

## Stabilisation of geodetic points in the surroundings of Johann Gregor Mendel Station, James Ross Island, Antarctica

Zdeněk Stachoň<sup>1\*</sup>, Jan Russnák<sup>1</sup>, Daniel Nývlt<sup>1,2</sup>, Filip Hrbáček<sup>1</sup>

<sup>1</sup>*Department of Geography, Faculty of Science, Masaryk University, Kotlářská 2, 611 37 Brno, Czech Republic*

<sup>2</sup>*Department of Experimental Biology, Faculty of Science, Masaryk University, Kotlářská 2, 611 37 Brno, Czech Republic*

### Abstract

The article is focused on issuing of the permanent stabilisation of geodetic points in the periglacial environment. Periglacial environment of ice-free areas of northern James Ross Island is characterised by specific geomorphological processes connected with freezing and thawing and mass movement processes in the superficial part of the ground. Variable intensity of periglacial processes creates main limitations for traditional methods of permanent geodetic point's stabilisation. This article describes periglacial processes with regards to the traditional stabilisation methods and suggests alternative solutions, which were practically applied and verified on the ice-free area of Ulu Peninsula, northern James Ross Island.

**Key words:** geodetic points, periglacial environment, permafrost, Antarctic Peninsula, James Ross Island, Antarctica

**DOI:** 10.5817/CPR2014-1-9

### Introduction

Czech Johann Gregor Mendel (JGM) Antarctic Research Station is situated at the northern coast of James Ross Island (JRI). This large semi-arid ice-free area of northern JRI is characterised by specific exogenous geomorphological processes connected with freezing and thawing and mass movement processes in the superficial part of the ground. Because of the unstable ground it is necessary to monitor

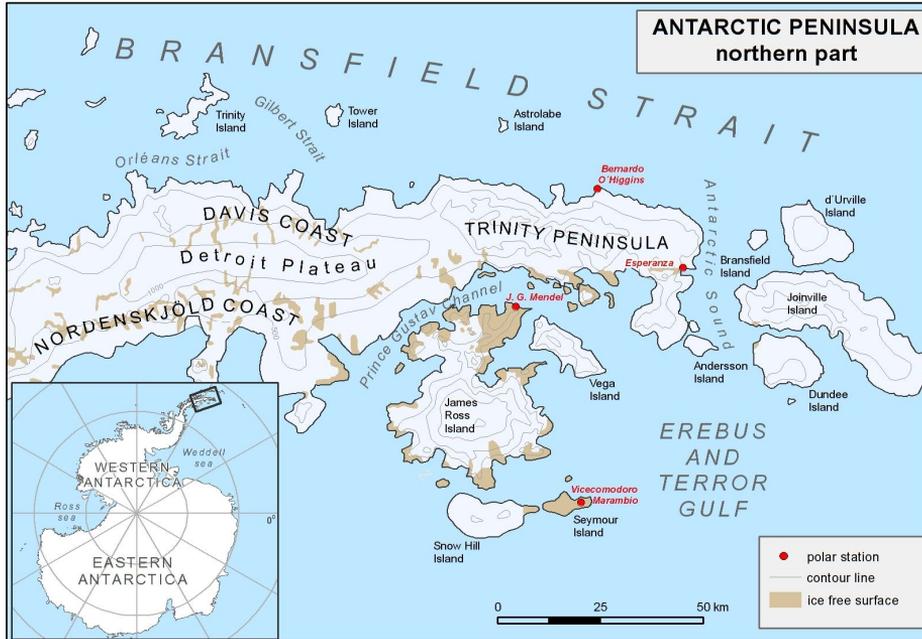
all potential movements of the building and other accessories of the JGM Station. Long term monitoring needs to be based on permanently stabilised geodetic points. Classical ways of stabilisation are limited due to specific environment. That is the reason for the intention to improve permanent geodetic point's stabilisation around the JGM Station.

---

Received May 23, 2014, accepted August 22, 2014.

