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GLACIOLOGICAL CHARACTERIZATION OF SMALL PALAEOGLACIERS FROM CĂLIMANI MOUNTAINS

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Abstract. We mapped moraines and headwalls in two cirques situated below Pietrosu Peak and Răchitiş Peak. The preserved landforms suggest at least two subsequent stages of glaciations during the Late Quaternary history at both sites, correspondingly. We outlined the supposed palaeoglacier margins considering the marginal landforms (moraine, headwall) and the present terrain. Glacioclimatological characterization of the realized glaciers was assessed by estimating the corresponding palaeo-equilibrium-line altitude (pELA) applying size specific accumulation-area ratio. The estimated elevation of pELA is 1840 m and 1915 m during the older while 1850 m and 1925 m during the younger glacial stage for Rachitis and Pietrosu cirques, respectively. The significant elevation difference between the pELAs for the two cirques could be due to their different exposure.

Keywords: *paleoglaciers, paleosnowline, Pietrosu cirque, Răchitiş cirque, Călimani Mts.*
Cuvinte cheie: *paleogheţari, paleolimita superioară a zăpezii; Circul Pietrosu, Circul Răchitiş, Munţii Călimani.*

1. INTRODUCTION

The 300 km long range of the Eastern Carpathians is a massive but – at the same time - is a lower part of the Carpathian Arc. Glacial landforms are abundant and characteristic in the neighbouring ranges (Southern Carpathians, Rodna Mts., Maramureş Mts.) (see Urdea, 2004; Reuther *et al.* 2007 and references therein) but appear scarcely on these less elevated terrains. Călimani Mts. is an exceptional member of the Eastern Carpathians where glacial features are clearly visible. The analysis of Călimani's glacial history is subject to special interest due to its transitional situation between the heavier glaciated southern and northern areas. Detailed investigation of glacial traces of Călimani Mts. could provide additional information for gaining a more precise evaluation of the characteristic environmental condition of the Carpathians' board region during the Late Quaternary.

As pioneer researchers on high mountain geomorphology of the area Naum (1970) identified, mapped and classified the glacial landforms and Ichim (1973, 1978) investigated the periglacial features. Naum (1970) positioned the Pleistocene snowline at 1750-1800 m altitude.

Periglacial landforms and processes were analysed and re-evaluated in many recent researches (Elekes, 2002; Nagy *et al.* 2004; Lovász 2005) but the glacial geomorphology was only marginally assessed in these papers.

2. SITE DESCRIPTION AND METHODS

The Călimani Mts is the highest volcanic range in the Carpathians. The central part is characterized by a northward opened caldera (Fig. 1). Steep slopes ascend from the inner depression to the rim of the caldera, while gentle slopes descend towards the pediment. The highest peaks are the mounds on the rim. The range culminates at the Pietrosu Peak (2102 m a.s.l.). Glacial landforms are situated at the inner, steep side of the central caldera.

Reconstruction of palaeoglaciers

The investigation has been launched by detailed mapping of the glacier related landforms. We used Mobile Mapper GPS receiver to survey the moraines and headwalls of the supposed palaeoglaciers.

Our original plan for the correction of GPS-measured elevation data by phase measurement failed due to technical difficulties. We had to apply a rather simple, less sophisticated method to estimate the difference between the GPS derived, above ellipsoid, and the real elevation above sea level. The altitude of the Rachitis meteo station (~2020 m a.s.l.) was measured in the mornings and in the afternoons of the work-days of mapping. The resulted elevation data scattered in the 2047.7-2052.5 m range suggesting roughly constant, 30 m overestimation for the GPS derived elevation data. To improve precision we reduced all elevation data by 30 m in the final calculations.

The gained digital data were fed to ArcGIS applications for data treatment and calculation.

