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Subsidence of Askja caldera 2000–2009: Modelling of deformation processes at an extensional plate boundary, constrained by time series InSAR analysis

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ABSTRACT

Many calderas in the world show long-term unrest in the form of elevated rates of deformation and seismicity, related to pressure changes and magma movements within their magmatic plumbing systems. We present new observations of the style of deformation at the Askja caldera, Iceland, since 2000, using interferometric analysis of synthetic aperture radar images (InSAR) acquired by the Canadian RADARSAT-2 satellite. When combined with previously acquired detailed geodetic observations, by various techniques, we obtain an overview of Askja's behaviour through more than four decades. The combined dataset reveals that, during this non-eruptive period, Askja continuously subsides at a rate of 2.5–3 cm/yr in 2000–2009, somewhat lower than the ~5 cm/yr rate inferred for the 1983–1998 period. This behaviour of Askja is evaluated and compared to those of other restless calderas. The wrapped interferograms show three main features: (1) concentric fringes depicting subsidence in the centre of the main Askja caldera, (2) oval fringes elongated along the rift portraying subsidence and (3) subsidence in an area north of the Vatnajökull glacier. The average line-of-sight (LOS) velocity from ground to satellite was used as input for inverse modelling, of a deflating pressure source beneath the caldera, embedded in a homogeneous, elastic half-space. Two different source geometries were tested: a point pressure source and a horizontal penny shaped crack. The concentric fringes centred in the Askja caldera are best fit by a point source located at 65.05°N 16.78°W, at a depth of 3.2–3.8 km with a volume decrease of 0.0012–0.0017 km^3/yr from 2000 to 2009, consistent with previous studies. Provisional 2D FEM models including structural complexities in the crustal layers indicate that the tectonic setting of Askja plays an important role in the continuous, long-term high subsidence rates observed there. In order to fully understand the cause and effects of the complicated tectonic setting we encourage the use of a more realistic rheological model of the area, which could lead to reinterpretation of previous model results.

1. Introduction and previous work

The Northern Volcanic Zone (NVZ) of Iceland is located on a divergent plate boundary between the Eurasian and North American plates, with a full spreading rate of ~2 cm/yr in the direction N106E° (Camitz et al., 1995). It is divided into five 'en echelon' spreading segments each hosting a fissure swarm with a centre of volcanic production (Einarsson and Saemundsson, 1987). The two most active, are those systems that have also developed collapse calderas, Askja and Krafla (Fig. 1). The Askja central volcano hosts at least three nested calderas: the youngest and smallest caldera has a diameter of 4.5 km and is filled by lake Öskjuvatn; the Askja caldera, centred at the Northwest shore of the lake, is 8-km across and 200–300 m deep, and finally a less prominent, older caldera is offset towards the North. The formation of the youngest caldera was related to a major eruption in 1875, but it continued to develop during an extended period of about 40 years following the eruption (Hartley and Thordarson, 2011). From 1921 to 1929 a fissure eruption south of the Askja caldera and small eruptions around the 1875 caldera, produced 0.3 km^3 and ~0.03 km^3 of lava (Sigvaldason et al., 1992). The most recent eruption occurred in 1961 when an east–west trending fissure opened within the Askja caldera (Thorarinsson and Sigvaldason, 1962). The ~0.09 km^3 of lava produced, flowed eastwards out of the caldera (Sigvaldason et al., 1992).

Monitoring efforts at Askja started with the installation of a levelling line in 1966 (Tryggvason, 1989), which was greatly expanded since then. In recent years GPS (Global Position System) geodesy observations (Sturkell and Sigmundsson, 2000; Sturkell et al., 2006) and InSAR (Pagli et al., 2006) have been extensively used. An uplift period occurred from 1970 to 1973, without any eruptive activity. No measurements were conducted between 1973 and 1982 but yearly measurements took place thereafter. Since at least 1983 the caldera has been subsiding continuously at a very high rate compared to other volcanoes worldwide (Tryggvason, 1989; Dzurisin

