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Supplement of

Modelling wet snow avalanche runout to assess road safety at a high-altitude mine in the central Andes

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Supplement Material

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Evaluating SNOWPACK model performance in 'Cajón del Rio Blanco'-Valley Codelco-Andina mine

This supplement provides an evaluation of the performance of the SNOWPACK model to simulate the snow cover in 'Cajón del Rio Blanco'-Valley Codelco-Andina mine. First, a comparison of simulated and measured snow depth and snow surface temperature at the meteorological station used to drive the SNOWPACK model is shown. Second, a comparison of the simulated snowpack microstructure with snow profiles made in the field is provided.

Snow depth and snow surface temperature

From the data from the automatic weather station, the snow depth measurements can be used to track whether the model simulates the snow depth and thereby the layering resulting from subsequent snow fall events correctly. The snow surface temperature measurements were not used to drive the model and can be used as a verification of the cold content of the snowpack. Fig. S1 shows the average difference in modelled vs. measured snow height and snow surface temperature over the winter seasons 2010-2015. The root mean square error in snow height is 6.33 cm and the average snow height difference is -1.6 cm. When we compare these values with the values obtained in the Weissflujoch measurement site where snowpack is extensively tested and calibrated the values are (RMSE) 4 cm for WFJ and ca. (difference) 0.9 cm for snow height difference (see Table 1 in Wever et al, 2015). For the snow surface temperature, the average difference is 2.3 °C in Chile and -1.5 °C for WFJ (see Wever et al, 2015).

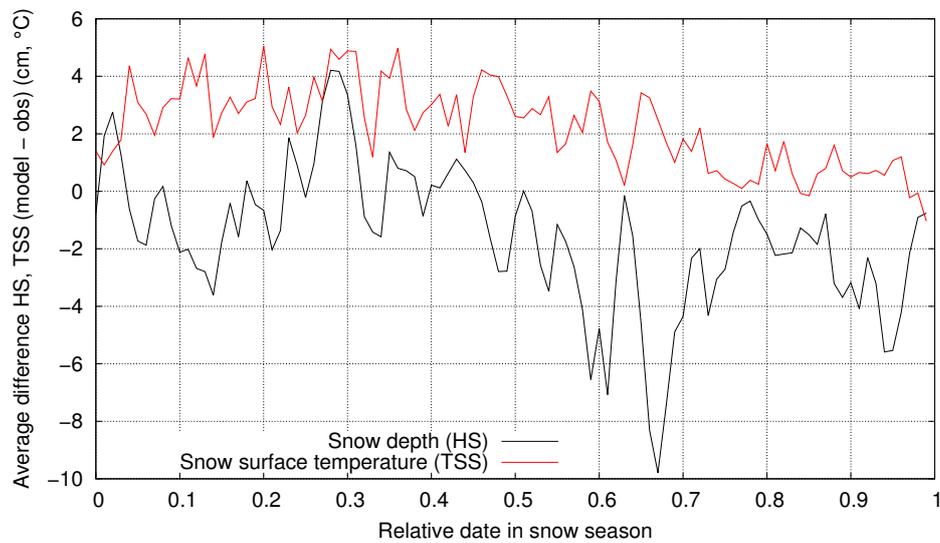
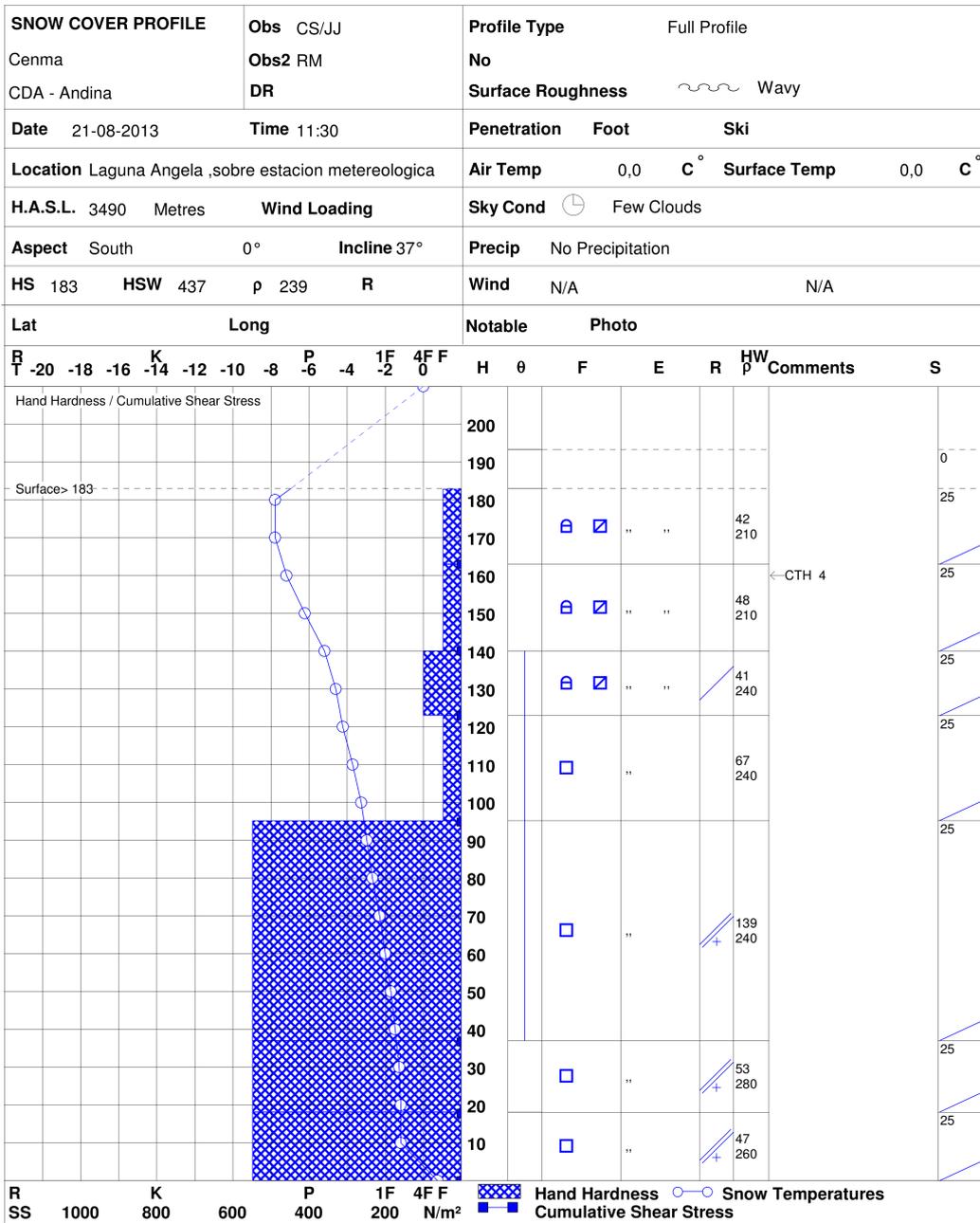


