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Mapping Mt. Kailash
An interdisciplinary project on cultural landscape documentation

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Abstract. Mt. Kailash in Western Tibet, P.R. of China, is considered the holiest mountain in the world and the goal of many millions of pilgrims of different religions. They do not climb its summit but perform the ritual of circumambulating the mountain to earn religious merit.

International interest in this mountain is extremely high, as can be seen in the large numbers of publications and cartographic products on the subject. However, all published sketch maps and topographic maps are unsatisfactory and do not meet requirements of high mountain cartography and cultural landscape documentation.

The aim of this project is to prepare a naturalistic representation of Mt. Kailash at a scale of 1:50 000 as a combined image-line map. The requirements for a Mandala-like representation have to be taken into account to prepare the map sheet in adequate design. This can only be realized using cutting edge technology (remote sensing, digital methods of photogrammetry and image processing) and innovative methodological assessments (digital orthophoto combined with manual rock drawing and terrain models with additional modulated hill shading) as well as results of field studies (GPS measurements). 4-colour printing has been chosen to represent the high mountain area around holy Kailash in a vivid and impressive way.

1. Introduction

1.1 Background

The world mountain Kailash (Kailas, Astapada, Tise, Meru, Kang Rinpoche) is considered the holiest mountain in the world (Fig.1). It is a pilgrimage place for many hundreds of millions of people: Hindus and members of the Jain religion in India, members of the Bon religion in Tibet, and Buddhists all over the world *(Gratzl, 2000)*. Its noble, aesthetic appearance north of lake Manasarovar in the Transhimalaya (Gangdise Shan, Kailas Range) with φ = 39°05´N and λ = 81°15´E and a height of H = 6714 m in India and international or H = 6638 m in Chinese sources, lends it a special spiritual power (Fig.2) . The goal of the pilgrims is not to climb its summit but to perform the ancient ritual of circumambulating the mountain - Parikrama - a goal which has become unattainable for a big number of believers due to financial or political reasons, the remoteness and height of the region etc. A visual representation of the mountain in cartographic manner can be helpful in this case.

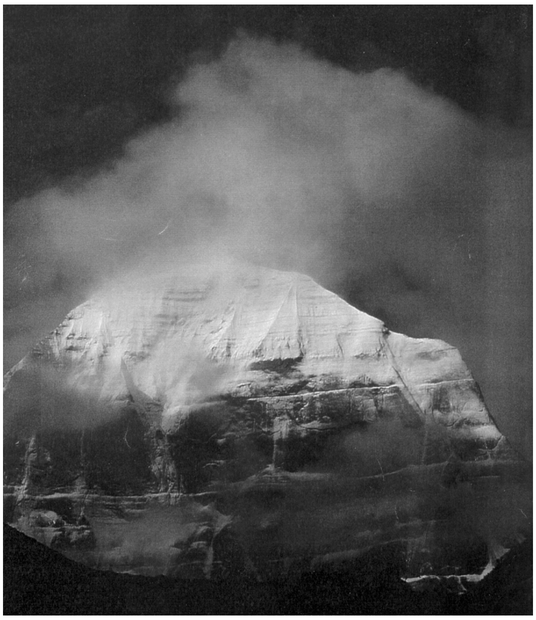

Fig.1: Northface of Mt. Kailash (Kostka,1998)

Fig.2: Oblique Satellite image (SSEOP) of the lakes Rakastal and Manasarowar and in the background the Transhimalaya with Mt. Kailash

1.2 Motivation

Since the foundation of the Austrian Alpine Association, high mountain research and mountain cartography have gained high priority in Austria *(Akademische Sektion Graz, ÖAV, 1992)*. This is not only valid for the Alps but also for the Andes in South America and the Hindu Kush – Himalaya region in South Asia.