\*Corresponding author: Zdeněk Stachoň <zstachon@geogr.muni.cz>

*Acknowledgements:* The authors thank to the Czech Antarctic Research Infrastructure and the crew of the Johann Gregor Mendel Station during the 2012–2014 field expeditions for the help and companionship. Daniel Nývlt work on this paper has been supported by the project „Employment of Best Young Scientists for International Cooperation Empowerment“ (CZ.1.07/2.3.00/30.0037) co-financed from European Social Fund and the state budget of the Czech Republic.



**Fig. 1.** Location of the Johann Gregor Mendel Station at the large ice-free northern coast of the James Ross Island.

### Paraglacial and periglacial processes in studied area

The large deglaciated area of northern JRI represents Antarctica's unique ice-free territory (Nedbalová *et al.* 2013). Only few dome glaciers cover volcanic mesas and some cirque, piedmont, apron and valley glaciers are located around these plateaux (Engel *et al.* 2012). The lower-lying areas are on the other hand mostly ice-free (Davies *et al.* 2013) and snow cover melts here during summer seasons. Therefore, paraglacial and periglacial geomorphological processes are at present dominant factors shaping the landscape (Davies *et al.* 2013).

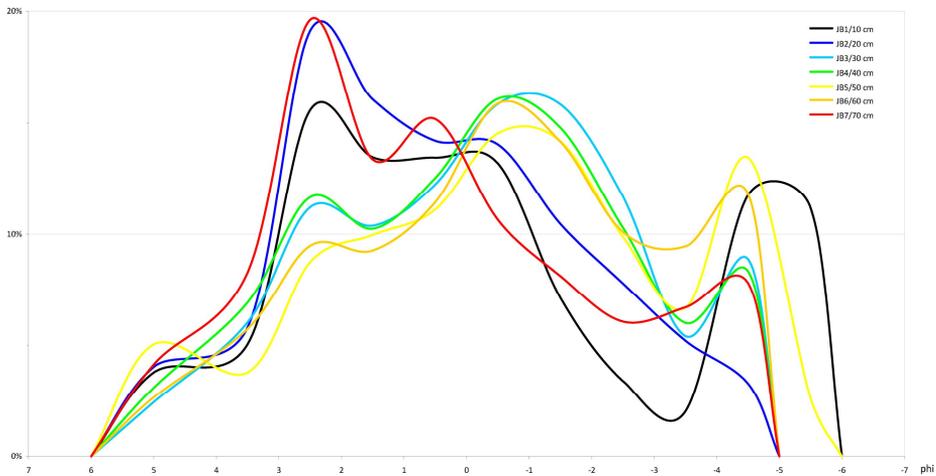
Barrier of Antarctic Peninsula effectively blocks prevalent westerly winds associated with cyclonic systems centred in the circumpolar trough (King *et al.* 2003), which limits precipitation in JRI area. Estimates of annual precipitation range from 200 and 500 mm of water

equivalent (Strelin *et al.* 1998, van Lipzig *et al.* 2004), which fall into the range of arid to semi-arid climate (Davies *et al.* 2013). Mean annual air temperature of  $-7.2^{\circ}\text{C}$  with the maximum-recorded temperature exceeding  $+8^{\circ}\text{C}$  originates from the automatic weather station located at the JGM Station (Láska *et al.* 2010). Very large interdiurnal variability of air temperature with the amplitude of  $>30^{\circ}\text{C}$  (Láska *et al.* 2010) allow for repeated thawing and freezing. However, strong interannual variability has been reported for this area during the last years (Láska *et al.* 2011). Westerly to southwesterly winds predominate due to the local topography and general circulation at the northern coast of JRI (Láska *et al.* 2012). Climate factors controls the rate of exogenous geomorphological processes during the warmer period of the year. Paraglacial

processes refer to processes, which took place during the readjustment period from glacial to nonglacial conditions, with the reworking and relaxation of glacial sediments and landforms (Ballantyne 2002, Davies et al. 2013). On northern JRI, the paraglacial group of processes important for this study includes marine erosional processes incl. beach and marine terrace formation, aeolian corrasion, deflation and deposition (Davies et al. 2013). Periglacial processes, which could potentially destabilise geodetic points in the surroundings of JGM Station include especially processes connected with freezing and thawing

and slow down-slope superficial and sub-surface mass-wasting in the active permafrost layer. The rate of freeze-thaw active layer processes is in low-lying areas controlled predominantly by lithology and aspect (Engel et al. 2010).

