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Geomorphic evidences and chronology of multiple neotectonic events in a cratonic area: Results from the Gavilgarh Fault Zone, central India

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ABSTRACT

The ENE–WSW trending Gavilgarh Fault Zone (GFZ) is an important tectonic lineament within the Central Indian shield. Geomorphological mapping and spatial analyses of rivers were carried out to elucidate the imprints of active tectonics on the fluvial systems of this region. The sinuosity index, width–depth ratio of river valleys, longitudinal profile, S–L index and hypsometric index of the rivers flowing from north to south across the GFZ lineament suggest that the northern side of GFZ was tectonically uplifted. Luminescence dating of sediments from river terraces and calculation of knickpoint migration rates in the rivers indicate occurrence of multiple neotectonic events in GFZ at ca. 65–80 ka, ca. 50 ka, ca. 30–40 ka, and ca. 14 ka. Evidences of neotectonic activity, presence of active geothermal springs, and occurrence of recent earthquakes along GFZ suggest that this lineament is tectonically active and there is a need for proper seismic monitoring of this fault zone.

1. Introduction

The central part of the Indian Peninsular Shield, commonly referred to as the Central Indian craton, comprises two Archaean cratonic fragments viz. the Bundelkhand craton in the north and the Dharwar–Bastar craton in the south. These cratonic blocks were stitched together along a major Proterozoic mobile belt through multiple events of Palaeo- to Neoproterozoic crustal accretion (Chattopadhyay and Khasdeo, 2011; Roy and Hanuma Prasad, 2003). This E–W trending crustal scale mobile belt is called the Central Indian Tectonic Zone (CITZ) (Fig. 1A: inset). Precambrian crystalline basement rocks of CITZ are overlain successively by: a) the coal-bearing Gondwana Supergroup of Permo-Triassic to Early Cretaceous age, b) vast expanses of Deccan Trap flood basalts of Late Cretaceous–Tertiary age and, c) fluvial sediments of Quaternary age (Fig. 1A). The Central Indian craton has generally been considered as a stable continental region with low strain build-up and a long earthquake recurrence period (Roy and Mohabey, 2003). However, this region experienced five devastating earthquakes in the recent past viz. at Koyna (1967, M = 6.5), Broach (1970, M = 5.7), Killari (1993. M = 6.2), Jabalpur (1997, M = 6.0) and Bhuj (2001, M = 7.7) (Roy and Devarajan, 2003). Neotectonic reactivation of old faults/shear zones was considered as the cause of these SCR (stable continental region) earthquakes (Acharyya and Roy, 2000; Bhattacharya, 2007; Rajendran et al., 1996). Faults responsible for these earthquakes are generally blind and difficult to identify in the field. As a result, their tectonic history is poorly understood. Delineation of neotectonic activity along known fault zones and tectonic lineaments within the central Indian craton is therefore necessary to understand the nature and behaviour of seismogenic faulting in the core region of the Indian Peninsular Shield.

The present contribution analyses the neotectonic activity of the Gavilgarh Fault Zone (GFZ) — a prominent tectonic lineament within the CITZ. GFZ is an ENE–WSW trending lineament, about ~250 km long and lies halfway between the Son-Narmada South Fault (SNSF) and the Central Indian Shear (CIS) (Fig. 1A). At places GFZ is known as the Satpura Foothill Fault where it marks the southern limit of the roughly E–W trending Satpura Mountains. On the ground, GFZ is marked by a fault line along which rocks of different ages (e.g. Gondwana Supergroup and Deccan Trap basalts) are juxtaposed against each other. Ravishanker (1987) identified the geothermal activity in this area and considered this fault (his 'Satpura Foothill Fault') as a major, tectonically active, element of the Narmada–Tapti rift system. The eastern part of the GFZ lineament is represented by a ductile shear zone comprising a variety of sheared Precambrian granitoids and gneisses, generally known as the Gavilgarh-Tan Shear zone (GTSZ) (Chattopadhyay and Khasdeo, 2011). In the present study area, the shear zone could not be directly observed, but its presence at depth was confirmed by the occurrence of a km-long tectonic sliver of granitic mylonite along the fault line.

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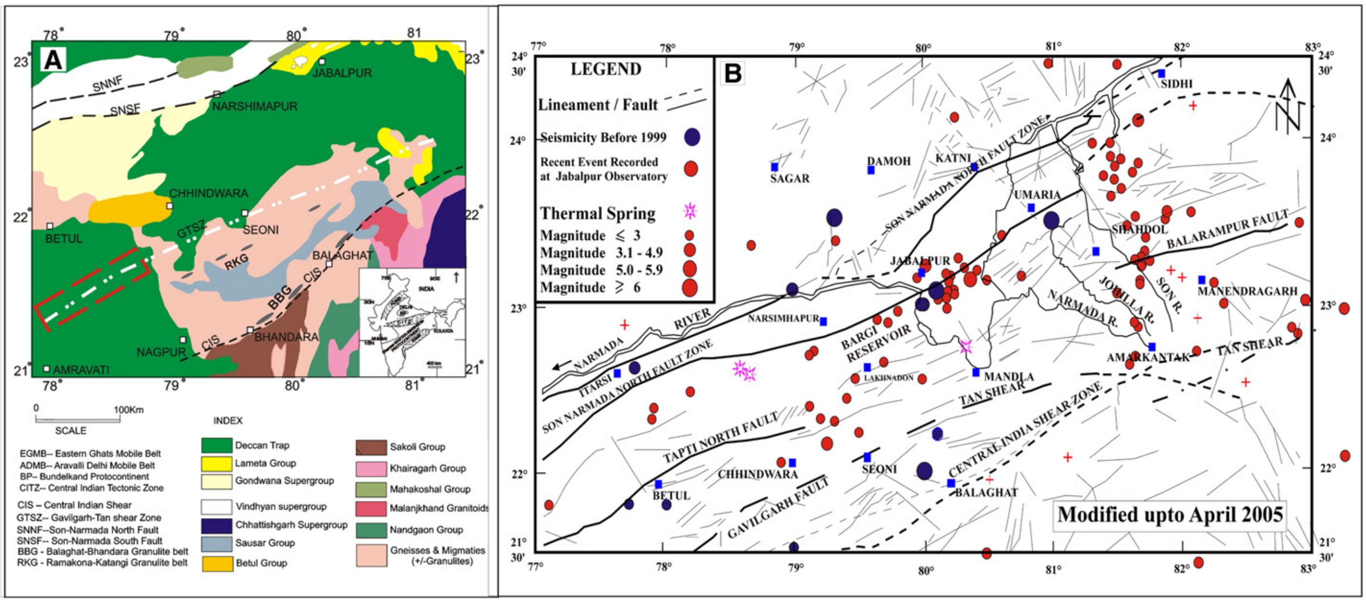

