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Stress field during early magmatism in the Ali Sabieh Dome, Djibouti, SE Afar rift

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ABSTRACT

The so-called Ali Sabieh range, SE Afar rift, exhibits an atypical antiform structure occurring in the overall extensional tectonic context of the Afar triple junction. We dynamically analyzed the brittle deformation of this specific structural high using four different methods in order to better constrain the tectonic evolution of this key-area in the Afar depression. Paleostress inversions appear highly consistent using the four methods, which a posteriori validates this approach. Computed paleostress fields document two major signals: an early E–W extensional field, and a later transcurrent field, kinematically consistent with the previous one. The Ali Sabieh range may have evolved continuously during Oligo-Miocene times from large-scale extensional to transcurrent tectonism, as the result of probable local stress permutation between $\sigma 1$ and $\sigma 2$ stress axes.

1. Introduction

1.1. Geological setting of the Ali Sabieh range

Tectonics of triple junction zones, of either continental or oceanic type, often lead to complex strain/stress patterns, generally caused by changes in the relative trajectories of the plates involved in the system. The corresponding far stress/strain fields may also interact with local fields of either tectonic or magmatic origin (Manighetti et al., 1997, 2001). Such a geodynamic configuration occurs in the Afar Depression, Horn of Africa, where three recent (<3 Ma) rift axes converge and disrupt the eastern edge of the earlier (30 Ma-old) Afar plume-induced volcanic province (e.g. Barberi and Varet, 1977; Courtillot, 1980; Hofmann et al., 1977). The current tectonics of the overall area is characterized by complex extensional plate tectonic processes and rift propagation, with potential stress rotation over the time (e.g. Tapponnier et al., 1990; Acton et al., 2000; Jestin et al., 1994; Huchon and Khanbari, 2003). Although the recent trap-like basaltic cover (3–1 Ma-old Stratoid Basalts) flooring the Afar Depression displays a dominant extensional strain, structural complexities are locally documented by active reverse faulting, inferred from focal mechanisms (Hofstetter and Beyth, 2003). They are interpreted in terms of local changes in the fault system due to variations in the rift propagation directions (Beyth, 1991). Paradoxal compressional tectonics is also assessed to have occurred at earlier rift stages in SE Afar. The reverse and strike-slip faults recorded by the ~3.6 Ma-old Ribta acidic volcanics in the NS-oriented Arta zone, southern margin of the Tadjoura Gulf of Djibouti, are assigned to stress permutation along an inferred transform fault structure (Arthaud et al., 1980).

The Ali Sabieh range (ASR), (Chessex et al., 1975; Muller and Boucarut, 1975), SE of the Afar rift in Djibouti (Fig. 1), is a 30 km-wide, deeply eroded, antiformal structure, plunging to the NNE, and culminating at ~1300 m to the south, where a >1000 m-thick pile of Mesozoic limestones (Jurassic) and grits (Cretaceous) (Black et al., 1972; Muller and Boucarut, 1975; Gasse et al., 1986) forms a large wavelength arch (Fig. 2). The large-scale antiform is cored by a mafic intrusive complex, interpreted as a laccolith that yielded 28–20 Ma K–Ar ages (Le Gall et al., 2010), much older than the Dalha-Somali (8.6–3.8 Ma) and Stratoid (3–1 Ma) basaltic trap-like complexes surrounding the ASR (Barberi et al., 1975; Barberi and Varet, 1977). The so-called Ali Sabieh mafic system also comprises effusive sequences, and their dense sill-dyke feeder system, that outline the outer rim of the antiform, above the Mesozoic pre-rift sequences (Fig. 2). The early synrift volcanics are unconformably overlain by the 20–9 Ma-old acidic lavas of the Mablas formation, which post-dated the onset of doming (Chessex et al., 1975; Varet

