WP7 Water resources

Action 7.1 – Report

Geochemical analyses of permafrost ice and of permafrost water springs

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(1) Study Site Lazaun, Schnals Valley

Location

The Lazaunkar, a N-NE facing cirque in the upper Schnals Valley west of Kurzras, contains several fossil and three active rock glaciers. The uppermost part of the cirque is occupied by a glacier (Lazaunferner – Vedretta di Lazaun), just below the Saldurspitze, between an altitude of 3400 and 2800 m a.s.l. (Fig. 1).

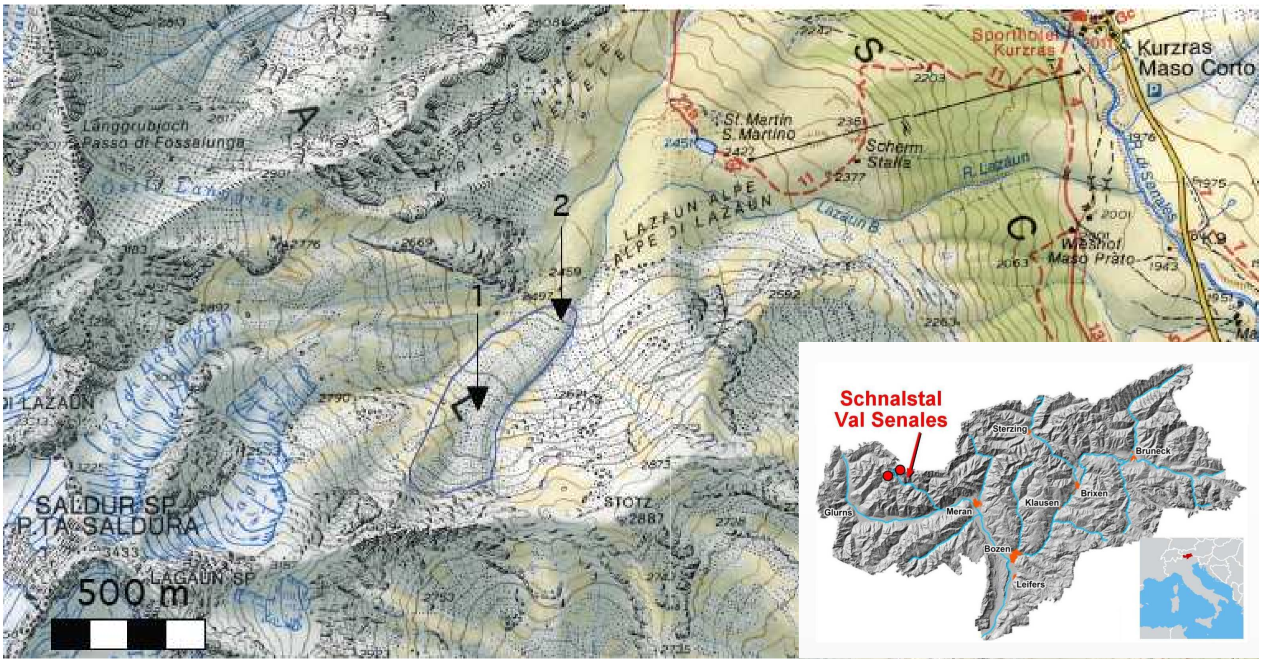

Fig.1: Topografic map with the location of the Lazaun cirque, indicated is the location of the two drillings.

Morphology

The cirque (Lazaunkar) is occupied by an active, tongue-shaped rock glacier, which is 660 m long, up to 200 m wide and covers an area of 0.12 km². The rock glacier extends from the rooting zone at 2700 m at the northern flank of the Stotz- to the front at 2480 m (Fig. 2).

The active rock glacier Lazaun is tongue-shaped, 660 m long, up to 200 m wide and covers an area of 0.12 km². The rock glacier extends from the rooting zone at approximately 2700 m above sea-level to

2480 m a.s.l. at the front. The rock glacier is supported with debris (mica schist and subordinately paragneiss) derived from frost weathering from the western part of the Stotz ridge.

The southern margin of the rock glacier is less steep than the northern margin. A depression in the frontal part divides the front into two lobes. The gradient of the front measures 35 – 45°. At the front the rock glacier is 29 m thick. The front of the rock glacier overrides an alpine meadow, on the northern margin a fan composed of debris flow deposits.

The surface of the rock glacier displays a pronounced morphology of longitudinal and transverse ridges and furrows. Longitudinal ridges and furrows occur in the upper part, transverse ridges and furrows are present in the lower part, particularly near the front.

Fig. 2: View on the active rock glacier at Lazaun (view towards SSW).

Water Chemistry

As one of the springs in the cirque, which is used as drinking water supply, contains high amounts of Ni (exceeding the upper limit of Ni in drinking water of 20µg/l three to four times) all springs in the cirque were sampled and analyzed:

- Rock glacier spring (**BG**)
- Capture of a spring for the Lazaunhütte (**QF**) in front of the 1850-moraine
- Glacier creek of the Lazaunferner (**GB**)
- Spring at the base of a lateral moraine (**Q 1**)
- Spring in front of a fossil rock glacier (**Q 2**) on the southern slope of Frischtele
- Rock glacier spring (talus rock glacier Stotz) (**Q 3**)
- Lake Lazaun (**LZ**)