It can be confirmed that the importance of mountain areas is increasing *(Ives, 1999)*. The United Nations General Assembly passed a resolution designating the year 2002 as " The International Year of the Mountains". The message "To strive for a better balance between mountain environment, development of resources and the well-being of mountain peoples" should be pushed to the fore. A special aspect in the Tibet – Himalaya region is that mountains considered spiritual centers and the residence of gods.

2 Project aim

The affinity between the holy mountain Kailash and the Buddhist conceptions of "Mandala" and "Stupa" has been pointed out in both older publications *(Tucci, 1932/1988)* and recent literature *(Snodergrass, 1992)*. In Tibet the relationship between landscape and Mandala *(Erhard, 1997)* also concerns hidden countries and spiritual places.
A large-scale map of the holiest mountain should represent the natural settings of the high mountain area and the path round it (Parikrama) in a way that it can be used by pilgrims or, generally, as an instrument of meditation.

The international interest in the cartographic representation of the area round the holiest mountain in the world is high. The results of available publications, such as sketch maps or topographic maps, are unsatisfactory or completely useless. This fact leads directly to the chosen research topic.

The project task is thus defined as follows:

- Definition of the requirements for this kind of maps, such as map section, information content and selection of color, to obtain a naturalistic impression
- Preparation of a map of Mt. Kailash at a scale of 1:50 000 with location diagrams for travel routes and other holy places.

Geographical extension of map content

Due to the above mentioned relationship between landscape and religious places, the geographical extension of the Kailash map had been determined by the following topographical elements:

- North-East corner: Passage to the head water area of the holy river *Indus* (approx. 31°10´N, 81°25´E)
- Center point (intersection of the map sheet diagonals): Peak of *Mount Kailash*
- South-West corner: Passage to the plateau of the holy lake *Manasarovar* (approx. 30°58´N, 81°13´E)

Taken into consideration this specification the resulting area leads to an map sheet size of 60 x 40 cm^2 .

3 Realization / Methodology

Information on remote sensing, digital photogrammetry, digital image processing and their possibilities of visualization is given in the extensive literature, partly in great detail. Special possibilities and existing problems of remote sensing data in high mountain cartography have also been pointed out *(Buchroithner, Kostka 1997).*
The applied methods constitute a further development of the cartographic process described and used by the authors for the production of the map sheet "Mustang area 1:50 000" (see Appendix), combining image and line elements *(Kostka 1996)*. The new methodological steps in the cartographic process include: remote sensing data and selection of color; digital photogrammetry and graphic rock drawing by hand; DTM and modulated hill shading; scanning and organization of data levels for a 4-color printing.

3.1 Ancillary data

Topographic maps

Most publications on this area deal with religious topics and the assignment of places to different gods *(Loseries, 1990)*. Only few publications, however, concentrate on the cartographic representation of the region itself, except for some general descriptions *(Allen, 1982; Uhlig, 1986; Kopp, 1989; etc.)*. Scientific interest began to rise in the middle of the 19th century *(e.g. Strachey, 1854/1983)*. A special relation to Austria is given through the adventurous journey of Herbert Tichy *(Tichy, 1953)*, who later on (in Bhaktapur/Nepal in autumn 1983) reported on it with great enthusiasm. In the past few years publications with cartographic representations *(Armington and Upadhyay, 1993; Sharma, 1995)* have become available as trekking guides for pilgrims and tourists. However, all cartographic representations, including also the detailed work of Prananvananda, were sketches with low geometric accuracy and without satisfactory relief representation.