Figure S1: Average error of the simulated snow height and snow surface temperature over measurements (denoted obs) during 6 snow seasons at the meteorological station used in this study. For every snow season, the first day with a snow cover is set at 0, the last day at 1.

SNOWPACK model performance compared with traditional snow pits

In the following section, we provide 5 manual snow pits taken by the winter operation crew in the vicinity of the automatic weather station together with the snow profiles as simulated by the SNOWPACK model using data from the same station. The comparison is done using the virtual slopes from the simulation that correspond to the exposition where the snow pits were made. Both the simulated SNOWPACK profile and the observed profile contain: snow height, grain type, hand harness, grain type information and snow temperature information. Snow profiles are plotted following the international standard, (Fierz et al, 2009).



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Manto estable con gradiente bajo de temperatura (0.03) metamorfosis destructiva.

Figure S2: Snow pit performed by the winter operation crew on the 21-08-2013 in the vicinity of the AWS.

Location: Laguna_Angela		Date / Time: 2013-08-21 12:00	
Observer:	Altitude: 3550 m	Air temp.:	
Profilenr.:	Exposition: S / Slope: 35°	Cloudiness:	
Snow water equivalent:	Coordinates: -33.07824 / -70.27279	Wind:	
Hasty Pit: No	Avg. density: 322 kg/m³	Avg. ram resistance:	
Weather / Precipitation:			
Remarks:			