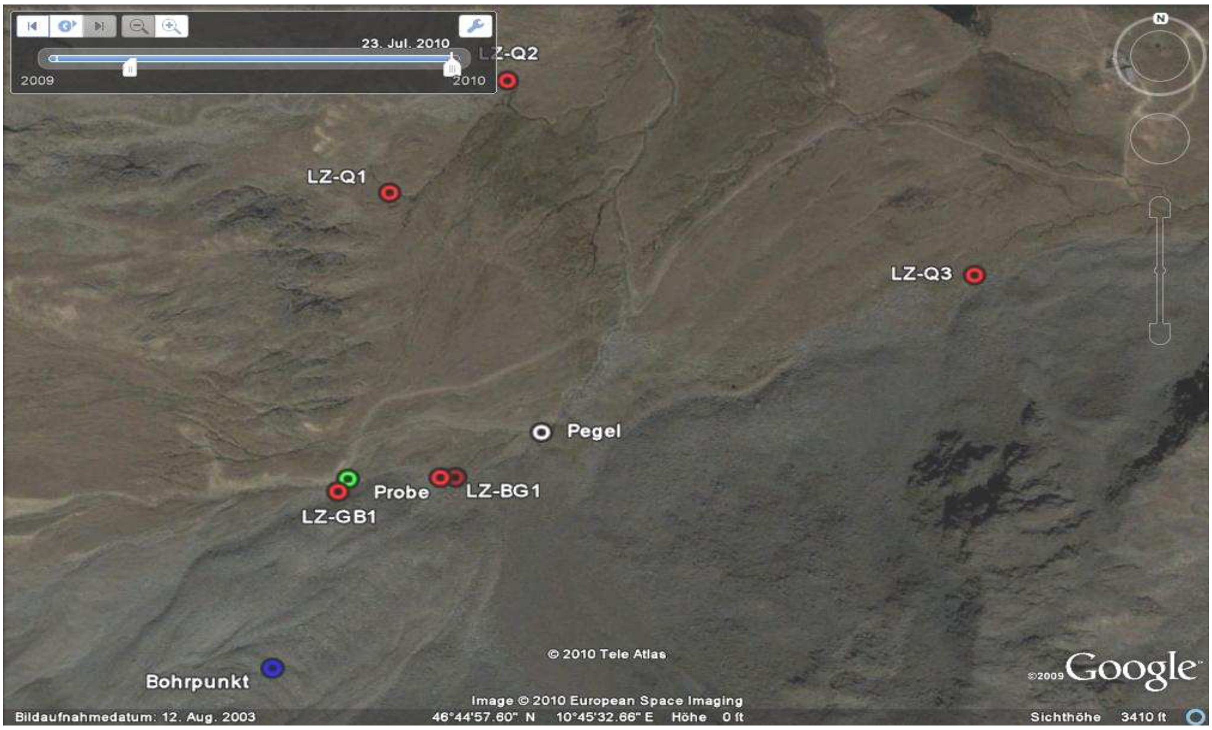

Fig. 3: Location of the analysed springs in the Lazaun cirque.

Water samples were analyzed for anions, kations (Ca2+, Mg2+, Na+, K+) and trace elements (Si P, Al, Ag, Ti, Fe, Mn, Sr, Ba, Rb, Co, Cu, Cr, Cd, Ni, Pb, Zn And V).

Two groups of springs are distinguished:

Springs characterized by low electric conductivity of 10 – 50 µS/cm (Q 1, Q 2 and Lake Lazaun) and Springs characterized by relatively high electric conductivity of 100 – 400 µS/cm (all springs derived from rock glaciers – BG, Q 3 – and from glaciers – QF, GB).

At all springs, electric conductivity is lowest during the snow-melt period in May and June, and increases towards autumn. Water temperature of the rock glacier spring is low (1°C or less) during the entire melt season.

All springs derived from rock glaciers and glaciers are characterized by high concentrations of Ni (springs BG, Q 3, GB and QF). The highest Ni concentrations (up to 0.175 mg/l) were recorded at spring Q 3 (Fig. 4) and exceeded drinking water limit of nickel by up to 8 times. In general, Ni concentration is lowest during the snow melt period in May and June and increases towards autumn. This indicates that Ni is probably released from permafrost ice and glacier ice. Rock analyses demonstrate that rocks in the catchment area do not contain higher concentrations of Ni. Besides Ni, Mn is also present in similar amounts. At present ice from the rock glacier (drill core) is analyzed to discover if the Ni is derived from the ice or not.

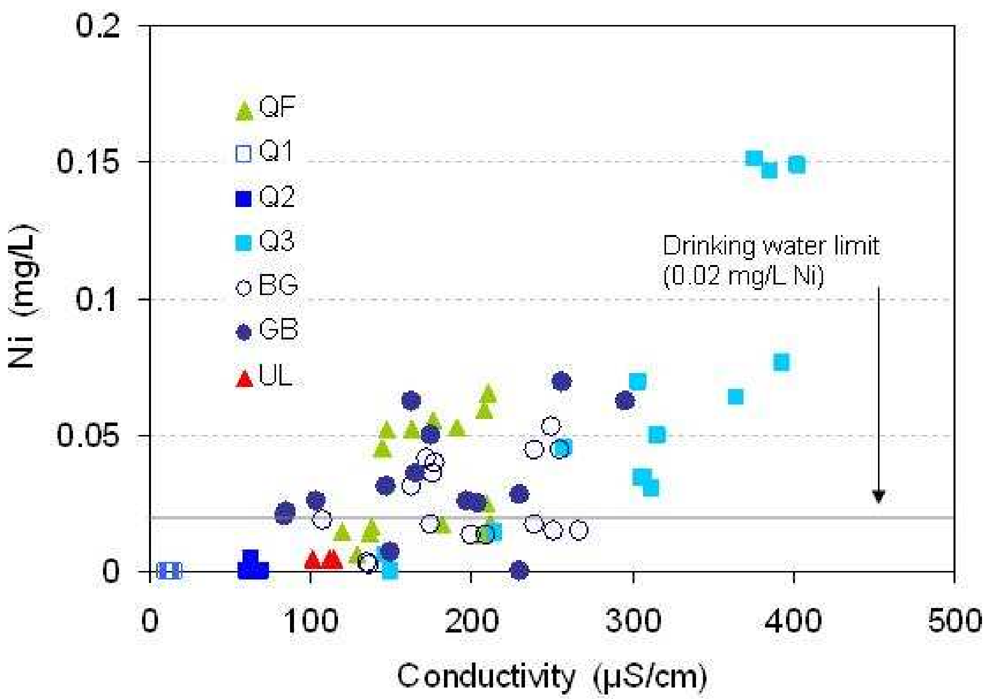

Fig. 4: Nickel concentration and conductivity of springs in the Lazaun cirque and at Ulten. Samples were taken in the years 2007, 2009 and 2010 (for abbreviations see above).

