Z. Geomorph. N.F.	Suppl.-Vol. 142	149 – 173	Berlin · Stuttgart	May 2006

Relief, soil and lost forests: Late Holocene environmental changes in southern Tibet under human impact

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with 5 figures and 4 tables

Summary. Results of pedogeomorphological, geochronological and paleobotanical investigations are presented covering the last ca. 4,000 years. The study sites are located in the heavily degraded Kyichu River catchment around Lhasa at 3,600–4,600 m a.s.l. Repeatedly, colluvial sediments have been recorded overlying paleosols. These deposits can be divided into i) coarse-grained sediments with a high proportion of stones and boulders originating from alluvial fans and debris flows, ii) matrix supported sediments with some stones and boulders originating from mudflows or combined colluvial processes such as hillwash plus rock fall, and iii) fine-grained sediments originating from hill wash. The IRSL multi-level dating of profile QUG 1 points to a short-time colluvial sedimentation between 1.0 ± 0.1 and 0.8 ± 0.1 ka. In contrast, dated paleosols of profile GAR 1 (7,908 ± 99 and 3,668 ± 57 BP) encompass a first colluvial episode. Here, the upper colluvial sedimentation took place during several periods between 2.6 ± 0.3 and 0.4 ± 0.1 ka. For the first time in Tibet, a systematic extraction, determination and dating of charcoals from buried paleosols was conducted. The charcoals confirm the Late Holocene presence of juniper forests or woodlands in a now treeless, barren environment. A pollen diagram from Lhasa shows a distinct decline of pollen of the *Juniperus*-type around 4,140 ± 50 BP, which is interpreted as indicating a clearing of forests on the adjacent slopes. It is assumed that the environmental changes from forests to desertic rangelands since ca. 4,000 BP have been at least reinforced by humans.

1 *Introduction*

The geoscientific perception of Late Holocene environmental changes in Central Asia is dominated by the assumption of prevailing climatic changes (e.g. STARKEL 1998, YUZHEN MA et al. 2004, SHEN JI et al. 2005). However, the impact of humans on the environment during the Holocene is often not considered, although it is known from archaeological research, that humans were present during the whole Holocene (e.g. ZHANG HONG et al. 2003, ALDENDERFER & ZHANG YINONG 2004, SEFERIADES 2004). Consequently, the paleoclimatic and paleoecological interpretations from archives assumedly not influenced by humans can go astray in certain circumstances.

This paper presents results of geoscientific and paleobotanical investigations on Late Holocene environmental changes *under human impact* in southern Tibet covering the last ca. 4,000 years. Our study area is the Kyichu River catchment around Lhasa (A.R. Xizang, China; Fig. 1), because even recent evaluations (SONG MINGHUA et al. 2004) perceive the present environment as natural. Generally, research on Late Quaternary climate and landscape history of Tibet performed so far has exclusively dealt with the 'pure' natural genesis (e.g. GASSE & DERBYSHIRE 1996, LEHMKUHL & HASELEIN 2000, HERZSCHUH et al. 2005, SHEN JI et al. 2005). The human impact on the environmental changes is hardly ever considered.

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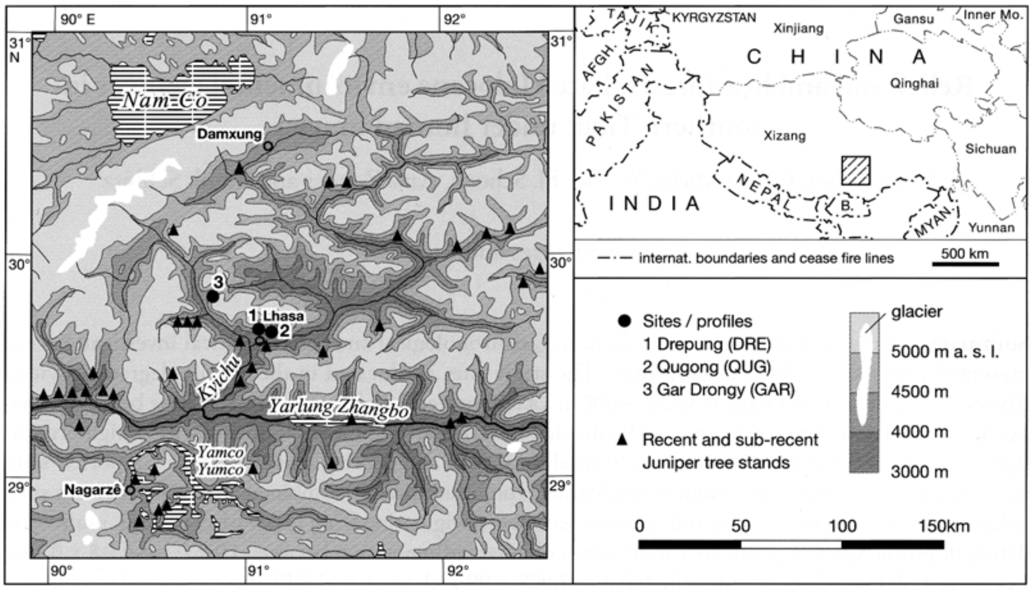

Fig. 1. Study area in southern Tibet (map quoted from MIEHE et al. 2001, modified).

Therefore the multidisciplinary research project 'Present-day dynamics and Holocene landscape history of fragmented forest biocoenoses in Tibet' (DFG-project Mi 271/15) was launched to clarify the more recent environmental history of Tibet. Even though the Kyichu River area is an easily accessible area of Tibet, the Late Quaternary landscape evolution of southern Tibet is in general astonishingly scarcely known. For instance, the conclusions on the Pleistocene glaciations are fiercely controversial (e.g. KUHLE 1998, FRENZEL & SHIJAN LIU 2001, LEHMKUHL & OWEN 2005) and, so far, paleobotanical results are rare (e.g. SCHLÜTZ 1999, TANG LINGYU et al. 2000) because research has been widely concentrated on the outer declivities of the Tibetan Plateau (e.g. THELAUS 1992, FRENZEL et al. 2003).

Human utilisation of mountainous and hilly landscapes unavoidably causes soil erosion by runoff. The correlate sediments are often colluvial sand bodies at footslopes and valley floors burying older soil surfaces. Thus it appears that colluvial sediments and related paleosols can be important sources for conclusions on the human impact in the past. During the last two decades, such geoarchives have been frequently investigated in Europe by geomorphologists and archaeologists to obtain proxy data for reconstructing past environments and land use (e.g. BELL & BOARDMAN 1992, BORK & LANG 2003, WILKINSON 2003). On the other hand, reliable methods for a *direct* dating of colluvial layers by means of luminescence techniques are an important scientific achievement only of recent years (e.g. KADEREIT et al. 2002, FUCHS et al. 2004). However, also unambiguous natural erosion can be represented by colluvial deposits; for instance in certain geomorphological situations (e.g. alluvial fans) or following a downward shift of vegetation zones caused by climatic changes (e.g. REIDER et al. 1988).

In the framework of the current research project, pedogeomorphological investigations were carried out at Holocene colluvial sediments and related paleosols in southern Tibet. They aimed at properties, dating and genesis of these geoarchives. Beside this, the detection and analysis of charcoals in soils contributing to the question whether larger forests once existed on the plateau set a further priority. It was partly possible to perform the geoscientific and paleobotanical investigations in conjunction with archaeological sites.

2 *Regional state of the art*

Pollen diagrams from eastern Tibet show that the re-establishment of forest in the Holocene was influenced by humans and at least from 5,000 BP pastures increasingly replaced forests (FRENZEL & ADAMCZYK 2004). Furthermore, the first emergence of a Neolithic culture in eastern Tibet comprising a so-called 'Neolithic cultural package' (domesticated plants and animals, ceramics, sedentary life) dates from ca. 5,000 BP (Karou site near Chamdo, ca. 600 km northeast of the study area). Several late Neolithic sites from south-eastern and southern Tibet have been recorded between ca. 3,800–3,000 BP (CHAYET 1994, ALDENDERFER & ZHANG YINONG 2004). In contrast, although several presumably Mesolithic sites have been discovered, the archaeology of the plateau between 11,0006,000 BP is essentially unknown.

Consequently, since the Neolithic anthropogenic environmental changes – similar to other regions of the world – may be expected in southern Tibet due to the economic practice of mixed farming. The human impact should have affected the whole environment at least on a local scale. There is some evidence for a quasi-continuity of settlement from the Neolithic via the 'Metal Ages' to Modern Times from some areas (CHAYET 1994). Accordingly, it is to be assumed that the Late Holocene landscape evolution in southern Tibet was determined by both natural and anthropogenic factors.

However, there has been no proof of an ancient human impact on the environment of southern Tibet so far. But comprehensive vegetation surveys since 1994 have revealed isolated forest stands of juniper in desertic environments stretching until 650 km west of the present forest border (MIEHE et al. 2001, 2003). The forests are mostly preserved at Buddhistic sacred sites and they are not bound to water surplus sites or any other favoured niche habitats. The trees are luxuriantly fruiting and regeneration is observed where grazing is excluded. Thus the hypothesis has been derived that southern Tibet once had forests consisting of *Juniperus tibetica* and *J. convallium* (FARJON et al. 2000). Recent modelling experiments support this view (BÖHNER & LEHMKUHL 2005) or do not consider the *Cupressaceae* (SONG MINGHUA et al. 2004).

