J. Mt. Sci. (2010) 7: 105–122
DOI: 10.1007/s11629-010-1116-1

Review on Dating Methods: Numerical Dating in the Quaternary Geology of High Asia

Matthias Kuhle* **and Sabine Kuhle**

Georg-August-University of Goettingen, Department of Geography and High Mountain Geomorphology, Goldschmidtstr. 5, 37077 Goettingen,Germany

* *Corresponding author, e-mail: mkuhle@gwdg.de*

Abstract: Over the past few years, OSL and TCN datings of glacial material from High Asia have come into fashion. To this day, however, these techniques do not permit safe calibration. The intensity of the cosmic ray flux is being modulated by the solar and terrestrial magnetic fields and their secular fluctuations in the past. So far, these variations cannot be converted into the respective local TCN production rates for High Asia. We have reason to believe that the ages that are being calculated despite these uncertainties are generally overestimated. This assessment is supported by conventional radiocarbon dates and above all by the glacial chronology developed independently on the basis of the Quaternary geological method. The strongly emerging evidence for a much more extensive LGM glaciation of High Asia is, however, either being ignored or rejected by many authors, solely on the basis of the above-mentioned uncalibrated datings. This self-conceit based on the "dating fallacy", as we call it, should be avoided since it goes decidedly against the standards of the scientific method established in Quaternary geology and makes a fundamental scientific discussion impossible.

Keywords: Calibration of numerical dating; Geomagnetic field excursions; Solar activity; Interface problem; Tibetan ice sheet; Dating fallacy

Received: 11 November 2009
Accepted: 15 March 2010

1 The Importance of Being Methodical

Method is something we rarely talk about in science – we have it and we apply it. To what extent scientific techniques do or do not form part of the method, is not entirely clear. What is clear, however, is the fact that the numerical dating techniques at present used and relied on in Quaternary geology do not form part of the Quaternary geological method. They all come from neighbouring disciplines like biochemistry, nuclear physics or astrophysics; i.e. they are imported yardsticks. If we nonetheless consider using these imported yardsticks (in a sensible way that is), we first have to make sure that the Quaternary geological subject matter meets certain requirements. In other words, there have to be appropriate *interface relations* existing between the Quaternary geological phenomena and the entities on which the chemical or physical measuring technique relies. It is almost needless to say that an inaccurateness of the interface relations cannot be compensated for by the exactness of the measuring. Before this background, it is truly surprising that the past ten years saw the introduction and establishment of two dating techniques – OSL and TCN dating – in Quaternary geology, which neither display a physically well-founded calibration nor a well-suited connection to the glacial geological phenomena.

Now, even in science such fashionable trends do not necessarily have to do any harm. Among other things, a solid and well-founded scientific method makes itself recognisable through its ability to digest, and subsequently part with, bad data. However, truly disastrous about the trend going on at present is that the dating techniques are more and more often mistaken for the Quaternary geological method itself so that the true, autochthonous method of Quaternary geology is supplanted wherever it is found to "interfere" with the former. The paralysis of the glacial geological method has indeed already progressed so far that the more recent publications on the glaciation of High Asia are *literally* devoid of every notion once considered the very essence of this method: the large-scale geomorphological detail analysis, the reconstruction of prehistoric glacial ice sheets, the extension of recent glaciation, the reconstruction of the prehistoric ELA, the extension of the recent ELA, the state of preservation of glacial indicators, or sedimentological analyses. At times, analyses do not even include a source assessment of the dated material: whether it was taken from a till, a landslide, a debris flow or something else – instead, the material is simply said to be a 'diamictite'. The information given often restricts itself to the location, the altitude, the applied dating technique and the estimated age of the sample (in the case of TCN, even the usually considered important boulder size and type of rock are often not mentioned). In such cases, the glacial geological argumentation is structured as follows: we are informed about the location of a glacier, e.g. the "Tanggula Glacier" in Central Tibet (altitude of the catchment area? end of the glacier tongue?); we are presented with a TCN dating: "<the> age of 31,900 +/- 3400 ^{10}Be yr comes from a boulder on an end moraine located about 3 km from the terminus of Tanggula Glacier" (Colgan et al. 2006: 337), and we are presented with a conclusion: "the limited extent of Tanggula Glacier suggests that it is unlikely that the Tanggula Shan were extensively glaciated at the LGM as suggested by Kuhle (1998)" (Colgan et al. 2006: 338). The entire line of argument, provided we allow this style of presentation to be one, focuses exclusively on the dating and does not even try to consider the glacial geological indications. By way of summarising the line of argument presented in a number of such publications, Owen et al. (2008: 515) finally conclude: "Now it is generally accepted that a large ice sheet did not cover the Tibetan Plateau, at least not during the past few glacial cycles". He who shares this point of view does not count on the glacial geological method any more, but sets everything on the numerical dating card – which, however, is not calibrated.

None of the studies cited by Owen et al. (2008) have succeeded or even so much as tried to contradict the glacial geological indicators laid out so comprehensively in favour of a large-scale LGM glaciation of High Asia (Kuhle 1974-2008); that is, no attempt whatsoever has been made to ascribe a different origin to these geological indicators other than glacial. The authors fully content themselves with dates for their sample material by which they can place it into the High Glacial or an even older cycle – when, according to our chronology, it must be attributed to the Post- and Late Glacial period. All other indicators not based on uncalibrated datings and speaking in favour of a considerably more extensive glaciation are simply being disqualified and dismissed with a wave of the hand. The only explanation occasionally offered for such indicators is that we must be dealing with relics of a much older glacial cycle. At the same time, however, the authors all agree on the fact that the canyons of the Karakoram and the Himalayas are among the Earth's regions most intensively exposed to the forces of erosion and disintegration and that accordingly it would be highly unlikely to find large-scale preservation of moraine deposits and glacial grindings from glacial cycles older than the LGM (Owen et al. 2008, Spencer & Owen 2004, Seong et al. 2008). In consequence, the authors should either be able to explain how it comes that these indicators do nonetheless exist (ascribed by them to glacial cycles much older than the LGM), or else they should be able to show that they are not *glacial* phenomena – however, they neglect to do both.

Indeed, at present the burden of proof rests most heavily on the shoulders of the proponents of the minimal glaciation theory, not the opposite standpoint. The evidence for a large-scale LGM glaciation of High Asia is based on the application of the classical, glacial geological method. The validity of this method cannot be called into question even by the proponents of the minimal glaciation theory, since it is the very method of their own discipline – there is not a single glaciation on Earth which has not been reconstructed on the basis of this method. Hence, the falsification of the glacial morphological indicators suggesting a High Asian ice sheet can only concern the detail analysis. By contrast, numerical datings do *not* belong to the method of glacial morphology – we are dealing here with imported techniques – and it is highly probable that these techniques are afflicted with *general* mistakes, the more so as they are still in their introductory phase. It is very easy to show that the conditions required for OSL and TCN dating to be applicable are only rarely, if at all, met by the glacial geological settings. Mere theoretical contemplation leads us further to predict that the resulting dating errors will not be random, but will generally take the form of *overestimated* age statements. The actual findings confirm this prediction and it is high time that we draw the consequences. Strangely enough, however, the advocates of the minimal glaciation theory seem to be more willing to throw the criteria of their own discipline overboard than to doubt the reliability of an imported numerical dating technique.

It may be worthwhile to recall a very similar precedence from almost 150 years ago, when the very first attempt was made to perform an absolute dating on a geological phenomenon. On the basis of innovative notions in thermodynamics, William Thomson, the future Lord Kelvin, had then estimated that the age of the Earth was roughly 100 million years (Burchfield 1974). This date now collided with the just previously published theory by Charles Darwin, whose painstaking assemblage of paleontological, geological, systematic morphological and embryological findings suggested a process of organismic evolution through the mechanism of natural selection. Thomson thought to have contradicted this theory on the sole basis of his own calculations: "The limitation of geological periods, imposed by physical science, cannot, of course, disprove the hypothesis of transmutation of species; but it does seem sufficient to disprove the doctrine that transmutation has taken place through 'descent with modification by natural selection'" (Thomson 1869). The conflict between the two parties is generally presented in such a way – and at the time was conceived of in very much the same light – that it was essentially Darwin who was facing a real dilemma and was left with the serious burden of proof, while Thomson and his lieges thought themselves on safe ground, having done a fair day's work of mathematical physical calculations. De facto, however, not a single element of the Darwinian line of argument had dissolved into thin air through Thomson's thermodynamic calculation – nothing had changed about the paleontological evidence for an organismic evolution. By claiming that the Theory of Natural Selection was *wrong*, Thomson, in his turn, should have been obliged to offer an alternative explanation for this body of evidence – something he never did and never was reproached for. Darwin, on the other hand, took great pains in dealing with Thomson's argument. In the face of his own scrupulously assembled empirical evidence, he eventually came to the conclusion that although he did not know where exactly the error lay, he was forced, with respect to his own evidence, to assume a much older age of the Earth than calculated by Thomson (Burchfield 1974).

Today we know that the contradiction between the two bodies of evidence, in this case too, resulted from a wrongly posited interface relation between physical dating techniques, on the one hand, and the empirical phenomena, on the other: thermodynamics does not provide us with the appropriate yardstick for calculating the cooling down of the Earth's radioactive core. Thomson could not have known this, but the paleontologic morphological evidence on which the Darwinian theory rested should at least have given him some cause for thought; even he should have been obliged to admit that there existed a serious problem – in reality, however, he simply ignored it.

The glacial morphological evidence which can teach us some cautiousness towards the applied numerical dating techniques in High Asia already exists. Moreover, there are clear indications of where more specifically the error of the datings might lie. There are thus very good reasons for taking a closer look at the interface relation between the dating techniques and the Quaternary geological findings.

2 Magnetic Field Excursions

Dating on the basis of Carbon-14 has by now become a very well-calibrated technique. Its major shortcomings lie in its relatively short temporal range (max. 60 ka BP) and in the scarcity of datable organic material in the relevant glacial deposits of High Asian mountain ranges.

