Journal of Asian Earth Sciences 50 (2012) 79–87

Contents lists available at SciVerse ScienceDirect

Journal of Asian Earth Sciences

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

Lateral structural variation along the Kalabagh Fault Zone, NW Himalayan foreland fold-and-thrust belt, Pakistan

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ARTICLE INFO

Article history:
Received 21 July 2011
Received in revised form 6 January 2012
Accepted 11 January 2012
Available online 21 February 2012

Keywords:
Himalayas
Strike slip faults
Thrust geometry
Pakistan
Foreland fold-and-thrust belt
Salt tectonics
Remote sensing
Seismic reflection

ABSTRACT

The NW Himalayan fold-and-thrust belt in Pakistan is of gentler regional slope and wider extent than the other parts of the convergent plate boundary between India and the rest of Asia. Large scale structural re-entrants typify the Main Frontal Thrust (MFT) of the NW Himalayan fold-and-thrust belt in Pakistan. Understanding dynamics of the formation of these structural variations has been hampered by the lack of information about the lateral structures bounding the re-entrants. Our mapping of the Kalabagh Fault Zone, a lateral ramp linking the Salt and the Surghar Ranges, advanced spaceborne thermal emission and reflection radiometer (ASTER) data, field investigations and the interpreted reprocessed 2D seismic data. This integration of surface and subsurface geology provides new insights on the geometry and evolution of the Kalabagh Fault Zone, by showing that it forms an oblique ramp to the Main Frontal Thrust, and at north a lateral ramp with right-lateral strike slip movement. Our results indicate that the presence and areal extent of the evaporates is the dominant factor controlling lateral structural variation in the NW Himalayan fold-and-thrust belt of Pakistan. The Kalabagh Fault Zone acts as a zone that accommodates differential shortening and structural variation along the orogenic trend.

1. Introduction

Overthrusting related to Indo–Asian continental collision has generated a major foreland fold-and-thrust belt in the Himalayan mountain range. From north to south, four tectonostratigraphic units are distinguished in the active foreland fold-and-thrust belt of Northern Pakistan (review by DiPietro and Pogue (2004)): (1) the Main Boundary Thrust (MBT) zone; (2) the Kohat, Potwar Plateaux and the Bannu Basin; (3) the Salt Range and the Trans-Indus Range; and (4) the Punjab Foreland Basin (Fig. 1). The Salt and the Trans-Indus Ranges are the surface expression of the leading edge of the foreland fold-and-thrust belt. The Main Frontal Thrust (MFT) lying at the foot of these ranges juxtaposes pre-Tertiary rocks detached at the base of a Precambrian–Cambrian sequence above younger rocks formed within the undeformed Punjab Foreland Basin. The map expression of MFT and its associated ranges is characterized by a sinous structural trend in North Pakistan giving rise to a couple of salients and reentrants which are bounded by strike slip faults at their margins. In contrast, the foreland fold-and-thrust belt between the MBT and the MFT in the Indian Himalayas is much narrower, simpler and exposes only the Tertiary sediments (Yin, 2006). The complex structural pattern and lateral structural variations of the MFT and associated ranges of north Pakistan are considered to be related to rheological and along strike variations along the basal decollement (Lillie et al., 1987 and Davis and Lillie, 1994) lithospheric scale, north south trending antiformal folding along the Hazara Kashmir syntaxis (Burg and Podladchikov, 1999) and shape of downgoing continental slab (Marshak, 2004). Along-strike changes in structure are reported from other places in the world, for example Perez-Estaun et al. (1997) described several along-strike structural changes in the foreland thrust and fold belt of the southern Urals, Harris and Milici (1977) in the Southern Appalachians and Elliott and Johnson (1980) from northwest Scotland. The Kalabagh Fault Zone, the western margin of the Potwar Plateau, is the eastern flank of the Kalabagh re-entrant, which represents a large lateral structural variation.

