Activities of Ancient People and their Natural Environments along the Silk Road (Turpan), Xinjiang – Theory, Methods and Practice
Imprint

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I Summary of the summer school

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1 Subject of the summer school

The subject of the summer school is the early human activity and the natural environment in Turpan. The main content is related to the agriculture, life style and cultures of people several thousand years ago. It also deals with strategies of early human survival and development under the challenging climatic and environmental conditions in arid areas. In the summer school, we will discuss how the ancient people in Turpan interacted with the natural environment and how they used the water resources. All the studies will help us to understand the processes of economic, commercial and cultural development in Turpan. It will also make us comprehend the impacts of the natural environment on the early human activity there.

Many areas where modern man lives today are as arid as the place where the summer school will be held. Turpan district belongs to the Gobi desert. In such arid conditions modern man still faces many problems, including environmental, socio-economic and cultural issues. Moreover, the factor of global warming adds to the old problems, causing the challenges in arid areas to become even more complex and aggravated. The selected Turpan region is remarkably well suited because it is situated at a branch of the famous Silk Road and at the desert margin, which has reacted and will continue to react highly sensitive to environmental changes.

Considering these problems, we will focus on the general situation of the early human activities and try to understand the influences of the environment. By introducing the special cases of early human activities from Turpan and other localities around the world, we will teach the participants new theories and technologies in relation to such problems. Moreover, we will show them the advances of comparable studies, especially the experiences of the selected teachers. The field work will combine theory and practice and will therefore enhance a better understanding of human-environmental interaction in the past, present and future, and the application of new techniques and instruments.

The investigations of the impact of global change in recent years have led to the development and application of multiple methods, ranging from simple environmental descriptions to more precise and quantitative levels. This became an international standard. Within geoarchaeology, advanced technologies such as seismic refraction, earth resistivity tomography and detailed geomorphological and sedimentological analyses are applied to archaeological studies. Based on data of historical localities and computer analyses, earth resistivity tomography can detect underground constructions of ancient times without destruction or excavation and therefore reveal new information. Percussion core drilling in lakes and floodplains allows the sampling of old sediments for further analyses. In addition, the seismic refraction technique gives information about the sediment structure up to 50 m below the surface and the depth of the underlying bedrock. Such techniques may also be helpful for the studies of the ancient environment and climate changes, the origin and dispersal of agriculture, etc. All these advanced techniques will be introduced theoretically, applied practically and analyzed exemplarily during the summer school. As a result the participants will become much more familiar with the theoretical background and the practical application of up-to-date geoarchaeological researches and will be able to understand complex human-environmental interactions.

In sum, the contents of the summer school will provide knowledge combining natural and social sciences. After the school the participants will have gained new insights into the fields of botany, climatology, geography, geology, anthropology and archaeology. This interdisciplinary approach will also help the participants to understand the impacts of the predicted climate change and to manage possible complex future human-environmental challenges in arid regions.

2 Importance of the topic and methods to be taught

With the development of societies and the intensification of human activity, the environment has changed and is changing to a great extent. More and more attention is paid to global change by governments and scientists from all over the world. Understanding the climate changes is not only the goal of modern environment studies but also the key to the prediction of environment changes in the future.

Global warming is one of the most important issues in the context of global environmental changes in modern time. It will lead to changes and rearrangements of the global and regional water cycles, for example due to the melting of glaciers and frozen soils. Drylands such as the region of Turpan will react extraordinarily sensitive to these changes. In Northwest China, higher rainfall variability and more frequent sand or dust storms are predicted. These effects will harm the ecological systems
and will influence the food supply and the living habits of people in the respective areas.

Glaciers store most of the fresh water on earth. Studies on glaciers over several decades tell us that the global glaciers are melting very fast. Especially in the areas that are located in the forelands of mountains, this melting will first cause flooding and then drought, due to the decreases of available water. Turpan District is such a typical area and the people there are relying on melt water from the glaciers of the Heavenly Mountains (Tianshan Mountains). Therefore, the Turpan District is a suitable locality for us to study such problems.

As we all know, water is the basic element of human life and activity. As there is hardly any natural rain fall, the main supply of water originates from the melted glacier in the Bogeda Mountains. Local people dug underground wells called Karez, a wonderful world famous underground irrigation system that protects the water from evaporation. Some of the water is utilized by the local people, but most of it is transferred to the other Karez in the Turpan area. This kind of water supply created and supported the oasis civilization over the last two thousand years.

In the context of global warming, the glaciers of the Bogeda Mountains are melting quickly, causing natural hazards such as flooding and, later on, water shortage due the shrinking glaciers. After that, with the water supply from the glaciers decreasing, the underground water supply will also be reduced. The local people will suffer from a lack of fresh water for drinking, living and irrigation. As a consequence the people there will have to manage the difficult situation by using water differently or more efficiently or by migrating to other places. Eventually, the oasis civilization in Turpan, which has lasted for several thousand years, will end.

The water surface of Aiding Lake near Turpan lies below the sea level (about -154 m). This is the lowest area in China and the second lowest on earth. The water of Aiding Lake also mainly originates from the melted glacier ice of the Heavenly Mountains. As the depth of the water changes, it probably reflects climate changes. The archaeological researches in Aiding Lake show us that one Neolithic relic is located at the edge of Aiding Lake at about -37 m, and two ward forts of the Han Dynasty and one of the Tang Dynasty are located at -141 m and -140 m respectively. Moreover, the water surface area of Aiding Lake is decreasing. During some periods of the year there is even no water in Aiding Lake at all. All these facts show the sensitivity of the Turpan area and the necessity for further interdisciplinary research.

The oasis culture in Turpan has developed over a long period of time. As early as the Neolithic period, man lived in the areas of the tombs of Gouxi and Astana, where stone knives were unearthed. In Yanghai and Subei Tombs, the artifacts show a colorful life style of the ancient people. In Yanghai Tombs, wheat, barley, broom corn and millet were found and show the development of agriculture. Moreover, a grapevine was discovered in Yanghai Tombs and is evidence of horticulture activities. This is the earliest record of grape cultivation in China. All the plants that were unearthed and well-preserved played an important role for studying early human activities and climate changes in Turpan.

In sum, Turpan is a key locality for the interdisciplinary study of past and recent environmental changes, human adaptation and human-environmental interaction in China, and can function as a prototype for other arid regions in the world. A summer school held there will be a benefit to the whole group for understanding these interactions. In addition, the results of the school will enhance the protection of the cultural heritage, the natural resources and the future ecological sustainability in Turpan.

3 State of research

Trade connections between China and Europe have existed for several thousand years. The German explorer Ferdinand v. Richthofen named the main trade route “Silk Road”. During the Han Dynasty (206 BC - 220 AD) trading along the Silk Road was very intensive, particularly with the Roman Empire. In the beginning of the Tang Dynasty (7th century and first half of the 8th century) the Silk Road experienced a second bloom (Wong 2007) but according to BAO ET AL. (2004) trade was interrupted several times due to political restraints and climatic oscillations.

The Silk Road splits into two branches to bypass the Tarim Basin and the Taklamakan Desert. Turpan and the ancient cities Jiaohe and Gaochang are located on the northern branch of the Silk Road. Jiaohe was founded as a ward fort during the western Han Dynasty (206 BC - 24 AD). From 618 to 907 AD, during the Tang Dynasty, Jiaohe experienced a period of prosperity. Since around the year 1400 the city has been abandoned (GUTER 2004), but the ruins are extraordinarily well preserved and are on the list of historical monuments in China.

The blooming period of the Silk Road from the 3rd century BC until the 5th century AD was also a period of favorable climatic conditions in Northwest China, with higher temperatures and more rainfall (BAO ET AL. 2004). Rivers flowed through the Taklamakan during that period and filled widespread lakes, i.e. the Lop Nor (BAO ET AL. 2004). After this climatic optimum phase, a lot of oases and lakes fell dry. The last wet phase in the Tarim Basin is recorded for the time span between 1450 and 1850 AD. For this period historical sources are available (Liu 1976), for the older phases climatic evidence is given by plant remnants and pollen (Campos 1996), fluvial, lacustrine and aeolian sediments as well as ice cores (Thompson 2000). Recent investigations and models imply that Northwest China reacts very sensitively to the predicted global warming (SHI ET AL. 2007).
4 Goals of the summer school

The summer school aims at conveying new advances in the studies on the early human activity and the natural environment in Turpan, Xinjiang. All the participants are young scholars, including post-doctor and Ph.D. candidates, as well as intercultural master and bachelor candidates. In the school, we will teach not only theory and methods, but also successful examples of research. Moreover, all the participants will learn how to do practical field work and operate the instruments.

In view of the main topic of this school, we will on the one hand focus on how the ancient people in Turpan adapted to their natural surroundings and utilized the given resources under conditions of low productivity and a challenging environment. On the other hand, we will concentrate on the influence of environmental changes on the activities of ancient people. For the latter we need detailed information from geoarchives.

