Glacial to Post-Glacial Fluvimarine Sedimentation System: Evidences from West Bokaro Coalfield

36th International Geological Congress, Delhi (NCR)

Field Trip Guide

ER009
PRE-CONGRESS FIELD TRIP

Glacial to Post-Glacial Fluvimarine Sedimentation System: Evidences from West Bokaro coal field

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Abstract

Earth crust isostatically reciprocates under the influence of thick cover of continental ice sheets. Isostatic adjustments, such as sagging during glaciations and rebound or uplift after deglaciation accompanied by changes in paleoclimatic conditions, strongly control the sedimentation pattern and the contemporary organic populations in post glacial environments. India, being a part of the Gondwanaland is repository of similar climatic and tectonic events in the form of thick clastic sedimentary succession (Gondwana Supergroup). Post glacial sedimentation and sediment organism interactions in response to late Paleozoic paleoclimatic changes and associated basinal adjustments are recorded in the Lower Gondwana successions, namely in the Talchir Formation, the Barakar Formation and the Barren Measure Formation, in the West Bokaro Coalfield, eastern India. These formations will be covered in two major traverses:

1. The Dudhi Nala section for study of glacially driven and post glacial sedimentations in the Talchir Formation in the frame of glacio-marine transitional setup and the Karharbari Formation which is resting uncomfortably over Talchir Formation.

2. Visit to Ara-Dumerbera area for study of the unconformable contact between Basement and coal bearing cyclic sedimentation in Lower Barakar Formation, the Middle-Upper Barakar Formation having fluvial to wave/tide influenced structures and finally to Chhota Nadi-Bokaro River confluence/the Bokaro River section near Duni village-marking the transitional changeover from dominantly fluvial Barakar Formation to wave and tide dominated Barren Measure Formation.

The field tour will provide a comprehensive idea on the transitional nature of the glacial-fluvial-marine interactive systems in the frame of post glacial transgressive-regressive setup. Such T-R cycles during the late Paleozoic Lower Gondwana sedimentation will be explained in terms of prograding and retrograding successions, sediment-organism interaction pattern, sea level fluctuations, sediment supply and basinal tectonics. The participants will be enlightened about such regressive-transgressive systems in the frame of changing net accommodation space due to base level fluctuations caused by post-glacial isostatic adjustments of the crustal blocks under significant climatic amelioration.

Chapter I: Logistics
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### Chapter I: Logistics

#### 1.1 Location and dates

Hazaribag District, Jharkhand (Lat. 23°44’ - 23°50’N and Log. 85°24’ - 85°42’E). Two days exclusive field work:

**Day 1 (February 26, 2020):**

Arrival from New Delhi to Ranchi by Air and transfer to Vinoba Bhave University, Hazaribag (Ranchi to Hazaribag – 110 km.) Inaugural/welcome and slide show about field excursion and Geo-tourism.

**Day 2 (February 27, 2020):**

a) 8:00 am to 4:30 pm – Field work at Dudhi Nala river section to visit deposition of glacio-marine sedimentation of Talchir Formation and high energy fluvial Karharbari Formation (Hazaribag to Dudhi Nala – 27 km). Working lunch at point 7 (traverse map day 2).

b) 7:00 pm to 8:30 pm – Cultural programme by students of Vinoba Bhave University, Hazaribag.

**Day 3 (February 28, 2020):**

a) 9:00 am to 1:00 pm – Visit to Ara-Dumerbera area for study of the unconformable contact between Basement and Lower Barakar Formation, coal bearing cyclic sedimentation in the Middle Barakar Formation and also having wave and tide generated structures (Hazaribag to Point 1-46 km; traverse map day 3)

b) Break/working lunch at the confluence of Bokaro and Chotha River, Duni village.

c) 2:00 pm to 4:00 pm – Visit to Chhota Nadi-Bokaro River confluence at Duni village—changeover from dominantly fluvial Barakar Formation to wave and tide dominated Barren Measure Formation.

(d) **7:30 pm to 9:00 pm – Cultural/night by professionals of Jharkhand.**

**Day 4 (February 29, 2020):**

8:00 am to 8:00 pm. Geo-picnic at Surajkund, Barhi, Hazaribag (Hazaribag to Surajkund–65 km)—the famous hot spring (temperature >80°C) and from there proceeding to Bodh Gaya (Surajkund to Bodh Gaya 110 km)—one of the most sacred Buddhist sites in the world, Bodh Gaya has risen to international fame as the place where Prince Siddhartha sat under the Bodhi tree and gained enlightenment some 2,600 years ago.

Place to be visited at Bodh Gaya:

1. Great Buddha Statue -80 feet tall stone statue near Mahabodhi temple

2. Archaeological Museum – it houses the idols and other materials found in the excavation of Mahabodhi temple area and nearby.
3. Mahabodhi temple and sacred Bodhi Tree – The main temple and Bodhi tree represent the primary attractions of Bodh Gaya with their historical spiritual and artistic importance. Today, these World Heritage Sites bring in thousands of pilgrims and tourists each year. More temples, monasteries and monuments dot the landscape, built by Buddhists from different nations in their own national styles.

Day 5 (March 1, 2020):
Dispersal for Ranchi and flight to New Delhi.