The best fitting polygon was drawn for each palaeoglacier through the corresponding moraines and headwalls adapting to terrain properties. The area of each palaeoglacier was estimated as area of the corresponding fitted polygon. We measured the horizontal distance (a) between the head and the terminal of the palaeoglaciers by the aid of Measure tool. We have calculated the elevation difference (h) subtracting the elevation of the highest head-point from the lowest terminal-point of the palaeoglacier. The mean slope angle (α) was calculated as α=arctan(h/a).

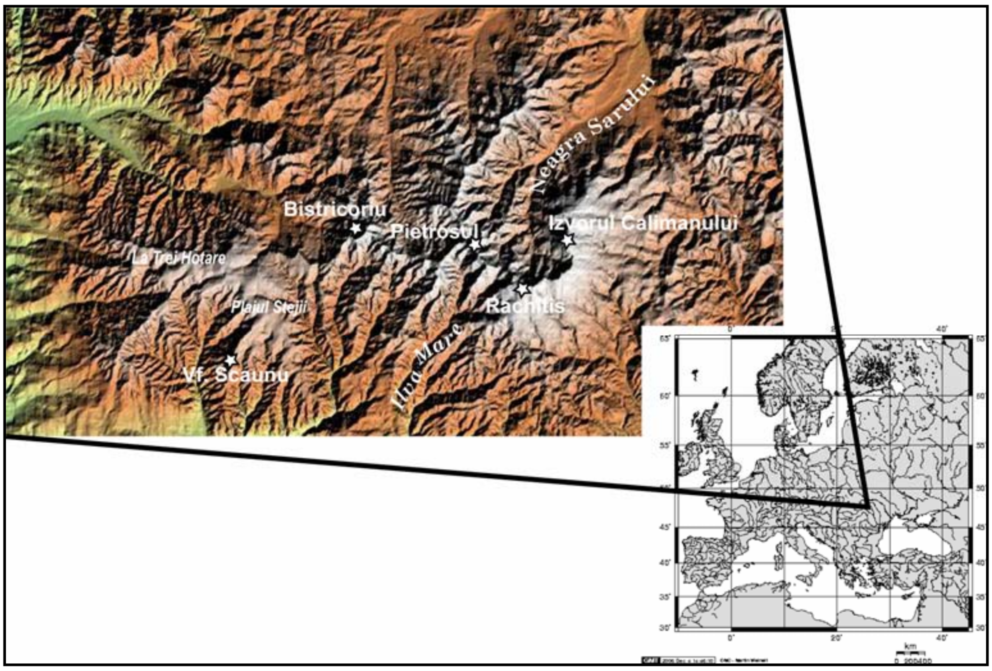

Fig. 1. *The most characteristic macro-landform of the Calimani Mts is the huge caldron shaped hollow opened and drained by Neagra Sarului Stream. Highest points of the range are located on the rim, glacial tracks are to be found on the steep northward exposed inner slope of the caldera.*

Estimating the altitude of palaeosnowline

As equilibrium line marks the borderline between accumulation and ablation area of the glacier it represents the snowline on the glacier's surface. The accumulation-area ratio (AAR) is the amount of accumulation area divided by the total area of the glacier (Meier, Post 1962). We have estimated the local palaeosnowline for the sites via determination of palaeo-equilibrium-line altitude (pELA) of the palaeoglaciers. Probably the most popular process determining ELA of past glacier is the method of accumulation-area ratio (*e.g.* see Porter, 1975).

Mapped palaeoglaciers can be classified as small size glaciers. Since a thorough analysis highlighted some special character of mass and energy balance of very small glaciers (Kuhn, 1995) we have investigated the AAR values of small size glaciers from balance years.

To do so, we selected small size (<1 km^2) Alpine glaciers from a global database (Dyurgerov, 2002) as potentially appropriate references to palaeoglaciers of Cãlimani Mts. Where more recent mass balance data were available we completed Dyurgerov's list from MBB7 and MBB8 (Haeberli *et al.* 2003, 2005).

