# Pliocene-Pleistocene break-up of the Sierra Nevada–White-Inyo Mountains block and formation of Owens Valley


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## ABSTRACT

The Pliocene-Pleistocene (2.3 m.y. old) Waucobi Lake beds provide a record of the formation of Owens Valley and uplift of the White-Inyo Mountains. Following late Pliocene formation of the eastern Sierra Nevada escarpment, Waucobi Lake formed in a depression in the previously unbroken Sierra Nevada–White-Inyo block. Shifting of the depocenter of the lake, movement of shorelines, and contribution of detritus from the Sierra Nevada and the White-Inyo Mountains indicate that the lake basin shifted toward the west as the White-Inyo Mountains were uplifted and Owens Valley was depressed. Relative uplift between Owens Valley and the White-Inyo Mountains may have been as much as 2,300 m during the past 2.3 m.y.


## INTRODUCTION

The Owens Valley (Fig. 1) is a north-trending fault-bounded depression between the Sierra Nevada and the White-Inyo Mountains. The White-Inyo Mountains are underlain principally by Precambrian and Paleozoic sedimentary and metasedimentary rocks and patches of Mesozoic intrusive rocks. Mesozoic intrusive rocks underlie most of the eastern Sierra Nevada.

The Waucobi Lake beds may be the oldest Cenozoic sedimentary deposits in the Owens Valley and appear to record the initial formation of the valley and the uplift of the White-Inyo Mountains. These Pliocene-Pleistocene sedimentary rocks are as much as 100 m thick and crop out in the Waucobi embayment on the flank of the White-Inyo Mountains, 7 km east of Big Pine (Fig. 1). They are overlapped on the east by younger alluvial-fan deposits, are tilted an average of 6° to the west, and are probably downdropped below the surface of Owens Valley on the west.

## WAUCOBI LAKE BEDS

The Waucobi Lake beds were described and named by Walcott (1897). They were further described by Trowbridge (1911), Knopf (1918), Nelson (1966), Hay (1964, 1966), and myself (Bachman, 1974, 1975). The beds crop out in a northwest-trending area (Fig. 1) of low relief, 8 km long and 4 km wide, near the western margin of the Waucobi embayment. The base of the lake beds is not exposed. The sedimentary rocks include buff, gray and brown, well-bedded mudstone, claystone, siltstone, fine to very coarse calcareous sandstone, tuff, and cinder beds.

The age of the Waucobi deposits is Pliocene-Pleistocene, as indicated by the occurrence of the gastropod *Cincinnatis cincinnatiensis* (Anthony) (Knopf, 1918) and by Hay's (1966) report of a K-Ar age of 2.3 m.y. for feldspar crystals in the upper part of the lake beds. Paleomagnetic work on the sedimentary rocks (K. P. Kodama, written commun.) reveals reversed polarity for

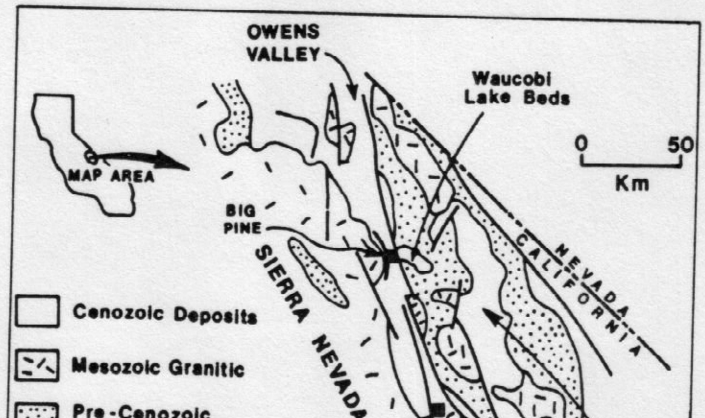


Figure 1. Generalized geologic map of Sierra Nevada, Owens Valley, and White-Inyo Mountains region.

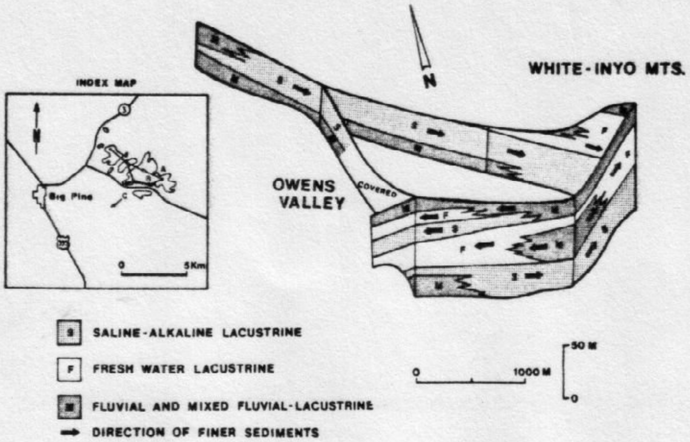


Figure 2. Fence diagram of Waucobi Lake beds, showing distribution of sedimentary facies and grain-size trends. Inset map shows location of diagram and depocenter positions discussed in text.

