In situ occurrence of *Vertebraria* roots in the Raniganj Formation of Singrauli Coalfield and its palaeoecological significance

The present study records exceptionally well preserved *in situ Vertebraria* Royle axes (rooting structure of glossopterid plants) and the horizontally preserved *Glossopteris* leaves from the Raniganj Formation of Singrauli Coalfield (M.P.), Son-Mahanadi Basin. The form genus *Vertebraria* has wide distribution from lowest Permian Talchir Formation to Lower Triassic Panchet Formation in all the peninsular Gondwana basins of India. It is characterized as an elongate, branched or unbranched axis with two or more longitudinal series of rectangular areas. The axes are mostly found preserved as impressions or fusanized compressions in the sediments and rarely as permineralized specimens or flattened cylindrical casts. The rooting nature of *Vertebraria* and its alliance to glossopterid plants has been suggested by various workers[1–6]. The orientation of the *Vertebraria* axes is either parallel or perpendicular to the bedding planes. It is the attitude and nature of roots in relation to the sedimentary layers/beddings that actually provide a means of judging whether the roots are preserved in their original place of growth or are drifted ones[3]. In comparison to the occurrences of horizontally preserved *Vertebraria* axes (generally regarded as the drifted ones) which are extensively reported in Indian Gondwana[7–13], the records of vertically preserved *in situ Vertebraria* are meagre. The prevalence of horizontally preserved *Vertebraria* axes along with dispersed specimens of leaves and fruiting structures, whereas the scantiness of vertically preserved roots and stems in the sediments has led to the theory of allochthonous or drifted deposition of Indian coal beds.

In situ preserved *Vertebraria* axes in the Indian Gondwana have earlier been recorded from the root beds in the floor of the coal seams in Saharjuri coalfield[14,15], Daltonganj coalfield[16,17]; Jharia and Wardha valley coalfields[18], Auranga coalfield[19] and Ib River coalfield[20]. These *in situ* records along with a supposed record of upright stems with branches bearing *Glossopteris* leaves occurring at right angles to the bedding plane and placed on vertically preserved *Vertebraria* roots with spreading side branches from the Barakar Formation, Saharjuri Basin, Jharkhand, India, however, advocate the theory of autochthonous deposition of Indian coal beds[21].

For the present study about 60 specimens of vertically oriented *Vertebraria* roots, some of them deeply penetrating across the sedimentary layers, were collected from the Raniganj Formation of Jhingurdah open cast colliery, Singrauli Coalfield, M.P. (Figure 1). The Singrauli Coalfield lies between 23°47′–24°12′N and 81°48′–82°52′E, and embodies the last deposits of the Gondwana sedimentation in the northern part of peninsular India. The total area of this coalfield is around 2200 sq. km. It has ten opencast collieries of which nine (with three coal seams, i.e. the lower Turra seam, middle Purewa bottom and upper Purewa top) belong to the Barakar Formation. Jhingurdah Colliery has two coal seams, i.e. Jhingurdah Top and Jhingurdah Bottom which belong to the Raniganj Formation. Jhingurdah Colliery has the thickest coal seam (134 m) in India and also has the deepest basinal area among all other collieries of this coalfield[22].

The *Vertebraria* bed (24°12′11.5″N; 82°43′16.1″E) occurs in a thin sequence of siltstone in Jhingurdah Top seam of the Raniganj Formation (Figure 2). The grey-coloured fine siltstone unit is 1–2 m thick and fining upwards, exhibiting gradational contact with the underlying grey mudstone/carbonaceous shale unit and a sharp contact with overlying fire clay unit. The lower part of the siltstone unit exhibits parallel laminations, whereas the middle and upper parts are homogeneous. The laminated part is 5–10 cm thick, and can be differentiated into two subunits of laminated bands delineated by very sparsely laminated middle subunit (Figure 3 *d* and *f*). The laminations are <2 mm thick, alternating with dark grey and greyish-white coloured lamellae. This complete siltstone unit clearly represents two sets of cyclic sedimentation. The lower thinly laminated unit with fining upwards signature depicts suspension-load sedimentation in a low-energy environment followed by the deposition of homogenous siltstone unit that might be the representative of poorly

