Abrupt lake level drops and the formation of down-stepping deltas

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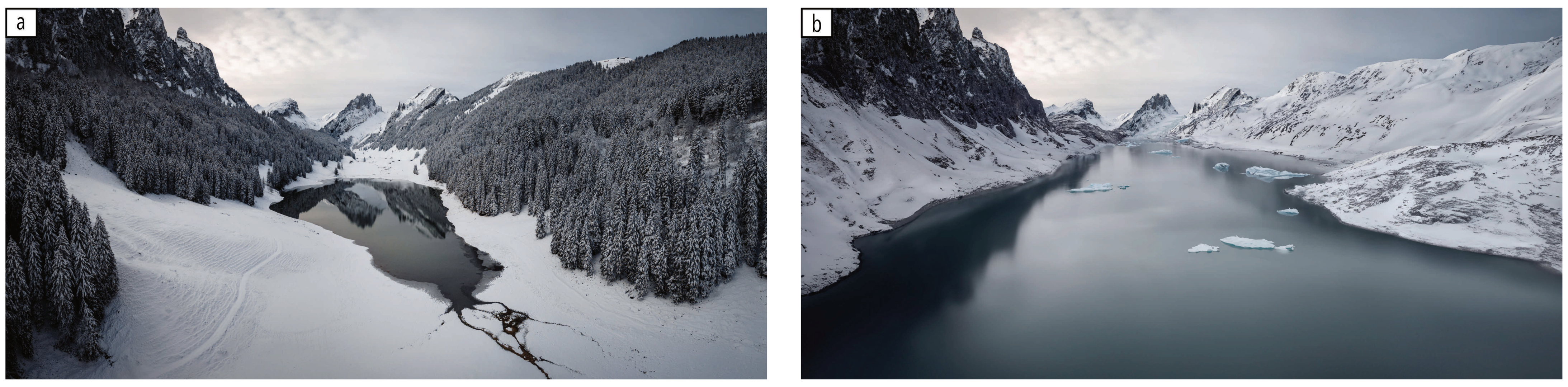

Fig. 1 | Lake Sämtisersee, today and during the Late Glacial (14'000-10'000 BP). (a) Photograph of Sämtis valley in November 2023. Sämtisersee (1207 m.a.s.l.) is drained through the subsurface karst system. (b) Visualization of Sämtis valley during the Late Glacial period (14'000-10'000 BP). Sämtisersee (1279 m.a.s.l.) is drained through the surface outflow at Plattenbödeli.