Reforestation experiments with *Juniperus convallium* and *Cupressus gigantea* on four plots on south-facing slopes above Lhasa since 1997 have proved the hypothesis that at least around Lhasa trees could grow (MIEHE et al. 2003). Rain-gauge measurements revealed 443 mm/a at the valley floor (3,650 m a.s.l.) increasing to 715 mm/a at the middle slope (4,650 m a.s.l.). Mean monthly temperatures from May to September are well above 10 °C, showing that this site has a 'forest climate'. The conclusion is that it is far more difficult to explain the absence of forests than the hypothesis that humans have destroyed forests and changed this environment to the present desertic badland over the millennia.

Up to now, no attention has been given to the potential of pedogeomorphological and geoarchaeological research possibly indicating the early human impact in southern Tibet (JUNGERIUS 1985, WATERS 1992). Only a few results concerning this matter have been published so far even from the adjacent areas of High Asia (e.g. CUI ZHIJIU et al. 1995, BAADE & MÄUSBACHER 2000, GELDMACHER et al. 2004).

Generally, only little pedogenic research from Tibet has been published in 'western' journals so far (e.g. SMITH et al. 1999, XIAOMIN FANG et al. 2003, KLINGE & LEHMKUHL 2005). Further research considering soils was focussed on soil-relevant substrates, such as aeolian sediments and moraines, or aimed at geochronological questions (e.g. LEHMKUHL et al. 2000, 2002). However, research dealing with the complex relationship soil-vegetation-man *and* its historic dimension has been performed only now (KAISER 2004, KAISER et al., subm.).

3 *Methods*

In 2003, a total of 23 soil profiles in the Lhasa region were recorded both at single sites and along geomorphological transects. The profiles were described and sampled according to both the international (FAO 1990) and the German soil science standard (AG Boden 1994). Horizon designations and soil types are given using WRB (ISSS-ISRIC-FAO 1998, slightly modified). Differing from the ordinary German practice, which prefers to reserve the term 'colluvial' for sediments poor in coarse matter, also badly sorted waterlain sands with stones and boulders originating from alluvial fans and slope processes shall be named as 'colluvial' in the following.

Only soil profiles having additional chronological and botanical data are documented here with selected parameters (Table 1, Fig. 2). After sieving to 2 mm, humus and carbonate destruction and dispersion with sodium pyrophosphate, a combined pipette and sieving test was used to determine the grain size distribution. Samples were treated by burning for two hours at 550 °C to estimate the organic content (loss-on-ignition = LOI). The LOI contains an overestimation of organic matter (silts = ca. 2%), which is caused by water bound in minerals and oxides. $CaCO_3$ was determined volumetrically (Scheibler-method). Soil ph was analysed potentiometrically in 0.01 M $CaCl_2$. Six AMS-radiocarbon dates, analysed in the Erlangen laboratory, were obtained from the profiles (Table 2). Additionally, two datings from the pollen diagram Lhasa 1 are documented. Normally, the ^{14}C ages discussed in the text are uncalibrated (BP-values). However, data of different chronological systems are declared expressly (calibrated ^{14}C ages = cal BP-values or BC-values, IRSL ages = ka-values).

Luminescence dating (IRSL) was carried out at the Marburg luminescence dating laboratory on polymineral fine grain (4–11 μm), using an additive dose multiple-aliquot protocol. Samples were prepared as described by FRECHEN et al. (1996). Laboratory irradiation was performed at room temperature with a $^{90}Sr/^{90}Y$ beta source ($\sim$ 6 Gy min^{-1}), and a maximum radiation doses of either 118 Gy and 353 Gy. All samples were stored at room temperature for 8 weeks, preheated (16 h at 160 °C) and stored for two more days. Luminescence measurements were carried out on a Risø TL-DA 15 reader using IR-Diodes (880 ± 80 nm) for stimulation (BØTTER-JENSEN et al. 1991) and a blue (390–480 nm) transmitting filter pack (Corning 7–59, Schott GG400 and Schott BG39) for detection. Equivalent doses were determined by integrating the first 40 s of the 200 s

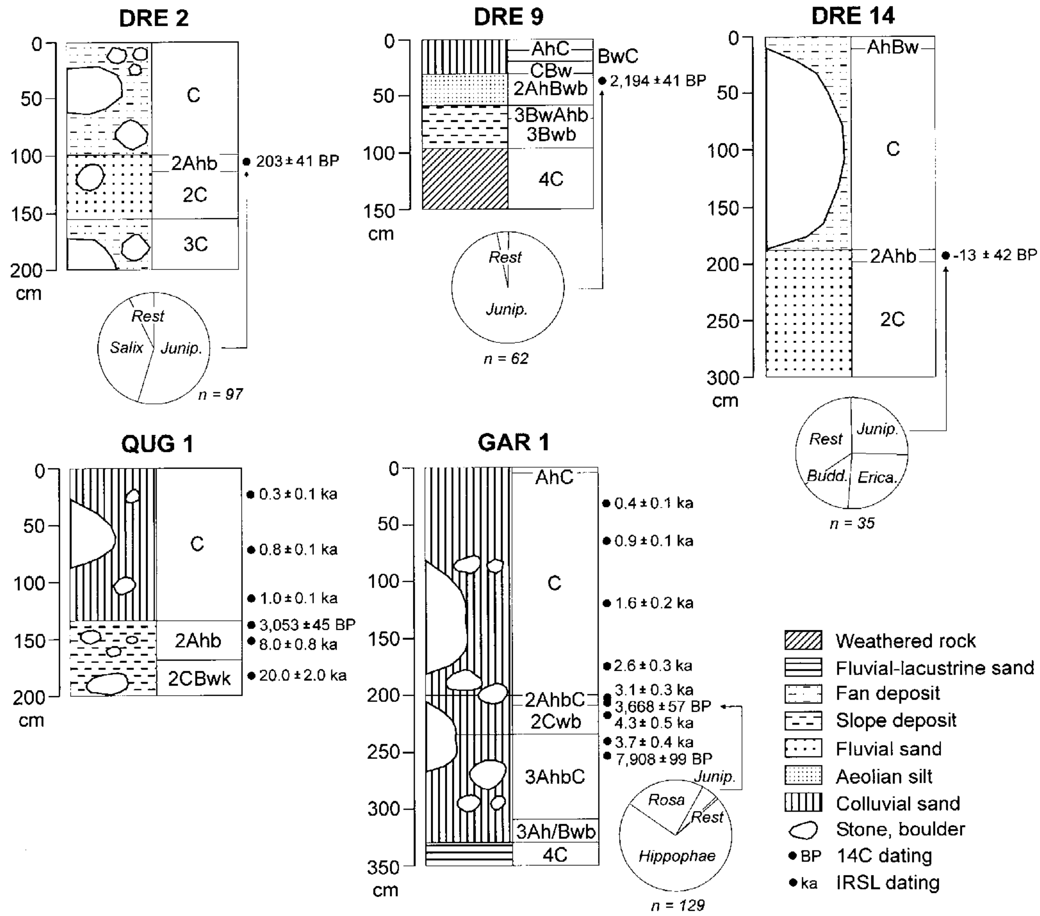

Fig. 2. Pedogeomorphological, geochronological and paleobotanical data of selected profiles.

IRSL shine down curves. The re-measured natural signal was subtracted as background. Annual sediment dose rates were determined by neutron activation analyses (NAA). A water content of 10 ± 5% was assumed for age calculation, although the natural water content of the samples was generally lower. Lhasa has an annual average precipitation of 443 mm (MIEHE et al. 2001) but the sampled sections were opened some years ago and hence they do not contain the original moisture. Anyhow, an assumed water content of 5 ± 3% would result in slightly younger ages estimates (~ 6%). Short time fading experiments carried out on three samples revealed no signal instabilities after 4 weeks storage. Analytical data and IRSL dating results are summarised in Table 3. Generally, IRSL dates correlate numerically with calibrated ^{14}C dates (cal BP-values).

The charcoal analysed derives from both buried soils, which represent archaeological occupation layers (GAR 1, DRE 2, DRE 14) and a simple buried soil (DRE 9; Table 4). An exact species identification requires an inspection of microscopic features (SCHWEINGRUBER 1990). These iden-

Table 1. Soil data.