The major problem with the dating via OSL (Optical Stimulated Luminiscence) concerns the prerequisite of the material's complete bleaching before its deposition. According to our knowledge of the glacial dynamics, generating a sub-, intra-, para-/ latero- and supra-glacial transport of sediments, we are essentially bound to the assumption of constant mixing between completely bleached, partially bleached and unbleached materials, where the mixing ratios remain unknown. Since the dating technique is only well-calibrated for completely bleached material, while the samples also contain some large or small proportions of unbleached material, the age calculations of the OSL technique will always tend towards overestimation of the actual age (Owen et al. 2008: 518).

Another important factor in the OSL calibration concerns the ratio of cosmic rays to which the material has been exposed after its deposition. However, this ratio can only be roughly estimated. As will be demonstrated in context with the TCN technique, it is very likely that this ratio is estimated too low, which again contributes to the overestimation of the material's age.[1)]

At first sight, the TCN technique (Terrestrial Cosmogenic Nuclides), i.a. on the basis of Beryllium-10, appears to be the most suitable method for assessing the age of moraines. The required material is in most cases available and instability factors like weathering, toppling, inheritance and shielding may possibly be taken into account in one's calculations and limited through the number of samples taken. One major problem, strongly under debate at present, are the appropriate scaling factors, which are beset with great uncertainties especially in low latitudes and high altitudes, i.e. in the entire High Asian region. At present, the differences among the scaling models amount to up to 30% (cf. Owen et al. 2008: 519). The difficulties are the following: the production of terrestrial cosmogenic nuclides (TCN) in the rock samples depends – in the specific region and across the specific time period – on the total amount of cosmic rays which the surface of the sample has been exposed to since breaking away from the in-situ material. De facto, however, the intensity of the cosmic rays is not homogeneous but is subject to temporal fluctuations depending on geomagnetic field variations and solar magnetic activity. In more detail, these intensity variations depend on: a) the turbulences in the heliosphere, caused by the solar wind changes in course of the solar activity cycle, the coronal mass ejections (CMEs), as well as the structure of the interplanetary magnetic field; b) the position of the sun/heliosphere in the interstellar medium; c) the solar activity across larger spaces of time; d) the intensity of the terrestrial magnetic field and its topology; and e) the constancy/variation of the cosmic rays-generating interstellar sources (e.g. super novae, Wolff-Rayet stars). These prehistoric fluctuations in the cosmic ray flux occurring across a large space of time can be approximately reconstructed via the variations of the C-14 and Be-10 cosmogenic isotopes in the Earth's atmosphere, whose chronology has been preserved in fossil wood, ice cores and marine sediments. Correlation analyses have revealed that minima of magnetic activities (i.e. periods of a weak geomagnetic field as well as minima of solar activity) generally coincide with maxima of the cosmic ray flux, which in turn coincide with the terrestrial cold phases (Usoskin et al. 2008, Dergachev et al. 2007). However, due to large-scale mixing and transport processes, the reconstruction of the cosmic ray flux via cosmogenic isotopes in the terrestrial atmosphere only delivers an average value, and is therefore not comparable to the amount of *local* TCN productivity, which is subject to strong variations and ultimately only measurable by means of ground based neutron

1) In a summarizing article Owen et al. (2008) confirm the problems connected with the OSL method. As they put it: it "<...> is extremely difficult to assess the validity of many published OSL ages" (Owen et al. 2008: 518). Consequently their article is focused on TCN datings, setting aside the OSL ages altogether.

monitors (NMs).[2] On the one hand, this local variation is dependent on the structure of the geomagnetic field – the shielding of the cosmic rays through the magnetic field is stronger in low latitudes than it is towards the poles; on the other, it depends on the atmospheric depth which has to be penetrated by the cosmic ray flux; i.e. the intensity of cosmic radiation increases with altitude above sea level. So far, there exists no general consensus as to the question of how these factors can be simulated through scaling models in such a way that the local variation does not distort the calculation of the age. Add to this the fact that in the past the terrestrial magnetic field has been subject to considerable fluctuations (in the interval between 10-100 ka BP, four geomagnetic excursions have been observed: Getenburg 15-20 ka ago, Mono 25-30 ka ago, Laschamp 35-45 ka ago and Kargopolovo 60-70 ka ago) in the course of which the North Geomagnetic Pole moved to the Southern Hemisphere for a short time and during which the geomagnetic field strength was close to zero (Dergachev et al. 2007: 110). Such excursions are accompanied by *positive* intensity variations of the cosmic ray flux, which so far cannot be safely converted into *local* TCN productivity (Kovaltsov & Usoskin 2007). The available scaling factors which model the geomagnetic shielding are accommodated to the present geomagnetic field strength and do not describe field strength fluctuations (Dunai 2000, 2001). The consideration of these secular variations in age estimations would require detailed records of *local* paleointensity and inclination for the past, which however do not exist at present (Dunai 2001: 198). Lifton et al. (2005), who try to incorporate these factors in scaling models, come to the same conclusion: “<...> how best to address past geomagnetic variability in CN scaling models remains an open question” (Lifton et al. 2005: 157). The effects of these variations maximize at latitudes <30°, and both the sensitivity to changes in the dipole strength and to changes in inclination increases with increasing altitude (Dunai 2001: 200-201, Lifton et al. 2005). In High Asia we would therefore, on theoretical grounds, expect to find the strongest effects from geomagnetic field variations, which are, however, at this point *de facto* not taken into account in the calculation of TCN ages. This deficit in the TCN dating is also acknowledged by Owen et al. (2008: 520): “Given the uncertainties between the different scaling models to calculate TCN ages we choose the time-constant scaling model of Lal (1991) and Stone (2000). This does not take into account varied production of TCNs due to changes in the Earth’s geomagnetic field”.

Unfortunately, this is not the only source of uncertainty: the point is that the secular variations of the geomagnetic field are being superimposed by influences of the solar activity (caused by the variability of the solar magnetic field), which, quite independently of the terrestrial magnetic field, is likewise subject to autochthonous variations (Benestad 2006: 165-248, Bothmer & Zhukov 2007, Russell 2007). In this case, too, solar minima correlate with maxima of the cosmic ray flux measured by terrestrial NMs (Usoskin et al. 2008: 442). However, the relationship seems to be complex so that a simple linear extrapolation into the past is not possible (Mursula et al. 2001). The scientific effort of taking into account the variations of the cosmic ray flux due to changes in solar activity when calculating the local TCN productivity is therefore still in its early stages (in particular the millennial-scale solar modulation requires further study; Lifton et al. 2005: 141) – what is clear, at any rate, is that at this stage it cannot possibly mend the inaccurateness of the TCN calculations imposed on High Asia.[3]

2) According to Beer (2000), the differences between natural neutron monitors, like atmospheric isotopes, and man-made monitors are the following: “The <natural> monitor does not record the local neutron flux but is representative for a certain part of the atmosphere, the size of which depends on the mixing and transport processes involved. The temporal resolution is limited by the mean atmospheric residence time of about 1 year and also depends on the precision of the dating of the ice. The interpretation of the cosmogenic nuclide signal is complicated because it is a combination of a production and a transport component.” (Beer 2000: 110). Stozhkov (2007) even draws the conclusion: “Thus, it seems to be unreasonable to use data on Be-10 and C-14 for reconstructing both galactic cosmic-ray fluxes and other characteristics of the solar activity in the past.” (Stozhkov 2007: 135).

3) The following statement in Seong et al. (2008b: 1657) “<...> changes in the cosmic ray flux over time are <...> dominantly caused by changes in the Earth’s magnetic field intensity. TCN calculations model these changes <...>” obviously does not take into account the influence of the solar magnetic activity, and is therefore incorrect. Moreover, Owen himself (who is the corresponding author of Seong et al. 2008b) contradicts this statement in Owen et al. (2008) by pointing out that the time-constant scaling model of Lal (1991) and Stone (2000), which they use for the TCN calculation, “does not take into account varied production of TCNs due to changes in the Earth’s geomagnetic field” (Owen et al. 2008: 520).

In summary, we may thus establish the following general observations: variations of the geomagnetic field intensity and solar activity are independently of each other influencing the intensity of the cosmic ray flux; the relevant scaling factors which would enable us to calculate the resulting variations in local TCN productivity of past times are either not available for both factors, or are not being taken into account (Owen et al. 2008: 520). The weakening of the geomagnetic shielding during geomagnetic field excursions (when the magnetic field strength was close to zero) had the greatest impact on the TCN productivity in low latitudes. Under such circumstances, however, the variations in solar activity, contrary to the existing conditions of today, must also have caused strong effects in low latitudes. There is also the fact that the high altitude in High Asia further enhances both effects. The combination of these factors – which are explicitly neglected by the TCN calculations adopted in Owen et al. (2008) – might easily add up to an increase of TCN productivity by the factor of ~4.5 over the last 30 ka when measured against a time-constant scaling model (Beer 2000: Figure 2 and Figure 4, Lifton et al. 2005, Pigati & Lifton 2004).

We would like to emphasize at this point that neither are we of the opinion that these are the only existing uncertainty factors with respect to the TCN method, nor are we interested in suggesting an exact correction factor. We simply want to demonstrate that there exist very good reasons for the assumption that the TCN ages so far calculated for High Asia are significantly overestimated. In particular, it follows from these observations that the Quaternary geological indicators suggesting a much more extensive LGM glaciation *cannot* be contradicted by TCN datings, but *must* themselves be considered indicators of a miscalibration existing in the TCN datings.

