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

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ABSTRACT

In this study we demonstrate that the recently declassified Corona KH-9 images can be used to measure ground deformation due to seismotectonic and volcanic events from optical sub-pixel correlation. We use high resolution (6-9 m) KH-9 satellite images, which are processed using COSI-Corr. Because the camera information for KH-9 images remains classified, we follow the approach of Surazakov, et al., (2009), who conclude the Hexagon KH-9 camera system is identical to the NASA Large Format Camera (LFC) system.

Using this approach, we successfully measure the surface deformation induced by the 1975-1984 Krafla rifting crisis in NE Iceland, by correlating a Hexagon image from 15th September 1977 with a SPOT5 image from 2002. During the period 1977-2002 we find an average E-W extension of 3±0.5 m across the rift, which extends NNE from Lake Myvatn in the south to Ásbyrgi canyon near the coast to the north (a distance of over 40 km) and were able to determine which faults were activated. Using the EW displacement field, we invert for the best fitting dike parameters and estimate the volume of material intruded and extruded during the crisis. Because the KH9 image misses the first 2 years of diking, we use aerial photos from 1957 to constrain the total extension across the rift zone, which is ~6 m and corresponds to a 8-9 m wide dike injection at depth (across the central section of the Krafla fissure swarm). The vertical deformation associated with a 8-9 m dike is ~2.5 m relative uplift of the rift flanks and is consistent with the 2-3 m of uplift we measure from DEM differencing between a 1957 and 1990 DEM. The examples discussed above highlight the potential for using inexpensive declassified Hexagon images and aerial photos to investigate tectonic deformation dating back to the onset of the KH9 program in 1971 and even earlier for aerial photography.

INTRODUCTION

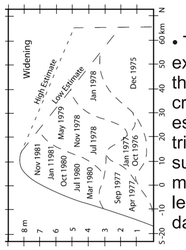
1 1975-1984 Krafla Rifting Crisis

• 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.

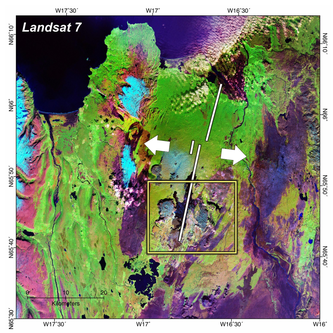
• A number of dikes were injected in the crust beneath the Krafla fissure swarm between 1975 and 1984, resulting in extension at the surface.

• 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 very poor.



OPTICAL IMAGE MATCHING OF KH-9 AND SPOT5 SATELLITE IMAGERY

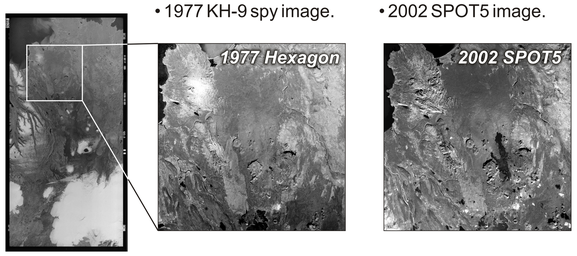
2 Optical Image Matching between KH-9 spy and SPOT5 satellite imagery

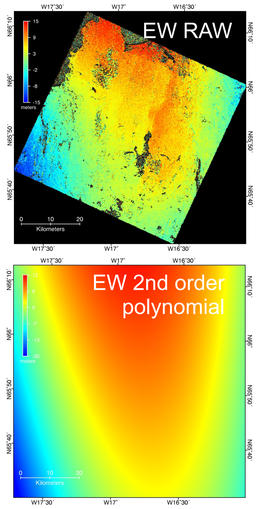
• We use COSI-Corr to orthorectify a 2002 SPOT5 image of the Krafla region of NE Iceland, using the ASTER GDEM topography as a horizontal and vertical reference source.