Drilling and Ice Content

Two cores were drilled on the lower part of Lazaun rock glacier (rotary core drilling) in summer 2010 (end of July and August) (Figs. 5- 9).

Fig. 5: Location of the drilling site Lazaun 2 near the steep front of the rock glacier (center of the photograph)

Fig. 6: Boring tackle at the drilling site Lazaun 1

<u>Lazaun 1</u> at an elevation of 2580 m, at a distance of about 240 m from the front, between GPS survey markers 54 and 55. The drilled core is 40 m long.

Fig. 7: Drill pipe with ice core, Lazaun 1

Lazaun 2 was drilled at an elevation of 2538 m near the front of the rock glacier, near GPS survey marker 8 (Fig. 7). The core is 32 m long. At both drillings an almost continuous core was obtained. Ice-containing cores were stored in cooling boxes at the drill site, and then transported to Kurzras by helicopter and to Innsbruck by cooling truck where the cores were stored in a cooling room at a temperature of -20°C.

Core Lazaun I

The active layer (unfrozen debris layer) is 2.8 m thick; a continuous frozen core (mixture of ice and debris) was obtained from 2.8 m to a depth of 13.5 m. From 13.5 m to 15.2 m almost ice-free debris is present, and from 15.2 to 24 m again a continuous frozen core was obtained. From 25 to 28 m coarse debris is present, underlain by debris with high amounts of fine-grained sediment down to a depth of 40 m (Figs. 8, 9).

Of interest is the core from 19.5 to 24 m which contains high amounts of dark colored, banded ice containing very fine-grained sediment. Few clasts with diameters up to several cm float in the banded ice (Fig. 9). Between 22.5 and 24 m the core contains higher amounts of sandy material.
From the frozen core samples were taken for geochemical analysis, isotope studies and palynology at an interval of approximately 10 cm resulting in a total of 149 samples. The samples (mixture of ice and debris) were melted and then the water was filtered from the debris to obtain pure water for chemical analysis.

Ion content of the samples showed a high variability along the core, which is revealed by conductivity values ranging from 40 to 1300 µS/cm (Fig. 10). Peak values were found in the ice fraction between 18 and 24 m depth with secondary maxima around 4 m and 12 m. Maximum conductivity in the ice was 3 to 4 times higher than maximum values in spring water in the Lazaun cirque.
The ice content of the samples varies considerably from almost zero up to 98%. The average ice content of core Lazaun I between 2.8 and 24 m is 43% (all values are vol.%; density of the rock – mica schist and paragneiss is estimated to be 2.6). The average ice content is higher between 2.8 and 14 m (48%) and between 19.5 and 24 m (51%). We assume that in the upper part of the rock glacier, particularly in the rooting zone the ice content is somewhat higher. Near the front (core Lazaun II) the ice content is 22%.

The average ice content of Lazaun rock glacier is approximately 35 – 40%. The total area of the rock glacier is 0.12 km², the area of the frozen core is estimated to be 0.1 km² resulting in a total ice volume of 740.000 to 850.000 m³ (average thickness of the frozen core 21 m).
The melting rate of ice of Lazaun rock glacier is in the order of 10 cm/year resulting in a total loss of ice by melting of 10.000 m³/year. Thus at present increased melting of permafrost ice causes a loss of about 1.2 – 1.3% of the total ice volume each year.