Against this background, we plan to present the students with study cases on the early human activities and their natural environments during the training course. Teachers will introduce the theory, the methods and comparable successful research examples from other arid regions of the world. The most important objective of the summer school is that students understand the regional and in arid regions in general, human-environmental interactions in the Turpan region and in arid regions in general.

The thematic goals of the summer school are to establish a deeper understanding in the following issues:

- human-environmental interactions in the Turpan region and in arid regions in general,
- interdisciplinary scientific approaches to investigate these interactions and
- the use of new methods and techniques that are transferable to a wealth of different scientific questions and practical applications such as climate research, non-destructive underground detection, detailed geomorphological and geoarchaeological investigations, archaeology, botany, earth and environmental sciences, and nature conservation.

The social and intercultural goals of the summer school are:

- to obtain insight into the similarities and the differences of the cultures, histories, and traditions of China and Germany
- to enhance communication and further future cooperation between all participants.

We feel very confident that our approach, which combines interdisciplinary scientific theory and practice with intercultural discussion, is suitable to achieve these goals.

5 References


II Xinjiang – Geographical background

Katharina Fricke, Heidelberg, Germany

1 Introduction

Turpan is situated in Xinjiang Uygur Autonomous Region, which covers an area of 1.66 mio. km² and lies in China’s Northwest. Xinjiang shares national borders with Tibet Autonomous Region, Gansu and Qinghai province and international borders with Mongolia, Russia, Kazakhstan, Kyrgyzstan, Tajikistan, Afghanistan and Kashmir. Xinjiang belongs geographically and ethnically to Central Asia and is situated on one of the routes of the Silk Road. Due to social and natural factors, it was the main channel of exchange on the land route for over 2000 years. As a site of adaptation and struggle of men against the natural environment, man has used the natural environment along rivers, groundwater and wells. It is situated also at a geostrategic position between several Turkish ethnics and the Chinese, and is therefore a crucial passageway for transportation and a stake in the region’s stability and security.

The region Xinjiang is characterized by large landscape structures of mountain ranges and basins (cf. Fig. 1). In the North, the Altay Mountains present the border to the boreal coniferous forests of Siberia, and in the South, the Karakorum Mountains, the Kunlun Shan and the Altan Shan separate Xinjiang from the Tibetan Plateau. In the West lie the Pamir Mountains and the Western Tianshan. The Eastern Tianshan that runs in East-West direction divides the northern Junggar Basin from the southern and larger Tarim Basin. The Turpan Basin is a smaller basin northeast of the Tarim Basin and is situated between the Bogeda Mountains to the north and the Kuluke Mountains to the south. The prefecture covers an area of about 69.324 km².
2 Climate

The climate in Xinjiang is in general continental and very dry. The extreme aridity is caused by the large distance to the oceans and the shadowing of precipitation by the mountain ranges in between. Xinjiang can be divided into two climatic regions: there are the continental basins with little precipitation and high temperatures and there are the mountains that receive relatively high precipitation and low temperatures due to their elevation.

Turpan District is characterized by an extreme continental desert climate (cf. Fig. 2). The average maximum temperature in July is 37.2 to 39.5 °C, with a maximum air temperature of 49.6 °C (in 1975). However, the temperatures in the winter fall as low as -28 °C (in 1978). Due to its continental position and the high mountains around the Turpan Basin, little or no rain falls. The annual precipitation here amounts to only 25.2 mm, but the evaporation rate is as high as 2500 mm. As a result, the climate of Turpan is very dry. According to Köppen’s classification, the climate in Xinjiang is a desert climate (BW) with a 100 % probability and extremely dry continental climate (YOSHINO 1992, 204). Other authors, including ZHao (1986, 169), DOMRÖS AND PENG (1988, 263) and ROBERTS (1993, 42), classify it as a middle temperate zone.

As it is shown in figure 3, the mountain ranges receive considerably more precipitation as they block humid air masses, causing rain to fall there. The mountains Kunlun Shan and Karakorum receive most of their precipitation from the Indian monsoon, while the Tianshan, Pamir and Altay get their water from the Atlantic Ocean and Northern Polar Sea. The wind-ward side of the mountains intercept the humid oceanic air masses and they release the moisture as rain or snow. In the higher reaches the moisture is stored in glaciers, permafrost and snow and delays the water delivery to the basins (ROBERTS 1987, 40). The mountain ranges also introduce different altitudinal belts with modified climatic conditions and geomorphologic processes. The horizontal temperature differentiation grows with increasing continentality and proximity to the centre of the basin, which is a cold pole in the winter and heats up in the summer. The vertical temperature differentiation shows an inversion with the altitude, where it is colder in the summer and warmer in the winter, and promotes the development of smog in the winter (ROBERTS 1987, 34ff; DOMRÖS AND PENG 1988, 263). The climatic conditions in the Junggar and the Tarim Basin differ as well (cf. Fig. 4). As the Tianshan Mountains act as a meteorological divide, the North receives more precipitation coming from the Central Asian Anticyclone, but is slightly cooler (cold temperate), while the South is almost totally isolated from humid air masses and has higher temperatures due to its latitude and the increased solar radiation/insolation (warm temperate).

The precipitation is fairly well distributed throughout the year, but has a peak in late spring (May-June) and a low in winter (Dec-Feb) at most stations when the Central Asian anticyclone is strongest. It also shows a high variability over the years. As one can see in figures 3 and 4, the regional distribution of precipitation and temperature in Xinjiang is extremely uneven, due to the altitude and the climate being divided by the Tianshan and Himalayan Mountains (ROBERTS 1987, 40).

Corresponding to the annual distribution of the temperature, the relative humidity is highest in winter and lowest in summer. It also changes with elevation as it increases with the altitude in summer and decreases in winter and lessens from Urumqi to the Junggar Basin (ROBERTS 1987, 40; DOMRÖS AND PENG 1988, 263).

3 Soils

3.1 Soil processes

Generally the conditions in the Junggar Basin are unfavourable for the development of a soil and vegetation cover: a continental climate with a large amplitude of annual temperatures, sharp changes in the seasons, extreme dryness and brevity of the vegetation period. The soil development begins with the physical weathering and fluvial and aeolian sedimentation processes, differentiated in altitude from the mountains to the basin. The vegetation cover is usually sparse due to the aridity and short vegetation season and reacts very sensitively to water deprivation. The climate also suppresses further biological activity, restrains transportation processes and deep soil development. Soils and ground are rich in anorganic nutrients, but lack thicker layers of top soil. Consequently, the soil is sensitive to utilization and erosion is expected due to slow regeneration and strong aeolian and fluvial forces. Characteristic for the climate are lime concretions, as the rare but intense rainfalls let the soil dry out during the time in between, then the soil water ascends capillary and lime accumulates in the upper horizons. Combined with the steppes vegetation on the widespread sediments and accumulation of humus and carbonates, a neutral or alkaline soil
Average annual temperature in Xinjiang[^1] (Source: modified according to Autonomous Region Bureau of Surveying and Mapping 2004, 12)

Average annual precipitation in Xinjiang[^2] (Source: modified according to Autonomous Region Bureau of Surveying and Mapping 2004, 12)

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[^1]: Fig. 3. Average annual temperature in Xinjiang [°C] (Source: modified according to Autonomous Region Bureau of Surveying and Mapping 2004, 12)

[^2]: Fig. 4. Average annual precipitation in Xinjiang [mm] (Source: modified according to Autonomous Region Bureau of Surveying and Mapping 2004, 12)
environment is common. But with a high groundwater table, impermeable layers of clay or agricultural utilization and irrigation, lime concretions tend to develop in the lower horizons and salinization can occur (Institute of Geography U.S.S.R. Academy of Science 1969, 198; Roberts 1987, 54ff; Domrös and Peng 1988, 263).

3.2 Soil types
(translated according to B. Winter)

The soils in Xinjiang are classified according to the FAO classification of 1990. The large basins of the Tarim River and the Junggarian are significantly influenced by aeolian dynamics. The high aridity, strong morphodynamics and the high proportion of quartz sands hinder the development of soils. According to Zech and Hintermaier-Erhard (2002) large areas are classified as Arenosols. Such a development is possible when the sands are stabilized by pioneer vegetation. It is also possible that the Arenosols were formed in more humid phases and until now have not been eroded or covered up. The largest areas however are classified as unconsolidated sands and dunes without any soil development.

Also widespread are Yermosols and Xerosols, which are soils of the deserts and semi-deserts according to the FAO classification. They are characterized by the low content of organic substances and typical characteristics such as desert pavement or desert varnish (Eitel 2001, 129; Schultz 2000, 378). In more recent classifications for the large part these would be found as Arenosols.

