A Possible Distal Exposure of the Vakkejokk Impact Ejecta Layer Suggesting Emplacement as Fluidized Ejecta.

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Abstract: At Roggenjarga peninsula in Lake Torneträsk, north Sweden there is a breccia exposure, possibly linked to the ejecta layer from the nearby Vakkejokk impact structure that formed in a marine environment 520Ma (cf. Ormö et al. 2017; Alwmark et al. 2019). The breccia at Roggenjarga can be separated into an about 10m thick lower bed deposited of a traction flow deposit, which is abruptly overlain by a ~4m thick bed deposited from aquatic transport.

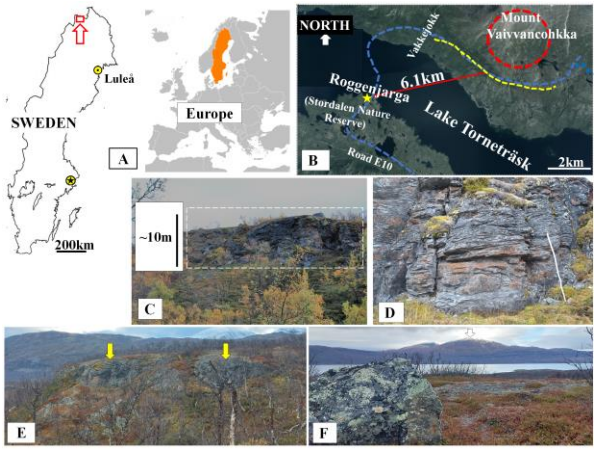

Fig.1: ***Location of the study area.*** *A: Sweden, in the northernmost Europe (the study area in the red rectangle). B: Locations and features mentioned in the text. The blue line shows the up to 170m thick early Cambrian shallow marine succession exposed at the eastern boarder of Scandes. To the East of the blue line is Precambrian basement and to the West of the blue line is the overthrust (Scandes) nappes. The yellow stippled line is marking the ~7km exposure of Vakkejokk Breccia (cf. Ormö et al. 2017). The red stippled circle indicates the by [5] inferred position of a possibly 3km wide impact (Vakkejokk) crater below Mount Vaivvancohkka. C: shows a photo of the Roggenjarga breccia exposure (photo facing South). D: shows a exposure of a dark fine grained sedimentary rock with soft sedimentary deformation structures located approximately 100m south of RB exposure (1,75m white pole for scale). Panel E: Photo facing South ~100m South from the top of the RB exposure, in the foreground are two dark sedimentary rock exposures with convolute bedding. Panel F: A photo facing North-East from top of the RB exposure with central part of Lake Torneträsk then the Mount Vaivvancohkka in the horizon (about 8 km away).*

Introduction: On the basis of field-observations I am reporting on an exposure of a breccia possibly related to the previously described Vakkejokk Breccia (Fig. 1). The Vakkejokk Breccia (VB) is a proximal, mainly ballistically emplaced ejecta layer [5]. In its uppermost parts there are beds of resurge deposits supporting the formation of the nearby impact crater in a shallow-marine (5-50m) target setting [5,6,7]. The here described new locality (68°22'2.2"N, 19°3'49.1"E; Fig.1B-E) is forming a hill on the Roggenjarga peninsula (Fig.1C) about 100m from the shore of Lake Torneträsk. According to an 120 years old report of the breccia exposure at Roggenjarga by Holmqvist, P.J. 1903 [1; p53] it can be described as follows -*translated from Swedish*- "At one place in the vicinity of the bottom conglomerate, at a small hill, occurs an outcrop of a broken brecciated rock whose nature reveals that it has an origin in a conglomerate or sandstone". For clarification, the bottom conglomerate is an by the Lower Cambrian transgression reworked saprolite on the crystalline basement, which in turn is overlain by the Torneträsk (siliclastic) Formation. The VB is intercalated in the lowermost part of the Torneträsk Formation [2,4,5]. This lowermost part of the formation consist of two members of an autochthonous ~25m thick early Cambrian shallow marine succession consisting of conglomerate, sand and siltstone. The succession is degraded and today seen as a thin veneer deposited along the eastern boarder of the Scandinavian Mountains at some places up to 170m thick and rests with depositional contact on the basement. The succession were deposited on the Baltoscandian peneplaned basement that was transgressed in Early Cambrian. The succession hosting the RB and the Vakkejokk Breccia [cf. 2,4,5] forms a part of a clastic sequence that has been sheltered against erosion by the from west derived overriding overthrust nappes of the Caledonian orogeny, but later uplift and erosion have exposed the succession [2-5]. The Roggenjarga breccia (RB) is located 6,1km to the SW of the thickest (~27 m) part of the VB (Fig.1B, 1F), which represents the ejecta layer from the Vakkejokk meteorite impact structure (possibly 3km diameter) [5,6]. Thus, a strong link between RB and the VB is inferred. My examination of the RB shows that it upholds the same stratigraphic position as the VB. The VB is intercalated in the lowermost part of the Torneträsk Formation [2,4,5]. The RB is here described (Fig.1C-E) and further compared with the VB on the north side of the Lake Torneträsk as well as compared with breccias at the Swedish marine-target Lockne impact crater (e.g., Lindström [cf.8]) and so-called rampart craters displaying fluidized ejecta [cf. 9], [cf. 10] and [cf. 11]. Further suggestion on to future research is reported.