1.2 Travel arrangements

Route plan:

i) The pre congress excursion will start on 27 February, 2020 in the forenoon at 8:00 am from Hazaribag to Dudhi Nala section to the road side of NH-33 by small 4W vehicles.

ii) Accommodation: The standard hotels such as Canary Inn or A. K. International are situated close to the geological exposures and all daily field trips will start and finish at this hotel. Blocks of single and double rooms will be reserved for participants and no additional arrangements required.

iii) Local transport: The exposures are located 27 to 50 km away from hotel. Exposures are well connected by metalled road and kachcha (earthy) roads. Small 4W vehicles with experienced driver and having first aid kit will be available. However, participants are advised to carry necessary medicines as per their requirements.

iv) Field logistics: Breakfast and dinner are usually associated with overnight accommodation. Lunches are planned in the nice outcrop such as at point 7 (traverse map day 2) on February 27, 2020 at the confluence of Duba Nala-Dudhi Nala and at Duni village (traverse map of day 3) on February 28, 2020. On February 29, 2020, visit to Surajkund (famous hot spring) at Barhi, Hazaribag and from there to Bodh Gaya, a world Heritage site have been planned. Lunch is planned at the Hotel Siddhartha Vihar, Bodh Gaya. Team will return to Hotel at Hazaribag late in night on same day.

v) Terrain specific instruction: During February, the days are sunny and temperature varies between 20-25°C in day time. Woolen/warm clothes are required.
Chapter II: Regional Geological Framework

2.1 Introduction

The name “Gondwana” was coined by H. B. Medlicot in 1872 after the ancient Kingdom of Gond tribe in Central India. It is characterized by a thick continental succession of sandstones and shales with coal seams, fossils of flora and fauna along with signatures of marine incursion at places.

The first Pangean distension by the close of the Paleozoic opened up a number of more or less elongated intra-to-peri continental depressions in which the Gondwana sedimentation began in Late Carboniferous. The Gondwana Basins are extensively developed in the Gondwanaland of southern hemisphere which comprises of South America, Africa, Australia, India and Antarctica (Veevers and Tewari, 1995) (Fig. 1).

Prof. Von Huene found an extraordinary resemblance between the dinosaurs of Madhya Pradesh in India and the Madagascar, Brazil, Uruguay and Argentina. It is an established fact that the widely separated continents with the characteristic Gondwana flora and fauna either formed parts of one unbroken continental tract or there must have been land connectivity in the southern hemisphere for a long span of time that allowed an unrestricted migration of the life. The term ‘Tethys’ was used by Suess (1885) as a great equatorial Mesozoic sea which separated the two old large land masses of Laurasia to the north and Gondwanaland to the south (Sinha et al. 1998). Gondwanaland was made up of South America, Africa, India, Australia and Antarctica. The fragmentation of these two primeval continents through drifting was visualized by several workers eg. Wegner (1912) and Du Toit (1937).

Fig. 1. Palaeogeography of the Gondwanaland showing location of field traverse (after Sinha et al. 2019)
The common characteristics of the Gondwana basins of different continents include the presence of a basal glacial bed, presence of large coal seams, common fossils and an end-phase of volcanic eruption, though not closely contemporaneous. The Gondwana sedimentary Basin evolved through a process of deepening into Basins and vertical accretion of sediments. The Gondwana of Peninsular India is mostly confined between Permo-Carboniferous and Triassic (290-208Ma) age (Fox, 1931; Robinson, 1967; Veevers and Tewari, 1995) and preserved in many discrete basins.

The central India is characterized to the impact of the Satpuran Orogeny (1600-900ma), recently popularly known as Central Indian Tectonic Zone (CITZ), a mobile belt, (Radhakrishna and Ramakrishnan, 1988; Mahadevan, 2002) is covered for a large part by the Gondwana sediments, Quaternary alluvium and Deccan Trap and consists of gneisses, supracrustal rocks, granites and boudin type granulites (Ramakrishana and Vaidyanadhan, 2008) (Fig.2).

**Fig.2.** Satpura mobile belt/Central Indian Tectonic Zone (CITZ) with its extensions and adjacent cratons (after Fermor, 1936). BK = Bundenlkhand Craton, SC = Singhbum Craton, BC = Bastar Craton, CGC = Chhotanagpur Granite Gneiss, MP = Meghalaya Plateau, MH = Mikir Hills.
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Fig.3. Geological map along Dudhi Nala (after Bhattacharya et al. 2005)
The intracratonic rift basins of Gondwana within the peninsular India are located to the ENE-WSW trending Narmada-Son-Damodar (NSD) valley, NNW-SSE trending Pranhita-Godavari (PG) valley and NW-SE trending Mahanadi (M) valley (Fig. 3a) (Chakraborty et al. 2003; Hota et al. 2011). The basins that occur along the NSD valley are significant due to huge coal deposits. They are Rewa, Karanpura, Bokaro, Jharia and Raniganj basins from west to east. These are sites for huge sedimentation of alluvial, lacustrine and deltaic nature (Sinha et al. 2019).

The Gondwana basins are intracratonic and considered as extensional rift basins due to presence of normal faults. The accumulation and subsidence of continental sediments in the Gondwana basins nucleated along the pre-existing zones of weakness of Precambrian lineaments and controlled by synsedimentary gravity faults (Chakraborty et al. 2003). The Bouguer gravity anomaly study as well as drill-hole data indicate a ~4 km thickness of subsurface Gondwana strata (Veevers and Tewari, 1995; Mishra et al. 1999). Permo-Carboniferous glaciogenic deposits at the base of the individual basin describe their evolution due to a global tectonic event (Casshyap and Tewari, 1999; Veevers and Tewari, 1995; Biswas, 1999). Fault analysis study from Gondwana basins indicates that all the Gondwana basins developed under a tectonic regime characterized by a roughly E-W motion. This caused preferential subsidence in locales of preexisting discontinuities in the Precambrian basement and led to development of an array of sedimentary basins of varied kinematics along the present day river valleys of Narmada-Son-Damodar, Pranhita-Godavari and Mahanadi (Chakraborty et al. 2003).

