Generation of a detailed geological map of the Antarctic Peninsula applying remote sensing methods

C. Kraus

GeoForschungsZentrum Potsdam GFZ, Telegrafenberg, 14473 Potsdam, Germany and Instituto Antártico Chileno, Plaza Muñoz Gamero 1055, Punta Arenas, Chile (ckraus@inach.cl)

Summary Antarctica is one of the most difficult continents to work on geologic aspects because of its permanent ice shield covering over 98%. On the Antarctic continent geological field work can only be done during austral summer but nevertheless during this warm period some ice-free areas still stay inaccessible for field work. This project which is concentrating on the Antarctic Peninsula and adjacent islands tries to solve this constitutional problem in applying a new methodology to gain the same results as a traditional geological mapping in unapproachable areas. Therefor satellite images from optical and radar sensors are used as well as aerial photograph. Whereas aerial photos only can give an overview with a preciseness depending on its spatial resolution images from optical sensors as ASTER or Landsat TM dispose of the ability to reveal chemical differences from the surface. Radar sensors instead are used to work on structural information as e.g. faults. The technique of using remote sensing data to discover geological features is already widely-used but has not been applied to any parts of the Antarctic continent because of difficulties in finding suitable datasets. High cloud coverage or non-existent datasets of specific areas for example are hindering factors in applying known methodologies on this area. For that reason this projects concentrates on discovering the best possible solution of a data combination leading to a precise and detailed geological map of the Antarctic Penin-sula and adjoining islands.

Citation: Kraus, C. (2007), Generation of a detailed geological map of the Antarctic Peninsula applying remote sensing methods*: in* Antarctica: A Keystone in a Changing World – Online Proceedings of the 10th ISAES, edited by A.K. Cooper and C.R. Raymond et al., USGS Open-File Report 2007-1047, Extended Abstract 189, 4 p.

Introduction

The Antarctic continent with its 12,093 million km² of which over 98 % are permanently covered by ice represents a difficult terrain for geological work. Only the remaining < 2 % are ice- and temporarily also snow-free and there-fore accessible to geological research. The ice-free regions are usually restricted to coastal areas and mountain rid-ges. Because of climatic changes the ice-free surface in coastal areas is constantly increasing, especially in the Ant-arctic Peninsula and adjacent islands. This project concentrates on those latter areas, which show the most significant changes due to climatic warming processes.

Since the 1960s, the British Antarctic Survey (BAS) published six geological maps at a scale of 1: 500 000 covering the entire Antarctic Peninsula. Individual areas were also mapped in greater detail either by BAS or other investigators, but up to now no detailed geological map could be achieved covering the complete area of the Antarctic Peninsula and the South Shetland Islands - mostly due to ice coverage and climatic conditions hindering field work.

This project uses remote sensing methods analysing satellite images including active and passive systems and furthermore aerial photographs to achieve geological information. The extracted information shall result in a detailed map that can provide a useful base for further investigations on the Antarctic Peninsula.

Functionality of the applied datasets

The project's initial approach was to use as much datasets as available. In the meanwhile it showed that some datasets are almost useless for the given purpose, therefore they were excluded from future processing. The remaining data types shall be used to determine specific dataset combinations that finally yield the best results in generating a detailed geological map. Four types of remote sensing data are available for this project at the moment: ASTER, Landsat TM 5, ERS 1/2 and aerial photographs. In the near future (after May 2007), the database will probably be extended by TerraSAR data (http://www.dlr.de/tsx/start_ge.htm).

- Passive satellite sensors such like ASTER or Landsat TM are capable of showing chemical features of the land surface, e.g. of rocks. The rock chemistry reveals itself by means of specific spectral signatures which are diagnostic for each chemical element. Spectral signatures in the electromagnetic wavelength range of 0.4-2.5 µm form because of electronic or vibrational processes of inter-atomic bonds (Bodechtel, 2001). In the range of the thermal infrared (TIR) between 8-12 µm they form because of fundamental vibrational frequencies (Vaughan et al., 2005). On account of chemical differences and thereof resulting variable signatures it is possible to distin-guish between diverse rock-types.
- Active satellite sensors such as ERS 1/2 or TerraSAR have an ability to show surface structures, depending on the roughness of the surface and the frequency of the used radar band. Due to its electrical characteristics of the

penetrated object (e.g. soil) and the wavelength, radar also has ground penetrating capacities (Lillesand et al., 2000).

