Estimation of the permafrost area in the Altai Mountains (Russia) in the framework of the preservation of the Frozen Tombs of the Altai Mountains

R. Goossens & A. De Wulf
Ghent University, Department of Geography, Krijgslaan 281, S8, B-9000, Ghent

W. Gheyle & J. Bourgeois
Ghent University, Department of Archaeology, Blandijnberg 2, B-9000, Ghent

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ABSTRACT: This paper is presenting a methodology for the mapping of the occurrence and evolution of permafrost on the basis of remotely sensed data, in the framework of the Frozen Tombs of the Altai Mountains project, directed by UNESCO. The tombs under focus belong to the Scytho-Siberian civilization, dating from about 800 to 300 BCE. Many of these graves or kurgans are very well preserved because they are constructed in permafrost soil. This makes them one of the most important sources of information for the study of the ancient history of Central Asia. It is believed that part of these graves, situated on lower altitudes, are located in former permafrost zones that recently disappeared. Scientific research shows that the limit of permafrost zones is slowly retreating, due to global warming.

In this research we use ASTER and Landsat ETM+ scenes to study this problem. The ASTER data were used for creating a DEM showing the overall relief in the study area, using Ground Control Points (GCP’s) measured during the field campaign in 2003. The analysis of the thermal band of Landsat gives an impression of temperature conditions in the study area. The image is dating from the summer period and gives therefore an idea of the “maximum of warming up” in the area. It should be noticed that this is only a test and is for sure statistically not relevant. A comparison of the temperature distribution with the DEM, more specific the altitude and the slope map, is made.

1 INTRODUCTION

1.1 Cultural background

The Altai Mountains are spread over the territory of four neighbouring countries: the Altai Republic (part of the Russian Federation), Mongolia, China and Kazakhstan (see Fig. 1). The rich archaeological heritage of the region is known as early as the 17th Century. In the 20th Century, the discovery of the frozen burials at Pazyryk (Altai) has made the Altai region to become quite famous archaeologically (see Rudenko 1970). All of these finds have been dated to the so-called Scytho-Siberian period, from the eight to the second Century BCE. The main source of information about this mainly nomadic civilisation, itself being unwritten, is the archaeological research. The typical Scythian burial mound, so-called kurgan, forms the main type of archaeological information, as the (temporary) settlements are mostly not preserved.

In the Altai Mountains, much of these kurgans are situated in a frozen context. This means that all of the tomb contents are preserved for over 2500 years: not only the infrastructure of the grave, but also all organic and inorganic materials that accompany the dead to the afterlife. These generally include textiles, wooden objects (like vessels, furniture), bone, bronze, iron and gold objects, either
ornamental or practical, weaponry, chariot with fully harnessed horses, and even food to survive the trip to the hereafter. The body of the deceased forms an even more important source of information, since it was mumified and comes to us in a perfect state of conservation, complete with clothing, hair dress, and in many cases wonderful tattoos, covering arms, shoulders, legs, hands, breast and back.

2 THE DISAPPEARING PERMAFROST

As Altai is situated on the border of the huge Siberian permafrost zone, there is discontinuous permafrost: it is only found on some places, depending on height, soil texture etc... Many of the frozen tombs are situated in a zone that has no frozen soil in summer time (in the present; the situation may have been different in the past, even recently). The specific construction of the kurgan, however, with huge stone mound and deep grave pit, acts as a very strong isolator in summer time. During the short but warm summer, the ice thaws in the surroundings, but exactly underneath the structure itself, a thick ice lens survives the warmth, preserving all archaeological materials.

Recently, the subtle equilibrium that enables the formation and subsistence of permafrost in the Altai Mountains is endangered by climatic changes. Over the past 100 years, there has been an increase in temperature of 1°C in the vast area encompassing Temperate Asia, although subregionally the changes might be higher (increase of 2 to 4°C) or lower (decrease of 1 to 2°C). The data from
Barnaul, located at the foot slopes of the Altai, indicate an increase of 2°C in the past 100 years for the average temperature. Moreover, the increase in temperature is much higher in winter and spring (e.g. January: 4.8°C in the past 100 years) than in summer and autumn (Bourgeois et al. 2000: 33-34). Because of these climatic changes, significant reduction or disappearance of permafrost is predicted for the middle of this century in the Altai Mountains. Mountain permafrost tends to be most sensitive to climate change because its average temperature is usually within one or two degrees of the freezing point (Marchenko 1999).