Fig. 8: Frozen core (mixture of debris and ice), Lazaun 1

Fig. 9: Ice core composed of banded ice and small clasts

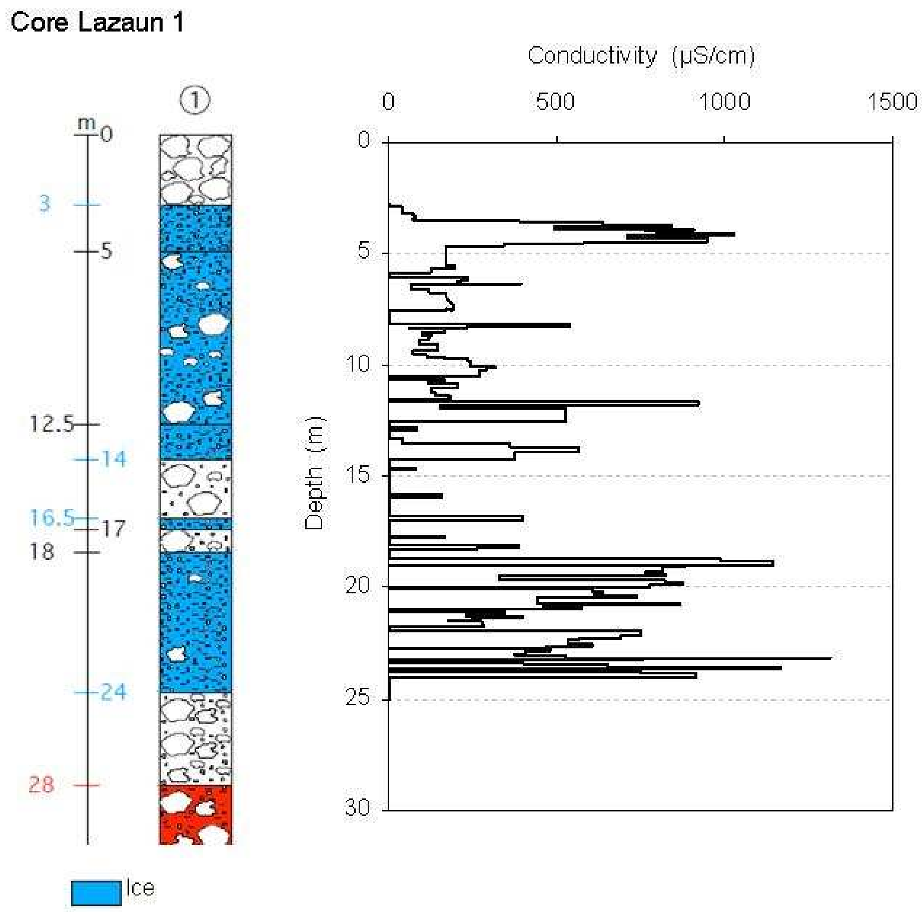

Fig. 10: Vertical profile of conductivity at core Lazaun 1.

Core Lazaun II

The core from the drilling Lazaun II, which is situated close to the front of the rock glacier, contains significantly lower amounts of ice compared to core Lazaun I.

The active Layer is thicker, the first ice was detected at a depth of 4.5 m. Ice is present from 4.5 m to 5.5m (mixture of debris and ice), from 6.65 to 7.7 m (coarse sandy material from 6.65 to 6.8 m, followed by mixture of debris and ice to 7.7 m), from 9.1 to 10.5 m (coarse debris with ice) and from 15.5 to 18.5 m (coarse debris with ice, large block at 18 m). From 18.5 to 24.5 m coarse debris with small amounts of fine sediment was obtained, whereas from 24.5 to 32 m coarse debris with high amounts of fine sediment occurred (figs. 12, 13, 14). The average ice content is 22%.

Ice-content varies considerably (<2 – 73%), is mostly < 12%. Higher ice contents were recorded at 5.15 – 5.50 m (32%), 6.65 – 6.8 m (73%), 7.20 – 7.35 m (47%), 7.35- 7.5 m (32%), 9.45 – 9.5 m (56%), 18.25 – 18.35 m (50%) and 18.35 – 18.50 m (26%).

Electric conductivity of the ice fraction ranges between 90 and 530 µS/cm (Fig. 11). Peak values of conductivity are found in the upper part of the core between 5 and 7 m depth, while core Lazaun 1 revealed the maximum ion content in the lower third of the vertical profile.

In sample LZ II-5 (9,45 – 9,50 m) high values of Ni (0,181 mg/l) were measured, the other samples yielded Ni contents up to 0,008 mg/l. Delta18O values of the samples from core Lazaun II range from -11,73 to -13,23.

The core from 9.45 – 9.5 m yielded a typical alpine pollen spectrum indicating a maximum age of about 2000 years. The core also contained small plant fragments (probably *Salix, Ericaceae*) which will be analyzed by ^{14}C.

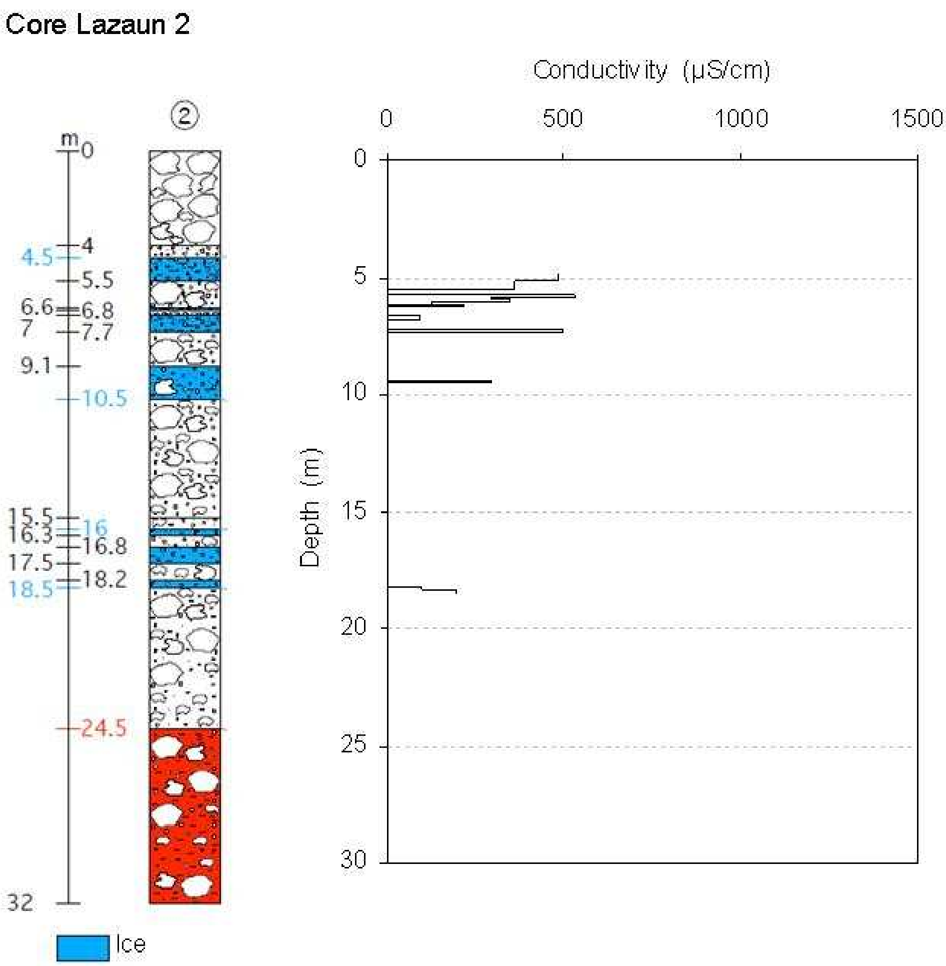

Fig. 11: Vertical profile of conductivity at core Lazaun 2.

