利用歷史光學影像測量 1975-1984 年冰島東北部克拉夫拉裂谷危機期間的變形

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摘要

我們使用光學影像關聯技術(optical image correlation)測量了 1975-1984 年冰島東北部 Krafla 裂谷危機引起的位移場。影像處理軟體為 COSI-Corr。地表伸張位於裂谷帶邊界正斷層及裂隙源自於深部的岩脈入侵。解密的 KH-9 和 SPOT5 衛星影像關聯揭示了 1977-2002 年間的伸張（平均 2.5 公尺的張裂延續逾 80 公里），而 1957-1990 年間航拍影像關聯提供了總伸張的測量值（平均 4.3 公尺的張裂延續逾 80 公里）。我們的結果顯示，在 Krafla 火山口正北有 8 m 的張裂，在裂谷的北端減少到 3-4 m。1957-1976 年航空影像關聯揭示了早期危機期間沿裂谷張裂的雙峰模式，這可能肇因於位在裂谷帶兩端有不同的岩漿源（相似 2005 年東非 Afar 裂谷危機）或裂谷沿線岩石強度的變化。我們的結果提供了岩脈入侵事件與長期板塊擴張之間的新線索，並提供了有關 Krafla 裂谷危機的更多細節。這項研究還強調了光學影像關聯技術的潛力，使用廉價的解密間諜衛星和航拍影像來測量數十年前的地球表面的變形，從而提供一種測量地球表面動力學的新工具，例如：冰川、山崩、海岸侵蝕、火山監測和地震研究，當 InSAR 和 GPS 數據不可用時。

關鍵字：影像關聯、COSI-Corr、地表變形、裂谷帶

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Deformation during the 1975–1984 Krafla rifting crisis, NE Iceland, measured from historical optical imagery

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[1] We measure the displacement field resulting from the 1975–1984 Krafla rifting crisis, NE Iceland, using optical image correlation. Images are processed using the COSI-Corr software package. Surface extension is accommodated on normal faults and fissures which bound the rift zone, in response to dike injection at depth. Correlation of declassified KH-9 spy and SPOT5 satellite images reveals extension between 1977–2002 (2.5 m average opening over 80 km), while correlation of aerial photos between 1957–1990 provide measurements of the total extension (average 4.3 m opening over 80 km). Our results show ~8 m of opening immediately north of Krafla caldera, decreasing to 3–4 m at the northern end of the rift. Correlation of aerial photos from 1957–1976 reveal a bi-modal pattern of opening along the rift during the early crisis, which may indicate either two different magma sources located at either end of the rift zone (a similar pattern of opening was observed in the 2005 Afar rift crisis in East Africa), or variations in rock strength along the rift. Our results provide new information on how past dike injection events accommodate long-term plate spreading, as well as providing more details on the Krafla rift crisis. This study also highlights the potential of optical image correlation using inexpensive declassified spy satellite and aerial photos to measure deformation of the Earth's surface going back many decades, thus providing a new tool for measuring Earth surface dynamics, e.g. glaciers, landsliding, coastal erosion, volcano monitoring and earthquake studies, when InSAR and GPS data are not available.

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1. Introduction

[2] With the obvious technical challenges in studying oceanic rift zones directly, our understanding of the processes that operate within rift zones and that influence their topographic and structural evolution remain relatively poor. The interplay between diking and faulting is a key factor controlling the structural development of spreading centers; differences in the amount of plate spreading accommodated by diking versus faulting ultimately lead to the very different topographic expressions of rift zones from around the world [*De Chabalier and Avouac*, 1994; *Buck et al.*, 2006]. Injection of dikes and slip on faults occur as instantaneous events in the geological record. Therefore, geodetic measurements which span a volcanic or tectonic event provide a method for measuring the displacement field associated with that event. Deformation associated with a single volcanic or seismic cycle can then be scaled up to see how it may produce the geological deformation we see preserved in the landscape. Obviously, this can only be achieved where the co-seismic and geologic ground displacements can be measured from remote sensing or geodesy.

[3] Recent studies from Afar and Tanzania have combined local seismicity and radar data to measure the intrusion of dikes where plate spreading is accommodated on land in the East African rift [*Wright et al.*, 2006; *Baer et al.*, 2008; *Calais et al.*, 2008; *Biggs et al.*, 2009; *Grandin et al.*, 2010b]. Along with dike injection during the 1978 Asal rifting crisis [*Abdallah et al.*, 1979; *Ruegg and Kasser*, 1987; *Cattin et al.*, 2005], these three rare examples show how long-term plate spreading in the East African rift is accommodated by short-term episodic dike injection.

[4] The only other region where plate spreading occurs on land, and may therefore be imaged geodetically, is Iceland. Recent injection of a dike in an off-rift setting in southern Iceland resulted in the Eyjafjallajökull eruption, the ash clouds from which caused major disruption to European air traffic in spring 2010 [*Sigmundsson et al.*, 2010]. Although no inner-rift dike injections have occurred in Iceland in the period of GPS and InSAR observation (1990s and later), a major volcanic episode occurred between 1975–1984, known as the Krafla rifting crisis, or 'Krafla Fires', during which around 20 dikes were injected into the crust within the Northern Volcanic Zone (NVZ) of NE Iceland (Figure 1) [see also *Tryggvason*, 1984; *Björnsson*, 1985; *Sigmundsson*,

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