Solid Earth Discuss., 6, C288–C293, 2014
www.solid-earth-discuss.net/6/C288/2014/

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Discussions
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Interactive comment on "Maskevarri Ráhppát in Finnmark, North Norway – is it an earthquake induced landform complex?" *by* R. Sutinen et al.

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Received and published: 16 April 2014

C. Pascal (Editor) SED 6, C99-C99, 2014: Maskevarri Ráhppát in Finnmark, North Norway âŤĂ is it an earthquake induced landform complex? by R. Sutinen et al. In the following, replies to referees:

Response to Referee Christian Brandes; As suggested by the referee, Results and Discussion are separated in the revised MS. Also scale bars have been added into Figs. 2 and 4B-4D. More literature on postglacial faults (Brandes et al., 2012 Quat. Sci. Rev. 38, 49-62: Brandes and Winsemann, 2013 International Journal of Earth Sciences; Jakobsson et al., 2014 Geology; Lund, 2005 SKBF/KBS Technical Report; Smith at al., 2014 International Journal of Earth Sciences) and push moraines (Bennett et al., 2004 Sedimentary Geology 192, 269-292; Boulton et al., 1999 Quat. Sci. Rev.

18, 339-371; Evans et al. 2014 Geomorphology 204, 86-113, Johnson et al., 2013 Proc. Geol. Assoc. 124, 738-752) is used in the revised MS. 1. We agree, that cross-sections would be informative. However, airborne LiDAR data are not available in the study area in Finnmark (cf. Sutinen et al., 2014. Global Planet. Change 115, 24-32). Unfortunately, sedimentary logs are not available. In addition, due to high amount of surface boulders, ground penetrating radar data would be full of hyperbolas effectively masking the inner structures (see e.g. Utting et al. 2009 Boreas 38, 471-481).

2. We have previously shown that the initial phase of the esker formation includes full-pipe flow as the dominant phase (Sutinen 1985, Striae 22, 21-25). Even though there are no exposures available in the remote Maskevarri Ráhppát study site, the anastomosing esker pattern is rather similar as described in Finnish Lapland (Sutinen et al. 2014 Global Planet. Change 115, 24-32). Glacial lake outburst floods are able to (subglacially) create anastomosing esker networks (Sutinen et al. 2009 Global Planet. Change 69, 16-28) and large-scale glaciofluvial corridors (Rampton, 2000 Can. J. Earth Sci. 37, 81-93; Utting et al. 2009 Boreas 38, 471-481), yet the morphological position of the Maskevarri Ráhppát does not fit into the concept of glacial lake outburst. However, the sinusoidality of the esker (esker-like) ridges strongly emphasizes the presence of subglacial water and suggests the origin to be associated with full-pipe flow mechanisms, not time-transgressive evolution at the ice margin (Banerjee and McDonald 1975 Spec. Publ. Soc. Econ. Paleont. Miner., Tulsa 23, 132-154; Clark and Walder 1994 Geol. Soc. Am. Bull. 106, 304-314). Possible source of water may be attributed to lithospheric hydromechanics (Neuzil 2012 Geofluids 12, 22-37) and the triggering meachanism may have been subglacial earthquake (or glacial earthquake; Ekström et al., 2006 Science 311, 1756-1758; Nettles and Ekström, 2010 Annu. Rev. Earth Planet. Sci. 38, 467-491; West et al., 2010 Geology 38, 319-322). A new paragraph on the esker sedimentation/network has been added into the discussion of the revised MS.