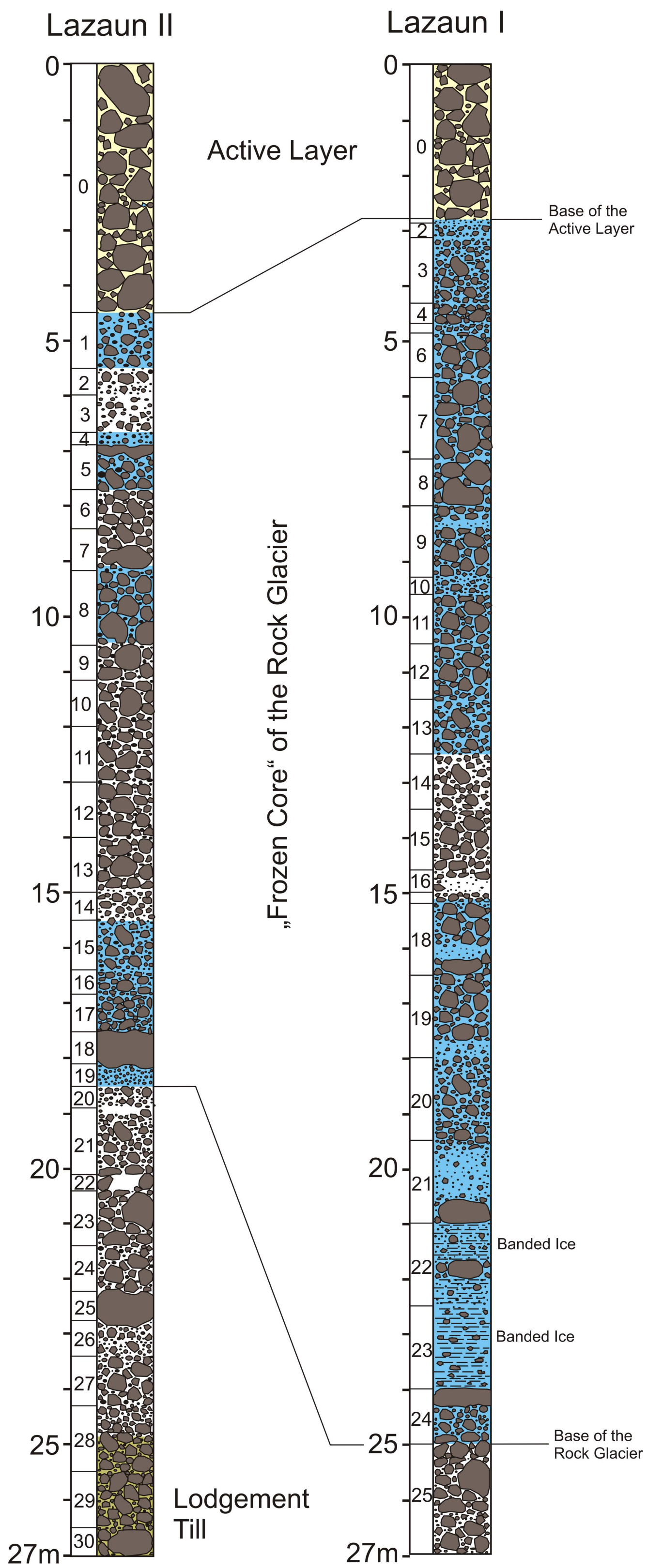

Fig. 12: Sections of the cores Lazaun 1 and 2

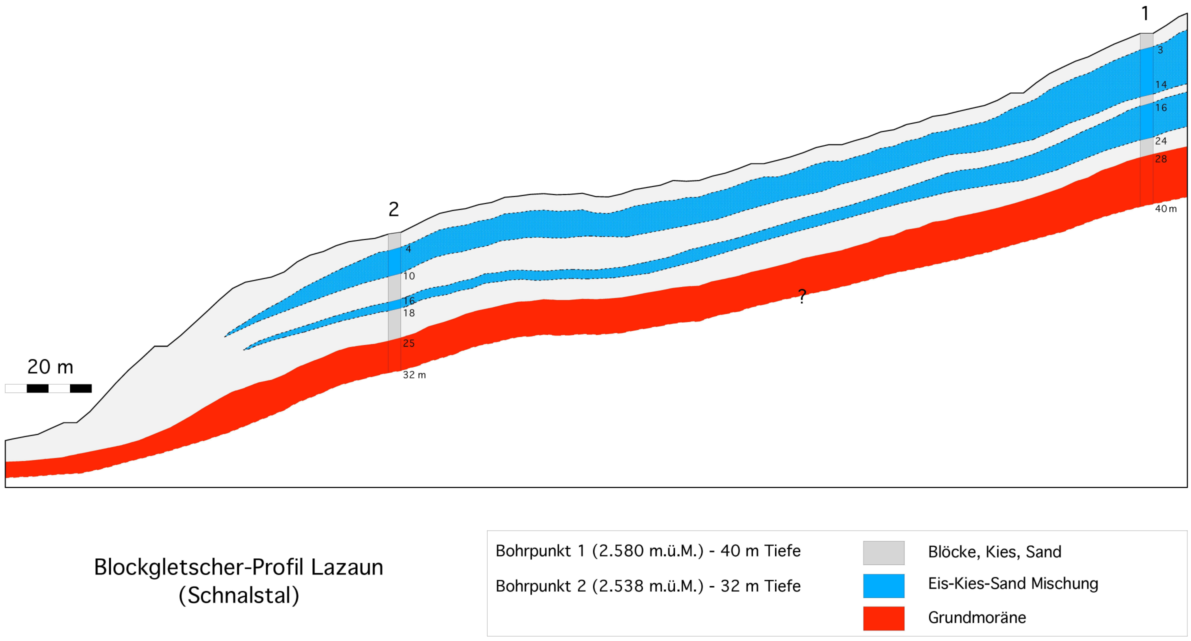

Fig. 13: Reconstruction of the frozen core in the lower part of Lazaun Rock Glacier (from core Lazaun 1 and 2). Blue: frozen core which thins towards the front, red: lodgement till at the base of the rock glacier.