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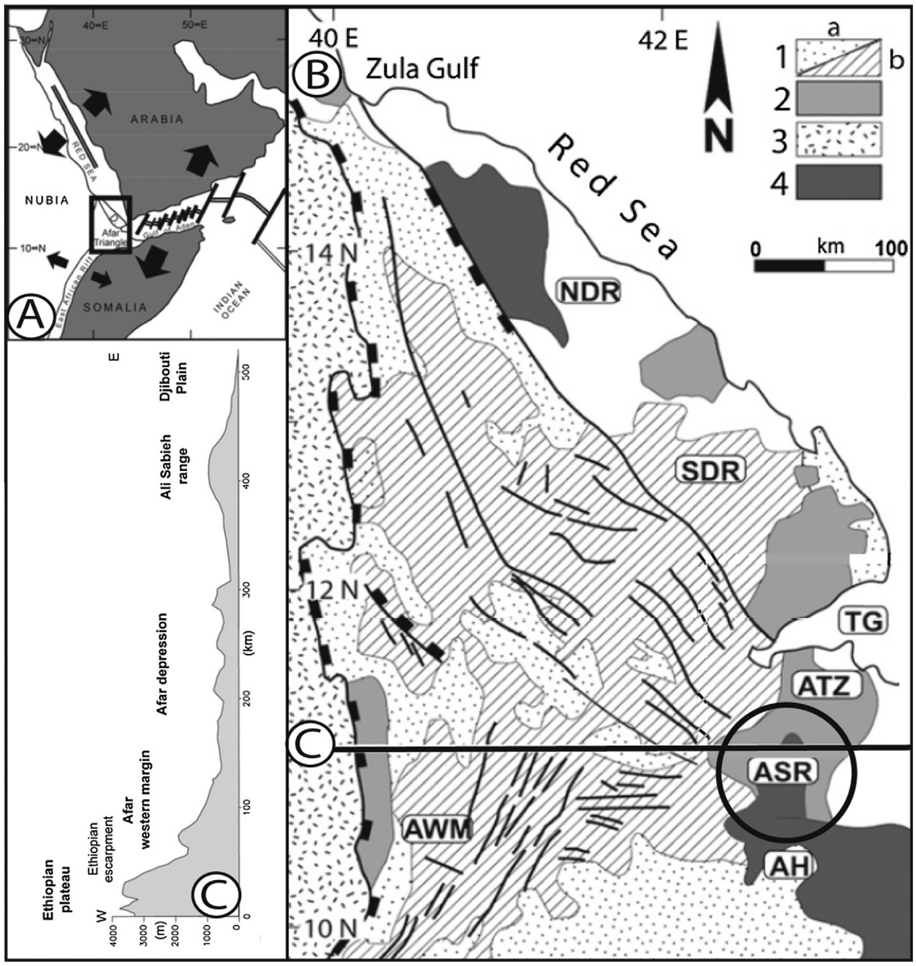

Fig. 1. Localization of the Ali Sabieh Range (ASR) within the global tectonic sketch of the Afar Triple Junction (modified after Le Gall et al., 2010). (A) Overall plate kinematics. (B) Geological framework with the main units: (1) <3 Ma-old series in the Afar depression, (1a) Lacustrine deposits, (1b) Stratoid basalts; (2) 29-3 Ma-old synrift volcanics; (3) 30 Ma-old trap complex; (4) >30 Ma-old substratum. AH, Aisha Horst; ASR, Ali Sabieh Range; ATZ, Arta Transverse Zone; AWM, Afar West Margin; NDR, North Danakil Range; SDR, South Danakil Range; TG, Tadjoura Gulf. The E–W bold line is the trace of the topographic profile (C). The circle localizes the target area of this study. (C) E–W topographic profile across the Afar Triple Junction area, showing the ASR structural high on the western edge of the Djibouti plain (vertical exaggeration 30).

and Gasse, 1978; Zumbo et al., 1995; Audin et al., 2004). The acidic dyke array spatially associated with, and parallel to, the submeridian and NE–SW-trending mafic dykes of the Ali Sabieh formation, likely represents the feeder intrusions of the Mablas series. These latter are, in turn, onlapped by extensive trap-like basaltic series of the 8.6–3.8 Ma Dalha series to the NW and of the 7.2–3.0 Ma Somali formation that floors the Djibouti Plain to the east (Gasse et al., 1986; Deniel et al., 1994). The magma-driven origin of the ASR antiform has primarily been argued by field observations, focused on the spatial relationships between the mafic laccolith coring the structure and its Mesozoic country-rocks that locally occur as discrete roof-pendants within the magma at the apex of the antiform (Le Gall et al., 2010). Two major fault networks cut through the ASR (Gasse et al., 1986). The sedimentary and volcanic series coring the ASR dome are dissected by NW–SE-trending faults that extend up to the Mablas acidic sequences. A NE–SW oriented fault system preferentially occurs on the eastern flank of the dome where it also involves Somali basalts.

1.2. Objectives of the study

The regional-scale ASR anticlinorium-like structure has first been linked to a compressional anticline (Clin and Pouchan, 1970). Alternative interpretations of the ASR antiform, as a horst-type structure, were later proposed (Gaulier and Huchon, 1991; Eagles et al., 2002). A third magma-driven kinematic model (doming) has recently been applied to the ASR from a structural study based on field-calibrated remote sensing data (Le Gall et al., 2010). The aim of the present paper is to complement and constrain this structural model using regional paleostress field determinations. The dynamic analysis of more than 500 fault–striae dataset using state of the art methods allows us to precisely characterize the brittle deformation and associated paleostress fields of the ASR, and to discuss their interpretations with regards to the SE-Afar extensional tectonic framework.

2. Brittle deformation

2.1. Field and remote sensing data

The ASTER satellite image covering the ASR shows linear traces of two prominent fault networks (Fig. 2). NW–SE-trending fault-like structures, 20 km-long, cut through the ASR mafic complex and Mesozoic overlying sedimentary series in the core of the antiform. One of these fault bounds to the east, with a still preserved morphologic expression, a SW-facing half-graben, filled with 28–20 Ma old effusive products of the AS mafic complex (Le Gall et al., 2010). Two additional NW–SE-oriented structures extend further west, outlined by elongated mafic bodies of the ASR complex (Fig. 1). Similarly-trending faults are documented at a