The basin fringes receive more precipitation and the drainage to the basin centre is the most important process. The material on the slopes is eroded and deposited with decreasing gradient. Especially on the southern slope of the Tianshan, but also in the southern Tarim Basin, soils developed in the alluvial quaternary sediments. Among other things there have to be carbonate sediments as today calcereous Fluvisols can be found (see Fig. 5). During arid conditions calcium carbonate can accumulate, but there are no Calcsols found in Xinjiang.

The development of the so-called salt pans are also caused by hydrological processes. Due to repeated water supply and high groundwater tables Solonchaks are formed. Large areas with Solonchaks are situated south of the Central Tianshan, in the western part of the Junggar Basin, and in the eastern part of the Tarim Basin. In eastern Xinjiang enormous areas are classified as gypsic Yermosols. During the restructuring of the classification concept of the FAO 1998 the Yermosols were omitted and replaced by soil types that feature their characteristic values. For example gypsic Yermosols

![Soil Map of The People’s Republic of China, reversed version 1990](image)
are probably replaced by yermic Gypsisols (Scheffer & Schachtschabel 2002, 526).

Not per se the extensive Leptosol areas in the Soil Map of Xinjiang can be assigned to the dryland soils as the precipitation in the mountains exceeds the potential evaporation. However, it can be assumed that to some extent in the lower altitudes with still relatively high relief energy arid conditions prevail. There, aridic Leptosols are possible. In the higher altitudes, temperatures are too low for intensive decomposition and weathering because cold arid conditions predominate.

In the Northwest, Kastanozems can be found. They are typical short grass steppe soils with a distinctive topsoil rich in humus (Errê 2001, 108). Equally worth mentioning is the cultivation and reclamation of large areas in Xinjiang into agricultural fields. Especially the irrigation agriculture changed the original soil attributes. These young and anthropogenically changed soils are classified as Anthrosols.

4 Vegetation

Xinjiang is located in the intersection of many phyto-geographical districts, with plenty elements of floras in these areas. Examples are the European-Siberia, Paleo-Asian, Mediterranean and Tian Shan-Pamir floras. There are many types of vegetation, including mountain forest, grassland and steppe, desert grassland, oasis vegetation and agriculture vegetation etc.

An example profile from the Tianshan Mountains to the Junggar Basins would be described as written below. In the mountains above 2,600 m but below the snow line, alpine meadows are common. Then follows a very narrow and sometimes discontinuous stripe of coniferous forest with Picea schrenkiana (Siberian spruce) on northern exposures. This zone is also used as summer pasture. Below 1,600–1,800 m continues a grassland and steppe, desert grassland, oasis vegetation and agriculture vegetation etc.

In the transition from the foothills to the alluvial fan zone below 1,200 m semi desert scrub and Artemisian semi desert follow and are used as a pasture in the spring. In the lower part of the alluvial fan are spots of Ulmus pumila forests and herbaceous grassland, which once were winter pasture but were the first to be turned into cultivated land due to fresh water supply and salt-free soils. On the spring zone around the lower boundary of the alluvial fan, lowlands with saline soils, halophytic or swamp vegetation developed, which have been meliorated and used for planting of cotton and sugar beet. In the sand desert, a sparse growth of Haloxylon ammadianum and Haloxylon persicum that fix dunes or lowland riparian forests with Populus diversifolia can be found (Betke et al. 1987, 72ff; Roberts 1993, 50; Zhao 1994, 279ff).

Excursus: WRB soil types

(IUSS Working Group WRB (2006))

ANTHROSOLS

Anthrosols comprise soils that have been modified profoundly through human activities, such as addition of organic materials or household wastes, irrigation and cultivation. The group includes soils otherwise known as: Plaggen soils, Paddy soils, Oasis soils, Terra Preta do Indio (Brazil), Agrozems (Russian Federation), Terrstrische anthropogene Böden (Germany), Anthroposols (Australia), and Anthrosols (China).

Summary description of Anthrosols

Connotation: Soils with prominent characteristics that result from human activities; from Greek anthropos, human being.

Parent material: Virtually any soil material, modified by long-continued cultivation or addition of material.

Environment: In many regions where people have been practising agriculture for a long time.

Profile development: Influence of humans is normally restricted to the surface horizons; the horizon differentiation of a buried soil may still be intact at some depth.

FLUVISOLS

Fluvisols accommodate genetically young, azonal soils in alluvial deposits. The name Fluvisols may be misleading in the sense that these soils are not confined only to river sediments (Latin fluvius, river); they also occur in lacustrine and marine deposits. Many Fluvisols correlate with: Alluvial soils (Russian Federation); Hydrosols (Australia); Fluvents and Fluvaquents (United States of America); Auenböden, Marschen, Strandböden, Watten and Unterwasserböden (Germany); Neossolos (Brazil); and Sols minéraux bruts d’apport alluvial ou colluvial or Sols peu évolués non climatiques d’apport alluvial ou colluvial (France).

Summary description of Fluvisols

Connotation: Soils developed in alluvial deposits; from Latin fluvius, river.

Parent material: Predominantly recent, fluvial, lacustrine and marine deposits.

Environment: Alluvial plains, river fans, valleys and tidal marshes on all continents and in all climate zones; many Fluvisols under natural conditions are flooded periodically.

Profile development: Profiles with evidence of stratification; weak horizon differentiation but a distinct topsoil horizon may be present. Redoximorphic features are common, in particular in the lower part of the profile.
**GYPSISOLS**

Gypsisols are soils with substantial secondary accumulation of gypsum (CaSO4.2H2O). These soils are found in the driest parts of the arid climate zone, which explains why leading soil classification systems labelled many of them Desert soils (former Soviet Union), and Yermosols or Xerosols (FAO–UNESCO, 1971–1981). The US Soil Taxonomy terms most of them Gypsids.

**Summary description of Gypsisols**

**Connotation:** Soils with substantial accumulation of secondary calcium sulphate; from Greek gypsos, gypsum.

**Parent material:** Mostly unconsolidated alluvial, colluvial or aeolian deposits of base-rich weathering material.

**Environment:** Predominantly level to hilly land and depression areas (e.g. former inland lakes) in regions with an arid climate. The natural vegetation is sparse and dominated by xerophytic shrubs and trees and/or ephemeral grasses.

**Profile development:** Light-coloured surface horizon; accumulation of calcium sulphate, with or without carbonates, is concentrated in the subsoil.

**LEPTOSOLS**

Leptosols are very shallow soils over continuous rock and soils that are extremely gravelly and/or stony. Leptosols are azonal soils and particularly common in mountainous regions. Leptosols include the: Lithosols of the Soil Map of the World (FAO–UNESCO, 1971–1981); Lithic subgroups of the Entisol order (United States of America); Leptic Rudosols and Tenosols (Australia); and Petrozems and Litozems (Russian Federation). In many national systems, Leptosols on calcareous rocks belong to Rendzinas, and those on other rocks to Rankers. Continuous rock at the surface is considered non-soil in many soil classification systems.

**Summary description of Leptosols**

**Connotation:** Shallow soils; from Greek leptos, thin.

**Parent material:** Various kinds of continuous rock or of unconsolidated materials with less than 20 percent (by volume) fine earth.

**Environment:** Mostly land at high or medium altitude and with strongly dissected topography. Leptosols are found in all climate zones (many of them in hot or cold dry regions), in particular in strongly eroding areas.

**Profile development:** Leptosols have continuous rock at or very close to the surface or are extremely gravelly. Leptosols in calcareous weathering material may have a mollic horizon.

**KASTANOZEMS**

Kastanozems accommodate dry grassland soils, among them the zonal soils of the short-grass steppe belt, south of the Eurasian tall-grass steppe belt with Chernozems. Kastanozems have a similar profile to that of Chernozems but the humus-rich surface horizon is thinner and not as dark as that of the Chernozems and they show more prominent accumulation of secondary carbonates. The chestnut-brown colour of the surface soil is reflected in the name Kastanozem; common names for many Kastanozems are: (Dark) Chestnut Soils (Russian Federation), Kalktschernoseme (Germany), (Dark) Brown Soils (Canada), and Ustolls and Xerolls (United States of America).

**Summary description of Kastanozems**

**Connotation:** Dark brown soils rich in organic matter; from Latin castanea and Russian kashtan, chestnut, and zemlja, earth or land.

**Parent material:** A wide range of unconsolidated materials; a large part of all Kastanozems has developed in loess.

**Environment:** Dry and continental with relatively cold winters and hot summers; flat to undulating grasslands dominated by ephemeral short grasses.

**Profile development:** A brown mollic horizon of medium depth, in many cases over a brown to cinnamon cambic or argic horizon; with secondary carbonates or a calcic horizon in the subsoil, in some cases also with secondary gypsum.

**SOLONCHAKS**

Solonchaks are soils that have a high concentration of soluble salts at some time in the year. Solonchaks are largely confined to the arid and semi-arid climate zones and to coastal regions in all climates. Common international names are saline soils and salt-affected soils. In national soil classification systems, many Solonchaks belong to: halomorphic soils (Russian Federation), Halosols (China), and Salids (United States of America).