Conclusions

Rock glacier Lazaun is an active, tongue-shaped rock glacier with a steep front with gradients of 30 – 50°. The depression in the rooting zone indicates melting of a massive ice core in this part of the rock glacier. Flow velocity measurements, BTS, water temperature of the springs, steep front and surface morphology demonstrate that the rock glacier is active and contains substantial amounts of ice, probably a massive ice core in the upper part.

Georadar data which show several reflectors within the frozen core support the idea that this rock glacier has a glacial origin (e.g. LANG 2006).

Two core drillings confirmed that the rock glacier contains a frozen core with locally high amounts of ice. The frozen core is largely composed of a mixture of debris and ice (“Ice-cemented rock glacier”, at the base of core Lazaun 1 banded ice with low amounts of debris are present.

The discharge pattern is typical for active rock glaciers and characterized by strong diurnal and seasonal variations. During winter (October until May) discharge is extremely low and electrical conductivity high. Highest discharge is recorded during the snowmelt period in June and July, and during rainfall events. Pronounced diurnal variations in discharge are recorded in May and June.

From the end of July until October discharge decreases, interrupted by single peaks caused by rainfall events. Warm weather periods in autumn may also cause a slight increase in discharge (increased melting of permafrost ice).

The rock glacier spring is characterized by relatively high electric conductivity and high concentrations of Ni and Mn. Analysis of the ice core showed that Ni is concentrated in a distinct level (9,45 – 9,50 m) in core II demonstrating that the high Ni concentrations in the spring water are derived from distinct levels of the permafrost ice. The average ice content of the rock glacier is approximately 35 – 40 vol.%. Increased melting of permafrost ice causes a loss of approximately 10.000m^3 ice/year which is 1.2 – 1.3 of the total ice volume of the rock glacier. Increased melting of permafrost ice of the rock glacier causes an average discharge of 0.6 l/s. This is only about 2.3% of the average discharge of the rock glacier which is approximately 26 l/s.

(2) Study Site Rossbänk, Ulten Valley

Location

Rock glacier „Rossbänk“ is one of 17 rock glaciers (9 active, 4 inactive, 4 fossil) which were mapped in the Ulten Valley in the area of Oberweissbrunn. The area is located in Stelvio National Park. Rock Glacier „Rossbänk“ is located in an east-facing cirque, surrounded by steep rock walls with Vordere Eggenspitze (3348m) being the highest summit (Figs. 14 and 15).

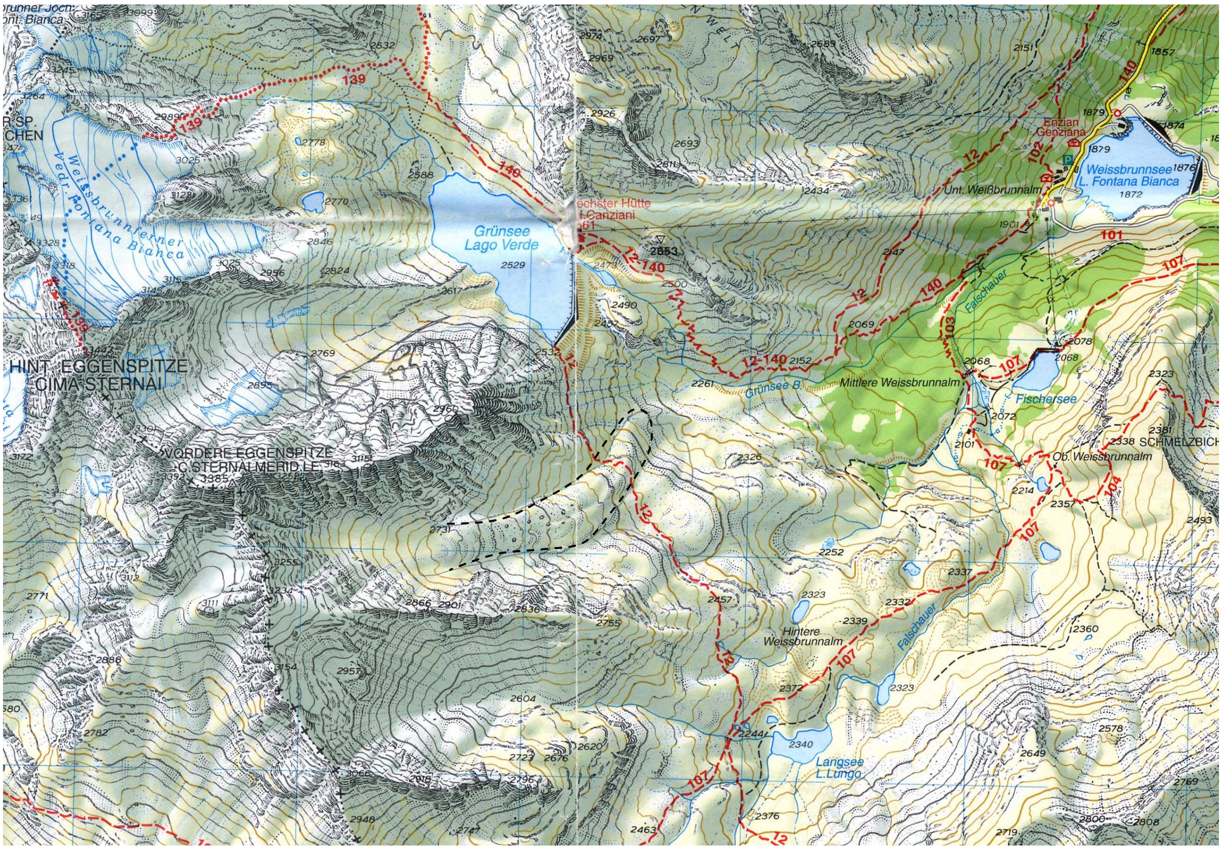

Fig. 14: Topografic map of the Rossbänk rock glacier in the Ulten valley.