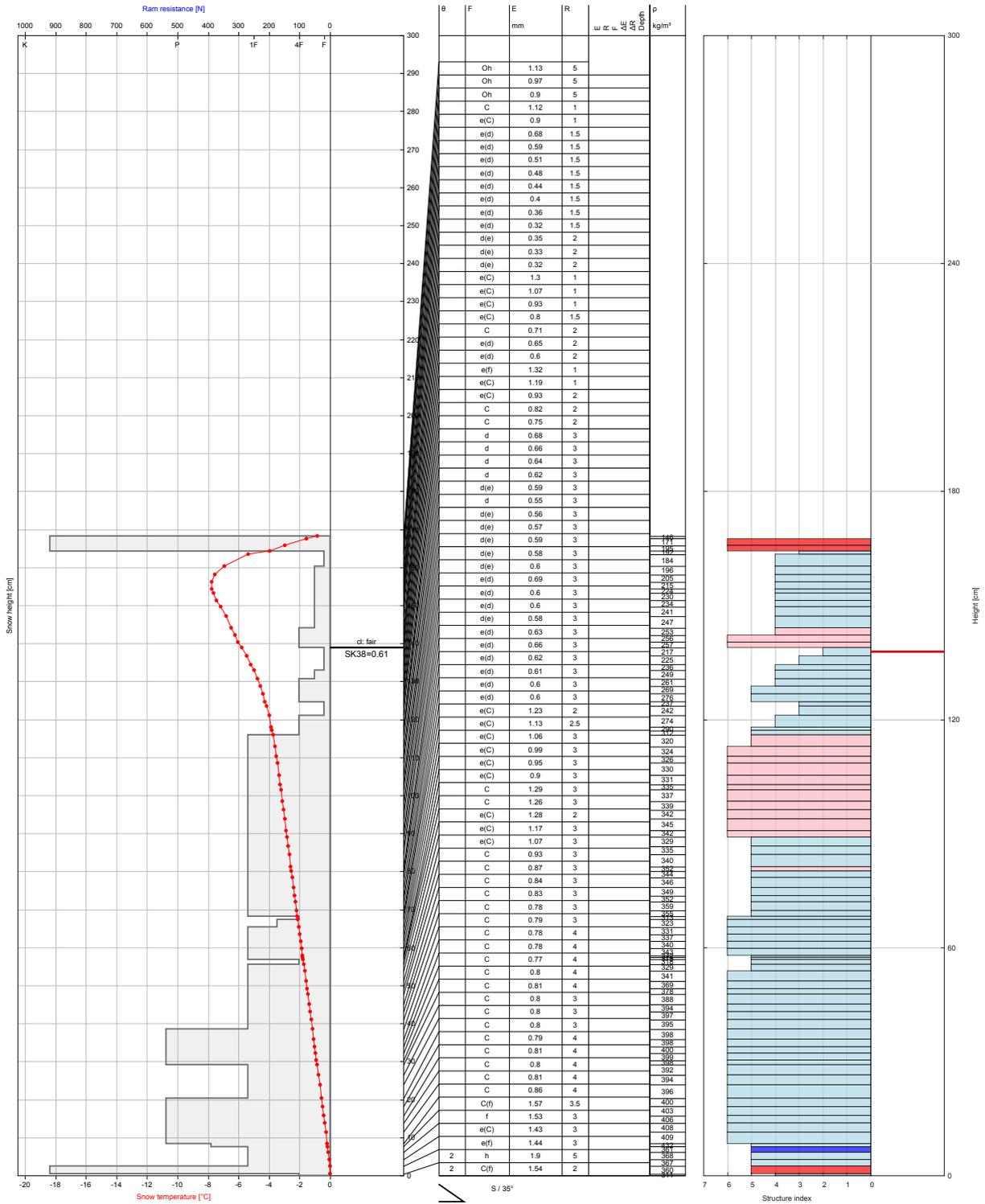


Figure S3: SNOWPACK simulation performed using the virtual slope concept matching with the exposition of the hand profile in Fig. S2 .

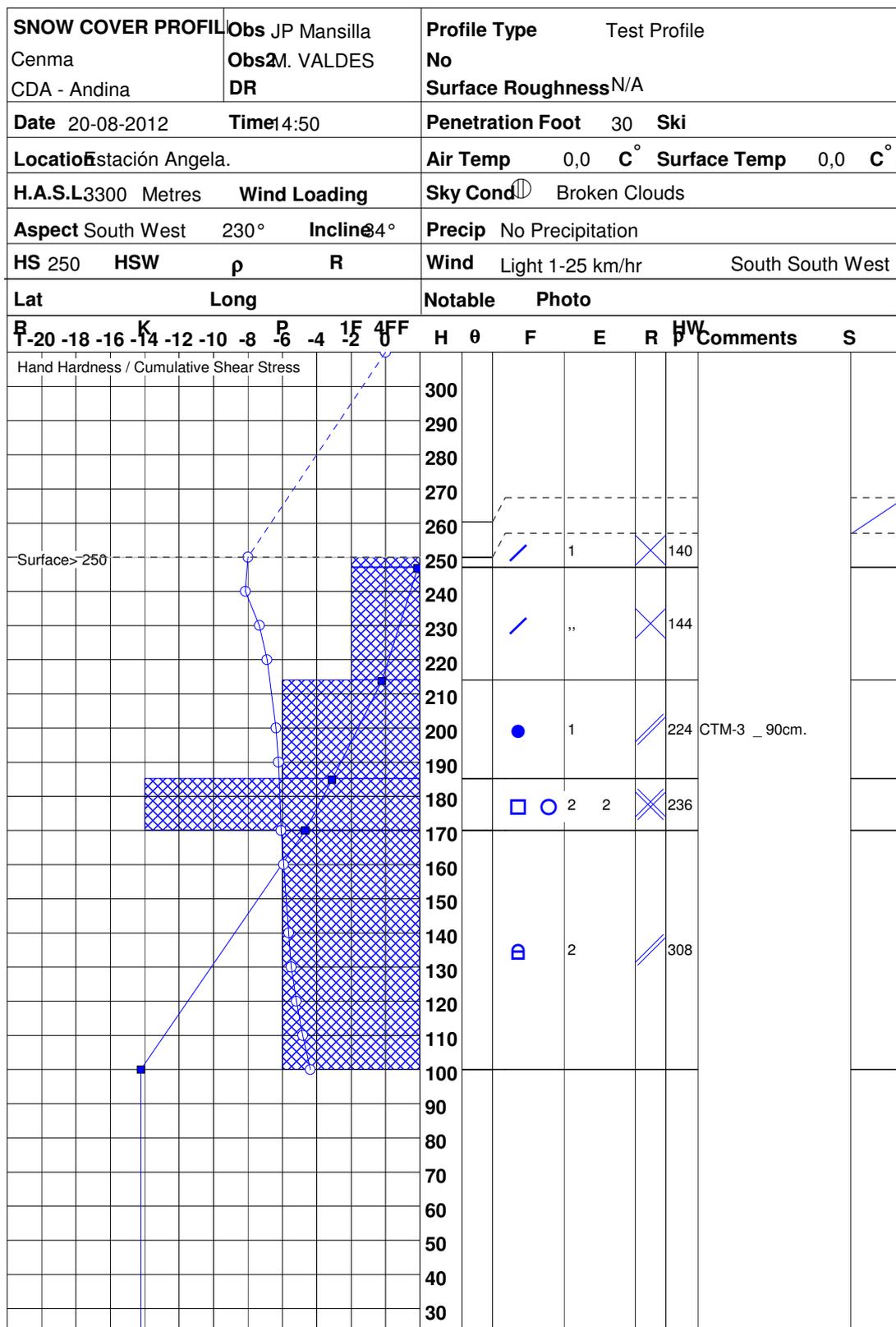


Figure S4: Snow pit performed by the winter operation crew on the 20-08-2012 in the vicinity of the AWS. Note that the observed profile was not done over the full depth, and that the total snow depth exceeds the profile depth.