Method: In the summer of 2016 I was spurred by the description of this breccia exposure in the work by Holmqvist [1] to conduct a field trip to the Roggenjarga peninsula to find the breccia exposure. In the autumn of 2022 a new field-trip was conducted to now observe, measure and also correlate the breccia outcrop with the local stratigraphy, with the objective to test it against the impact hypothesis suggested by its proximity to the Vakkejokk impact site.

Observations: At the northern slope of the hill there is an about 50m wide and 10m high natural breccia exposure (Fig.1C and Fig.2A). The top of the hill is flat and the northern hillside is steep to almost vertical. At the scarp (Fig.2B), the RB is overlain by light green cm-thick siltstone beds (Fig.2B-C). This layer of green siltstone forms a marker-horizon in the Torneträsk area [2-5] and overly the Vakkejokk Breccia [2-5]. About 3m below the top of the vertical scarp occurs a some few meters wide what reminds of clastic dyke (Fig.2D) of a grey noticeably gritty, non-layered, comparatively homogenous silty/sandstone (Fig.2E) bordering a ~5dm thick disrupted mudstone bed (Fig.2F). In the (what I call) clastic dyke there is a 2m wide round clast (Fig.2G) of a polymictic, matrix-supported breccia (i.e., breccia within breccia) reminding of the normal bottom reworked lithified saprolite in the Torneträsk area, that in turn contains ~10cm size, round, brownish, coarse grained granit-

ic clasts, as well as a 15cm size rusty clast of an unknown lithology. About 1m East of the dyke is a planar surface of glossy mudstone (unfortunately too steep to be closely examined) containing at least two dm-size coarse light grey granitic clasts a muddy matrix (Fig.2H) and a peculiar 2dm blemish (Fig.2I) the planar surface likely a result of faulting. In the lowermost part of the exposure, there is a sedimentary breccia with sandstone clasts (Fig.3) that are contorted and thrusted. The sedimentary breccia has a rapid transition (possibly with an erosive contact) into an overlying dark mud-rich breccia partly containing scattered sub-rounded clasts here and there (e.g., Fig.4). Three other exposures about 100m to the south of the RB exposure at the hill show a very fine grained dark rock (Fig.1D and Fig.1E) with scattered clasts. However, its stratigraphic position in relation to the Roggenjarga breccia is unknown due to lack of marker-horizons and faults that complicates a correlation. Nevertheless, the outcrops (Fig.1D; Fig1E) are about 3-5 meter high with soft-sedimentary deformation structures like convolute bedding and meter-scale slumping. At the upper dark sedimentary rock containing soft deformation structures (mentioned) and at one place there is a obviously single protruding 5dm clast of possibly crystalline rock (Fig.5) as well as a several dm size rocks that appears chalky.