3. In the revised MS, two new paragraphs (w. citations) has been added to discuss on

SED
6, C288–C293, 2014

the periglacial features. We have argued that pingos and palsas are typically located on flat terrains (Jones et al., 2012 Geomorphology 138, 1-14; Seppälä, 2011 Quat. Res. 75, 366-370; Tabuchi and Seppälä, 2012, Polar Science 6, 237-251; Wetterich et al., 2012 Quat. Sci.Rev. 39, 26-44), not on the slope of the fell. Also, pingos tend to be formed of soft-sediments, palsas are ice-cored peat hummocks. We are aware that in some cases thermokarst features can develop on push moraines, such as those in Yukon, Canada (Lenz et al. 2013 Palaeogeogr. Palaeoclim. Palaeoecol 381-382, 15-25). Soft-sediments are absent in the Maskevarri Ráhppát. The lake/pond pattern in Maskevarri is different from talik lakes in the arctic (Grunblatt and Atwood, 2014. Int. J. Appl. Earth Obs. and Geoinf. 27, 63-69; Morgestern et al. 2013 Geomorphology 201, 262-379). One of the arguments is that no evidence has been found to indicate that permafrost persisted through the Holocene in the Maskevarri area (Lilleøren et al., 2012, Global Planet. Change 92-93, 209-223). Although mountain permafrost is commonly found in Norway (Lilleøren et al., 2012, Global Planet. Change 92-93, 209-223) and many of the mountain rockslide deformations in northern Norway are permafrost-controlled (Blikra and Christiansen, 2014 Geomorphology 208, 34-49), the morphology of the rockslide talus deformations is, however, dissimilar to bouldery esker ridges and mounds in Maskevarri Ráhppát.

4. New references on push moraines are added into the revised MS (Bennett et al. 2004 Geology 172, 269-292; Boulton et al. 1999 Qaut. Sci. Rev. 18, 339-371; Evans et al 2014 Geomorphology 204, 86-113; Johnson et al. 2013 Proc. Geol. Assoc. 124, 738-752). We consider morphology of the anastomosing eskers and electrical sedimentary in these ridges to argue against the push moraine genesis in Masskevarri.

5. As far as we know, no similar features have been described attributed to recent earthquakes. Most resent features are paleolandslides (as far the best estimate is 5055 cal. yr BP; Sutinen et al. 2014, Int. J. Appl. Earth Obs. and Geoinf. 27, 91-99). The earthquakes (or glacial earthquakes; see Nettles & Ekström, Ann. Rev. Earth Planet. Sci. 2010) beneath the modern glaciers may generate similar features.

6. We have cited Sutinen et al. 2014 (Global Planet. Change 115, 24-32), where we discussed esker formation via pressurized full-pipe flows. Furthermore, some morainic landforms seem to have built up through squeezing processes in the subglacial crevasses, presumably attributed to seismic event(s). The old cartoon as presented by Hoppe (1952 Geografiska Annaler 34, 1-72) for the squeezing mechanism is still valid.

7. In the discussion we have cited Lagerbäck and Sundh (2008 Sver. Geol. Unders. C386) as well as Brandes and Winsemann (2013 Int. J. Earth Sci.) to indicate that seismites are of great importance in judging neotectonic origin of the landforms. However, seismites are best seen on soft-sediments, not necessarily in the bouldery (esker-like) ridges of the Maskevarri Ráhppát. In addition, the site is logistically extremely difficult for excavator.

Response to Referee Michael Sebrier; (1) Rather than being negative, we raised an alternative option for the genesis of the Maskevarri Ráhppát. This was because it has been previously classified as push moraine of the Tromsø-Lyngen sub-stage in Finnmark (Sollid et al., 1973), marginal moraine by the Nordkalott Project (1986), and as ablation hummocky moraine in the Quaternary map by Olsen et al. (1996). Push moraine involves active ice movement whereas ablation moraine is developed in stagnant ice conditions and often from supraglacial debris. On the basis of morphology (surface roughness, anastomosing esker pattern, absence of surface streamlining) and sedimentary-anisotropy (parallel-to-ridge crests of the sinusoidal eskers) we argue that other mechanism than ice-frontal pushing or stagnant ablation is needed to explain the Maskevarri Ráhppát.