- Aerial photographs display the entire visible wavelength range (VIS: 0.4-0.7 µm) in one image (Lillesand et al., 2000). This fact effectuates the application of aerial photographs for the distinction of chemical features almost impossible. Nevertheless, these images provide a precise view of the area because of their high spatial resolution and also can be used for structural analysis.

Evaluation of datasets used

- A first intent was made with Landsat TM data which can only give an overview of the working area. Land-sat TM disposes of seven spectral bands, six of them covering the electromagnetic wavelength range of 0.4-2.5 µm and providing a spatial resolution of 30 m per pixel. Additionally, the so-called sixth band records the wave-length range of 10.40-12.50 µm and shows a spatial resolution of 120 m (http://eros.usgs.gov/products/satellite/band.html).
- ASTER data provides a couple of advantages as compared to Landsat TM data: the visible to near infrared (VNIR) is covered by three spectral bands at a spatial resolution of 15 m; the wavelength range of 1.6-2.5 µm by six spectral bands at a pixel size of 30 m and the range of the TIR by five bands at a spatial resolution of 90 m. Additionally, the third band of the ASTER sensor disposes of a backward looking ability, allowing to create digital elevation models (DEM) (http://asterweb.jpl. nasa.gov/characteristics.asp). ASTER data therefore allows the extraction of far more details than by using Landsat TM data.
- ERS 1/2-systems work with a C-Band (5.3 GHz) providing a spatial resolution of 30 m along track and 26.3 m across track (http://earth.esa.int/rootcollection/eeo4.10075/eeo3.298.html). From 1995 to 1998, the ERS mission was operated as tandem flight with a one day offset in order to produce interferometric data for the ge-neration of DEMs (http://earth.esa.int/images/INSI/insi_frameset. html).
- The TerraSAR satellite will be launched at the end of May 2007 and will be equipped with a X-Band (9.65 GHz) providing a spatial resolution of 6 m down to 1 m (http://www.dlr.de/rd/fachprog/eo/terrasar-x). TerraSAR will also be able to process interferometric data by using a dual-pass antenna (http://www.dlr.de/rd/fachprog/eo/terrasar-x/hintergrund). However, detailed plans for a tandem mission utilizing a second TerraSAR that shall be launched in 2008 already exist. The goal of the mission will be to collect high resolution interferometric data going down to a geometric accuracy of 2 m (http://www.terrasar.de/en/prod/tandem/index.ph).

Methodology of image processing

In a first step, usable datasets of test areas were collected which undergo geo- and (in case of optical images) also atmospheric corrections. Subsequently, DEMs will be created from ASTER data (as mentioned before the ASTER sensor is equipped with a backward looking band, allowing the construction of DEMs). These ASTER-generated DEM probably can be enhanced tremendously be using future TerraSAR images. The 3D-models will serve as back-ground layer for band-combination images like false colour images and band ratios gained from optical sensors data. These multi-band images combine 2 and more bands and will be generated in a next step. According to (Kusky, et al. 2002), band ratios 5/1, 5/7 and 5/4 x 3/4 are suitable to distinguish between basic and acid rocks. The Landsat TM combination 5/1 and for ASTER data consequently 4/1 (SWIR/VIR) also offers the possibility to identify clay minerals. In a following step, the chemical information obtained from the optical images will be enhanced by the structural information extracted from radar images. Attention will be given especially to upcoming TerraSAR data because of its precise spatial resolution that could reveal more important morphologic structures than its older com-petitor ERS 1/2. The fieldwork-derived information on different rock-types and spectral measurements done on rock samples in the laboratory will be used to run a supervised classification. As final result the combined datasets and extracted information shall allow a generation of the geological map.

