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SHALLOW SHEAR WAVE REFLECTION SURVEYING ON ALPINE GLACIERS – INSIGHTS, CHALLENGES, AND OPPORTUNITIES FROM GEPATSCHFERNER GLACIER AND COLLE GNIFETTI

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Summary

In the summer season 2010, a shallow reflection seismic experiment using the small vibrator source ELVIS was carried out on the overburden firn and ice cover of the Colle Gnifetti, Monte Rosa group, Swiss/Italian Alps. This site is widely used for method testing, since the physical properties of ice are similar to those of polar regions. The unique experiment approved for the first time the shallow high-resolution vibroseis method using P- and S-waves for seismic targets on firn and ice masses at least to nearly 60 m depth. As a consequence of this successful experiment, the method was subsequently applied in April 2012 on the Gepatschferner, a glacier in the Austrian Alps, using S-waves only. In contrast to the commonly planted receivers at Colle Gnifetti, a land streamer modified for snow application was used as receiver system. The source was slightly modified by a ski to support operation on soft snow. The recorded data at Gepatschferner achieved clear reflections from the ice base boundary in nearly 150 m depth and from the glacier bed below.

Equipment transportation to the test sites is only possible by helicopter cargo, which restricts the investigations to flight cargo adapted geophysical equipment of max. 400 kg per flight.

Fig. 2: Impression from the seismic survey setup above the clouds in an altitude of about 4500 m a.s.l. at Colle Gnifetti. Vertical (for an additional P-wave survey) and horizontal geophones were planted simply at the snow surface.

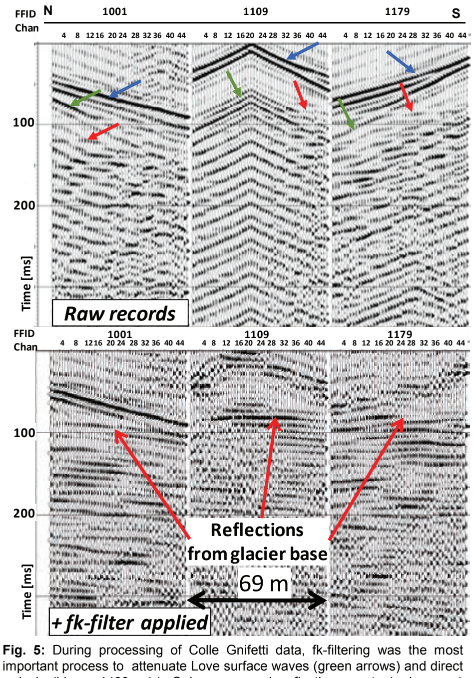

Fig. 5: During processing of Colle Gnifetti data, fk-filtering was the most important process to attenuate Love surface waves (green arrows) and direct arrivals (blue, ~1400 m/s). Only some weak reflection events (red arrows) could be observed in the raw data prior to fk-filtering, whereas clear basement reflections are visible after filter application.

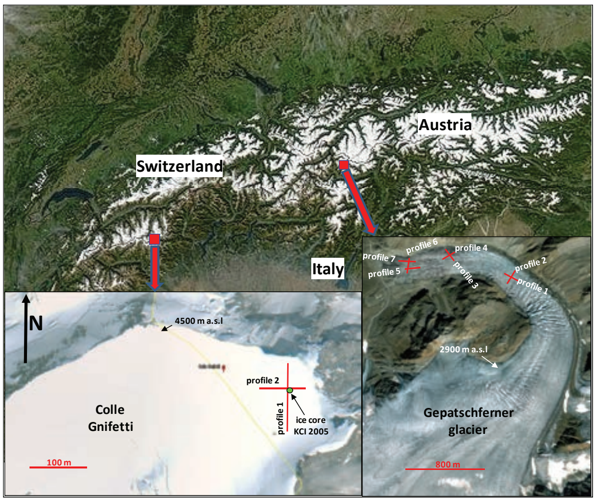

Fig. 1: Locations of the Colle Gnifetti and Gepatschferner investigation sites in the Alps. On the Colle Gnifetti firn and ice saddle at the Swiss-Italian boarder (yellow line, small photo left) two crossing profiles were carried out in August 2010. Seven profiles were carried out on the tongue of the Gepatschferner glacier close to the Austrian-Italian boarder (small photo right) in April 2012 in three cross arrangements, two of them at the lower part of tongue, where ice melting and glacier recession took place. Examples shown here are from profile 1 (parallel to ice flow direction) and 2 (perpendicular to ice flow direction) in the middle part of the tongue.