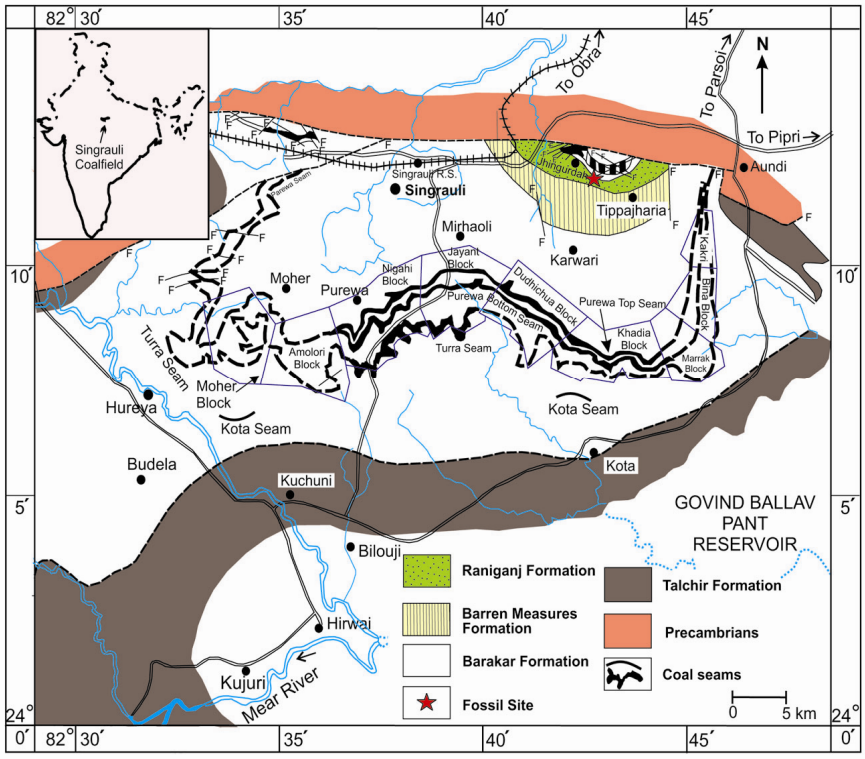

Figure 1. Location map of the Singrauli Coalfield showing Jhingurdah Colliery (after Raja Rao[26]).

developed palaeosol horizon. However, geochemical data are still needed to ascertain this.

A big chunk of the bed displaying large *Vertebraria* roots on a weathered exposed surface was removed and further fragmented in order to observe internal imprints of rooting structures and their relationship with sedimentary matrix. Eight large rock specimens (measuring about 20–80 cm in height and 18–30 cm in length) with single or branching roots along with other smaller specimens were collected from the fine-grained siltstone unit. These specimens in their lower parts exhibit thin lamellae (<2 mm thick) of sedimentary layers which are continuous and parallel with occasional undulations. Mostly the *Vertebraria* axes are seen as poorly preserved casts, clearly penetrating the sedimentary layers, and are vertical or near vertical to the bedding planes (Figure 3 *d* and *f*). They measure 6–30 cm in height and 1–2 cm in width consisting of 2–3 linear series of rectangular areas, separated by median septa. Many specimens reveal lateral or secondary branching, again inclined to the bedding planes. One of the specimens clearly shows lateral branching of roots arising from a primary thick root (Figure 3 *g*). All the specimens are deposited in the repository of Birbal Sahni Institute of Palaeobotany, Lucknow vide statement no. 1401. In addition to *Vertebraria*, a large number of *Glossopteris* leaves were also collected from grey shale and mudstone units. In contrast to the *Vertebraria* roots, *Glossopteris* leaves were preserved horizontally. Besides these two fossil occurrences, no other fossils could be found in the Jhingurdah Colliery. However, a large number of stem fragments were found entrapped inside pinkish to yellowish sandstones existing at higher stratigraphic level than the *Vertebraria* bed. Stems are mostly preserved as casts embedded in coarse-grained matrix of the sandstone with occasional carbonized crust. No internal tissue is preserved in the stems.

