Division of GPS,
Caltech,
MC 100-23
Pasadena,
CA, 91125, USA
Tel. 626-395-6177

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

***James Hollingsworth**, Sébastien Leprince, François Ayoub and Jean-Philippe Avouac*

*** james@gps.caltech.edu**

ABSTRACT

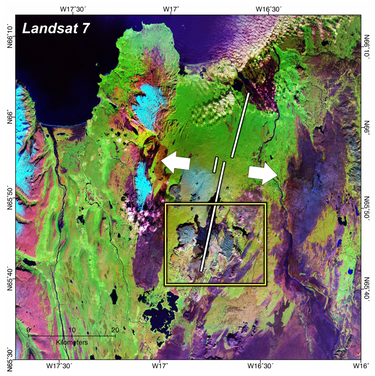
This study provides new constraints on the displacement field resulting from the 1975-1984 Krafla rifting crisis, NE Iceland. Extension at the surface is accommodated primarily by normal faults which bound the rift zone, while extension is accommodated at depth by dike injection. Correlation of a declassified 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

• Between 1975 and 1984 a number of dikes were injected beneath the Krafla region, NE Iceland.

• Despite the large amount of geodetic data already available for this past event, our understanding of the spatial pattern of extension is relatively poor (due to the lack of widespread geodetic measurements, which would be offered by modern geodetic techniques, such as InSAR).



OPTICAL IMAGE MATCHING OF KH-9 AND SPOT5 SATELLITE IMAGERY

2 Image Correlation (1977-2002): KH-9 / SPOT5 satellite imagery

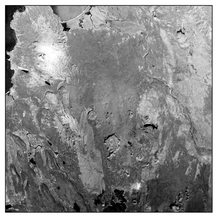
• We use COSI-Corr to orthorectify a 2002 SPOT5 image of the Krafla region of NE Iceland, using the ASTER GDEM topography as a horizontal and vertical reference source.

• 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.

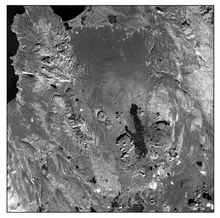
• Because the KH-9 camera information remains classified, we approximate it using the camera parameters of the declassified Large Format Camera system (NASA).

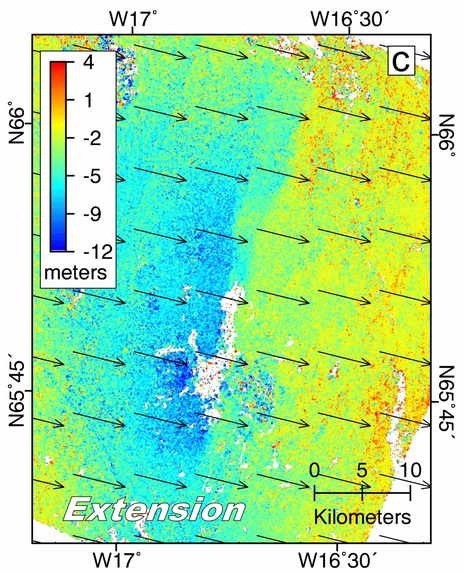
• Film distortions and unmodelled optical distortion produce long wavelength deformation signals in the E-W and N-S direction. However, the short wavelength deformation signal (fault slip / fissure opening) is well resolved.

• 1977 KH-9 spy image.



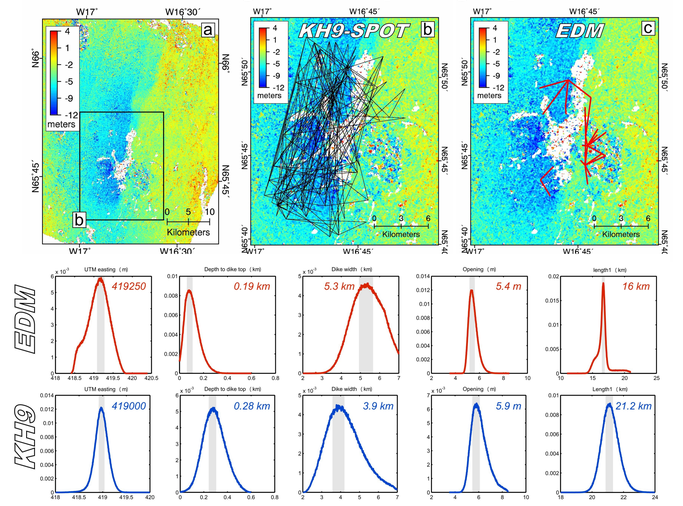
• 2002 SPOT5 image.





• The ~E-W displacement map reveals how much the surface extended by between 1977 and 2002.

Inverting for dike opening/depth



• We invert for the best fitting depth range and opening values for a single dike (representing the sum of all the individual dike injections), by exploring a range of dike models using the Metropolis-Hastings algorithm (where different models are accepted or rejected based on the ratio of the current model likelihood function with the previous model.

• Between 1977 and the end of the crisis, average dike opening near the caldera was 5-6 m (~surface opening is 60-70% of the opening at depth). The dikes extend to depth of 4-5 km.

AIRPHOTO CORRELATION RESULTS

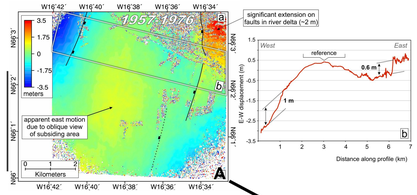
3 Opening estimates from correlation of airphotos:

• We correlate airphotos from before, during and after the Krafla rifting crisis using COSI-Corr (opticl image correlation).