We have chosen glaciers, which had annual mass balance (bn) data for ten years, at least. The standard deviation (σ) was calculated based on all available observation years. We regarded σ as index of natural variability of bn for the individual glacier basins. Afterwards, the annual AAR values were grouped when bn fell within the 0±½σ range which we designated as balance year. Finally, the mean of balance year AARs generated the AAR for small size glaciers.

Results and Discussion

We found two distinctly independent generations of moraines at Pietrosu (Fig. 2a, Fig. 3a) and Rãchitiş (Fig. 2b, Fig. 3b). We signed Pietrosu and Rãchitiş large and small as PL, RL and PS, RS, respectively. Their estimated surface and length (Tab. 1) quantitatively certify Naum's (1970) opinion about the small size of Quaternary glaciers of Cãlimani Mts.

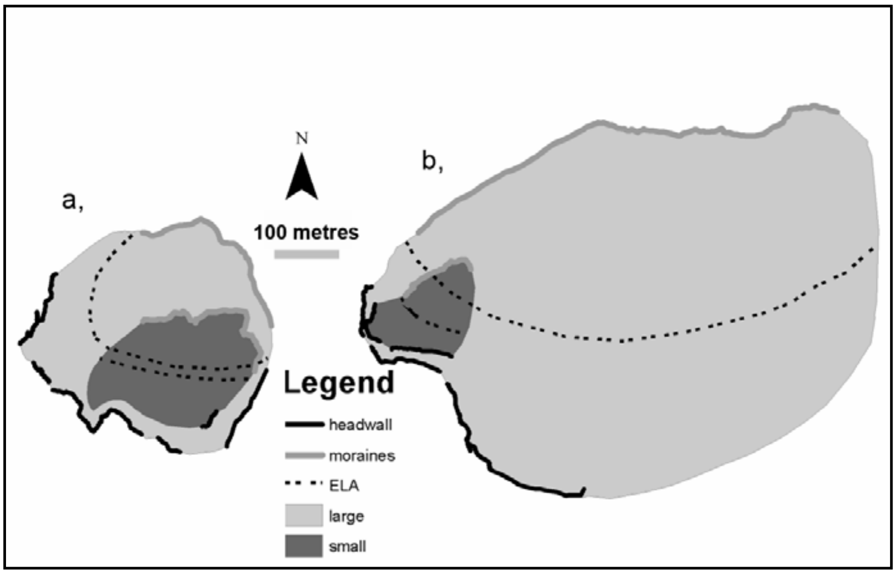

***Fig. 2**. Mapped moraines and headwalls from the Pietrosu (a) and Rachitis (b) cirque with the outlines and estimated pELAs of palaeoglaciers.*