The marine terrace with remnants of raised beach at JGM Station has a flat upper surface located at 9–12 m a.s.l. Local shallow marine to beach deposits are composed of gravely sand. Strong variation of grain-size distribution could however be seen with the depth of the active permafrost layer on the surface of marine terrace (*see* Fig. 2).



**Fig. 2.** Grain-size distribution (in phi units) of marine terrace sediments at JGM Station. Depths below undisturbed ground surface.

The surface of the terrace is stabilised by a pebble-boulder hamada-like pavement with common desert varnish on large stones. Pebble-boulder surface lag originated by winnowing of fines and superficial accumulation of stones by frost heave (French 2007) and rock varnish on stone surfaces originates owing to the wind transported mineral grains induced oxidation (Matsuoka 1995, Bockheim 2010). Gravely sand of these marine sediments have mostly bi- to tri-modal grain-

size distribution, with maxima in fine sand, coarse sand to granule and coarse part of fine pebbles (Fig. 2). The uppermost 10 cm are enriched in coarse pebble fraction and depleted on the other hand in granule and fine pebble fraction. The middle part of active layer has a predominant grain-size fraction at coarse sand and granule. The lowermost part of active layer close to the permafrost table is typified by the predominance of fine to coarse sand and depleted in granule to fine pebble frac-

tion, which is caused by downward migration of finer particles (predominantly fine sand) due to active layer thawing and their accumulation above the permafrost table. Permafrost active layer thickness differs here during individual summer seasons between 42 and 77 cm (Engel *et al.* 2010). Therefore, the sampled depth of 70 cm lies just above the permafrost table during the maximum recent thawing seasons and highest accumulation of fines is to be expected here.

Sea spray commonly reported from this area (*e.g.* Nedbalová *et al.* 2013) represents important factor, which enhance chemical disintegration of superficial material (André *et al.* 2005). Wave erosion in the surfing zone results in over-steepening and lateral erosion of uplifted marine terrace sediments, which affects not only fine sediments, but also larger released erratic boulders, which are commonly found on present beach (Davies *et al.* 2013). Granule to fine pebble particles could in some circumstances be effectively transported from the beach also by flotation during a rising tide (Möller *et al.* Ingólfsson 1994). Nivation processes connected with the thawing of snowfields accumulated along the coast with larger slope gradient could also steepen and undercut cliffs and transport the material to the littoral zone. The construction of JGM Station main building and containers (Prošek *et al.* 2013) elevated snow accumulation, which induce accelerated nivation processes on the surface of the marine terrace. Thawing water surface drainage has especially been dangerous for constructions on the eastern margin of marine terrace surface, where protective plastic wall in active permafrost layer has been constructed in 2012, *i.e.* 6 years after the construction. However, not only surface erosion is provoked by snow accumulation. Downward percolation of thawing water through the active layer effectively removes fine muddy particles and accumulates them primarily just

above the permafrost table (as described above). Permafrost table is generally parallel with surface and fine particles are therefore mostly transported towards the coast. This subsurface wash could eventually in irregular surface lowering and damages in JGM Station infrastructure.

Ephemeral braided stream of Bohemian Stream undercut the southeastern margin of the marine terrace at JGM Station. It has two contrasting fluvial styles according to the discharge: multi-channel, high-sinuosity braiding style during low discharge and low-sinuosity style with one principal channel during high discharge (Davies *et al.* 2013). Braided stream transports substantial amount of suspended load (Prošek *et al.* 2013) originating from glacial sediments and Cretaceous bedrock (Davies *et al.* 2013).

