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Macrostructures vs microstructures in evaporite detachments: An example from the Salt Range, Pakistan

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ABSTRACT

The Salt Range, Pakistan is the surface expression of an evaporite detachment over which the Potwar Plateau fold-thrust belt has moved. Whilst previous publications regarding this region have focused on the petroleum prospectivity, deformation, and large-scale processes, this paper characterises the Salt Range detachment at the meso-(10 cm to 10s of metres) and micro-scale (cm to μm) and examines correlations to the macro-scale (10s of metres to kms). Two detailed scaled cross sections are analysed alongside structural measurements to characterise the detachment at the meso-scale with optical analysis of microstructures that formed during deformation characterising the micro-scale. Both ductile and brittle features observed in cross section indicate composite deformation processes acting simultaneously; this contrasts with models of salt detachments behaving homogeneously. Microstructural analysis indicates processes of grain boundary migration and crystal lattice distortions. The microstructurally revealed competition between intra-crystalline deformation and recrystallization at shallow depths and low temperatures links passes up-scale to mesoscale evaporite mylonites and progressively in the weaker units, whereas more brittle processes operate in the stronger lithologies in this near-unique outcrop of a the emergent toe of a major salt-bearing detachment fault.

1. Introduction

Shortening of the Earth's crust is commonly accommodated by fold-thrust belts that are mechanically decoupled from the underlying rocks by a detachment zone or horizon (Dahlstrom, 1969; Davis et al., 1983). The creation of fold-thrust belts is typically the result of far-field stresses, near-field stresses, or a combination of both (e.g. King et al., 2010; King and Backé, 2010; Morley et al., 2011b). The driving force of deformation defines whether the fold-thrust belt is thin-skinned, internally driven deformation, or thick-skinned where far-field stresses are dominant; a combination of both is possible depending on the nature and number of active detachment layers (Morley and Guerin, 1996; King et al., 2010; Morley et al., 2011b). Detachments are typically units of overpressured shale or salt and it is the extent of these units that determines the area of related deformation (Dahlstrom, 1990; Morley and Guerin, 1996; Rowan et al., 2004). The style of deformation within fold-thrust belts is strongly influenced by the nature of the detachment, such as strength of the overlying strata, lithology, pore-pressure, coefficient of friction, dip and dip direction of the detachment (Davis et al., 1983; Jaumé and Lillie, 1988; Dahlstrom, 1990; Koyi and Vendeville, 2003; Suppe, 2007; Simpson, 2010).

The South Potwar Basin, Pakistan, is an example of a distal foreland fold-thrust belt detaching over a thick salt layer, the Salt Range Formation (Krishnan, 1966; Jaumé and Lillie, 1988; Jaswal et al., 1997). The fold-thrust belt is being driven by a combination of far-field stresses (continent–continent collision) and near-field stresses (gravity gliding) (Jaumé and Lillie, 1988; Davis and Lillie, 1994) and represents the southernmost expression of the Himalayan orogenic deformation (Jaumé and Lillie, 1988; Davis and Lillie, 1994; Grelaud et al., 2002). Sediments of the Potwar Plateau are transported aseismically over the 2 ± 1° northward dipping basement, though local asperities within the detachment facilitate some seismic activity (Davis and Lillie, 1994; Satyabala

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et al., 2012). A down-to-the-north, normal, basement fault observed in seismic section (lines CW-13 and KK-4) causes the Salt Range Thrust to propagate to the surface forming the eponymous Salt Range (Fig. 1C) (Lillie et al., 1987; Baker et al., 1988). Buttressing of the southward-moving allochthonous Potwar Plateau against this fault accumulated stress at the site of this basement fault (Davis and Lillie, 1994; Cotton and Koyi, 2000). The increased stress, distal sediment loading, and salt lubricated faulting resulted in thrusting of the Neoproterozoic to Eocene rocks comprising The Salt Range above Quaternary sediments of the Punjab Plain (Fig. 1D) (Jaswal et al., 1997; Yeats et al., 1984).

Analyses of fold-thrust belts are extensively documented at the macro-scale (10's of kms), in the form of regional cross-sections, seismic interpretation, satellite data, and physical and numerical modelling (Lillie et al., 1987; Dirkzwager and Dooley, 2008; Chen and Khan, 2009; King et al., 2010; Morley et al., 2011b); yet few have attempted to explore the detailed structure of detachments at outcrop or smaller scale (e.g. Hansberry et al., 2014). Studying detachments at outcrop scale presents a number of difficulties; the majority of currently active detachments occur in inaccessible submarine settings, whilst the few active subaerial fold-thrust belts have insufficient degrees of erosion to allow surface outcrop of the detachment (Hansberry et al., 2014). Our recent fieldwork, carried out in the area of Khewra, Pakistan, has focused on the structures within the Salt Range Detachment (Fig. 1A and B). Here, we present structural observations and cross-sections within the Salt Range Formation and use these to characterise the meso-scale structure of the detachment. Samples taken along these cross-sections were analysed using an optical microscope to characterise the microstructural features of the detachment. We then discuss the meso- and micro-scale control on the larger-scale fold-thrust belt geometry.

