^{14}C Dating of Tufa Deposits Around Lake Nam Co, Tibet

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Abstract

Dating of lake shorelines around Lake Nam Co is a vital part of a project to estimate the effective viscosity of the Tibetan mid crust. Previous dating studies have focused on ^{14}C dating of carbon-bearing mud, gastropod shells and water plants and the results show a large amount of scatter for different heights above the lake. This scatter can be partly explained by the mix of extraneous detrital carbonaceous material in the mud and plant material. Measurements of water from restricted basins and the open lake show significant differences in $^{14}C/^{12}C$ ratios, and samples formed in equilibrium with restricted basins will have a different reservoir effect to those formed in equilibrium with the main body of the Lake. Sampling of tufa deposited from lake water is largely unaffected by detrital material and is potentially a good material to estimate the age of shorelines. However, tufa may also form much later than the lake shoreline at some depth in the sedimentary pile and may be formed in equilibrium with water containing old C. These problems can be minimized by using samples that are attached firmly to rock substrate and in regions where the overall dip of the shoreline is steep and formation of restricted lagoons is unlikely. Preliminary results using this sampling strategy give an age of around 6,000 years ago for a height of 11m. This is in very good agreement with two OSL dates for shorelines and the associate heights reported in the literature.

Keywords: Tibet, Nam Co, radiocarbon dating, tufa, lake shorelines

1. Introduction

The mid crust beneath Tibet is generally thought to be highly mobile low viscosity material [e.g. *Beaumont et al.*, 2004; *Cook and Royden*, 2008; *Copley and McKenzie*, 2007]. A low viscosity layer of mid crustal material can account for the relatively flat nature of the high plateau—high elevation but low relief—and injection of mid crust into low lying regions around the Tibetan Plateau is thought to be one of the main processes involved in the expansion of the Plateau. Mechanical modeling shows that many of the first order features of the Tibetan Topography can be explained by the presence of a mid crust with a viscosity of 10^{19} Pa s or less [*Beaumont et al.*, 2004; *Clark and Royden*, 2000; *Copley and McKenzie*, 2007]. However, there has been no independent quantitative estimate of the effective viscosity of the mid crust. Lake shorelines offer a way to achieve this.

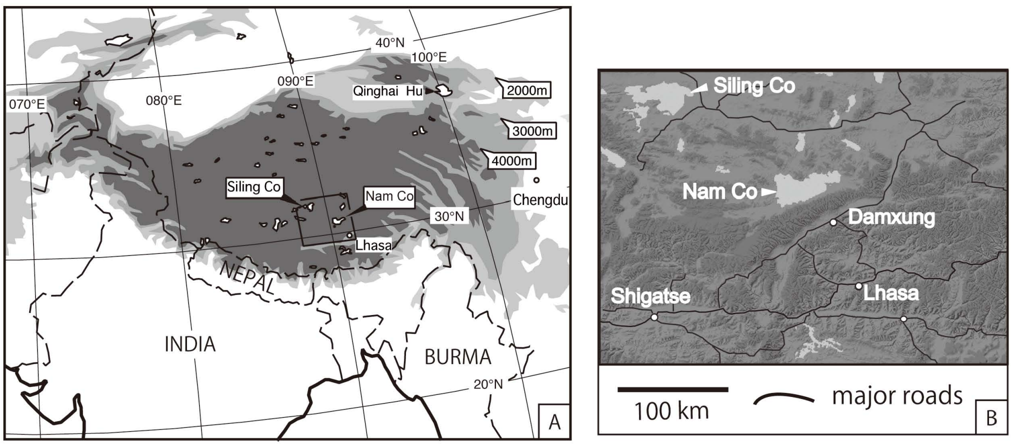

Fig. 1. A) Overview map of the Tibetan-Himalayan orogen showing the location of major lakes.
B) Location of Nam Co and Siling Co with respect to the capital city, Lhasa.