Aeolian deflation produces a very slow lowering of the marine terrace surface due to the winnowing of finer particles (mostly silty- to fine sand-sized) from its surface. Rather dry conditions at flat surfaces allowed for enhanced wind-blown of fine particles. The winnowed material is generally deposited in the sea or local streams, however it is frequently fixed on the surfaces of snowfield, where it can produce aeolian accumulations up to several metres thick after snowfield decay (Davies *et al.* 2013). These snowfields are generally on leeward sides of prevailing winds and their thawing produces local concentration of niveo-aeolian deposits with prevailing fine sand to granule fractions. Pitting and ventifaction represents also a typical process of local aeolian corrosion. Ventifacts made of James Ross Island Volcanic Group basalts (Nelson 1966, Košler *et al.* 2009) and Antarctic Peninsula granitoids originating from Neogene to Pleistocene advances of Antarctic Peninsula ice streams (*e.g.* Nývlt *et al.* 2011, Nývlt *et al.* in press) have been wind-faceted by prevalent westerly to southwesterly winds (Láska *et al.* 2012).

### Traditional stabilisation methods

Most of the National mapping agencies (NMA) including the Czech Office for Surveying, Mapping and Cadastre determine stabilisation of survey control points in the common ground. Common ground means in this case stable basement in temperate zone. Particular point stabilisation is performed by using permanent or temporary marks based on their importance. As temporary mark is usually used a wooden peg, which is for orientation marked with a cross or nail (Staněk et al. 2007).

Permanent trigonometric points are typically stabilised by a stone about 0.8 m long with an above the surface obtrusive part. The worked stone cube is made with an edge of 0.2 m. The middle of the upper side is marked with a small cross. This mark is secured by two underground marks. These stone board and glass disc are labelled by a small cross placed under the stone. All these three marks have to be vertically placed with an accuracy of 3 mm. In the case of the upper point damage, the

underground marks enable the point reconstruction. Only one underground mark could be used in some cases. The hole is filled by various materials without any restrictions (Hánek et Koza 2004).

Points of detailed planimetric survey are also stabilised by a stone cube, plastic marks with steel drill into the ground or marks on rocks set in concrete. It is possible to use iron bar of 0.5 m above the ground for minor geodetic control. The exact point for orientation is signalled by small cross or drilled hole. The bar is thrust into the ground usually deeper than 2 m (Hánek et Koza 2004).

Depth stabilisation could also be used for constructions. One of these methods puts concrete circles deep into the ground under the depth of frost penetration. These circles are filled by concrete and steel and build the stable base of the new point (Staněk et al. 2007).

Most of the points are signalled by a pole, survey beacon or observation tower.

### Stabilisation in unstable ground

The need of precise measurements in surroundings of the JGM Station for scientific reasons forced to develop non-traditional method of stabilisation. Some of the traditional stabilisation methods used in temperate environment could be functional also in unstable locations. Periglacial areas are typical of significant ground movements of permafrost active layer (*see above*), which affects the uppermost ~1 m based on various factors. Therefore a cheap, functional and feasible method to build permanent geodetic point's stabilisation in periglacial environment is needed.

Freezing and thawing of the ground are generally problematic for the stabilisation, as the points have to be stabilised deep in

the stable permafrost. There was an effort to find usable compromise of common stabilisation methods and apply it for building permanent geodetic points around JGM Station. The necessity of fixing the points into the permanently frozen ground has become obvious.

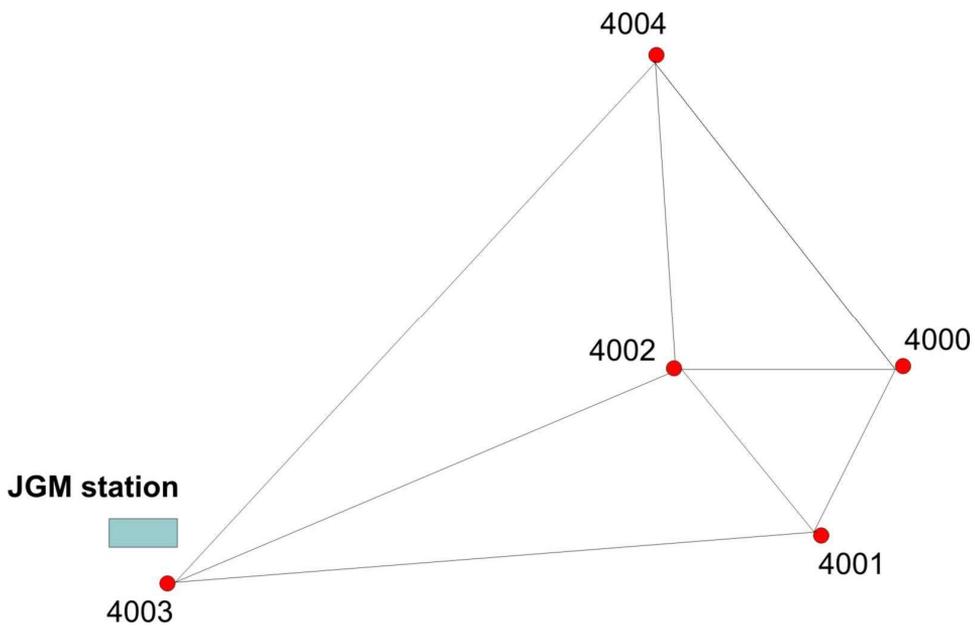
The first geodetic works on James Ross Island have been done by British topographers in 1960's. Two geodetic points have been constructed near the present JGM Station during their expeditions. These two points (numbered 4000 and 4001) were included to the construction of the new geodetic network (Fig. 3). Existing points were subsequently supplemented by three additional points (Fig. 4).

