Morphometric analysis of glacial landforms in the Northern part of the Slovak High Tatra Mountains

Veronika KUPKOVÁ[1]* and Pavel MENTLÍK[1]
[1]University of West Bohemia, Plzeň

* Correspondence to: Veronika Kupková, University of West Bohemia, Plzeň, Czech Republic. E-mail: kupkovav@students.zcu.cz

doi: 10.4316/GEOREVIEW.2012.21.1.59

Article history
Received: August 2012
Received in revised form: October 2012
Accepted: November 2012
Available online: Jan. 2013

ABSTRACT: The High Tatra Mountains were glaciated during the European Last Glacial Maximum (LGM), dating back to 20 000 BP. Several studies (e.g. Midriak, 1983; Lindner *et al.*, 2003) showed that all the main valleys, on both Slovak and Polish sides, were glaciated. We can identify glacial landforms typical of a high mountain environment: glacial cirques, complex cirques, troughs, and depositional zones. These form segments of a cascade system where ice accumulated in the upper parts (cirques) and flowed down-valley. Cirque morphometric characteristics (e.g. width, length, altitude, azimuth) were measured in GIS on the basis of the geomorphological map of Lukniš (1973).

KEY WORDS: glacial cirques, cirque morphometry, the High Tatras

1. Introduction

The High Tatra Mountains form a 26.5 km long mountain range consisting mainly of granite. It is located on the Polish-Slovak borders in Central Europe and is the highest part of the Carpathian mountain range, formed in the Tertiary during the Alpine orogenesis. The highest peak reaches 2655 m a.s.l. (Gerlach, Slovakia).

A remarkable symmetry of valleys (called *dolina* in Slovakia), which are separated by side-ridges descending to the piedmont area, is typical for the High Tatras. From the geological point of view the High Tatras are defined as a *horst* with the southern slope uplifted (Lukniš, 1973). This gives southern valleys higher average altitudes than northern slope valleys (Midriak, 1983).

1.1. Former glaciation

During the LGM there were probably 31 glaciers within the Slovak High Tatras (Lukniš, 1973): three of them exceed 10 km in length (Biala Voda, Kôprova and Mengusovska valleys). On the southern slope glaciers covered approximately 8471 ha but on the northern slope only 6529 ha (Midriak, 1983).

We continued the research of Batko (2009), who dealt with glaciated valleys on the southern slope (Furkotska, Mlynicka, Mengusovska, Batizovska, Velicka, Slavkovska, Velka Studena, Mala Studena and Skalnata Valleys). We extended the study area by measurements in five valleys on the northern slope: the Kôprova, Biela Voda, Javorova, Kolova and Zadne Medodoly Valleys (see *Fig. 1*), plus several further valleys on the southern and eastern slopes. The valleys were divided (in GIS) according to the glacial cascade system into cirques, complex cirques, troughs, depositional zones.