Horizon [WRB]	Horizon [KA4]	Depth [cm]	Colour [Munsell]	LOI [%]	$CaCO_3$ [%]	pH [$CaCl_2$]	Clay, Silt, Sand [%]	Texture class [KA4]	>2 mm [%]
QUG 1, *3,679 m a.s.l., 29°42'03.9"N, 91°07'42.2"E, Colluvisol / Arenosol, colluvial sand (1) / slope deposit (2)*									
C	M	0–135	10YR4/4	1,5	0	7,5	8, 24, 68	Sl2	12
2Ahb	II fAh	135–170	10YR5/2	2,5	1,1	7,3	9, 32, 59	Sl3	10
2CBwk	fBcv-C	170–200+	2.5Y5/4	1,4	3,6	7,4	12, 29, 59	Sl4	4
DRE 2, *3,654 m a.s.l., 29°40'04.6"N, 91°02'57.4"E, Colluvisol / Arenosol, fan sediment (1) / fluvial sand (2) / fan sediment (3)*									
C	M	0–100	10YR5/4	0,9	0	6,8	7, 18, 75	Sl2	20-30
2Ahb	II fAh	100–115	10YR5/2	4,0	0	6,8	4, 12, 84	Su2	10
2C	lCn	115–155	10YR6/4	1,7	0	6,7	4, 23, 73	Su2	10
3C	III lCn	155–180+	–	–	–	–	–	–	90
DRE 14, *3,846 m a.s.l., 29°40'42.8"N, 91°02'58.0"E, Colluvisol / Arenosol, colluvial sand (1) / fluvial sand (2)*									
AhBw	M–Bv–Ah	0–20	–	–	–	–	–	Su3	10
C	M	20–190	–	–	–	–	–	Su3	10 (90)
2Ahb	II fAh	190–200	–	4,3	4,7	–	7, 31, 62	Su3	–
2C	lCn	200–300+	–	1,5	0	6,7	9, 46, 45	Slu	–
DRE 9, *4,583m a.s.l., 29°41'42.1"N, 91°03'01.8"E, Colluvisol / Cambisol, coll. sand (1) / aeol. silt (2) / slope deposit (3) / weath. granite (4)*									
AhC	M–Ah	0–10	10YR3/4	–	–	–	–	Sl4	2
BwC	M–Bv	10–20	10YR5/4	2,9	0	6,6	13, 29, 58	Sl4	5
CBw	Bv–M	20–30	10YR4/3	–	–	–	–	Uls	5
2AhBwb	II fBv–Ah	30–57	10YR4/2	3,3	0	6,6	15, 50, 35	Uls	0
3BwAhb	III fAh–Bv	57–72	2.5Y4/3	–	–	–	–	Su2	0
3Bwb	fBv	72–97	10YR5/6	1,8	0	6,6	5, 19, 76	Su2	0
4C	IV lCv	97–110+	multicol.	–	–	–	–	–	75
GAR 1, *3,800m a.s.l., 29°44'25.5"N, 90°49'49.3"E, Colluvisol / Colluvisol / Phaeozem?, colluvial sand (1–3) / fluvial–lacustrine sand (4)*									
AhC	M–Ai	0–3	10YR6/3	2,3	0	5,7	8, 26, 66	Sl3	0
C	M	3–200	10YR6/3	1,4	0	5,8	8, 15, 77	Sl2	5
2AhbC	II fM–Ah	200–208	10YR3/1	5,8	0	6,0	12, 21, 67	Sl4	1
2Cwb	fBv–M	208–235	10YR4/3	1,6	0	6,1	10, 19, 71	Sl3	2
3AhbC	III fM?–A(c)h	235–310	10YR3/2	2,0	0	6,3	12, 23, 65	Sl4	2
3Ah/Bwb	fM?–Ah+Bv	310–330	10YR3/2	2,2	0	6,5	12, 20, 68	Sl4	3
4C	IV flCn	330–350+	2.5Y6/4	2,7	13,7	6,6	18, 8, 74	St3	0

tifications were performed by means of comparison with preparations from living material or from digital photographs of transverse, radial and tangential sections of recent wood species. For these charcoals microscopic examination was carried out on fracture surfaces of the air-dried charcoal bits with a magnification of 5-50 x. It was possible to identify almost all indigenous woods with ease, although the charcoals were often in some parts a glass-like, amorphous mass, or they were blown up by gas pressure during the burning process. In some cases, it is in principle not possible to determine the species: e.g. the *Juniperus* species present in the area cannot be distinguished from each other on the basis of their wood anatomy.

Table 2. Radiocarbon dates. The calibrated ages were calculated using the software Calib Rev4.4.2 (STUIVER & REIMER 2004).

Profile	Depth [cm]	Lab. No.	^{14}C age [years BP]	Age calibrated [years BP]	Material dated	$\delta^{13}C$ [‰]
QUG 1	140-145	Erl-6783	3,053 ± 45	3,339-3,210	bone	-14.8
DRE 2	100-115	Erl-6776	203 ± 41	194-146	Juniperus charcoal	-21.6
DRE 14	190-200	Erl-6778	-13 ± 42	–	Juniperus charcoal	-21.6
DRE 9	30-57	Erl-6777	2,194 ± 41	2,306-2,235	Juniperus charcoal	-21.0
GAR 1	200-208	Erl-6782	3,668 ± 57	4,085-3,909	Juniperus charcoal	-20.5
GAR 1	250-255	Erl-8070	7,908 ± 99	8,783-8,599	humic acids	-21.7
Lhasa 1	81-86	Hv-21331	575 ± 120	659-510	peat	-26,9
Lhasa 1	132-148	Poz-8406	4,140 ± 50	4,813-4,571	organic detritus	-29.6

4 *Settings*

The sites investigated belong to the lower Kyichu River catchment of southern Tibet (total catchment area = 32,588 km^2, total river length = 530 km, total altitude difference = 1,810 m; SØRENSEN 2003; Figs. 1, 3), which is part of the Yarlung Zangbo system. The valley slopes under consideration emerge from the wetlands of the Kyichu River floodplain in 3,650 m a.s.l. (Qugong and Drepung site) and the gravel terrace of the Tolungchu River in 3,750 m a.s.l. (Gar Drongy site), while the mountains surrounding them rise up to more than 5,000 m a.s.l. The main geological structures are W-E- and NW-SE-oriented dissecting bedrock of granite (Atlas of Tibet Plateau 1990). A high gradient in altitude and the tectonic setting have produced a wide variety of geomorphological processes, sediments and soils. According to LEHMKUHL et al. (2002), the Lhasa area is characterised vertically by following geomorphological zones: i) zone of fluvial processes and sand fields/dunes (up to ca. 3,800 m a.s.l.), ii) zone of torrent valleys and gully erosion (up to ca. 4,200 m a.s.l.), iii) zone of steppe gullies (up to ca. 5,100 m a.s.l.) and iv) zone of periglacial processes (above ca. 5,100 m a.s.l.). The recent snowline is calculated at about 5,800 to 6,000 m a.s.l. However, during the Pleistocene glacial periods the lowering of the snowline was about 300 to 800 m.

Pedologically, the Lhasa area belongs to the zone of 'Cold calcic soils, Brown calcic soils and Aga soils (Kastanozems?)' of southern Tibet (Atlas of Tibet Plateau 1990). So far, the pedological records available only allow a raw characterisation of the soil distribution in this area (Atlas of Tibet Plateau 1990, SCHRIEVER 1998, SMITH et al. 1999, KAISER 2004): The permanently active floodplain of the braided Kyichu River is characterised by mobile gravels and sands. Temporarily active or inactive parts of the floodplain (e.g. terraces) have Gleysols and Colluvisols developed from fluvial sands and silts/loams. Chernozems, Calcaric Cambisols and colluvial soils occur on inactive parts of alluvial fans, footslopes and lower slopes. Locally, active aeolian sand fields cover the upper floodplain and parts of the slopes. The middle slopes are dominated by Cambisols developed from silty loesses. Leptic Cambisols, Leptosols as well as barren rock associated with inactive and active periglacial forms follow on the upper slopes and top positions.

Table 3. Dosimetry data and IRSL dates. The ages were calculated using an alpha efficiency of 0.08 ± 0.02 and a water content of 10 ± 5%. [1] = KosmDL v1.0 software (Karelin 2000), [2] = Neutron activation analyses, [3] = max. beta dose of 353 Gy.