From this theoretical contemplation, we may thus draw the following conclusions: 1) TCN dating techniques are directly dependent on the amount of cosmic ray flux, whose temporal and spatial variations in intensity are at present not reliably calculable; OSL dating is also, but to a minor degree, dependent on the CR flux and has not solved the problem of partial bleaching; both dating techniques tend to produce overestimated ages. They cannot be used for each other's calibration. The C-14 dating method alone can be recruited by both dating techniques for establishing an independent check value, because this method does not rely on the direct, i.e. local CR intensity (but relies only indirectly on the production of C-14 isotopes in the Earth's atmosphere, for which a sufficiently reliable chronology exists).[4] 2) If OSL and TCN dating techniques *generally* produce overestimated ages, it should be possible to assume that they still capture and represent the correct *relative* chronology of glacial stages. The preservation of the relative chronology can therefore *not* be considered an argument in favour of the correctness of the *absolute* datings. Due to the fact that the OSL technique has a dominant uncertainty factor through the incomplete bleaching effect, which has nothing to do with the chronology, one can expect to find that the OSL ages will deviate more significantly from the relative chronology than will the TCN ages.

These predictions shall now be tested by examining a number of examples.

3 Empirical Evidence for General Overestimation

Spencer & Owen (2004) have tried to set up a comparison between OSL and TCN datings in the Hunza Valley (Karakoram). In addition, there are two C-14 ages available, which may at least serve as a reference point for calibration. The two C-14 dates originate from an end moraine of the Minapin Glacier and provide an age of 325 +/- 60 and 830 +/- 80 yrs BP, respectively (Derbyshire et al. 1984, cit. after Spencer & Owen 2004: 187). These dates are being attributed to the Pasu I Glacial Stage (t7). From this same Stage (t7), Spencer & Owen (2004) receive an OSL age estimation of 8.4 +/- 0.9 and 4.3 +/- 0.4 ka at the 60 km distant Batura Glacier (Spencer & Owen 2004: 187). In view of the fact that the moraines from the Pasu I Stage are located very near to the current glacier tongues, Spencer & Owen (2004) conclude that their OSL ages must be

4) It is for the same reason that the CRONUS-Earth project still draws on specific 'Production Rate Calibration Sites', which rely on conventional radiocarbon dates, in order to improve current scaling models which are still not sufficiently reliable.

overestimated and that the C-14 ages must be realistic. We essentially agree with Spencer & Owen's assessment of this data, but we also think that by the same token consequences should be drawn for the remaining OSL ages, which have not coincidentally been corrected through C-14 datings. That is to say, if one further considers all the other ages given in Table 3 of Spencer & Owen (2004: 185), we can clearly see that the discarded OSL ages for Stage t7 (see above) integrate quite regularly into the relative chronology of all the other OSL ages. Note that from this perspective it is not recognisable that the ages of the samples are overestimated by a factor of at least 10(!). Nothing changes in this respect when juxtaposing the OSL ages from Stage t7 to the respective TCN ages (according to the TCN datings, the next older Stage t6 lies at 9.0-10.8 ka). The TCN ages provide us with a more coherent picture with regard to the relative stage chronology than do the OSL ages. In the case of the OSL ages, some samples simply drop out of the chronological order, sometimes exceeding the respective TCN age by a factor of three (UCR lab no. 057), and sometimes falling short of it by a factor of 0.5 (UCR lab no. 055). The t4 Stage, which is only a few kilometres distant from the current glacier tongue, and which has been attributed to the LGM by Spencer & Owen (2004), has an OSL age of 31.5 +/- 5 ka and a TCN age of 21.8 - 25.7 ka. By carefully assuming that the OSL age will only be overestimated in this case by the factor of 5 (not 10), the actual age reduces itself to approx. 6 ka and the TCN age, accordingly, turns out to be overestimated by the factor of 4.

Let us continue to follow this working hypothesis by further applying it to the TCN datings in Seong et al. (2008a), as they have been established for the neighbouring K2 Baltoro Glacier in the Central Karakoram. The inhomogeneity among the TCN datings immediately catches one's eye: In the Hunza Valley, Spencer & Owen (2004) ascribe the LGM to a glacial advance of only a few kilometres, for which the estimated TCN age is ~24 ka. In the Baltoro region located 30-70 (~50) km to the South-East, on the other hand, Seong et al. (2008a) ascribe the LGM (MIS 2) to a glacial advance of more than 100 km, the respective TCN age here being no more than 16 ka! Under normal circumstances, this age should be attributed to the *late glacial* Heinrich I event.[5] The reason why Seong et al. (2008a) feel compelled to associate the LGM with such young dates relates to the fact that they were not able to find any lower-reaching moraines further down the valley, or rather, that the ones they did find valley downwards on Karpochi Rock provided them with such old ages, an average of ~125 ka (Seong et al. 2008a: 7), that they had to ascribe them to the MIS 6. Seong et al. (2008a: 19) interpret the apparent "lack" of actual LGM moraines as follows: "The lack of evidence for a glacial advance during the early part of the last glacial cycle is likely due to the poor preservation potential in this high energy environment as paraglacial and post-glacial processes easily rework and destroy glacial landforms. <...> it is likely that glacial, paraglacial and post-glacial processes destroyed the evidence of former glacial deposits" (Seong et al. 2008a: 19).

All authors who have worked in the Karakoram and the Himalayas agree on the fact that it is one of those regions on Earth, if not *the* region on Earth exhibiting the highest rates of erosion (Hewitt 2009, Owen et al. 2008, Seong et al. 2008a), so that it is rather unlikely to find *older* moraine deposits than those from the LGM – in particular, in the extremely steep and erosive valley flanks. We share this view without limitation. What we do not agree with, however, is the claim that these potential LGM moraines do not exist. In Kuhle (1997, 2001, 2006), high-altitude moraine deposits, glacial grindings and erratic boulders (Photo 1) have been clearly identified for the above-mentioned Baltoro and Hunza regions, and were accordingly used to reconstruct a large LGM glaciation extending across both regions and reaching into the Indus Valley, with the Indus Valley Glacier terminating below 870 m asl. These findings and their glacial geologically founded ascription to the LGM have since been confirmed by Hewitt (2009), while Spencer & Owen (2004) as well as Seong et al. (2008a) continue to ignore these findings, without being able to offer any

5) This is by no means the only case where the ascription of numerical dates to the chronology of the glacial stages happens quite randomly and without further consideration of the large-scale Quaternary geological context. Taylor & Mitchell (2002) critically remark on a similar case of arbitrariness existing in Owen et al. (2001)'s discussion of the Lahul Himalaya: "In dismissing previous OSL dates with little explanation, the work of Owen et al. (2001) raises serious questions as to the accuracy of existing chronologies based on OSL dating and whether comparison between these and the new chronology can be made." (Taylor & Mitchell 2002: 278).

Photo 1 Erratic granite boulder on vertically layered evaporites in the orographic right-hand flank of the Hunza valley, north-western Karakoram (36°28'30"N 74°00'50"E), at 3370 m asl, 900 m above the thalweg. The location of this erratic boulder proves a minimum thickness of the valley glacier of roughly 900-1000 m in the cross-profile of the main valley. The moraines found on the opposite valley flank give evidence of a minimum ice thickness of about 1600-1700 m. Analogue photo M. Kuhle.

alternative explanation for these facts (Kuhle 2008). The only alleged counterargument they are accustomed to bring forward is their numerical datings; however, here too they persist in ignoring the blatant contradictions occurring in their analyses.

Just consider the following climatological dubiousness: According to Seong et al., the high glacial Baltoro Glacier had an ELA depression of ~700 m, whereas the only ~50 km distant Hunza Valley supposedly had a high glacial ELA depression of max. 150 m. What further contributes to the scurrility of this assessment is the fact that the Hunza Valley is nurtured by winter precipitation from the West, while the Baltoro region to the East is only exposed to the current monsoon precipitation, which was disrupted during the last glacial period. This suggests that during the LGM, the Baltoro region must have had a *smaller* ELA depression than the Hunza region. According to Seong et al.'s calculation, however, the exact opposite was the case – but once again the only proof for this climatological "wonder" comes in the shape of the notorious TCN datings!

By simply considering the TCN dates of the boulders from Karpochi Rock – Karpochi Rock is a roche moutonnée in the middle of the 10 km wide Skardu Basin (Indus Valley), where consequently rockfalls and debris flows do not play a role –, the scatter range of ages alone, ranging between 170 and 70 ka, must strike one as suspicious. If one takes the average age of the boulders of 125 ka and reduces it by the factor of 4 (see above), one arrives at the age of ~31 ka and thus not at the age of MIS 6 but of MIS 2. If one takes the youngest age of 70 ka and does the same, one arrives at ~18 ka and thus at exactly the same late glacial age to which the moraines of Karpochi Rock have already been ascribed by Kuhle (2001: ~ 15,000 YBP: e.g. 338).[6)]

In summary, we can say the following: When merely compared among themselves, the age estimations originating from OSL and TCN datings in the Karakoram exhibit a considerable scatter range and a considerable degree of incoherency. Underestimations do not seem to occur whereas overestimations by factors of between 4 and 10 do occur.

