Tibetan Ice Sheet

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The Pleistocene Glaciation of Tibet and the Onset of Ice Ages – An Autocycle Hypothesis

Reconstruction of the 2.4 million km² late Pleistocene Ice Sheet on the Tibetan Plateau and its impact in the global climate

Result of 35 years Research on Glacier History in High Asia

Empirical induction

Figure 1

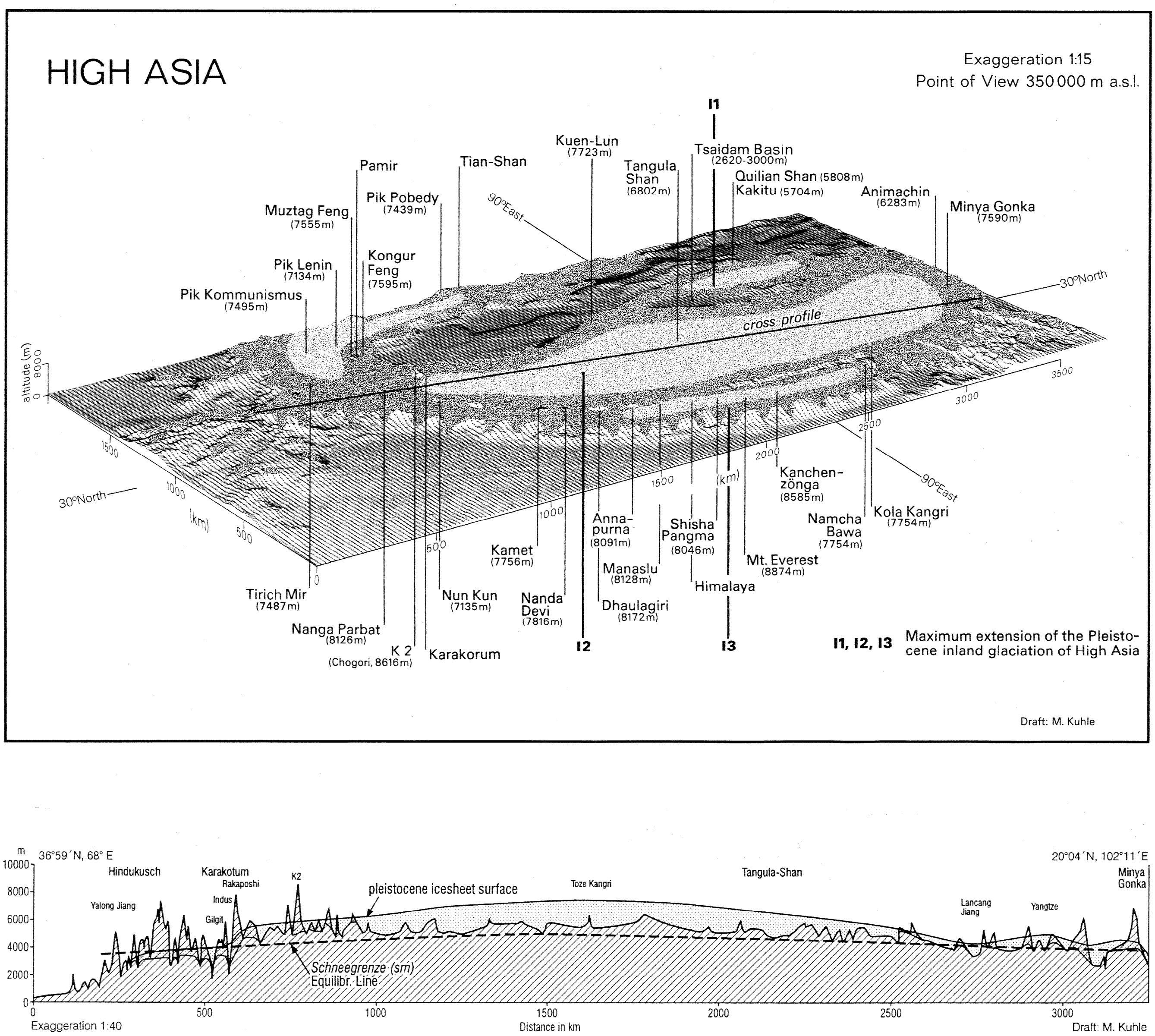


Fig. 1: (top) The reconstructed 2.4 million km² ice sheet, or ice stream network, covering the Tibetan plateau (Kuhle 1980, 1982a, 1982c, 1985, 1987a,b, 1988c,d, 1990d, 1991a,b,1993, 1994, 1995b, 996a,b, 1997, 1998, 1999, 2001, 2003, 2004), with the three centres I 1, I 2, I 3. Only peaks higher than 6000 m rise above the ice surface.
(bottom) Cross profile of the central ice sheet from Hindu Kush in the west to Minya Gonka in the east.