It is accepted that the Gondwana sedimentation began around 260 Ma and subsidence of basin floor continued till 205 Ma to accommodate the entire pile of Gondwana sediments. It was then followed by a period of quiescence for 135 million years i.e. upto 70 Ma. Then uplift and erosion began during Cenozoic Himalayan-Alpine orogeny and continued till date (Bardhan and Ghosh, 1999).

2.2 Stratigraphy / Geological Framework

The large part of Gondwana sediments are covered along the Central Indian Tectonic Zone (CITZ) and are exposed in four major linear belts corresponding to the trends of present day river valleys viz. the Damodar-Koel valley, Son-Mahanadi valley, Pranita-Godavari valley and Satpura areas and follow several prominent lineaments of long antiquity in the Precambrian Craton (Fig.- 3a). Apart from these, there are several other basins like north-south trending Rajmahal hills and east-west trending Giridih-Itkholi belt.

There has been a long standing controversy regarding the classification of the Gondwana Supergroup of India. Two schemes of classification have been proposed on the basis of their lithological and paleontological considerations: (a) two fold divisions proposed by W. T. Blanford, who divided the Gondwana sequence into lower and upper divisions. The plane of separation was kept at the top surface of the Panchet Stage. (Carnic to Noric). The lower and upper Gondwanas are characterized by the Glossopteris and Ptilophyllum floras respectively.

(b) The tripartite classification was proposed by Feistmantel (1880) on the basis of floral records, a mixed flora called Dicroidium in between the Glossopteris and Ptilophyllum floras. Vredenburg also proposed a three fold classification and his middle division included "Kamthi Series" "Panchet Series" and "Maleri Series" (Vaidyanathan & Ramakrishnan, 2008). However, the two fold classification has been more popular and is being followed in most of the publications.
The present pre-conference field traverse is confined to west Bokaro coalfield (Fig. 4) which is a part of Damodar valley. The important coalfields of Damodar valley include Raniganj, Jharia, Bokaro, North Karanpura, Ramgarh, South Karanpura, Auranga, Hutar Daltonganj, Giridih and other coalfields.

The generalized stratigraphic succession of West Bokaro has been shown in fig. 5 and of Damodar valley coal basins in table 1.

Table 1. Generalized stratigraphic succession of Damodar Valley basin.

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<th>Lower Gondwana</th>
<th>Supra-Panchet on top and beneath that Panchet Fm</th>
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<td>Damuda Group</td>
<td>Raniganj Formation</td>
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<td>Barran Measures Formation</td>
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<td>Barakar Formation</td>
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<td>Karharbari Formation</td>
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<td>Talchir Formation</td>
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<td>Basement</td>
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Fig. 4. Geological map of West Bokaro Basin (after Bhattacharya and Banerjee, 2015)
Talchir Formation:
The Talchir Formation derives its name from the former state of Talcher in Orissa, where this formation was first reported. This formation overlies the Precambrian basement with unconformable contact in the Damodar valley and characterized by Boulder bed/tillite, rhythmite, green needle shale and light green sandstone lithology. The boulder bed tillite is made up of angular, poorly sorted pebble to boulder size clasts supported by sandy matrix. Dropstones are a common feature of this formation. The maximum thickness of ~300 m of this formation has been reported from Daltonganj coalfield. The evidence of marine incursion has been found in this formation supported by marine fauna comprising *Eurydesma*, *Priondomya* and *Fenestella*. The sedimentary features indicate glacial-glaciomarine-fluvial environment with palaeoslope WNW (Vaidyanathan and Ramakrishnan, 2008.)

Karharbari Formation:
The 200m thick Karharbari Formation derived its name after a village of the Giridih Basin. This formation is also recognized in Karanpura, Bokaro, Auranga and Hutar coalfields. Talchir Formation is overlain by this formation with a disconformable contact. However, sharp and overstep nature of contact is also found in some basin attributing to local unconformity between the two formations. This main lithology is cobble-pebble conglomerate, pebbly sandstone, carbonaceous sandstone siltstone, shale and coal streaks and thin coal bands in West Bokaro Coalfield. The basal lithofacies of monomictic cobble-pebble conglomerate reveals a channel lag deposits with fining upward sequences. The drainage in the Bokaro Basin during Karharbari was from SSE to the NNW with low sinuosity along with secondary current system that flowed from NE to SW. Several plant fossils have been recorded from this formation such as *Schizonenra gondwanensis*, *Glossopteris indica*, *Noeggerathiopsis hislopi* etc. (Mahadeven, 2002; Vaidyanadhan and Ramakrishan, 2008).

Barakar Formation:
The Barakar Formation is the most important of Lower Gondwana because it is a repository of coal deposits. It is characterized by sandstone, shale, carbonaceous shale and coal which reveals fining upward sequence. This formation attains a maximum thickness of 1053m in the south Karanpura Basin. In the West and East Bokaro coalfields the thickness varies from 600 to 900m. This formation is known for a cyclic succession and the sequences of beds are as follows:
- a. Pebbly very coarse sandstone (bottom).
- b. Coarse to medium sandstone.
- c. Fine sandstone.
- d. Interbedded fine to medium sandstone, siltstone and shale.
- e. Carbonaceous siltstone and shale.
- f. Coal, shaly coal.

Most of the cycles are generally truncated cyclothems and a complete cycle may not be always present. Thick coal seams are developed in the middle part of the cyclothem of this formation. Sandstone is feldspathic and displays large scale tabular and trough cross bedding whose palaeocurrent is W to NW. The Barakar Formation does not yield any diagnostic fossils of high resolution for age. However, palynological study reveals non-striate disaccate spores at lower zone and striate disaccates at the upper zone (Mahadeven, 2002; Vaidyanadhan & Ramakrishnan, 2008).