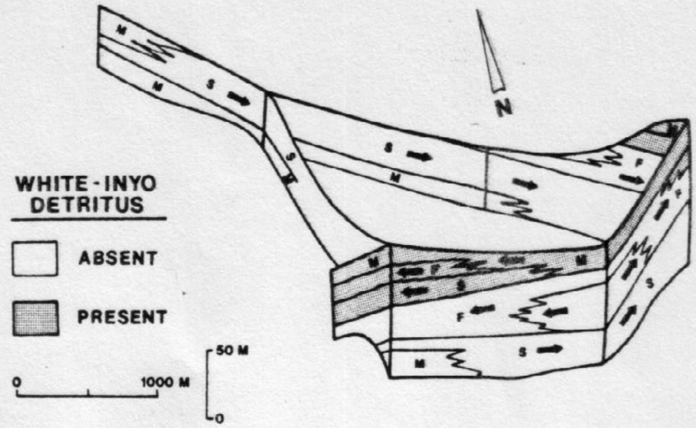


Figure 3. Fence diagram of Waucobi Lake beds, showing distribution of White-Inyo detritus. See Figure 2 for explanation of symbols.

all beds below those dated by Hay. Thus, the lowest beds exposed were probably deposited during the Matuyama reversal, sometime after 2.43 m.y. B.P. and before 0.69 m.y. B.P. (Cox, 1969).

Hay (1964) defined facies in part of the Waucobi Lake beds, and I broadened his work to include all of the lake-bed exposures (Bachman, 1974, 1975). The three major facies are saline-alkaline lacustrine, fresh-water lacustrine, and fluvial with minor lacustrine beds. Figure 2 summarizes the distribution of Waucobi Lake facies. Paleocurrent indicators suggest that currents were related to local shoreline irregularities and prevailing wind directions. The depocenter of the lake at any point in time can be determined by using three criteria: (1) greatest sediment thickness, (2) decrease in grain size basinward, and (3) a shoreline facies of fluvial deposits surrounding the depocenter. As suggested by Figure 2, the depocenter of Waucobi Lake progressively shifted from an easterly position (location A, Fig. 2), during the first saline episode of deposition, to the area of the exposed beds (location B), during the first fresh-water episode of deposition, and then to a westerly position (location C), coinciding with the present Owens Valley, in the latest episodes of deposition.

Two sources of detritus are evident in the Waucobi Lake beds. Sedimentary and metasedimentary detritus could only have come from the White-Inyo Mountains to the east. Some granitic detritus may have come from the small plutons in the White-Inyo Mountains, but the major source was probably the Sierra Nevada. Granitic detritus is found only in the lower saline and fresh-water deposits of Waucobi Lake. The first sedimentary and metasedimentary detritus from the White-Inyo source was deposited during the late stages of the lower fresh-water episode (Fig. 3) and became the dominant sediment type in all of the upper beds. This first occurrence of metasedimentary detritus coincides with the beginning of the westward shift of the basin. The change in sediment source direction and shift in location of the depocenter may mark the beginning of significant uplift of the White-Inyo Mountains and depression of Owens Valley.

## UPLIFT OF WAUCOBI BEDS

The Waucobi embayment is represented by a gently dipping surface that rises from an elevation of 1,200 m on the west to

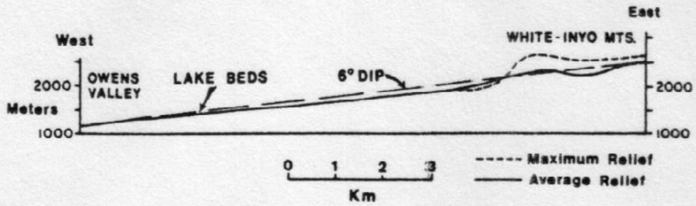


Figure 4. Profile east of Big Pine. Dip of Waucobi Lake beds is projected to intersection with crest of White-Inyo Mountains, showing both average and maximum present relief.

2,200 m on the east. The constant westward dip and continuous outcrops of lake-bed and younger alluvial-fan deposits suggest that sediment and bedrock in the embayment were tilted as a unit. Upward projection of the 6° dip of the lake beds eastward to the crest of the White-Inyo Mountains (Fig. 4) allows one to calculate the amount of uplift of the White-Inyo Mountains relative to the Waucobi embayment since deposition of the lake beds. If the base level of Waucobi Lake (represented by this projection line) was rigidly tilted to the west along with the White-Inyo Mountains, the difference in elevation along the base line from the west end of the exposed lake beds to the intersection with the White-Inyo crest approximates the amount of uplift or downdrop. This elevation difference ranges from 1,000 to 1,100 m. Restoration of known vertical throw on faults in the embayment increases the estimated uplift by at least 100 m. Hence, the amount of uplift in the Waucobi embayment in the last 2.3 m.y. was roughly 1,200 m.