**Summary description of Solonchaks**

**Connotation:** Saline soils; from Russian sol, salt.

**Parent material:** Virtually any unconsolidated material.

**Environment:** Arid and semi-arid regions, notably in areas where ascending groundwater reaches the solum, with vegetation of grasses and/or halophytic herbs, and in inadequately managed irrigation areas. Solonchaks in coastal areas occur in all climates.

**Profile development:** From weakly to strongly weathered, many Solonchaks have a gleyic colour pattern at some depth. In low-lying areas with a shallow water table, salt accumulation is strongest at the soil surface of the soil (external Solonchaks). Solonchaks where ascending groundwater does not reach the topsoil (or even the solum) have the greatest accumulation of salts at some depth below the soil surface (internal Solonchaks).
Along the rivers, the natural vegetation would be dense broad leaved and riverian forests, respectively, with Ulmus pumila, Tamarix, Populus and Salix species. Secondary forests can be found in Ili Valley and around the Irtysch River, planted as shelterbelts or economic forests. Anthropogenic changes in the vegetation cover were especially large in the alluvial fan zone, where swamp and semi-desert vegetation or risparian forests were replaced by irrigated crops and settlement areas (Betke et al. 1987, 75; Roberts 1993, 50). Roberts (1987, 68ff) emphasizes that the boundaries of the basin and shores of rivers and lakes have been the main area of settlement and anthropogenic influences on the natural vegetation. In the history of development, the vegetation cover is still very unstable and continuously adapting to the climatic circumstances, restrained by climatic and hydrologic features. Interventions in the water cycle and vegetation will have inevitable consequences for more demanding species, especially the climax vegetation. Oases are now 7.1×104km² in size, occupying only 4.3 % of the land in Xinjiang. More than half of the area is used as farmland. Agricultural production includes temperate zone crops such as wheat, corn, and paddy rice as main crops. Furthermore, cotton, vegetables (tomatoes), fruits, especially grapes and melons, are cultivated (Statistics Bureau of Xinjiang Uygur Autonomous Region 2006).

5 References


III  Introduction to Geoarchaeology

Prof. Olaf Bubenzer, Heidelberg, Germany

Geoarchaeology can be defined as the science of investigating geo-bio-archives in an archaeological context with the methods of geography, geosciences and archaeology. The objective is to reconstruct the evolution of former landscapes and ecosystems. This is done particularly with regard to the interrelations between man and the environment. In short: geoarchaeology addresses archaeological issues with geoscientific and archaeological concepts, methods and skills (comp. Brückner & Gerlach 2007).

Following Butzer (1982), however, geoarchaeologists are dedicated to elucidating environmental contextual issues and must be more than casual practitioners of applied science. “Geo-archaeology must extend its roots deep within archaeology, the better to serve the discipline” (Butzer 1982, 42). Geoarchaeology therefore is an interdisciplinary field of research par excellence.

To this day, man has engaged himself in almost all natural ecosystems and even altered some of them irreversibly. Time, form and consequences of human impact are documented in the landscape archives by the appearance of direct settlement indicators such as pottery, crop pollen or certain heavy metals. Indirect evidence is provided for example by an increasing sedimentation rate due to soil erosion, heightened phosphate contents or truncated soil profiles. The approach of geoarchaeology makes it possible to gain entirely new insights into man-environment-relations in time and space (Rapp & Hill 2006, Brückner & Gerlach 2007, Brückner & Gerlach 2008).

Subjects of this still young field of science are for example the investigation of the evolution of cultural landscapes as a precondition for understanding today’s living spaces, the transformation of the environment by man throughout history or the resource management of former societies, balancing between sustainable usage and excessive waste.

Geoarchaeology has the potential to answer questions regarding the flexibility of societies as well as social systems and their ability to respond to a changing environment. The importance of palaeogeographic research for archaeological and historical sciences and vice versa shows itself time and again. At best, the results of looking back can be used to forecast future scenarios (Brückner & Vött 2008).

References

1 Geophysical methods in geoarchaeology

In medicine tomographic methods for x-raying our body have belonged to the standard repertoire of physical examinations for years. For the "x-ray examination" and imaging of the shallow subsurface to reveal archaeological treasures, several geophysical methods are now available, two of which – geoelectrical tomography (also earth resistivity tomography, ERT) and seismic refraction – will be illustrated in more detail below. They both generate a two-dimensional cross-section of the underground, representing changes in resistivity respectively wave velocity. "Real" tomographies require a threedimensional data set. Other geophysical methods exist besides these, for example magnetic prospecting, ground penetrating radar (georadar), etc. (KNÖDEL ET AL. 2005, BEBLO 1997).

There are essentially two areas in which to apply geophysical methods within (geo)archaeological research. On the one hand, they can be used directly on the archaeological site (on-site studies) to map small-scale archaeological structures with the highest resolution possible and display them in their spatial position in the subsurface. For so-called off-site studies on the other hand, reconstructing the environment in the surroundings of the archaeological site, less-detailed surveys are often sufficient. Instead, for aspects of landscape genesis information across greater distances is important. According to these distinct demands different methods or method configurations come into operation.

A major advantage of these geophysical methods of sediment tomography is that they allow a non-destructive, seamless and often high-resolution prospection of areas of archaeological potential along a measurement profile or across a surface. For investigations on landscape reconstruction (off-site studies) only selective, punctual information used to be available, gathered for example from drillings; the areas in between always harbored a certain amount of insecurity when interpreting the results. For archaeological prospection in a narrower sense (on-site studies), seamless, detailed information with high resolution is even an indispensable prerequisite to detect small-scale archaeological structures such as wall remains, post holes or pits in the measurement data.

What often poses a problem when interpreting geoelectrical or seismic refraction data is the ambiguity of the measurement results (comp. e.g. LANGE 2005 or KIRSCH & RABBEL 1997); this means that several solutions present themselves as possible explanations for the measured data when generating a model of the near-surface underground. Under favorable measurement conditions they can usually be reduced to small-scaled questions of detail. Another difficulty consists in the correct interpretation of the results, since value anomalies in the measured data can reflect both natural variations of soil and sediment structures as well as anthropogenic influences with archaeological relevance. This is where interdisciplinary collaboration between geoscientists and archaeologists is essential to exclude misinterpretations.

Geoelectrical and seismic refraction methods can be applied in different areas of archaeological and geoarchaeological research. While seismic refraction is especially suitable to distinguish unconsolidated substrate from bedrock, the geoelectrical tomography is better suited to differentiate within different loose sediments and identify archaeological structures. Thus, the seismic refraction methods are rather used in off-site studies, whereas the geoelectrical tomography can be applied for both off-site and on-site studies.

1.1 Geoelectrical earth resistivity tomography (ERT)

Geoelectrical methods are applied to map the electrical resistivity of the subsurface. In order to identify natural or anthropogenic structures with this method it is necessary that the resistivity values (measured in Ωm) differ significantly from each other. A methodological complication arises from the fact that the values for certain rocks or substrates may vary considerably (Tab. 1). This means that one cannot directly infer a specific type of rock from a certain measurement value. For a correct interpretation it is essential to compare and verify the results with additional information from boreholes, other geophysical methods or archaeological findings.

The electrical characteristics of rocks are influenced by various factors. In addition to the chemical and mine-
14 | Sediment tomography for archaeological purposes

Tab. 1. Electrical resistivity of different rocks and substrates (compiled according to Greinwald & Thierbach 1997)

<table>
<thead>
<tr>
<th>Rock/Substrate</th>
<th>Resistivity (Ωm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soil, sandy</td>
<td>150-7,000</td>
</tr>
<tr>
<td>Soil, loamy</td>
<td>50-9,000</td>
</tr>
<tr>
<td>Soil, clayey</td>
<td>20-4,000</td>
</tr>
<tr>
<td>Sand</td>
<td>1,000-10,000</td>
</tr>
<tr>
<td>Silt</td>
<td>10-1,000</td>
</tr>
<tr>
<td>Clay</td>
<td>1-1,000</td>
</tr>
<tr>
<td>Limestone</td>
<td>100-7,000</td>
</tr>
<tr>
<td>Granite</td>
<td>300-30,000</td>
</tr>
</tbody>
</table>


eological composition the most relevant parameters are the structure and porosity as well as the geological constitution and formation of the rocks (Greinwald & Thierbach 1997). The water content thereby plays an important role, reflected for example in the grain size distribution of unconsolidated sediments. Fine-grained substrates can store more rain water than coarse-grained substrates, which due to their better permeability tend to be drier. These manifold influencing factors can lead to a wide spectrum of electrical resistivity for certain rocks.