Fig. 1. (A) Simplified geological map of Central Indian Tectonic Zone (CITZ) with the major lineaments shown on the map. Red box indicates the present study area along GFZ (modified after Chattopadhyay and Khasdeo, 2011); (B) spatial distribution of low to moderate magnitude earthquakes within CITZ (modified after Pimprikar and Rao, 2000).

Roy and Devarajan (2003) characterized recent seismicity within CITZ as deep intraplate earthquakes triggered by reactivation of crustal scale faults near the crust–mantle boundary. These authors marked the Gavilgarh Fault (i.e. GFZ) as a potential seismic zone due to its favourable orientation for fault reactivation under the current plate-tectonic stress regime. Numerous low to moderate magnitude earthquakes have been recorded along the GFZ/GTSZ lineament during the last century (Fig. 1B), suggesting that it is tectonically active. Pimprikar and Rao (2000) suggested that the Son-Narmada South Fault (SNSF) and GFZ together account for about 99% of the seismic energy released in CITZ.

In view of the above, the present study attempts to reconstruct the history of neotectonic activity in GFZ using changes in fluvial morphology of the drainage basins of the area. Rivers flowing N–S and cutting across the GFZ lineament were selected to document changes in geomorphic features across the fault line. Geomorphic features such as drainage anomalies, inferred from remote sensing data, were validated in the field and appropriate terrace sediment samples were dated by the Optically Stimulated Luminescence (OSL) method. The luminescence ages, along with the ages calculated from knickpoint migration rates, provide a chronology of the neotectonic events in GFZ.

2. Geology of the study area

The study area exposes a variety of rocks of Precambrian to Quaternary age. The oldest lithounit is a Neoproterozoic granite mylonite (Chattopadhyay et al., 2014) exposed along GFZ at Salbardi as a small (1 km long and 200 m wide) tectonic slice, bounded on all sides by crushed and sheared contacts with surrounding rocks. North of GFZ, this mylonite unit is successively overlain by cross-bedded sandstone units of the Permian–Early Cretaceous Gondwana Supergroup, calcareous units belonging to the Lameta Formation of Late Cretaceous age and Deccan Trap basalts of Late Cretaceous–Tertiary age. South of the GFZ, only Deccan Trap basalts are exposed. At some places e.g. Salbardi, Dhamandas, Kumandera, Dharul and Palaskheri, Gondwana sandstones are directly juxtaposed with the Deccan basalt along the fault line (Fig. 2A). Evidences of brittle movements and crushing are observed at the contacts of different litho-tectonic units. For example, a thin layer of crushed basalt occurs along the contact of granite mylonite and Gondwana sandstone in the Maru riverbed near Salbardi. Intermittent geothermal activity, in the form of hot springs, is seen along the entire stretch of the GFZ. The conductive temperature gradient in these geothermal springs is ~65 ± 8 °C/km and the average heat flow in the entire area is 125 ± 15 MW/m^2 which is twice the global average. Such a high heat flow was earlier interpreted as an indicator of neotectonic activity along this fault zone (Ravishanker, 1995). However, the exact nature of neotectonic movements along GFZ was not systematically characterized.

Basaltic flows constitute the high hills of the Satpura Mountain Ranges in the north of GFZ. Major rivers like Wardha, Maru, Purna and Arna and their tributaries of different orders flow down the southern slope of Satpura and cross the GFZ to travel farther south (Fig. 2B). The Deccan Trap is the major basement rock for these rivers which have a catchment area of up to a few hundred km^2. In the following sections we describe the morpho-tectonic analyses of these rivers, followed by a discussion on their tectonic significance.

3. Methodology

3.1. Geomorphic analysis

Imprints of tectonics on fluvial patterns were analysed through cross-sectional forms (longitudinal profile and S–L index), planform features (channel sinuosity) and hypsometric integrals. ASTER DEM images of 30 m spatial resolution were processed in ArcGIS™ for morphometric analysis of the selected rivers. Fluvial geomorphology of rivers e.g. Wardha, Maru, Purna, Arna, and Nag and their tributaries that cut across the GFZ and drain into the Tapti-Purna basin, was studied in detail.

3.1.1. Longitudinal profile and S–L index

Longitudinal profiles of the rivers were generated from ASTER DEM data through extraction of the coordinates, elevations and flow accumulation values for each pixel along a particular drainage. After rearranging the pixels in the order of increasing flow accumulation values, cumulative distance between consecutive pixels gave the along-stream lengths of the rivers. The cumulative distance was then plotted against elevation to make a longitudinal profile. The slope–length (SL) index was