First step for establishing of new point was the identification of the most suitable locations, which are possibly least affected by mass movement. Several locations were

identified. For the point numbered 4002 top of a small hillock has been chosen as the most suitable place.



**Fig. 3.** Example of British stabilised points (Nr. 4001).



**Fig. 4.** Schematic position of the stabilised points (Southern orientation).

### Point Nr. 4002 stabilisation

Based on the previously mentioned facts on the selected location was performed digging to the base of permanently frozen ground (approx. 1.2 m) *see* Fig. 5. Hole was subsequently extended by drilling about further 1 m. Stainless pole (2.5 m long, 25 mm diameter) was placed into the

hole and tighten with mixture of extracted material with water. Remaining part of the pole (approx. 0.3 m) above the surface was adjusted for signalisation purposes and in cased by stones (*see* Fig. 6).

Similar procedure was used for the stabilisation of the point Nr. 4004.



Fig. 5. Stabilisation of point Nr. 4002.

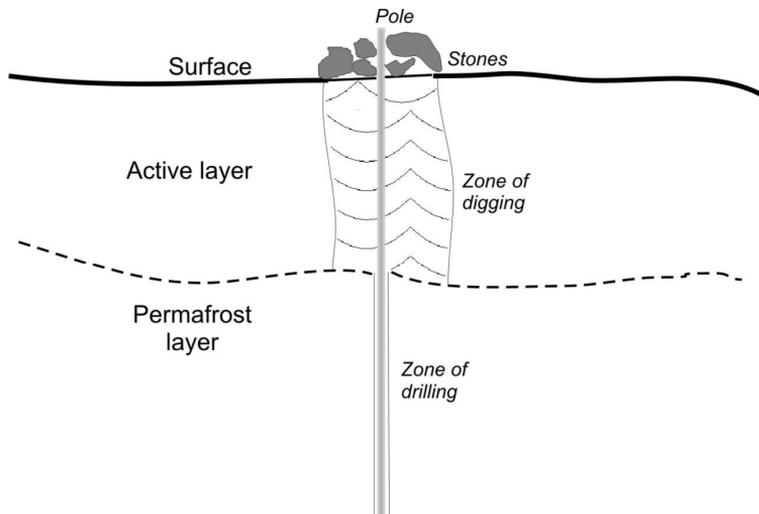


Fig. 6. Schema of point Nr. 4002 stabilisation.

### Point Nr. 4003 stabilisation

Different procedure was used for stabilisation of the point Nr. 4003 which was located on the erratic boulder surface situated only 70 m north from the JGM station. Erratic boulder seemed to be the most problematic point for stabilisation due to its possible movement. Its main advantage

was the close location to the main building of the JGM station (*see* Fig. 7 and 4).

The stabilisation was performed by drilling to the depth 120 mm. Hole was subsequently filled with epoxy resin. Signalisation is carried out by stainless spike placed into the epoxy resin.