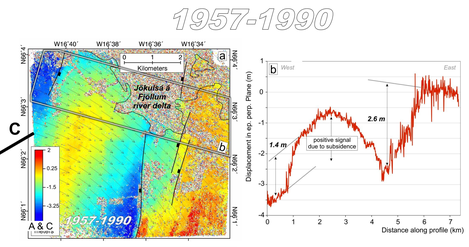
• The resulting displacement fields show variation of surface opening along the Krafla fissure swarm throughout the crisis.

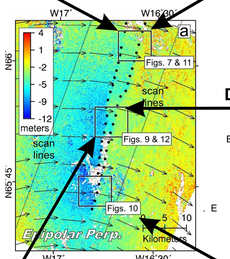
• Airphotos are 0.5 m resolution. Therefore, we can resolve displacements of 5-10 cm and greater.

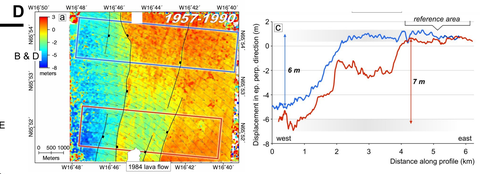
1957-1976

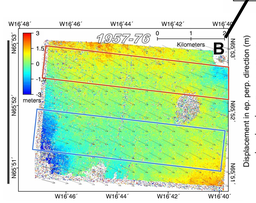


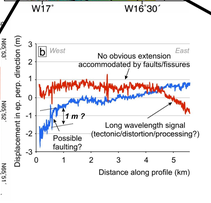
1957-1990

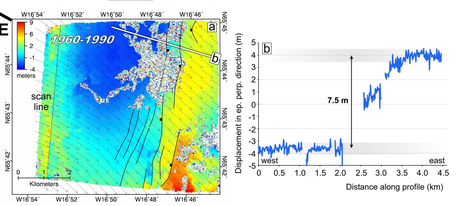












• First 9 months of crisis :

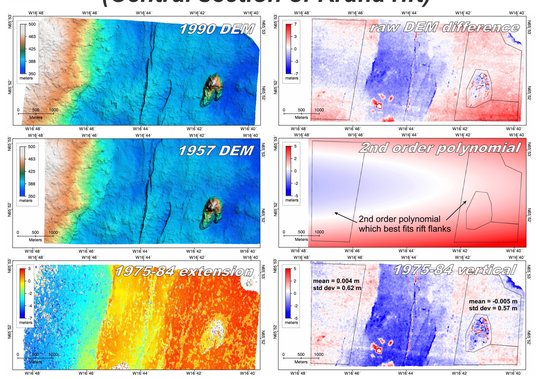
>3 m of opening across the north end of the rift

<1 m opening across central section of the rift

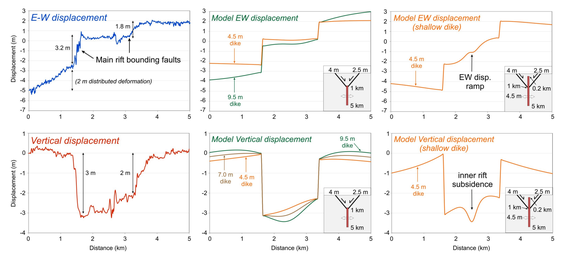
• Volcanism and seismic activity in the caldera suggests opening across the southern rift section.

FAULT / DIKE GEOMETRY

4 Geometry of faulting & diking: (Central section of Krafla rift)



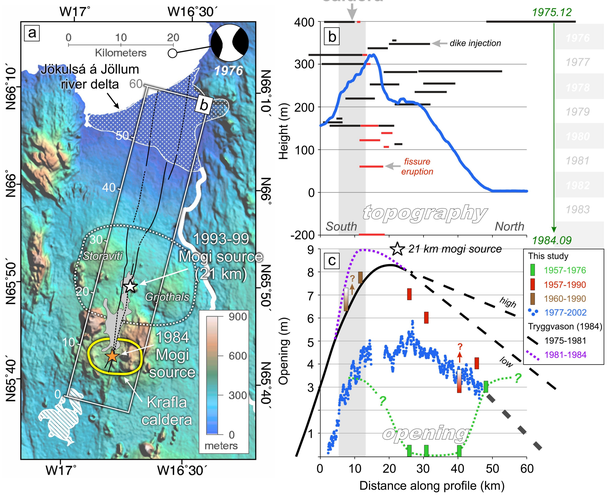
• DEM differencing reveals magnitude of vertical fault displacements, while image correlation reveals the total horizontal extnsion.



• Comparison of EW and vertical displacement profiles, and the results from elastic dislocation modelling of different dike/fault geometries

SUMMARY OF OPENING

5 Summary of extension



• 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 decreases 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

6 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.

ACKNOWLEDGEMENTS

This work benefitted from helpful discussions with Mark Simons, Arzhan Surazakhov, Alex Copley, Anthony Sladen, Marion Thomas and Sylvain Barbot and Lisa Christiansen. Aerial photos were purchased from the Icelandic Land Survey, KH-9 data from the USGS and SPOT5 data from SPOT. Optical data was co-registered and correlated using the COSI-CORR software package. This work was supported by the Gordon & Betty Moore Foundation.