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Extension during the 1975-84 Krafia Rift Crisis, NE Iceland, constrained by optical image matching

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ABSTRACT

This study provides new constraints on the displacement field resulting from the 1975-1984 Krafla rifting crisis, NE Iceland. Extension at the surface is accommodated primarily by normal faults which bound the rift zone, while extension is accommodated at depth by dike injection. Correlation of a declassified KH9 spy satellite image with a SPOT5 satellite image reveals the regional deformation pattern between 1977-2002 (3.7 m average opening), while correlation of aerial photos between 1957-1990 provide local measurements of the total extension close to the rift zone (average 6.2 m opening). Our results provide new insights into the deformation accommodated at the northern end of the rift, where earlier geodetic measurements were relatively sparse. Correlation of aerial photos from 1957-1976 reveal the magnitude and extent of opening during the early stages of the crisis. A bimodal pattern of opening along the rift during this period could be produced by two different magma sources, located at the northern and southern ends of the rift zone. This is consistent with observations from the Afar rift zone in East Africa, where extensive and precise geodetic measurements allow the determination of dike opening and fault slip throughout the rift zone. Variations in the amount of opening along the Krafla rift zone require that either different sections of the rift zone are subject to dike injection events at different times, or the remaining deformation is accommodated elsewhere in the region, such as the neighboring Theistareykir fissure swarm. Our results are significant as they provide new information on how past dike injection events accommodate long-term plate spreading. Perhaps of greater significance, however, is the potential of optical image correlation using inexpensive declassified spy satellite and aerial photography to measure deformation of the Earth's surface going back many decades. This latter point highlights the potential of image correlation for providing important contributions to other areas of Earth surface observation, and for which InSAR and GPS data are not available, such as glacial studies, landsliding, coastal erosion, volcano monitoring as well as earthquake studies.

INTRODUCTION

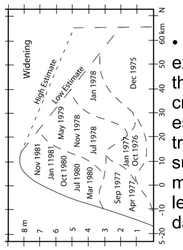
1 1975-1984 Krafla Rifting Crisis

• As a result of the increased melt beneath Iceland due to a mantle plume, the Mid-Atlantic spreading becomes exposed on land.

• As such, Iceland represents an excellent place to study how plates spread due to processes such as episodic dike injection.

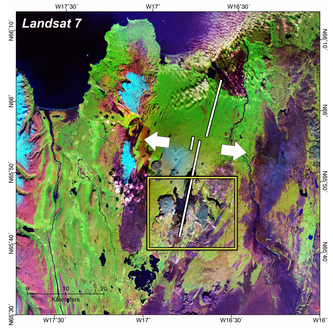
• A number of dikes were injected in the crust beneath the Krafla fissure swarm between 1975 and 1984, resulting in extension at the surface.

• Ultimately, the far field plate spreading rate of 20 mm/yr is accommodated by episodic dike injection along the Krafla fissure zone.



• The E-W extension throughout the crisis was estimated using trigonometric surveys, EDM measurements, levelling and tilt data.

• Despite the amount of geodetic data already available for this relatively old event, our understanding of the spatial pattern of extension is poor.



OPTICAL IMAGE MATCHING OF KH-9 AND SPOT5 SATELLITE IMAGERY

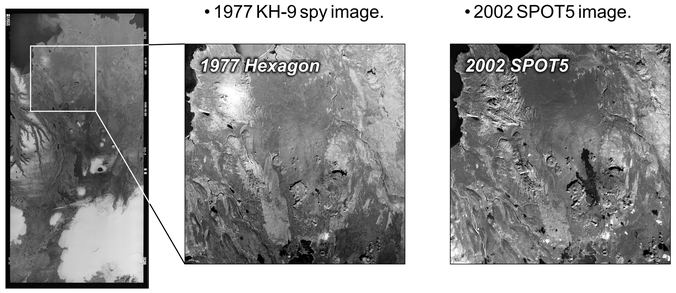
2 Optical Image Correlation (1977-2002): KH-9 spy and SPOT5 satellite imagery