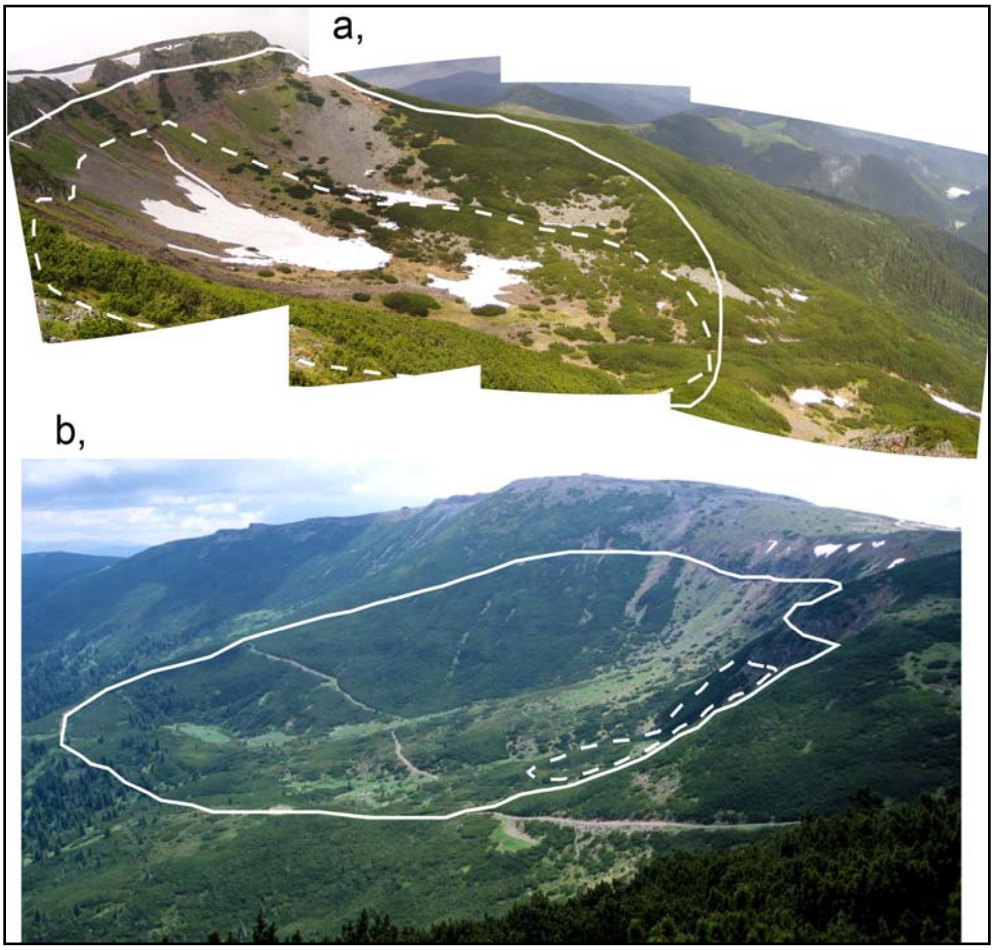

Fig. 3. *Thick lines show the supposed margin of the paleoglaciers at the older/larger stage and dashed lines mark them for the younger/smaller stage.*

The presently available rough DTM gives large uncertainty on volume estimation of palaeoglaciers, but we suggest the basal shear stress of minor ice bodies from the later stage could have been hardly enough for real ice-flow. They could have been more likely perennial ice/firn lenses and the dominant forming process of boulder ridges was more similar to a nivation ridge whereas the protruding, ablating origin must have been less significant.

The small size Alpine glaciers yielded 0.45 as balance year AAR. This quotient is significantly lower than the widely applied values (Porter, 1975; Meierding 1982; Dahl, Nesje 1992; Maisch 2000; Bacon *et al* 2001; Bavec *et al.* 2004; Reuther *et al.* 2004; Kuhlemann *et al.* 2005). The lower value means that in the case of a small size glacier a relatively smaller area is able to sustain the mass and energetic balance. The plausible explanation could be that the zone close to the headwall having the most positive mass and most negative energetic balance has relatively higher importance on a small glacier.

Applying this value (0.45) we determined the pELAs (Fig. 2; Tab. 1).

The elevation difference between the two phases is in perfect agreement (10 m), implying that they might represent the same glacial stages. However, significant discrepancy (75 m) could be realized between the elevation of pELA of Rãchitiş and Pietrosu palaeoglaciers.

The most evident difference between the corries is their exposition. To assess the possibility that the facing difference might answer the elevation difference Dyurgerov's (2002) database was used again. We searched for reference glaciers from the Eastern Alps which annual ELA data are available for a common period. Three northward exposed (Jamtalferner, Ochsentaler Glacier, Vermuntgletscher) and three eastward exposed (Sonnblick Kees, Kesselwandferner, Hintereisferner) glaciers were chosen. Their annual ELA were recorded and reported for the 1991-1999 common period. The mean elevation of ELA for the common period in the north group is 2984 m while in the East group yielded 3056.5 m. The comparison resulted 72.5 m higher ELA position for the eastward facing glacial basins, which reasonably agrees with our pELA elevation difference at similarly exposed cirques from Calimani Mts.