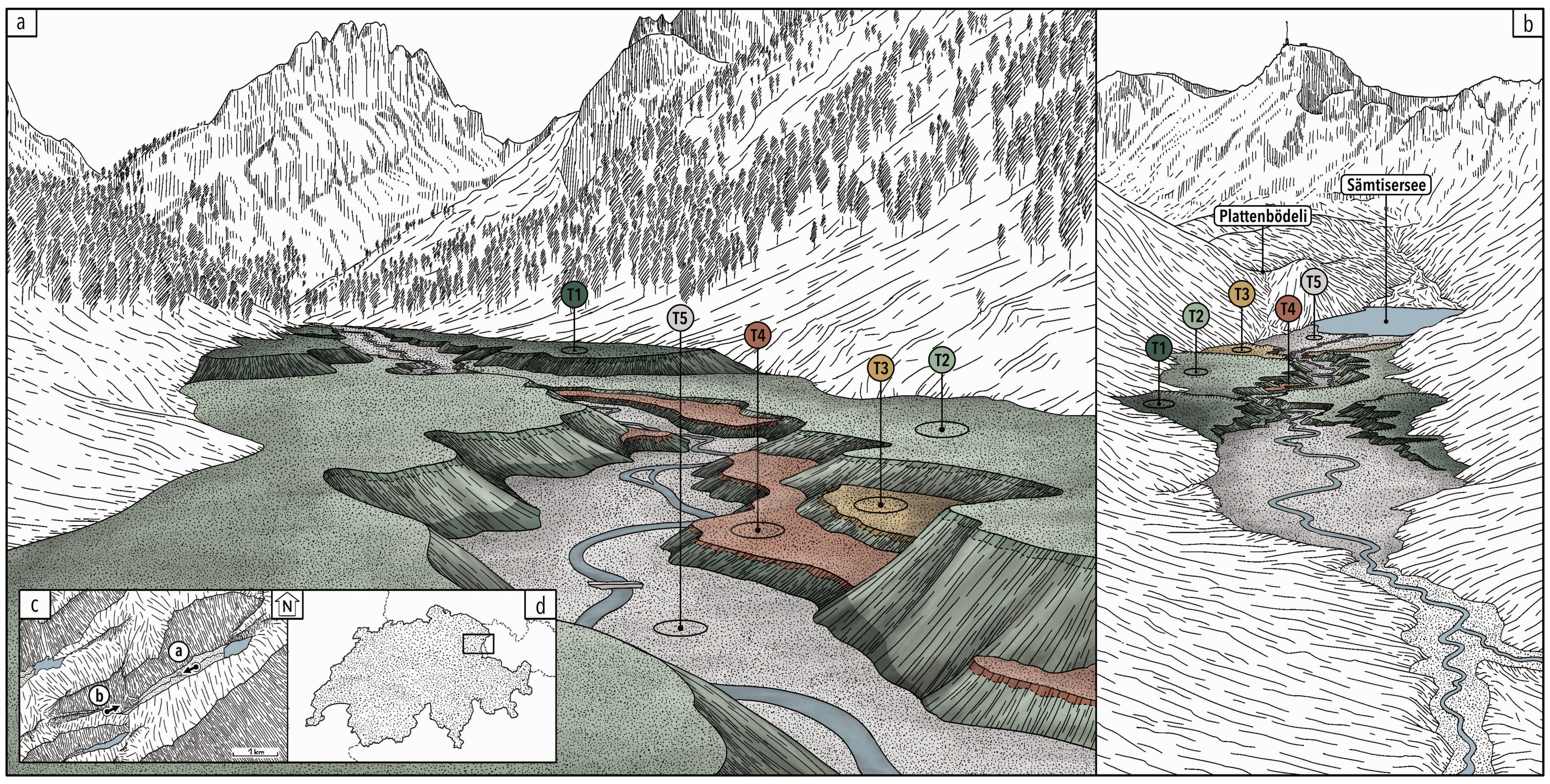

Fig. 2 | Delta terraces in the rear part of Sämtis valley. (a) Simplified sketch of Sämtis valley today, viewing the terrace topography from (47°15'57''N 9°26'38'' E) towards southwest. All terrace levels as well as the river channel that cuts through them are visible in this sketch. The isolated terrace fragments in the river channel are associated with downcutting mechanisms and the formation of a new delta plain. The colors refer to the terrace formation stage (or respective terrace level top T1/2/3/4/5) during which the sediment was deposited. Some sediments of T3/T4 only remain as shallow gravel deposits from past and partially eroded channel beds. (b) View from further up-valley (47°15'27''N 9°25'11'' E) towards northeast. (c) Location of the viewpoints within the surrounding mountains of Sämtis valley. (d) Location of the valley within Switzerland.

Methodology

An in-field mapping of Sämtis valley was performed with the assistance of the digital elevation model (DEM) SwissALTI-3D. The mapped outcrops were visually analyzed for their sediment composition and structures. The bulk of the analyses occurred on one ideally preserved varve outcrop found in the sidewall of the down-cutting river channel. High-resolution photography was performed to document and analyze the varve microstructures (Fig. 3). Dating of these sediments was attempted using radiocarbon (C-14) dating (unsuccessful) and optically stimulated luminescence (OSL) (work in progress).

Results

The 3.3km long valley floor of Sämtis valley features three distinct terraces, each spanning multiple hundreds of meters and dipping with an angle of 3° towards Sämtisersee. Though this inclination is barely noticeable in the field, within a full terrace length, altitude differences of more than 30 meters occur. The three terraces are separated by steep (15-22°), abrupt steps from one terrace to the next. They are attributed to three respective terrace formation stages T1-3 (Fig. 4). In today's stage T5, the river channel that cuts through the terraces reveals outcrops into the sedimentology of these terraces. Six isolated terrace fragments, spread out over 700 meters within the river channel, can further be attributed to the stage T4. They do not connect to another full-scale terrace in front of the T3 terrace. Thus, the current delta plain T5 reaching into Sämtisersee follows out of the river channel, just below the step from the T3 terrace.

The outcrops formed by the river channel can be separated into three types of common delta sediments: unsorted gravels (top-sets), cross-stratified sands and gravels (fore-sets) as well as sandy to silty varves (bottom-sets). One of the outcrops (SAM-1) shows a total of 75±8 coupled varve layers consisting of thick brown sandy layers (turbidites) and white silty layers. Towards the top of the outcrop, the sand becomes coarser and the turbidite layers are increasingly replaced by ripples with a wavelength of up to 12 centimeters.