Location: Laguna_Angela
Observer:
Profiler:
Altitude: 3550 m
Exposition: S / Slope: 35°
Coordinates: -33.07824 / -70.27279
Avg. density: 301 kg/m³
Date / Time: 2012-08-20 09:00
Air temp.:
Cloudiness:
Wind:
Avg. ram resistance:
Show water equivalent:
Hasty Plt. No:
Weather / Precipitation:
Remarks:

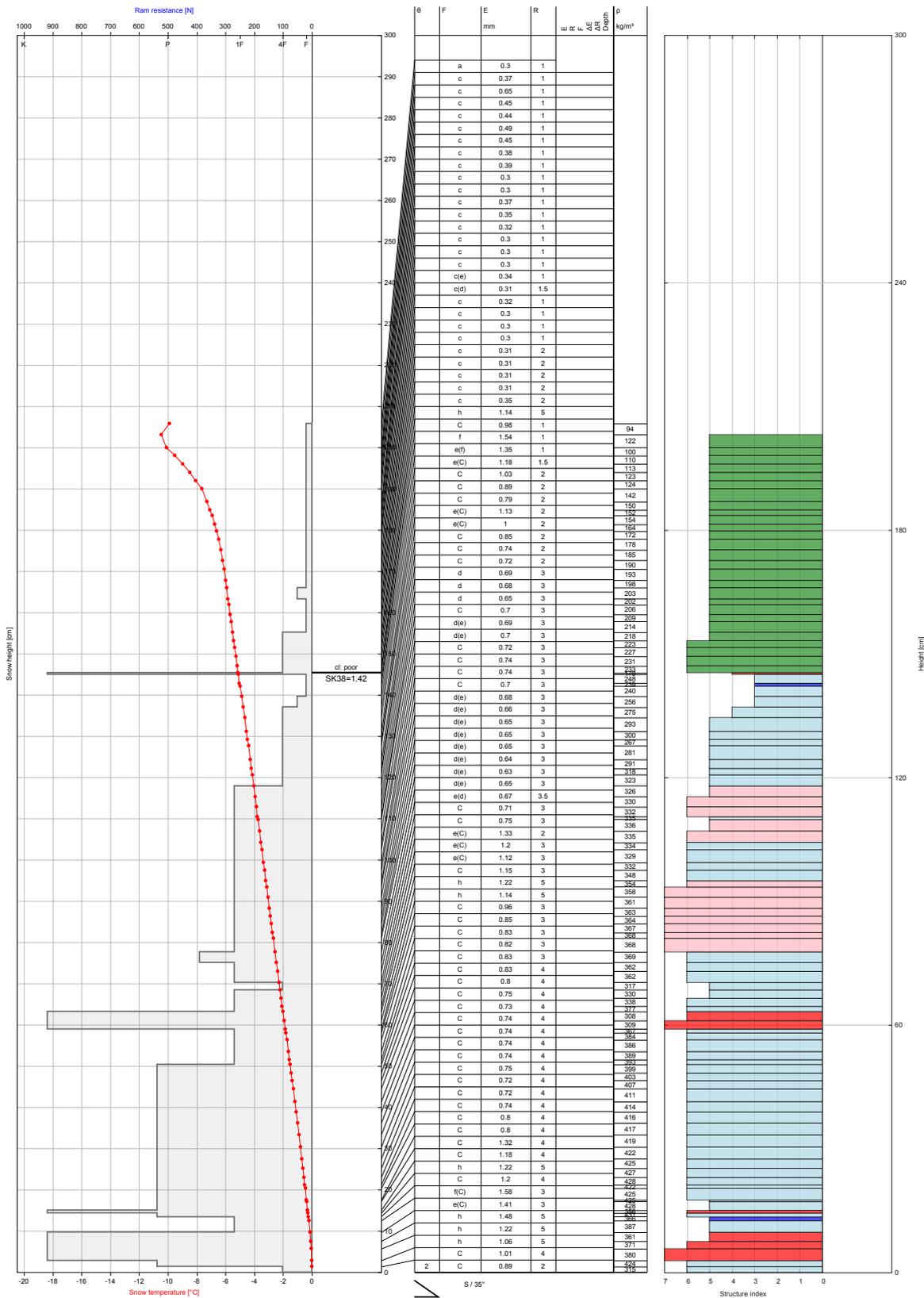
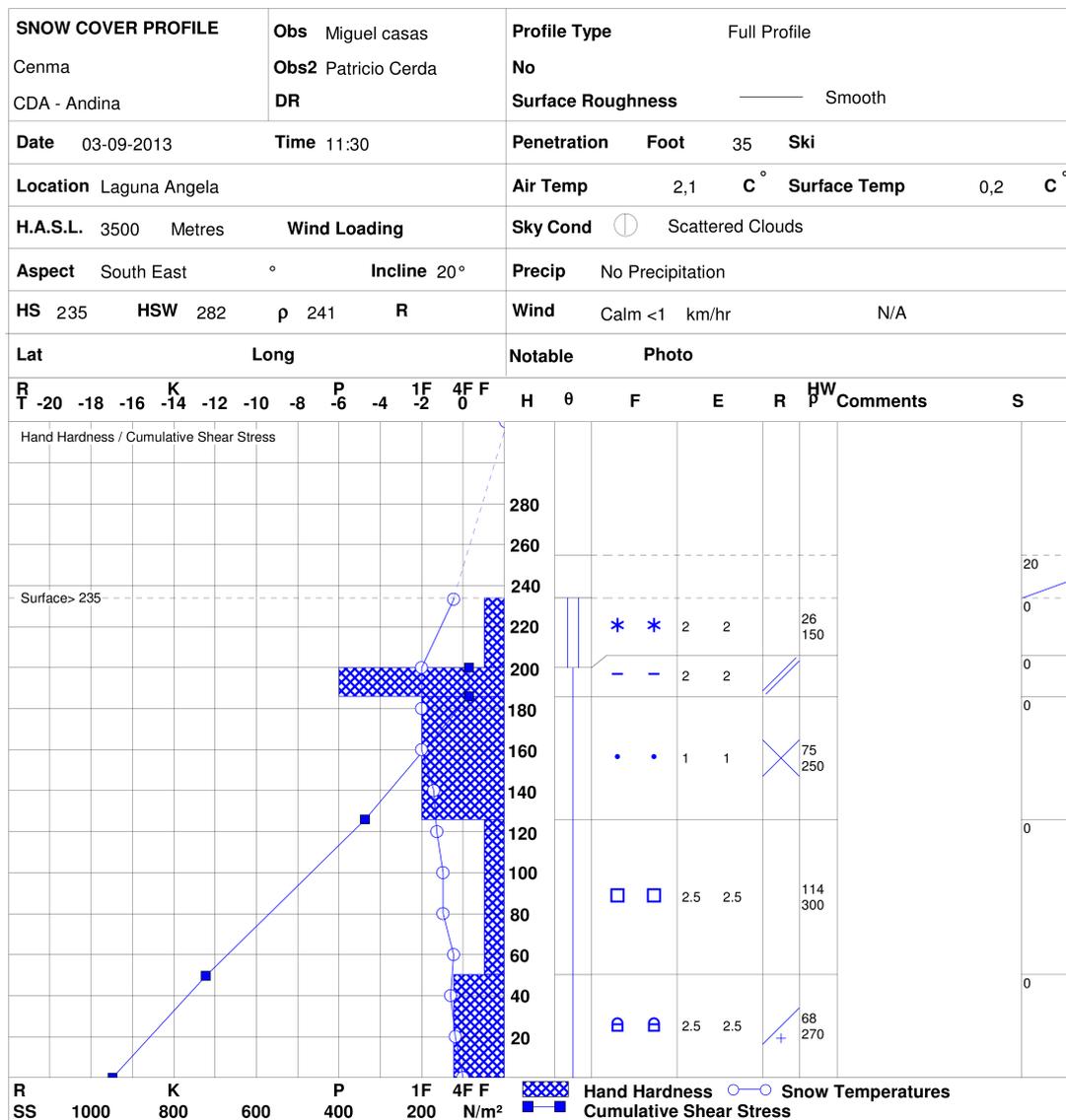