It is observed that the genus *Vertebraria* is either absent or, if present, it is less common in the beds where prolific numbers of *Glossopteris* leaves are found[22,23]. It is interesting that both *Glossopteris* and *Vertebraria* are abundant in the Jhingurdah Colliery and are found in the respective beds existing close to each other but with distinct lithologies[24] (Figure 2 *b*). Most of the macrofloral remains (*Glossopteris* leaves and equisetalean stems) are found preserved in the grey shales and mudstones whereas the *in situ Vertebraria* axes are recorded from the thinly laminated siltstone and homogeneous siltstone units. The orientation of the *Vertebraria* axes in relation to the sedimentary layers clearly demonstrates that the roots are preserved at their original place of growth. Preserved *Glossopteris* leaves are smaller in size, mostly intact and are found in thick mats with little matrix. This indicates that the influx of vegetal matter was uninterrupted into the depositional site. The setting of these fossiliferous intervals suggests that the depositional site was not very far from the original growing site.

It is generally found that the coal beds rest on a bed of carbonaceous clay or sheet earth and this floor bed is often characterized with the root beds (*Vertebraria* in case of Gondwana coal)[3,14,17,21,25] and sometimes by other plant fossil leaves. Nonetheless, in the case of Jhingurdah Colliery, the root bed is found to occur above the carbonaceous shale (with fossil leaves) and coal bed units. A close observation of positioning of all the fossiliferous horizons with respect to other nearby facies association reveals that this depositional cycle took place in a basin that was already filled substantially with previous sedimentation. The deposition of grey shale and mudstone units with *Glossopteris* leaves took place in a low-energy environment of a quiet water body (swamp), which changed to moderate energy environment as evidenced by the occurrence of siltstone units with alternate undulatory parallel laminations and subsequent deposition of carbonaceous shale followed by massive sandstone units. On the basis of all the evidences, it is envisaged that the preserved vertical roots belong to a glossopterid plant that grew at the margin of the nearly filled basin by the germination of a seed brought in from nearby *Glossopteris* forest and later on, with the growth of the plant its roots had penetrated through the underlying sediments. The leaves of this plant may not be preserved in sandy facies accumulated during subsequent sedimentation. However, the occurrence of a number of stem fragments in the yellow sandstones provides sufficient evidence that glossopterid

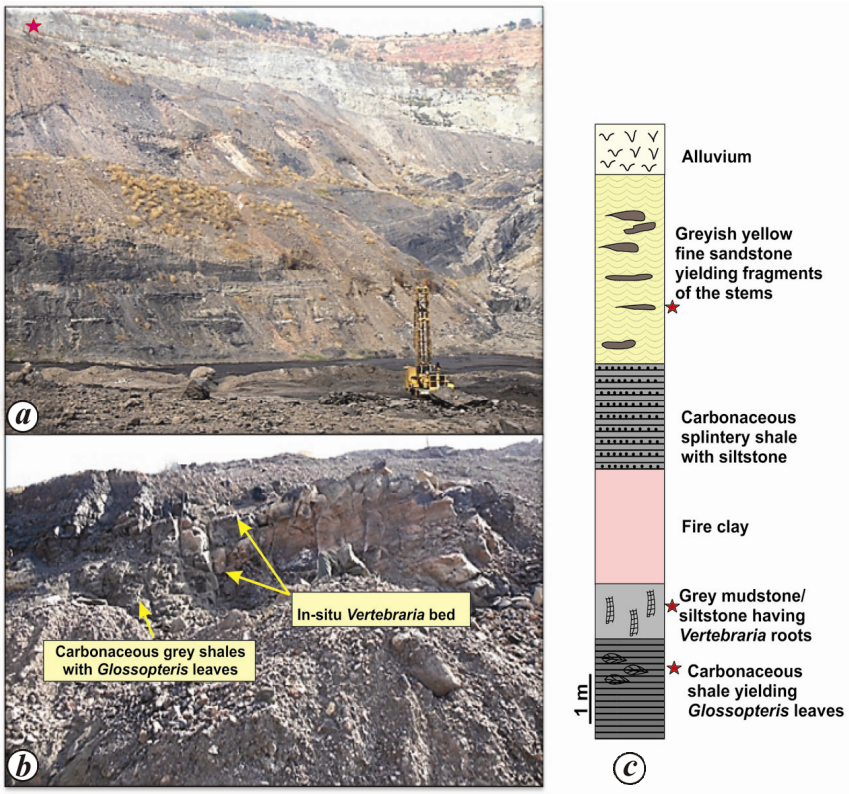

Figure 2. ***a***, Panoramic view of a part of Jhingurdah Colliery. Star indicates the position of (***b***). ***b***, Photograph of the section yielding megafossil assemblage. ***c***, Generalized litholog of Jhingurdah Top coal seam. Stars indicate fossil-bearing horizons.