Fig. 15: Lower and middle part of Rossbänk Rock Glacier in the uppermost Ulten Valley with steep front

Morphology

Rock glacier „Rossbänk" is 1700 m long, 200 – 600 m wide, extends from an altitude of 2310 m (fossile front) to 2840 m (rooting zone) and covers an area of 55 ha. The rock glacier is tongue-shaped, the front of the active part ends at an altitude of 2470 m and overrides two tongues of an inactive rock glacier, which end at 2375 m and overlie a fossil rock glacier which extends to an altitude of 2310 m. The slope of the front of the active as well as of the inactive and fossil rock glacier is up to 40° steep.

The rock glacier derives debris produced by frost weathering from the steep wall of the Vordere Eggenspitze. A depression is developed in the rooting zone which is filled with meltwater during summer.

The surface layer of the rock glacier is very coarse-grained. In the upper part of the rock glacier longitudinal ridges and furrows are well developed, in the middle and lower part transverse ridges and furrows (lobes) are present. The front of the active rock glacier is not well developed, the maximum slope measures 40°.

Hydrology

Water temperature was measured at the spring of the rock glacier several times. The water temperature always was below 1°C (0.4 – 0.7°C) which indicates the presence of permafrost. The water temperature of the the springs of the rock glaciers Nr. 6, 8, 9 and 12 also were mostly below 1°C, rarely increased to a maximum of 1.8°C at rock glacier Nr. 12 and to 1.4°C at rock glacier Nr. 6 (Juen 1999, 2000). These temperatures indicate that these rock glaciers very probably also contain ice. At the spring of rock glacier Nr. 2 the temperature ranges between 1.2 and 1.9°C also indicating that some ice may still be present. Significantly higher water temperatures of 2.3 – 5.1°C were recorded at the gauging station in front of the steep snout of the fossil rock glacier Nr. 4.

The gauging station was installed at a distance of about 30 m off the springs. Daily variations of the water temperature at the gauging station demonstrate that at this short distance the water temperature increases of up to more than 1°C on warm days during summer. During May the water temperature of the springs measured 0.2 – 0.8°C.

At the springs of the rock glaciers Nr. 4, 6, 8 and 12 the electrical conductivity was measured several times during summer. At all springs the lowest values (86 – 130 µS/cm) were recorded immediately after the beginning of the snowmelt during May and June and increased to values of > 300 µS/cm in autumn. The highest value of 360 µS/cm was recorded at the spring of rock glacier Nr. 12 in September.

In front of the fossil rock glacier Rossbänk a gauging station was installed from May until October 2007. During this time the discharge was characterized by pronounced seasonal variations. During May and June diurnal variations were recorded too. Due to snowmelt discharge is highest during May, June and July. Periods with cold weather cause a significant decrease of discharge to values < 20 l/s. Precipitation events during summer cause short peak discharge of more than 100 l/s. A pronounced rainfall event during August caused a significant peak discharge of more than 200 l/s.

During August and September discharge generally decreases, interrupted by few single peaks caused by rainfall events. During September discharge varied between 13 and 28 l/s. During October a rainfall event caused a peak discharge of 60 l/s, followed by a continuous decrease until the springs fell completely dry by the end of November (Fig. 16).

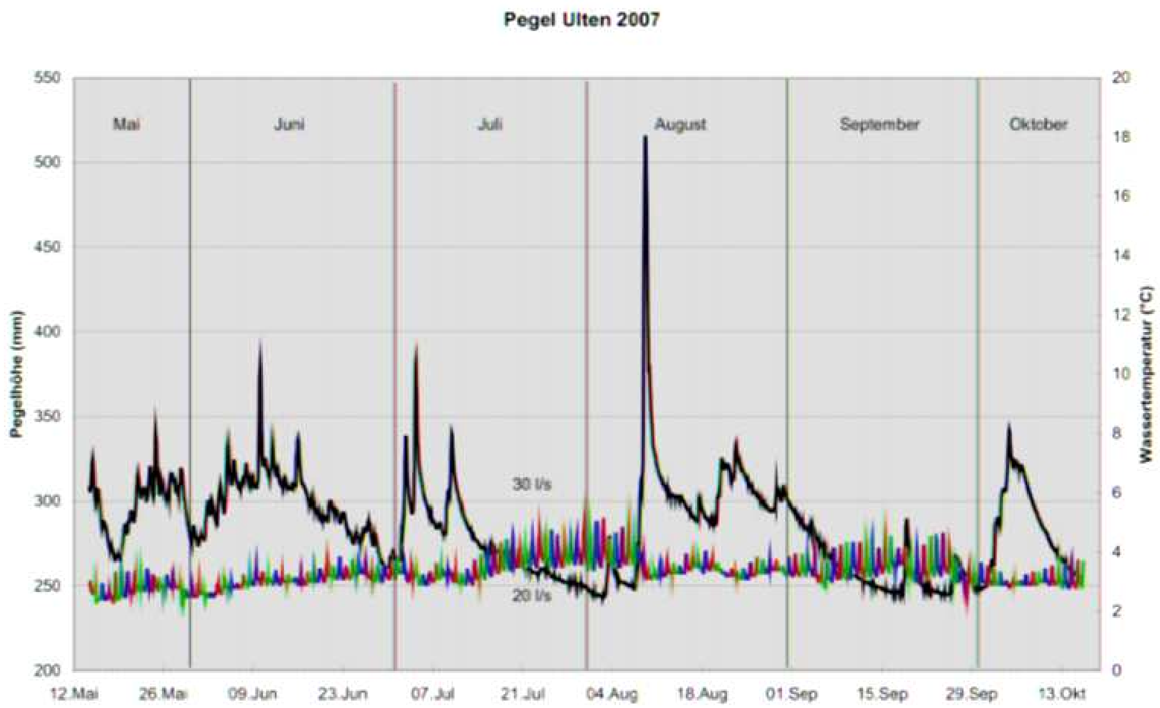

Fig. 16: Hydrograph (black line) and water temperature (red line) for the meltwater stream in front of Rossbänk Rock Glacier for the period May 12 until October 16 2007.