Figure S5: SNOWPACK simulation performed using the virtual slope concept matching with the exposition of the hand profile in Fig. S4 .



Test de compresión rompe bajo la capa de los 60 cm. al tercer golpe de la primera serie.

Figure S6: Snow pit performed by the winter operation crew on the 03-09-2013 in the vicinity of the AWS.

Location: Laguna_Angela
 Observer: Altitude: 3550 m
 Profile: Exposition: S / Slope: 35°
 Snow water equivalent: Coordinates: -33.07824 / -70.27279
 Hasty Plt. No: Avg. density: 301 kg/m³
 Weather / Precipitation: Avg. ram resistance:
 Remarks:

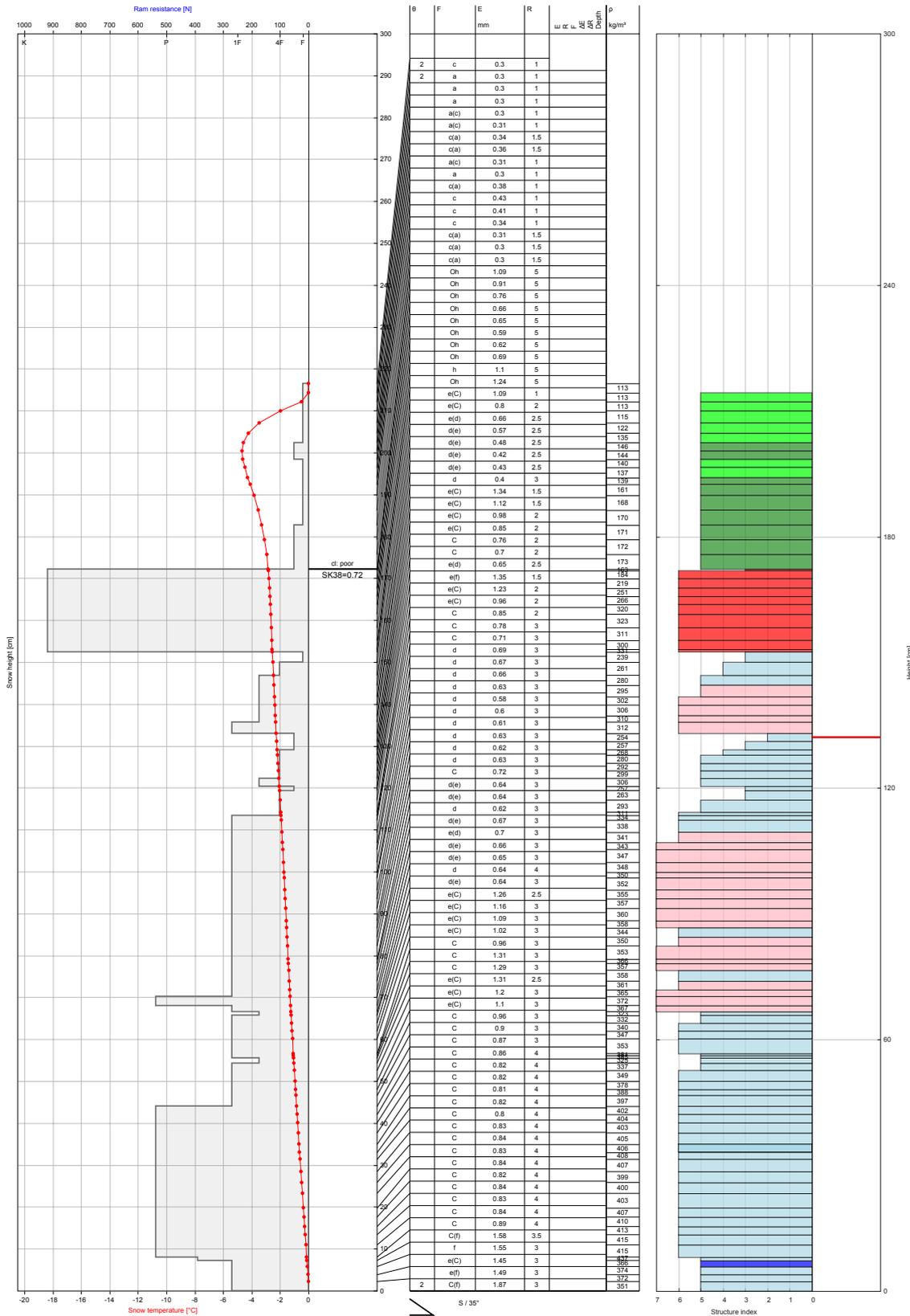


Figure S7: SNOWPACK simulation performed using the virtual slope concept matching with the exposition of the hand profile in Fig. S6.

