recognizable.

At Deadman Pass the till contains a few angular boulders of a variety of Two Teats quartz latite. This is similar to that found near the summit of Two Teats, 5 km northwest, along the ridge crest. Since the Two Teats quartz latite sample dated by Dalrymple (*2*) was collected from the area of the summit of Two Teats, I collected another sample of the quartz latite from the ridge crest 1 km northwest of Deadman Pass for further radiometric dating. The sample locality is approximately 40 m stratigraphically above a till sheet 40 m thick containing some material that could only have been derived from the Ritter Range, 10 km west across a canyon that is now 760 m deep. Separate dates were determined by G. H. Curtis at the University of California in Berkeley on both plagioclase (KA 1956) and biotite (KA 1955) from this sample (Table 1). These two age determinations indicate ages of 2.70 × 10^6 and 2.74 × 10^6 years for this sample of the Two Teats quartz latite.

The Two Teats quartz latite was first described by Erwin (*3*), who thought it consisted of two distinct flow units. He differentiated a light colored unit and a darker glassy unit which he thought was contemporaneous with the Mammoth Mountain quartz latite, outcropping 4 km south of the southernmost exposures of the Two Teats rock. Since then, the Mammoth Mountain rock has been dated at 370,000 years and thus differentiated from the Two Teats unit (*2*), even though the two are lithologically almost identical.

Probably the Two Teats quartz latite, as most recently mapped (*1*), is actually a composite of flows and domes that erupted intermittently from two or more vents along, and east of, the present drainage divide between 3.1 and at least 2.7 × 10^6 years ago. The darker flow unit, dated at about 2.7 × 10^6 years, appears to have originated from a fissure in the lighter quartz latite on the south side of Two Teats mountain, and flowed southeastward over a till sheet deposited on the gently dipping surface of the Tertiary andesite flow. Since the quartz latite is now restricted to ridge crests, it is possible that the region has under-

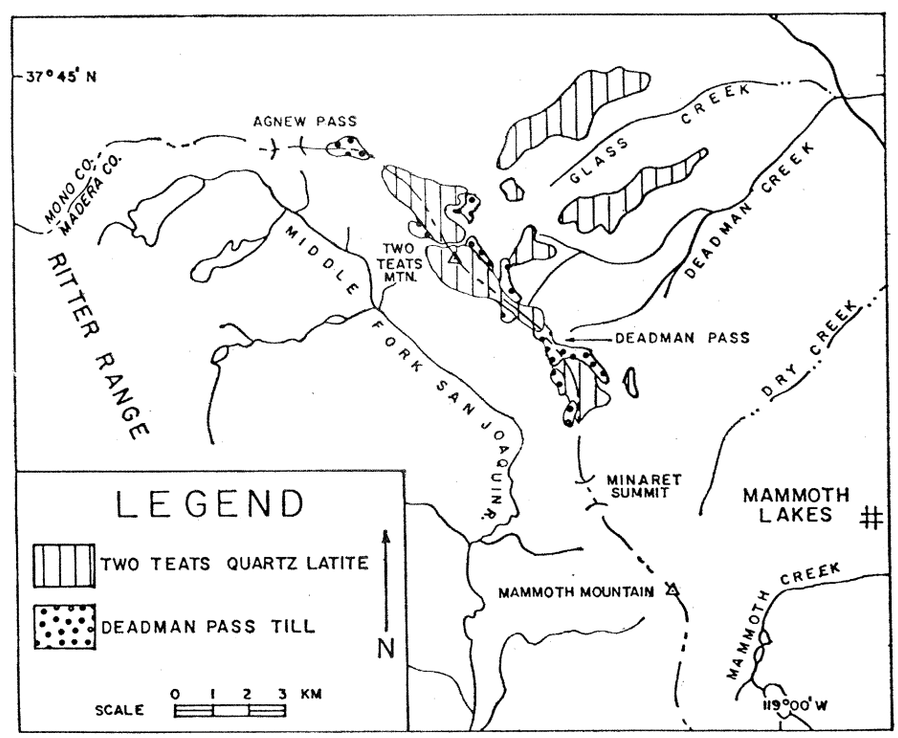

Fig. 1. Map of the Mammoth Lakes area, California, showing distribution of the outcrops of the Deadman Pass till and the overlying Two Teats quartz latite.

Table 1. Analytical data for potassium-argon age determinations; my, million years.