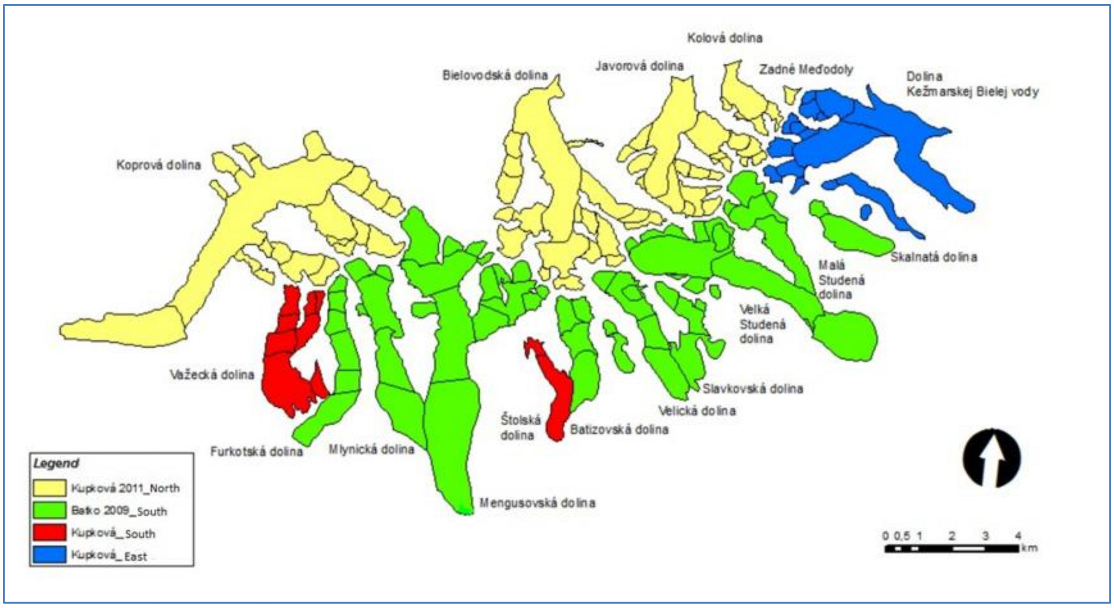

Figure 1. The High Tatra Mountains: segmentation of former glaciers into glacial landforms of the glacial cascade system. This figure is available in colour online at www.georeview.ro.

1.2. Research questions

Four main questions (hypotheses) were posed following Batko's (2009) results:

Size and volume of glacial landforms on the northern slope of the High Tatras are more developed than on the southern slope of the mountain range (1)

The size of glaciers was connected with the height of headwall – the greater the rise between a cirque floor and the peak above, the larger the former glacier (2)

Behind higher peaks there should be a greater glaciation – higher peaks provided shade for larger areas where snow could accumulate for longer period (3)

Glacial landforms are better developed in the western part of the range than the eastern as prevailing winds brought greater precipitation (4)

2. Methods

To identify the basic morphometric characteristics, the analysis was focused on the *size* (length, width, height), *shape* (L/W ratio, L/H ratio, estimated volume L.W.H, area), and *other variables* (minimum altitude, maximum altitude, average altitude). Moreover, we considered also *location* of the landforms (azimuth). The methodology was based on similar studies (e.g. Evans & Cox, 2005; García-Ruiz *et al.*, 2000; Steffanová & Mentlík, 2007) performed in other European mountain regions.

All these indices were calculated on the basis of the geomorphological map of Lukniš (1973) in GIS (ArcGIS 9.3). The accuracy of measurments was checked through Google Earth (see *Fig. 2*). The geodatabase thus generated was further analysed statistically.