Three possible explanations have been suggested for the formation of the Kalabagh Fault Zone: (1) it is an en-echelon branch of the Chaman Fault, which is a transform plate boundary between the Indian and the Asian plates in Pakistan and Afghanistan (Treloar et al., 1992); (2) it is a lateral ramp of the MFT (Butler et al., 1987); and (3) it is a transpressional strike-slip fault (McDougall and Khan, 1990). In order to find out which, if any, of these three possibilities best explains the formation of the Kalabagh Fault Zone, we integrated ASTER data with information from seismic lines to make a new interpretation of the structure of the Kalabagh Fault Zone. Cross-sections have been constructed to help

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doi:10.1016/j.jseaes.2012.01.009

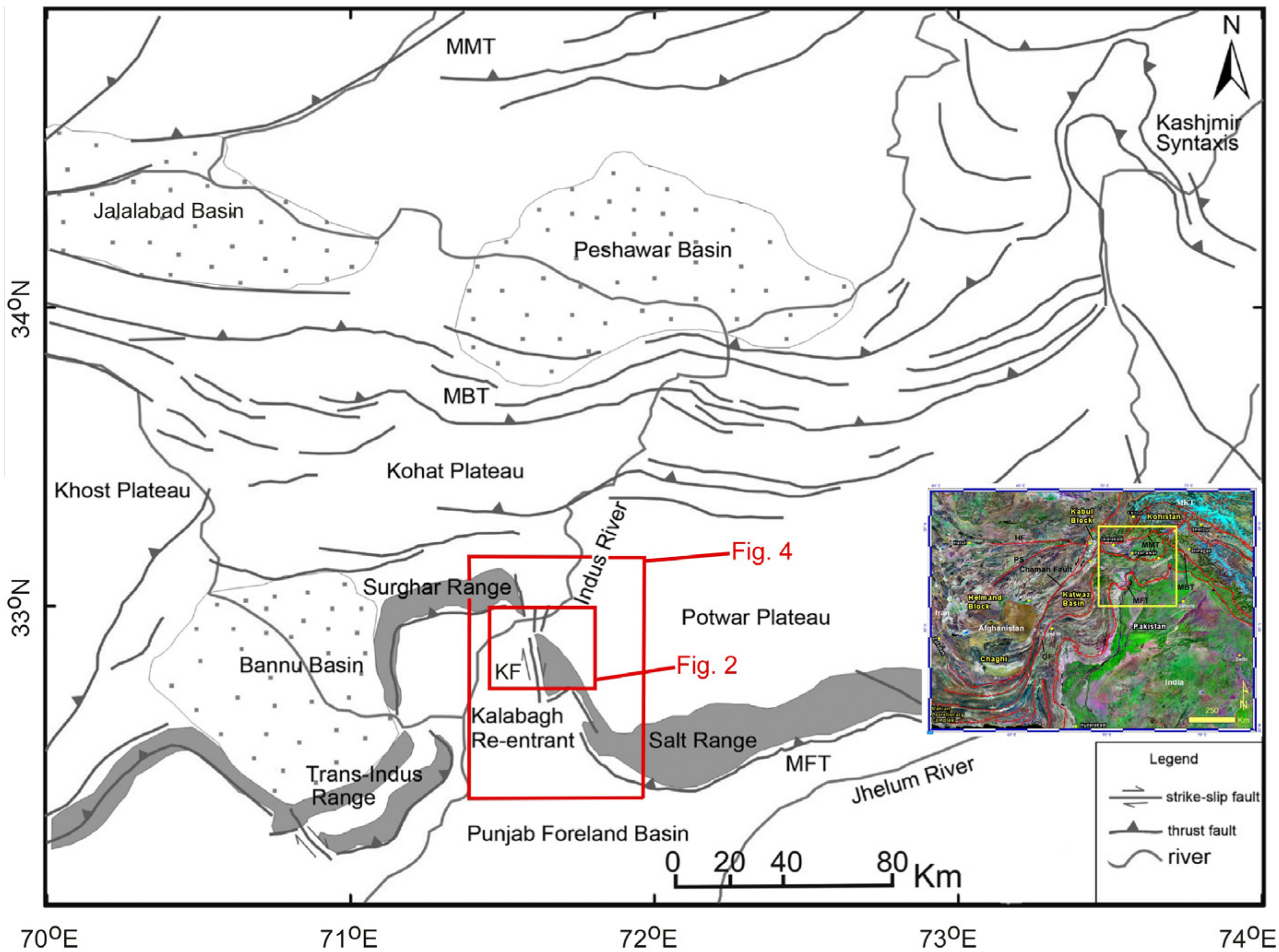

Fig. 1. Map showing the NW Himalayan foreland fold-and-thrust belt in Pakistan. MMT = Main Mantle Thrust; MBT = Main Boundary Thrust; MFT = Main Frontal Thrust; KF = Kalabagh Fault. The gray part is the active ranges at the front of the foreland fold-and-thrust belt. The rectangular box around the KF is the area of Figs. 2 and 5. Structures modified from Chen and Khan (2009, 2010). Inset map modified from Khan et al. (2009) showing tectonic sketch map of southeast Asia. GF = Ghazband Fault; PF = Panjao Shear; HF = Heart Fault; MKT = Main Karakoram Thrust.

understand fault geometry and the role of salt in the structural variations of the NW Himalayan foreland fold-and-thrust belt.

2. Tectonic setting and stratigraphy

The basement of the NW Himalayan foreland fold-and-thrust belt is formed of granites and gneisses of the Indian Shield and younger Precambrian meta-sediments and meta-igneous rocks (Davies and Crawford, 1971; Kochhar, 1982). The overlying stratigraphy can be divided into three major units: the Salt Range Formation, the overlying platform sediments, and the molasse sediments (Khan et al., 1986). The oldest sedimentary rocks, the Salt Range Formation (Precambrian), unconformably overlie the Precambrian basement rocks (Shah, 1977). This Precambrian evaporitic sequence is exposed in the Salt Range and the Kalabagh Fault Zone and is considered to represent a weak décollement beneath the foreland fold-and-thrust belt. Its thickness varies from tens to thousands of meters at different localities. The average thickness is about one thousand meters in the western Potwar Plateau (Butler et al., 1987).