*Fig.5. Generalized stratigraphic succession of West Bokaro (after Varma et al. 2014)*
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- Coal, shaly coal.
- Carbonaceous siltstone and shale.
- Interbedded fine to medium sandstone, siltstone and shale.
- Fine sandstone
- Coarse to medium sandstone.
- Pebbly very coarse sandstone (bottom).

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Barren Measures:

The Barakar Formation has gradational contact with overlying Barren Measures characterized by brown to reddish clastic sequence of cross bedded sandstones, micaceous and ferruginous shale and/or siliceous sandstones. The Barren Measure Formation is economically the non-coaliferous lithounit which was interpreted as continental fluvio-lacustrine deposits. Recent reports of tidalites in this formation attributes to sedimentation in shallow sub-tidal to inter-tidal estuarine settings. (Bhattacharya and Banerjee, 2015). Fossils remain of this formation includes Pteridospermae, Cordaitales, Ichnofossils etc.

Raniganj Formation:

The topmost succession of Damuda Group represented by Raniganj Formation of late Permian age which lies below the Panchet Formation of early Triassic age. Lithologically, this formation attains maximum thickness of 800m and includes an alternate sequence of white and grayish white, fine to medium grained sandstone, gray siltshale and coal. (Sinha et al. 2019). This sandstone is fine grained than those in the Barakar Formation. The known plant fossils of this formation are: *Phyllotheca indica*; *Sphenophyllum speciosum*; *Glossopteris indica*; *Noeggerathiopsis hislopi*; *Gangamopteirs whittiana*; *Vertebraria indica*; shark teeth and fish scales etc. (Mahadevan, 2002).

Panchet Formation:

The Panchet Formation lies with an unconformity over the Damuda Group formations and comprises of greenish, buff and brown colored current bedded sandstone, shale and siltstone. The strata attest the repeated fining upward sequences defining typical fluvial regime. The continental P/T boundary has been demarcated in the Raniganj Basin (Patel et al., 2014).

Supra-Panchet (Mahadeva Group):

This formation is well developed in the Bokaro Basin attaining maximum thickness of 600m and overlies the Panchet Formation in the Lugu Hill. Lithologically, it comprises variegated coarse to very coarse sandstone inter-bedded with conglomerate consisting of quartzite, quartz and jaspar quartzite, micaceous ferruginous silt and clay. Deposition of these sediments took place in a shallow water condition and palaeocurrent direction is N or NW and a source area in the south (Mahadevan, 2002).

2.3 Tectonics and structure

The Gondwana sediments are confined mainly in a trough like depressions and basins within the Precambrian basement. These depressions are arranged along several linear belts within the Precambrian crystalline. These belts are attributed to fault and shear zones in the apparently stable shield which is inactive since long geological past. This fact has been supported by gravity lows and steep Bouger gravity anomaly gradients associated with these basins.

The Gondwana basins are characterized by three major groups of faults and are generally termed “boundary faults" which are basin margin faults, intrabasinal faults and basin marginal cross faults. All these faults are conspicuous in the Jharia and Raniganj coalfields. The basin marginal faults have given rise to half graben, homoclinal dips and sometimes asymmetric synclinal basins. These faults range in age from early Talchir times to close of Gondwana sedimentation i.e. early Cretaceous. (Vaidyanathan and Ramakrishnan, 2008). In fact, the Gondwana basins evolved due to normal
faulting and it is generally considered and compared the graben configuration of basin to that of East African Rift system.

2.4 Paleontology

Life in Gondwana is characterized by flora, palynomorphs, fauna, invertebrates and trace fossils. Majority of plant fossils are common in the most of the formations of Lower Gondwana viz; *Glossopteris indica* has been reported from Talchir to Panchet formations where as *Gangamopteris cyclopteroides* appears at Talchir and disappear from Barren Measure Formation. Similarly *Noeggerathiopsis hislopi* has a continuous presence till Raniganj Formation. The arid condition prevailed during the Triassic period and characteristic flora of Permian age such as *Glassopteris*, *Gangamopteris*, *Schizoneura* slowly disappeared. *Dicroidium* is widely distributed in the Triassic of Gondwana. Fossil wood and *Dadoxylontree* trunk with well marked growth rings have been found from Bokaro and Raniganj coalfields.

Palynomorphs have also been reported from Talchir to Panchet formations. This includes radial monosaccate, pollen with dense and thin central body and haploxylonoid / diploxylonoid construction, tetrad of spores, *Callunispora* and *Densipollenites* (Mahadevan 2002). Variety of vertebrate fossils is also reported from Upper Gondwana. These fossils are crustaceans, insects, ostracodes, fishes, reptiles and mammals.

*Kotatherium haldenii* is the first report of earliest mammal from India. Turtle (*Indochelys spatulata*) and flying reptile (*Campylognathoides indicus*) have been reported from the Kota Formation (Carnic/Middle Triassic age). Dinosaur skeleton of *Kotosaurus yamanapalliensis* is also reported from Mesozoic Era. (Vaidyanadhan & Ramakrishnan, 2008).

Ichnofossils are also reported from the Lower Gondwana mainly characterized by *Skolithos* and *Cruziana* attributes to a short lived shallow marine incursion. The marine influence in the Lower Gondwana (Talchir Formation) succession is also supported by the record of bryozoa and brachiopods (Vaidyanathan and Ramakrishnan, 2008).

2.5 Palaeocurrents, depositional environments and basin configuration

The palaeocurrent analysis based on the directional structures reveal the fluvial system was from east to west in the Koel-Damodar basin and SE to NW to Son-Mahanadi and Pranita-Godavari basin. However, the palaeocurrent of major Gondwana basins attributes to northwest drainage systems which had its origin from unbroken Australia or Antarctica (Vaidyanadhan and Ramakrishnan, 2008) continents.