The high-resolution geoelectrical tomography developed from the classical "four-point-method" (see e.g. Berktold 1997): two electrodes induct the current into the underground ("feed-in-dipole"), while the two other electrodes function as the "potential dipole", where the electrical resistivity is measured. A multitude of such four-point-measurements constitutes the modern multi-electrode system, which generates a cross-section of the subsurface resistivity distribution. For this the electrodes are arranged in a linear array – for example 100 electrodes spaced at a distance of 1 m each – and several hundreds and thousands of individual measurements are conducted. A two-dimensional layout of the electrodes allows the measurement of the three-dimensional distribution of resistivity values. This technique is also based on the four-point-method. Strictly speaking, only a 3D-exploration is a tomography in the truest sense of the word. Depending on the research question different electrode configurations can be used, each exhibiting different sensitivities regarding the lateral/horizontal or vertical resolution of the resistivity distribution. The dipole-dipole configuration offers the best results with regard to the lateral differentiation of a resistivity measurement (compare f.ex. Lange 2005, Kneisel 2003) and is therefore particularly suitable for a detailed detection of archaeological structures. For 3D-measurements the pole-pole configuration achieves the best compromise for small-scale measurements with close electrode spacings (Loke & Barker 1996).

1.2 Seismic refraction tomography (SRT)

The seismic refraction method is based on the varying travel times of seismic waves in different rocks and substrates. To successfully apply this technique the travel times (propagation velocities) must differ considerably. An impact source and signal transmitter (e.g. a hammer) provides the seismic energy and generates seismic waves, which can be detected on the surface using a linear array of receivers (geophones) (Fig. 6).

In the case of seismic refraction studies, only first breaks of the compressional waves (p-waves), which are

Fig. 6. The concept of seismic refraction for a two-layer case (Hecht 2001)
refracted at the interfaces of subsurface layers before returning to the surface, are considered. They register at the receivers faster than the reflection or surface waves. Dynamic effects, such as amplitudes, frequencies etc. are not taken into account. Similar to the earth resistivity tomography measurements it is not possible to detect a specific rock type from a certain velocity value (comp. LANKSTON 1990). Table 2 shows the partly great range of p-wave velocities for different rocks and substrates, which means that additional data are required for the correct interpretation of the data.

Different methods exist for processing and interpreting seismic refraction data: direct inversion methods (standard inversion methods), methods of iterative modeling and methods of seismic refraction tomography (KIRSCH & RABBEL 1997). With the direct inversion methods the layer boundaries and velocities can be derived directly from the travel times, while the iterative and tomographic methods require a starting model of the underground conditions (BRÜCKL ET AL. 2005). The intercept-time method as well as the Generalized Reciprocal Method (GRM) are among the most common direct evaluation processes for seismic refraction data (KIRSCH & RABBEL 1997). Their advantage is that clear-cut boundaries can be generated, with which the depth and profile of layers can be reconstructed. To verify and assess the quality of the results the ray tracing method should be applied, where synthetic travel time data are compared to the measured data. The model is then corrected successively (iteratively) until the measured values show good agreement with the calculated values (comp. SANDMEIER & LIEBHARDT 2005). The method of seismic refraction tomography determines the distribution of p-wave velocities in the subsurface in high detail along a measurement profile. This procedure needs dense coverage with traveltime data over the complete study area (UTECHT 2005). For optimal results, over-laying receiver spreads by as much as half the spread length should be employed. For the interpretation of seismic traveltime data the software packages Reflexw and Rayfract are used.

2 Conclusions and outlook

The application of sediment tomography in hyperarid environments produce promising results in the context of (geo-)archaeological investigations. Although the main focus of sediment tomography lies on the geoelectric investigation for archaeological prospection, the results of seismic refraction tomography can reveal valuable data, particularly in the field of landscape evolu-

![Diagram of p-wave velocities in different media](image)

Tab. 2. P-wave velocities in different media (compiled from FETRIC, complemented by other authors and own measurements (HECHT 2001))
tion. Information on soils and sediment structures even of the deeper subsurface is an essential prerequisite for the interpretation of archaeological sites or settlements with regard to the environment and its changes through history (Hecht 2007). Even more the combination of geoelectric with magnetic surveys is exceptionally suitable for archaeological purposes. Magnetic measurements can quickly yield detailed information about very large areas on the basis of which more narrowly focused investigations, such as earth resistivity tomography, can provide precise information about the depth and topology of archaeological structures (Fassbinder & Hecht 2004).

If possible, 2D and 3D geoelectric surveys should be performed together, because of the different strengths of each procedure: 3D measurements are appropriate to obtain a clear layout of archaeological structures, whereas 2D tomographies, especially in the case of dipole-dipole arrays, normally provide more detailed data along a line because of a higher spatial resolution. Therefore, the improvement of the spatial resolution of 3D geoelectric surveys is one big challenge for the future from a methodological point of view. In addition, the measuring time in extremely dry substrata is two to three times longer than under humid conditions and should be reduced. To learn more about the characteristics of resistivity values of archaeological findings it is of particular importance that the results of the tomographies be compared to archaeological excavations directly. The more geophysical and archaeological data are compared, the better the interpretation of resistivity tomographies should be even if no excavations are carried out. Moreover, a better understanding of geoelectric data on archaeological sites will help to achieve a better understanding of the archaeological sites themselves.

3 References


V Case study: Buried in the sand – 3000 years of man and environment along the Silk Road

Dr. Stefan Hecht, Prof. Dr. Olaf Bubenzer, Dr. Bertil Mächtle, and Gerd Schukraft Heidelberg, Germany

1 Preliminaries

In April 2008 first investigations and research was conducted in Turpan, Xinjiang, funded by the Academia Turfanica, the Chinese Academy of Sciences and the Heidelberg University, Project Global Networks. The research objectives were to test geophysical and geomorphological-geoarchaeological methods. All planned activities in Turpan were realised. The main focus was placed on geoelectrical earth resistivity tomography research of the ancient cities Jiaohoe and Gaochang, important tourist destinations along the Silk Road. In Gaochang the central part of the city was investigated while in Jiaohe, a site protected and preserved by the UNESCO, the field work concentrated on an important burial ground. In addition, an excursion into the surrounding area gave an impression of the geoscientific potential of the region. A test pit was dug on the northern edge of the Ai Ding Salt

Fig 7. Location of the research areas of Jiaohe, Gaochang and Ai Ding (own draft).
Lake in the lowest part of the Turpan depression.

First results of the geoelectrical earth resistivity measurements could already be presented in Turpan. These presentations showed the potential of the method, inspired further interdisciplinary discussions and strengthened mutual confidence. The local television station visited the group and broadcast an interview (2:35 min). These first investigations provided the basis for the summer school.

2 Introduction and scientific objectives

Numerous archaeological findings in the Turpan area (Northwest China) document the long history of the northern section of the Silk Road, which once was the most important trade route on earth. Up to now, the archaeological sites around Turpan have only been superficially investigated and the reason for the decline and downfall of the ancient cities remains unclear. One possibility is a correlation with changes in the palaeoenvironment.

The cooperation of the Academia Turfanica, the Chinese Academy of Sciences and the Heidelberg Department of Geography aims at looking into this question and geoarchaeologically investigating this area.

3 Approach

Besides establishing contacts and initiating cooperation, the following scientific goals were pursued:

- evaluating the potential of the geoelectrical earth resistivity tomography for further geoarchaeological investigation in the areas of the famous ancient Silk Road cities Jiaohe and Gaochang and
- finding new geoarchives for reconstructing man-environment interactions.

4 Results

The main activities of the first field work phase in April 2008 focussed on earth resistivity tomographies of the ruins of Gaochang and of the important burial ground Goubei at the famous city Jiaohe (see Fig. 7).

Additionally, short overview excursions demonstrated the huge geoscientific potential of the region for reconstructing both palaeoenvironmental conditions as well as recent changes associated with global change. For example, a distinct soil horizon was found in the Jiaohe area and is to be further examined. Also a test pit was dug on the north side of Ai Diting Lake, located at the lowest elevation of the Turpan depression (154 m below sea level), and yielded first sedimentological and chronological results.

4.1 Earth resistivity tomography in Gaochang and Goubei

Between April 21 and 24, 2008, several 2D and 3D earth resistivity tomographies were measured in the area of the ancient city of Gaochang. In addition, 2D tomographies were conducted on the Goubei burial grounds of the deserted city Jiaohe. The objective of the measurements was to explore the near-surface underground at selected sites where archaeological findings were expected, in order to identify them and present them in their spatial position. A multi-electrode resistivity measurement system (Geotom) with a maximum of 100 electrodes was used.