Relying on these results, on the basis of geomorphologic parallelisation we suggest that PL-RL and PS-RS represent two corresponding glacial stages from the Late Quaternary history of the Cãlimani Mts.

The RS occupied significantly smaller proportion of the corrie than PS does. We suppose that another small ice body might have coexisted with RS situating in the central part of the Rãchitiş cirque. But periglacial processes erased the accumulational landforms of this palaeoglacier.

Morphological analysis of the well-preserved fossil rock-glacier (Nagy *et al.* 2004) confirms this hypothesis because the mapped depression on the surface of the rock glacier is unambiguously contributed to thawing due to melt of buried ice core (Corte 1987).

CONCLUSIONS

We mapped remains of moraine ridges and headwalls at two ice-free cirques of the Cãlimani Mts. These cirques are situated below Pietrosu Peak and Rãchitiş Peak. The preserved morphological elements suggest at least two subsequent stages of glaciations during the Late Quaternary history at both sites, correspondingly.

Table 1. Estimated surface, maximum length and palaeo-equilibrium line altitude (pELA) of the observed glacial stages at the two study-sites. (Ex: exposure, L: length, A: surface, α: mean slope, pELA-R: raw calculated pELA in metres above ellipsoid, pELA: corrected values in m above sea level).

	Pietrosu						**Răchitiş**					
	Ex	**L (m)**	**A (km^2)**	**α (deg)**	**pELA-R (m ae)**	**pELA (m)**	**Ex**	**L (m)**	**A (km^2)**	**α (deg)**	**pELA-R (m ae)**	**pELA (m)**
Large	NE	364	0.1	17.75	1945	1915	N	583	0.34	17.63	1870	1840
Small	NE	235	0.03	17.57	1955	1925	N	154	0.02	22	1880	1850

The same elevation difference of the two pELAs in the cirques support the opinion that the PL-RL and PS-RS represent the local ice expansion of the same glacial stages.

The estimated elevation of pELA, which approximates the palaeosnowline, are 1840 m and 1915 m during the older while 1850 m and 1925 m during the younger glacial stage for Rãchitiş and Pietrosu cirques, respectively.

Our calculations resulted in significant elevation difference between the pELAs for the two sites. However, comparison of averaged ELA for 3 northward and 3 eastward exposed glaciers in the Eastern Alps during a 9 year-long period yielded highly similar result.

Presented results imply higher snowline-elevation for both investigated glacial stages than Naum (1970) supposed.

REFERENCES

Bacon, S., Chinn, T., Van Dissen, R., Tillinghast, S., Goldstein, H., Burke, R., (2001), Paleo-equilibrium line altitude estimates from late Quaternary glacial features in the Inland Kaikoura Range, South Island, New Zealand, *New Zealand Journal of Geology and Geophysics,* **44,** 55-67.

Bavec, M., Tulaczyk, S., Mahan, S., Stock, G., (2004), Late Quaternary glaciation of the Upper Soča River Region, (Southern Julian Alps, *NW* Slovenia), *Sedimentary Geology*, **165**, 265-283.

Corte, A., (1987), Central Andes rock glaciers, in: Giardino, J. R., Shroder, J. F., Vitek J. D. (eds.) 1987, *Rock Glaciers*, Allen&Unwin, Boston, 289–303.

Dahl, S., Nesje, A., (1992), Paleoclimatic implications based on equilibrium-line altitude depression of reconstructed Younger Dryas and Holocene cirque glaciers in inner Nordfjord, western Norway*, Palaeogeography, Palaeoclimatology, Palaeoecology,* **94,** 87-97.

Dyurgerov, M., (2002), *Glacier Mass Balance and Regime: Data of Measurements and Analysis.* Occasional paper, No. **55**, Institute of Arctic and Alpine Research, University of Colorado, 272 p.