2. Geological setting

2.1. Regional setting

The Salt Range exposes Neoproterozoic to Eocene sedimentary rocks of the Salt Range, Jhelum, Nilawahan, and Chharat Groups up to the Eocene Sakesar Limestone Formation, which forms the highest peak (Fig. 1D). The interior and direct hanging-wall of the Salt Range Thrust is composed of the Neoproterozoic Salt Range Formation, which forms the detachment underlying the associated fold-thrust belt to the north. This detachment is responsible for the observed thin-skinned contractional wedge geometry in the fold-thrust belt (Lillie et al., 1987). On a larger scale, the Salt Range mirrors the geometry of the Himalayan Orogen displaying a roughly E-W trend as it is a distal structure of the same orogenic event.

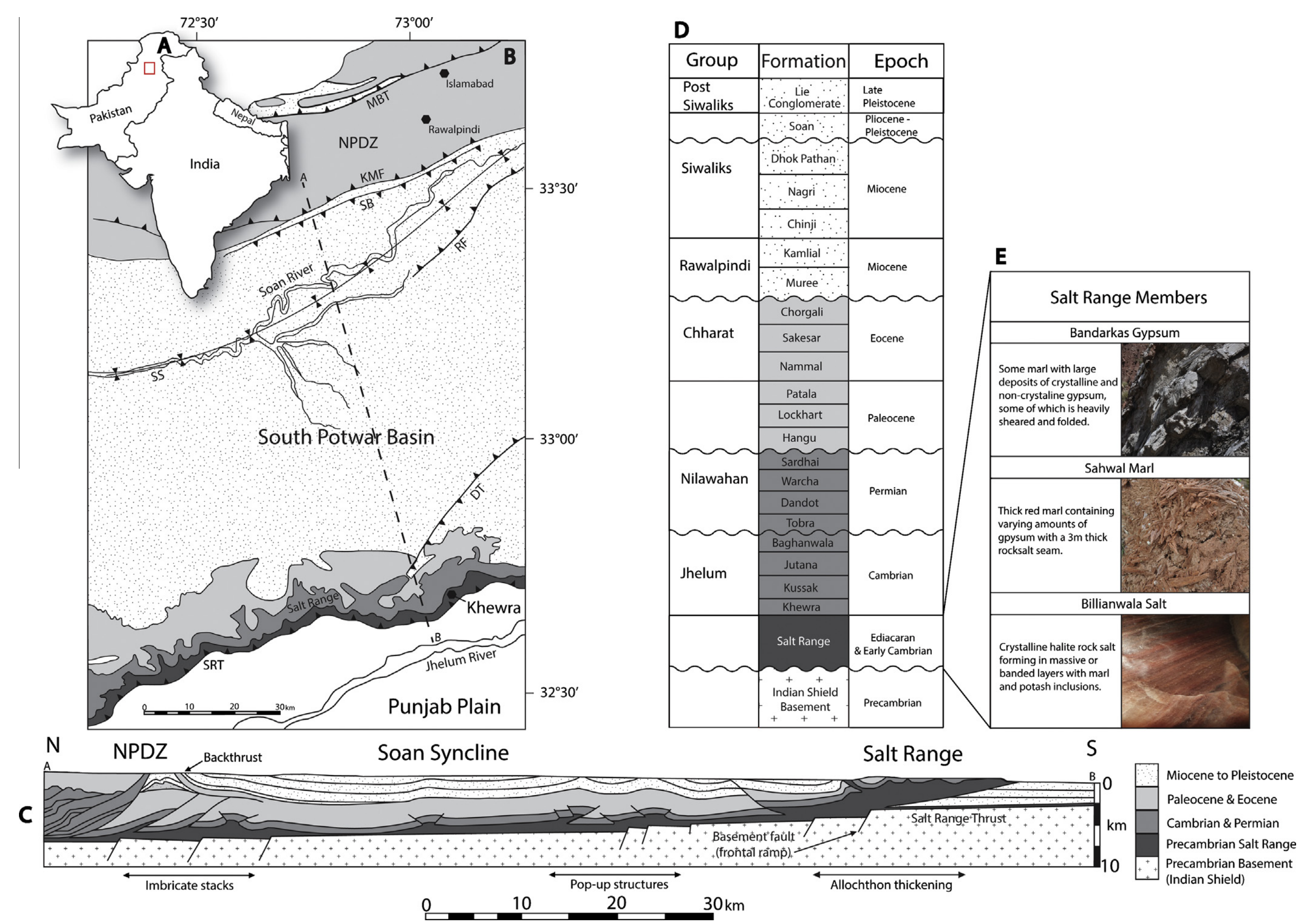

Fig. 1. Location map, cross section, stratigraphy column. (A) Location map of the study area. (B) Geological map of the eastern Salt Range and Potwar Plateau. The dashed line AB indicates the approximate transect of the cross section in (C). MBT = Main Boundary Thrust, NPDZ = North Potwar Deformation Zone, KMF = Khari Murat Fault, SB = Soan Backthrust, SS = Soan Syncline, RF = Riwat Fault, DT = Domeli Thrust, SRT = Salt Range Thrust (after Kovalevych et al., 2006). (C) Cross section through the NPDZ, SS, and Salt Range showing imbricate stacking, pop-up and/or pop-down structures, and a thickened zone of salt above a basement fault, respectively (after Cotton and Koyi, 2000). (D) Stratigraphic column of the units within the study area (after Grelaud et al., 2002). (E) Salt Range Member subdivisions (After Sameeni, 2009 and Ghazi et al., 2012).