(1) Observations of standard forms of glacial accumulation and erosion are evidence of large-scale Pleistocene glacier cover of the Tibetan highland. Marginal sites at 2000–460 m a.s.l. in all of the surrounding mountains of Tibet are evidence of an equilibrium line depression of 1100–1660 m to 4720–3250 m a.s.l. The Ice Age equilibrium line thus ran up to 600 m below 85% of the Tibetan surface. This resulted in a $2.4x10^6$ km² inland ice mass with a thickness of 700-2000 m (and possibly up to 2700 m), (cf. Fig. 1). Its volume was the equivalent of an approximately 5.4-6.5 m drop in sea level.

(2) 14C ages substantiate the formation of inland ice at a date more recent than 120 ka and older than 9 ka (Würm glacial period).

(3) Amounts of uplift of Central Tibet of more than 10 to 521 mm per annum, are far in excess of the tectonically younger Himalaya, and are consequently interpreted as glacio-isostatic.

(4) Presently consisting of 99% rock and scree, the Tibetan surface reflects only 15-20% of the high subtropical radiation coming from space. This results in a global heating effect of the atmosphere. Covering 97% of Tibet and reflecting 85-90% of the radiation, inland ice achieved a global cooling effect that is four times greater than at the latitudes of Nordic inland ice.

Theoretical deduction

(1) Even an uplift of the Tibetan Plateau of 500 m or an equilibrium line depression of 500 m (=3.5℃ drop in temperature) as a result of c yclical changes in the parameters of the earth´s orbit was bound to lead to the formation of larger glacier areas in Tibet. According to this the highland necessarily was a pacemaker for the Ice Age (cf. Fig. 3). The initial glacier cover of one third of Tibet caused further autocyclic equilibrium line depressions, aided by the 85% albedo of high subtropical incoming radiation. The resulting ice increase in Tibet aided global cooling and led to an approximately $46x10^6$ km² global High Ice Age glacier area, $26.3x10^6$ km² of which is Nordic inland ice (cf. Fig. 2). These data do not include the Siberian inland ice sheet of Grosswald (1983).

(2) Milankovic radiation anomalies operated during the Pre-Pleistocene, without giving rise to an ice age (cf. Fig.3). The glaciation of a subtropical energy-effective high plateau appears to trigger the Ice Age proper.

(3) In accordance with insolation being four times higher than at Nordic glaciated areas, the Tibetan ice was a much more influential global climatic body. Only 15% of the energy that previously heated the atmosphere before glaciation remained available for ablation. The reversal from a heating to cooling surface was also four times more effective and implies a corresponding increase in the self-intensification of glaciation from high to low latitudes.

(4) In Tibet even a net precipitation of 200 mm/year, would lead to an ice cover having an average thickness of 1100 m within a little less than 10,000 years. This shows that in terms of time – from 90 to 60 ka, for instance – Tibetan ice would have been able to fulfill its role as a pacemaker.

(5) An alimentation model in based on an analogy developed by Meinardus (1938) for the Antarctic ice: a depression that drew in humidity lay above a cold and shallow anticyclone situated over the ice cap.

(6) With four times less cloud cover in the subtropics that at high latitudes, a subtropicial inland ice sheet was bound to exert a particularly large global cooling effect.