Drilling

Drilling on rock glacier Rossbänk (Ulten) started on September 14, 2010. Drilling was difficult due to the lack of water which had to be transported to the drilling site by helicopter, and particularly due to the very coarse material of the rock glacier (Figs. 17, 18, 19).

Fig. 17: Drilling station on Rossbänk Rock Glacier, view towards the east.

Fig. 18, 19: Drilling station on Rossbänk Rock Glacier.

Coarse, ice-free debris ("active layer") was drilled to a depth of 5 m. From 6 m to 8 m a frozen core (mixture of debris and ice) was drilled (Fig. 20). From 8 m to a depth of 18 m the drilling penetrated very coarse debris with very small amounts of fine sediment. The core did not contain ice, but this is probably caused by technical problems.

Electrical conductivity of the ice fraction between 6 and 8 m depth ranged from 100 to 1200 µS/cm and showed a similar variability as cores Lazaun 1 and Lazaun 2 (Fig. 21).

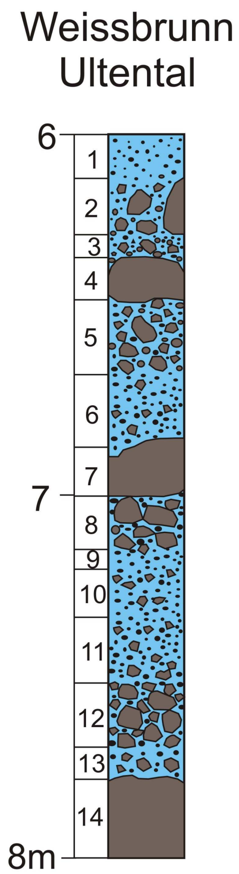

Fig. 20: Profile of the drilled core from Rossbänk Rock Glacier at Weissbrunn, Ulten Valley

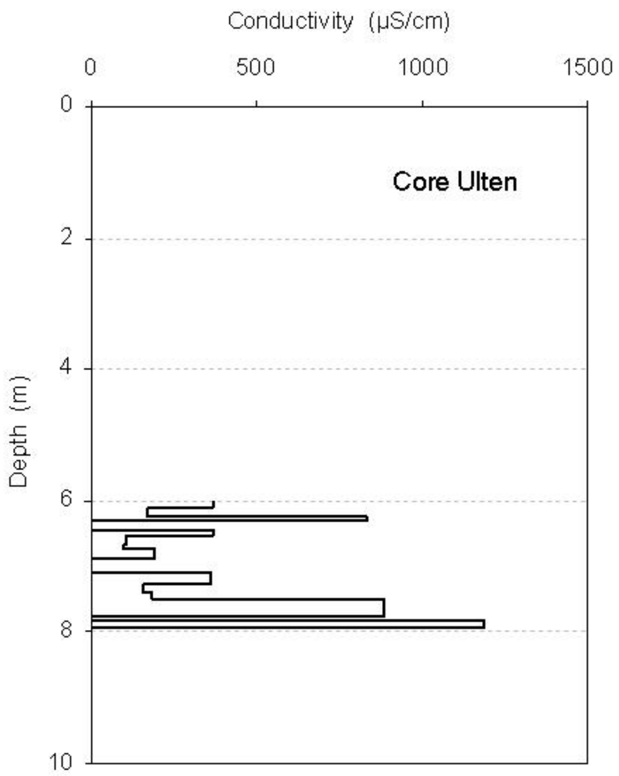

Fig. 21: Profile of conductivity at Rossbänk Rock Glacier at Weissbrunn, Ulten Valley.

Conclusion

Rock glacier „Rossbänk" is one of the largest rock glaciers of South Tyrol. It is a tongue-shaped active rock glacier with a steep front and a typical surface morphology of transverse furrows and ridges in the lower part. The depression in the rooting zone indicates melting of massive ice in the subsurface. The debris layer is extremely coarse-grained with individual blocks exceeding 10 m in diameter. Data obtained from BTS, geophysical surveying and flow velocity measurements document that this is an active rock glacier.

The active rock glacier overrides an inactive rock glacier which itself overlies a fossil rock glacier. This indicates that the debris layer of the cirque, composed of three rock glaciers is thick and therefore the surface of the bedrock could not be detected by georadar.

The morphology in the upper part of the rock glacier (longitudinal furrows and ridges) indicates extensional flow, whereas the transverse ridges and furrows in the lower part point to compressional flow.

Annual flow velocities are highest along the axis and decrease towards both margins and also towards the front.

BTS-temperatures are significantly lower on the rock glacier than beside the rock glacier on permafrost-free ground clearly indicating the presence of ice within the rock glacier.

Meltwater of the active rock glacier is released at springs at the front of the underlying fossil rock glacier. The low temperature of these springs (1.4°), although the meltwater flows through the inactive and fossil rock glacier for several 100 m, also indicates the presence of ice

The discharge pattern is similar to that of other active rock glaciers and characterized by distinct seasonal and during the snowmelt period also distinct diurnal variations. Heavy rainfall events during summer and early fall cause extreme maxima in discharge. Electrical conductivity of the meltwater released from the rock glacier shows values typical for rock glaciers with metamorphic bedrocks. Electrical conductivity is lowest during snowmelt (dilution effect caused by meltwater) and increases towards fall, indicating increasing amount of higher mineralized groundwater.