**Fig. 7.** Stabilisation of point n. 4003.

Point Nr.	Distance 2013	Distance 2014	Distance diff.
4002 – 4001	219.717	219.72	0.003
4002 – 4000	284.009	284.002	-0.007
4002 – 4003	537.37	537.379	0.009

*Tab.1. Distances of stabilised points in 2012–2013 a 2013–2014 (meters).*

### Verification of the stability of stabilised points

New procedures of stabilisation in variable periglacial environment need to be verified in the following seasons. Dimensions of triangulated network created by stabilised points was observed with the one year period in the seasons 2012–2013

and 2013–2014 by robotic total station GPS 9003 with an accuracy of  $\pm (2 \text{ mm} + 2 \text{ ppm} \times D^*)$  m.s.e.

Differences in the observed distances are under or on the accuracy limit of used total station (*see* Table 1).

## Discussion and conclusions

Surroundings of JGM Station have high potential for various scientific studies. For purposes of spatial oriented studies in close surroundings was established a network of the geodetic stabilised points. Non traditional procedure to the selected point stabilisation has been developed and applied due to the high variability of the environment.

Stability of established network was verified in the subsequent seasons. Measurements showed no significant movements of stabilised points, therefore the designed method is suitable for geologically and climatologically specific environment of the

northern part of James Ross Island.

The network of stabilised points is used for long-term monitoring of the influence of the objects of the JGM Station to its surroundings, monitoring of the permafrost active layer depth and its recent changes. Currently, long term GPS measurements are carried out on the stabilised points.

Established network will be further observed, maintained and extended according to the needs of contemporary scientific projects. There is also a possibility of establishing seasonal differential GPS measurements on selected suitable point.

## References

- ANDRÉ, M.-F., HALL, K. (2005): Honeycomb development on Alexander Island, glacial history of George VI Sound and palaeoclimatic implications (Two Step Cliffs/Mars Oasis, W Antarctica). *Geomorphology*, 65: 117-138.
- BALLANTYNE, C. K. (2002): Paraglacial geomorphology. *Quaternary Science Reviews*, 21: 1935-2017.
- BOCKHEIM, J. G. (2010): Evolution of desert pavements and the vesicular layer in soils of the Transantarctic Mountains. *Geomorphology*, 118: 433-443.
- DAVIES, B. J., GLASSER, N. F., CARRIVICK, J. L., HAMBREY, M. J., SMELLIE, J. L. and NÝVLT, D. (2013): Landscape evolution and ice-sheet behaviour in a semi-arid polar environment: James Ross Island, NE Antarctic Peninsula. In: Hambrey, M. J., Barker, P. F., Barrett, P. J., Bowman, V., Davies, B., Smellie, J. L. and Tranter, M. (eds): Antarctic Palaeoenvironments and Earth-Surface Processes. *Geological Society, London, Special Publication*, 381: 353-395.
- ENGEL, Z., LÁSKA, K., FRANTA, T., MÁČKA, Z. and MARVÁNEK, O. (2010): Recent changes of permafrost active layer on the James Ross Island, Maritime Antarctic. Third European Conference on Permafrost, Longyearbyen, Svalbard, pp. 129-129.
- ENGEL, Z., NÝVLT, D. and LÁSKA, K. (2012): Ice thickness, areal and volumetric changes of Davies Dome and Whisky Glacier (James Ross Island, Antarctic Peninsula) in 1979–2006. *Journal of Glaciology*, 58(211): 904-914.
- FRENCH, H. M. (2007): The Periglacial Environment. Third Edition. *Wiley*, Chichester.
- HÁNEK, P., KOZA, P. (2004): Geodzie pro SPŠ stavební. Vydání třetí, 340 s., Sobotáles, Praha.
- HAUF, M. a kol. (1982): Geodézie. Státní nakladatelství technické literatury, Praha, 544 s.
- KING, J. C., TURNER, J., MARSHALL, G. J., CONNOLLEY, W. M. and LACHLAN-COPE, T. A. (2003): Antarctic Peninsula climate variability and its causes as revealed by analysis of instrumental records. In: Domack, E. W., Leventer, A., Burnett, A., Conley, P., Kirby, M. and Bindshadler, R. (eds): Antarctic Peninsula climate variability: a historical and paleoenvironmental perspective. *Antarctic Research Series*, 79: 17-30, AGU, Washington D.C.
- KOŠLER, J., MAGNA, T., MLČOCH, B., MIXA, P., NÝVLT, D. and HOLUB, F. V. (2009): Combined Sr, Nd, Pb and Li isotope geochemistry of alkaline lavas from northern James Ross Island (Antarctic Peninsula) and implications for back-arc magma formation. *Chemical Geology*, 258: 207-218.

