RECONSTRUCTING ANCIENT AVALANCHES OF THE SIERRA NEVADA RANGE

P.R.Caterino, Alpengroup

The surface elevations of the lakes of the Sierra Nevada have stood considerably lower than the present for extended periods of time. The magnitude of drops in the levels of these lakes is supported by existing paleoenvironmental evidence; by a series of radiocarbon dates on trees drowned by the rising waters, by submerged archaeological features in the lake, and by historical documentation of lower lake levels. This data has implications for local and regional paleoclimatic trends, which in turn affect the existing avalanche influence zones. In lakes ranging from Tenaya Lake, Yosemite National Park, in the southern Sierra Nevada to Lake Tahoe, Donner Lake, and Independence Lake in the northern range, there have been compelling evidence of sustained lower lake levels. Through SCUBA surveys, stumps that have been dated, range from 4,800 B.P. to 6,300 B.P. in Lake Tahoe to 600-700 B.P. in other lakes of the Sierra Nevada. Research supports that during the rise of the lake levels there was a substantial and rapid increase in precipitation, such that the increase in avalanche activity caused the destruction of the forest that appeared during the lower lake elevations (approximately 150 years). Because of the low water temperature and dissolved oxygen rates in these lakes any organic materials that have been rapidly submerged are very well preserved. Many of the trees that were sampled and dated between 600-700 B.P. still had bark and coloration intact. The submerged avalanche debris fans that are located in 5 to 50 m of water, generally occur within the present day avalanche influence zones.

KEYWORDS: avalanches, snow cover, snow precipitation

The Sierra Nevada, with its rugged topography, varied resources and rich varieties of flora and fauna, is a dominant feature of California. A unified mountain range that extends approximately 580 km from Mt. Lassen at the north to the edge of Walker Pass, east of Bakerfield. It varies from 96 to 128 km in width and trends roughly from Northwest to southeast. All of the Sierra Nevada, with the exception of the Carson Range on the east slope, lies with California. The Sierra consists essentially of a massive granite block that is tilted so that western side, to 104 km broad, has a gradual slope of only 2 to 6 percent. In contrast, the eastern side of the Sierra rises abruptly from the low valleys that are 1200 m in elevation to 4200 m in the distance of only 8 km along the Owens Valley. The crest of the range consequently is near the eastern border. The summits increase gradually in altitude from north to south, from 1800 to 2400 m in the Feather River country, to 3000 m at Lake Tahoe, 3900 m in the Yosemite region, and to the highest in the area near Mt. Whitney, where there are twelve peaks that exceed 4200 m above sea level. The entire range includes fully 500 peaks that exceed 3600 m in altitude. (Storer and Usinger 1963)

There are more than 1500 lakes in the Sierra, varying from rock pools 6 to 15 m across to Lake Tahoe which is nearly 19 km wide. Scouring by ice and accumulations of rock debris have made the high country a land of lakes. The scooping by glaciers near their origins left many shallow basins (tarns) that became lakes with narrow sandy beaches. Their waters freeze and thaw repeatedly throughout the year. Lake Tahoe being the exception to this since the lake water is always in motion. Each year the cold water on the surface sinks while the warm water rises from the deep, allowing the surface waters to never cool to 0 centigrade and thus remaining ice-free during the winter.

The pure water found in these lakes lacks the minerals essential for growth of algae, diatoms and minute animals in the food chains for fish. Consequently few of them contain native trout. While this is problematic for making the Sierra a mecca for sport fishing like other mountain ranges the cold water and lack of oxygen in the Sierran lakes has been the catalyst for preserving a visual record of the climatic changes over the last 10,000 years.

The current annual precipitation in the Sierra Nevada ranges from about 38 cm in the central part of the range to more than 114 cm along the western crest of the range. Most precipitation comes in the form of snow, with average temperature ranging from 3 to 1 centigrade in the winter to 15 to 18 centigrade in the summer. This contemporary dry summer, wet winter precipitation

Philippe R. Caterino, Alpengroup, P.O. Box 3538, Lake Tahoe, Nevada, 89449; tel: 530-541-8714; fax: 530-541-8715; email: alpengrp@sierra.net

pattern did not prevail continuously in the past, and variable climatic regimes may have allowed for year-around residence in the Sierra by local tribes at some times and prohibited even seasonal occupation at other times. The scientific record documents considerable climatic change on short-term scales, a pattern that residents of the region witness today. Environmental history studies can address issues crucial to the current and future environmental health in the Sierra. Paleoenvironmental data can contribute to an understanding of the frequencies, magnitudes and rates of change that the environment has experienced over time and their human correlates.

