HIGH RESOLUTION DEFORMATION ESTIMATION USING DISTRIBUTED SCATTERER INTERFEROMETRY APPROACH WITHIN DOBI GRABEN, THE AFAR DEPRESSION, ETHIOPIA

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Abstract

The Quaternary Dobi Graben in NE Ethiopia is situated in the intensely faulted East Central Block (ECB) of the Afar Depression that represents a triple junction. One of the most important unresolved questions in this region is how the strain is partitioned and localized, which is typically due to both spatial and temporal change. Understanding these changes requires a model that predicts the link between the geological processes and their genesis. In this paper, we resolved complete 3D time series displacements from Interferometric Synthetic Aperture Radar (InSAR) measurements for ~ 10 years. We first employed offset-tracking and multi-aperture InSAR techniques, with which the surface displacement in the azimuth direction can be measured together with the line of sight (LOS) displacement. The combination of multi-pass LOS and azimuth measurements integrated with GPS data revealed that the Dobi graben has experienced a clockwise rotation among individual fault blocks and confirmed the existence of the ongoing NE and SW remote stresses that cause an active differential extension. Results from persistent scatter and small baseline approaches shown that Dobi graben exhibits an asymmetrical full graben morphology but shows an almost mirror image LOS velocity and lateral displacement on both sides of the rift axis. In the middle, an average of 6.3 mm/year SE trending to 5.8 mm/year NW trending LOS velocity is shown. Furthermore, the high frequency changes seen in the displacement curves and large magnitude changes of velocity along a short distance of LOS measurement reveal the presence of sinistral strike slip faults near the center of the floor and along the Dobi relay zone. In the southern region of the Dobi graben, a maximum NW trending LOS velocity of 7.78 mm/ year toward NW and an opposite SE trending LOS displacement with 6.73 mm/year velocity near the graben center is observed. It should be noted that in this portion of the graben, a sharp, quick LOS polarity change can be seen and is interpreted as the presence of antithetic and synthetic blocks. The uplift and subsidence curves detect lack of significant shallow magmatic activity in the Dobi graben. The kinematics measurements we performed on some of the major faults indicated that lateral and vertical slip rates of the order of 10+/- 6 mm/year. Such fast rate in the Dobi imply that major faults initiated recently, at least < 0.35 Ma.

Study Area

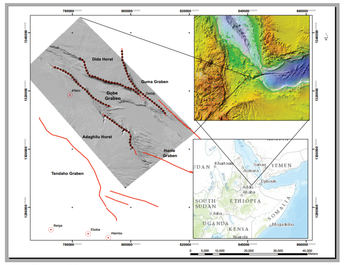

Figure. 1A

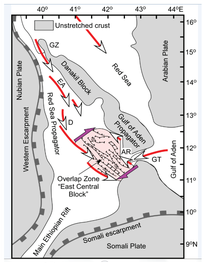

Figure. 1B

Figure 1 A. The study area.
Figure 1 B. General rift propagation direction within the Afar Depression.

Tectonic History and Geology

The kinematics of the Dobe graben is explained in terms of a bookshelf model in which differential extension across overlapping Red Sea propagator (RSP) and Gulf of Aden propagator (GAP) exerted a dextral strike-slip shear couple at the NW and SE margins of the block (Figs. 2A, 2B and 2C), (Tapponnier et al., 1990; Manighetti et al., 2001). The bookshelf model indicated the dextral strike-slip shearing, in turn, resulted in clockwise rotation of the micro-blocks and that the clockwise rotation of the micro-blocks was resolved as sinistral strike-slip faults reactivating among the NW-trending normal faults.

Objectives

1. We plan to study strain partitioning and localizations within the Dobe graben with the implication of ECB.
2. To evaluate existing kinematics models that had been proposed for the ECB and their framework with the evolution of the Dobi graben.

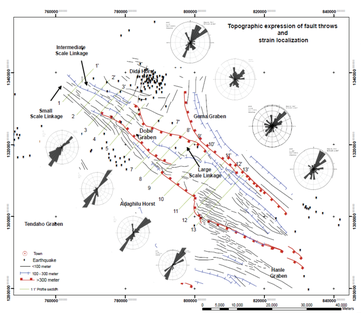

Figure 2B. Structural map of the Dobi graben produced from the interpretation of the Landsat ETM+ and RADARSAT and one arc second SRTM.

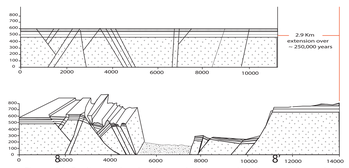

Figure 2A. Profile section 8 - 8' revealing normal faulting, block rotation and strike slip movement

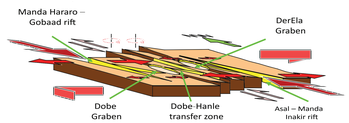

Figure 2C. Bookshelf model of the East Central Block of the Afar Depression modified after Tapponnier et al. (1990) and Manighetti et al. (1998).