Conclusions

The bottom-sets as well as the cross-stratified fore-sets clearly point towards prograding river deltas being the dominant mechanism in the formation of the terraces attributed to stages T1-3. The inclination of the terrace top can be explained through forced regression (the continuously lowered lake level leads to the delta's progradation). The abrupt steps from one terrace level to the next likely occurred through sudden lake level drops. The river channel then eroded into the terrace to follow the new erosional base level and develop a new delta plain in front and lower than the old plain. The terrace fragments from T4 and T5 are attributed to the same, currently active delta plain in front of Sämtisersee. They can only be differentiated in the area between 1400-2300m away from Plattenbödeli where increased erosion during stage T5 made the earlier river channel from stage T4 visible in the form of preserved terrace fragments. Overall, the lake level dropped over 70 meters since the onset of T1 until today. For this to have occurred, a basin without an active surface outflow but still enough inflow for sustaining a lake is required. Furthermore, sudden triggers that permanently shift the lake level are required for the formation of such step-like delta terraces.

Outlook and open questions

Whether the changes in the lake level were primarily controlled by changing inflow patters (deglaciation until extinction of Sämtis glacier) or varying outflow patterns (subaquatic karst holes) is not determined yet. The reason for localized erosion that led to the differentiation of T4 and T5 is not yet cleared, either. Results for the formation age of the terraces will be acquired through optically stimulated luminescence dating.

Introduction

River deltas in their most basic function are lake level indicators. The occurrence of river deltas in a step-like formation, as they are exposed in Sämtis valley, suggests the lake level having shifted more than 70 meters. Moreover, sudden lake level drops of more than 4 meters are implied!

The geomorphology of Sämtis valley is quite unique. At an altitude of 1207 m.a.s.l. Lake Sämtisersee lies in a cryptorheic basin, a topographic depression with no surface water outflow. The overflow point of the valley is located at Plattenbödeli at 1279 m.a.s.l., more than 70 meters above today's lake level (Fig. 1). Today, the lake drains through the subsurface karst system (Haering et al., 1994). Thus, the water level of Sämtisersee varies significantly in the course of a year. During the last few decades Sämtisersee dried up multiple times, as in the summers of 1998, 2017 and 2018 (Büchler, 2014).

The rear part of Sämtis valley features multiple hundreds of meters long terraces that are incised by the river channel feeding Sämtisersee. Unlike fluvial terraces where the terrace steps occur orthogonal to the valley axis (Delchiaro et al., 2024), the terrace steps in Sämtis valley are primarily oriented along the valley axis (Fig. 2). Only within the river channel itself do these orthogonal steps occur as well.

***What processes** have led to the formation of these terraces?*

***When** did the formation of these terraces occur?*

***Why** are such terraces so rare in the Alpine environment – or anywhere else?*

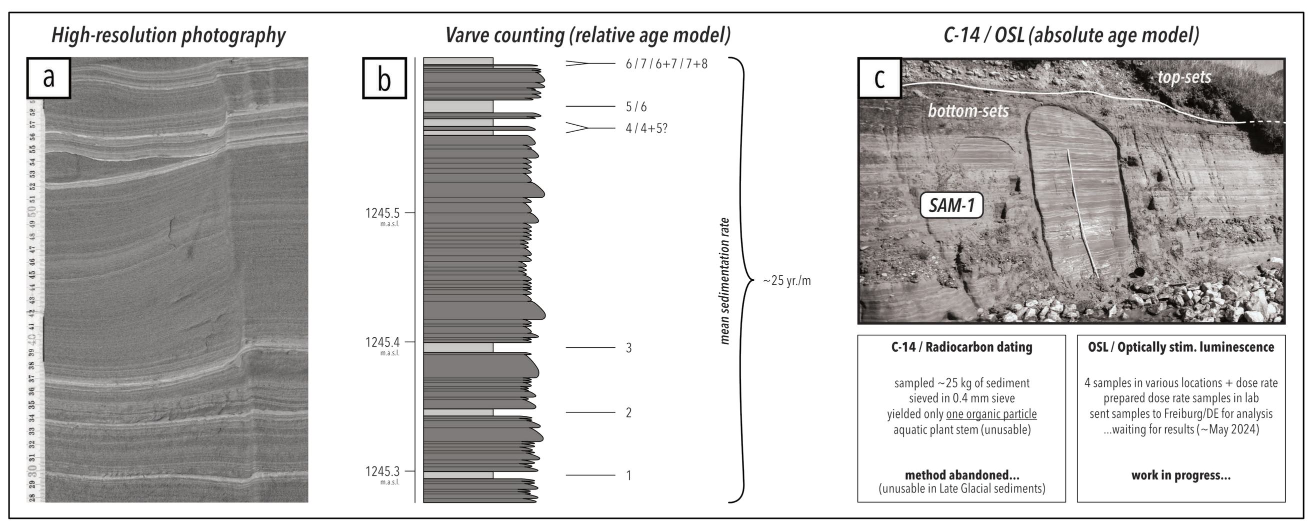

Fig. 3 | Developing a relative age model through varve counting. (a) Photograph from the lower part of the outcrop SAM-1, featuring multiple dark sandy layers with fine whiteish silty layers in-between. (b) Varve counting under the assumption of white layers representing winter deposits. In certain cases the differentiation of one, two or even more closely located silty (winter) layers leads to uncertainties regarding the exact amount of documented years. A mean sedimentation rate of ~25 years per meter of bottom-sets can still be determined. (c) Full view of the outcrop SAM-1, where C-14 and OSL dating were attempted.