Two test-sites Hurd Peninsula and Fildes Peninsula

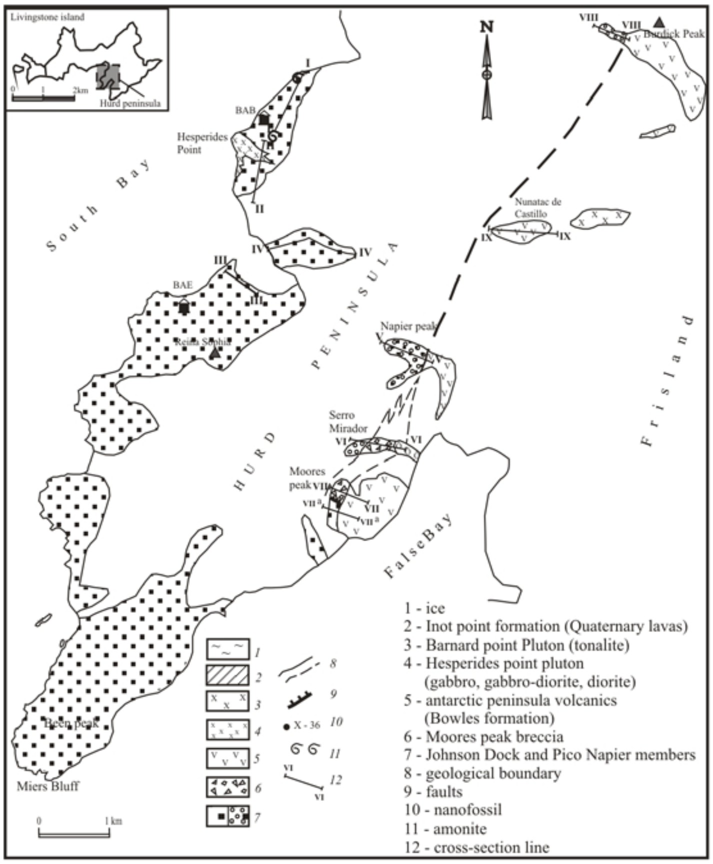
Two test-sites have been sampled so far and the material collected in the field will be used to test the applicability of the remote sensing methodology.

Hurd Peninsula on Livingston Island (South Shetland Islands) has been selected as test-site for the following reasons:

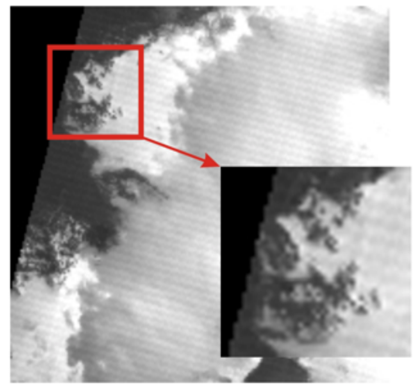
1. Hurd Peninsula (62° 40’ S / 60° 22’ W) comprises of about 27 km², including an ice-free area of about 10 km². It therefore represents one of the largest ice-free areas either on the South Shetland Islands and the Antarctic Peninsula.
2. Detailed geological maps are available of the test-site that can be used as reference information to veri-fy the quality of the results obtained from the remote sensing processing.
3. The lithology of Hurd Peninsula is well known, even though discussions on specific topics still continue.

Fildes Peninsula on King George Island (South Shetland Islands) was selected for the following reasons (points 1., 2. and 3. are almost the same as in case of Hurd Peninsula – but the ice-free area is almost twice as big on Fildes Peninsula):

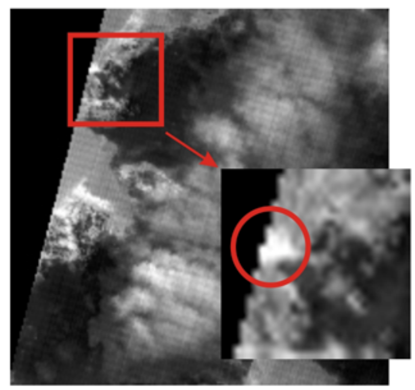
1. Unfortunately its lithology is not very variable (rock-types mainly range from basalts to andesites). On the other hand this offers the possibility to determine the resolution of the developed methods, i.e. to which degree the detection of even small chemical differences is possible.