The following three maps are the only examples of rather large-scale topographic maps of this region including relief representation:

- The map MANASAROVAR (Tsho Maphan) at a scale of 1:250 000 prepared by the *Army Map Service (1958)*. The relief is given in contour-line manner, the equidistance is 500 feet, in the area of the Transhimalaya the accuracy is very low.
- The map KANGRIMBOQE FENG 1:150 000 in the book "A guide to Mountaineering in China" *(Zhang Chun Shi, 1993)*. The relief is shown by means of contour lines at 100 m intervals (Fig.3). The plain south of Mt. Kailash with the village Darchen, the starting point of the pilgrimage around the mountain, is not part of the map.
- The map sheet KAILAS *(Gondoni, 1997)* at a scale of 1:250 000 with equidistant contour lines (500 m). This map does not give a visual impression of the high mountain relief.
- The Trekking map KAILASH 1:50 000 prepared by *Karto-Atellier, Forch, Switzerland (1999)*. The terrain is represented by a shaded relief (hill-shading manner) including contour lines with a equidistance in height of 100m. Comparing to the geological situation in this region the contour lines are too smooth and do not represent the topography in the quality expected for a 1:50 000 map (Fig.4).

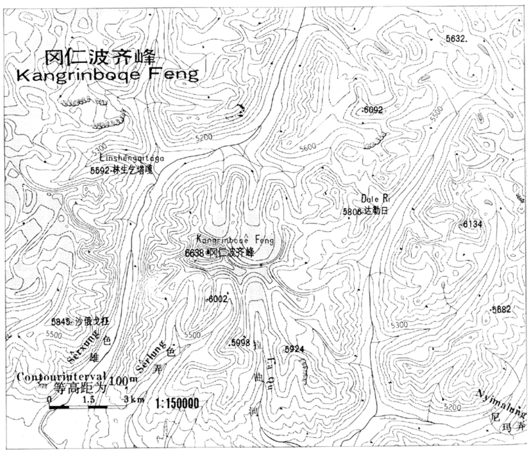

Fig.3: Map sheet Kangrimboqe Feng 1:150 000

Fig.4: Smoothed CTL´s of map Kailash 1:50 000

Field survey for ground control

In order to obtain an impression of the research area and to establish a number of ground control points, Mount Kailash had been visited in July 1998.

During this visit GPS measurements as well as barometric altimeter measurements were taken on suitable points already identified on the existing maps (mostly path bifurcations, passes, isolated buildings, bridges etc.). These observations were taken to provide the independent coordinates needed for points identified in the remote sensing data.

Because of difficulties to realize geodetic measurements during the field trip, the surveying work had to be done secretly. Therefore only *absolute measurements* were taken using a hand-held *Trimble Ensign*^{TM} GPS receiver. The horizontal position accuracy was specified with about 100 m by a probability of 95% for this method (till May 2000). The accuracy of the vertical position (height) was even 1.5 times worse.

Taking measurements for a longer time - such as 10 to 20 minutes - may increase the accuracy up to three times for a single point position. In the field work an observation period of 15 minutes had been used. Furthermore also the PDOP value (Position Dilution of Precision) had been registered, to exclude measurements taken at bad satellite constellations in terms of geometry.

Aneroid barometer measurements were made to enhance the precision of the height component of the control points.

Analog/Digital remote sensing data sets

In order to use satellite images for for high mountain cartography purposes, two important prerequisites have to be fulfilled: Firstly, the cloud- and snow cover of the image should be very low. Secondly, in order to avoid or to reduce shadow effects the image acquisition time should be close to midday. This is especially important in areas with high relief energy, e.g. mountainous areas with small-structured rock arrangements.
These two points have to be taken care of when ordering satellite data.
For map productions at a scale of 1:50 000 remote sensing images with a geometric resolution up to 30 m are commonly used. The RS products used in this project are shown in Table 1:

Sensor	Resolution	Scene	Date of acquisition
CORONA	Nadir 2m	D104173	17.09.1971
CORONA	Nadir 2m	D104174	17.09.1971
LANDSAT TM 7	pan15m ; MS 30m	LS7_144-38	24.09.2000
LANDSAT TM 7	pan15m ; MS 30m	LS7_144-39	24.09.2000

Table 1: Remote sensing data used in the project

3.2 Data preprocessing

Control point

In the data evaluation of the GPS measurements the well-known problems of the different geodetic reference systems used for cartographic representations of the Tibetan Himalaya had been taken in consideration *(Heine and Kostka, 1998)*.
As the lowest common denominator of all map coordinate systems used in the project a UTM projection based on the WGS84 were selected. The transformation of the geographic coordinates to UTM-Zone 44 coordinates were realized using the LEICA^{TM} GPS post processing Software SKI Pro^{TM} (Table 2).