Lab. No.	Sample	Depth [cm]	Cosmic. dose [µGy a^{-1}] [1]	U [2] [µg g^{-1}]	Th [2] [µg g^{-1}]	K [2] [%]	Do [Gy ka^{-1}]	Natural moisture [%]	ED [Gy]	IRSL age [ka]
MR0389	QUG1	25	332 ± 17	6.04 ± 0.30	32.20 ± 1.61	2.36 ± 0.12	9.0 ± 1.0	0.19	3.1 ± 0.6	0.3 ± 0.1
MR0390	QUG2	73	321 ± 16	5.45 ± 0.27	35.30 ± 1.77	2.42 ± 0.12	9.2 ± 1.0	0.25	7.0 ± 0.6	0.8 ± 0.1
MR0391	QUG3	115	312 ± 16	4.36 ± 0.22	28.00 ± 1.40	2.85 ± 0.14	8.3 ± 0.8	0.29	8.3 ± 0.5	1.0 ± 0.1
MR0392	QUG4	122	310 ± 15	5.10 ± 0.26	31.80 ± 1.59	2.72 ± 0.14	8.9 ± 0.9	1.22	71.4 ± 1.3 [3]	8.0 ± 0.8
MR0393	QUG5	153	303 ± 15	3.73 ± 0.19	31.30 ± 1.57	2.51 ± 0.13	8.1 ± 0.8	0.81	162 ± 2.0 [3]	20.0 ± 2.0
MR0394	GAR1	31	328 ± 16	4.71 ± 0.24	29.70 ± 1.49	2.62 ± 0.13	8.4 ± 0.8	2.21	3.6 ± 0.8	0.4 ± 0.1
MR0395	GAR2	65	320 ± 16	6.06 ± 0.30	35.50 ± 1.78	2.94 ± 0.15	10.0 ± 1.0	3.70	8.7 ± 0.6	0.9 ± 0.1
MR0396	GAR3	120	308 ± 15	6.23 ± 0.31	40.50 ± 2.03	2.79 ± 0.14	10.5 ± 1.1	3.54	16.7 ± 0.8	1.6 ± 0.2
MR0397	GAR4	175	296 ± 15	5.74 ± 0.29	40.90 ± 2.05	3.07 ± 0.15	10.6 ± 1.1	2.51	27.6 ± 0.8	2.6 ± 0.3
MR0398	GAR5	204	290 ± 14	5.36 ± 0.27	33.80 ± 1.69	2.41 ± 0.12	9.0 ± 0.9	5.98	28.1 ± 0.7	3.1 ± 0.3
MR0399	GAR6	218	288 ± 14	4.90 ± 0.25	32.00 ± 1.60	2.28 ± 0.11	8.4 ± 0.9	3.44	35.8 ± 1.1 [3]	4.3 ± 0.5
MR0400	GAR7	243	283 ± 14	6.22 ± 0.31	42.10 ± 2.11	3.09 ± 0.15	11.0 ± 1.1	6.10	41.1 ± 1.3 [3]	3.7 ± 0.4

Table 4. Charcoal determinations.

Taxa	Profile							
	DRE 2		DRE 14		DRE 9		GAR 1	
	3,654 m a.s.l.		3,846 m a.s.l.		4,583 m a.s.l.		3,800 m a.s.l.	
	[n]	[%]	[n]	[%]	[n]	[%]	[n]	[%]
Betula	–	–	1	2,9	–	–	–	–
Buddleja	–	–	5	14,3	–	–	–	–
Caragana	–	–	–	–	1	1,6	–	–
Clematis	–	–	2	5,7	–	–	–	–
Ericaceae, cf. Rhododendron	3	3,1	4	11,4	–	–	–	–
Ericaceae, cf. Vaccinium	–	–	5	14,3	–	–	–	–
Gramineae	–	–	1	2,9	–	–	1	0,8
Hippophae	2	2,1	2	5,7	–	–	91	70,5
Juniperus	53	54,6	9	25,7	60	96,8	7	5,4
Lonicera	–	–	–	–	1	1,6	–	–
Pinus	–	–	2	5,7	–	–	–	–
Populus	–	–	2	5,7	–	–	–	–
Rosa	2	2,1	1	2,9	–	–	30	23,3
Salix	37	38,1	1	2,9	–	–	–	–
Σ	97	100	35	100	62	100	129	100

The present climate of Lhasa (3,650 m a.s.l.) is characterised by a mean annual temperature of 7.7 °C, summer temperatures of more than 15.5 °C and winter temperatures below -2.1 °C as well as a mean annual precipitation of 443 mm (DOMRÖS & PENG 1988, MIEHE et al. 2001).

Livestock grazing and fuel wood extraction have widely replaced the natural vegetation and left eroded badlands behind. The remnants of the natural plant cover have been nearly eliminated with the effect that the present desertic pastures are considered as natural (ZHANG JINWEI 1988, Atlas of Tibet Plateau 1990, SONG MINGHUA et al. 2004).

The alluvial fans and footslopes are exposed to a strong, year-round grazing impact of cattle, sheep and goats. Although out of reach for humans and livestock, also steep cliffs of active gullies cut into colluvial sediments as well as deeply weathered granite bedrock lack any larger shrubs or trees. Such sites are not stable enough for shrubs and trees. The cover and size of woody phanerophytes depends on human impact by woodcutting for fuel use or browsing of livestock. The prevailing thorny shrubs of *Sophora moorcroftiana* rarely exceed 0.8 m in height, but can reach 2 m at safe sites. This applies also to the dominant wormwood *Artemisia santolinifolia*, which is commonly browsed down to the woody base during winter. Larger shrubs of *Buddleja* spp. and *Cotoneaster* can potentially grow as trees of 5 m if not cut or browsed, but are rarely found larger then 0.8 m at accessible sites. The cover of rhizomatous and trampling-resistant grasses depends on the actual grazing pressure and rarely exceeds 20%. Among herbs, annual grazing weeds and ruderal weeds are common, covering less than 20%. Barren surfaces not affected by permanent trampling are sealed with blue algae and liverworts. In the shelter of residual granite boulders a large quantity of trampling-sensitive herbs grow in between luxuriant shrub thickets. This plants have been recorded also from *Cupressus* and *Quercus* forest at present 200 km further to the east.

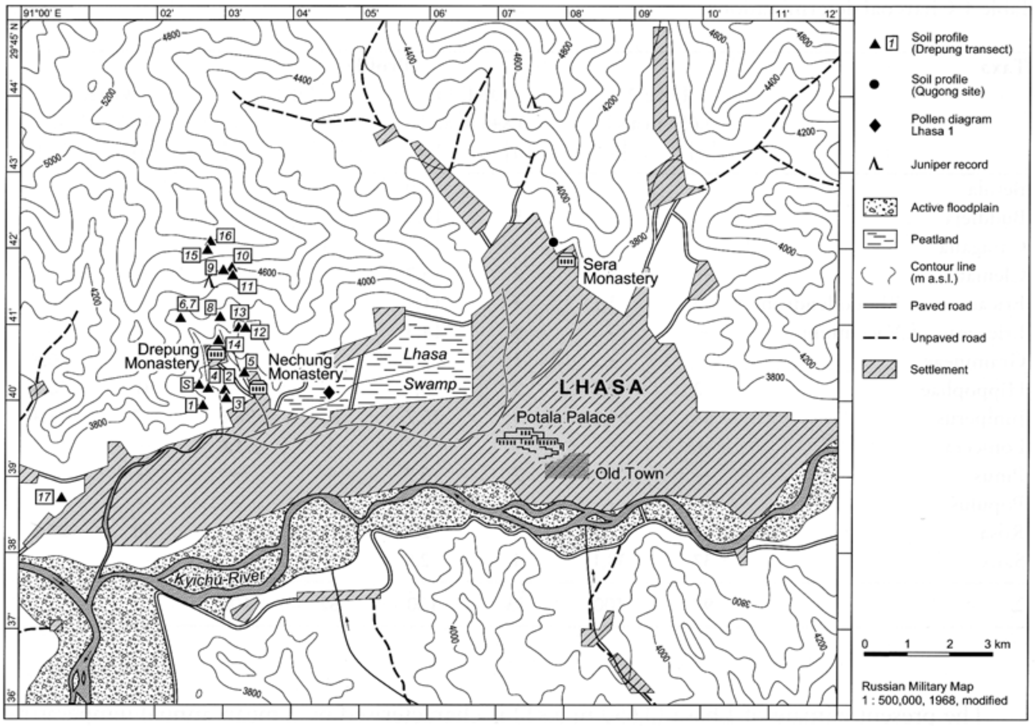

Fig. 3. Topography and sites investigated in the Lhasa area.

With increasing humidity (not necessary lower grazing pressure) above 4,100 m a.s.l., the plant cover reaches 60 to 80%. Only on easily accessible ridges is the ground cover kept open due to a higher trampling impact. Shrubs form dense thickets of 2 to 3 m in height, which are accompanied by tall forbs at their margins. Grazed slopes bear pastures with *Kobresia* and *Stipa* as the main graminoids. Gully erosion is less frequent than below 4,100 m a.s.l., but chafing sites of yaks with barren soil increase. Above 4,600 m a.s.l. alpine pastures of *Kobresia pygmaea* accompanied by cushions are dominant. In this zone, the associated felty sedge turf is nearly closed and protects the slopes against trampling damage and erosion. However, subalpine thickets around boulders show that the prevailing sedge turfs and cushions replace a taller vegetation more sensitive to grazing, browsing and trampling.

Forests or even trees are absent in the surroundings, although the species composition of the pastures and the thickets in less accessible sites partly show a forest flora. A comprehensive survey of the last ten years, however, revealed a few remaining trees of *Juniperus convallium* above Lhasa-Qugong in cliffs at 4,600 m a.s.l. (MIEHE et al. 2000, 2003) and a *Juniperus pingii* shrub on the Lhasa-Drepung slope at 4,530 m a.s.l. found in 2003 (Fig. 3).

The assumption that the present-day vegetation cover of the mountains around Lhasa is not natural, is corroborated by fenced plots of grazing exclosure experiments on the slopes above Lhasa-Nechung (3,750–4,650 m a.s.l.) and west of Lhasa-Sera (3,750–4,600 m a.s.l.) established in

1997 (MIEHE et al. 2003). In the strongly degraded pastures on the footslopes, the vegetation cover increased to 100% and notorious grazing weeds disappeared. Moreover, the successful cultivation of non-irrigated tree species of southern Tibet (*Juniperus convallium, Cupressus gigantea*) in these exclosures since 1999 most probably show that the south-facing slopes of the Kyichu River catchment are potentially forested. While *Juniperus convallium* relics occur only a few kilometres away from the plots, *Cupressus gigantea* relics are found down the Yarlung Zhangbo River valley 200 km to the east. The largest cypress saplings in the plots reached 1 m in height after five years. During the dry season in 2003/04 two plots at 3,750 m a.s.l. were set on fire, giving evidence that the phytomass recovers in only five years time to a state in which fire-clearing can be a successful tool of humans.