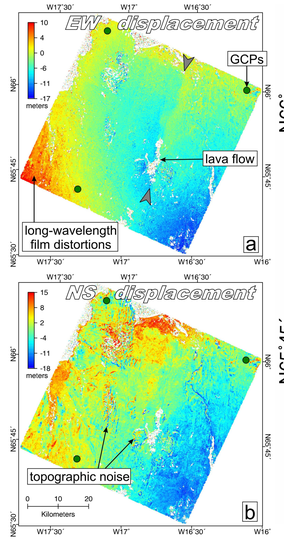
• We use COSI-Corr to orthorectify a 2002 SPOT5 image of the Krafla region of NE Iceland, using the ASTER GDEM topography as a horizontal and vertical reference source.

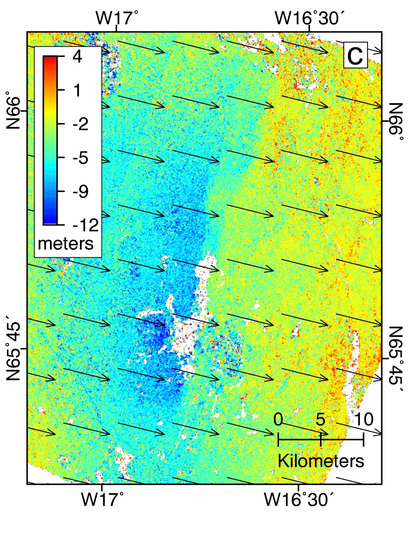
• We then co-register a KH-9 Hexagon image from 1977 (of the same region) to the SPOT5 ortho-image using Tie Points collected far from the deforming area.

• Because the KH-9 camera information remains classified, we approximate it using the camera parameters of the declassified Large Format Camera system (NASA).

• Film distortions and unmodelled optical distortion produce long wavelength deformation signals in the E-W and N-S direction. However, the short wavelength deformation signal (fault slip / fissure opening) is well resolved.







• The majority of opening was in the E-W direction (due to injection of dikes with a NNE orientation). The E-W displacement map reveals where the dike was injected and how much the surface extended by between 1977 and 2002.

• Because some topographic residuals remain in the E-W and N-S directions, we re-project the displacement field into the epipolar perpendicular plane (shown by the arrows in c), which is free from any topographic signal.

AIRPHOTO CORRELATION RESULTS

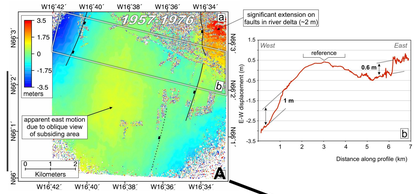
3 Opening estimates from correlation of airphotos:

• We correlate airphotos from before, during and after the Krafla rifting crisis using COSI-CORR.

• The resulting displacement fields show how surface opening varied along the Krafla fissure swarm throughout the crisis.

• Airphotos are 0.5 m resolution. Therefore, we can resolve displacements of 5-10 cm and greater.

1957-1976

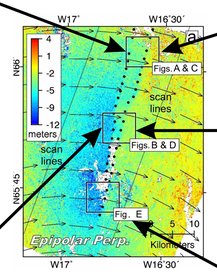


• During the first 9 months of the crisis we find:

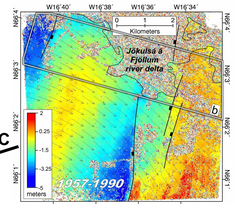
>3 m of opening across the Northern end of the rift

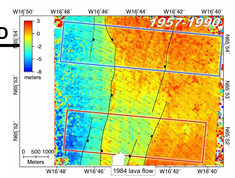
<1 m opening across the central section of the rift

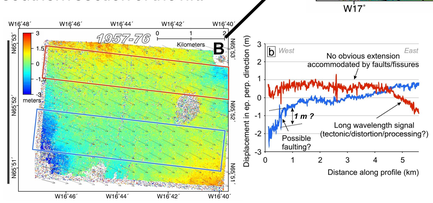
• Volcanisms and seismic activity in the Krafla caldera suggests significant opening across the southern section of the rift.