Two very important avenues of paleo-environmental study track fluctuations in lake levels and changes in vegetation. Lake level drops are detected by the presence of submerged tree stumps in lakes and their tributary streams. Transformation in plant communities are monitored through variations in pollen and plant macrofossils, both of which are found in the nest of cave-dwelling woodrats. Through the study of these features, regional climate changes can be measured against the resulting responses by both natural and human communities.

While most of the paleoenvironmental evidence has involved Lake Tahoe and lakes in the Tahoe region there is considerable evidence from Tenaya Lake in Yosemite (Stein 1992,1994) that directly corresponds to the tree dates found in the Walker River and Mono Lake area. For this paper we have chosen Tenaya Lake and Fallen Leaf Lake to present our case for interpreting ancient avalanches and its relevance for avalanche professionals in the future.

Prior to 10,000 years before present (BP), glaciers occupied much of the Sierra Nevada and Carson Range, and a vast lake (known as Lake Lahontan) flooded much of the Western Great Basin. During the Early Holocene, 10,000-7,000 years BP, climates warmed and dried rapidly, causing glaciers to melt and Lake Lahontan to shrink, although climates remained relatively cool and moist, with increased winter precipitation. Pollen studies at Osgood Swamp near South Lake Tahoe (Adam 1976) indicate that a cold-dry sagebrush steppe prevailed until about 10,000 BP, where there was a shift to a coniferous forest.

The Early Holocene was followed by a much warmer and dryer Mid-Holocene period from 7,000-4,000 BP, which resulted in the desiccation of many lakes in the western great Basin; lakes Tahoe and Pyramid declined but are the only ones that did not dry up during this time. Fossil pollen taken from Osgood Swamp near South Lake Tahoe (Adams 1976) and Little Valley in the Carson Range (Wigend et al 1995, 1996; Wigand and Rhode 1999) indicates the presence of more drought tolerant species by the end of this period. Mid-Holocene aridity in the Tahoe Sierra is further documented by the remains of submerged tree stumps, which stand rooted on the lake floor up to 6 meters below the source of Lake Tahoe. These ancient drowned forests date between 6,300-4,800 BP (Lindstrom 1990).

Climates returned to a cooler and moister period by 4,000 BP causing the rebirth of some Great Basin lakes and minor glacial advances in the Sierra. After about 4,000 BP, the onset of the Late Holocene record is marked again at Osgood Swamp and Little Valley, where there is shift from the xeric vegetation to the dominant conifer species that are present in the Tahoe Sierra today. Pollen evidence indicated the formation a marsh along the lower reaches of Taylor Creek (the outlet of Fallen Leak Lake) due to a rise in ground water levels from about 5,000-4,000 BP and before 2,900 BP (West in Lindstrom 1985). Pyramid Lake (the final destination of waters from Lake Tahoe) in Nevada, began to rise after about 3,200 BP (Born 1972). At Squaw Valley, about this time small stream deposits became coarser, indicating increased flows (Eston et al. 1977). The Late Holocene record since 3,200 BP is unclear and appears to be punctuated by alternating intervals of cool-moist and warm dry periods. A winter-wet climate prevailed with the renewal of cirque glaciers in the Sierra Nevada between 3,200-2,000 BP (Born 1972). Pyramid Lake rose and the Walker River filled Walker Lake. A diatomite deposit, indicative of an open water environment, is documented at a marsh along Taylor Creek around 2,800 BP (West in Lindstorm 1985). A subsequent dry interval may have persisted from 2,200-1,600 BP. Pyramid Lake receded (Born 1972) and Eagle Lake in Lassen County fell after 2,000 BP. Continuing dry conditions are indicated from 1,345-1,145 BP, as trees grew on Ralston Ridge Bog south of Lake Tahoe due to low water tables (Sereij and Adam 1975). A brief wet interval is suggested within the last 1,100 years by the presence of buried A-horizon soils in association with a sand lens near Taylor Creek, indication a rise in the level of Lake Tahoe and deposition of lake deposits as sand (Blanchard in Lindstrom 1985).