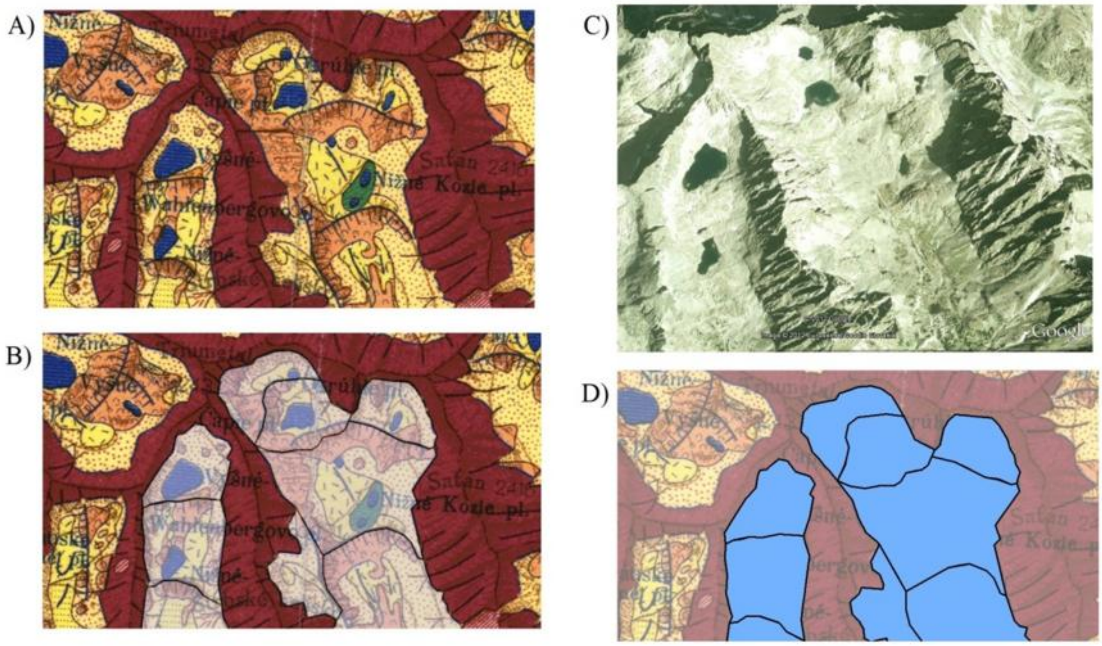

Figure 2. The demarcation of glacial landforms: A) Digitized geomorphological map of Lukniš (1973) as the basis, B) First delimitation of glacial landforms on the basis of map of Lukniš (1973), C) Verification of demarcated landfoms via Google Earth, D) Final demarcation. This figure is available in colour online at www.georeview.ro.

3. Results and discussion

Data obtained from GIS were analysed through basic descriptive statistical indexes and visualized in MS Excel, with particular emphasis on cirques. As the upper part of the glacial cascade system, cirques are places with the longest duration of glaciation. They are a source (accumulation) area, as well as a terminal area where snow remains during deglaciation. As a result, glacial processes can operate for a long time there.

Previous studies (e.g. Lukniš, 1973) located the cirque floors as approximately between 1700 m and 2300 m a.s.l. In our area of interest some of them were even lower, for example in the Žabia Bielovodska Valley (1300 m a.s.l.) and the Nefcerka Valley (1450 m a.s.l.). On the other hand, the highest cirque floor is located within the Sucha Valley (Pod Ladovym stitom, 2150 m a.s.l.). Out of a total of 47 cirques on the northern slope of the High Tatras, 34 cirque floors lie above 1700 m a.s.l. Thirteen northern cirques contain lakes and they were thus classified according to Mîndrescu *et al.* (2010) as *classic cirques with a large rock basin lake*. How to define cirque floor altitudes when a glacial lake is present is a question for further research.

Turning now to the estimated volume of cirques depending on the height of headwall, we can say that below higher headwalls (300 – 600 m high) more extensive glaciation can be expected. For example, Zmrzle lake cirque headwall, which is 500 m high, allowed a cirque with an estimated volume of 470 million m^3 to develop. In contrast, the cirque of Vysne Temnosmrecinske Lake is shaded by a headwall only 75 m high, and its estimated volume is 40 million m^3. However, it is not a general rule that a higher headwall causes a bigger volume, e.g. the headwall of cirque Pod Krivanom is 535 m long but the estimated volume is only 100 million m^3.

Table 1. Frequency of cirque headwall heights on both slopes of the Slovak High Tatras.

Height of cirque headwall H [m]	Northern slope of the Slovak High Tatras		Southern slope of the Slovak High Tatras	
	amount of cirques	**[%]**	**amount of cirques**	**[%]**
more than 150	7	14.9	15	45.5
151 – 299	20	42.5	13	39.4
300 – 449	14	29.8	3	9.1
450 – 590 (resp. 772 for southern slope)	6	12.8	2	6.0
Total	47	100	33	100

Table 1 implies that on the northern slope there is a higher probability of forming larger cirques (in terms of bigger volume) because more cirque headwalls (20) reach at least 300 m. On the southern slope such a probability is connected with only five cirques.

Focusing on cirque azimuth, we can notice that on the northern slope the majority of cirques face west-north-west (see *Fig. 3*). On the other hand, cirques on the southern slope mostly face south-south-east (*Fig. 4*).

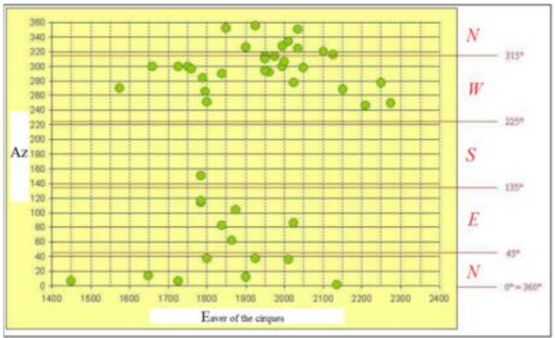

Figure 3. Azimuth of cirques (northern slope) in relation to average altitude (E_{aver}). This figure is available in colour online at www.georeview.ro.