Elekes, B., (2002), The periglacial morphology development of the special periglacial forms identified during the course of new observations (in Hungarian), *Földtani Közlöny*, **132**, 83–91.

Haeberli, W., Frauenfelder, R., Hoelzle, M., Zemp, M., (eds.) (2003), *Glacier Mass Balance Bulletin,* No. **7**, 2000–2001, IAHS(ICSI), 87 p.

Haeberli, W., Noetzli, J., Zemp, M., Baumann, S., Frauenfelder, R., Hoelzle, M., (eds) (2005), *Glacier Mass Balance Bulletin* No. **8**, 2002–2003, IUGG(CCS), 100 p.

Ichim, I., (1973), Problema teraselor de crioplanație din Masivul Călimani*, Lucr. Staț. de Cercet. „Stejarul”,* 83-92.

Ichim, I., (1978), Preliminary observations on the rock glaciers phenomenon in the Romanian Carpatians, *Rev. Roum. Geol. Geophys. Geogr., Geographie*, **23, 2**, p. 295–299.

Kuhlemann, J., Frisch, W., Székely, B., Dunkl, I., Danišík, M., Krumrei, I. (2005), Würmian maximum glaciation in Corsica*, Austrian Journal of Earth Sciences* **97**, 68-81.

Kuhn, M., (1995), The mass balance of very small glaciers, *Zeitschrift für Gletscherkunde und Glazialgeologie,* **31 (1),** 171-179.

Lovász, P., (2005), *Periglacial landforms in the Calimani Mountains. (in Hungarian),* TDK study, Babeş-Bolyai University, Cluj, 15 p.

Maisch, M., (2000), The longterm signal of climate change in the Swiss Alps: Glacier retreat since the end of the Little Ice Age and future ice decay scenarios, *Geografia Fisica e Dinamica Quaternaria* **23/2**,139-151.

Meier, M., Post, A., (1962), *Recent variations in mass net budgets of glaciers in western North America,* IUGG/IAHS Committee on Snow and Ice, General Assembly, IAHS publications **58**, 63-77.

Meierding, T., (1982), Late Pleistocene glacial equilibrium-line altitudes in the Colorado Front Range: a comparison of methods, *Quaternary Research***, 18,** 289-310.

Nagy, B., Kern, Z., Bugya, É., Kohán, B., (2004), Investigation of postglacial surface-evolution in the alpine region of the Călimani Mountains – with an outlook to the cirque region of the Rodnei Mountains, *Analele Universității de Vest din Timişoara, GEOGRAFIE,* **XIV,** 101-118.

Naum, T., (1970), Complexul de modelare nivo-glaciar din Masivul Căliman*, Analele Universității Bucureşti, Geografie,* **19,** 67-75.

Porter, S., (1975) Equilibrium-line altitudes of late Quaternary glaciers in the southern Alps, New Zealand. *Quaternary Research,* **5**, 27–47.

Reuther, A., Geiger, C., Urdea, P., Niller, H., Heine, K., (2004) Determining the glacial equilibrium line altitude (ELA) for the northern Retezat Mountains, Southern Carpathians and resulting paleoclimatic implications for the last glacial cycle, *Analele Universității de Vest din Timişoara*, *GEOGRAFIE*, **XIV,** 9-32.

Reuther, A., Urdea, P., Geiger, C., Ivy-Ochs, S., Niller, H., Kubik, P., Heine, K., (2007) Late Pleistocene glacial chronology of the Pietrele Valley, Retezat Mountains, Southern Carpathians constrained by ^{10}Be exposure ages and pedological investigations, *Quaternary International,* **164-165**, 151-169.

Urdea, P., (2004), The Pleistocene glaciation of the Romanian Carpathians*,* in Ehlers*, J.,* Gibbard, P.L., *Quaternary Glaciations – Extent and Chronology,* Part 1 Europe, Elsevier B.V., 301–308.