Despite its low rainfall, Tibet contains a large number of lakes (Fig. 1) due to the lack of water outlets from the central plateau. Many of these lakes are surrounded by well-preserved paleo shorelines. The presence of these shorelines shows that the lakes were once much larger than they are now. Figure 2 shows a set of well-developed shorelines around one of the largest lakes in Tibet, Nam Co, which lies 150 km to the north of Lhasa. When there is a drop in the water level of a lake, it reduces the weight on the underlying crust and resulting in a buoyancy force that tends to uplift the substrate. The maximum uplift possible is determined by the ratio of the densities of water to rock: approximately 1 m of uplift for every 3 m decrease of the water level. The reason for the uplift is the inflow of mobile rock at depth. Re-equilibration will not be instantaneous—it will take time for crustal flow to occur. The time scale for this crustal flow depends mainly on the geometry of the lake basin and the viscosity of the crust. The geometry is well known and viscosity can then be estimated from measurements of the amount of uplift and the time that it took for the uplift to occur. Shorelines are palaeo-horizontal markers and, therefore, any uplift can be recognized by careful measurement that reveals present day deviations from horizontal. The second data set required to estimate the mid crustal viscosity is the ages of shorelines and age dating of the shorelines is the subject of this contribution.

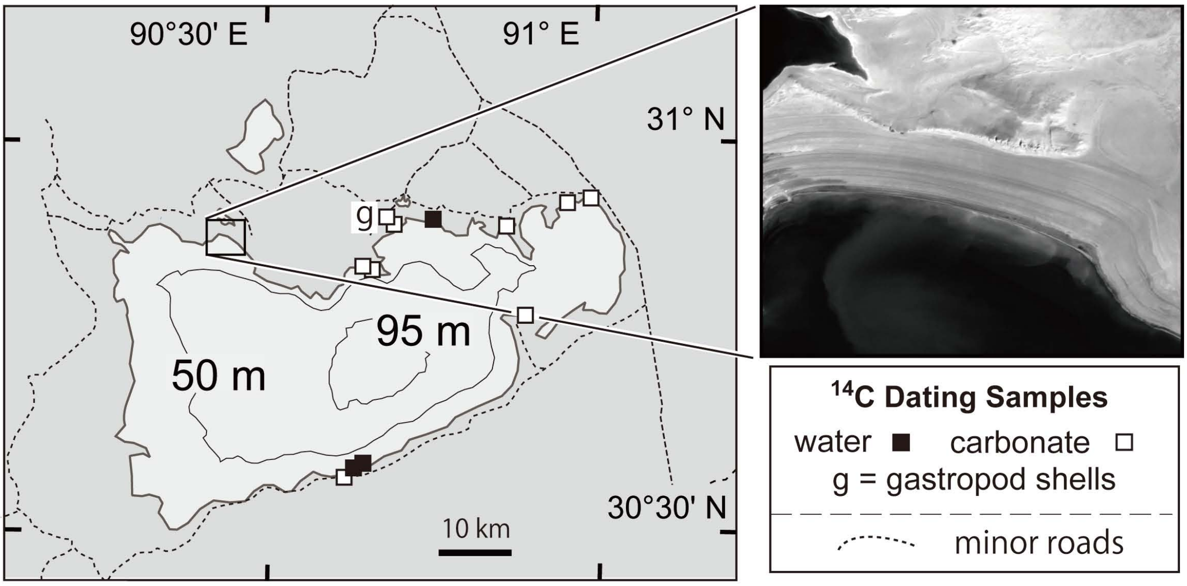

Fig. 2. Map of Lake Nam Co showing the main tracks around the Lake, the depth contours [*Wang et al.*, 2009] and location of samples used in this study. The inset shows part of a PRISM satellite image of the shorelines in the northwestern part of the Lake.

2. Previous Studies

There are several previous studies that report ages of material around Nam Co. U–Th series dating shows that the higher shorelines possibly up to heights of 140 m above the preset lake were formed around 120 ka: before the last glacial maximum [*Wu et al.*, 2004; *Zhu et al.*, 2002]. Seismic studies of the lake also reveal shorelines below the present water level suggesting the water level was much shallower in the past [*Daut et al.*, 2010]. This is confirmed by boring cores that suggest Nam Co probably went through a period of very low water levels probably including complete dessication [*Daut et al.*, 2010]. This stage of low stand in the history of lake Nam Co can be correlated with similar low stands seen in other lakes of the Tibetan plateau, which are related to the cold dry period during the last glacial maximum [*Wu et al.*, 2006; *Yu and Kelts*, 2002].

Field observations show that glacial deposits are overprinted by paleoshorelines up to heights of about 30 m [*Lehmkuhl and Haselein*, 2000; *Wallis et al.*, 2010]. This represents a younger post-glacial sequence of shorelines. The post glacial sequence of shorelines are well preserved and are more likely to represent a simple history of lake level decrease. We therefore concentrate on these shorelines for measurement of heights and estimates of ages of formation.