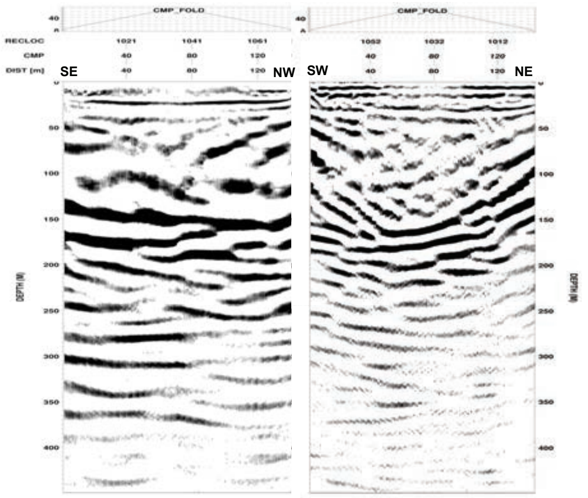

Fig. 4: Depth converted, fd-migrated time sections of profile1 (left) and profile 2 (right) from the Gepatschferner glacier. Depth conversion based on reflection velocity analysis only could not be calibrated due to missing borehole data, so reflector depths differ slightly due to individual velocity fields. Data of profile 1, parallel to glacier flow direction, shows significantly lower frequency content and less resolution compared to profile 2, which is oriented nearly perpendicular to the glacier flow direction. Section of profile 2 clearly images the asymmetric form of the tongue bed.

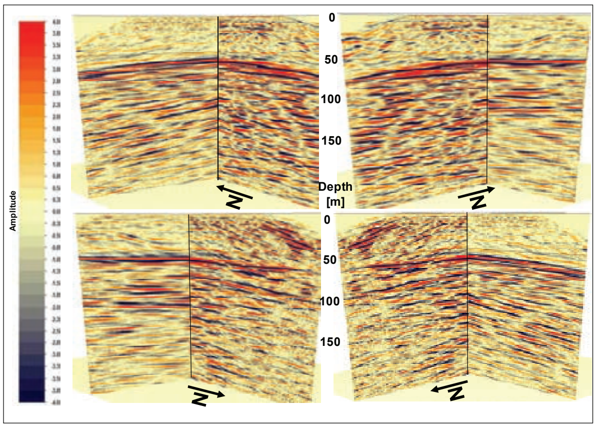

Fig. 7: Spatial views of depth-converted poststack migration sections of Colle Gnifetti data show a good fit of the basement structures which are visible along both profiles. The dip of basement is southwest. The depth conversion based on stacking velocities only meets the 62 m of the ice core drilling nearly perfect without any corrections. However, it is not known whether this depth is the depth of the basement because ice core drilling was stopped when the first gravel parts occurred in the core.

Site description

The Colle Gnifetti is a saddle formation at the top of the Monte Rosa group, crossed by the boarder of Swiss Alps and Italian Alps, in an altitude of nearly 4500 m asl. (**Figure 1**). It is covered by a nearly horizontally layered package of ice and firn tens of meters thick. The firn formation at the top is about 30 m, as evaluated by an ice core to a depth of 62 m below surface. The Monte Rosa rock mass below the ice formation consists of gneiss and granite, strongly faulted during the uplift of the Alps. Due to the climatic conditions and the topographic settings at the flat plateau, the physical properties of firn and ice are comparable to polar regions. Therefore, the location is widely used for paleoclimatic investigations and testing of methods.