Next, we will apply our working hypothesis to yet another region which has been well documented by way of OSL and TCN datings: the south face of the Mt Everest range. There are quite a number of studies to choose from and most of them are being summarised in Finkel et al. (2003) and Owen et al. (2008). Apart from this, there is also a large-scale and very detailed glacial geological analysis of the region by Kuhle (1986, 1987a, b, 2005), where also C-14 dates have been gained, which can serve for calibration purposes. In the side valleys of the Ngozumpa Drangka – a neighbouring valley to the west of the Khumbu-

6) At this point we should like to correct a false statement made by Seong et al. (2008b). They state: "Kuhle (2008) highlights, for example, that he had <...> recognized the till on Karpochi rock (Kuhle, 2001). He failed to note, however, that earlier authors had also mapped these landforms, including Drew (1873), Cronin (1982) and Owen (1988), and others." This accusation is false. In Kuhle (2008), we *exclusively* refer to the *temporal classification* of the till; it is not suggested in any way that we had first "recognized" it. In Kuhle (2001) then, Owen is cited with two articles in this context (Owen 1988a, 1988b) and discussed in three different text passages (Kuhle 2001: 157, 158, 345, 396). The article by Cronin (1982, unpublished) is not cited by Seong et al. (2008a) either; instead, they cite Cronin (1989), and this same article is also cited in Kuhle (2001). Drew (1873) is of minor significance, mainly due to the fact that it was preceded by the fundamental work of Godwin-Austen (1864), which is cited by Kuhle (2001) but not by Seong et al. (2008a), who furthermore, neglect to include the equally relevant works of Lydekker (1881, 1883), Oestreich (1906) and Norin (1925) in their reference list. The accusation of insufficient, neglected citation is therefore completely unfounded and only appears somewhat strange in the face of Seong et al. (2008a)'s total dismissal of Kuhle (2001) and other relevant works by Kuhle (e.g. 1994, 2006).

and Tshola Drangka and located only 10 km from the sampling locations referred to by Finkel et al. (2003) and Owen et al. (2008) (see below) – six C-14 dates between 2,1 and 4,2 ka were gained and attributed to the three neoglacial stages V (Nauri stade), VI (Older Dhaulagiri stade) and 'VII (Middle Dhaulagiri stade) (Kuhle 1986, 1987a: 408, 2005: Figure 19, Table 2). The dates are glacial-geologically consistent with end moraine chronologies and with the respective ELA rising stages from old to young. According to the relative chronology, these three neoglacial stages correspond with the ELA depression of between 560 and 280 m (Kuhle 2005: Table 3, Table 4). In accordance with the chronology as well as the state of preservation, the moraine in the main valley at Periche can be attributed to Stage V (Kuhle 2005: Figure 3, Photo 78-80: V). For this Periche Stage, Finkel et al. (2003) provided TCN datings which placed it into the last High Glacial (23 +/- 3 ka) and hinted at an even weaker glacial advance at around 16 +/- 2 ka. Thus, when compared to the C-14 dates, the TCN dates turn out to be overestimated by a factor of no less than 6.5.

The oldest and most extensive glaciation in the Khumbu region is reconstructed by Finkel et al. (2003) on the basis of till boulders lying up-valley at the bottom of the Tsola-Khola (Tshola Drangka) above 4500 m asl. Here the TCN dates yield age calculations between 86 and 33 ka. Interestingly enough, the current glacier tongue of the Tsola Glacier is already located at 4500 m asl (Kuhle 2005: Photo 66) so that during the Periche Stage this location must have been overridden by ice up to at least 4800 m asl – this, by the way, is also indicated in the map showing the glacial reconstruction of the Khumbu region by Owen et al. (2008: 526, Figure 13B). Hence the, as usual, insufficient description of the locations in Finkel et al. (2003) leaves room for two speculations: either the samples really do stem from above 4500 m asl, from which must then follow that they are time-equivalent with the Periche Stage so that we would be dealing with a variation factor of around 4 *among* the TCN dates for one and the same stage; or, alternatively, the samples were in fact located above at least 4800 m asl and could thus be the remnants of an older stage. By assuming a TCN age of 86 ka and an overestimation factor of 6.5, the age of these moraines is reduced to a late glacial age of ~13 ka, which corresponds directly with the late glacial Stage IV (Sirkung stade) reconstructed by us for the same location via glacial sedimentological and geomorphological indicators (Kuhle 1987a, 2005: Table 4, Photo 66, Photo 78-79: IV).

Interestingly enough, Finkel et al. (2003), as well as Owen et al. (2008), claim that remnants of a more extensive glaciation in the Khumbu region than the ones identified by them do not exist "because intense erosion and slope instability have destroyed much of the glacial evidence" (Finkel et al., 2003: 562). However, as Kuhle (1987a, b; 1998) and in particular the detailed discussion in Kuhle (2005) have demonstrated, this assumption is false. In 4850 m asl, i.e. roughly 750 m higher up the slope in the same transverse profile of the alleged LGM glacier tongue termination at Periche (Finkel et al. 2003: Figure 1), there exist extensive moraine sheets with erratic boulders on the orographic right side of the valley (Kuhle 2005: Photo 78-80). These moraine sheets persist for roughly 30 km down the valley (Photo 2) on both sides of the thalweg (Kuhle 2005: Photo 66, Photo 77, Photo 83-84, Photo 87-89, Photo 90-93, Photo 94-96, Photo 98-99, Photo 101-105, Photo 143, Photo 148-154, Photo 156-160, Photo 211, Photo 221-233, as well as the corresponding granulometrical and morphoscopic sediment analyses: Figure 37-45, 47-51, 58-71, 87-95; Figure 3, 4, 11; and the schematic glacial geological transverse valley profiles 12, 16, 17, 22, 28-30).

With respect to the above findings, the lowest terminus of the glacier tongue belonging to the Imja-Dhud-Koshi-Parent Glacier was reconstructed at ~900 m asl in the confluence area of the Inkhu Khola at 27°28'30'' N/86°43'20'' E (Kuhle 2005: 315, Figure 11, Figure 4, Figure 2 / No.1). The extent and state of preservation of the moraine deposits (Photo 3) – located in a region commonly considered to be the most erosive region on Earth – make it impossible to attribute this ice stage to any other than the Last Glacial. Moreover, the C-14 dates for the Khumbu region also indicate that the OSL and TCN dates are overestimated to the same degree as previously suggested for the Karakoram region.

Finkel et al. (2003) and Owen et al. (2008) do not devote a single word to the C-14 dates first published in Kuhle (1986) and the other glacial

Photo 2 Taken at 3665 m asl from the mountain spur between Phunki Drangka and Imja Drangka (continuation of the Khumbu Drangka valley downwards) (27°50'02" N 86°45'20" E), West from and below Tengpoche Gonda, facing East. The spur is covered with moraine material and, in addition, with glaciolimnic sands. Visible is one of the 1.8 up to 3.4 m long (person for scale) round-edged erratic gneiss boulders with a fresh surface, sitting in a labile position on the outcropping schist in the underground. Here the boulders lie – presumably after having rolled down from the moraine slope, i.e. slightly dislocated from their original location – on glaciolimnic sands which have been deposited in a medial moraine lake, which formerly existed between the orographic right Late Glacial lateral moraine of the Phunki glacier and the orographic left lateral moraine of the respective Imja glacier approx. 300 m above the adjacent valley bottoms. Analogue photo M. Kuhle.

Photo 3 Picture taken at 4390 m asl of the orographic right side of the mid Bote Koshi Drangka (Khumbu Himal), a western parallel valley of the Khumbu Drangka, 12 km down-valley from the current valley glacier (Nangpa-Lunag Glacier), showing the remnants of the ground moraine pedestal (27°52'05" N 86°37'45" E), facing SE down the main valley to the 6369 m high Kusum Kanguru (background), behind the junction with Imja Drangka at 2900 m asl. The erratic gneiss boulder in the foreground has the size of a hut (see person in front) and shows a very fresh surface; it is situated about 100 m away from the foot of the slope. Its source material does not outcrop on this slope. This huge boulder lies 480 m above the valley trail on the cross-profile of the Bote Koshi and approx. 1500 m above the confluence area of the LGP Bote Koshi glacier and Imja glacier with the Dhud Koshi trunk glacier. Analogue photo M. Kuhle.

geological evidence by Kuhle (e.g. 1987a, b, 1988b, 1998, 2005) suggesting a much more extensive LGM glaciation than previously (and currently) supposed. In other words, these comprehensive glacial geological findings in the Khumbu region are simply being ignored by them; however, without offering any alternative explanation.

Furthermore, in their summarizing work, Owen et al. (2008) make the claim that north of the Himalayan main range an ELA depression of merely 300 m during the LGM made for an even smaller glaciation than the one reconstructed by them for the southern slopes (Owen et al. 2008: Figure 13a and Figure 4d). However here too, we are provided with C-14 dates – apart from the comprehensive glacial geological body of evidence (see below and Photo 4) – which once again suggest another interpretation (Kuhle 1988a, b, 1991, 1998, 2002a), and which once again have been ignored by the above-mentioned authors: In the area of the Tsangpo bend in SE Tibet (29°18' N/94°21' E, 3090 m asl) a last strong glacier advance was reconstructed for about and after 9820 +/- 350 YBP. Moreover, there exist datings of trees from an 80 m high exposure, which was analysed in 1989 (Kuhle 1991: Photos 53, 54, 55). The eight C-14 samples stem from the (32 m high) lower part of the exposure and show ages of up to 48,580 YBP (Kuhle 1998: Table 2). The basal limnic sands in which the trunks were embedded have been overlaid by 8 m thick varved clays. They provide evidence of an ice-dammed lake (Kuhle 1991: 198-201, 228-230: Figure 24-27, 43) in this lower section of the Tsangpo Valley at merely ~3000 m asl. Accordingly, this ice-dammed lake is of the same age or younger than 48,580 to at least 9820 YBP. Therefore it is classified as belonging to the LGM (Kuhle 1998: Table 1, Glacier stade 0) up to the Late Glacial (Kuhle 1998: Table 1 Glacier stade I-IV). The counting of the varves yielded that the lake existed for approx. 1000 years. It was situated between the ice complexes I2 and I3 (Kuhle 1998: Figure 23, left-hand side of Namcha Bawa) and was dammed up by the Nyang Qu

Photo 4 Taken at 5280-5300 m asl N of the Khumbu Himal (Cho Oyu) in S-Tibet, from the orographic left-hand flank of the still very wide Kyetrak valley (28°19'30'' N 86°34' E) facing to the S. Visible are far-travelled, light-coloured erratic granite boulders, partly well-rounded, in the foreground (see seated person to compare the proportions). They lie on superficially weathered reddish bedrock sandstones. But also angular local moraine boulders consisting of limestone, which have been moved but little, are preserved here. They prove a complete ice sheet cover on this part of the Plateau with outlet-glaciers through the Himalayan main range. Analogue photo M. Kuhle.