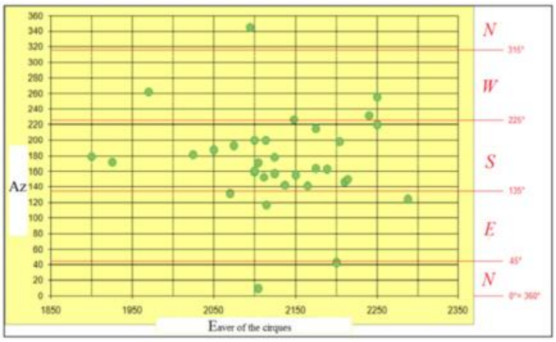

Figure 4. Azimuth of cirques (southern slope) in relation to average altitude (E_{aver}). This figure is available in colour online at www.georeview.ro.

Following *Figs. 3* and *4* a graph of frequency was designed (*Fig. 5*) dealing with average altitudes of cirques. It shows that more than 70% of cirques located on the northern slope of the High Tatras reach their E_{aver} between 1750 – 2050 m a.s.l. More than 25% of northern cirques have E_{aver} between 1950 – 2050 m a.s.l. which provides evidence for a former snow line.

Cirques on the southern slope reach E_{aver} mostly between 2050 – 2250 m a.s.l. (82%). Almost half of the southern cirques lie between 2050 – 2150 m a.s.l. (E_{aver}) which means that the snow line here was approximately 200 m higher than on the northern slope. In comparison, the snow line in the Sumava Mountains (farther west, on the Czech-German border) was determined around 1000 m a.s.l. (Mentlík *et al.*, 2009).

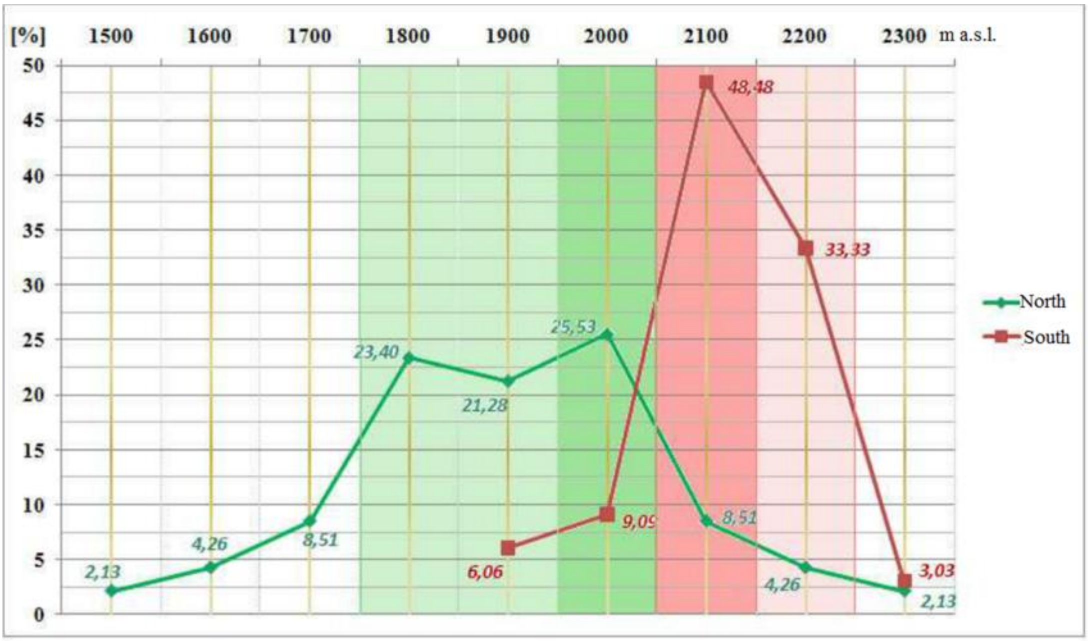

Figure 5. Frequency distribution of E_{aver} of cirques on both slopes of the High Tatras. This figure is available in colour online at www.georeview.ro

4. Discussion

To summarize the main results of this cirque morphometry analysis (*Tab. 2*), we can clearly see some differences between northern and southern slopes. The distribution of cirque floors (E_{min}) is one of the characteristics with significant variation between these two slopes. Cirques in the northern part are located ≥1300 m a.s.l. while in the southern part their floors are found much higher (1751 m a.s.l.). Meaningful differences were found also in E_{max} and E_{aver}, in both cases higher in the south, except that differencies in maxima are slight – partly because many cirques are on opposite slopes of the same summit.