The height measurements obtained in the field were reduced to the level of the official maps of the Chinese Academy of Sciences *(Shi Zuhui, 1990)*, where the height of Mount Kailash is defined with 6638 m (Table 2).

Point description	Northing [m]	Easting [m]	(barometric) Height [m]
Tirthapuri	3443759	476296	4240
Darchen	3427205	527628	4520
Latze	3428947	524641	4620
Torchoerten	3431286	524747	4580
Shershong	3432444	525419	4580
Zusammenfluss	3439771	527555	4770
Zusam-fluss_Dirapuk_G	3441384	530426	4870
Camp_Gebetsfahnen_Kail	3440957	530461	4900
Dolma_La	3440222	535262	5420
Schulter_ueber_Haupttal	3438233	536989	5180
Steinbruecke	3439317	538462	5020
Zusam-fluss_100_m_westl	3432707	534770	4700
Kloster_Zuthul_Phuk	3429921	534655	4660
Durchbruchstal_Nord	3426164	531280	4590
Ticket_Office	3425369	530434	4520
Bei_Hoehlen_Purang	3352342	516378	3810

Table 2: UTM coordinates and orthometric heights of control points

Digital image processing

In order to adapt satellite images to a reference system, a geometrical transformation has to be executed - geocoding. The transformation parameters are determined using ground control points *(HILDEBRANDT, 1996)*.
In this case the GPS measured ground control points were used for geocoding the *Landsat TM* satellite images.
If available, the geocoding process involves a digital elevation model (DEM) in order to compensate distortions due to the terrain relief. In our case, no DEM was available which means that geocoding errors of up to 250 meters are possible if the region of interest is situated at the margins of the satellite image. Fortunately, the Mount Kailash is close to the nadir point of both satellite scenes (*Corona* and *Landsat TM*) meaning that the geocoding errors due to the terrain are negligible. More precisely, the geometrical accuracy required for cartographical tasks is sufficient.
The *Landsat TM* sensor provides a panchromatic image with high spatial resolution (15m ground pixel size) and multispectral data with 30m ground pixel size. In order to take advantage of both types of data, a pixel level fusion has been performed. In this case, hue-saturation-intensity (HSI) transform *(LILLESAND, 1994:1)* has been used for combining the panchromatic and the multispectral data. The aim is to integrate disparate and complementary data to exploit the information content in the images as well as to increase the reliability of the interpretation *(POHL, 1996:31)*.

For map creation, two *Landsat TM* images with different spectral band combination were used.

- A 543-band combination displaying the near- and mid-infrared reflectance allows a high differentiation of vegetation covering (Fig.5).
- For geomorphologic issues, a 321-band combination (real-colour image) is produced (Fig.6-).

Both colour compositions are HSI-transformed to increase the spatial resolution.

Due to the unknown geometrical characteristics of the *Corona* data, an image to image transform was used to geo-code the high resolution *Corona* satellite image (Fig.7). Applying this process the required geometrical conformity of both data sets, the *Landsat* data and the *Corona* data, led to an useful result.

Fig.5: *Landsat TM* 543-band combination

Fig.6: *Landsat TM* 321-band combination (real-colour image)

Contour line extraction

As mentioned above the geometrical representation of the topography of Mount Kailash is of poor quality in the existing map products. In each of these products the contour lines, as the main cartographic element to describe the geometry of the terrain, do not consider the geomorphologic situation of this high mountain area in an adequate way.
As we did not posses stereo images as well as man labor to measure a digital terrain model (DTM) of the hole project area, the contour lines (CTL) were assessed by using three different data sources:

- the height information was taken from the maps KANGRINBOQE FENG 1:150 000 and KAILASH 1:50 000 and
- the geomorphologic information (geometric form of the CTL´s) was derived from the geo-referenced *Corona* image

The only way to obtain the expected CTL quality was to do this work totally by hand. Of each of the two maps a duplicate was made on a transparent plastic film, which were used as 2nd and 3rd layers superposing the *Corona* satellite image map (1st layer). The final contour lines were drawn onto the 4th layer (Fig.8) without disagreement with the satellite image layer (Fig.7).