Below, selected measurements from Gaochang and Goubei are presented. All findings and respective interpretations were considered reasonable and were in principle confirmed by archaeologists from the Academia Turfanica, based on long years of excavating experience.
4.1.1 Earth resistivity tomography (2D) in Gaochang 1

The tomography Gaochang 1 was measured in the central area of Gaochang, where yet undetected chambers and connecting passages are suspected (see Photo 1). At intervals of 1 m, 99 electrodes were placed and measured with a dipole-dipole configuration. The resulting data in Fig. 1 show relatively high resistivity values at the base, 4 m deep and below, which probably represent fluvial gravel or sand. Above this follows an almost continuous layer of very low resistivity values (blue colors, R < 50 Ωm), which can be assigned to the overlying loess (or derivatives thereof). Sections of higher resistivity (green, yellow and red colors, R > 100 Ωm) disrupt the loess and indicate archeological findings. Within the top two meters very high values (red colors) are recorded, which can also point to archaeological remains. In some cases old subsurface excavation sites are detected, where the loose sediments of the refill cause very high resistivity values. Especially interesting for future excavations are those areas where higher values extend several meters deep (e.g. profile meter 25-30 or 65-70, see Fig. 8).

4.1.2 Earth resistivity tomography (3D) Gaochang 3D

Also within the central area, a 3D tomography was measured in order to explore the structures and the exact spatial location of the suspected underground chambers and passages. For this purpose 100 electrodes were arranged in a two-dimensional layout, spaced at a distance of 1 meter each (measuring field 9 x 9 m) and measured with a pole-pole configuration. Fig. 9 displays the resistivity values at several horizontal depth levels. The extremely high values (red colors, R > 5000 Ωm) outline a tunnel, whose entrance can be made out at the top edge of each image, approximately 1-2 m below the surface (top row, left and middle images, depth levels 0-70 cm and 70-150 cm). In the depth level below (150-243 cm), a continuous green band from the left to the right might indicate a second connecting tunnel. Since the resistivity values are not very high here, this section of the tunnel has probably collapsed.

4.1.3 Earth resistivity tomography (2D) Goubei 1

On the burial grounds Goubei of the deserted city Jia-oh-e a profile transecting a suspected grave mound was measured (see Photo 2). Given its size and its exposed location, this seems to be the most important grave in Goubei. The distribution of resistivity values along the cross-section shows comparatively high values at the base (red colors, R > 2000 Ωm), which can presumably be assigned to fluvial terrace sediments. The lower values above this (blue colors, R < 100 Ωm) represent loess or loess derivatives. Conspicuous vertical structures with intermediate resistivity values interrupt this area, possibly indicating subsurface burial chambers. Archaeological excavations of similar burial mounds in Goubei had already revealed several such burial chambers. The most distinct feature can be identified approximately 2.5 m below the surface between profile meter 26 and 30. A second vertical structure can be distinguished at a similar depth in the profile section 17 to 20 m. During the projected summer school this grave is to be examined in more detail by means of parallel 2D profiles and additional 3D tomographies, so as to obtain a complete three-dimensional image of the entire burial mound and its internal structure.
Fig. 9. Earth resistivity tomography (3D) Gaochang 3D: horizontal distribution of the resistivity values, recorded at increasing depth levels (100 electrodes, unit electrode spacing: 1 m, pole-pole configuration, see text for explanations).

Photo 2. Set-up of cables and electrodes across the burial mound of Goubei (foreground with security camera). Ruins of the Silk Road city Jiaohe in the background.
4.2 Test pit at Ai Ding Salt Lake

A test pit, 1.5 m deep, was dug in the deepest part of the Turpan depression, on the northern edge of Ai Ding Lake, probably the area of thickest and most complete sediment conservation (cf. Photo 3). We found a stratified sediment composition. Therefore it was planned to apply the well-proven method of percussion core drilling to reach deeper sediment layers.

5 Conclusions and outlook

The visited sites in the Turpan area are extraordinarily well-suited for future investigations regarding geoarchaeological questions within our project „Buried in the Sand – 3000 Years of Man and Environment along the Silk Road“.

The interdisciplinary cooperation of the disciplines Geography (Heidelberg), Archaeology (Academia Turfanica) and Palaeobotany (Prof. Li, Chin. Academy of Sciences, Beijing) provides an excellent opportunity for a future joint research project „Reconstruction of palaeoenvironmental changes along the northern Silk Road and impacts on its historical development“ in the Turpan region.
Satellite data and digital elevation models as tools for landscape reconstruction

Dr. Andreas Bolten, Cologne, Germany

1 Satellite data

The use of satellite data has become more and more important during the last 20 years. Even in less accessible regions, satellite data can assist in many types of questions. In addition, they can be used as a map substitute in regions barely covered with cartographic data. For these regions, maps up to scales of 1:50,000 with additional information layers (e.g. waypoints or tracks) are now available on demand. This chapter reflects on the use of free or low cost satellite and elevation data for landscape reconstruction and the combination options with other data sources of the same region to get an added value of interdisciplinary work.

The fundamental difference of the satellite data used is the time of admission and the spatial resolution, which describes the edge length of each pixel. Figure 11 gives an overview of the position of each cell in a raster dataset, its cell size and additional information of each pixel (e.g. the elevation corresponding with the pixel, the type of surface).

In addition, the spectral resolution of the data is very important. Besides the colours red, green and blue, sensors are able to absorb radiation in a very broad range in the close and near infrared (Fig. 12). Table 3 gives an overview of satellite data which can be acquired at no or low costs and Figure 13 shows the different resolutions of the satellite images. The highest resolution with a cell size of 60 cm is taken from satellite data with costs (QuickBird).

2 Elevation model from satellite data

Different techniques and data bases exist for the development of a digital elevation model. The Shuttle Radar Topography Mission (SRTM) obtained area-wide topography data of the earth's surface between 60° N and 56°S latitude. The radar-instrument consisted of a main antenna located in the payload bay of the Space Shuttle Endeavour, a mast connected to the main antenna truss, and an outboard antenna connected to the end of the mast. The active remote sensing method registered the emitted radar radiation and calculated the elevation by an interferogram. The SRTM-3 model has a resolution of three arc seconds (approx. 90 m), was calculated from
Tab. 3. Short overview of selected satellite data with resolution, bands and additional information.

<table>
<thead>
<tr>
<th>Name</th>
<th>Resolution (pixel size)</th>
<th>Bands</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>MODIS</td>
<td>250-1000 m</td>
<td>36</td>
<td>2 bands with 250 m resolution</td>
</tr>
<tr>
<td>Landsat 7</td>
<td>14.25 m</td>
<td>Panchromatic 6</td>
<td>Free of charge until ca. 2002</td>
</tr>
<tr>
<td></td>
<td>28.5 m</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SRTM</td>
<td>90 m</td>
<td>1</td>
<td>Elevation model (60°N-56°S)</td>
</tr>
<tr>
<td>ASTER</td>
<td>15 m</td>
<td>VNIR 3 (1 stereo)</td>
<td>Low cost, ca. 70 € each scene, each 3600 km²</td>
</tr>
<tr>
<td></td>
<td>30 m</td>
<td>SWIR 6</td>
<td></td>
</tr>
<tr>
<td></td>
<td>90 m</td>
<td>TIR 5</td>
<td></td>
</tr>
<tr>
<td>ASTER GDEM</td>
<td>30 m</td>
<td>1</td>
<td>Global elevation model</td>
</tr>
</tbody>
</table>

Fig. 13. Different resolutions of satellite images of the Turpan region. The highest resolution is taken from satellite data not free of charge (QuickBird) with a cell size of 60 cm. The black frame in the boxes A-C indicates the extent of the next detail (C-D). The MODIS image (A) shows a very natural colour layout with sand, bedrock and oasis ground. The Landsat 7 (B) and ASTER (C) images highlight the vegetation; ASTER in red colours as a result of an infrared shifted red colour channel. The QuickBird image (D) shows a remarkably high resolution of about 60 cm.
the more detailed SRTM-1 model, and is available free of charge in different processing steps.

The ASTER instrument is used for different types of questions. With a resolution of 15 m for the spectral area of green, red and near infrared a good natural appearance and a use of maps up to 1:50,000 is possible. Additionally, the scenes are often multitemporally available and comparable to the Landsat 7 images and analyses techniques.

For every ASTER-scene taken in nadir position a second backward image is taken several seconds later with another camera positioned at a discrete angle to the first image (Fig. 14). With the help of computer software it is possible to derive a digital elevation model which has half the resolution of the original pixel size (30 m). Combining the elevation data and the satellite images enables to display a 3-dimensional image. Figure 15 shows a model of the summer school region in Turpan.

Since August 2009 a global elevation model from ASTER data is available free of charge and can be obtained via the Internet. However, only a few quality studies are presented, the GDEM provides a 9 times higher resolved elevation model than the SRTM-model. However, the advances in the spatial resolution of satellite images are still in progress. In 2009, the WorldView II satellites will launch. With a spatial resolution better than 50 cm (identical to the present WorldView I) it will obtain nearly 20 % more pixels and data per area than QuickBird-data. Additionally, in comparison to the QuickBird-data (cf. Fig. 13 D), more channels are planned to enable multispectral analysis in highest resolution.