To calculate the amount of uplift of the White-Inyo Mountains relative to the basement surface below Owens Valley, faulting along the east side of Owens Valley must be taken into account. From gravity modeling, Pakiser and others (1964) and Kane and Pakiser (1961) estimated that pre-Cenozoic bedrock has faulted down 2,100 m along the eastern margin of Owens Valley. Using densities of 2.65 $g/cm^3$ for Owens Valley basement (Oliver, 1977) and 2.0 $g/cm^3$ for Owens Valley fill (Bachman, 1974, 1975), I calculate vertical displacement from Pakiser's model at about 1,100 m (Fig. 5).

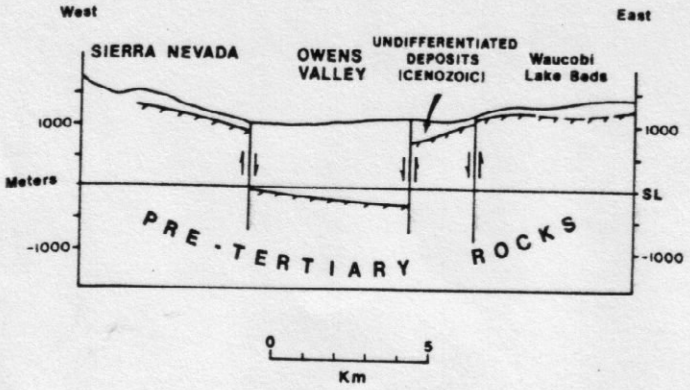


Figure 5. Geologic cross section near Big Pine, modeled from gravity studies by Pakiser and others (1964).

TABLE 1. UPLIFT RATES IN OWENS VALLEY, LONG VALLEY, AND MONO BASIN

| Site, reference | Horizon | Rate per 1,000 yr (m) |
|---|---|---|
| East of Big Pine this study | Waucobi Lake beds (2.3 m.y.) | As much as 1.0 |
| Owens Gorge Curry (1971) | Owens Gorge basalt (3.2 m.y.) and pollen flora | 0.3 |
| San Joaquin crest Curry (1971) | Two Teats quartz latite (2.7 m.y.) | 0.25 |
| | Bishop tuff (0.7 m.y.) | 0.34 |
| | Andesite of Deadman Pass (3.1 m.y.) | 0.37 |
| Mono Basin Gilbert and others (1968) | Mono Lake rocks (3 m.y. and younger) | 0.3 - 0.6 Possibly 0.6 - 1.2 |

If one assumes the extreme case in which the Waucobi Lake beds were deposited directly on Owens Valley bedrock, the west end of the lake beds would have been downfaulted a maximum of 1,100 m. Adding this offset to the uplift in the embayment results in total differential movement between Owens Valley and the White-Inyo Mountains of as much as 2,300 m in the last 2.3 m.y. For comparison, a summary of late Cenozoic uplift rates in the eastern Sierra Nevada region is given in Table 1.

## DISCUSSION

On the basis of evidence presented in this paper, together with published data, the following late Cenozoic tectonic history in the Owens Valley depression is indicated.

1. In early and middle Pliocene time, the mountain block in the area now occupied by the Sierra Nevada, Owens Valley, Long Valley, and the White-Inyo Mountains was a topographic high. As in early Tertiary time (Bateman and Wahrhaftig, 1966), the crest of the Sierra Nevada block was east of its present crest, with westward drainage across the present divide (Curry, 1971).

2. The Sierran escarpment began to form in late Pliocene time (2.3 to 3.4 m.y. B.P.) by downwarp flexure, followed by faulting and volcanism (Putnam, 1960; Axelrod, 1962; Christensen, 1966; Curry, 1971).

3. Waucobi Lake formed 2.3 to 2.43 m.y. ago on the Sierra Nevada–White-Inyo block, in a depression that may have been initiated by growth of the Sierran escarpment. Granitic debris derived from the newly formed Sierran escarpment was the primary detritus in the early lake.

4. Soon after the formation of Waucobi Lake, uplift of the White-Inyo Mountains began. This uplift shifted the Waucobi Lake basin to the west and shed metasedimentary detritus westward into the lake.

5. Fault movement along the Sierran escarpment and the east side of Owens Valley, as well as westward tilting of the White-Inyo Mountains, shifted the Waucobi Lake basin to the position of the present Owens Valley.

6. Present topography formed during the past 2.3 m.y. as Owens Valley continued to be downfaulted. Relative uplift between Owens Valley and the White-Inyo Mountains may have been as much as 2,300 m during this time.

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