Primary sedimentary structures, lithology, fossil, flora and fauna reveal much about the palaeoenvironment of deposition of Gondwana Basin. Tillites, striated pavements, dropstone, insitu breccias, logged breccias and other features indicate glacial condition during the Talchir Formation of early Permian age. The study on Talchir Formation reveals that the glaciers were derived from ice caps on certain highlands. Presence of invertebrate fossils, trace fossils (*Psammichnite*, *Thalassinoides*) etc. indicates marine influence during the deposition of Talchir sedimentation.

The possible depositional environments form Talchir to Supra-Panchet can be summarized following ways (Mahadevan, 2002):
3.1 Geological overview along the transect

Earth crust isostatically reciprocates under the influence of thick cover of continental ice sheets. Isostatic adjustments, such as sagging during glaciations and rebound or uplift after deglaciation accompanied by changes in paleoclimatic conditions, strongly control the sedimentation pattern and the contemporary organic populations in post-glacial environments. India, being a part of the Gondwanaland, is repository of similar climatic and tectonic events in the form of thick clastic sedimentary succession (Gondwana Supergroup). Post-glacial sedimentation and sediment-organism interactions in response to late Paleozoic paleoclimatic changes and associated basinal adjustments are recorded in the Lower Gondwana successions, namely in Talchir, Barakar and Barren Measure formations etc. in the West Bokaro Coalfield, eastern India.

The Bokaro Coalfield named after the Bokaro River which meanders through this coalfield of Damodar valley. This coalfield is located in the Hazaribag and Ramgarh districts of the Jharkhand State and it is the third in the chain of the Damodar Valley basins from east to west, in which Raniganj and Jharia are the first and second respectively (Varma et al. 2014). The Lugu hill (978.40m) is the landmark of the area that divides the whole Bokaro basin into two parts i.e., East Bokaro and West Bokaro basins.

The West Bokaro basin covers an area of 207 km² within the latitudes of 23°44'N to 23°50'30''N and longitudes 85°24'E to 85°44'30''E (Fig. 4). The generalized succession of the West Bokaro basin has been shown in Fig. 5 and the stratigraphic sequence in Table-2.

The West Bokaro basin is characterized by a broad syncline with its axis trending E-W and exhibits a twin synformal structure separated by a central poorly preserved antifoam in an E-W direction. Intrusive of various compositions such as dolerite dykes, lamprophyre and mica peridotite sills are reported from this basin (Varma et al. 2014). The field traverse will cover parts of Talchir, Karharbari, Barakar and Barren Measure formations in two days field trip.

Chapter III: Field trips

a) Rapid transport and deposition in an uneven glacial valley and fluvial/marine water bodies during Talchir Formation.

b) Uplift, rapid transport along steeper slopes, rapid subsidence and rapid to slow deposition during Karhabari and Barakar formations.

c) Slow transport by sinuous rivers with gentle slopes. Rapid subsidence and slow to rapid deposition. Marine influenced structures in Barrean Measures and Raniganj formation.

d) Panchet and Supra-Panchet are characterized by uplift, rapid transport, rapid subsidence and rapid deposition.

Hence, the Gondwana environment commenced with a glacio-marine environment followed by a humid fluvial environment and finally semi-arid to arid climates continued until the close of Gondwana deposition (Vaidyanadhan and Ramakrishnan, 2008).

Several basins of Damodar valley were part of one large connected master basin due to similarities in sedimentary succession. The Giridih Basin represents an isolated circular basin. The Hutar, Daltonganj and Auranga Basin are irregular in shape. The Bokaro, Karanpurra, Ramgarh, Jharia and Raniganj Basins form a major liner belt along the Damodar valley. All these basins have an easterly to southeasterly elongation (Mahadevan, 2002).
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The Basement

The Gondwana sediments rests unconformably on the Chhotanagpur Granite Gneiss Complex (CGGC) which comprises granites with pegmatitic veins, amphibolites (supra crustal rock), epidiorites, mica-schist and porphyritic gneisses etc. Its age is considered as Archaean (?) to Proterozoic. To the north of the coalfield the Precambrian rocks are separated from the Gondwanas by a boundary fault while to the South and West the Gondwana overlies the basement with unconformity.

Talchir Formation

The base of the Gondwana sequence is marked by a thick pile of glacial and fluvio-glacial deposits characterized by associations of several insert and after facies represented by jagged breccias, in situ breccias, lodgement tillite, stacked tabular clast conglomerate, reverse grading conglomerates, angular and rounded conglomerates, dropstones, ice-rafted pebbles, soft sediment deformation structures such as convolute, flame and synsedimentary faults etc. indicating seismic activity. Hummocky cross beds, burrows, marine fossil Polyplacophora, Psammichnite, wave generated structures attributes to marine transgression in Talchir Formation. This formation is well exposed along the Dudhi Nala section (Fig. 6) (23°50’- 85°30’). This formation is not developed in other parts of the basin.
Table 2. The stratigraphic succession of the West Bokaro coalfield.