(2) Due to lithospheric plate stresses and glacio-isostatic rebound postglacial fault deformations are common features in northern Fennoscandia. The faults most commonly are trending NE-SW, yet the lineaments and faults in Finnmark are trending WNW-ESE (Roberts et al. 1997 Tectonophysics 270, 1-13; Ottesen et al. 2008 Quat. Sci. Rev. 27, 922-940; Tanner 1930 Bull. Geol. Finl.). Even though the latter orientation is

also found at Maskevarri, reactivation of the old structures should be seen indirectly as landslides (Sutinen et al. 2009 Global Planet. Change 69, 16-28), Pulju moraines and anastomosing esker systems (Sutinen et al. 2014 Global Planet. Change 115, 24-32) and/or seismites (Lagerbäck and Sundh 2008 Sver. Geol. Unders. C386; Brandes and Winsemann (2013 Int. J. Earth Sci.). The only evidence suggesting indirectly seismic event(s) was the anastomosing esker system on the slope of the Maskevarri fell. Since we don't have diamond drillings to verify the PGFs (cf. Sutinen et al. 2014 Int. J. Appl. Earth Obs. and Geoinf. 27, 91-99) we have replaced the term three terraces by three elevations, the word escarpment has also been removed. It is our conjecture that earthquake(s) occurred subglacially in a similar manner as the Kultima fault in Finnish Lapland (Sutinen et al. 2014 Global Planet. Change 115, 24-32).

(3) In the revised MS, two new paragraphs (w. citations) has been added to discuss on the periglacial features. We have argued that pingos and palsas are typically located on flat terrains (Jones et al., 2012 Geomorphology 138, 1-14; Seppälä, 2011 Quat. Res. 75, 366-370; Tabuchi and Seppälä, 2012, Polar Science 6, 237-251; Wetterich et al., 2012 Quat. Sci.Rev. 39, 26-44), not on the slope of the fell. Also, pingos tend to be formed of soft-sediments, palsas are ice-cored peat hummocks. We are aware that in some cases thermokarst features can develop on push moraines, such as those in Yukon, Canada (Lenz et al. 2013 Palaeogeogr. Palaeoclim. Palaeoecol 381-382, 15-25). Soft-sediments are absent in the Maskevarri Ráhppát. The lake/pond pattern in Maskevarri is different from talik lakes in the arctic (Grunblatt and Atwood, 2014. Int. J. Appl. Earth Obs. and Geoinf. 27, 63-69; Morgestern et al. 2013 Geomorphology 201, 262-379). One of the arguments is that no evidence has been found to indicate that permafrost persisted through the Holocene in the Maskevarri area (Lilleøren et al., 2012, Global Planet. Change 92-93, 209-223). Although mountain permafrost is commonly found in Norway (Lilleøren et al., 2012, Global Planet. Change 92-93, 209-223) and many of the mountain rockslide deformations in northern Norway are permafrost-controlled (Blikra and Christiansen, 2014 Geomorphology 208, 34-49), the morphology of the rockslide talus deformations is, however, dissimilar to bouldery esker

ridges and mounds in Maskevarri Ráhppát.

(4) Sinusoidality of the esker (esker-like) ridges strongly emphasizes the presence of subglacial water and suggests the origin to be associated with full-pipe flow mechanisms, not time-transgressive evolution at the ice margin (Banerjee and McDonald 1975 Spec. Publ. Soc. Econ. Paleont. Miner., Tulsa 23, 132-154; Clark and Walder 1994 Geol. Soc. Am. Bull. 106, 304-314). Possible source of water may be attributed to lithospheric hydromechanics (Neuzil 2012 Geofluids 12, 22-37) and the triggering meachanism may have been subglacial earthquake (or glacial earthquake; Ekström et al., 2006 Science 311, 1756-1758; Nettles and Ekström, 2010 Annu. Rev. Earth Planet. Sci. 38, 467-491; West et al., 2010 Geology 38, 319-322). A new paragraph on the esker sedimentation/network has been added into the discussion of the revised MS.

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