The Gepatschferner is the second largest glacier in the Austrian Alps, located in the Ötztal Alps close to the Austria-Italian boarder and covers nearly 25 km². Its volume consists mostly of ice, firn is rarely present. Its main trunk flows nearly 6 km towards North-East before turning for nearly 3 km to West. Its glacier terminus with nearly 2000 m a.s.l. is one of the lowest glacier altitudes in the Alps, the mean glacial recession in the recent decade is at least 16 m/year. The maximum thickness of the tongue was estimated to be 250 m in 1996, the ice flow velocity is around 50 m/year. The tongue is fissured by a lot of crevasses, mostly directed perpendicular to the main flow direction, which hamper seismic operation and require careful and experienced site scouting supported by GPR, prior to seismic profiling arrangement.

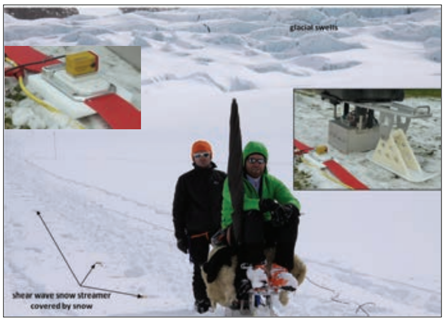

Fig. 3: ELVIS horizontal vibrator source in operation on Gepatschferner profile 1. The land streamer is almost covered by fresh fallen snow.

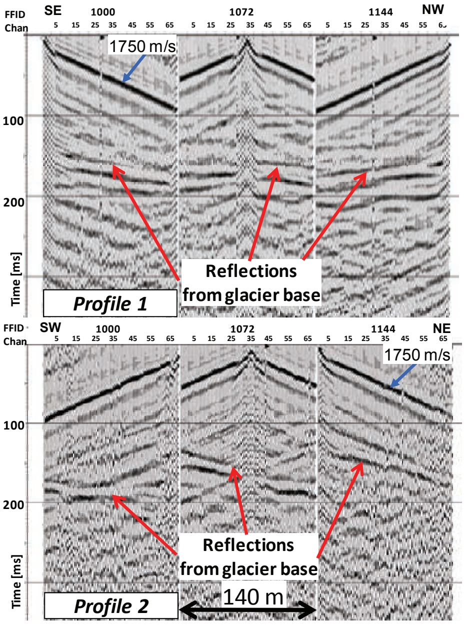

Fig. 6: During processing of Gepatschferner data, fk-filtering was of less importance. Reflections from the basement below the ice could be clearly detected in the raw records. Probably due to the fresh fallen snow at the surface, frequency content of the data was lower compared to the Colle Gnifetti data.

Conclusions and Outlook

The shallow reflection shear wave seismic surveys at Colle Gnifetti and on Gepatschferner glacier demonstrated the principal capabilities while using shear waves for the investigation of shallow firn and ice masses. As an advantage compared to GPR methods, also the exploration of the upper part of the underlying basement can be carried out. In addition to structural analysis in higher resolution than for P-waves it enables the calculation of the dynamic shear modulus also, which can be an indicator for the mechanical stiffness of such systems.

Both data sets show a very different behaviour of the individual firn and ice formations, and confirmed the applicability of the method to detect the ice basement and structures below, as well as elastic parameter derivation for the firn and ice mass.

In contrast to common impulse source methods on snow and ice, usually done by drilling and blasting, the vibratory source method seems to be a key

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for the investigation of snow- and ice- covered targets. Compared to the results of an earlier P-wave experiment carried out at Colle Gnifetti in 2008 using an explosive charge source, the resulting data quality was significantly better and achieved better resolution by a strongly increased productivity during operation.

In the follow-up of these initial experiments, additional experiments were carried out on firn and ice formations in Antarctica and also in a second survey campaign on the Gepatschferner glacier in 2013. The aim of this time-lapse experiment still under data processing is to study the glacier variances in time, the influence of local variations e.g. snow coverage and ice clefts to the seismic data acquisition, and their influence to the data processing.

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Impressions from seismic survey at Gepatschferner glacier, April 2012 & 2013

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