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Thick sedimentary sequence around Bahraich in the northern part of the central Ganga foreland basin

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ABSTRACT

We present the results of a magnetotelluric study along a 285 km long profile between Hamirpur and Rupadia (Nepal border) across the central Ganga basin. The electrical resistivity image obtained by combining 1-D Occam inversion models for 39 sites reveals a significant contrast in the subsurface structure from south to north along the profile. At the southern end, the Bundelkhand massif is delineated as a high resistivity block buried beneath 250–300 m thick sediments. The thickness of sediments gradually increases to about 500–600 m at Kanpur, and to about 1.2 km at Lucknow. Here, the basement depth increases to more than 2.5 km within a profile distance of 20 km, which could be attributed to the Lucknow fault. The underlying rocks also have moderate resistivity and possibly represent the Vindhyans. The sedimentary sequence at the northern end of the profile around Bahraich is more than 9 km thick. Integrating the resistivity image with a published seismic velocity structure from the region and the lithology from the 3927 m deep Matera-I well reveals that the top 4 km succession is constituted of highly conductive Oligocene and younger rocks of the Matera Formation and the Siwaliks, and recent sediments whereas the underlying >5 km section is composed of sedimentary rocks of the Bahraich Group overlying the Archean basement. The high conductivity of sediments in conjunction with the low seismic velocity and large Vp/Vs obtained by receiver function analysis implies poor consolidation of sediments and thus high seismic hazard potential. The present results have implications for hydrocarbon exploration, hazard potential scenario of the central Ganga basin, and flexural strength of the Indian Plate.

1. Introduction

The Ganga basin constitutes the central part of the Indo-Gangetic–Brahmaputra plains. This approximately 300 km wide sedimentary basin lies between the Indian Peninsular Shield and the Himalaya and follows the strike of the Himalayan belt. The basin is bounded in the west by the Delhi–Sargodha Ridge and in the east by the Monghyr–Saharsa Ridge. Siwalik foothills form its northern boundary and the Vindhyans and the Bundelkhand massif form its southern limit (Sastri et al., 1971; Shukla et al., 1994). Presently, it is a peripheral foreland basin formed by the flexure of the Indian Plate in response to the load of the Himalaya in which Neogene sediments have been deposited on pre-orogenic Paleogene shelf suites. This region was considered as an intra-cratonic rift in Early Proterozoic that subsequently changed over to a peri-cratonic set-up (Pramanik et al., 1996).

The sediments brought and deposited by the network of major rivers Ganga, Yamuna, Indus, and Brahmaputra, and their tributaries form a thick alluvial cover masking the entire geological structure of the basin. Therefore, the underlying geology of the Ganga basin is largely inaccessible and speculations have been made about the continuation of major structural and tectonic features of the peninsular shield, e.g., Bundelkhand massif, Vindhyan Group of rocks, and Aravalli–Delhi fold belt, beneath the Ganga basin (Krishnan and Swaminathan, 1959; Sastri et al., 1971). Bundelkhand massif, exposed at the southern fringe of basin, is considered to be forming the basement of the central Ganga basin and extending in a NE direction below the alluvial cover as Faizabad Ridge (Sastri et al., 1971; Sengupta, 1962).

The presence of thick sediments evoked interest in the basin for its hydrocarbon potential leading to extensive geophysical surveys in the fifties and sixties followed by deep drillings by Oil and Natural Gas Corporation (ONGC) Limited, especially along the Himalayan foothills regions where the thickness of sediments was anticipated to be the maximum. The details of these geophysical surveys are described in the next section. Besides hydrocarbon potential, the Ganga basin provides constraints for flexural models of the Indian Plate and thus the basement structure can help in constraining the models of the mechanical strength of the Indian Plate and evolutionary model of the Himalaya. In recent years, there is renewed interest in the basement structure of the basin because of earthquakes induced hazard potential due to the possible presence of thick sediments in the basin. Many devastating earthquakes have occurred all along the Himalayan frontal belt. The highly populated Indo-Gangetic plains have been severely affected by these earthquakes. The 1934 Bihar–Nepal earthquake is a classical

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example that caused damage up to far-off places (Auden and Ghosh, 1934).

Despite the availability of fairly good information on the structure of the sedimentary basin at the foothills of the Himalaya due to hydrocarbon exploration activities, very little is known about the basement structure of the entire basin and the fabric of the geological structure of the peninsular shield extending below the sedimentary cover. Here, we present the basin configuration along a profile across the central Ganga basin using magnetotelluric (MT) method. Earlier, Singh et al. (1992, 1995) carried out MT study in the southern part of the Ganga basin. In view of the seismic vulnerability of the region, we have carried out MT study to delineate the basement structure and the electrical resistivity of the sediments and sedimentary rocks overlying the Indian Plate. As the electrical resistivity is sensitive to the presence of pore fluids, the subsurface electrical resistivity image in conjunction with seismic velocity structure could be used to identify possible zones of weakness within the sedimentary strata.

2. Geophysical studies

Initial regional aeromagnetic survey of the Indo-Gangetic basin revealed very large thickness of sediments (about 10–15 km) in some sections of the basin, especially at the Himalayan foothills (Agocs, 1957) which led to extensive hydrocarbon exploration activity by ONGC Limited and creation of a wealth of information about the basement configuration from the geophysical data and some deep exploratory wells drilled in the plains of Punjab, Uttar Pradesh, Bihar, and Bengal (Agarwal, 1977; Chand et al., 2012; Fuloria, 1996; Raiverman et al., 1983; Rao, 1973; Rao and Sengupta, 1964; Sastri et al., 1971). Seismic data from the Ganga plain and the sub-Himalayan thrust belt indicate partitioning of the Ganga basin in a succession of spurs and depressions (Raiverman et al., 1983). Based on seismic data, the Ganga basin is subdivided into shelf areas that are separated by transverse ridges (Sastri et al., 1971). Exploratory wells provide the details of the subsurface stratigraphy and have revealed a thick succession (500–1500 m) of Neogene (Siwalik) sediments beneath the Ganga alluvium. Many workers (e.g., Pramanik et al., 1996; Shukla et al., 1994) opined that the pre-Tertiary sequence of the Ganga basin is the northern subsurface extension of the Proterozoic Vindhyan sediments.