Previous studies on the younger set of lower shoreline material give a variety of different ages (Fig. 3). Most of these ages were derived from ^{14}C studies. In addition two OSL ages are also available [*Lehmkuhl and Haselein*, 2000]. The results show considerable scatter and there is no clear relationship between height and age. However, many of these previous studies were not specifically aimed at dating the shorelines and used a wide variety of different material. In this study we have looked at possible reasons for the scatter in previous data and report initial results that may help determine the relationship between the height of shorelines and their age of formation.

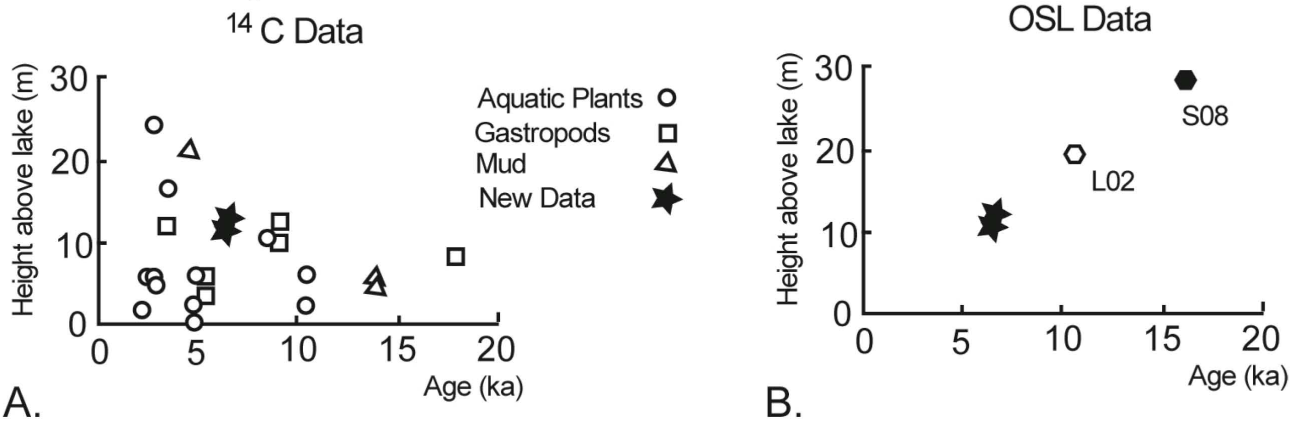

Fig.3 A) Compilation of available ^{14}C dates from around Nam Co plotted against height above the lake up to about 30 m. The results show considerable scatter and no clear correlation between height and age. Two new data points from this study are also shown. For details of sample material etc. see main text. B) Two available OSL dates for shorelines around Nam Co and the two new ^{14}C dates plotted against height above the Lake surface. These data are limited in number but show a good correlation. L02 = Lehmkuhl et al. [2002]; S08 = Schütt et al [2008]

3. Sample Material

In order to estimate the ages, we took three different types of sample material from Nam Co and its surroundings: calcareous chemically deposited beach rock or tufa, mollusk shells and lake water (Fig. 4). The shell material and tufa both develop in equilibrium with water and not the atmosphere, so in order to estimate the age using methods calibrated for the atmosphere it is necessary to make some correction for the isotopic composition of the water.

