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Rate of Moment Accumulation on the Húsavík-Flatey Fault from GPS

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Key information for assessing the earthquake hazard in North Iceland is to know how large and how frequent major earthquakes on the Húsavík-Flatey Fault (HFF) likely are. Historical accounts provide some information, but the location and size of the earthquakes in 1872, 1838 and 1755 on the HFF is inaccurate (*Thorgeirsson,* 2011). Historical accounts from before 1700 are incomplete and provide limited information. Therefore, it is important to estimate how fast moment is currently accumulating on the fault and how the transform motion in the Tjörnes Fracture Zone is divided between the two parallel transform structures, the HFF in the south and the Grímsey Oblique Rift (GOR) to the north.

To answer these questions, the North Iceland GPS network was installed in 1995 around the HFF and it was remeasured and improved several times during the following two decades (*Jouanne et al.,* 1999; 2006; *Metzger et al.* 2013). The last full occupations of the network were in 2007, 2010, and 2013. In addition, ten continuous GPS stations (CGPS) were installed in North Iceland in 2006-7 (*Metzger et al.,* 2011) and added to the three CGPS stations that had been in operation since 2000-2002 in Akureyri (AKUR), Árholt on Tjörnes (ARHO) and Raufarhöfn (RHOF). Several more CGPS stations have been added in North Iceland since 2007, two in Húsavík (SJUK and BAUG), in Eyjafjörður (HELC), in Theistareykir (THRC), and three stations near Lake Mývatn and Krafla. The NICE network now consists of 18 continuous GPS stations and over 60 survey sites (Fig. 1). The full campaign GPS network will be measured again in August 2016.

To determine the moment accumulation rate on the HFF we use elastic back-slip modelling of the observed inter-seismic deformation. Our current best knowledge of these parameters is based on measurements up to 2010 and reported in *Metzger and Jónsson* (2014). After testing a number of models, a few different modelling assumptions, and both GPS and InSAR data, the results indicate that the slip rate of the HFF is 6-9 mm/year with a locking depth of 6-10 km. These rangers of model parameters come from different modelling setups and by using different data, while the statistical error of the modelling parameters was usually significantly smaller for each modelling setup. Together, the modelling results indicate that about 1/3 or more of the transform motion in the Tjörnes Fracture Zone is focused on the HFF, with the rest on the GOR. This means that the moment accumulated on the fault since the last major earthquake in 1872 is equivalent to a magnitude 6.8-7.0 earthquake (*Metzger and Jónsson,* 2014).

While the results indicate that significant moment is currently stored in the HFF system, it is important to look into the assumptions on which these numbers are based. The model simplifies the earth as an elastic halfspace and does not take into account variations of inter-seismic strain accumulation during the earthquake cycle nor include possible influence from major geological events, such as the Krafla rifting episode. Among other assumptions and simplifications are:

- In our modelling and moment accumulation calculation the locking depth is assumed to be uniform along the entire HFF. The GPS data primarily constrain the locking depth in the east, near the volcanic zone, where thermal gradients are high. The locking depth along the central and western sections of the HFF is likely higher due to lower thermal gradients (*Flóvenz and Sæmundsson,* 1993). This appears to be supported by depth of earthquakes in the west. An increasing locking depth towards the west would tend to increase the moment accumulation rate on the HFF by up to 50% if the locking depth in the west is twice that found in the east.
- We assume all moment was released in the last major events in 1872 and that the accumulation has been steady since then. The accumulation appears to have been steady during the past 20 years at least. However, the Krafla rifting episode caused major stress changes all over North Iceland. The inferred stress changes put the eastern half of the HFF under compression, shutting off its seismicity (*Maccaferri et al.,* 2013). While the shear-stress change on the HFF by the Krafla episode is small in comparison, this would tend to delay next major earthquakes, but also possibly lead to larger moment release once they occur.
- Energetic seismic swarms have occurred on the western third of the HFF during the past 20 years. Recent results indicate that significant, possibly all of the accumulated moment on that part of the fault has been released in these swarms (*Rivalta et al.,* 2016). The swarms show migration with time and are likely due to propagating slow slip on the fault system. Data of seismic swarms north of Iceland before 1995 are not accurate, but it is possible that swarms have been releasing large part of the moment on the western third of the HFF before 1995 as well. The best case scenario would be that all accumulated moment of the western third of the fault is released in swarms, which would lower the overall moment accumulated since 1872 by a third, or even more if the locking depth in the west is larger than in the east.