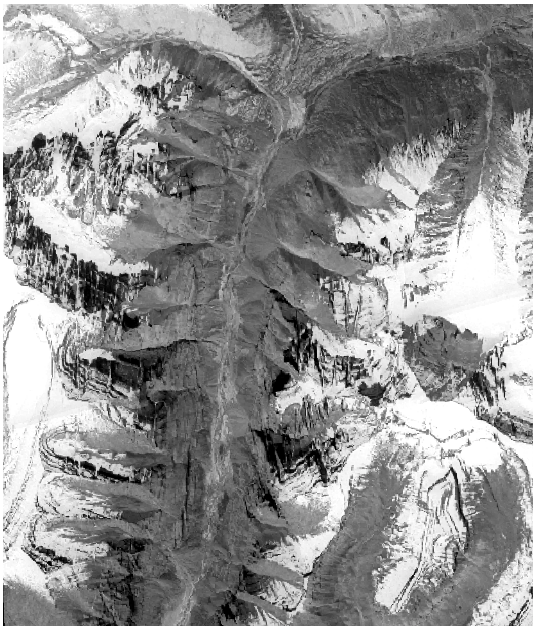

Fig.7: High resolution *Corona* satellite image

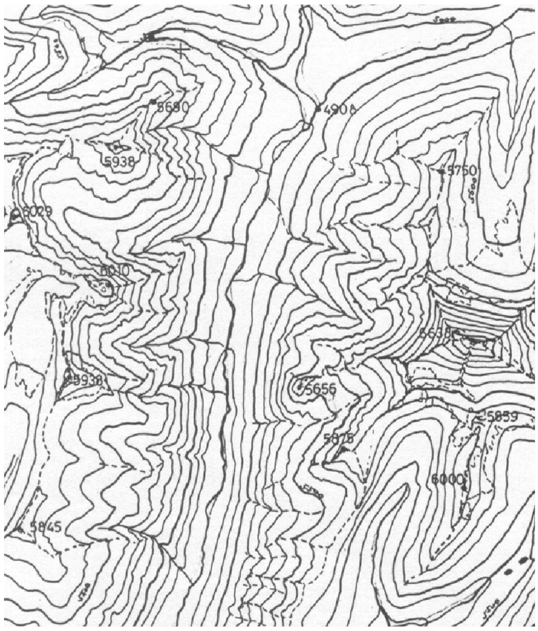

Fig.8: CTL´s representing the high mountainous topography

3.3 Cartographic compilation

The entire cartographic work is not yet finished. It is going on in responsibility of H.Krottendorfer, cartographer in Vienna and Tatabaya/Hungary.

This work includes:

- map design, including title photos and location diagram of Kailash – Manasarovar region
- relief representation by modulated hill shading based on CTL and satellite image data

- rock and snow/glacier representation
- signatures and lettering.

Subsequent the layers for the final map sheet will be scanned to provided a fully digital product for the reprographic and printing process.

Result / Conclusion

The final goal of the map making process is to represent the high mountainous region of Mt. Kailash in a naturalistic way showing relief, glaciers and rocky details.
So the noble beauty and the holiness of the mountain can be presented to interested people, who can not reach this area.
In a symbolic way it would serve as a tool for meditation and therefore it can be a source of pleasure for them.

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Appendix: **Heine et al. : Mapping Mt. Kailash**
Map sheet TSARAN – GHELIN 1:50 000; Mustang District, Nepal