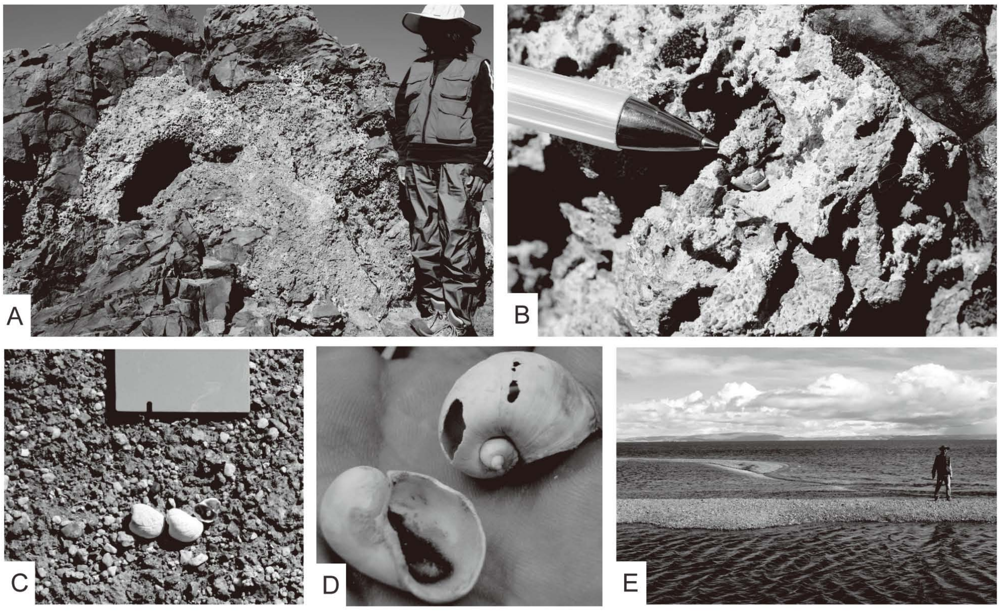

Fig. 4. Photos of the sample material used in this study. A) Tufa deposits attached to basement rock. B) Close up of Tufa showing porous nature. C) Aquatic gastropods found on the surface and within paleoshorelines with a depositional origin. D) Close up of aquatic gastropod shells belonging to the genus Lymnaea. E) Water samples were taken from within restricted lagoons behind shoreline bars and water regions in direct connection with the main lake body.

The tufa can be observed forming at the lakeside at the present day where repeated covering by water and subsequent drying has left a series of calcareous coats on the surface (Fig. 4a, b). Significant build-ups of tufa are generally formed just below the water surface of lakes. Tufa deposits are also formed associated with mineral springs. However, no such springs were observed in the area, and we assume that the tufa deposits we observed were all formed close to the water level of the lake.

The aquatic gastropods (Fig. 4c, d) used in this study were identified as belonging to the genus Lymnaea and were found either on beach shorelines or buried within them. The age of such shells can then help determine the age of the shoreline formation.

4. Results of C Isotopic Analysis

Water samples were taken from three separate sites (Figs. 2, 4e). Two of these were facing the main body of the open lake. A third was sampled from a small lagoon behind a beach. The two samples from the main body of the lake show very similar apparent ages (Table 1) and indicate the water is isotopically homogenous. However, the sample from the restricted body of water shows a much older apparent age (Table 1). This indicates the mixing with old carbon and raises a difficult with accurately dating material associated with such lagoons: it will not be clear whether this sample developed in equilibrium with the main body of the lake or with water that has a significantly different isotopic composition. This uncertainty can introduce a significant scatter in the age data.

Material	^{14}C Age (yr BP)	Error (1 sigma)
Shell (surface)	5088	36
Shell (5 cm depth)	5351	36
Water (lagoon)	1101	32
Water (open lake)	297	30
Water (open lake)	286	30
Shell on surface	5088	36
Tufa at 15 cm depth	3829	34

Table 1. Results of ^{14}C dating of various samples and C isotopic composition of lake water.

Two shells were measured in this study, one on the surface of a depositional shoreline and one 5 cm below the surface (Table 2). They give very similar ages of around 5.3–5.0 ka for a shoreline with a height of 11 m. Three samples of tufa were taken for ^{14}C analysis. One of these formed at a depth of 15 cm within the same shoreline as the shells. However, the apparent age is much younger. This suggests that the tufa in this case is secondary and formed after the shoreline.

For further samples of tufa we restricted the sampling locations to material that was cemented to firm rock substrate and was not therefore the result of secondary subsurface deposition. We also restricted the samples to areas with relatively steep surface where there was no evidence for lagoon formation in the present or in the past. The two samples of tufa selected from these regions gave ages of 6.8 ka and 6.6 ka for heights of 13 m and 11 m respectively (Table 2, Fig. 3).

Sample No.	Height (m)	^{14}C concentration	Age (yr BP)	Error (1 sigma)
NC-10	13	0.4287	6805	39
NC-12	11	0.4376	6638	37

Table 2. ^{14}C Ages of tufa deposits sampled on rock substrate at heights of 13 and 11 meters above the lake surface.

