Journal of Volcanology and Geothermal Research 188 (2009) 297–304

Contents lists available at ScienceDirect

Journal of Volcanology and Geothermal Research

journal homepage: www.elsevier.com/locate/jvolgeores

Recent magmatotectonic activity in the Eastern Snake River Plain–Island Park region revealed by SAR interferometry

M.H. Aly *, D.W. Rodgers, G.D. Thackray, S.S. Hughes

Department of Geosciences, Idaho State University, Pocatello, Idaho 83209-8072, United States

ARTICLE INFO

Article history:
Received 19 May 2008
Accepted 20 May 2009
Available online 6 June 2009

Keywords:
Eastern Snake River Plain
Island Park
Yellowstone
Synthetic Aperture Radar Interferometry
crustal deformation
magmatic processes

ABSTRACT

Synthetic Aperture Radar Interferometry (InSAR) has been applied in this study to address crustal deformation in a 10,000-km^2 region located immediately west of the Yellowstone hotspot. InSAR results show that surface movements in the study area were non-linear and episodic during the period of observation (1993–2006). The Island Park region and its adjacent Eastern Snake River Plain (ESRP) were characterized by northeast-trending zones of uplift ($+1$ cm yr^{-1}) and subsidence (-1 cm yr^{-1}) with various extents through time. The western edge of Yellowstone caldera experienced episodes of subsidence (-1 cm yr^{-1}) during 1997–2000 and uplift ($+3$ cm yr^{-1}) during 2004–2006. Differential surface movements of varying rates were also detected between 1993 and 2006 in the vicinity of Basin and Range normal faults to the north of Henrys Fork caldera. Throughout the study area, surface displacements across the Island Park region, the ESRP, and the adjacent Basin and Range province generally reversed the movement direction in 2004, in concert with displacement reversal to uplift in the Yellowstone caldera. Crustal deformation in the general vicinity of major Basin and Range faults is interpreted to reflect diffuse extensional strain adjacent to the deeper segments of faults, rather than near-surface slip. The northeast-trending displacement zones in the ESRP and the Island Park region may indicate folding in response to converging zones of extension in the surrounding Basin and Range province. Surface displacements of the Yellowstone caldera are interpreted to reflect migration of magma or hydrothermal fluids. The inverse relation between vertical displacements in Yellowstone and its surrounding regions may reflect an upper crustal flexural response or a large-scale movement of hydrothermal fluids, though neither hypothesis is completely supported by the processed data.

1. Introduction

The Snake River Plain–Yellowstone volcano-tectonic province was created by late Cenozoic volcanism when North America migrated over a relatively stationary mantle hotspot (plume) (Morgan, 1972; Armstrong et al., 1975; Pierce and Morgan, 1992; Smith and Braile, 1993; Camp, 1995; Camp and Hanan, 2008; Shervais and Hanan, 2008). The Snake River Plain marks the older path of tectonic drift and is considered the largest actively subsiding volcanic basin in North America with regard to spatial extent and cumulative subsidence. The hotspot currently underlies the Yellowstone Plateau, and most recently erupted catastrophically ca. 640,000 years ago (Christiansen, 2001). The Yellowstone caldera, which formed at that time, is currently characterized by multiple episodes of uplift and subsidence over short-time periods (Wicks et al., 1998, 2006; Smith et al., 2006; Chang et al., 2007).

The Eastern Snake River Plain (ESRP) has existed for approximately 10 million years (Morgan and McIntosh, 2005) and its decadal to millennial subsidence is manifested by several geomorphic and geodetic indicators (Kirkham, 1931; Reilinger et al., 1977; Rodgers et al., 2002). Crustal processes that might induce subsidence of the ESRP physiographic province include: (1) heat loss leading to thermal contraction (Brott et al., 1981; Blackwell et al., 1992); (2) isostatic subsidence resulting from emplacement of dense dikes and sills (Anders and Sleep, 1992; McQuarrie and Rodgers, 1998); and (3) lower crustal flow to the adjacent Basin and Range province (McQuarrie, 1997; McQuarrie and Rodgers, 1998).

Numerous previous studies reported several remarkable manifestations of surface subsidence across the ESRP. These include (1) the immediately adjacent basins and ranges are downwarped near the ESRP, with about 1500 m decrease in surface elevation (Kirkham, 1931); (2) surface elevation of the ESRP diminishes steadily from northeast to southwest, interpreted as progressive subsidence caused by thermal contraction (Brott et al., 1981) and/or crustal loading (Anders and Sleep, 1992); (3) the ESRP and surrounding regions are characterized by axial drainage patterns, wherein tributaries flow toward the ESRP and its trunk river, which itself flows southwest along the margin of ESRP; (4) strath terraces along the southern ESRP margin are perched 900 m (late Miocene) and 200 m (early to middle Pleistocene) above the recent ESRP surface (Rodgers et al., 2002);

* Corresponding author. Tel.: +1 208 282 3439; fax: +1 208 282 4414.
E-mail address: aly@isu.edu (M.H. Aly).

0377-0273/$ – see front matter © 2009 Published by Elsevier B.V.
doi:10.1016/j.jvolgeores.2009.05.015

(5) the Lost River Trough, which is a Quaternary fluvio-lacustrine basin within the ESRP, provides evidence of long-lived but localized subsidence within the ESRP (Geslin et al., 2001); and (6) traditional land surveys indicate cm-scale decadal subsidence of the ESRP relative to its adjacent Basin and Range province (Reilinger et al., 1977).

The aforementioned geologic and geomorphic indicators imply that the ESRP subsidence is an active, ongoing process. Regional subsidence of the ESRP surface relative to the Basin and Range province and Yellowstone Plateau is, thus, anticipated. Vertical movements associated with the active Basin and Range faults, which surround the ESRP, are also probable. However, until recently it has not been possible to examine crustal motions across the broad region at issue.