Since the sites investigated belong to different types of micro-landscapes, more detailed descriptions of the natural environment will be given in the results chapter.

5 *Results*

5.1 *Lhasa-Qugong site*

The second major Neolithic site found on the Tibetan Plateau – after Karou site, Chamdo – is Qugong, located 5 km north of Lhasa-City next to the Sera Monastery at an elevation of 3,680 m a.s.l. (Institute of Archaeology 1999, ALDENDERFER & ZHANG 2004, Fig. 3). The site is situated along the footslope of a hill at the base of a higher mountain ridge. Between 1990 and 1992, archaeological excavations took place in an area of ca. 4,000 m^2. Besides archaeological investigations, also minor studies in zoology, paleobotany, geochronology and geochemistry were performed. The site is divided into a settlement and a necropolis. According to published radiocarbon dates, the site was occupied as early as 1,750 BC (ca. 3,700 BP), and was probably abandoned by ca. 1,100 BC (ca. 3,000 BP). The faunal remains indicate animal husbandry (sheep, pig) as well as hunting activities (e.g. yak, musk deer, red deer – the latter is known from forests or woodlands!). Unfortunately, there is no clear information with regard to plant cultivation directly from the site. However, the archaeological material allows the conclusion that the subsistence of the Qugong people was characterised by a mix of hunting, animal husbandry and plant cultivation. They used chopping tools for land reclamation, cutting implements for crop harvest and rotary querns for corn processing (Institute of Archaeology 1999).

As the trenches of the excavations were still open, it was convenient to record and sample a section located in the settlement area of the site. Profile QUG 1 is located at a hill's footslope, which is a few decametres high and mostly exposing barren granite. Bedrock outcrops only 10 m up-slope the profile. QUG 1 forms a sequence of a topping colluvial sediment and a buried paleosol developed from slope deposit (Fig. 2, Table 1). All horizons consist of loamy sand. With increasing depth, the amount of clay rises slightly. On the other hand, the proportion of coarse matter (>2 mm) decreases from 12 to 4%.

The topping colluvial layer bears some stones and boulders of 150 cm maximum axis length. Due to the lack of a topsoil horizon (e.g. Ah), this layer probably was subjected to minor post-depositional erosion. The modern soil is assigned to a Colluvisol.

The 35-cm-thick upper part of a buried paleosol (2Ahb) represents the occupation layer. As visible in adjacent sections and also deduced on the basis of the published data, there is only one but relatively thick occupation layer at Qugong site. This greyish brown 2Ahb horizon contains a large quantity of burned and broken stones, pot shards, bones and stone flakes. A distinct enrichment of organic matter is proven by a LOI of 2.5%. Both the absence of mollic properties and the downwards following weakly developed 2CBwk horizon assign this paleosol to an Arenosol.

The underlying 2CBwk horizon is dominated by features of the parent material. However, the light brownish colour and the enrichment of secondary carbonates points to a weak pedogenic imprinting of the layer. The largest stone is of 20 cm axis length.

One radiocarbon sample of animal bone was taken from the 2Ahb horizon and yielded an age of 3,053 ± 45 BP (= ca. 3,270 cal BP; Fig. 2, Table 2). Unfortunately, only some very small and smeary pieces of charcoal have been found, not allowing extraction from the soil and further analysis. The IRSL age estimates indicate an accumulation of the overlying layer of colluvial sand within the last thousand years (Fig. 2, Table 3). Two samples from the underlying slope deposits yielded ages of 8.0 ± 0.8 ka and 20.0 ± 2.0 ka.

5.2 *Lhasa-Drepung site*

The Drepung site comprises a number of soil profiles along a geomorphological transect from 3,640 to 4,890 m a.s.l. in the north-western periphery of Lhasa (Fig. 3). This transect covers the main geomorphological units i) valley of the Kyichu River, ii) alluvial fan and footslope, and iii) steep mountain slope (Fig. 4).

On the upper and middle slopes, shallow soils and barren granite rock dominate. The lower slope and the alluvial fan, however, are composed of thick sediment sequences. Here, alternating slope deposits, fluvial and aeolian sediments attain a maximum thickness of ca. 15 m. The fan is subdivided into a proximal part consisting of several accreted fan cones disemboguing from small mountain valleys. On the other hand, the distal part consists of one large weakly inclined plain. Both parts are heavily dissected by gullies. Some of them have permanently flowing streams.

Chernozems, (Calcaric) Cambisols and colluvial soils have been found on the fan. Cambisols developed from slope deposits and loess dominate the middle slope. A local water surplus site is occupied by a Humic Gleysol. Inactive periglacial forms (sorted stripes, solifluction lobes, small depressions) as well as Cambisols were found on the upper slope at around 4,800 m a.s.l. Leptic Cambisols, Leptosols and barren rock follow higher than 4,900 m a.s.l. A topsoil horizon of sedge-turf occurs above 4,400 m a.s.l., which is attributed to the *Kobresia*-vegetation. In the transect, this horizon has a thickness of only a few centimetres and consists of felty remains of fine sedge-roots, amorphous humus and minerogenic matter (designation: 'Afe', suffix *fe* from *fe*lty; KAISER 2004).

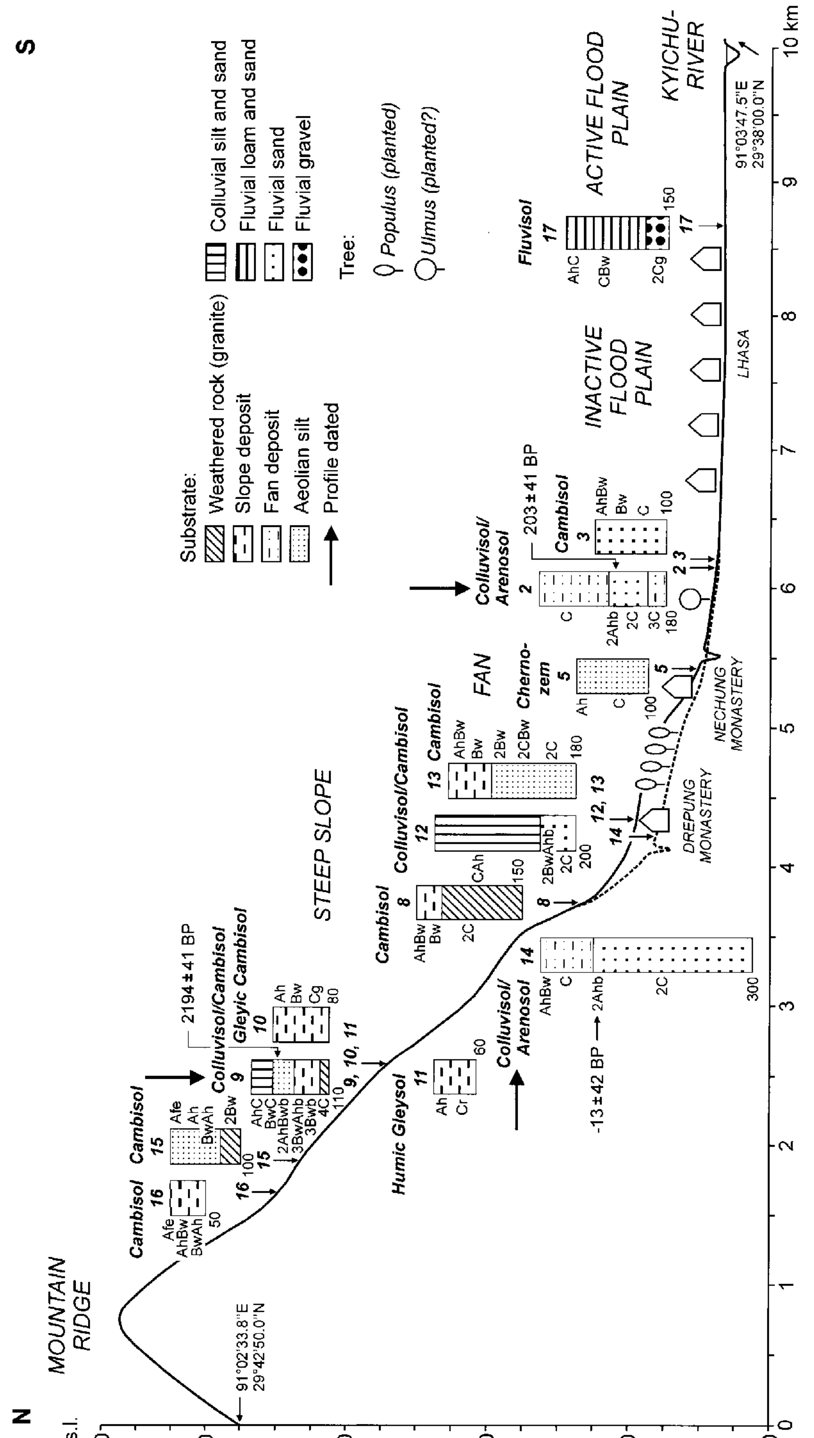

Fig. 4. Lhasa-Drepung transect.