3 Combination of elevation and field data

On the basis of the digital elevation models further information can be deduced. These are basic data such as inclination or exposition of the slopes as well as hydrological data, e.g. the flow direction or the watershed of fluvial systems. In an interdisciplinary investigation such data can be combined with other data obtained by other disciplines. For instance, every archaeological remnant or archaeological site can be combined with its elevation data and the derived data from the elevation model. Hence, an interdisciplinary dataset is generated connected in a spatial matrix. In result, the dataset with the external data and the internal elevation parameters...
can be compared statistically to find relations between the datasets.

Using this technique for the western Desert of Egypt, the change in land use between the early and the middle Holocene could be verified (cf. Fig. 16).

4 Further readings


**Bolten, A., Bubenzer, O., 2006.** New Elevation Data (SRTM/ASTER) for Geomorphological and Geoarchaeological Research in Arid Regions. ZFG, Suppl. 142(142): 265-279.


**Bubenz, O., Bolten, A., 2006.** The use of new elevation data (SRTM/ASTER) for the detection and morphometric quantification of Pleistocene megadunes (draa) in the eastern Sahara and the southern Namib. Geomorphology, 102: 221-231.


Fig. 16. Combination of archaeological data of a finding region in the western Desert of Egypt and the parameters of the elevation model (flow accumulation and the relative topographic position) to verify the change in land use from the early to the middle Holocene based on a climate change.


5 Examples of satellite images of the Turpan region
Satellite data and digital elevation models

Fig. 20. 1:5,000 - QuickBird - GoogleEarth.

Fig. 21. 1:2,500 - QuickBird - GoogleEarth.
Fig. 22. 1:5,000 - QuickBird - GoogleEarth.
Basics of laser scanning
Dirk Hoffmeister, Cologne, Germany

1 Introduction

Although this new technique cannot be demonstrated during the summer school, this chapter is presented to show the potential of this method for geomorphological and archaeological usage. Laser scanning is a high-precision measurement technique. It uses laser-light, mostly with near-infrared wave lengths. In contrast to hand devices or total stations it does not measure one or several points at a time, but thousands of single points in a second.

After generating these huge unstructured point clouds they need to be interpreted unlike former geodetic surveying. Overall, the acquisition of objects is revolutionized by this technique. It uses photogrammetric and geodetic principles and is an active remote sensing technique (Fig. 23).

3D laser scanners are used extensively in a wide variety of applications including: as-built documentation, architecture, heritage restoration, facility management, forestry, agriculture, power/piping, construction, surveying, forensics, accident reconstruction, films/movies, and game development. Laser scanners can be distinguished by their mode, carrier and sensor.

2 Mode

Laser scanners work either in a 2D or 3D mode. 2D means that the laser beam direction can only be redirected in one direction, e.g. up and down a single line. 3D laser scanners can move in two different directions. Usually the head can be moved. The latter may be switched to a 2D-mode.

3 Carrier

Airborne laser scanning (ALS), alternatively referred to as Lidar (Light Detecting and Ranging), is the most developed method. Other possibilities are terrestrial laser scanning (TLS), mobile laser scanning (MLS) and kinematic laser scanning (KLS).

With ALS, airborne vehicles carry a 2D laser scanner. The scanned distances are relative to the position of the airplane. To obtain the absolute position of a point on the ground, a high-accuracy inertial navigation system (INS) is used, which consists of inertial measuring units (IMUs) and a global navigation satellite system (GNSS). With this method highly accurate digital height models (DHM) derived or digital elevation models (DEM) can be obtained. The point spacing and accuracy can be less than 30 cm. This data is essential for generating 3D-city models and is used for a huge amount of geographical issues, like hydrological modeling.

TLS is ground-based, the scanner is usually mounted on a tripod and normally uses a 3D-scanner. To achieve a whole 3D object, like a house or a large rock, it is necessary to scan the object from different positions. The resulting partial point clouds should then be registered to create one complete point cloud of the object of interest. Laser scanners can be equipped with a digital...
camera for colorization of the point cloud and texturing the object, for photo-realistic representations.

MLS is a technique where laser scanners are mounted on moveable vehicles like cars or boats. Equipped with an INS, they are capable of recording a huge amount of data by passing the objects of interests, e.g. coast lines, harbors, streets or whole cities. This technique matches ALS-data with a side perspective. Moveable targets such as trucks or bridges can also be surveyed, this method being called Kinematic Laser Scanning (KLS).

4 Sensors

There are at least three different types of sensors, each with different pros and cons. Sensors can be based on principles of triangulation, phase-shift, or time-of-flight range detection. All use a mirror to deflect the laser beam.

Triangulation scanners shine a laser dot on the object which then is received and measured by a camera. This technique is called triangulation because the laser dot, the camera and the laser emitter form a triangle. The length of one side of the triangle, the distance between the camera and the laser sensor and the corresponding angle (right-angle) is known. Therefore the distance and angle to the object can be calculated. These laser scanners have a maximum range of about 10 m and an accuracy of 0.5 mm. They are usually used for archaeological documentation of small objects, like vases, figures and so on.

Phase-shift laser scanners use laser light at three different phases to capture data on the object. The sensor analyzes the phase-shift of the reflected beam on the surface. A phase-shift laser has a maximum range of 80 m and an accuracy of 1 mm.

Time-of-flight laser scanners analyze the distance to an object by measuring the time difference taken from sending out the laser pulse until its reflection. The speed of light is a known and the round-trip time – twice the distance between the scanner and the surface – is measured. The distance to the object can then be calculated. This technique has a maximum range of more than 1 km and an accuracy of 1 cm and is the most common.

5 Post-processing

The post-processing phase is more important than in alternative surveying techniques. Usually scans are registered or georeferenced first, then the whole point cloud of an object is selected and can then be used for further analysis. This further analysis depends on the scientific question.

6 Georeferencing /Registration

In the case of ALS or MLS scans can be geoferenced by INS data in a global coordinate system. Different TLS scan positions can be registered to one another and transformed into one single project coordinate system by using the same special reflectors (automatic detection), known and selected common points or data-driven algorithms (comp. Fig. 24). This single project coordinate system then can be translated to a global coordinate system by using known surveying points (indirect detection of the laser sensor) or GNSS measurements (direct detection of the laser sensor).

7 Further analysis

After selecting the point cloud of the object of interest, there are two possible ways for further analyses. Overall these analyses can be divided into two major categories: data-driven (or iconic) approaches and interpreting (or symbolic) approaches. Iconic analysis directly uses the points and triangulates them to surfaces, which then can be analyzed and textured (Fig. 25).

Symbolic analyses use the point clouds indirectly, usually in CAD programmes, to rebuild objects with the
high-accuracy measurements of the scanner. It is a kind of generalization process (cf. Fig. 26).

8 Geomorphological and archaeological usage

As mentioned above there is a wide field of use. For geomorphological and archaeological questions there are specific usages.

Geomorphology:

- Boulder mass detection (Armesto et al. 2008)
- Fault displacement (Oldow & Singleton 2008)
- Cliff erosion (Rosser et al. 2005)
- Landslides (Teza et al. 2007; Dunning et al. 2009)

Documentation of cultural heritage:

- Detection of archaeological areas in forests by ALS (Doneus et al. 2007)
- 3D modeling of sites, e.g. Pinchango Alto, Palpa, Peru (Lambers et al. 2007)
- Reconstruction of building components (Herdt & Jones, 2008)

9 References

9.1 Basic literature


9.2 Specific Literature


Fig. 26. Symbolic analysis in a CAD programme. From left to right and above to below: outline detection, offset by using point cloud information, 3D volume, further building of roof and architectonic features.
Investigation, sampling and interpretation of soil profiles and fluvial sediments

Prof. Olaf Bubenzer, Heidelberg, Germany

Information on the morphological and pedological conditions is not only relevant for geoscientific issues but also for archaeological ones. Understanding the sedimentation circumstances and soil formations helps to evaluate the state of preservation of near-surface archaeological sites and to locate possible buried finds. Moreover, this knowledge provides an indication of present and past land use forms. Thus, buried (fossil) soils in arid environments are evidence of more humid climates, while sediment layers deposited by wind indicate dryer climatic conditions. The sediments at hand and the geomorphological context allow drawing conclusions about the presently and formerly active surface processes, for example whether the sedimentation was controlled by flowing or standing water, wind or sliding processes (gravity). Therefore, investigations of relief, sediments and soils form the basis of geoarchaeology.

During the summer school, soil profiles and fluvial sediments at selected sites will be investigated and sampled, based on the knowledge of the natural context (see chapter II). Outside of river and groundwater influenced locations the current hyperarid climatic conditions in the Turfan depression admit only very sparse vegetation or none at all. Consequently, the soils are only weakly developed and poor in organic substance. In addition, these locations are strongly influenced by the wind, so that in exposed (windward) positions in the terrain sediments are eroded by deflation while in sheltered (leeward) positions sediments are deposited.