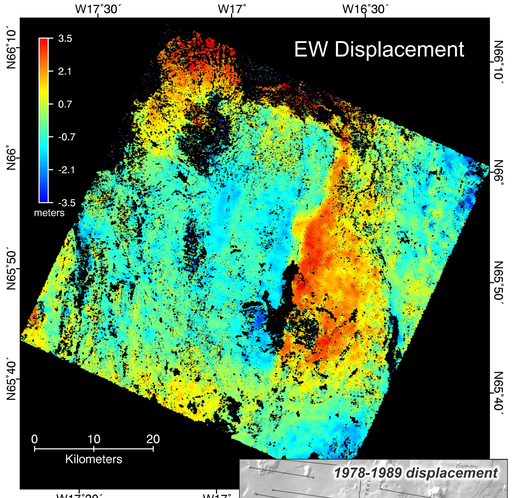
• We then co-register a KH-9 Hexagon image from 1977 (of the same region) to the SPOT5 ortho-image using Tie Points collected away from the region of deformation.

• Because the camera information remains declassified, we use the same camera parameters as the Large Format Camera system (NASA).

• Film distortions produce a very long wavelength E-W deformation signal, which we remove by subtracting a best fitting 2nd order polynomial.

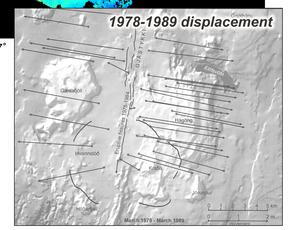






• The filtered E-W displacement map reveals where the dike was injected and how much the surface extended by between 1977 and 2002.

• We can combine this information with independent EDM measurements from almost the same time period to model the best fitting dike parameters.

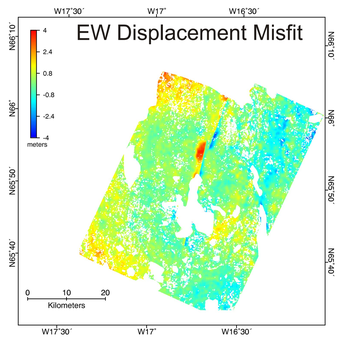


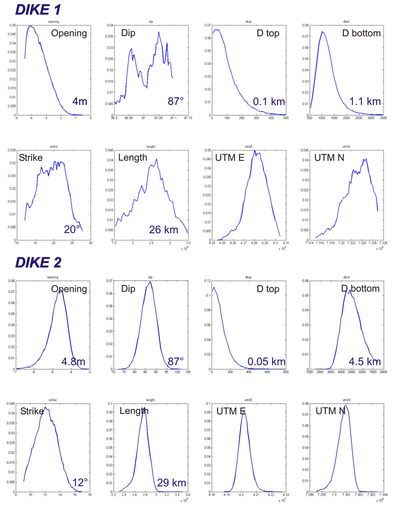
INVERSION OF IMAGE CORRELATION & EDM DATA

3 Data Inversion: Best Fitting Dike Parameters

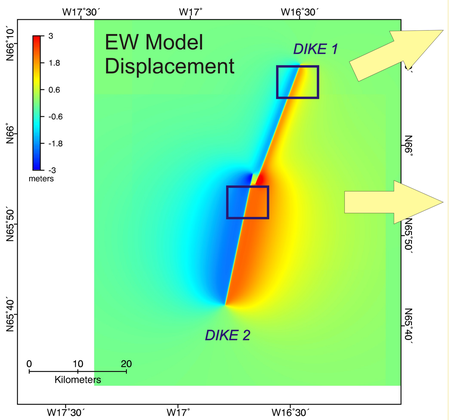
• We select 250 points randomly from each side of the extension zone (but not further away than 5 km) - see section 2. We also use EDM data collected from the southern section of the fissure swarm.

• Using the elastic dislocation code of Okada, we vary the parameters for 2 dikes and see how they fit the correlation and EDM data, keeping the data when the fit is improved upon (we use the Metropolis algorithm to fully explore the dike parameter space).