The platform rocks consist of Middle-lower Cambrian to Lower Eocene rocks that thins eastward (Shah, 1977; Yeats and Hussain, 1987). The platform rock assemblages record a fairly quiet period of continuous sedimentation in a shallow sea concomitant with the down-sagging of the Kohat–Potwar trough. The sagging was occasionally interrupted by block uplifts, often of prolonged duration that resulted in disconformities that spread over a vast time span. Two major unconformities within the platform sequence dip very gently towards the east (Gee, 1980). The older unconformity separates the Permian rocks from Cambrian rocks, whereas the second one separates the Tertiary rocks from the older formations. After the deposition during the Middle Eocene sequence, the initial phase of the Himalayan orogeny initiated and the sea receded from the Kohat–Potwar Basin, leaving a fluvial–lacustrine environment. The event is marked by the widespread Oligocene unconformity. In Mio-Pliocene and Pleistocene, the area received an enormous amount of detrital material in fluvial and lacutrine environments of sedimentation with a gradual westward younging from the Salt Range in the east up to the Trans Indus Ranges in the west. The post-platform sequence consists of a lower unit referred to as the 'Rawalpindi Group' and includes the Murree and the Kamlial formations. The Siwalik Group, which lies above the Rawalpindi Group consist of the Chinji, the Nagri, the Dhok Pathan and the Soan formations. The sedimentary sequence exposed along Kalabagh hills is comprised of Salt Range Formation at the base followed by platform and molasse sequence similar to elsewhere in Salt Range (Gee, 1980). It is important to know that the exposure of the Precambrian salt is confined to the Kalabagh hills located along the eastern margin of the Kalabagh reentrant and has not