Sample	Material	Weight (g.)	K (%)	$Ar^{at}40$ (%)	$Ar^{r}40/K_{40}$	Age (my)
KA 1955, Two Teats quartz latite	Biotite	5.91	6.92	48	14.54×10^{-4}	$2.74 \pm .1$
KA 1956, Two Teats quartz latite	Plagioclase	15.98	0.80	75	14.30×10^{-4}	$2.70 \pm .1$

gone topographic reversal in the last 2.7×10^6 years. At least some of the quartz latite existed before the formation of the till at Deadman Pass, because the till incorporates locally-derived angular material similar to the lighter colored latite dated at 3.0×10^6 years. The presence of a lahar that appears to underlie the till 2 km north of Deadman Pass also suggests that the quartz latite existed before the formation of the till, because this volcanic mudflow deposit contains boulders of light-colored quartz latite in a matrix of ash and pumice.

The till that outcrops at Deadman Pass and is overlain by quartz latite under the hill immediately south of Deadman Pass is here termed the Deadman Pass till. The glaciation that deposited the till is termed the Deadman Pass glaciation. This glaciation occurred, probably as a series of multiple advances, between 3.1 and 2.7×10^6 years ago. The presence of latite in the till (similar to that dated at 3.0×10^6 years), the intimate association of the till with large quantities of ash and pumice, and the presence of the lahar under the till in one area all suggest that the Deadman Pass glaciation may have been penecontemporaneous with the extrusion of the darker quartz latite; if so, it may have occurred about $2.7 \pm 0.1 \times 10^6$ years ago.

The Deadman Pass glaciation is thus the earliest radiometrically established glaciation yet recognized in temperate latitudes. Its existence supports the suggestion by many Pleistocene vertebrate paleontologists that general climatic cooling in temperate latitudes began about the time of this glaciation (*4*). Other workers (*5*) have reported evidences of cooling or glaciation or both in polar areas, beginning within the period 2.5 to 3.0×10^6 years ago. Opdyke (*5*), through paleomagnetic analyses of deep-sea cores from the Bellingshausen Sea, showed that the first polar oceanic glaciofluvial detritus occurred shortly after the Mammoth geomagnetic polarity event. Work by Wensink (*5*) also suggested that the onset of glaciation in Iceland occurred just after the Mammoth event, about 3.0×10^6 years ago. The Deadman Pass deposits establish that glaciation on a global scale actually began shortly after the Mammoth event.

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Nebraskan and Kansan Stades: Complexity and Importance

Abstract. *Several Early Pleistocene stadial tills and related soils in Kansas and Nebraska indicate a complex history of ice-sheet fluctuations. It is impossible to assign ages to individual till sheets solely on the basis of position in a stratigraphic column; all Early Pleistocene correlations must be re-evaluated.*

A series of soils or weathering zones has been found within a complex alternation of Early Pleistocene glacial and nonglacial deposits in northeastern Kansas. This discovery, coupled with recognition of several Early Pleistocene till layers in eastern Nebraska, makes necessary a thorough restudy of all glacial deposits and associated sediments believed to have been formed during the first half of Pleistocene time.

Early acceptance of a generalized fourfold history of Pleistocene continental glaciation first led to adoption in field correlation of a kind of "numbers system." In the north central United States the highest till in a stratigraphic section was commonly correlated with the Wisconsin glaciation; the first underlying till, with the Illinoian (or sometimes Iowan) advance; and so on. There developed, however, gradual recognition of evidence of a complex sequence of retreats and minor readvances of the generally waning ice sheet, and of the occurrence of nonsynchronous maxima of separate though adjacent lobes. This knowledge caused abandonment of such a simple approach to the chronology of, first, the Wisconsin and, later, the Illinoian stage, and criteria were sought to permit positive identification of single stratigraphic units without reference to the entire section, often incomplete, in which they occurred.

In the contiguous parts of Nebraska, Kansas, Missouri, and southern Iowa that were subjected to glaciation only in Early Pleistocene time, the "numbers system" has continued in use: if two tills are present in a given exposure, the upper one is automatically considered to be of Kansan age; the lower one, of Nebraskan. Thus the presumption has continued that Early Pleistocene glaciations were each comprised of a simple advance and retreat that deposited only a single layer of till, even though it is well known that the later glaciations were not as simple as that. However, recent discoveries clearly indicate that the Early Pleistocene glacial episodes were just as complex as those that followed.

The Early Pleistocene record in Nebraska is at present interpreted (*1*) as indicating two stadial advances of the continental glacier during Nebraskan time and three stadial advances during Kansan time. Each of these advances is represented by a till body, and retreatal episodes are marked by the development of soils and erosion surfaces. This proposed sequence in Nebraska is composite, resulting from interpretive correlation of surface and subsurface data from a number of localities; the evidence is not found in any one section.

The earlier Nebraskan (Elk Creek) till (*1*) rests on proglacial (David City) sand and gravel; its upper surface is considerably eroded. The later Nebraskan (Iowa Point) till is dated on the basis of its position above silt (Seward) believed to be the periglacial equivalent of the earlier Nebraskan till.

Overlying a well-developed Aftonian interglacial soil, commonly dark gray