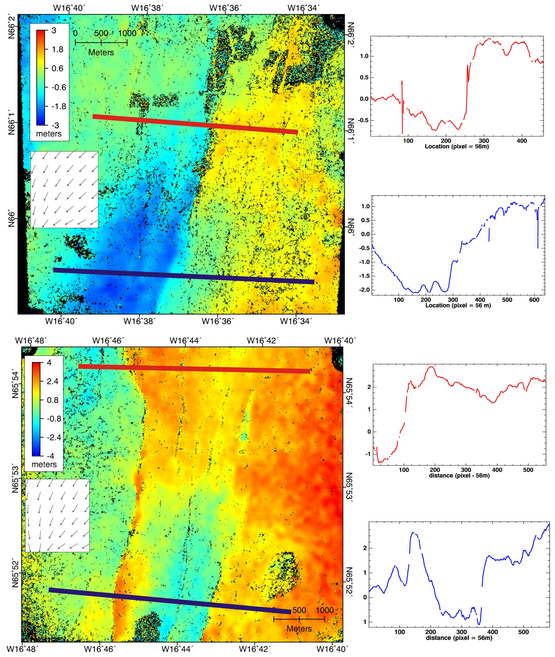


• Between 1977-2002, about 1 km^3 was in/extruded .



TOTAL EXTENSION FROM AIRPHOTO CORRELATIONS

4 1957-1990 Airphoto Correlations And DEM differencing

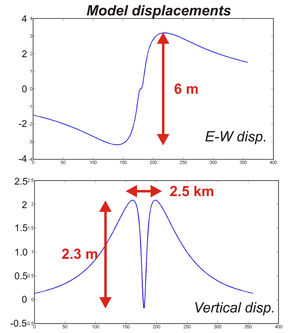


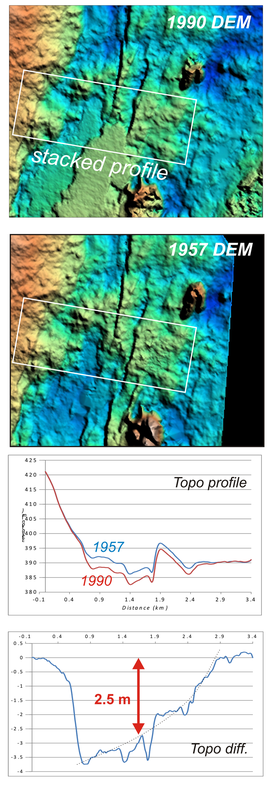
• Because we miss the first 2 years of extension, we correlate aerial photos from 1957 and 1990 to measure the total extension.

• Along the central part of the fissure swarm, the total extension is about 6 m. Along the northern section of the fissure swarm, extension is lower at 3-4 m. This implies that there was not significantly more extension in the first 2 years than in subsequent years.

• DEM's were made from the 1957 and 1990 aerial photos, the difference of which reveals the vertical change throughout the crisis.

• Relative subsidence of ~2.5 m and extension of ~6 m can be produced by a dike opening by 8-9 m between 0.4-4.5 km depth. The width of the vertical deformation is 2.5 km, the same as the width of the fissure.





CONCLUSIONS

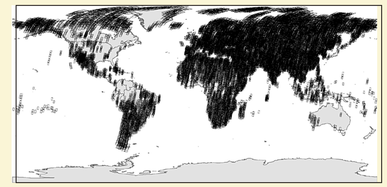
5 Conclusions

• Extension during the Krafla rifting crisis resulted from the injection of many dikes equivalent to a single dike 8-9 m wide, decreasing to 5 m in the north.

• At the surface extension is accommodated by slip on normal faults and opening of fissures above the dike.

• If the total amount of vertical displacement (i.e. 2.5 m) during the crisis is typical, only 4-6 similar events are required to produce the vertical displacement measured from the post-glacial Storaviti lava surface. Therefore, the repeat time for such dike injections is ~2,000 years.

• The global coverage of KH-9 images offers huge potential for investigating 20th Century tectonic displacements.



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