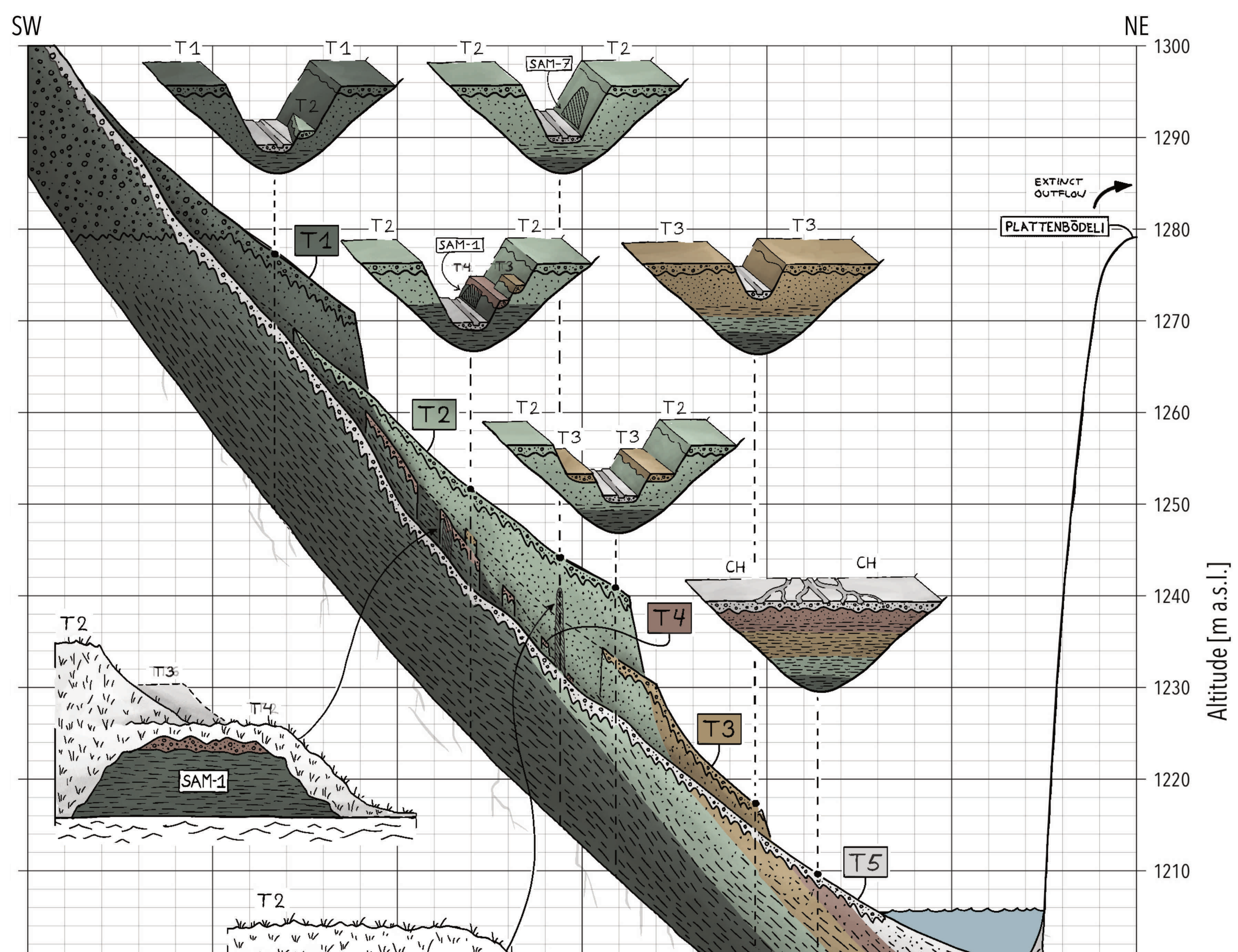

Fig. 4 | Vertically exaggerated profile through the delta terraces of Sämtis valley. The 40x vertically exaggerated profile follows the valley axis through the river channel towards Sämtisersee and projects the terraces onto the section. The sediment composition of the terraces is visualized. Cross sections in six locations within the whole valley further exemplify the valley topography and how the terrace fragments in the river channel are composed of a thin layer of young top-sets on older bottom-sets or fore-sets.

Acknowledgements

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