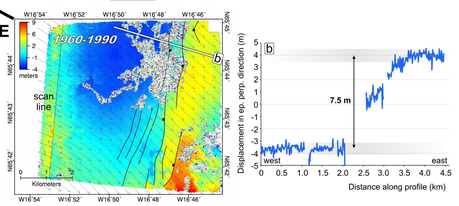


1957-1990



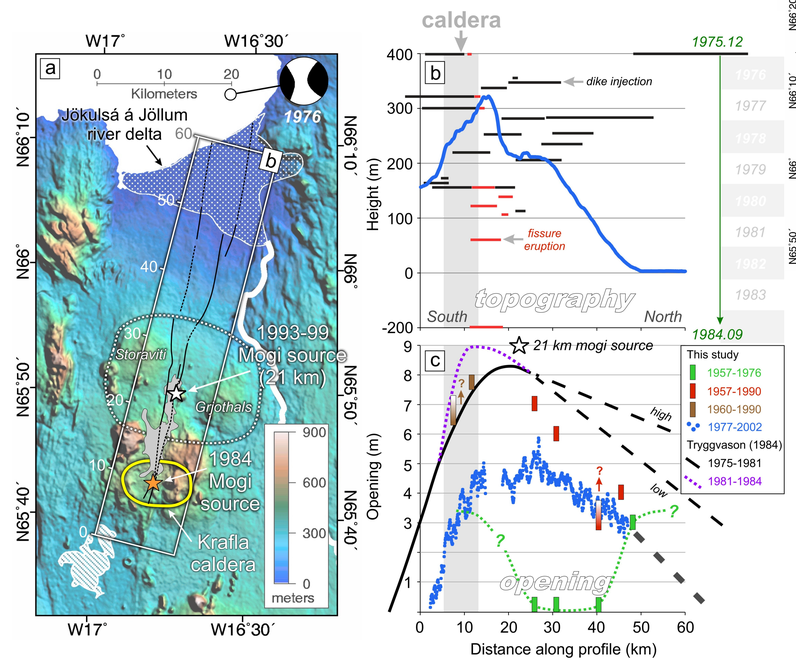




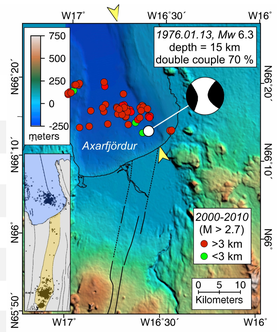


SUMMARY OF OPENING

4 Summary of extension during the Krafla rift crisis



• Summary of opening across the Krafla fissure swarm during the 1975-84 rifting crisis.



• Opening estimates from image correlation are consistent with previous measurements for the caldera region, but provide new constraints for the northern end of the rift.

• The greatest opening occurred immediately north of the caldera (8 m), and decreses to 3-4 m at the northern end of the rift.

• No opening occurs in the central section of the rift zone during the first 9 months of the crisis. Opening at the northern end may therefore result from dike injection sourced from a northern magma chamber.

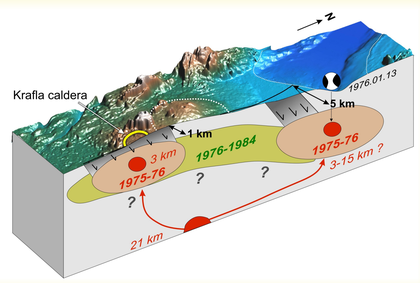
CONCLUSIONS

5 Conclusions

• During the Krafla rift crisis, an average 6.2 m opening was accommodated between 1975-84, and 3.7 m between 1977-1984. Therefore, 40% of the total opening was accommodated in the first 20% of the crisis.

• At the surface, extension is accommodated by slip on normal faults which bound the 1-5 km rift zone. Normal faults localize above dikes at depth.

• The global coverage of KH-9 imagery, as well as other declassified spy data and aerial photos, offers huge potential for investigating 20th Century volcanic and tectonic deformation.



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