A period of substantial drought from 1,100-900 BP and again around 700-500 BP is suggested by several lines of evidence. Relict Jeffrey pine stumps, rooted in the Walker River streambed, date to 920 BP and 660 BP. Submerged stumps along the Walker Lake shore also yielded carbon-14 ages of 980 BP. The relationship between tree growth and stream flow in the upper Truckee River watershed indicated that intermittent drought conditions prevail around 675 BP (Hardman and Reil 1936). A dry period around 669 BP is supported by a series of submerged tree stumps, which indicated a substantial drop in Independence Lake north of Lake Tahoe (Lindstorm 1990).

During the last 500 years, a wet climate, punctuated by intermittent but substantial droughts, began to dominate the region, and lake levels again rose and cirques glaciers reformed in the Sierra. A series of substantial droughts are documented during this period, however. Dozens of submerged tree stumps are located up to 300 feet below the present day level of Donner Lake a tributary of the Truckee River; carbon –14 samples from one stump date from AD 1433 (Lindstrom and Bloomer 1994). Another warm period, documented by tree-ring studies and Truckee River run-off, dated between AD 1579-1585, and again around AD 1630 (Hardman and Reil 1936). It is possible that Lake Tahoe contributed relatively little water to the Truckee River during the last 200 years. During the century between the mid 1700s to mid 1800s, the level of Lake Tahoe may have been below its rim, with no water flow into the Truckee River. This is documented by a submerged stump in the Upper Truckee River Delta dating from AD 1720 (Lindstrom 1996a), one from Donner Lake dating from AD 1800 (Lindstrom and Bloomer 1994) and one in Emerald Bay dating to AD 1840 (Lindstrom 1992). The 40 years between AD 1875-1915 were the longest period during which the flow of the Truckee River was above the average. During the AD 1930s drought, Lake Tahoe ceased to flow from its outlet for six consecutive years. Drought within the last decade (late 1980s to 1990s) either stopped Tahoe's flow into the Truckee or reduced it to almost nothing.

The internal details of the three-part model of climatic change during the 10,000 year Holocene period are not without controversy, especially as they apply to the timing, magnitude, and course of paleoenvironmental change in the Sierra Nevada. Current reconstructions lack resolution, and climatic trends are necessarily presented as broad time brackets. But the fundamental issues concerning the nature and timing of environmental associations, in particular; active avalanche periods can be brought into more detail though a systematic mapping and dating of submerged trees, both rooted and those in the submerged debris fields of Tenaya and Fallen Leaf Lake.

The dynamics of Fallen Leaf Lake's ecosystem are quite responsive due to the small size of the drainage, lake stream and basin systems. In fact the hydraulic residence time for water in Fallen Leaf Lake is only eight years compared to Lake Tahoe's where it is approximately 700 years. Because of the proximity of Fallen Leak Lake to Lake Tahoe and also due to the similarities in the ecosystems it is felt that Fallen Leaf Lake is a microcosm of Lake Tahoe and as such offers a multitude of research opportunities that will be directly applicable to the overall Lake Tahoe Region. (Kleppe 1998)

Fallen Leaf Lake is located within the Lake Tahoe Basin, which is slightly more than 1295 sq km. Approximately 815 sq km is uplands and the remaining 494 km is water surface. This alpine basin is in an eastward bulge of the Sierra Nevada; the Carson Range forms highlands to the east, and the true Sierran Crest forms the highlands directly to the west of Fallen Leaf Lake. This area is known as the Crystal Range. About two thirds of the Tahoe Basin is in California, with the remaining third in Nevada. Elevations range from about 1897 m (Lake Tahoe Datum) to 3318 m.