AvaNet Snow Profile



Organization: Aprendica

Location: Laguna Angela Sur DAN

Date: 2015-09-11 11:00 am

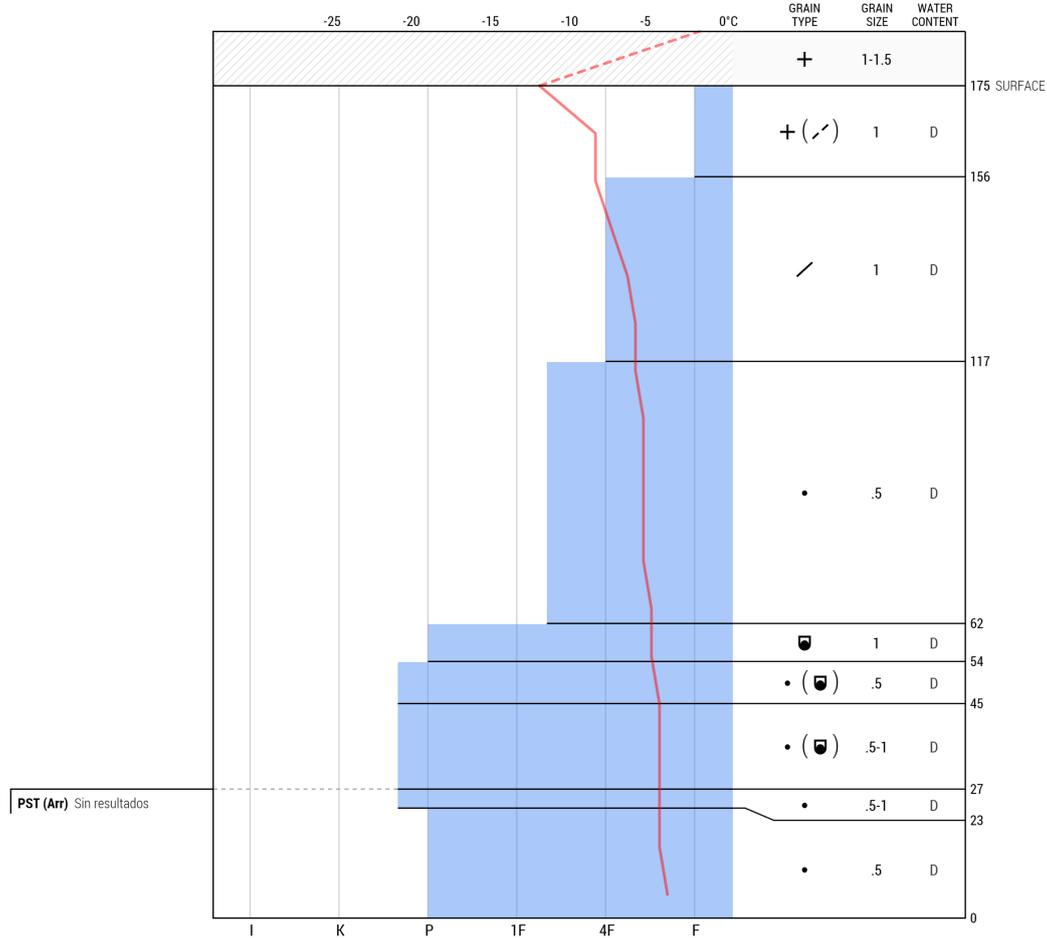
Snowpit depth: 175 cm

Lat/Lng: -33.0752710, -70.2696700

Observer: Aike Parvex Pichaida

Snowpack depth: 291 cm

Elevation: 3,550 m	Wind: Calm, 315° NW	Manto en su mayoría estables con buen asentamiento.
Slope: 35°	Blowing snow: Moderate, 135° SE	
Aspect: 161° SSE	Precipitation: No Precipitation	
Air temp.: -2.0°C	Foot Pen. (PF): 50 cm	
Sky: ○ Clear	Ski Pen. (PS): --	

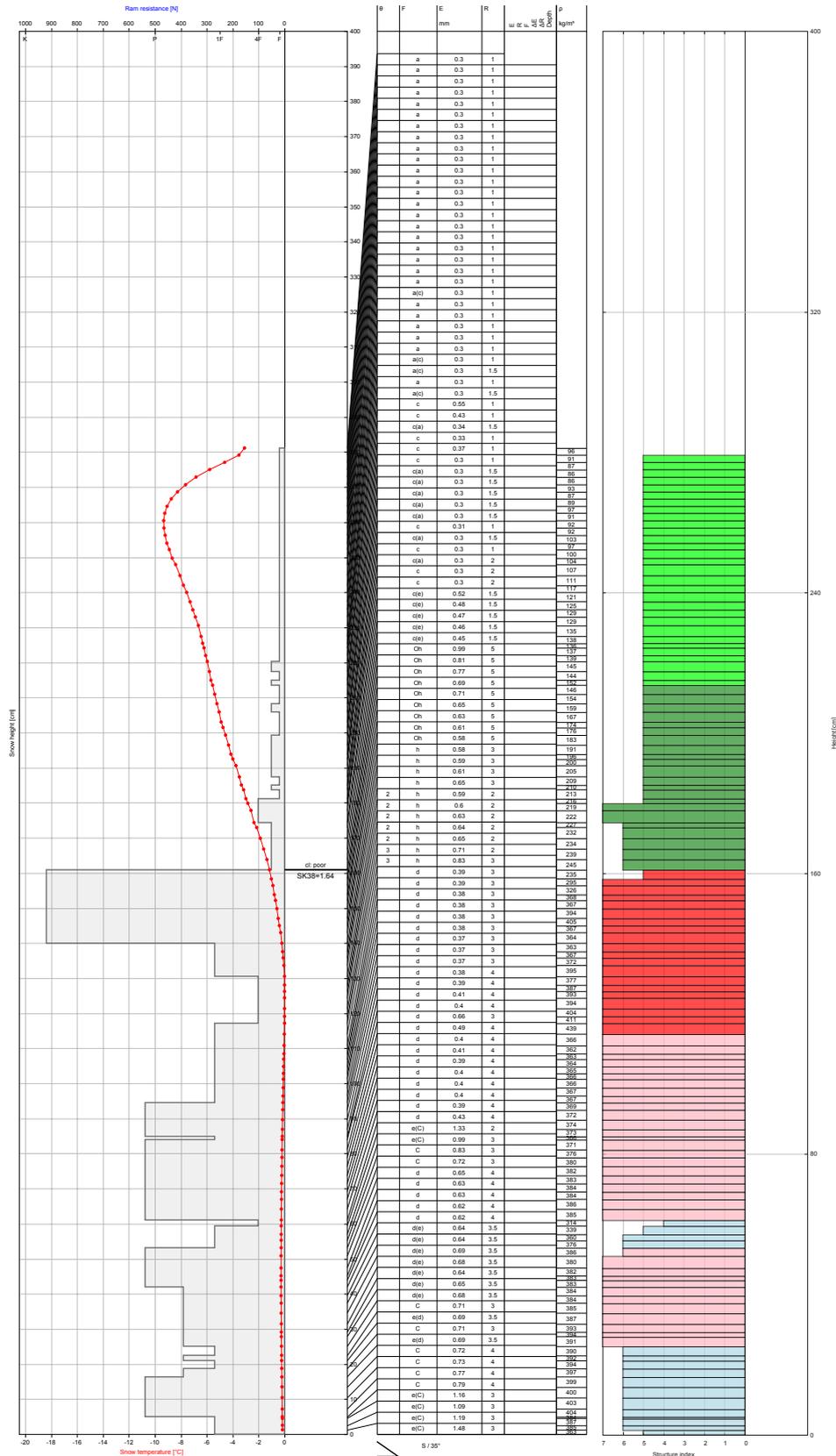


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Figure S8: Snow pit performed by the winter operation crew on the 11-09-2015 in the vicinity of the AWS. Note that the observed profile was not done over the full depth, and that the total snow depth exceeds the profile depth.