Glacier. The Nyang Qu Glacier, which was an outlet glacier of the ice sheet complex I2, ran down the Nyang Qu valley and eventually reached the Tsangpo Valley (Kuhle 1998: Figure 2, No. 38) 17,5 km down-valley from the exposure (see above). Ground- and lateral moraines (Kuhle 1998: Figure 2, No. 36, 39, 40) (Kuhle 1991: 168-178: Photos 48-52, 56-57; Figure 10-13, 28, 43) confirm that the glacier bended into the Tsangpo Valley. Thus the ice-dammed lake came into being. On the one hand, these C-14 datings give evidence of the timing of the inland glaciation of Central Tibet during the LGM. At the same time, these findings demonstrate that this today entirely glacier-free region north of the Himalayas must once have been covered by an immense glacial ice sheet, extending even to the lowest parts of the Tsangpo Valley at about 3000 m asl, for which an ELA depression of at least 700-800 m was necessary.

By contrast, Burbank & Kang (1991), on whom Owen et al. base parts of their discussion, derive an ELA depression of no more than 100-150 m for the north face of Mt Everest (Burbank & Kang erroneously speak of roughly 400 m) (Burbank & Kang 1991: 16), which is not possible, because the ice stage on which they draw their calculations is located only 200 m below the current glacier termination, which yields: 200: 2 = 100 and not 400). In their tiny research area of merely 8 km in length, the authors ascribe the lowest prehistoric ice stage to Stage 6 (Middle Pleistocene) (Burbank & Kang 1991: 3, 16), but without presenting any datings and by having assessed no more than the relative degrees of weathering. All this is presented and discussed without any reference to and consideration of the comparatively high number (5-7) of lower end moraines and ice stages lying down-valley far outside the above mentioned research area, which had long been mapped and published for neighbouring regions (Kuhle 1987a, 1988a, b, 1990b). Likewise did they ignore the erratic boulders and massive ground moraine sheets lying high above the thalweg in several localities many kilometres down-valley within the Rongbuk Valley: for example, at 4350 m asl (Kuhle 1988b: Figure 2, No. 36, 493-495), or at 3950 m asl in the lower continuation of the Rongbuk Valley, the Dzakar Chu, or in the valley chamber of Kadar in the Pum Qu (the upper Arun Valley), which is another continuation of the Rongbuk Valley and the Dzakar Chu – here, the glacial indicators are found high above the thalweg of the valley which, in this part of the valley, runs at merely 3700 m (Kuhle 1991: 200-205, Photo 80, 82-86; Figure 29-30, 43).

Based on his ice stage chronology, Kuhle ascribed the discussed ice stage in the upper Rongbuk Valley to the oldest neoglacial stage (Nauri Stage V; ~4000-4500 and 5500 YBP, respectively; Middle Holocene) (Kuhle 1988b: 495-500) and not, like Burbank & Kang (1991), to the Middle Pleistocene. To posit a depression of 100-150 m as the maximal ELA depression of the Pleistocene from Stage 6 (Middle Pleistocene) up until today, as this is done by Burbank & Kang, means positing a singularity on Earth which lies beyond the reach of any climatological physical explanation.

The work by Colgan et al. (2006) on TCN datings from Tanggula Shan in Central Tibet provide us with yet another example. From a moraine in 3 km distance from the current glacier, the authors receive a TCN age of ~32 ka. If we assume an overestimation factor of between 4 and 6.5, we receive an age of ~5-8 ka. This age sounds realistic in the face of the Quaternary geological findings in Kuhle (1991). In the Gêladaindong Range (Kuhle 1991: Figure 43, No. 1), the highest adjacent mountain range within the Tanggula Shan, lying to the NW and in 50 km distance from Colgan et al.'s research area, one can even now find stagnant ice remnants in a few decametre distance from the current glacier tongue of the Gêladaindong Glacier (Kuhle 1991: Photo 1 and 5), and in up to about 1-1.5 km distance from the current glacier tongue the vegetation of the surrounding area has not even begun to gain a foothold there; that is, it is largely missing (Kuhle 1991: Photo 3 and 6). These are indicators which repeat themselves at neighbouring glaciers (Kuhle 1991: Photo 3), and which demonstrate how young the most recent glacial retreat of the Tanggula Shan glaciers in question really are. The respective, obviously *historical* moraines have a horizontal distance of merely a few kilometres and a vertical distance of no more than 100-200 m from the glacial margins belonging to the neoglacial high stage (Nauri stade V) from approx. 4000-5500 YBP (Kuhle 1991: 134-139, Figure 6-8, No. 1-2, Photo 5-6). The immediate surrounding of Colgan et al.'s TCN-tested research area north of the Tanggula Shan Pass shows exactly the same Quaternary geological characteristics as well as the same extremely small vertical distances from the current, historical and neoglacial stages (Kuhle 1991: Photo 9, Figure 43, No.4). Quite apart from the above-mentioned glacial geological and vegetation-informed indicators which confirm the historical and neoglacial age ascribed to them by Kuhle, those TCN dates of Colgan et al.'s would suggest an ELA depression of 100 m for the LGM, which would amount to an unprecedented global novelty. Moreover, the ground moraines and glacial landforms extending for over 100 km N and S from the Tanggula Pass, itself covered in ground moraine, are proof enough of an ice sheet covering the Tibetan Plateau in this region (Kuhle 1991: 134-143, Figure 9, 43, No. 2-6, Kuhle 1995: Figure 13-14).

We could easily extend this list of examples, but the fundamental error, resulting from an attempt to reconstruct the glacial chronology solely on the basis of allegedly absolute datings without consulting the comprehensive Quaternary geological body of evidence, should have become sufficiently clear by now.

The entire 12-to-14-level scale of the glacial stages ranging from the high stage of the Wuerm Glacial, MIS 3-2, to the current glacial stages between 1950 and 1980 (Kuhle 1998: Table 1) has not only been captured in the C-14 framework for the regions in S-Tibet and the Himalayas, but has also been applied to various other regions of High Asia, including the Karakoram, Kuenlun, Animachin, Nanshan, Kakitu and Tienshan (Kuhle 2004). Accordingly, in combination with the ELA reconstructions, we have by now been able to establish a very comprehensive and consistent overall picture for all the relevant glacial stages including the LGM glaciation, the Late Glacial stages, the Neoglacial stages and the Historical glacial stages.

To summarise and conclude this section:

The OSL and TCN datings applied to glacial deposits in High Asia are highly inconsistent and contradictory. When measured against the well-calibrated conventional radiocarbon dates, they turn out to be overestimated. The factor of the overestimation lies somewhere between 4 and 10, whereby the TCN-dated samples, which have been ascribed to the LGM or an even older glacial stage, suggest an overestimation factor of between 4 and 6.5.

A possible reason for this overestimation of the OSL and TCN datings lies in the up-to-now imperfect calculation of the scaling factors with regard to glacial High Asia. At any rate, what is certain is that due to the atmospheric cosmogenic isotopes chronology the intensity of the cosmic ray flux was generally higher during the cold phases than it is today. However, since the age calculation crucially depends on the *local* cosmic ray intensity, whose modulation in past times is determined by the complex interrelations between the solar and terrestrial magnetic fields and their secular excursions, a reliable calibration of the OSL and TCN dating techniques in application to High Asia is not possible at present. The overestimation of the ages could indicate that the existing scaling models underestimate the cosmic ray flux during cold phases, and hence lead to the calculation of overestimated ages. If minima of the terrestrial and the solar magnetic field overlap – as has been the case more than once in the past –, the TCN productivity should roughly have exceeded today's by the factor of 4.5 (see above); i.e., a radiation of 1 ka would then be sufficient to simulate an age of 4.5 ka. What is at any rate certain is that such a miscalibration can never be detectable in the dates themselves. For this reason, the CRONUS-Earth project recommends the targeted search for 'Production Rate Calibration Sites' secured, for example, by conventional radiocarbon dates. But even more important is the fact that a calibration of the TCN technique can only proceed on the basis of an already existing Quaternary geological chronology and not the other way round. The currently existing works on High Asia which draw on OSL and TCN datings do not proceed on this principle. What all of these works have in common, however, is that they are all based on a circular argument which we call the "dating fallacy": when moraine material a short distance away from the current glacier tongue is being attributed to the High Glacial on the basis of OSL and TCN datings and when for this very reason indications for a much more extensive glaciation are either being ignored or shoved back to an older glacial stage, without providing a single additional argument which could be said to be independent of the dating techniques previously employed. This is to say that an uncalibrated scale is being taken for an absolute measurement and at the same time one's own scientific method, the glacial geological method, is being abandoned.

There exists a comprehensive body of thoroughly documented and hitherto unrefuted Quaternary geological indicators demonstrating an LGM glaciation in High Asia with an ELA depression of between 1200 and 1500 m, which is not only consistent with the ELA depression of the Northern Hemisphere Glaciation but also parallels the latter in its temporal progression. This is supported by the relative chronology of stages, the extent and state of preservation of the glacigenic indicators, as well as by the respective C-14 datings of High Asia.

4 The Intuition of Aridity

In the face of the questionable findings based on numerical datings as outlined in the discussion above, Owen et al. (2008)'s following statement does not summarise a scientific proof but merely voices a general intuition: "Now it is generally accepted that a large ice sheet did not cover the Tibetan Plateau, at least not during the past few glacial cycles" (Owen et al. 2008: 515). In this point, the "dating fallacy" joins itself seamlessly together with the old story – first brought into being by v. Wissmann (1959) – of 'too much aridity' in High Asia, which allegedly made a glaciation impossible.

It must be admitted that mere intuitions are bad advisors in science. In the first edition of *The Origin of Species*, Darwin suggested in a thought experiment that bears could potentially evolve into whales through gradual steps of evolution (Darwin, 1964: 184). This thought experiment, which was not even meant as a proper argument (Lennox 1991), was counterintuitive to the mind of the audience to such an extent and brought such mockery to Darwin's doorstep that he excluded the passage from future editions of his book. Admittedly, his train of thought may have had a touch of the speculative, but it remains questionable whether Darwin would have been more successful in convincing his readership, had he approached the truth with the more realistic suggestion that whales had evolved from small, antelope-like animals who lingered in coastal areas and lived on fish (Gingerich et al. 2001).