<table>
<thead>
<tr>
<th>Age</th>
<th>Formation</th>
<th>Thickness</th>
<th>Generalized Lithology</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jurassic</td>
<td>Intrusive bodies</td>
<td></td>
<td>Basic and ultrabasic dykes and sills.</td>
</tr>
<tr>
<td>Upper Triassic</td>
<td>Supra-Panchet (Mahadeva)</td>
<td>~600m</td>
<td>Conglomerates, ferruginous sandstone and siltstones.</td>
</tr>
<tr>
<td>Lower Triassic</td>
<td>Panchet</td>
<td>~450m</td>
<td>Fine grained sandstone, green shales and red and chocolate colored shale and clay.</td>
</tr>
<tr>
<td>Upper Permian</td>
<td>Raniganj</td>
<td>~550m</td>
<td>Find grained sandstone, siltstone, carbonaceous and grey shales with thin coal seams.</td>
</tr>
<tr>
<td>Middle Permian</td>
<td>Barren Measures</td>
<td>~300m</td>
<td>Sandstone, Carbonaceous shales, grey micaceous shales with iron stone.</td>
</tr>
<tr>
<td>Lower Permian</td>
<td>Barakar</td>
<td>~610m</td>
<td>Conglomerates, pebbly sandstone, coarse grained to fine grained sandstone, grey shale, carbonaceous shale and coal.</td>
</tr>
<tr>
<td>Upper Carboniferous</td>
<td>Karharbari</td>
<td>~40-60m</td>
<td>Conglomerates, coarse grained sandstones, carbonaceous shale and thin coal seams.</td>
</tr>
<tr>
<td></td>
<td>Talchir</td>
<td>~160m</td>
<td>Diamictites, fine to medium grained greenish and buff colored sandstones, shale, rhythmites, turbidites etc.</td>
</tr>
<tr>
<td></td>
<td>Unconformity</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Precambrian</td>
<td></td>
<td></td>
<td>Granites, gneisses, amphibolites etc.</td>
</tr>
</tbody>
</table>

Karharbari Formation

Karharbari Formation is well exposed in the Dudhi Nala section and in the Western part of the field where it overlies the Talchir beds with a structural/disconformable contact. This formation consists of conglomerate, sandstone, mudstone and thin beds of coal seam. Some of the clasts of the Karharbari beds have been derived from the restoring of the Talchir rocks.

Barakar Formation

The Barakar Formation covers the major parts of the West Bokaro coalfield and has an aerial extent of 125 sq.km. The formation is characterized by cyclic sequence of conglomeratic sandstone, fine to very coarse grained sandstone, grey and carbonaceous shales and thick coal seams. The characteristic feature of this formation is presence of the burnt rocks due to baking, fusion and brecciation of sandstone, siltstone and shale. The Barakar Formation has been divided in three parts based on specific character. The Lower Barakar is characterized by predominant arenaceous facies with few coal seams (seams number ‘0’ and ‘1’) and the thickness varies from 60 to 200 m.
The Middle Barakar member is characterized by an increase in the proportion of argillaceous materials. The ratio of coal to non-coal litho-units rises from 1:50 in the lower member to about 1:2 to 1:3 in middle. The bottom part of middle Barakar member is composed of grayish fine to coarse sandstone and carbonaceous shale and thick coal seams with fine to coarse grained sandstone partings. Most of the good quality sub-bituminous coal seams such as IV, V, VI and VII occur in this zone. Barakar Formation is very well exposed in and around Ara- Dumerbera area (map of Day-3). At point 1, the contact between Lower Barakar and Basement is unconformable attributing to an erosional feature (Fig. –7).

The Upper Barakar is characterized by a further increase in the proportion of argillaceous materials. The ratio of the coal to non-coal litho-units decrease from about 1:3 in the middle member to about 1:8.5 in the upper member.

This unit is mainly composed of grey shale and alternate beds of grey shale / carbonaceous shales and fine to medium grained cross bedded sandstones with a number of relatively thin coal seams.

**Barren Measures Formation**

This formation is well exposed along Bokaro River near Duni River. The contact between Barakar and Barren Measure formations is gradational (Fig.-7). This formation is characterized by a thick sequence of Carbonaceous shale with thin inter beds of fine to medium grain hard and compact ferruginous and siliceous sandstone. This unit is economically non-coaliferous. This formation has been recognized recently as a marginal marine tide-wave interference environment of deposition. Various features such as tidalites, tidal bundle sequence with reactivation surfaces are well exposed along the Bokaro River in and around Duni village. These features attest the sedimentation in sub tidal to inter-tidal shallow marine environment.

**Intrusives:**

The Gondwana Formation of this area is traversed by several dolorite and lamprophyre (Fig. 6) dykes. The lamprophyre intrusive varies widely in texture and colour. Many of them are leucocratic to mesocratic in nature.

**Structure of Basin:**

The West Bokaro Coalfield represents a broad half basin configuration, open towards the east and with a closure to the west. The other half of the basin is represented by East Bokaro Coalfield. The coalfield assumes a broad East-West elongated synclinal structure closing to the west with younger horizons cropping out progressively towards east, Gondwana-Precambrian boundary in the north is marked by E-W trending set of faults. The southern boundary of the basin, however, is generally one of natural disposition but faulted at some localized places with an erosional unconformity in between the Basement and Barakar Formation (Plate 5).

Due to the E-W elongated synclinal structure of the coalfield, the Barakar Formation is exposed on both the northern and southern limbs of the syncline, while the axial region is covered by younger Barren Measures and Raniganj formations. In the middle part of the field, where the basin is presumably deepest, younger Panchet and Supra-Panchet formations are preserved. A perfect basinal structure is seen around Lugu Pahar.

The Gondwana strata are affected by several major and minor interbasinal faults. Consequently, the beds within the various faulted blocks have been tilted to varying degrees.
The faults have either E-W or NW-SE trends. The E-W faults or the strike faults are parallel to the boundary faults and are older than the NW-SE faults which have frequently displaced the East-West strike faults.