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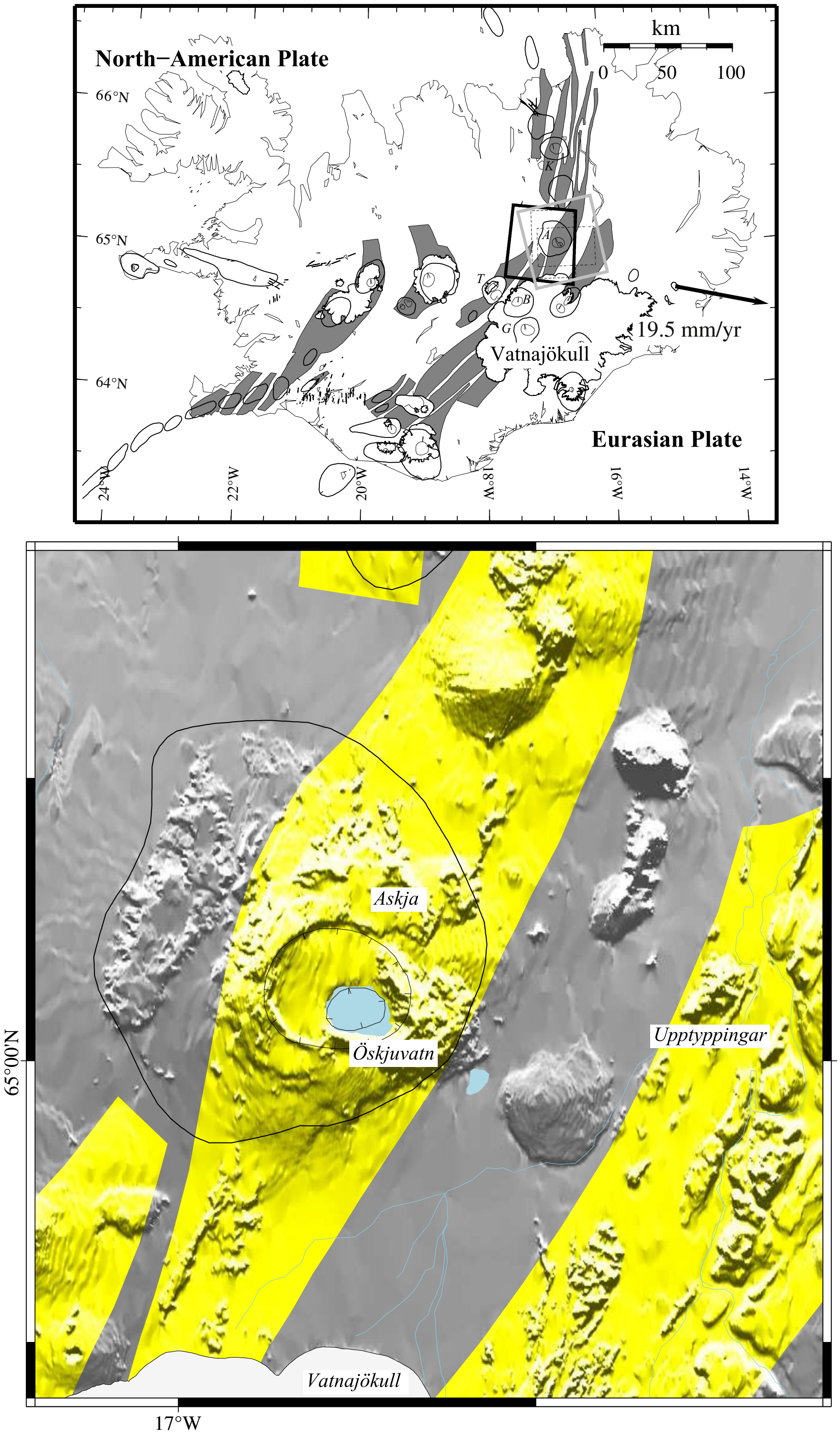

Fig. 1. Volcanic systems in Iceland (upper figure) with their fissure swarms in grey, central volcanoes and calderas, and ice caps (after Einarsson and Saemundsson, 1987). The black box shows the coverage of RADARSAT images in the F5 frame and the grey box those of the F1 frame, with the fine black line displaying the area shown in Figs. 2 and 3. The following volcanoes are annotated: Askja (A), Krafla (K), Bárdarbunga (B), Grimsvötn (G) and Tungnafjellsjökull (T). Arrow shows the full spreading vector across the plate boundary. Lower figure is a digital elevation model of the study area. Lake Öskjuvatn is a nested caldera, located within the main Askja caldera (both indicated by depression contours). Mt. Upptyppingar is located 20–25 km to the east of Askja.

et al., 2002; Gottsmann et al., 2006; Kwoun et al., 2006; Sturkell et al., 2006; Peltier et al., 2009). The precise cause of the subsidence is still uncertain, as various models have been presented through the years.

GPS and precise levelling measurements have indicated that the rate of subsidence at Askja is slowly decaying (Sturkell et al., 2006). Some of the measurements were interpreted with the use of two point pressure sources embedded in a homogeneous, elastic, half