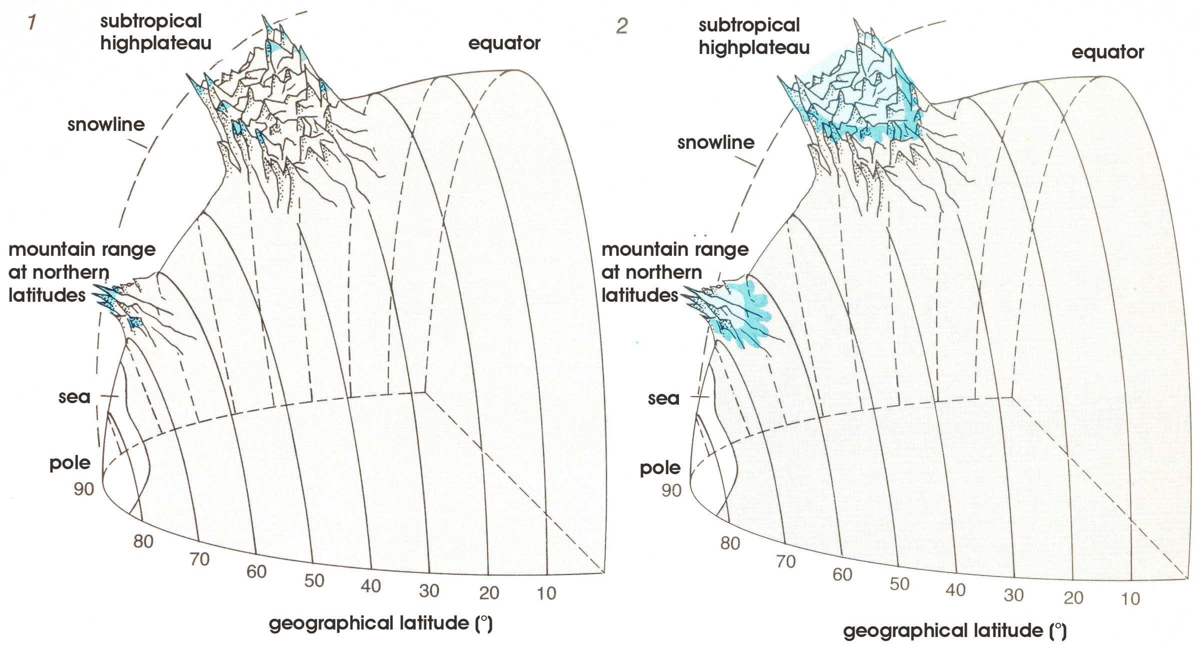
(7) The termination of the ice age cycle originated from the Nordic lowland ice. The end of extraterrestrial cooling (Milankociv cycle) led to a rise of the equilibrium line by 500 m. The marginal and steep high plateau ice was initially not reduced during this ELA rise. By contrast, the vast lowland ice was bound to undergo an extreme loss of area. A lowland albedo loss led to global rewarming and an interglacial period.

(8) In their role of pacemakers the uplift of a subtropical plateau above the ELA as well as its glaciation were triggers of the Ice Age on condition of the reliefspecific Ice Age mechanism. This mechanism is based on global radiation geometry. The spherical geometry of the earth and the position of the earth´s axis are the neccessary requirements for the formation of large lowland ice sheets at high latitudes, while subtropical glaciers occur at extreme elevations and are therefore restricted to small areas. Their small extent is compensated by a very high radiation energy, so that a minimal area of ice cover triggers the Ice Age (cf. Fig. 3). A small rise in the equilibrium line is all that is needed to begin global rewarming through loss of glacier surface area. Proven moraines from that time, plus the reconstructions of their positions, will certainly permit a later corroboration of the kind of orogeny that extended up into the vicinity of the equilibrium line during the Permo-Carboniferous glaciation, for instance.

(9) Extraterrestrial cooling is not needed to trigger the ice ages. The Tibetan Plateau would only require an uplift of an additional 500-1000 m for a glaciation to occur without this cooling. An uplift of this kind could occur within 50-100 ka, so that a renewed Ice Age – accelerated extraterrestrically – might take place in a few dozen millennia. The denudation of the Tibetan High Plateau will terminate the Ice Age of the Pleistocene Era.

(10) The uplift of Tibet came to its Early Pleistocene end as a result of the loading of inland ice. This ensured the deglaciation of the plateau as a continuation of the wasting begun by the lowland ice. The present extreme uplifts in Tibet are to be regarded as compensatory glacioisostatic movements. Altitudes of plateaus and highlands of earth are climatically controlled by the position of the equilibrium line. The greatest possible plateau altitudes are found in subtropical latitudes.