Profile DRE 2

DRE 2 (3,654 m a.s.l.) represents a cliff section of a 2- to 3-m-deep gully lying on the middle portion of the large alluvial fan. The profile consists of a topping layer of fan sediment, an intermediate layer of fluvial sand including buried paleosol and a basal layer of fan sediment (Fig. 2, Table 1). The fine matter of the layers analysed is badly sorted loamy and silty sand.

The upper layer contains well-rounded stones and boulders with 140 cm axis length in maximum. The sandy matrix is nearly free of organic matter. Topsoil horizons lack due to anthropogenic disturbances on the surface. The present soil is classified as Colluvisol.

A subsequent 15-cm-thick 2Ahb horizon is developed from fluvial sand and has a distinct enrichment of organic matter (4.0% LOI). It contains a broad spectrum of artefacts (pot shards, bone ships, charcoal). The charcoal analysis shows a dominance of *Juniperus* (54.6%, Table 4) followed by high portion of *Salix* (38.1%). A radiocarbon sample of juniper charcoal yielded an age of 203 ± 41 BP (= ca. 170 cal BP; Table 2). Provided that there was no reduction of the thickness of the horizon and considering the subsequent 2C horizon, the paleosol is assigned to an Arenosol.

The basal layer of fan sediment is dominated by coarse matter (90%) consisting of stones and boulders with an axis length of 180 cm in maximum.

Profile DRE 14

DRE 14 (3,846 m a.s.l.) was recorded in a sand quarry lying on a small alluvial fan in a stream valley. The wall of the Drepung Monastery is located at a distance of only 20 m.

The profile is divided into an upper layer of fan sediment containing boulders (4.0 x 1.5 m in maximum) and a lower layer of badly sorted fluvial sand containing a buried Arenosol (Fig. 2, Table 1).

The 2Ahb horizon is characterised by an enrichment of both humus (LOI = 4.3%) and carbonate ($CaCO_3$ = 4.7%) and contains lots of artificial objects (pot shards, charcoals, broken bones, excrements). The charcoal determination reveals a broad spectrum of species dominated by *Juniperus* (25.7%, Table 4). Shrubs and dwarf-shrubs such as *Buddleja* (14.3%) and *Rhododendron* (11.4%) are further species occurring in great quantity. The occurrence of *Pinus* (5.7%) and *Vaccinium* (14.3%) probably reflects a certain proportion of not-indigenous wood. A radiocarbon age of -13 ± 42 BP from juniper charcoal indicates the recent-past (Table 2). According to CURRIE (2004), atmospheric nuclear testing had a profound impact on ^{14}C concentrations in modern material, which results in negative radiocarbon ages.

Profile DRE 9

DRE 9 (4,583 m a.s.l.) is situated on the middle slope and comprises a sequence of four layers in an only 150-cm-thick exposure. The upper colluvial layer has a thickness of 30 cm and consists of loamy sand (Fig. 2, Table 1). A clear subdivision into soil horizons containing Bw properties points to recent silicate weathering at this sector of the slope.

The soil buried beneath is developed from aeolian silt and can be classified as Cambisol. There is an only weak enrichment of organic matter according to the LOI value in the 2AhBwb horizon (3.3%). The charcoal spectrum is dominated by *Juniperus* (96.8%, Table 4). Juniper charcoal gave a radiocarbon age of 2,194 ± 41 BP (= ca. 2,270 cal BP; Table 2).

5.3 *Gar Drongy site*

In 2002, this archaeological site was discovered ca. 30 km northwest of Lhasa in a sand quarry lying at ca. 3,800 m a.s.l. on the northeastern valley side of the Tolungchu River, which is a tributary of the Kyichu River (Fig. 1). The site is situated on the footslope of a mountain ridge a few hundred metres high. The adjacent slope is dominated by barren granite showing a core-boulder weathering. Only small parts of neighbouring slope sections are uneroded and consist of loess-slope deposit-rock-sequences. The geomorphic structure of the river valley (e.g. sediments, terraces), however, is essentially unknown so far. Open dwarf-shrublands cover the site and surroundings.

Profile GAR 1 comprises a succession of different colluvial layers of loamy sand overlying a fluvial-lacustrine sand (Fig. 2, Table 1). The upper colluvial layer is 200 cm thick and contains a higher proportion of dispersed coarse matter such as stones and boulders of granite up to a size of 80 x 40 cm. A stone layer occurs directly above and partly penetrates the 2AhbC horizon.

The 2AhbC horizon, developed from colluvial sand, represents an occupation layer. Pot shards, lithic artefacts, bones and charcoal as well as some metal objects such as slag have been detected in this horizon. Typologically, the pot shards are comparable with the Qugong site representing the late Neolithic (Gen Dun, Tibet-Museum Lhasa, pers. com.).

A large quantity of coarse and fine pieces of charcoal has caused a marked black colouration and a relatively high amount of LOI (5.8%). Shrubs dominate the charcoal spectrum (*Hippophae* 70.5%, *Rosa* 23.3%, Table 4). Only a small portion is represented by *Juniperus* (5.4%). With ca. 10 cm step height, there is a noticeable strong undulation of the lower boundary of this horizon, which is possibly caused by the overlying stones.

The radiocarbon dating on juniper charcoal from the 2AhbC horizon yielded an age of 3,668 ± 57 BP (= ca. 4,000 cal BP; Table 2). IRSL age estimates obtained for the upper 250 cm of the profile point to a successive deposition of the colluvial sands within the last 4.3 ± 0.5 ka. IRSL from the adjacent sediment of the radiocarbon sample yielded 3.1 ± 0.3 ka.

The underlying 2Cwb and 3AhbC horizons contain a boulder of 70 x 40 cm. Furthermore, the dark colour and the accumulated thickness (95 cm) of the 3AhbC and 3Ah/Bwb horizons are remarkable. Typologically, it is assigned to a Phaeozem, because of the lack of carbonates and the existence of distinct properties of silicate weathering in the 3Ah/Bwb horizon. For the 3AhbC horizon radiocarbon dating on humic acids yielded an age of 7,908 ± 99 BP (= ca. 8,690 cal BP; Table 2).

The basal 4C horizon shows some exceptional properties. On the one hand, this layer is unconsolidated and has a light-coloured appearance (light yellowish brown). On the other hand, the dominance of coarse grained sand is accompanied by a relatively large amount of clay and nearly 14% of $CaCO_3$. Although microfaunistic investigations are lacking, it seems very likely that this sediment represents a fluvial-lacustrine facies due to a carbonate-free micro-catchment and the absence of calcretes (caliche) in this section of the river valley.

5.4 *Pollen diagram Lhasa 1*

The pollen diagram Lhasa 1 provides additional information on the Late Holocene landscape evolution of the Lhasa area (Fig. 5). It was already published in SCHLÜTZ (1999) and has been revised after recent insights into the restricted transport of the *Juniperus*-type pollen and dating of the profile base (MIEHE et al., subm.).

The profile is located in a wetland within the Kyichu River (paleo-) floodplain northwest of the city of Lhasa at 3,650 m a.s.l. (29°40'N, 91°04'E; Fig. 3). Colluvial deposits of the mountains base occur in 800 m distance. The slope reaches up to over 5,000 m a.s.l. Nearest remains of the ancient forest vegetation (*Juniperus convallium*) grow at a distance of 10 km. *Juniperus pingii*, a common subalpine shrub in southern Tibet, has been discovered above Drepung at a distance of 4 km. *Cupressaceae* now present around the site are trees of *Platycladus* planted in irrigated monastery gardens. Its natural distribution area lies within the outer declivities of the Tibetan Plateau. It was probably brought by pilgrims as an ornamental plant. The pollen of both *Juniperus* and *Platycladus* belong to the *Juniperus*-type.

The profile is 150 cm thick. Its lower 60 cm consists of minerogenic sediment presumably deposited from the adjacent slope. The diagram is divided into four local pollen zones (PZ). On the basis of vegetation surveys conducted on slopes of the catchment area ecological groups can be differentiated within the pollen spectra.

There is a distinct decline of pollen of the *Juniperus*-type at the base of zone 1 around 4,140 ± 50 BP (= ca. 4,690 cal BP). Floristic elements of woodlands and shrublands such as *Betula platyphylla*, *Rhododendron anthopogonoides* and *Hippophae* as well as *Cichorioideae*, *Brassicaeae*, *Thalictrum*, *Anemone*, *Ranunculus* and *Aster*-type occur. Right after the decline of forest pollen, human indicator pollen (*Polygonum aviculare*, *Plantago depressa*-type, *Chenopodiaceae*) increase for the first time.

PZ 2 documents an open water with waterplants such as *Myriophyllum* and *Nymphaea* around 575 ± 120 BP (= ca. 580 cal BP). Nitrogen plants such as *Urtica* and *Rumex* occur. Common trampling and ruderal indicators (*Tribulus*, *Erodium*, *Malvaceae*) appear for the first time. *Stellera chamejasme*, which is a widespread grazing weed in rangelands of High Asia, occurs in this zone.