### 3.2 Excursion stops

#### 3.2.1 Stop

The Dudhi Nala section will be visited on February 27, 2020 where deposition of glacio-marine sedimentation of Talchir Formation and high energy fluvial Karharbari Formation is well exposed (Fig. 6)

There are altogether 13 stops along the Dudhi Nala Section (Fig. 6 – Day 2):

**Stop 1. Fracture filling by injection of sediment-laden water**

The sub-horizontal crack within the basement (CGGC) has been filled up by siltstone/fine sandstone. The fracture in the basement may be formed as a result of thermal contraction.

The clastic rock within the fracture is crudely laminated, but locally grading and suggests forceful injection of sediment laden water within the sub-horizontal cracks.

**Stop 2. Breccia-insitu and Jagged and lodgement tillite**

Insitu breccia is characterized by nearly equidimensional or polygonal blocks of granite gneiss and amphibolites with matching boundaries resulting from the load of a glacier and lodgement tillites.

Jagged breccias results by the downslope creep and slump of materials by dragging and pushing by ice masses. The matching boundaries between the blocks lost at early stage of ice movement.

**Stop 3. Graded and inversely graded bedding**

The inversely graded beds are bounded above and below by a thin laminated sandstone. The bed undersurfaces are non-erosive but few small local scours are present. Large pebbles are aligned parallel to the bedding; sandstones inter-beds are well sorted, pebbles are good rounded. The reverse graded conglomerate sandstone alternations indicates final emplacement by sediment gravity flow of the glacial tills (Bose et al. 1992). Kinetic sieving is also a possible mechanism. Dropstones and multistoried sand bodies are found here. The multistoried sand body reveals predominance of wave activity and abundance of dropstone attributes to climatic amelioration (Bose et al. 1992).

**Stop 4. Hummocky cross stratified sandstone**

The hummockycross stratification (HCS) represents one of the characteristic wave generated structures with a strong strom wave surges. Some trace fossils are also found indicating shallow marine environment.
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Fig. 6. Traverse and different spots along Dudhi Nala section
Stop 5. Climbing deposition under combined flow

Climbing ripples are a definite ripple topography associated with the climbing of one ripple up the stoss side of the ripple immediately downstream. At this point well developed climbing structures are associated with sandstone reveals.

Stop 6. Deformation structures, convolute etc.

Syn-sedimentary faults are confined in sandstone formed by gravity tectonic/seismite slump. The convolute bed is confined in a thin bed of coarse silt and sand in the form of a fold. It dies out towards the base and top of the bed.

Stop 7. Wave generated structures

At the confluence of Dudhi and Duba Nalas, wave generated bundle up building structures are found in sandstone indicating wave influence. Swollen lens, mud drape are interesting features here.

Stop 8. Syn-sedimentary fault, ball and pillow, flame etc.

At this stop, a series of syn-sedimentary faults are present. The ball and pillow structures confined in silty shale layers enclosed in a muddy layer above. The silty shale/ fine sand layer is broken into several pillow shaped and in an ellipsoidal form. These pillow are isolated and connected to each other and sometimes look floating in a muddy matrix. Due to unequal loading and liquefaction, the mud layer moved up in the form of tongues into overlying fine sand unit forming flames.

Stop 9. Convolute, channel fill sediments

The channels are flat and filled up by sandstone-siltstone association in a very high channel width. At the base the channel fill fine sandstone is plane laminated and ripples drift cross lamination upward (Bhattacharya et al. 2005).

Stop 10. Hummocky cross stratified beds

Small scale thin bedded hummocky cross stratified sandstone occurs as blanket sediments which grades upward to normally grades and plane laminated sandy siltstone (Bhattacharya et al. 2005).

Stop 11. Trace fossil

Several trace fossils embedded in shale in the form of fanning upward is common feature eg. Thalassinoides / Polyplacophora

Stop 12 & 13. Talchir- Karharbari contact

The contact between Talchir and Karharbari is a disconformity. The basal part of Karharbari Formation is characterized by coarse gritty sandstone, siltstone, chocolate and carbonaceous shale with thin streaks of coal. The conglomerate of the basal part of Karharbari Formation is rounded and this is followed by the conglomerate-sandstone-mudstone association forming fining upward sequence. The Talchir-Karharbari contact reveals an abrupt change over from glacio-marine to terrestrial fluio-lacustrine depositional environment (Bhattacharya et al. 2005).
Traverse of Day 3 along Ara Area and Bokaro River (Fig. 7)

**Stop 1. Unconformable contact between Basement (CGGC) and Gondwana (Lower Barakar):**

The contact between Basement and Barakar Formation is marked by unconformity which is identified as an erosional contact. CGGC is represented as undulating surface over which the deposition of pebbles of quartzite, gneiss, schist etc. (polymictic) laid down. The conglomerate is overlain by thick, coarse grained and multistoried sandstone.

**Stop 2. Coal bearing cyclic sedimentation is middle Barakar having wave and tide generated structures:**

The middle Barakar is characterized by an increase in the proportion of argillaceous and carbonaceous matter. The sandstone is well sorted to poorly sorted arkosic to sub-arkosic arenite with thick interbeds of coal seams and carbonaceous shale. Wave and tide generated structures are found indicating wave condition prevailed with a feeble tidal environment. Bioturbation and Skolithos are common features along with trough cross lithification.

**Stop 3. Reactivation surface, channel fill sand:**

The rocks of the Barren Measure formation, resting conformably on the sandstone-shale-coal cyclothemic succession of the Barakar Formation. At this stop the contact between these formations is gradational and reactivation surfaces are easily recognized by change in foreset direction, grain size and thickness of lamination.

**Stop 4. Bioturbation (Diplocraterion), in situ plant roots:**

Bioturbation and vertical burrows with *Diplocraterion* are significant trace fossil reveals marine (intertidal/estuaries). There are few in situ root traces present also.

