USING PORTABLE CORE DRILLING EQUIPMENT FOR THE STUDY OF RESURGE DEPOSITS AT THE PROPOSED VAKKEJOKK IMPACT SITE IN THE SCANDINAVIAN ARCTIC. J. Ormö[1], P. Minde[2], A.T. Nielsen[3], and C. Alwmark[4], [1]Centro de Astrobiologia (INTA-CSIC), Torrejon de Ardoz, Spain (ormoj@cab.inta-csic.es), [2]Dept. of Geological Sciences, Stockholm University, Sweden, [3] Dept. of Geosciences and Natural Resource Management, University of Copenhagen, Denmark, [4]Department of Geology, Lund University, Sweden

Introduction: The ≤27m thick Vakkejokk Breccia (VB) is semi-continuously exposed along the steep southern slope of Mount Váivvánčohkka north of Lake Torneträsk, northernmost Sweden, for a stretch of about 7km [1, 2]. Recent studies suggest the breccia to be impact related [3, 4]. The VB is intercalated in a shallow marine succession that was deposited when the peneplanized Precambrian basement was transgressed in the Early Cambrian. The sedimentary strata hosting the breccia form an authochthonous sequence that has been protected against erosion by overriding Caledonian nappes. Later uplift and erosion (notably glacial) have exposed the breccia. The authochthonous sequence begins with a transgressive conglomerate and a sandstone unit, the ~5m thick Lower Sandstone member. It is in turn overlain by siltstone, intercalated by numerous thin sandstone beds, the Lower Siltstone member (LSM). It is this unit that in the study area is partially replaced by the VB. In its unaffected parts the LSM is about 17-20m thick. The LSM, and in the study area the VB, are in turn abruptly overlain by the 15-25m thick Red and Green Siltstone member. All together this suggests a marine target setting for the inferred impact. Based on sequence stratigraphical reasoning the VB can be correlated to an absolute age of ≈520Ma [4].

After field campaigns in the summers of 2012, 2014, and 2015 Ormö et al. [4] were able to divide the breccia unit into four subunits, document shock evidence, and propose a model for the formation of the VB as a proximal ejecta layer. However, the crater has not yet been located. Ormö et al. [4] estimate its diameter to be 2-3km, and suggest that it is most likely located below the overthrusts of Mount Váivvánčohkka.

The lower part of the VB is characterized by highly disturbed blocks of the Lower Sandstone member and LSM intermingled with clasts deriving from the Precambrian basement, some of decameter dimensions. This sub-unit is referred to as the ‘lower polymict breccia’ (LPB), and is suggested to have formed by ballistic bombardment of the sedimentary strata surrounding the crater by crystalline basement ejecta. Overlying the LPB with a usually rapid transition is a polymict breccia, most commonly meter-thick and often graded. It occurs as both matrix-supported (most commonly a greenish, silty matrix), and as clast-supported, often in the upper half. Grading is obvious in the clast-supported variety, but occurs in the matrix-supported part as well, and led Ormö et al. [4] to call this subunit ‘graded polymict breccia’ (GPB). It is at some sites overlain by an up to a few dm thick bed of quartzitic sand (‘top sandstone’, TS). It is from the GPB and TS that grains of shocked quartz have been retrieved [4]. These sub-units are suggested to have formed by marine resurge carrying ejecta and rip-up material back towards the crater. Locally the TS seems to be replaced by a mostly matrix-supported conglomerate that is suggested to originate from later slumps associated with degradation of the crater rim.

Aim of study: It is known from marine-target craters such as Lockne, Tvären, and Chesapeake Bay that the resurge deposits are essential for disentangling the cratering process and estimating target water depth [e.g., 5, 6]. Nevertheless, in the usually weathered exposures of the VB it is not always easy to see the sedimentological relations between the TS, GPB, and underlying LPB, notably whether there are gradual transitions, or erosive boundaries. This is more readily investigated in fresh drill-cores. Thus, the study area was revisited in 2016 by J. Ormö and student P. Minde in an attempt to retrieve short cores through the contact between the TS and the GPB, and if possible also between the GPB and the LPB. Given the remote location of the study area, drilling must be performed with equipment that can be transported by helicopter as well as carried through rough terrain. The cores need to be a few cm in diameter to allow sedimentological studies and search for shocked minerals.