Schematic geological map of Hurd Peninsula.
Slightly modified after C. Pimpirev and D. Dimov (Univ. of Sofia, Bulgaria, kind p.c.).



ASTER image showing part of the Hurd Peninsula
Band 1 (556 nm) of ASTER dataset
close up: Hesperides Point and surroundings



Band ratio 4/1 (band 4: 1656 nm) of ASTER dataset shown above. Marked area in close up displays Hesperides Point

Figure 1. geolocial map of Hurd Peninsula (left) and two ASTER images displaying part of Hurd Peninsula (right).

Data processing, results and discussion

A first approach included processing of an ASTER-scene from Hurd Peninsula and georeferencing it to UTM Zone 21S, WGS 84. Subsequently, other data corrections and band ratios were processed from this scene to clarify geological features in the area. ASTER-band ratio combinations of 4/1, 4/9, and 4/3 x 2/3 were produced which corres-pond to band ratios 5/1, 5/7 and 5/4 x 3/4 of Landsat TM data as mentioned before.

The ASTER ratio 4/1 shows a distinctive signature around Hesperides Point (NW of the Hurd Pensinsula, Fig. 1) which is discussed consecutively. Hesperides Point marks the location of a pluton of gabbroic to dioritic composition which is surrounded by the meta-sedimentary rocks of the Miers Bluff Formation (MBF). The MBF consists of very low-grade metamorphic turbiditic arkoses, arkosicwackes, mudstones, conglomerates and breccias. Mudstones do not play a major role in the surroundings of Hesperides Point and can therefore not be traced in the ratio images. Obviously, Hesperides Point can be clearly distinguished from the surrounding MBF in the ratio 4/1 image (Fig. 1, right side). This might be for two reasons: either a varied amount of exposed clay minerals on the surface of the two rock-types, or different degree of plant cover (lichens, mosses). During the field work it was discovered that the up-per parts of Hesperides Point are strongly overgrown by lichens, whereas the MBF does almost not show any plant cover. Hence the significant spectral signature shown in Fig. 1 can either be caused by clay minerals derived from alteration – which was also observed – or by the lichen cover which might contain a chemical substance that pro-duces the results observed in this spectral analysis. A combination of the two effects also is possible and will be checked for in the upcoming laboratory work.

Summary

The first results described above show that the distinction of geological features on Hurd Peninsula (therefore probably conferrable also onto the Antarctic Peninsula) by using ASTER-scenes is possible to a certain degree. Accordingly, it can be assumed that the combination of further datasets from different sensor types will help to improve the results and could lead to the generation of a geological map of the Antarctic Peninsula and adjacent islands.

Acknowledgements. I would like to thank my reviewer Stefan Kraus for his constructive critics, my German supervisors Prof. Dr. Hermann Kaufmann and Dr. Helmut Echtler, my supervisor on-site in Chile Dr. Ricardo Jaña, Dr. Steffen Vogt for his data support and my guest-institute - the Chilean Antarctic Institute for offering all logistics and support.

References

Bodechtel, J. (2001): Requirements on optical sensors for quantitative definition of surface parameters multispectral - hyperspectral. Advances in Space Research 28 (1): 241-250.

Kusky, T. M. and Ramadan, T. M. (2002): Structural controls on Neoproterozoic mineralization in the South Eastern Desert, Egypt: an integrated field, Landsat TM, and SIR-C/X SAR approach. Journal of African Earth Sciences 35 107-121.

Lillesand, T. M. and Kiefer, R. W. (2000). Remote Sensing and Image Interpretation. New York, Wiley.

Vaughan, R. G., Hook, S. J., Calvin, W. M. and Taranik, J. V. (2005): Surface mineral mapping at Steamboat Springs, Nevada, USA, with multi-wavelength thermal infrared images. Remote Sensing of Environment 99 140-158.