Surprisingly, minimum headwall height (80 m) corresponds on both slopes, as does cirque length (148 m and 145 m). Considerable differences were found in the analysis of cirque shape (particularly L/H and L/W) and size (mainly maximum values, L). Average values of the shape and size characteristics correspond quite well (with no fundamental differences) on both slopes of the High Tatras. Ranges of W and L are greater on the southern slope, but maxima for shape ratios are greater on the northern slope.

Table 2. Cirque characteristics for both slopes of the Slovak High Tatras.

	E_{min} [m a.s.l.]		E_{max} [m a.s.l.]		E_{aver} [m a.s.l.]		H [m]	
	N	S	N	S	N	S	N	S
minimum	1 300	1 751	1 600	2 000	1 450	1 900	80	80
maximum	2 150	2 200	2 500	2 523	2 275	2 288	590	772
average value	1 775	2 023	2 051	2 232	1 913	2 127	276	209
	W [m]		**L [m]**		**L/W**		**L/H**	
	N	S	N	S	N	S	N	S
minimum	193	162	148	145	0.15	0.21	0.57	0.67
maximum	1 128	1 317	1 112	1 819	5.76	3.82	9.18	6.58
average value	513	530	570	583	1.29	1.24	2.52	2.92

5. Conclusions

The main purpose of this paper was to investigate basic morphometric characteristics of glacial landforms in the High Tatras, Slovakia. It follows on from the research of Batko (2009) who set up a methodology, and focused on the southern slopes. Therefore this work extends the study area to the north, and deals with morphometric characteristics of all glacial cirques in the whole area of the Slovak High Tatras. The data are represented as a geodatabase created in GIS; attributes were exported into MS Excel.

Four hypotheses were tested, based on Batko´s results. The first hypothesis was not conclusively demonstrated and further research in that area is needed. Hypothesis 2, 3, and 4 were partly verified, and their fully authentication could be reached in future through more sophisticated statistical and GIS tools.

The research suggested that the glacial landforms of the area of interest were formed during different conditions. Whereas the northern side of the range was more affected by the west-east aspect, the southern side of the range was affected by the altitude and geological uplifting. The analysis of glacial landform morphometry, particularly that of other characteristics (such as headwall gradient, 3D area, or vector analysis) could extend the results reached in this research.

References

Batko P. 2009. *Morfometrická analýza vybraných glaciálních forem ve Vysokých Tatrách* [Bachelor thesis]. 55 s.: il. + 1 CD-ROM.

Evans I. S., Cox N. J. 2005. Global variations of local asymmetry in glacier altitude: separation of north-south and east-west components. *Journal of glaciology* 51 (174): 469-482.

García-Ruiz M. J., Gómez-Villar A., Ortigosa L., Martí-Bono C. 2000. Morphometry of Glacial Cirques in the Central Spanish Pyrenees. *Geografiska Annaler* 82 A, 4: 433-442.

Lindner L., Dzierżek J., Marciniak B., Nitychoruk J. 2003. Outline of Quaternary glaciations in the Tatra Mts.: their development, age and limits. *Geological Quarterly* 47 (3): 269–280. Warszawa.

Lukniš M. 1973. *Reliéf Vysokých Tatier a ich predpolia*. Bratislava: Slovenská akadémia vied. Vyd. 1. 375 s.: il.

Mentlík P., Minár J., Břízová E., Lisá L., Tábořík P., Stacke V. 2009. Glaciation in the surroundings of Prášilské Lake (Bohemian Forest, Czech Republic). *Geomorphology*, doi: 10.1016/j.geomorph.2009.12.001.

Midriak R. 1983. *Morfogenéza povrchu vysokých pohorí*. Bratislava: Veda, nakladatelství SAV. Vyd. 1. 516 s.: il.

Mîndrescu, M., Evans, I. S., Cox, N. J. 2010. Climatic implications of cirque distribution in the Romanian Carpathians: palaeowind directions during glacial periods. *J. Quaternary Sci*., Vol. 25. pp. 875-888. ISSN 0267-8179.

Steffanová P., Mentlík P. 2007. Comparison of morphometric characteristics of cirques in the Bohemian Forest. In Silva Gabreta. Vimperk: Správa Národního parku Šumava, vol. 13 (3): 191–204.