The resulting surface conditions significantly determine the soil formations found there. Thus, on blowout surfaces with angular weathering debris (hamada) so-called Leptosols dominate, poorly developed, shallow soils, usually with large amounts of gravel, able to store only little water. On sand as well as gravel plains (serir) Arenosols (poorly developed sandy soils with a high infiltration rate during precipitation but low long-term water storage capacity, and mostly low soil fertility), Calcisoils (soils with little organic substance, substantial secondary accumulation of carbonates, high water storage but low circulation capacity) and Gipsisols (lightbrown/brown to white due to secondary accumulation of gypsum, middle to high water storage capacity) prevail.

In lower areas (wadis and depressions) sediment input, both by wind and – if present – by ground or surface water (melt water, rain water), usually predominates. The episodical, periodical or permanent discharge of water in the wadis, along with possible ground water, provides sedimentary input (wadi sediments) and more humid conditions. Depending on the flow rate of the water particles of varying grain size were and are eroded, transported and deposited. The prevailing soils on fluvial sediments are characterized by finely laminated soil material. The ability to circulate and store water is strongly dependent on the proximity to the ground water and the present grain sizes. The fertile soils of the oases in the region of Turfan can therefore be found along the rivers and on the edge of depressions, where the melt water from the surrounding mountains can be used as surface or emerging ground water. After longer periods of drought, though, salts and sulfides can accumulate.

In the mostly endorheic basins (depressions) the surface run-off collects. In addition, the ground water table in the Turfan depression lies close to the surface. High rates of evaporation as a result of the predominating arid climatic conditions therefore lead to an accumulation especially of salt in the predominantly fine-grained sediments. The prevailing soils are Solonchacks, saline soils with a puffy, porose structure or – in the case of a high concentration – encrustation.

In the past, longer periods of humidity (several hundreds to thousands of years) resulted in the formation of distinct soils. Subsequently deposited fluvial and/or aeolian sediments buried these paleosols, which is why they are also called fossil soils. They offer an insight into the past climatic conditions and possible anthropogenic land use forms.

For the detailed description and sampling of sediments and soils different instruments and methods will be presented in the field and parameters such as grain size, pH-value, calcium carbonate concentration, structure, color and humus content will be measured or estimated. Additionally, with the help of the following forms, as many of the surrounding positions as possible shall be consistently characterized with regard to their relief, substrates and soils.
Geoarchaeological Summer School Turfan 2009 -
Standard Form “Relief, Bedrock, Sediments and Soils”

<table>
<thead>
<tr>
<th>Editor:</th>
<th>Date:</th>
<th>Time:</th>
<th>Location:</th>
<th>Photo(s):</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Altitude (m a.s.l.): __________

Relief: □ Ridge □ Top □ Slope Shoulder¹ □ Upper Slope □ Middle Slope □ Lower Slope □ Slope Base

Slope position: □ Plateau □ Basin □ Plain □ Wadi Bottom □ Escarpment² □ Alluvial Fan

Prominent landmarks (visible on the satellite image):

[Vicinity & location of such landmarks (distance [m] & bearing [compass]). Example: Situated at the southern edge of a wadi mouth, 2 km southwest = 225° of a dune head / a bedrock outcrop / a single tree / an escarpment edge. Or: Southern end of an eastern barchan horn on a dark sandstone hamada surface with average stone diameters of 3–5 cm; around 2 km south of an escarpment.]

Slope: ______ °  Exposition: ______ °  [Only for slopes: direction of the slope inclination]

Vertical curvature [along the main slope gradient]: □ concave □ convex □ elongated

Horizontal curvature [parallel to the contour lines]: □ concave □ convex □ elongated

Subsurface Character:

- □ Bedrock
- □ Alluvial Sediments
- □ Serir³
- □ Hamada⁴
- □ Dune⁵
- □ Sandsheet
- □ Wadi
- □ Wadi terrace
- □ Former lake bottom
- □ Other

Soil:

<table>
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<tr>
<th>Grain size</th>
<th>stony</th>
<th>sandy</th>
<th>silty</th>
<th>clayey</th>
<th>salty</th>
<th>gypsic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thickness</td>
<td>______ cm</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Moisture</td>
<td>□ moist □ dry</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Remarks</td>
<td>__________________________</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Colour [MUNSELL-Value]</td>
<td>= __________</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

[e.g. 7.5 YR 6/3 = light brown or light brown (Description without MUNSELL-Value)]

Sample(s): ____________________ Depth(s): __________ cm

Vegetation:

- □ nonexistent
- □ existent
- □ Grass
- □ Herbs
- □ Shrubs
- □ Trees

Coverage ______ %  Coverage living plants [partly green] ______ %  dead ______ %

Actual morphodynamics [prevailing morphodynamic processes]:

- □ Aeolian: □ Accumulation □ Erosion □ Deflation [by wind] □ Corrasion [by wind]
- □ Fluvial: □ Accumulation □ Erosion □ linear □ area wide (Denudation)

Gravitative Processes:

[e.g. Rock Fan from coarse blocks with grain sizes of 10–50 cm.]

¹ = Transition plain/slope.
² E.g. in combination with „lower slope“.
³ Pebble (rounded scree material), by trend of small diameter (up to around 5 cm), e.g. alluvial fan.
⁴ Angular/sharp-edged, by trend of big blocks (diameter mostly > 5 cm).
⁵ When indicated differentiate between barchan, parabolic dune, longitudinal dune, mega dune (Draa), star dune, grid dune.
Sketch of the situation(s)\(^6\) or detailed photo documentation(s) [View/compass, zoom lens, scale]:

\(^6\) e.g. location of the reference point within a slope profile and/or the archaeological site.
1 Percussion drilling

The mobility of the percussion drilling equipment and its easy and practical use are the reasons that percussion drilling has carved out its own place beside standard hand drilling methods.

In the case of percussion drilling the core sampler, filled with a liner tube and fitted with a hardened cutting head (see Fig. 27), is driven into the soil using a gasoline powered percussion hammer. By executing this procedure step-wise, meter by meter, the introduction and extraction of the core sampler is simplified and contamination is avoided as much as possible (cf. Fig. 28). Samples taken using percussion drilling suffer minimal disturbance.

Percussion drilling is for instance applied for research on soil and sediment stratigraphy, grain size distribution, general soil classification, profile descriptions, soil pollution etc. It is usually applied when drilling has to be executed in harder soils, possibly containing layers of gravel and stones. The percussion core sampler can penetrate rubble and thus can also be deployed on dump sites or in urban areas. It can be used above as well as below the groundwater level.

A percussion drilling installation is a complete and many-sided sampling system for not too hard types of sediments, up to a depth of about 10 to 15 meters with 1 meter extension rods. When drilling in muddy or clayey soils, however, there is a risk of partially losing sediments because of their bypassing the opening of the percussion core sampler. Also, drilling in wet sand or gravel below the groundwater level can plug the core sampler with coarse material, which will lead to the same filling being extracted in spite of deeper drilling. In this case a tubing of the borehole is necessary.

Fig. 27. Percussion drilling equipment with core sampler, transparent pvc-liner, cutting head, core catcher, striking pen for gasoline percussion hammer, extension rod.

Fig. 28. Step-wise sampling by using percussion drilling equipment.
<table>
<thead>
<tr>
<th>Lecturers</th>
</tr>
</thead>
</table>
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Cheng-Sen Li began to study geosciences at the Department of Geology, Peking University, in 1973 and obtained a B.A. degree in 1977. From 1978 to 1986 he studied biological sciences at the Institute of Botany, CAS, and was conferred M.Sc. and Ph.D. degrees. He took post-doctorate and research associate positions at the Institute of Palaeontology, Bonn University, and the Senckenberg Institute, Frankfurt, Germany, from 1987 to 1989. Afterwards he lectured as visiting scholar at the University of Wales, UK, and the University of Liege, Belgium. In 1990, Dr. Cheng-Sen Li was promoted to be Full Professor at the Institute of Botany, CAS. He served as Director of the Department of Palaeobotany, Director of the National Museum of Plant History and Deputy Director of the Institute of Botany, CAS (until 1998).

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In 2007 he became professor at the Department of Geography, University of Heidelberg, representing Prof. B. Eitel’s chair of Physical Geography during his incumbency as president of the University of Heidelberg. Since 2008 he is Vice-Dean of the Faculty of Chemistry and Geosciences of the University of Heidelberg and Chairman of the working group "Desert Margin Research" of the German Association for Geography. In 2009 he was elected a Marsilius Fellow of the Excellence Initiative of the University of Heidelberg for one year. His research interests include geoarchaeology and landscape reconstruction in arid regions, aeolian and fluvial morphodynamics in arid regions, and quaternary geochronology and application of dating techniques in Africa, East Asia and Australia.

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