Research done by a team of geographers from the Free University of Brussels (VUB) during four consecutive summer field seasons in the period 1997-2000 has detected major changes in some of the glaciers of the North and South Chuya Range (Kosh-Agatsh region, Altai Republic). On the Sofiyskiy Glacier, for example, the field observations revealed that this glacier retreated steadily during the 20th Century at a rate of 18.3 m/a; the front of the glacier has moved 1800 meter as compared to photographs dating from 1898 (Pattyn et al. 2003: 286-292).

It is clear that the remaining frozen kurgans are extremely vulnerable to these climatic changes and will most likely disappear. Partly destroyed tombs, due to thawing, have already been found during archaeological excavations in the last decade. It would be unforgivable not to locate and protect the remaining frozen tombs as valuable witnesses of the ancient nomad cultures of the Eurasian steppe.

In this context, UNESCO has launched a long-term initiative to protect the valuable monuments of Altai Mountains. As a first step, the Flemish/UNESCO Fund in Trust for Culture sponsors phase I of the project, covering 2005 and 2006, that plans the detailed archaeological inventory of some study areas in the Altai Mountains and a preliminary study of the permafrost occurrence.

3 PROPOSED METHODOLOGY

Detailed information on the situation of the permafrost is only scarcely available in this remote area. For the survey of permafrost occurrence in relation to archaeological monuments, one needs much more detailed information. Due to the extent of the area under research and the difficulties in accessing the terrain, extensive fieldwork cannot solve our problem. Instead, remote sensing seems to be the best tool to gather information about the permafrost situation. The long-term period of image recording in the thermal part of the spectrum seems to be the way of gathering information about the presence/non presence of the permafrost.

Permafrost formation is conditioned by several parameters as temperature, soil texture, precipitation, soil humidity, sun exposure etc… Not all of these parameters can be studied by aims of remote sensing. In a first stage, only two parameters were taken into consideration: temperature and, also taking in consideration the placement of the archaeological sites, the degree of inclination of the surface.

As the tombs are always situated on alluvial and terrace deposits, and the permafrost is present in soils and not on bedrocks, we needed to define the flat alluvial and terrace relief forms. Topographical maps of appropriate scale are not available over the area; therefore a DEM was created based on an ASTER scene from August 9th 2003.

Secondly, the presence of permafrost is conditioned by the overall annual temperature. To obtain information about the soil surface temperature, a Landsat ETM+ scene, dating from July 22nd 2000, was used. This scene is one of the few cloud free images over the area in summertime, and a winter scene is not appropriate due to the snow cover.

4 MATERIALS

- Landsat 7, sensor ETM+: scene p144r025_7t20000722-z45, July 22nd 2000.
- Ground Control Points: a total of 43 points measured by the UGent team during the archaeological
and geographical fieldwork in 2003, with the differential C-NAV GPS (C&C Technologies) (Gheyle et al. 2005: 3-10).


4.1 Creation of the DEM and Slope Map

For the creation of the DEM, band 3N and 3B from the ASTER scene were used. As the GCP’s were initially measured and used for the photogrammetric restitution of CORONA images (Gheyle et al. 2004: 391-403), only 7 out of 43 measured Ground Control Points could be used for the ASTER restitution, due to the resolution difference between the two image types (KH-4A: 2.7 m resolution – ASTER NIR: 15 m). The absolute orientation with the VirtuoZo 3.2 software yielded RMS errors of 12.55 m in x; 8.45 m in y; 15.13 m in xy and 12.01 m in z. These errors are within the limits of the image resolution, and the process resulted in an ortho-image and a DEM. This DEM was the base for the calculation of the slope map of the study area.