In PZ 3 *Artemisia santolinifolia* and dwarf-shrubs of *Ceratostigma* became dominant as well as annual *Chenopodiaceae*. Trampling indicators such as *Tribulus*, *Koenigia* and the *Plantago depressa*-type are more frequent than ever. Remarkably, the *Juniperus*-type increases again.

PZ 4 shows a dominance of *Artemisia santolinifolia*. *Hippophae* has retreated and *Salix* has increased strongly.

6 *Discussion*

There are some stones and boulders in both the topping colluvial layer and the underlying slope deposits of profile QUG 1. Since other geomorphic facies such as alluvial fan, debris flow and solifluction can be excluded after site and sediment properties (MOSS & WALKER 1978, VAN VLIET-LANOË 1998, BERTRAN & TEXIER 1999), the sediment orginates most likely from mudflow or combined colluvial processes such as hillwash plus rock fall. The same applies to the colluvial

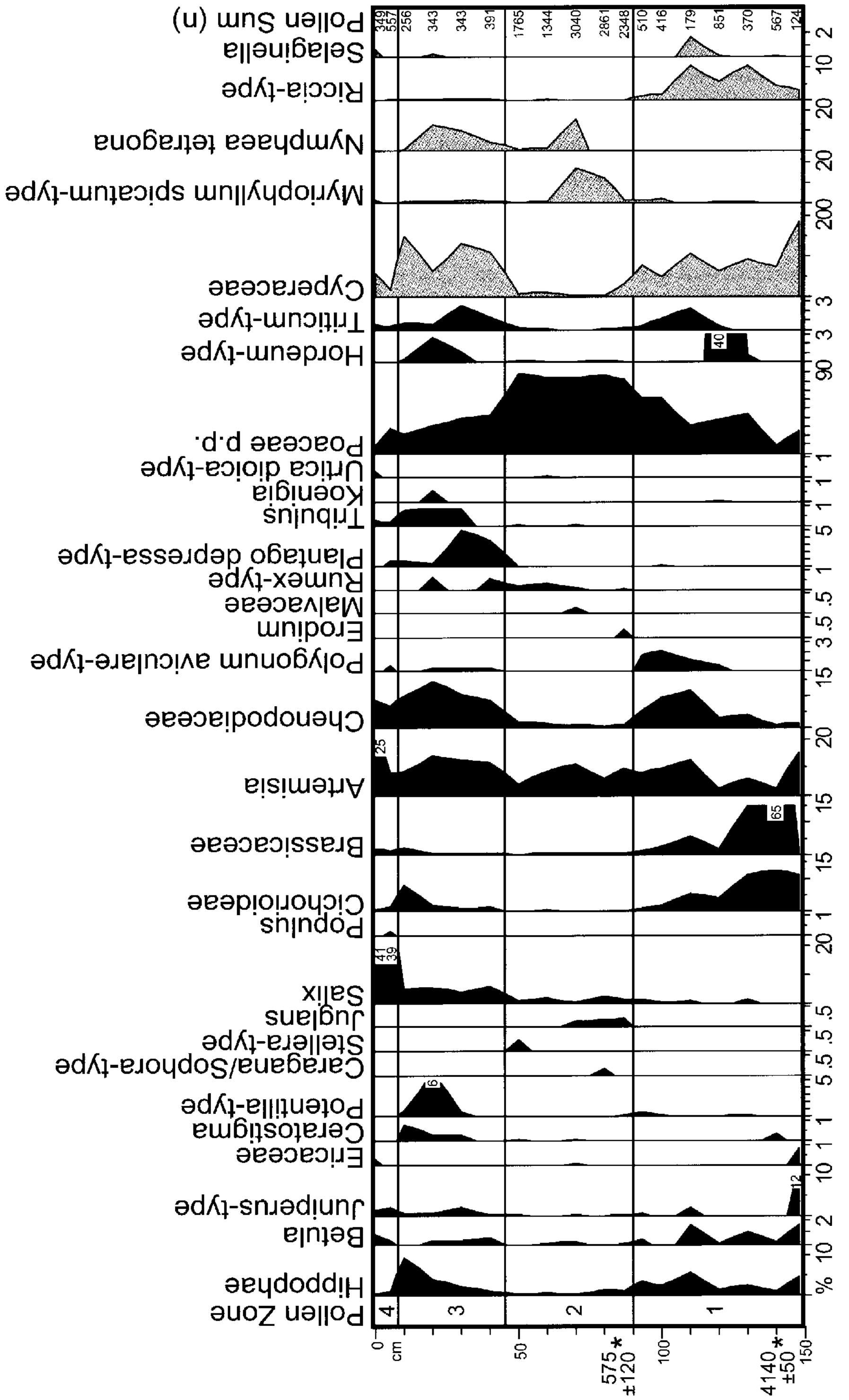

Fig. 5. Simplified pollen diagram Lhasa 1, 3,650 m a.s.l. (pollen sum = all pollen taxa except *Cyperaceae*, water plants and spores). Note different scales. Sediments: top = *Cyperaceae*-peat, 10-90 cm = peat/gyttja, base = silty and sandy minerogenic (colluvial?) sediments. Datings given in ^{14}C years BP.

layers of profile GAR 1. In contrast, according to location and amount of coarse matter, the topping colluvial layers of profiles DRE 2 and DRE 14 represent typical deposits of a alluvial fan. Furthermore, large boulders up to a size of 15 x 8 m (!) partly occur on the surface and in the sediments of the Drepung fan orginating probably from debris flows. Here, the absence of deep-lying paleosols and the lacking organic content in deeper sections indicate most probably a mainly Pleistocene age of the fan and footslope sediments. Finally, the thin sandy-silty colluvial layer of profile DRE 9 represents a fine-grained hillwash.

The multi-level dating of profile QUG 1 points to a relatively long hiatus of ca. 2,000 years between the buried paleosol (3,053 ± 45 BP = ca. 3,260 cal BP) and the colluvial layer (1.0 ± 0.1 to 0.3 ± 0.1 ka). The colluvial sedimentation mainly took place in a short interval between 1.0 ± 0.1 and 0.8 ± 0.1 ka. Two samples from the underlying slope deposits (8.0 ± 0.8 and 20.0 ± 2.0 ka) indicate sedimentation during the Early Holocene and the Last Glacial Maximum. This conforms stratigraphically with the radiocarbon age from the buried Ah horizon. Nevertheless, the IRSL age obtained for the lowermost sample is also likely to represent the deposition age of an aeolian component in the sediments, if the material was not bleached at all during the final slope transport. High dust flux and loess accumulation rates during the Last Glacial Maximum have been established for most of the northern hemisphere as well as for the Tibetan Plateau and adjacent areas (e.g. LEHMKUHL & HASELEIN 2000).

The upper paleosol of profile GAR 1 (3,668 ± 57 BP = ca. 4,000 cal BP) is already developed from a colluvial layer. Thus this paleosol postdates a first colluvial episode, which is predated by the lower paleosol (7,908 ± 99 BP = ca. 8,690 cal BP). IRSL age estimates obtained for the upper 250 cm of this profile point to a successive deposition of the colluvial sands within the last 4.3 ± 0.5 ka. The values increase with depth and are in agreement within the 1 sigma error. IRSL from the adjacent sediment of the radiocarbon sample yielded 3.1 ± 0.3 ka. This would suggest either that the charcoal was already incorporated in the sediments before the final transportation and bleaching process or that the sediment was later reworked by human influence. This horizon represents a human occupation layer and subsequent reworking is therefore very likely. There is a relatively long hiatus of ca. 1,500 years between the upper paleosol and a second colluvial episode around 2.6 ± 0.3 ka. The IRSL datings show that the upper colluvial sedimentation took place during several periods between 2.6 ± 0.3 ('Metal Ages') and 0.4 ± 0.1 ka.

In Tibet, luminescence dating has been mainly performed on aeolian silts (loess) und lacustrine sediments so far (e.g. LEHMKUHL et al. 2000, 2002, STOKES et al. 2003, XIAOMIN FANG et al. 2003, ZHANG et al. 2003). The results from profiles QUG 1 and GAR 1 demonstrate that IRSL is also suitable for dating colluvial sediments, even if they experienced short-distance transport. The results are in stratigraphic order and show no evidence of age overestimation in consequence of incomplete or partial bleaching. They correlate well with independent age control provided by radiocarbon dating. Both dose rate and natural signal are high and therefore the signal to noise ratio is satisfactory, even for the uppermost young samples. Subtraction of the background signal yielded extended ED plateaus over the whole shine down range.

Concerning the pedogenic reflection of climatic changes, the 3AhbC and 3Ah/Bwb horizons of profile GAR 1 provide valuable information. This buried soil has properties of a well developed Phaeozem (thick Ah horizon, black colour, mollic horizon, no carbonates). However, it could be a matter of a former Chernozem-like soil, which is developed from colluvial material and was affected by decalcification. As far as known, modern terrestrial soils of comparable altitudes in the Lhasa region (ca. 3,650 to 4,000 m a.s.l.) do not have such relatively 'wet' appearances. Similar pedogenic successions from 'wet' to 'dry' features have been described from Mid to Late Holocene sections of central and eastern Tibet (LEHMKUHL et al. 2002, KLINGE & LEHMKUHL 2005). All records might represent an aridification corroborating the conclusions of e.g. STARKEL (1998) and LEHMKUHL & HASELEIN (2000) on the climatic tendency at the Tibetan Plateau in that time to cool and dry.