Synthetic Aperture Radar Interferometry (InSAR), which is an active microwave system capable of providing a spatially dense series of crustal deformation measurements with a millimeter-level accuracy, has been applied in this study to detect and measure the spatio-temporal patterns of deformation in the ESRP and the Island Park region during 1993–2006. More specifically, the study has been conducted to test the hypothesis that the ESRP experiences short-term regional subsidence, with respect to its adjacent Basin and Range province and Yellowstone Plateau, and to investigate the possible vertical displacements associated with the active tectonics in the Basin and Range province. This InSAR investigation not only reveals the spatial and temporal patterns of crustal movements in the study area, but also has important implications for the time-transgressive nature of the complex Yellowstone system during the period of observation. This, in turn, provides a better understanding of how the lithospheric crust and mantle evolve in response to large-scale magmatism and tectonism, and it improves the understanding of earthquake cycles in the region.

2. Volcano-tectonic setting

The ESRP, which is approximately 300-km long and 80-km wide, trends northeasterly and is bounded north and south by the Basin and Range province (Fig. 1). Silicic magmatism occurred on the ESRP approximately 10 to 4 Ma ago, generally progressing to the northeast as North America migrated southwest over the Yellowstone hotspot (Armstrong et al., 1975; Pierce and Morgan, 1992; Morgan and McIntosh, 2005). The ESRP has been in the wake of the hotspot since then, and younger pulses of Pliocene-Quaternary basaltic magmatism have emanated from fissures and generated a 1-to-2 km thick layer of lava across the older silicic rocks (Kuntz et al., 1992). Lava and interbedded sediment have accumulated in the ESRP because its land surface is topographically lower than its surrounding Basin and Range province and Yellowstone Plateau.

The 1.3-Ma Henrys Fork caldera, which is situated within the Island Park region between the ESRP and the Yellowstone caldera, is nested within the southwest corner of the 2.05-Ma Huckleberry Ridge caldera (Christiansen, 2001) and shares the same rim on the southwestern sides. The Henrys Fork caldera represents the second of three major eruptive cycles on the Yellowstone Plateau and is the major contributor to the geologic history of Island Park, and is a collapse structure about 16 km in diameter (Fig. 1). The western portion of the caldera scarp is exposed; however, the eastern portion is buried under post-caldera rhyolite flows from the adjacent Yellowstone caldera to the east. The crest of the western rim of the caldera that is shared with the

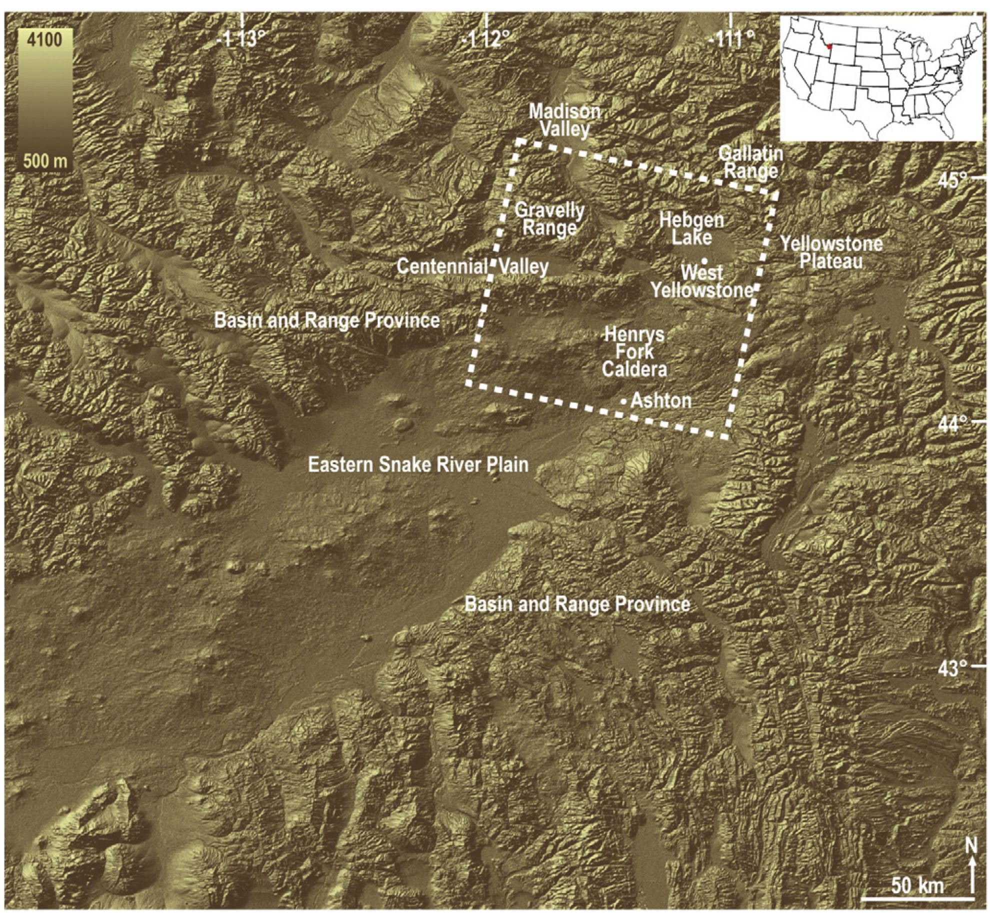

Fig. 1. Shaded relief image of the study area. The dotted white box shows the coverage of ERS data used in this interferometric investigation. All location names mentioned in the article are labeled in this figure.