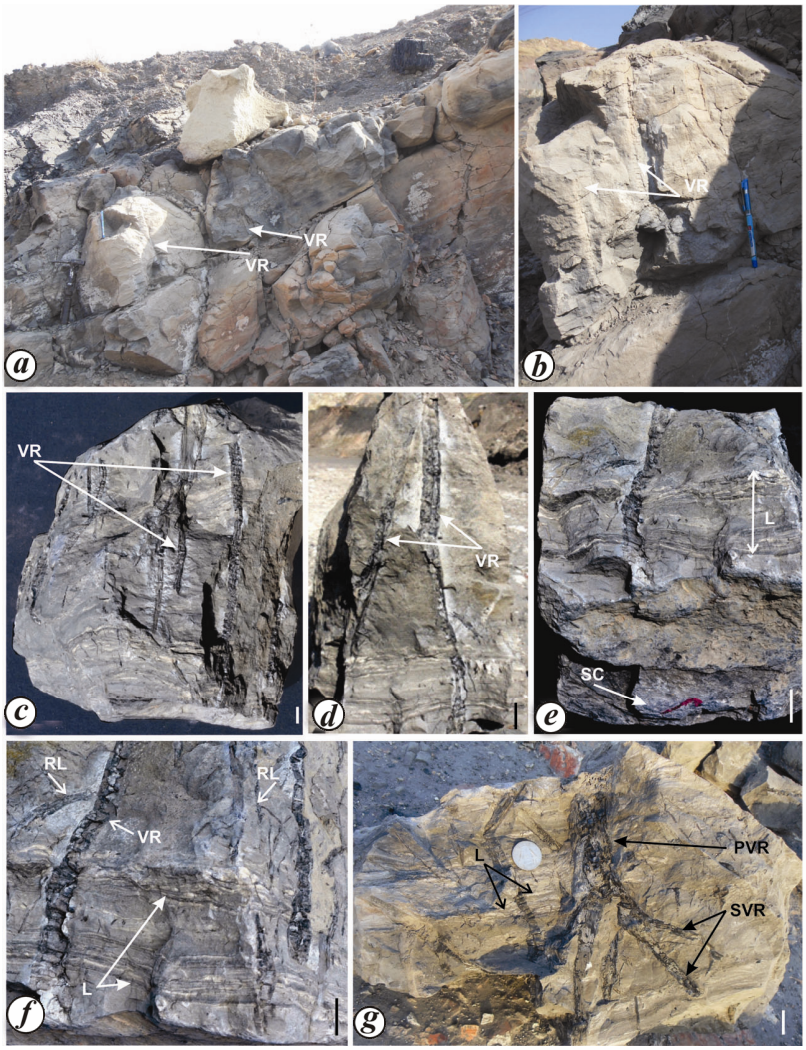

Figure 3. Photographs of the outcrops and specimens showing *in situ* preserved *Vertebraria* roots. ***a***, On-site photograph of the outcrop showing the vertical *Vertebraia* roots. ***b***, Closer view of the same bed (***a***) depicting two longitudinal series of rectangular areas in the *Vertebraria* root. ***c***, ***d***, Specimens with long and vertically preserved *Vertebraria* roots (VR; scale bar = 2 cm; BSIP museum specimen nos. 40667, 40668). ***e***, Back side of the specimen shown in (***c***) with roots penetrating through the parallel lamellae (L) and a horizontally preserved stem cast (SC) at the base of the specimen (scale bar = 2 cm). ***f***, Enlarged part of the specimen shown in (***e***) clearly depicting vertical and inclined roots, rootlets (RL) and laminations (scale bar = 2 cm). ***g***, Specimen exhibiting the root system with primary (PVR) and secondary *Vertebraria* roots (SVR) (scale bar = 2 cm; BSIP museum specimen no. 40669).

plants continued to grow in the saturated upper part of the Jhingurdah basin.

On the basis of evidences collected so far, these beds can be attributed to represent both allocthonous (horizontally preserved *Glossopteris* leaves) as well as autocthonous (vertically preserved *Vertebraria*) preservation in the same sedimentary sequence.

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