Methods and Data

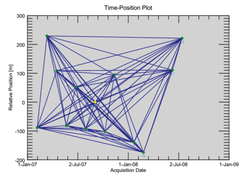

Figure 3A. Time position Delaunay 3D plot.

Envisat ASAR data was obtained from European Space Agency (ESA). The data is in raw format and focused to single look complex data for each RADAR pair. This work and the displacement measurement is generated using SarScape ENVI and ArcGIS software.

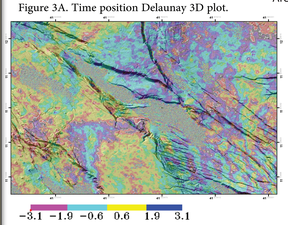

Figure 3B. D-Interferometric (11/25/2003 and 12/23/2008).

Substracting the phase from two synthetic aperture radar (SAR) images acquired at different times,maps of range change between the SAR and ground can be obtained with millimeter precision. Topographic corrections were made using a one arc-second digital elevation model (DEM) generated by the NASA Shuttle Radar Topography Mission.

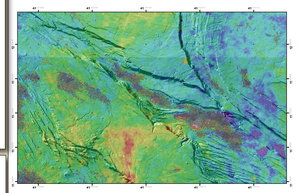

Figure 3C. Reflattening and re-unwarpping between 11/25/2003 and 12/23/2008.

Interferograms are filtered using a power spectrum filter (Goldstein & Werner 1998) and unwrapped using the branch cut algorithm Goldsteinet et al. 1988). The unwrapped interferograms are checked for any unwrapping errors and corrected.

Results

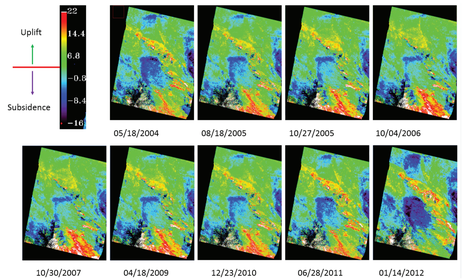

Figure 4A. Average LOS subsidence and uplift measurement 2003 - 2012.

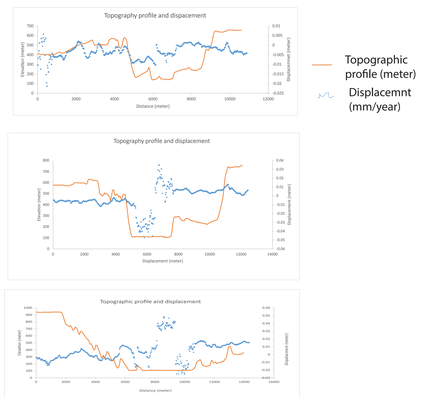

Figure 4B. Subsidence and uplift curves interpreted as lack of significant shallow magmatic activity in the Dobi graben.

Results Cont.

Displacement in the azimuth direction (N215ºE), and inclination angle of 15º

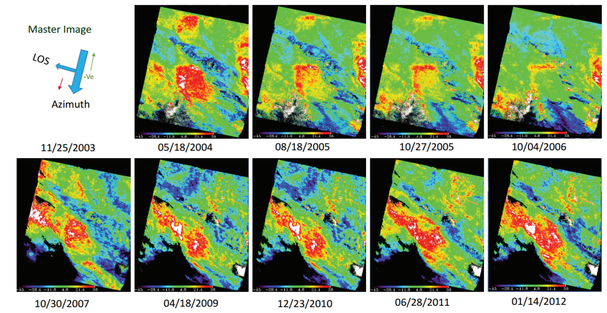

Figure. 5A

Figure 5A. Average displacements (A) in the satellite Azimuth direction from 2003 to 2012 (B) in the satellite line-of-sight (LOS) from 2003 to 2012 (C) Time-series of cumulative displacement with SBA approch and (D) Time-series of cumulative displacement using Persistent Scatterers approach.