Figure 2



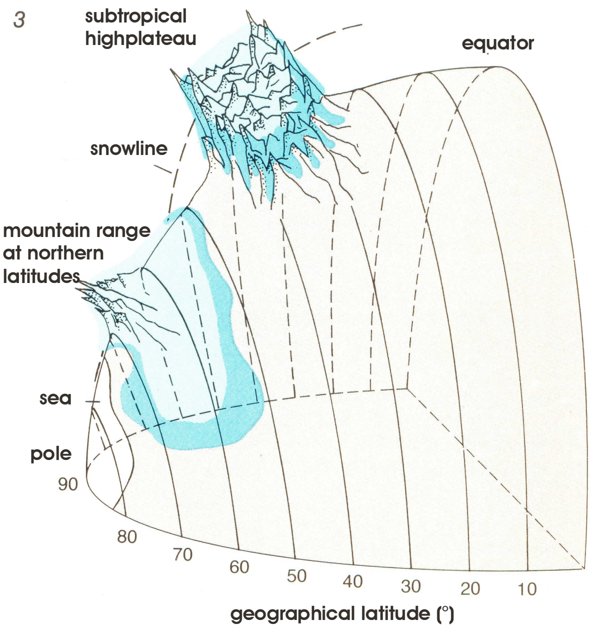


Fig. 2: Schematized presentation of the principle of the relief-related origin and termination of ice ages. The causative intensification of the cooling-down process emanates from a subtropical high plateau (such as the Tibetan Plateau) due to the fact that the initial lowering of the equilibrium line by approx. 500 m leads to the glacier´s descent by 1000 m from the mountains, thus suddenly glaciating large plateau areas (step 1 to 2). Mountain chains at higher latitudes experience the same amount of equilibrium line lowering as a result of the cooling down by 3.5°C during a change in the parameters of the earth´s orbit. Since the altitudinal distance of the present glaciation to the height of the foreland areas is too great, glaciation has had little effect on area and thus on reflection (2). As the subtropical high plateau has undergone large-scale glaciation, with the transformation of a formerly very effective "heating panel" into an area of reflection, the further cooling down of the atmosphere caused in this way leads to a renewed lowering of the equilibrium line. The consequence is a chain-reaction-like worldwide enlargement of glacier areas. This advanced particularly fast in all those places where the lowering of the glaciation line reaches the flat mountain forelands (step 2 to 3). The sequence of additions of mountain foreland glaciation depends on the particular altitudinal distance of pre-ice age hanging glacier ends from the altitudinal level of the foreland. Although, due to the conditions of radiation, the cooling effect per glacier area is greatest in the subtropics, the areal gain of glaciers increases significantly with the decreasing equilibrium line at higher latitudes (3). The reason for this is the fact that the equilibrium line dips towards the polar regions, and that the starting point of equilibrium line heights becomes progressively lower towards the lowlands. In the end the ice areas of the high latitudes outnumber those of subtropical high plateaus and mountains by approximately 8:1, by which time their cooling effect has increased around twofold. Nonetheless, such far-reaching glaciation would not have occurred without the impact of the subtropical inland ice. The cooling, which reacts upon the impact of the subtropical plateau ice as well, can hardly result in any further increase of the area of ice there because the glaciers cannot reach the lowlands when flowing over the edge of the plateau (step 2 to 3). In a reverse process (steps 3 to 1) the end of the Ice Age begins in the N and S lowland plains: on the return to normal values of solar radiation and a rise in temperatures by those initial 3.5°C the corresponding rise in the equilibrium line by 500 m with a rise in the glacier ends by 1000 m becomes particularly effective for areas of flat lowland glaciation (step 3 to 2). Whilst lowland ice areas experience extreme reductions, thus forcing a global warming, the surface areas of the subtropical highland ice will remain almost constant, because only the steeply descending outlet of glacier tongues on the margins will become shorter on the initial upward more of the equilibrium line, whereas the reduction in glaciation is far from reaching the flat plateau ice proper (step 3 to 2). Only when the further warming of the earth has been initiated and has progressed through the disappearance of lowland ice, will the subtropical highland areas also be freed from ice (step 2 to 1); (after Kuhle 1987).