5. Discussion

We have identified two significant potential sources of error in ^{14}C dating of lake shore material in the Nam Co area: the presence of localized bodies of water that may contain large amounts of old C and the formation of tufa at sub surface levels can occur significantly after the surface.

The distinct isotopic composition of limited bodies of water—for instance those behind depositional shorelines (Fig. 4e)—will affect the composition of shells of any gastropods living in the shallow water. Shells of gastropods living in equilibrium with the main body of the lake are then likely to be distinct. These differences mean that ages of shells calculated using any fixed estimate of the reservoir effect will show considerable scatter. The variable reservoir effect may also be part of the reason for the scatter in the apparent ages of the mud and water plant samples. However, for these samples there is also the possibility that extraneous detrital material causes some of the scatter.

The use of tufa deposited from the lake water minimizes the potential effects of detrital material with various formation ages being mixed with the sample. Tufa does, however, have the potential to be influenced by variable reservoir effects and primary tufa formed on the surface needs to be distinguished from secondary tufa formed within the sedimentary pile. Only tufa formed on the surface will give a reliable estimate of the age of the underlying shoreline. Our sampling strategy was to samples fixed firmly to a rock substrate and which could not form within a sedimentary pile. We also sampled areas where there was a steep slope to the lake basin minimizing the possibility that restricted lagoons formed behind sedimentary shorelines and sand bars. Tufa samples selected using this approach give an age of around 6,000 years for shorelines at 11 m above the present lake. Some test of the suitability of these ages is provided by a comparison with OSL ages that do not have problems with a C reservoir effect. There are two such published ages. When their heights are plotted with our new ^{14}C results, the data show a good linear relationship (Fig. 3). This suggests our methodology has potential to provide useful constraints on the age of formation of ages.

Our results suggest an average rate of lowering of the lake surface of 1.7–1.8 m/ka since around 15 ka when the lake surface was about 30 m higher than it is at present. This is in good agreement with the observation that the lake shorelines lower than 30 m cut glacial deposits on the south of the lake [*Lehmkuhl et al.*, 2002; *Wallis et al.*, 2010] and the estimates for the end of the last glacial maximum around 15 ka.

Conclusions

Dating of lake shorelines around lake Nam Co is an important part of a project to estimate the effective viscosity of the mid crust in Tibet from deformed shorelines. Previous dating studies show a wide scatter of results. One reason for this scatter is a variable reservoir effect. Tufa deposited from the lake water does not suffer from the problem of the effects of detrital material derived from an unknown source region. Tufa may, however, form secondarily after the shoreline by deposition with the sedimentary pile. A sampling strategy that focuses on 1) tufa deposited from the lake in regions where isolated bodies of water with distinct C isotopic rations are unlikely to have formed, and 2) material attached to rock substrate and not formed within the sedimentary pile can minimize the problems associated with these issues. Our initial results suggest the shoreline around 11m formed about 6,000 years ago.

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日本語要旨

ナムツォ湖周辺に分布する古段丘の年大決定はチベット高原の中部地殻の有効粘性を推定するための研究プロジェクトにおいて必要不可欠である。従来の年代研究は炭素 14 の年代法を用いて巻き貝・泥・水生植物の試料に着目してきたが、推定年代は大きくばらつき、湖水面からの高さと有意な相関を示さない。泥と水生植物破片測定値のばらつく原因として外来砕屑性の炭質物の混在があげられる。また、湖の主要な水域から隔離された潟の水は湖の本水域の組成と大きく異なる $^{14}C/^{12}C$ 比を示し、これらの水体と平衡に形成した試料はそれぞれの炭素同位体比を反映し、リサーバー効果は大きく変動する可能性がある。湖水から沈殿したトゥファは砕屑性の混入物の問題は少なく、段丘の年代を推定するのに適しているものである可能性が高い。ただし、トゥファは段丘形成後、堆積物の中で成長するものもあり、このような二次的に形成したものは段丘の形成年代を示さない。 これらの段丘の形成年代決定の不確定要素を最小限になるように基盤岩に固着したものを選別し、また湖底傾斜が大きく、潟など隔離された水域の形成は考えにくい地域で試料を採取することは有効である 。この試料採取作戦を適応した年代測定結果、湖水面から約 11m の高さにある古段丘の年代は約 6.5ka であることは明らかになった。 この高さと年代は２つの既存の OSL 段丘年代と高さと調和的である。