Where does the intuition of the aridity in High Asia, which makes a glacial ice sheet impossible,

Photo 5 Metre-sized erratic granite boulder on a very flat pass at 4200 m asl (34°39'30"N98°02'40"E). It must have travelled over at least 60 km from the Bayan Har Mountain Range, its source area in the South-West. The Bayan Har Range is completely unglaciated today. The boulder lies in a very clayey ground moraine matrix on metamorphic sedimentary bedrock in the underground. Its location documents a glaciation extending over the entire high plateau relief. Analogue photo M. Kuhle.

come from? It comes, as Owen et al. (2008: Figure 4A, B) illustrate, from authors like Klute (1930) and v. Wissmann (1959), neither of whom had ever worked in High Asia and who both contented themselves with drawing on the literature and research of others, next to their own theoretical prejudices. Whilst these works are being valued as "detailed work" in Owen et al. (2008: 517), the reconstruction of an extensive inland ice sheet by Kuhle (Owen et al. 2008: Figure 4C) is being dismissed as "based on field observations and extrapolation of large ELA depressions (> 1,000 m) from the margins of Tibet into the interior regions" (Owen et al. 2008: 517). The assumption that the glaciation of the Tibetan Plateau had been derived merely by extrapolation of the Δ ELA is also suggested in Seong et al. (2008b).[7] It is not entirely clear what Owen et al. and Seong et al. insinuate when they use the word "extrapolation" because as a matter of course the *positioning of the ELA* with regard to a prehistoric Tibetan ice sheet can *only* be reconstructed through its outer margins and *not* through its centerpiece; that is, for the centerpiece of an ice sheet there is *no other way* but to extrapolate the position of the ELA. It is equally self-explanatory and a matter of course that the scientific *proof for the existence* of a Tibetan ice sheet must not rest on *extrapolation*, but must be established through local indicators at all the relevant sites, including the Plateau Centre (Photos 5 and 6). If, on the other hand, the "extrapolation" remark is supposed to mean that concrete glacial geological indicators in favor of a large-scale glaciation in the Plateau Centre are nonexistent, then this is a false statement. The existence of a Tibetan ice sheet during the LGM was demonstrated in great detail (Kuhle 2004) through the identification of extensive moraine coverage as well as the existence of erratic boulders (Photos 4-6) and glacial polishing – in other words,

Photo 6 This large erratic granite boulder (hut size) is located several hundred meters East from the current shoreline of Lake Nako Tso (Na-K'ot Ts'o), facing towards Central Tibet, and has been deposited by the inland ice (Tibetan ice sheet) in an area far away from any current glaciers. Locality: 4225 m asl; 33°33'N/ 79°57'E. Direction: facing E (left margin). Here we are in the lowest and most arid area of Central W-Tibet. Visible are further depositions of huge, light-coloured erratic granite boulders on the highest slope sections of the ridge; signs that they indicate that this ridge was completely overthrust by the ice sheet. The boulders are incorporated into a lighter ground moraine cover lying on dark-coloured metamorphic bedrock, of which the local glacially streamlined mountain ridges are made. Late Glacial and postglacial slope rills, funnels and grooves have been cut into the bedrock. Small flat fans consisting of ground- and ablation moraine were removed after deglaciation. Analogue photo M. Kuhle.

the reconstruction of the Tibetan ice sheet was based on the identification of the same set of glacial geological indicators which had previously been exploited for the reconstruction of the respective large-scale glaciations in North America and Northern Europe. None of Kuhle's indicators have so far been contradicted by anyone. It is symptomatic, in this context, that Owen et al. (2008) consistently endeavour to ignore Kuhle's empirical findings, documented in great detail through terrestrial photography, and instead

7) Seong et al. (2008b) claim that the reconstruction of a Tibetan ice sheet by Kuhle (1974-2008) is due to the fact that "<...> the Δ ELA was <...> erroneously extrapolated across the Tibetan Plateau to argue for an ice sheet at the gLGM" (ibid.). Moreover, Seong et al. (2008b) refer to Kuhle's primary empirical findings in sedimentology and glacial morphology cursorily as "<...> rather equivocal field evidence, including exotic boulders and eroded landforms <...>," which Kuhle apparently used in order "<...> to hypothesise that an ice sheet existed over Tibet during the last glacial." By contrast, Seong et al. refer to the works of those other authors whose views correspond to their own opinion as "extensive studies <...> who present glacial geologic evidence that shows that an ice sheet could not have existed on the Tibetan Plateau during at least the last two glacial cycles". The fact is that, up to now, neither Seong et al. nor any of the authors cited by them have even done so much as *suggest* an alternative explanation for any of the glacial indicators referred to the LGM or LGP by Kuhle. Therefore the labeling of Kuhle's findings (which are documented on ~1700 printed photos and photo panoramas) as "equivocal field evidence", on the basis of which Kuhle supposedly "extrapolated" and "hypothesized", presents an unfounded defamatory polemic. The *only* argument brought forward by Seong et al. and the authors cited by them in opposition to the existence of a Tibetan ice sheet during the last LGM is their OSL and TCN datings, which lack a reliable calibration.

strongly recommend "remote sensing" as the adequate means for reconstructing the former glacier extension in High Asia (Owen et al. 2008: 515).

The argument of 'too much aridity' bases itself on two considerations: First, the cause for a strongly reduced amount of precipitation is commonly seen in connection with the collapse of the Indian summer monsoon during the LGM (Owen et al. 2008: 523). This disruption of the monsoon cycle has been convincingly reconstructed on the basis of various independent indicators (for a comprehensive report see Kuhle 2002b). And second, scientists generally agree on the fact that the existence of the summer monsoon is tightly correlated with the existence of an ice-sheet-free Tibetan Plateau, because the latter serves as subtropical heating surface high above sea level generating the necessary thermodynamics which drive the monsoon. Now, the only available explanation for a high-glacial disruption of the monsoon cycle is that the Tibetan heating surface was during that period of time nonexistent – and this would be achieved if the entire Plateau was covered by a perennial snow sheet (cf. discussion in Kuhle 2002b). In this context, we don't think it is too much to ask that Quaternary geologists accept the idea that such a perennial snow cover can over the years develop into a continuous ice sheet, considering the fact that biologists managed to live with the idea that antelope-like creatures can in due course develop into whales, and further considering that such an idea has already been accepted with regard to the emergence of the Nordic lowland ice sheets.

All that is necessary for such an ice sheet to emerge is an amount of precipitation above 0 and an annual average temperature of below -6°C to -8°C. Even today, large parts of the Plateau surface lie above the permafrost line, thus indicating an annual average temperature of between -4°C and -8°C (Kuhle 1990a, 1997: Photo 138). In the case of a high-glacial N-hemispheric temperature decline by only approx. 8°C down to around -12°C to -16°C, the entire Plateau surface will already be above the snowline, even under otherwise arid-cold conditions. As the model calculations by Kuhle, Herterich & Calov (1989: 204-206, Kuhle 1997: Figure 46-48) have shown, a precipitation of 100 mm/a may already suffice under such conditions in order to make the development of an approx. 1000 m thick inland ice sheet within 10 ka possible. The amount of precipitation necessary for the creation of such an ice sheet lies significantly below that of the current precipitation level (Owen et al. 2008: Figure 3A). And add to this the fact that the large lakes located directly north of the Tibetan Plateau during the LGM, e.g. in the Qaidam Basin, Tarim Basin and the Gobi (Tengger) Desert (Chen & Bowler 1986, Pachur & Wünnemann 1995, Rhodes et al. 1996, Wünnemann & Pachur 1998), must have contributed, esp. towards the north, to the degree of humidity. All climatological model calculations demonstrate that under glacial temperature conditions a permanent glaciation of the Tibetan Plateau is inevitable from a climatological point of view (cf. discussion in Kuhle 2002b).

Moreover, the following problem should not be left unmentioned: If Owen et al. (2008) and Seong et al. (2008b) are certain that during "at least the last two glacial cycles" no ice sheet could have existed on the Plateau, then how do they explain the fact that according to the C-14 datings by Kashiwaya et al. (1991), Van Campo & Gasse (1993), Gasse et al. (1996) and Avouac et al. (1996) the lakes on the Plateau are *all younger than the LGM*? In all of these cases the discrepancy between the C-14 datings, on the one hand, and the OSL and TCN datings, on the other, hints at a general miscalibration of the latter.

To conclude, the problem does not merely lie with the OSL and TCN datings in High Asia which are highly inconsistent and inhomogenous and therefore not at all credible, but also with the climatological and glacial geological consequences for an ice-sheet-free Tibetan Plateau during the LGM, confronting us with massive contradictions. It is – against all intuition – much more difficult to embrace the idea that the Tibetan inland ice sheet did *not* exist during the LGM than vice versa.

Those who nevertheless stand fast by the nonglaciation theory should at least be able to provide some good evidence in support of their position. In this context, the discussed OSL and TCN datings do neither provide *good* evidence, nor can they be considered proper arguments because, whatever the methodological point of view, nevermore do they pass as *indicators* of the nonexistence of a Tibetan ice sheet.

Acknowledgements

We thank Anneliese Kuhle for translating the text into English. We are also grateful to Volker Bothmer (Institute for Astrophysics Universität Göttingen) for valuable discussions and for drawing our attention to important references.

References

Avouac, J.Ph., Dobremez, J.F., and Bourjot, L. 1996. Palaeoclimatic Interpretation of a Topographic Profile Across Middle Holocene Regressive Shorelines of Longmu Co (Western Tibet). Palaeogeography, Palaeoclimatology, Palaeoecology **120**:93-104.

Beer, J. 2000. Neutron Monitor Records in Broader Historical Context. Space Science Reviews **93**:107-119.

Benestad, R.E. 2006. Solar Activity and Earth's Climate. Springer, Berlin/ Heidelberg/ New York.