Location: Laguna_Angela
 Observer: Altitude: 3550 m Air temp.:
 Profile: Exposition: S / Slope: 30° Cloudiness:
 Coordinates: -33.07824 / -70.27279 Wind:
 Snow water equivalent: Avg. density: 280 kg/m³ Avg. ram resistance:
 Hasty Pft. No.
 Weather / Precipitation:
 Remarks:



Ort: Laguna_Angela	Höhe ü. M.: 3550 m	Datum / Zeit: 2016-05-26 11:00
Beobachter:	Exposition: S / Neigung: 35°	Lufttemp.:
Profilnr.:	Koordinaten: -33.07824 / -70.27279	Bewölkung:
Gesamtwasserwert:	Mittl. Dichte: 295 kg/m³	Wind:
Hasty Pit: Nein		Mittl. Rammwiderstand:
Wetter / Niederschlag:		
Bemerkungen:		

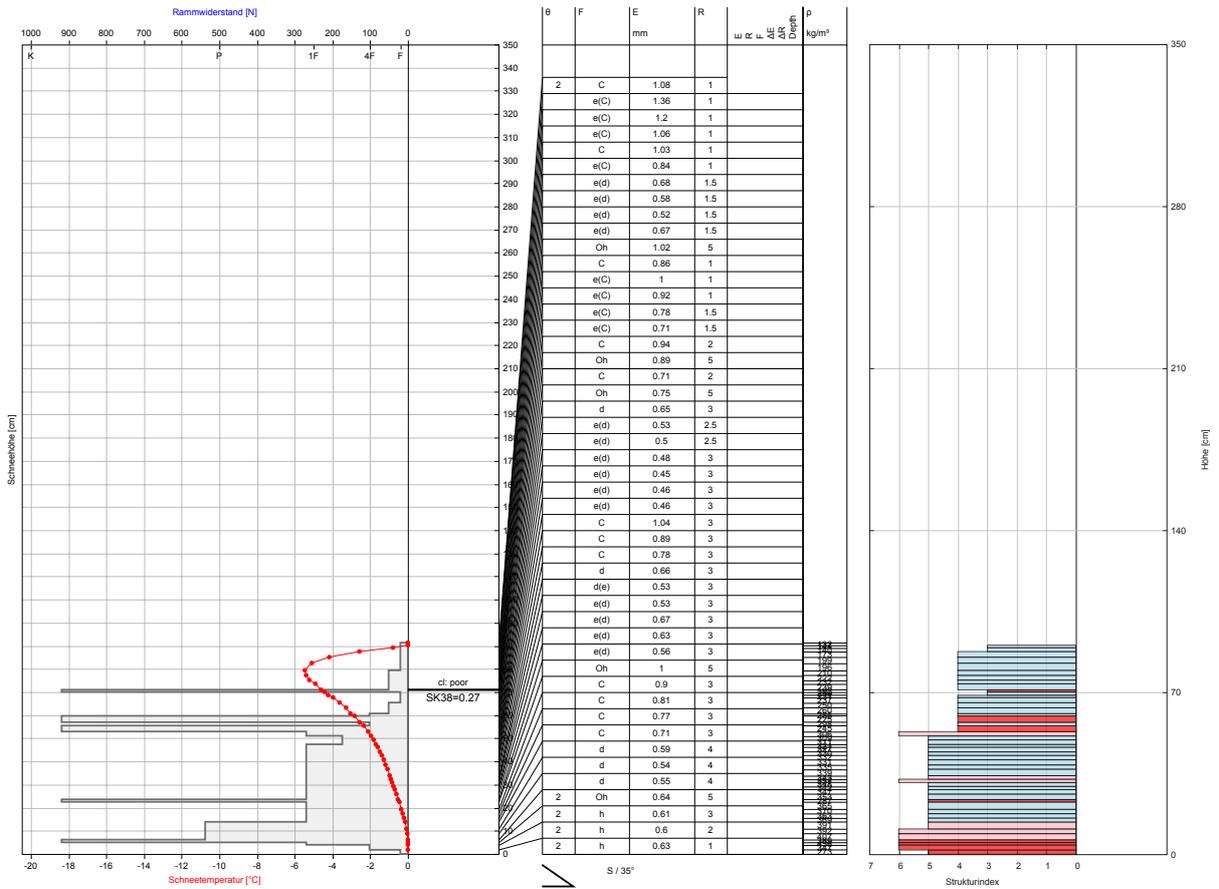


Figure S11: SNOWPACK simulation performed using the virtual slope concept matching with the exposition of the hand profile in Fig. S10.