4.2 Estimation of the Soil Surface Temperature

Temperature is of course the most important factor in the occurrence of permafrost. We can assume that the surface temperature is related to the depth of the permafrost, as the insolation and the daily warming up of the top soil are responsible for the heat conduction into the depth. If the temperature of the top soil is higher, the permafrost will be deeper, or completely absent. Figure 2 shows us the temperature profiles as measured during the fieldwork in the Kalanegir Valley (Altai Republic) in 1997 by Jari H. Mikkelsen and Wim Van Huele, Ghent University and Free University Brussels (Bourgeois et al. 2000, 191-196).

![Figure 2. Temperature measurements in the Kalanegir Valley, Altai Republic, made during the 1996-1997 summer prospecting campaigns, indicating the permafrost depth (source: Jari H. Mikkelsen, Department of Geography, Ghent University).]

To estimate the soil surface temperature based on band 6 of the Landsat ETM+, the radiance values were first converted towards degrees Kelvin and recalculated to degrees centigrade. The resulting temperature is a ‘black soil’ temperature (Fig. 3).
The fieldwork of 1997 in the Kalanegir Valley was used as a key tool to relate top soil temperatures and permafrost depth, based on the soil profile descriptions. The coordinates of the profile descriptions, where the permafrost was found at a depth of 80 to 160 cm, were put on the georeferenced degrees centigrade image. The value for the corresponding pixels was 32.7°C at surface. This seems a very high value, but it is a realistic one, and it can be explained by several facts: (i) as we can see in Figure 4 (Sheffer 1998), the temperature can change a lot in the course of one day, up to 20°C at a depth of 1 cm. The Landsat image was taken on a sunny day (no cloud cover) in July, the hottest month of the year; (ii) Figure 2 shows us that the temperature of the top soil in Kalanegir was between 10 and 20°C, even at a depth of 10 cm, at the time of the 1996-1997 research. It is certainly possible that the surface temperature is some 15 degrees higher, as we observed during the archaeological and geographical fieldwork of July 2005; (iii) observations during the same campaign in 2005, involving temperature measurements of soil profiles, in a neighbouring valley, the Dzhazator, proved that the top soil can be very warm when there is a lot of sun, even if permafrost is present at low depth.

Figure 3. An overview of the research area (outline) on the Landsat 7 ETM+ image, band 6, after conversion to degrees centigrade.

Figure 4. This scheme gives an indication of the evolution of soil temperatures during the day, in relation to the depth, in Siberia (Sheffer 1998).
We used the value 32.7°C as a threshold, and included all parts of the image that had lower pixel values in the zone of "possible permafrost occurrence". Figure 5 shows this area in pink (on the accompanying CD-Rom, you will find all colour images). The lower parts of the valleys and the huge Chuya steppe (at a height of 1800 m) are excluded (blue), while all higher valleys (with heights varying from 1900 up to 3400 m asl) are shown as possible areas of permafrost. Also insolation is important; in some valleys we see that the northern slope is excluded (facing the sun), while the southern slope appears to be cold enough following our criterion.

As only flat areas are important for the archaeological research, and permafrost is formed on areas with soil formation (no steep slopes or rocky surfaces), we filtered all flat areas out of the slope map. As test cases we used a threshold of 10° (the limit of stable slopes) and of 7° (a more realistic limit for the construction of huge burial mounds). The resulting images were combined with the temperature image. In the following images, Figures 6 and 7, the pink surfaces are possible permafrost areas with a slope of, respectively, less than 10° and less than 7°.
5 CONCLUSION

Although we are convinced this method gives us valuable information on the possible occurrence of permafrost and the location of possible frozen tombs, it has to be considered as a first test with preliminary results. Other criteria have to be taken into consideration, such as the facing of the slopes and the degree of insolation, the soil properties etc… It would also be interesting to investigate the winter situation, as the snow cover can isolate the sub-soil from the very cold air. Also, it should be possible to detect areas where cold air is concentrated. The problem with the winter images is that they are very difficult to georeference, as they are completely white due to the snow cover. More fieldwork will also refine our criteria, and it would be very interesting to do temperature measurements in function of the satellite data. In July 2005, temperature measurements of soil profiles were taken in a neighbouring valley and precisely located with GPS.

Once the methodology is perfected, we plan to compare the results with earlier Landsat images of the 80’s, in order to evaluate the evolution of the upward movement of the permafrost zone in the Altai Mountains.

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