While there have only recently been rooted trees found in Fallen Leaf Lake, there is a considerable amount of avalanche debris located beneath the waters of the lake. The current trees have recently been sampled and the dating available in the fall of 1998. The size and scope of the tree discovered dwarfs all other trees that have been discovered in the Sierra. It appears to be a Jeffery Pine that is over 27.5 m tall and a diameter at breast height (dbh) of over 244 cm. It raises many questions on how severe a drought was that lowered the lake level by a 30.5 m and remained there long enough for a tree to root and grow this size before being submerged by a more wet climate regime.

However, modern scientific observations on Fallen Leaf Lake are augmented by a rich and ancient Washoe oral tradition that provides unconventional commentary on landscape changes observed by generations of Washoe. Ancient observations on the rise and fall of lakes in the Tahoe Basin have prompted at least two traditional accounts that center around the area, explained through the antics of the "Weasel Brothers" and the fearsome activities of "Waterbabies".

"Pawsetsile (Big Weasel) sent *Damollale* (Little Weasel) to fetch some water from the lake; while there he saw a water baby sitting on Cave Rock combing her long beautiful hair; a warning that if he took her hair the lake would swallow him up went unheeded and a fight and chase ensued. The lake began to rise and all were finally saved when *Damollale* encountered his wiser brother *Pawstsile* who insisted that his brother throw the hair back; which he did- the water retreated and left water in all the depressions in the area; that is why there are so many lakes in the mountains around Lake Tahoe today." (d'Azevedo 1956:50)

There are numerous active avalanche paths along most of shoreline of Fallen Leaf Lake. When a SCUBA survey was completed in the runout zones that directly enter the lake, it was found to have a large amount of debris directly attributed to the paths on the upslope. Sampling and dating is currently underway on the trees both rooted and lying on the lake bottom. Given our past experience with visual observation over the last seven years, it would appear that nearly ever site we have dived on in Fallen Leaf Lake has a debris field that has several,series of dated debris. Some obviously, as recent as last year and some appear very ancient. Some of the recent trees that have been deposited, still with most branches and needles attached, can be matched up with the broken stumps on the slopes above.

Tenaya Lake, located in Yosemite National Park, lies in the Tuolumne Meadow area of the park. At 2621 m high it is not far from the eastern entrance of the park at Tioga Pass. Tuolumne Meadows is about 19 km long including the Lyell Canyon, and in many places at least a .8 km across. It is rimmed by a number of mountains, of which, Cathedral Peak is the headwaters for Tenaya Lake. While the lake was named for the chief of the Yosemite Indians by soldiers it already had a name by the natives, Py-we-ack, "Lake of the Glistening Rocks". The trees that have been dated so far in this lake are the most southern evidence that has been found in the Sierra Nevada. The radiocarbon dates from Tenaya Lake are around 915-920 and 660-670 BP. These correspond to the dates from the lakes in the northern Sierra.

Because of the south facing slopes above Tenaya Lake are mostly granite slabs the timber is sparse and thusly the debris fields in the lake would be thought to yield very few specimens for sampling. But since we are looking at a repository that is in effect a cold storage vault, we find that like Fallen Leaf Lake, there are numerous trees in the debris field that by visual observation appear to be differentiated by hundreds of years. Sampling will give a better overview in the future. A future ethnographic study of the Mono, Miwok, and Yosemite Indians oral history may shed some light and provide unconventional commentary on landscape changes observed by past generations of natives in this region.

If in fact there was an increased avalanche activity in the present avalanche influence zones during the changing periods of the Holocene, when the dry climate was in a period of change to an increased precipitation regime, will mapping and dating of these apparently preserved deposition zones that are submerged in the Sierra Nevada provide any information that will be useful for avalanche professionals in the present?

Even without more extensive mapping and dating completed at either site, there is enough convincing evidence accumulated from the last seven years of diving in over a 100 lakes in the Sierra Nevada, to advise those in the profession that have to make the call for an opening or evacuation; *that you may never know what kind of extremes in winter storms, in either intensity or duration, can be produced by a changing climate regime.* The avalanche community in the Sierra, may see in their lifetime, a storm of such intensity and/or duration that it will be a standard for all to be measured by.

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