Methodology: Based on the previous mapping by Ormö et al. [4] three drill sites were selected where the TS overlies the GPB. The first drilling, Vakk-CH1, was made at locality Vakk19 (N68˚ 22.259’, E19˚ 14.132’). About 100m west of Vakk19 the other two drill sites, Vakk-CH2A&B, were made only 1.5m apart at locality Vakk20 (N68˚ 22.269’, E19˚ 14.013’) and, thus, they share the same GPS coordinate. Positioning was done with a handheld Garmin GPSMAP60CS, and the coordinates are in Degrees Minutes with the WGS84 map datum. The drilling equipment was a HILTI DD-200 powered by two portable generators, and with a 52mm drill crown and extension rods, all kindly provided by the company Hyreslandslaget in

Kiruna. Such equipment is most commonly used by construction companies to drill holes through concrete walls and it is not specifically designed for geological core drilling. Nevertheless, the equipment allows the penetration of rocks, and it generates in our case cores approximately 45cm long and with a diameter of 45mm. The extension rods permit continued coring to a depth mainly limited by the pressure of the cooling water (in our case self-pressure from a water jar 1.5m above ground level) and the practical retrieval of the core pieces from the hole. As the relatively basic equipment has no core catcher each core needs to be retrieved from the hole in some other way. We used a 3m long PVC tube of the same dimension as the core. In the end of the tube we had cut some slits that helped the tube to pass over and hold on to the core pieces.

The obtained cores were transported to Centro de Astrobiologia in Spain where they were cut into halves. One half was polished to allow detailed logging. A first granulometric log was made by applying the line-logging technique given by [5, 6] allthough our short cores did not allow the statistical treatment of clast granulometry per meter as needed for reliable results. Thus, our absolute values can only be regarded as indicative. The polished half was also photographed in high resolution so the photos can be used for a currently ongoing statistically more relevant granulometric logging with the software JMicroVision.

Preliminary results and discussion: At the time of writing we can report that Vakk-CH1 produced a 135cm long core with only 0.7% core loss. The upper 40cm is a normally graded arenite with a rapid transition from medium to coarse sand at 16cm depth. The general color is light green-gray, likely due to a matrix of the commonly greenish LSM, whereas sand grains appear mostly granitic. At 40-60cm there is a transition zone with downwards increased clast size, with up to 4cm granitic clasts in a green silty matrix. The breccia becomes increasingly matrix-supported downwards. From 60 cm and downwards the breccia is matrix-supported with only sporadic crystalline clasts (< 2 cm diameter). At 70cm the silty matrix changes color to become dark brown-red with greenish flames.

A 30cm high morphological ledge at the outcrop was taken to indicate an erosive contact between the TS and the underlying GPB [4]. However, the transition is gradual in the core. The continuation downwards into the underlying LPB seems to be transitional as well, mainly manifested by a drop in the crystalline clast frequency.Vakk-CH2A produced an 85cm long core with 1.2% core loss, and Vakk-CH2B a 135cm long core with no loss. The CH2A&B cores confirm the transition from a muddy matrix-supported lower part with a gradual transition into a clast-supported, generally normally graded upper part of the GPB. However, at this location the upper arenite (TS) is coarser than at Vakk19, sometimes with repeated beds and even in parts with reverse grading. Notable are also up to 4cm (even larger in outcrop) large siltstone clasts that float in the mainly granitic sandstone. All in all, the GPB and TS are very similar to the resurge deposits described from the Lockne crater [e.g., 5, 7] especially at locations just outside the crater rim.

In addition to providing valuable information on the resurge deposits, the study also shows the usefulness of portable core drilling equipment for remote locations. Here, the system was optimized to reach a depth of about 1.5m, but it should be possible to perform successful coring to a depth of about 3m, maybe even more, with this equipment if complemented with more extension rods, and a more efficient water pump and core retrieval system.

Drilling of Vakk-CH2B in the summer of 2016.

References: [1] Kulling O. (1964) *Sveriges Geologiska Undersökning, Ba 19,* 1-166 (In Swedish). [2] Thelander T. (1982) *Sveriges Geologiska Undersökning, C 789,* 1-41. [3] Nielsen A. T. and Schovsbo N. H. (2011) *Earth Sci. Rev., 107,* 207-310. [4] Ormö J. et al. (In press) *Meteoritics & Planet. Sci..* [5] Ormö et al. (2007) *Meteoritics & Planet. Sci., 42,* 1929-1943. [6] Ormö et al. (2009) *Geol. Soc. Am. Spec. Pap., 458,* 617-632. [7] Lindström et al. (2005) *Impact Studies.* Springer-Verlag, Berlin Heidelberg. 357-388.

Acknowledgements: The work by J. Ormö was partially supported by grants ESP2014-59789-P, and ESP2015-65712-C5-1-R from the Spanish Ministry of Economy and competitiveness and Fondo Europeo de Desarrollo Regional.