Bothmer, V. and Zhukov, A. 2007. The Sun as the Prime Source of Space Weather. In: Space Weather - Physics and Effects. (Eds.) Bothmer, V. and Daglis, I.A.. Springer, Berlin /Heidelberg /New York; Pp. 31-102.

Burbank, D.W., Kangjiang CHEN. 1991. Relative Dating of Quaternary Moraines, Rongbuk Valley, Mount Everest, Tibet: Implications for an Ice Sheet on the Tibetan Plateau. Quaternary Research **36**: 1-18.

Burchfield, J.D. 1974. Darwin and the Dilemma of Geological Time. Isis **65**(3): 301-321.

Chen K., Bowler J.M. 1986. Late Pleistocene Evolution of Salt Lakes in the Qaidam Basin, Qinghai Province, China. Palaeogeogr Palaeoclimatol Palaeoecol **54**:87-104.

Colgan, P.M., Munroe, J.S., ZHOU Shangzhe 2006. Cosmogenic Radionuclide Evidence for the Limited Extent of Last Glacial Maximum Glaciers in the Tanggula Shan of the Central Tibetan Plateau. Quaternary Research **65**: 336-339.

Cronin, V.S. 1982. Physical and Magnetic Polarity Stratigraphy of the Skardu Basin, Baltistan, Northern Pakistan. Unpublished MA Thesis, Dartmouth College, New Hampshire, Pp. 226.

Cronin, V.S. 1989. Structural Setting of the Skardu Intermontane Basin, Karakoram Himalaya, Pakistan. – Geological Society of America Special Paper, 232 (Tectonics of the Western Himalayas, Eds: Manlinconico, L.L.; Lillie, R.J.), 183-201.

Darwin, C. 1964. On the Origin of Species. - A Facsimile of the First Edition. Harvard University Press, Cambridge/MA.

Derbyshire, E., LI Jijun, Perrott, F.A., XU Shuying, Waters, R.S., 1984. Quaternary Glacial History of the Hunza Valley, Karakoram Mountains, Pakistan. In: Miller, K. (Ed.), International Karakoram Project. Cambridge, Pp. 456-495.

Dergachev, V.A., Dmitriev, P.B., Raspopov, O.M., Jungner, H., 2007. Cosmic Ray Flux Variations, Modulated by the Solar and Terrestrial Magnetic Fields, and Climate Changes. Part 2: The Time Interval from ~10 000 to ~100 000 Years Ago. Geomagnetism and Aeronomy **47** (1): 109-117.

Drew, F. 1873. Alluvial and Lacustrine Deposits and Glacial Records of the Upper Indus Basin; Part 1. Alluvial deposits. Geological Society of London Quaterly Journal **29**: 449-471.

Dunai, T.J. 2000. Scaling Factors for Production Rates of in Situ Produced Cosmogenic Nuclides: A Critical Revaluation. Earth and Planetary Science Letters **176**: 157-169.

Dunai, T.J. 2001. Influence of Secular Variation of the Geomagnetic Field on Production Rates of in situ Produced Cosmogenic Nuclides. Earth and Planetary Science Letters **193**: 197-212.

Finkel, R.C., Owen, L.A., Barnard, P.L., Caffee, M.W. 2003. Beryllium-10 Dating of Mount Everest Moraines Indicates A Strong Monsoon Influence and Glacial Synchroneity Throughout the Himalaya. Geology **31**: 561-564.

Gasse, F., Fontes, J.Ch., Van Campo, E., Wei, K. 1996. Holocene Environmental Changes in Bangong Co Basin (Western Tibet). Part 4: Discussion and Conclusions. Palaeogeography, Palaeoclimatology, Palaeoecology **120**: 79-92.

Gingerich, P.D., ul Haq, M., Zalmout, I.S., Khan, I.H., Malkani, M.S. 2001. Origin of Whales from Early Artiodactyls: Hands and Feet of Eocene Protocetidae from Pakistan. Science **293**: 2239-2242.

Godwin-Austen, H.H. 1864. On the Glaciers of the Muztagh Range. – Proceedings of the Royal Geographical Society **34**: 19-56.

Hewitt, K. 2009. Catastrophic Rock Slope Failures and Late Quaternary Developments in the Naga Parbat – Haramosh Massif, Uper Indus Basin, Northern Pakistan. Quaternary Science Reviews, doi: 10.1016/j.quascirev.2008.12019.

Kashiwaya, K., Yaskawa, K., Yuan, B., Liu, J., Gu, Z., Cong, S., Masuzawa, T. 1991. Paleohydrological Processes in Siling-Co (Lake) in the Qing-Zang (Tibetan) Plateau based on the Physical Properties of its Bottom Sediments. Geophysical Research Letters **18** (9): 1779-1781.

Kovaltsov, G.A., Usoskin, I.G. 2007. Regional Cosmic Ray Induced Ionization and Geomagnetic Field Changes. Advanced Geosciences **13**: 31-35.

Klute, F. 1930. Verschiebung der Klimagebiete der letzten Eiszeit. Petermanns Mitteilungen Ergänzungsheft **209**: 166-182.

Kuhle, M. 1986. Former Glacial Stades in the Mountain Areas Surrounding Tibet - In the Himalayas (27-29°N: Dhaulagiri-, Annapurna-, Cho Qyu-, Gyachung Kang-areas) in the South and in the Kuen Lun and Quilian Shan (34-38°N: Animachin, Kakitu) in the North. In Joshi S.C., Haigh M.J., Pangtey Y.P.S., Joshi D.R., Dani D.D (eds), Nepal-Himalaya - Geo-Ecological Perspektives, Pp. 437-473.

Kuhle, M. 1987a. Subtropical Mountain- and Highland-Glaciation as Ice Age Triggers and the Waning of the Glacial Periods in the Pleistocene. GeoJournal **14** (4): 393-421.

Kuhle, M. 1987b. Absolute Datierungen zur jüngeren Gletschergeschichte im Mt Everest-Gebiet und die mathematische Korrektur von Schneegrenzberechnungen. In Hütteroth W.-D. (ed), Tagungsbericht und wissenschaftliche Abhandlungen des 45. Deutschen Geographentages Berlin 1985, Pp. 200-208.

Kuhle, M. 1988a. The Pleistocene Glaciation of Tibet and the Onset of Ice Ages- An Autocycle Hypothesis. - GeoJournal **17** (4, Tibet and High-Asia. Results of the Sino-German Joint Expeditions (I), Eds: Kuhle, M.; WANG Wenjing), 581-596.

Kuhle, M. 1988b. Geomorphological Findings on the Build-up of Pleistocene Glaciation in Southern Tibet, and on the Problem of Inland Ice. Results of the Shisha Pangma and Mt. Everest Expedition 1984. - GeoJournal **17** (4, Tibet and High-Asia, Results of the Sino-German Joint Expeditions (I), Eds: Kuhle, M.; WANG Wenjing), 457-513.

Kuhle, M. 1990a. The Cold Deserts of High Asia (Tibet and Contiguous Mountains). - GeoJournal **20** (3): 319-323.

Kuhle, M. 1990b. New Data on the Pleistocene Glacial Cover of the Southern Border of Tibet: The Glaciation of the

Kangchendzönga Massif (8585m, E-Himalaya). - GeoJournal **20**: 415-421.

Kuhle, M. 1991. Observations Supporting the Pleistocene Inland Glaciation of High Asia.- GeoJournal **25** (2/3, Tibet and High Asia, Results of the Sino-German Joint Expeditons (II), Eds: Kuhle, M.; XU Daoming), 133-233.

Kuhle, M. 1994. Present and Pleistocene Glaciation on the North-Western Margin of Tibet between the Karakorum Main Ridge and the Tarim Basin Supporting the Evidence of a Pleistocene Inland Glaciation in Tibet.- GeoJournal **33** (2/3, Tibet and High Asia, Results of the Sino-German and Russian-German Joint Expeditions (III), Ed: Kuhle, M.), 133-272.

Kuhle, M. 1995. Glacial Isostatic Uplift of Tibet as a Consequence of a Former Ice Sheet. - GeoJournal **37** (4): 431-449.

Kuhle, M. 1997. New Findings concerning the Ice Age (Last Glacial Maximum) Glacier Cover of the East-Pamir, of the Nanga Parbat up to the Central Himalaya and of Tibet, as well as the Age of the Tibetan Inland Ice.- GeoJournal **42** (2-3, Tibet and High Asia. Results of Investigations into High Mountain Geomorphology, Paleo- Glaciology and Climatology of the Pleistocene (Ice Age Research) IV, Ed: Kuhle, M.), 87-257.

Kuhle, M. 1998. Reconstruction of the 2.4 Million qkm Late Pleistocene Ice Sheet on the Tibetan Plateau and its Impact on the Global Climate.- Quaternary International **45/46**, 71-108 (Erratum: Vol. 47/48:173-182 (1998) included).

Kuhle M. 1999. Reconstruction of an Approximately Complete Quaternary Tibetan Inland Glaciation between the Mt. Everest- and Cho Oyu Massifs and the Aksai Chin. - A New Glaciogeomorphological Southeast-northwest Diagonal Profile through Tibet and its Consequences for the Glacial Isostasy and Ice Age cycle. GeoJournal 47 (1-2) (Kuhle M. (ed), Tibet and High Asia (V), Results of Investigations into High Mountain Geomorphology, Paleo-Glaciology and Climatology of the Pleistocene), 3-276.

Kuhle, M. 2001. The Maximum Ice Age (LGM) Glaciation of the Central- and South Karakorum: an Investigation of the Heights of its Glacier Levels and Ice Thicknesses as well as Lowest Prehistoric Ice Margin Positions in the Hindukush, Himalaya and in East-Tibet on the Minya Konka-massif. GeoJournal 54 (2-4), 55 (1), Tibet and High Asia (VI): Glaciogeomorphology and Prehistoric Glaciation in the Karakorum and Himalaya. Kluwer Academic Publishers, Dordrecht/Boston/London, 109-396.