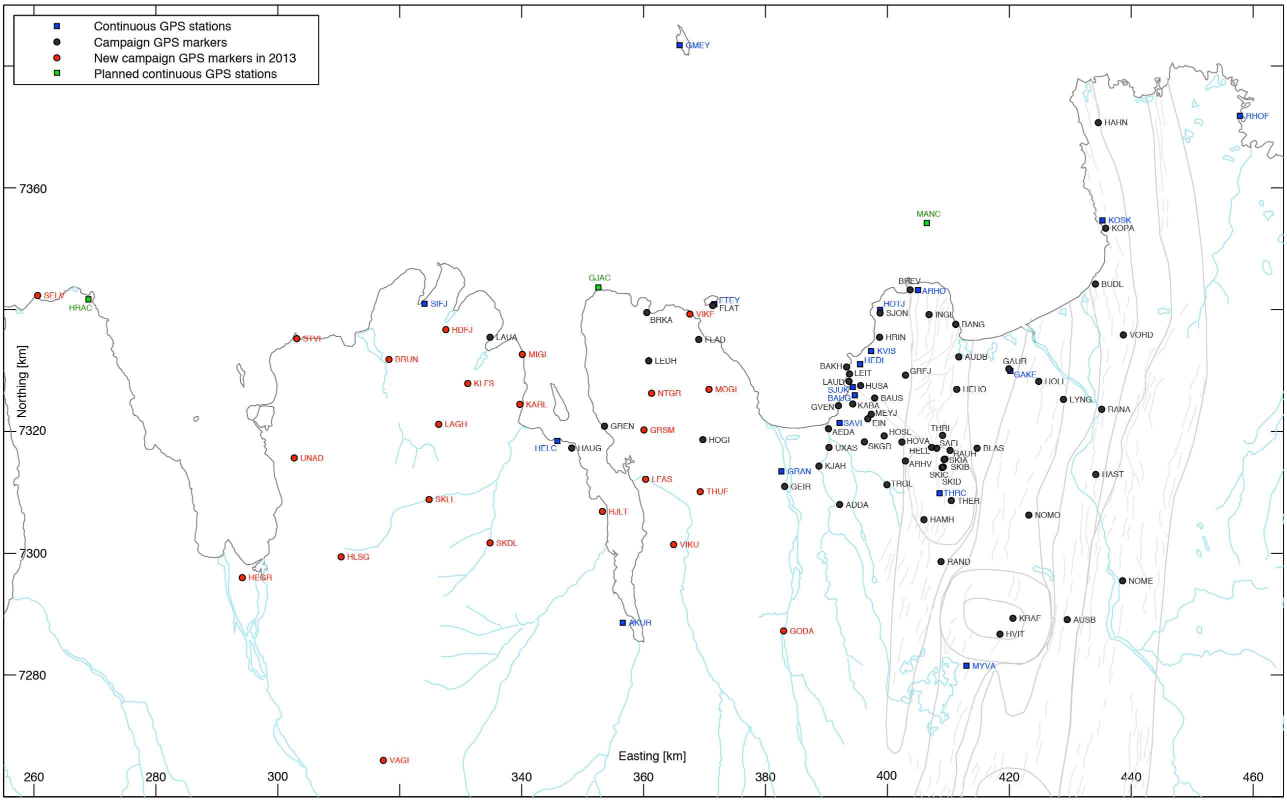

Figure 1. The current continuous and campaign GPS network in North Iceland after expansion of the network to the west in 2013 and after addition of a few CGPS stations.

Many questions remain unanswered about the rate of moment accumulation on faults in North Iceland. The structure of the GOR is significantly different than the HFF and moment release in the GOR does not occur on a single fault, but probably on multiple parallel north-south striking faults. Deformation and earthquake occurrence between and away from the HFF and GOR are significant, manifested by the occurrence of the large earthquakes in 1910 (likely between HFF and GOR), 1934 (Dalvík), and 1963 (north of Skagafjörður). Some distributed deformation seems to be occurring on the Tröllaskagi peninsula, as indicated by incoherent motion of the CGPS sites in Akureyri and Siglufjörður. For this reason, we expanded the campaign GPS network in 2013 to the west to better cover the Tröllaskagi peninsula and Skagafjörður (Fig. 1). In addition, we plan to add CGPS stations on the north coast west of Skagafjörður and on Gjögurtá, as well as on Mánáreyjar islands.

In conclusion, the GPS data and modelling to date suggest that about a third of the transform motion in the Tjörnes Fracture Zone is focused on the HFF with the other two thirds on the GOR. The results also indicate that the accumulated moment on the HFF since the last earthquake in 1872 is equivalent to a magnitude 6.8-7.0 earthquake, although many uncertainties remain. The GPS campaign in August 2016 and other future measurements in North Iceland will help reducing these uncertainties and help constraining further the rate of moment accumulation on the HFF.

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