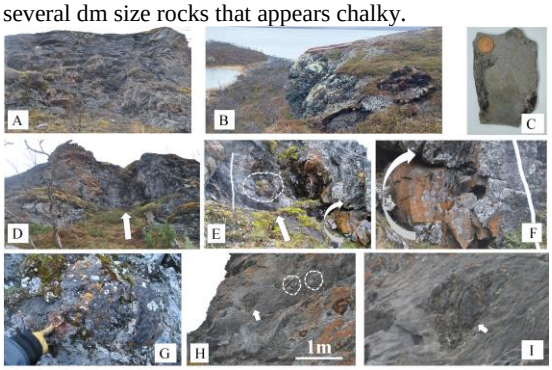

Fig.2: ***Megascopic observation of the exposed Roggenjarga breccia (RB) outcrop.*** *A: The central part of the ~50m wide RB exposure (view towards South). B: A view towards North-East from top of the hill where a scarp/cliff edge on top of the RB in the foreground. In the horizon is the foot of Mount Vaivvancohkka visible (also Fig.1F). A piece of the moss scraped off on the crest and under is in-situ green siltstone (a marker horizon in the area). C: A Green siltstone sample (Krona coin for scale) from exposure in Fig.2B. D: The Western part of the exposure. E: Part of the RB exposure with a putative clastic dyke and an overturned bed seen to the lower right (1,75m pole for scale). F: An upturned bed from Fig.2E, 1,75m pole for scale. G: An conglomerate clast in the clastic dyke(?) (a yellow glove for scale) located (see Fig.E) about 1m to the right of the pole. H: Matrix supported part of RB with flow structures and two, easy seen, grey granitic and what seems be a intraformational clast (see I).*

Fig.3: *Brittle deformed lower RB breccia (1,75m pole for scale).*

Fig.4: *Dark bedded sedimentary rock (~3m high exposure).*

Fig.5: *Ductile deformed sedimentary rock. A crystalline clast see the yellow arrow (1,75m white pole for scale).*

Discussion and conclusion: The ~10m RB exposure at the Roggenjarga locality shows brittle deformation in the lower part (~6m) nearest to the basement and ductile deformation in the upper part. The RB consist of at least two subunits; a lower brittle breccia (~6m) overlain, with erosive contact by a ductile breccia (~4m), likely deposited as a mud or debris flow. The lower unit likely formed by earthquake and ballistic bombardment during the contact and excavation stages and followed by a fluidized-ejecta mudflow. The RB shows in its lower part some similarities to the Ynntjärnen Breccia (Lockne impact crater in Jämtland, Sweden), which is a mainly autochthonous, sedimentary breccia formed by bombardment of both solid (including crystalline basement rock) and water ejecta, as well as seismic shaking by the cratering and collapse of the water cavity [cf. 8;Fig8]. The upper parts of the RB show evidence for fluidized emplacement of the ejecta, thus possibly indicating the Vakkejokk structure to be a rampart impact crater (cf. [9; Fig3,Fig9], [10; Fig4,Fig11],[11; Fig1,Fig10]). The faults at the Roggenjarga breccia locality exposure remain unexplained but [12] describe and discuss what they call the Torneträsk Mega Lineament orogen transverse Proterozoic fault zones in the basement. There may also be effects of Caledonian tectonics, or if the faults are a primary feature, they may be generated by fluidized ejecta stacking of shear planes [cf. 10;Fig11]. As a side note the RB hill and surrounding area is old bottom and shore of the Glacial Lake Torneträsk, today dry land.

All the structurgeological phenomena displayed at the RB exposure is subject for further study and this contribution is to be seen as preliminary. So far, no lithologies of the kind described by [7] at the VB shown to contain quartz grains with planar deformation features diagnostic for impact-related shock metamorphism of quartz have yet been encountered at the Roggenjarga breccia locality. However, this will be investigated in a forthcoming study.

References: [1] Holmquist, P. J. (1903) *GFF 25.1*, 27-75 [2] Nielsen, A. T., & Schovsbo, N. (2011) *Earth-Scie. Rev., 107*. [3] Kulling, O. (1964), *Swe.G:U. Ba no:19*. [4] Thelander (1982), *Swe.G:U. C no:789*. [5] Ormö, J., et al (2017). *Met. & Plan. Sci. 52(4),* 623-645. [6] Alwmark, C., et al (2019). *Met. & Plan. Sci. 54(3),* 609-620 [7] Ormö, J., et al (2019). *Met. Plan. Sci. 54:* 1246-1261. [8] Lindström, M., et al (2008). *The G.S.A. 437*. 17-37. [9] Baratoux, D. et al., (2019). *Met. & Plan. Sci. 54*(10), 2541-2556. [10] Kenkmann, T., & Schönian, F. (2006). *Met. & Plan. Sci. 41.10* 1587-1603. [11] Niu, She., et al (2022). *Jour. of Geophys. Resea. Plan, 127*(3). [12] Romer, R. et al (1994). *Schwei. Min. & Petro. Mit. 74* (3), 469-481.