Kuhle, M. 2002a. Outlet Glaciers of the Pleistocene (LGM) South Tibetian ice sheet between Cho Oyu and Shisha Pangma as Potenial Sources of Former Mega-floods. In Martini P., Baker V.R., Garzón G. (eds), Flood and Megaflood Processes and Deposits: Recent and Ancient Examples. Special Publication of the International Association of Sedimentologists (IAS). Vol. **32**, pp. 291-302.

Kuhle, M. 2002b. A Relief-specific Model of the Ice Age on the Basis of Uplift-controlled Glacier Areas in Tibet and the Corresponding Albedo Increase as well as their Positive Climatological Feedback by Means of the Global Radiation Geometry. Climate Research **20:** 1-7.

Kuhle, M. 2004. The High Glacial (Last Ice Age and LGM) ice cover in High and Central Asia. Development in Quaternary Science 2c (Quaternary Glaciation - Extent and Chronology, Part III: South America, Asia, Africa, Australia, Antarctica, Eds: Ehlers, J.; Gibbard, P.L.), 175-199. (Elsevier B.V., Amsterdam).

Kuhle, M. 2005. The Maximum Ice Age(Würmian, Last Ice Age, LGM) Glaciation of the Himalaya- a Glaciogeomorphological Investigation of Glacier Trim-lines, Ice Thicknesses and Lowest Former Ice Margin Positions in the Mt. Everest-Makalu-Cho Oyu Massifs (Khumbu and Khumbakarna Himal) Including Informations on Late-glacial, Neoglacial and Historical Glacier Stages, their Snow-line Depressions and Ages. GeoJournal 62 No.3-4 (Tibet and High Asia(VII): Glaciogeomorphology and Former Glaciation in the Himalaya and Karakorum, Ed: Kuhle, M.), 191-650.

Kuhle, M. 2006. The Past Hunza Glacier in Connection with a Pleistocene Karakorum Ice Stream Network during the Last Ice Age (Würm). In: Karakoram in Transition. (Ed: Kreutzmann, H.) Saijid, A., Oxford University Press, Karachi, Pakistan, ISBN-13: 978-0-19-547210-3, 24-48.

Kuhle, M. 2007. Critical Approach to the Methods of Glacier Reconstruction in High Asia (Qinghai-Xizang(Tibet) Plateau, West Sichuan Plateau, Himalaya, Karakorum, Pamir, Kuenlun, Tienshan) and Discussion of the Probability of a Qinghai-Xizang (Tibetan) Inland Ice. Journal of Mountain Science **4** (2): 91-123.

Kuhle, M. 2008. Correspondence to Online Edition (doi.101016/jj. quascirev.2007.09.015 Elsevier) of Quaternary Science Reviews (QSR) article "Quaternary Glacier History of the Central Karakorum" by Yeong Bae Seong, Lewis A. Owen, Michael P. Bishop, Andrew Bush, Penny Cendon, Luke Copland, Robert Finkel, Ulrich Kamp,John F. Shroder Jr. Quaternary Science Reviews **27**: 1655-1656.

Kuhle, M., Herterich, K., Calov, R. 1989. On the Ice Age Glaciation of the Tibetan Highlands and its Transformation into a 3-D Model. GeoJournal **19** (2): 201-206.

Lal, D. 1991. Cosmic Ray Labeling of Erosion Surfaces; in situ Nuclide Production Rates and Erosion Models. Earth and Planetary Science Letters **104**: 429-439.

Lennox, J. G. 1991. Darwinian Thought Experiments: A Function for just-so Stories. In: Horowitz, T. and Massey, G. J. (eds.), Thought Experiments in Science and Philosophy. Rowman & Littlefield, Savage Md, Pp. 223-246.

Lifton, N.A., Bieber, J.W., Clem, J.M., Duldig, M.L., Evenson, P., Humble, J.E., Pyle, R. 2005. Addressing Solar Modulation and Long-term Uncertainties in Scaling Secondary Cosmic Rays for in situ Cosmogenic Nuclide Applications. Earth and Planetary Science Letters **239**: 140-161.

Lydekker, R. 1881. Geology of Part of Dardistan, Baltistan and Neighbouring Districts.– Rec. GsuI. 14.

Lydekker, R. 1883. The Geology of Kashmir and Chamba Territories.– Mem. Gsul. 22.

Mursula, K., Usoskin, I.G., Kovaltsov, G.A. 2001. Long-term Cosmic Ray Intensity vs. Solar Proxies: A Simple Linear Relation Does Not Work. Proceedings of ICRC 2001, 3838, Copernicus Gesellschaft.

Norin, E. 1925. Preliminary Notes on the Late Quaternary Glaciation of the Northwest Himalaya. – Geografiske Annaler, 7.

Oestreich, K. 1906. Die Täler des nordwestlichen Himalaya.– Petermanns Geographische Mitteilungen, Ergänzungsband, 155: 1-106.

Owen, L.A. 1988a. Terraces, Uplift and Climate, in the Karakoram Mountains, northern Pakistan. Unpublished Ph.D. thesis, Department of Geography, University of Leicester, UK (unpublished).

Owen, L.A. 1988b. Wet-sediment Deformation of Quaternary and Recent Sediments in the Skardu Basin, Karakoram mountains, Pakistan.– In: Grott, D.G. (Ed): Glaciotectonics. Forms and Processes; Rotterdam (Balkema).

Owen, L.A., Gualtieri, L., Finkel, R.C., Caffee, M.W., Benn, D.I., Sharma M.C. 2001. Cosmogenic Radionuclide Dating of Glacial Landforms in the Lahul Himalaya, Northern India: Defining the Timing of Late Quaternary glaciation. Journal of Quaternary Science **16**: 555-563.

Owen, L.A., Caffee, M.W., Finkel, R.C., Yeong Bae Seong 2008. Quaternary Glaciation of the Himalayan-Tibetan Orogen. Journal of Quaternary Science **23**: 513-531.

Pachur, H.J., Wünnemann, B. 1995. Lake Evolution in the Tengger Desert, Northwestern China, during the last 40,000 Years. Quaternary Research **44**: 171-180.

Pigati, J.S., Lifton, N.A. 2004. Geomagnetic Effects on Time-integrated Cosmogenic Nuclide Production with Emphasis on in situ ^{14}C and ^{10}Be. Earth and Planetary Science Letters **226**: 193-205.

Rhodes, T.E., Gasse, F., Lin Ruifen, Fontes, J.Ch., et al. 1996. A Late Pleistocene- Holocene Lacustrine Record from Lake

Manas, Zunggar (Northern Xinjiang, Western China). Palaeogeogr Palaeoclimatol Palaeoecol **120**: 105-118.
Russell, C.T. 2007. The Coupling of the Solar Wind to the Earth's Magnetosphere. In: Bothmer, V., Daglis, I.A., (eds.): Space Weather – Physics and Effects. Springer, Berlin/Heidelberg/ New York; Pp. 103-130.
Seong, Y.B., Owen, L.A., Bishop, M.P., Bush, A., Clendon, P., Copland, L., Finkel, R., Kamp, U., Shroder Jr., J.F. 2008a. Quaternary Glacial History of the Central Karakoram. Quaternary Science Reviews, doi:10.1016/j.quascirev.2007. 09. 015.
Seong, Y.B., Owen, L.A., Bishop, M.P., Bush, A., Clendon, P., Copland, L., Finkel, R., Kamp, U., Shroder Jr., J.F. 2008 b. Reply to Comments by Matthias Kuhle (2008) on "Quaternary Glacier History of the Central Karakorum" by Yeong Bae Seong, Lewis A. Owen, Michael P. Bishop, Andrew Bush, Penny Clendon, Luke Copland, Robert Finkel, Ulrich Kamp,John F. Shroder Jr.. Quaternary Science Reviews **27**: 1655-1656.
Spencer, J.Q., Owen, L.A. 2004. Optically Stimulated Luminescence Dating of Late Quaternary Glaciogenic Sediments in the upper Hunza Valley: Validating the Timing of Glaciation and Assessing Dating Methods. Quaternary Science Reviews **23:** 175-191.
Stone, J.O. 2000. Air Pressure and Cosmogenic Isotope Production. Journal of Geophysical Research **105**: 23753 -23759.
Stozhkov, Yu.I. 2007. What Can Be Extracted from Data on the Concentrations of Be-10 and C-14 Natural Radionuclides? Bulletin of the Lebedev Physics Insitute **34**(5): 135-141.
Taylor, P.J. and Mitchell, W.A. 2002. Comment: Cosmogenic Radionuclide Dating of Glacial Landforms in the Lahul Himalaya, Northern India: Defining the Timing of Late Quaternary Glaciation. Owen, L.A. et al. (2001). Journal of Quaternary Science **17**(3): 277-281.
Thomson, W. 1869. Of Geological Dynamics. Popular Lectures Vol. II, pp 73-131, read to the Glasgow Geological Society, Apr. 5, 1896.
Usoskin, I.G., Kovaltsov, G.A. 2008. Cosmic Rays and Climate of the Earth: Possible Connection. C. R. Geoscience **340**: 441-450.
Van Campo, E., Gasse, F. 1993. Pollen- and Diatom-inferred Climatic and Hydrological Changes in Sumix Co Basin (Western Tibet) since 13 000 yr B.P. Quaternary Research **39**: 300-313.
von Wissmann, H. 1959. Die heutige Vergletscherung und Schneegrenze in Hochasien mit Hinweisen auf die Vergletscherung der letzten Eiszeit. Akademie der Wissenschaften und der Literatur in Mainz, Abhandlungen der Mathematisch-Naturwissenschaftlichen Klasse **14**: 121-123.
Wünnemann, B., Pachur, H.J., Li, J., Zhang, H. 1998. Chronologie der pleistozänen und holozänen Seespiegelschwankungen des Gaxun Nur/Sogo Nur und Baijian Hu, Innere Mongolei, Nordwestchina. Petermanns Geographische Mitteilungen **142**(3+4): 191206.