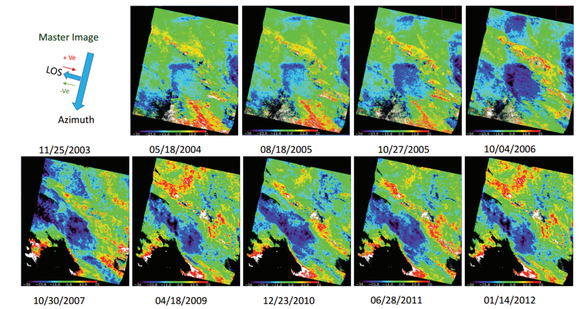

Figure. 5B

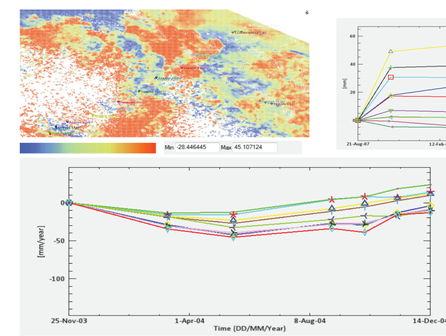

Figure. 5C

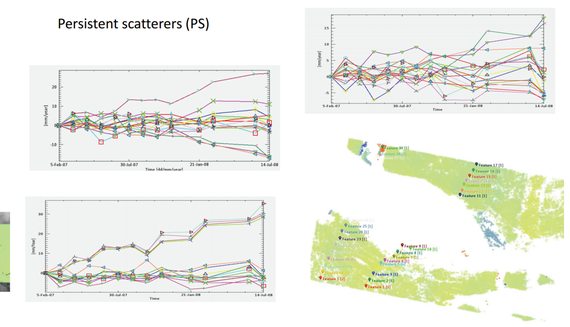

Figure. 5D

Discussion

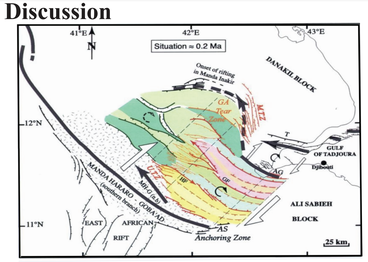

Figure 6 A. Simplified, synthetic structural map of Central Afar, Showing measured paleomagnetic rotations (Manighetti et al., 2001).

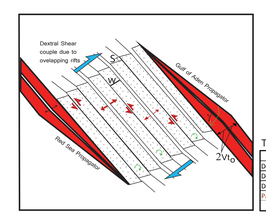

Figure 6 B. Bookshelf faulting model, modified from Tapponnier et al (1990). Overlapping rifts are shaded red. Blocks are bounded by normal-left lateral faults; open arrows for shear due to coeval opening of rifts; curved arrows for horizontal rotations; 2Vo is total amount of extension accommodated; γ is rotation angle, L, block length; W, width.

Given the length of the Dobi graben 17 km, 20.1km and 19.75 km for domain 3, 2 and 1 respectively, their respcective dispalcement velocity derived from InSAR, paleomagnetic rotation amouts that measured for the first order blocks, the bookshelf faulting model predicts an initial evolution period of the Dobi graben and the left lateral offset.

$$\gamma = \arctan\left(\frac{2V_o\alpha t}{L}\right)$$

Where, γ is rotation angle, L is block lengt, W is block width, S, total left lateral slip and α is 0.85

$$s = W_b \tan\gamma$$

Table 1. Kinematics measurements used to calculate the Left lateral offset derived from plaeomagnetic data.

	Width (mm)	γ (degree)	Tan(rad)γ	S (Total left lateral slip) (mm/year)
Domain 3	15000000	14.5	0.258617584	16.64
Domain2	11000000	14.5	0.258617584	10.03
Domain 1	6000000	14.5	0.258617584	4.34

Table 2. simplified trignometric equation of the bookshelf model used to show when extension become localized in the Dobi graben.

	Velocity(NE) (mm/year)	Velocity (SW) (mm/year)	2Vo (mm/year)	γ (degree)	Tan(rad)γ	Length(mm)	Time 1 (Year)	γ (degree)	Tan(rad)γ	Time 2 (year)
Domain 3	7.59	14.6	22.19	25	0.466307658	17000000	420286	14.5	0.258617584	233094
Domain 2	13.56	8	21.56	25	0.466307658	20100000	511447	14.5	0.258617584	283652
Domain 1	9	7.8	16.8	25	0.466307658	19750000	644928	14.5	0.258617584	357682
Pagali et al. (2014)	Arabia - Nubia Plates		18	25	0.466307658	17000000	518120	14.5	0.258617584	287353
	Arabia -Somalia plates		16	25	0.466307658	17000000	582885	14.5	0.258617584	323272

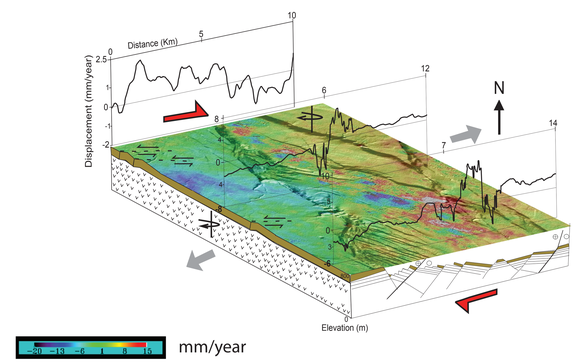

Figure 6 C. Kinematic model for Dobi graben. Dextral shearing of the ECB (Figs. 2D and 6B) is accompanied by sinistral shearing within the Dobi graben as evidenced by displacement curves from DInSAR image draped over SRTM and geologic cross section.

Conclusions

There is lack of significant shallow magmatic activity, therefore, the Dobi graben is amagmatic where strain is partioned by normal left lateral faults. We also conclude that episodes of rift localization appears to be initiated after 0.35 Ma.

References

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