- LÁSKA, K., PROŠEK, P. and BUDÍK, L. (2010): Seasonal variation of air temperature at the Mendel Station, James Ross Island in the period of 2006-2009. *Geophysical Research Abstracts*, 12: EGU2010-3880.
- LÁSKA, K., NÝVLT, D., ENGEL, Z. and KOPAČKOVÁ, V. (2011): Meteorological data and mass balance measurements on Davies Dome and Whisky Glacier in 2006–2010, James Ross Island, Antarctica. *Geophysical Research Abstracts*, 13: EGU2011-4858.
- LÁSKA, K., NÝVLT, D., ENGEL, Z. and BUDÍK, L. (2012): Seasonal variation of meteorological variables and recent surface ablation / accumulation rates on Davies Dome and Whisky Glacier, James Ross Island, Antarctica. *Geophysical Research Abstracts*, 14: EGU2012-5545.
- MATSUOKA, N. (1995): Rock weathering processes and landform development in the Sor Rondane Mountains, Antarctica. *Geomorphology*, 12: 323-339.
- MÖLLER, P., INGÓLFSSON, Ó. (1994): Gravel and sand flotation: A sediment dispersal process important in certain nearshore marine environments. *Journal of Sedimentary Research*, A64: 894-898.
- NEDBALOVÁ, L., NÝVLT, D., KOPÁČEK, J., ŠOBR, M. and ELSTER, J. (2013): Freshwater lakes of Ulu Peninsula, James Ross Island, north-east Antarctic Peninsula: origin, geomorphology and physical and chemical limnology. *Antarctic Science*, 25: 358-372.
- NELSON, P. H. H. (1966): The James Ross Island Volcanic Group of North-East Graham Land. *British Antarctic Survey Scientific Report*, 54, 62 pp.
- NÝVLT, D., KOŠLER, J., MLČOCH, B., MIXA, P., LISÁ, L., BUBÍK, M. and HENDRIKS, B. W. H. (2011): The Mendel Formation: Evidence for Late Miocene climatic cyclicity at the northern tip of the Antarctic Peninsula. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 299: 363-384.
- NÝVLT, D., BRAUCHER, R., ENGEL, Z., MLČOCH, B. and ASTER TEAM (in press): Timing of the Northern Prince Gustav Ice Stream retreat and the deglaciation of northern James Ross Island, Antarctic Peninsula during the last glacial-interglacial transition. *Quaternary Research*, <http://dx.doi.org/10.1016/j.yqres.2014.05.003>
- PROŠEK, P., BARTÁK, M., LÁSKA, K., SUCHÁNEK, A., HÁJEK, J. and KAPLER, P. (2013): Facilities of J. G. Mendel Antarctic station: Technical and technological solutions with a special respect to energy sources. *Czech Polar Reports*, 3: 38-57.
- STANĚK, V., HOSTINOVÁ, G. and KOPÁČIK, A. (2007): Geodézia v stavebníctve. Jaga Group, Bratislava, 110 s.
- STRELIN, J. A., SONE, T. (1998): Rock glaciers on James Ross Island, Antarctica. PERMAFROST – *Seventh International Conference (Proceedings)*, Yellowknife (Canada), *Collection Nordicana*, 55: 1027-1033.
- VAN LIPZIG, N. P. M., KING, J. C., LACHLAN-COPE, T. A. and VAN DEN BROECKE, M. R. (2004): Precipitation, sublimation and snow drift in the Antarctic Peninsula region from a regional atmospheric model. *Journal of Geophysical Research*, 109: D24106.

## Web sources

Terminologický slovník zeměměřičství a katastru nemovitostí [online] VÚGTK, 2013  
<<http://www.vugtk.cz/slovník>>