The first systematic extraction, determination and dating of charcoals from buried paleosols in southern Tibet provides valuable paleobotanical information and also is advantageous for an accurate radiocarbon dating of paleosols. Similar charcoal and radiocarbon dating studies documenting environmental changes in High Asia are rare (e.g. BYERS 2005, KAISER et al. submitted). Up to now, most of the ^{14}C datings on Tibetan paleosols have been carried out by means of humic acids (KLINGE & LEHMKUHL 2005). However, a radiocarbon age of humic acids from a buried soil reflects the mean residence time of the organic constituents of that soil plus the time of burial, thereby normally resulting in an overestimation of the time of burial (MARTIN & JOHNSON 1995).

Generally, charcoal is one of the most frequent organic remains in buried soils and archaeological occupation layers. It can be found dispersed in the sediments and soils (profile DRE 9) or associated with distinct archaeological features such as hearths, pits and occupation layers (profiles DRE 2, DRE 14, GAR 1). Outside of ancient settlements, charcoal can reflect human impact producing fire or simply represents natural fires (SCHOCH 1986). Because humans use fire on a daily basis, dispersed charcoal from archaeological remains reflects numerous intervals of wood gathering. It is a sampling of the vegetation during the period of human occupation of a site, and as a result, paleoecological interpretation is feasible. The charcoals analysed from the Lhasa area confirm the Late Holocene presence of *Juniperus* forests or woodlands in a now treeless, barren environment.

In pollen diagram Lhasa 1, the distinct decline of *Juniperus*-type at the base of PZ 1 around 4,140 ± 50 BP can be interpreted as clearing of forests on the adjacent south-facing slopes, because *Juniperus* pollen is detected to derive from the neighbouring slopes. Whether the *Juniperus* forest burned down because of lightning or human-ignited fires is not yet unambiguously answerable. Apparently quite large amounts of open substrate were exposed after the deforestation, which have been colonised by liverworts (*Riccia*-type) and *Selaginella*. Similar to palynological results from the Tibetan Himalaya (MIEHE et al. 2002) as well as the Hindukush and Karakoram (SCHLÜTZ 1999), the forest flora contained Cichorioideae, Brassicaeae, *Thalictrum*, *Anemone*, *Ranunculus* and *Aster*-type. It is likely that in the beginning of PZ 1 also north-facing slopes were forested mainly with *Betula platyphylla* and *Rhododendron anthopogonoides*. *Hippophae* (buckthorn) as a phreatophytic tree species indicates accordant shrublands in the Kyichu River floodplain. Already the founding legends of the city of Lhasa comprise references to buckthorn forests (SØRENSEN 2003). Pollen of cereal-types may point to the first presence of plant cultivation (barley, wheat).

In PZ 2, the nitrogen plants detected points most probably to a higher dung influx, which was caused by an increase in cattle numbers around this potential watering place. By the occurrence of the insect pollinated *Caragana/Sophora*-type one can conclude that in this time at the latest *Sophora moorcroftiana* was established as the most important replacement vegetation. Today, the trampling indicators detected (*Tribulus*, *Erodium*, *Malvaceae*) are frequent only where firewood is harvested, browsing and trampling occurs and thus woody phanerophytes are pushed back until they cover less than 20% of the surface and the cover of higher plants in general seldom exceeds 50%. The occurrence of *Stellera chamejasme* points to an increase of selective grazing.

In PZ 3, high percentages of *Artemisia santolinifolia*, dwarf-shrubs and trampling indicators show the increased degradation of the slope vegetation. The increase of *Juniperus*-type indicates the planting of *Platycladus* which may have started already together with that of *Juglans* as fruit tree in PZ 2.

PZ 4 demonstrates the dominance of *Artemisia santolinifolia* on the slopes. In the floodplain, *Hippophae* woodlands have retreated due to stronger anthropogenic pressure. On the other hand, also the increase of *Salix* is caused by man: Willow and poplar cultivation have proliferated recently to meet the demands for construction and fire wood.

A partly unsolved problem of the investigations presented above relates to the local extension of pedogeomorphic properties and thus to aspects of the stratigraphical and geomorphic interpretation. As the sites have been only observed selectively, there are some uncertainties with respect to a proper determination of the sediment genesis and stages of erosion/colluvation. Generally, for comparative purposes, studies dealing with (natural) mass movements in Tibet are rare (e.g. LEHMKUHL & PÖRTGE 1991, YANJUN SHANG et al. 2003, CHENG ZUNLAN et al. 2005). A further aspect concerns the broad lack of independent control evidence apart from the sites investigated. A sufficient quantity of adjoining pollen diagrams could provide a clear proof of the presence of man. A decision, whether rather the man than the climate has caused the intensified geomorphodynamics, would maybe possible. With the exception of the Qugong site, in this study the level of accompanied archaeological research had a very limited scale and thus significance.

7 *Conclusions*

Generally, natural (e.g. exceptional rainfalls, climatic changes) and anthropogenic causes (slope instability after forest clearing, agriculture) can be claimed for the formation of colluvial sediments. Also a combination of both causes – secondary human enhancement of a primary opening of the landscape by increasing aridity and/or coolness – is imaginable.

The investigations reveal the existence of Late Holocene colluvial sediments overlying paleosols in southern Tibet. In general, the colluvial sediments detected can be divided into i) coarse-grained sediments with a high proportion of stones and boulders originating from (high-energy) alluvial fans and debris flows (DRE 2, DRE 14), ii) matrix supported sediments with only some stones and boulders originating from mudflows or combined colluvial processes such as hillwash plus rock fall (QUG 1, GAR 1), and iii) more or less fine-grained sediments originating from (low-energy) hill wash (DRE 9). The first can be claimed widely for natural processes lasting up to the present. However, human impact can enforce the frequency and magnitude of these events. The second and third might be caused by human induced erosion following a clearing of forests and increasing grazing.

All profiles investigated show a marked difference in vegetation between the buried paleosols with charcoal of trees and the present surfaces with open dwarf-shrubland pastures. The pollen diagram Lhasa 1 points in an analogous direction. It most probably represents the development of thorny shrub rangelands as a replacement vegetation for former *Cupressaceae* forests. As the parallel presence of man in the Lhasa region has been confirmed since the late Neolithic (Qugong and Gar Drongy site), it is assumed, that the environmental changes such as loss of forest and erosion at least have been reinforced by humans. Consequently, the assumptions of MIEHE et al. (2003) for southern Tibet and FRENZEL & ADAMCZYK (2004) for the eastern declivities concerning a distinct human impact on the vegetation in the past can be corroborated on a local scale. Furthermore, historical mural paintings in the Jokhang Temple of Lhasa, show how construction wood from the slopes are being carried to the construction site situated in a wetland. The conclusion from that illustration would be that the slopes around Lhasa were still bearing timber usable as construction wood when this paintings were executed.

The investigations presented have revealed a large potential for research in landscape history and geoarchaeology of the Lhasa region. Obviously, despite numerous clearly visible cultural relics (e.g. field terraces, scattering of cairns) as well as some detected buried occupation layers, the archaeological survey of sites is still in its infancy (ALDENDERFER & ZHANG YINONG 2004). Further combined geoscientific and archaeological investigations could contribute to raise the number of archaeological sites and to provide a stratigraphical context. Additional archives, which have not so far been exploited, are valley floors, swamps, river terraces, caves and rock shelters. A larger quantity of archaeological, stratigraphical and paleoecological data is prerequisite for quantified statements as a basis for reliable conclusions on the landscape evolution on a regional scale.

In southern Tibet, a close relationship between history-oriented pedogeomorphological and botanical research is doubly advantageous. On the one hand, the regular integration of paleobotanical investigations (charcoal, pollen and macrofossil analysis) into pedogeomorphological studies is vitally important in order to exploit the archive potential inherent in sediments and soils to the full. On the other hand, the relic forests detected by geobotanical research offer an excellent starting point for geoscientific studies with larger areal and temporal depth.

Acknowledgements

We are grateful to Gen Dun, Lhasa, whose knowledge in regional archaeology enabled us to investigate the sites Qugong and Gar Drongy. The sections of both sites were sampled with the friendly support of La Duo, Lhasa. Simone Burgheim and Nils Hempelmann, Marburg, assisted in carrying out soil analyses and IRSL datings. Armin Schriever and Ubbo Wündisch, Marburg, cored the pollen profile in 1994. We are indebted to Christiane Enderle, Marburg, for preparation of figures 1 and 3. We also thank James Fanning, Greifswald, for improving the English draft. Finally, we owe Frank Lehmkuhl, Aachen, and an anonymous referee constructive reviews, which improved the quality of the paper. The investigations were kindly supported by the German Research Council (DFG Mi 271/15).

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