Figure 3

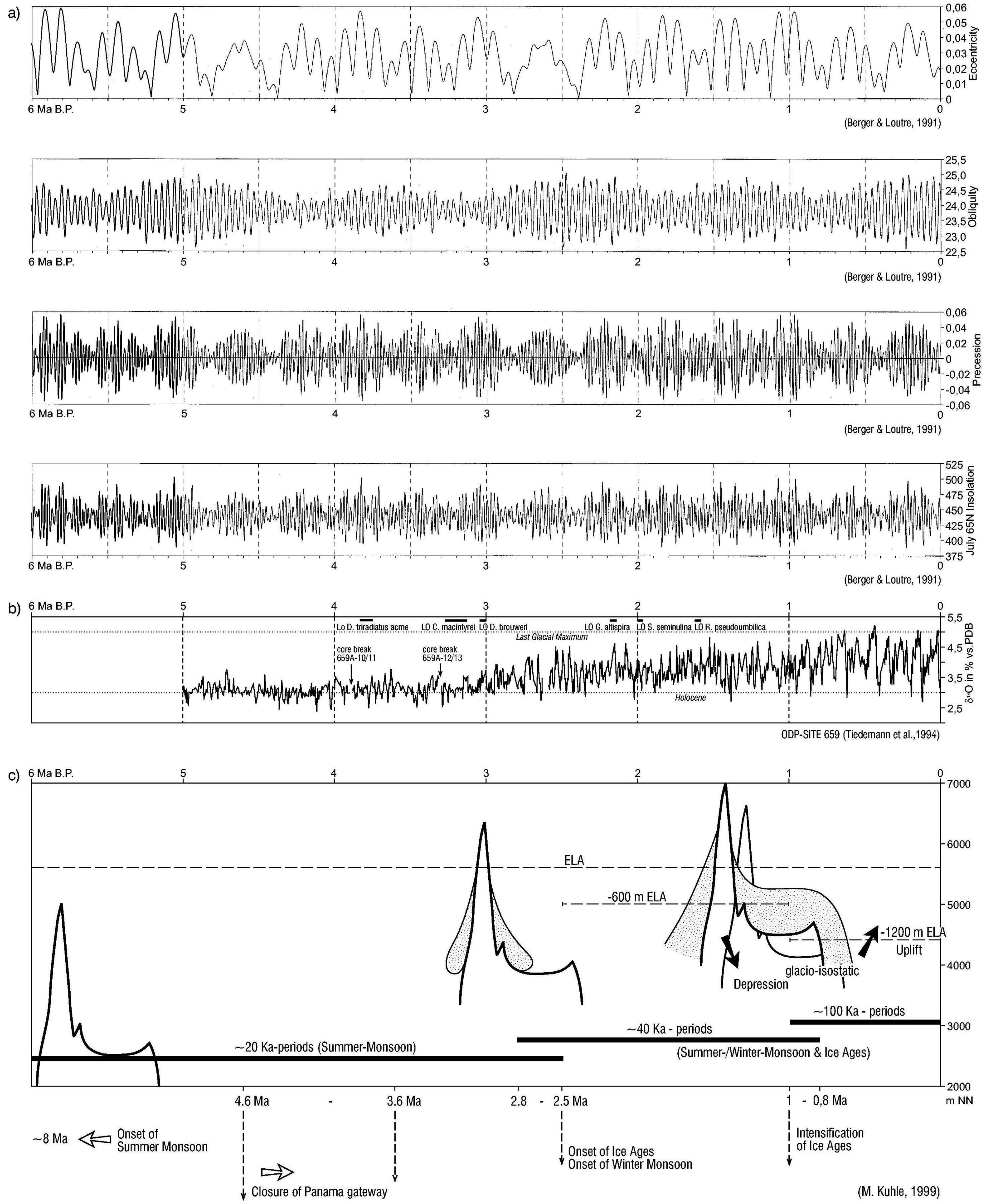


Fig. 3: (a) Astronomical parameters of the earth's orbit and rotation and corresponding insolation values for 65°N for the last 6 million years according to Berger & Loutre (1991).

(b) Benthic oxygen isotope records from Ocean Drilling Program Site 659 according to Tiedemann et al. (1994). The fluctuations in the $\delta^{18}O$ content of the foraminifera reflect the fluctuations of the global ice volume, with high values corresponding to the glacials and low values to the interglacials. Neither the beginning nor the intensification of the Quaternary glaciation period is correlated with the insolation (a).

(c) Synopsis of the uplift and glaciation of the Tibetan plateau in their relation to other geoecological events. Comparison between a) and b) shows that an additional factor apart from orbital variations is required to explain both the start of the ice ages about 2.8 Ma and their increasing intensity from 1 Ma onwards. The closure of the Panama gateway occurred too early to be the terrestrial cause. The uplift of the Tibetan plateau, as far as it can be reconstructed from the onset of the summer- and winter monsoons, and, derived from this, the begin of an autochthonous glaciation of Tibet from ~2.5 Ma B.P. onwards, were synchronous with the onset of the global ice ages. Evidence that variations of the summer- and winter monsoon intensity documented by marine dust flux records and loess-palaeosol sequences on the Chinese loess plateau occurred in phase not with the insolation variation but with glacial-interglacial cycles (40 ky and ~100 ky periods) , is a strong pointer to the existence of a Tibetan glaciation. Gradual uplift of the Tibetan Plateau towards the ELA (equilibrium line) level enabled an ice sheet of 2.4 million km^2 to grow from ~1 Ma B.P. onwards; the resulting cooling effect permitted a maximum expansion of the Nordic lowland ice sheets (- 1200 m ELA). The now beginning glacio-isostatic depression, deglaciation and following rebound of the plateau were responsible for the occurrence and duration of interglacial-glacial cycles (~100 ky periods).