Recently, Srinivas et al. (2013) estimated the thicknesses of sedimentary layers, shear wave velocities, and Vp/Vs at ten broadband seismic stations located along a profile between 79°E–81°E and 24°N–29°N within the Indo-Gangetic plains. Their results reveal a single sedimentary layer of less than 1 km thickness and Vp/Vs of about 2.7 before Lucknow and a two-layered model for the sites further north. The second layer has shear wave velocity of 2.32–2.40 km/s and Vp/Vs of 1.87–1.99. The thickness of the sedimentary column at Lucknow is 1.2 km, which increases to 3.7 km at the northernmost site BSR (Fig. 1).

Barring a few MT surveys carried out in the foothills region extending Himalayan transects into the Indo-Gangetic plains, the vast tracts of this basin remain unexplored for their electrical conductivity structure. Earlier, Arora and Mahashabde (1987) delineated a mid-crustal conductor, the Delhi–Hardwar Ridge, across the western Ganga basin by magneto-variational studies. Singh et al. (1992, 1995) conducted MT surveys along the Kanpur–Nepal border (K–NB) profile across the central Ganga basin and another profile at the southern fringe of the basin. The stations' coverage however was inadequate to delineate the detailed basement structure of the basin. Singh et al. (1992) inferred, based on 1-D modeling of MT data of seven sites along the K–NB profile, an anticlinal structure around the Bahraich area and lithospheric upwarp, with the lithosphere rising from the depth of 90 km at Kanpur to about 40 km between Lucknow and Bahraich. Singh et al. (1995) corrected the MT data for the screening effect of the electrically conductive thick alluvial sediments to delineate the deeper structure. They estimated the total conductance and assumed a layered model in which the top alluvial layer had laterally varying resistivity. In this model, the

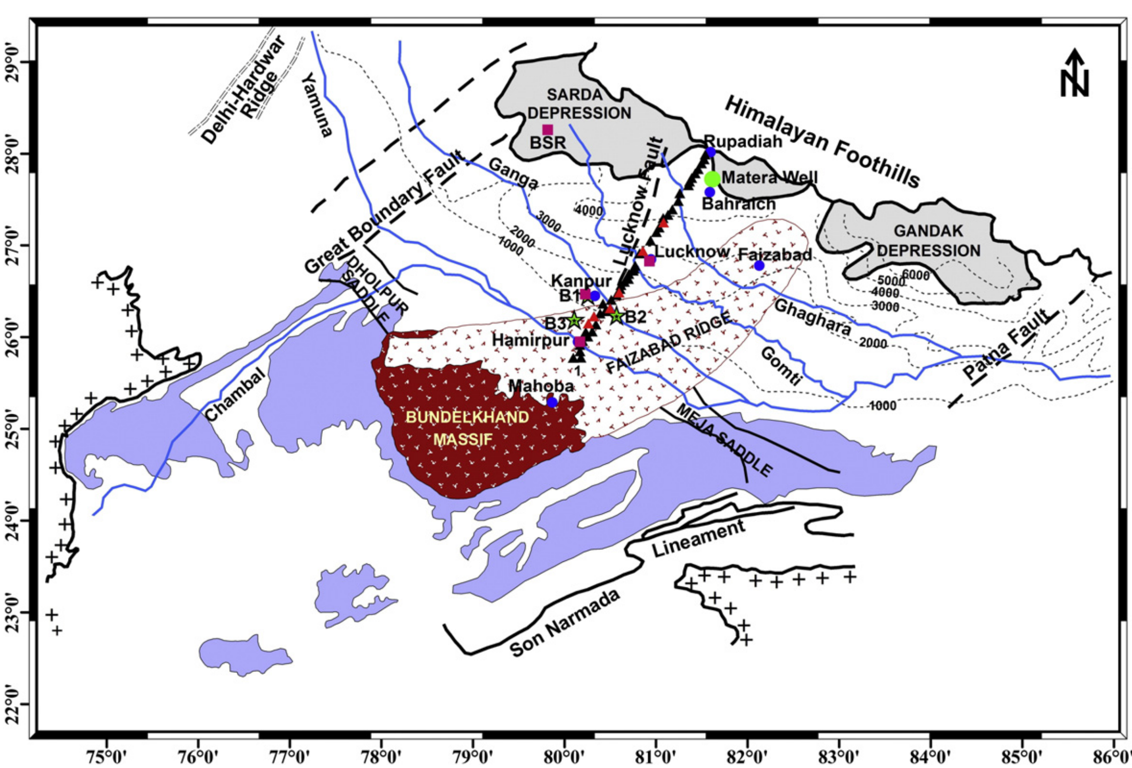

Fig. 1. Map of the Ganga basin with inferred subsurface extension of the Bundelkhand massif (after Rao, 1973 and Srivastava et al., 1983). Black triangles represent MT sites used in the present study and red triangles are the discarded sites. Pink rectangles are seismological sites and stars are the locations of the deep bore wells for groundwater. Green circle is the Matera-I deep borehole. Gray shaded areas along the Himalayan foothills are the regions inferred to be having thickest sediments based on hydrocarbon exploration studies. Dashed contours represent the basement depth obtained by aeromagnetic and other geophysical studies and the numbers refer to the depth in meter.