**Stop 5. 3D hummocky cross strata:**

Hummocky cross stratified thick sandstone bed is a characteristic feature exposed at the base of the succession. This sandstone bed is overlain by the wave ripple sandstone beds.

**Stop 6 to 7. Tidal rhythmites, tidalites, different types of wave ripple, tidal bundle, tidal bars**

Abundant tide generated and wave modified depositional features are interesting features, eg. tidalites, tidal bundles and tidal rhythmites. Large tidalites characterized by mud-drapped sandstone foresets with variable foreset thickness are developed in *thick*-bedded, trough cross stratified sandstone. Ripple drift cross laminae are abundantly present along with bidirectional strata bundles sets.

The facies architecture of Barren Measures Formation manifests fining upward and deepening sequence as indicated by increasing shale thickness and decreasing sandstone beds and relative scarcity of the tide and wave influenced sediment package. Repetitive occurrence of such sequences in the lower part of sequence suggests quick fluctuations between sub-tidal-intertidal-sub-tidal settings.
3.2.2 Section:
Following sections will be covered –

i)  The Dudhi Nala section for study of glacially-driven and post-glacial sedimentations in the Talchir Formation in the frame of glacio-marine transitional setup and the Karharbari Formation which is resting unconformably over Talchir Formation.

ii)    Visit to Ara-Dumerbera area for study of the unconformable contact between Basement and Lower Barakar Formation, coal bearing cyclic sedimentation in the Middle Barakar Formation having wave and tide influenced structures and finally to Chhota Nadi-Bokaro River confluence—the Bokaro River section near Duni village, marking the changeover from fluviomarine Barakar Formation to marine-dominated Barren Measure Formation.

3.2.3 Location:

i) Dudhi Nala  – E 85°26' to 85°28' and N23°49'

ii) Ara-Bokaro river  - E 85°32' - N23°45'

3.2.4 Approach: Both sections are well connected by road to NH33

3.3  Geoheritage sites:

i) Visit to Surajkund on February 29, 2020 (forenoon)

The thermal spring of Surajkund (24°8'58" N; 85°38'43.14" E) is located along the SON-NARMADA-TAPTI (SONATA) mega lineament in central India and lies on the Chotanagpur Granite Gneiss Complex (CGGC). This thermal spring lies over E-W trending fault (Fig.-8). The issuing temperature of this hot spring 88° Centigrade and water is alkaline in nature. The large negative gravity anomaly depression around Surajkund thermal spring indicates presence of a deep seated fault (Singh et al. 2015).

ii) Visit to Bodh Gaya on February 29, 2020 (afternoon)

Sacred Buddhist sites in the world, Bodh Gaya has risen to international fame as the place where prince Siddhartha sat under the Bodhi tree and gained enlightenment some 2,600 years ago. Places to be visited at Bodh Gaya-

1. Great Buddha Statue – 80 feet tall stone statue near Mahabodhi temple

2. Archaeological Museum—it houses the idols and other materials found in the excavation of Mahabodhi temple area and nearby.

3. Mahabodhi Temple and sacred Bodhi Tree—the main temple and Bodhi tree represent the primary attractions of Bodh Gaya, with their historical, spiritual and artistic importance; today, these world Heritage Sites bring in thousands of pilgrims and tourists each year. More temples, monasteries and monuments dot the landscape, built by Buddhists from different nations in their own national styles.

Fig.7. Traverse and different spots along Bokaro River and Ara area.
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Plate 1: Field photographs of Talchir Formation

Fracture filling in the basement (CGGC) by very fine sandstone. Pen marks the thickness of fissure.

In situ breccia, matching boundaries between the blocks.

Logged breccia, hammer and pen marks the dislocation of the blocks.

Lodgement tillite. Facets and high polished clast of different sizes.

Inversely graded beds and faceted bullet clast in clast supported conglomerate.

Matrix supported angular to sub rounded clast of different sizes.

Plate 2: Field photographs of Talchir Formation

Fig. 8. Location of Surajkund (Hot spring) in regional geological setting (after Kumar and Ahmad, 2007).
Plate 1: Field photographs of Talchir Formation

Fracture filling in the basement (CGGC) by very fine sandstone. Pen marks the thickness of fissure.

In situ breccia, matching boundaries between the blocks.

Logged breccia, hammer and pen marks the dislocation of the blocks.

Plate 2: Field photographs of Talchir Formation

Lodgement tillite. Facets and high polished clast of different sizes.

Inversely graded beds and faceted bullet clast in clast supported conglomerate.

Matrix supported angular to sub rounded clast of different sizes.
Plate 3: Field photographs of Talchir Formation

Channel fill sediments in sandstone-siltstone facies.

SSDS-flame structure by liquefaction-syn depositional disturbances.

Hummocky cross stratification

Plate 4: Field photographs of Talchir Formation

Convolute structure, seismites

Ichnofossils in green shale/siltstone

Ichnofossils / burrows
Plate 5: Field photographs of Barakar and Barren Measures Formations

Unconformable erosional contact between CGGC (Basement) and Lower Barakar. Rounded to sub rounded pebbles (polymictic) indicates evidence of transportation.

3D view of Hummock cross bedding in Lower Barren Measures Formation.
Plate 6: Field photographs of Barren Measures Formation

Tidalites and Tidal rhythmites – tide generated depositional feature.

Wave generated structure

Herring bone structure

Bioturbation (Diplo克拉ereon) at transition zone from Barakar Fm. to Barren Measures.
Plate 6: Field photographs of Barren Measures Formation

Bioturbation (Diplocratereon) at transition zone from Barakar Fm. to Barren Measures.

Tidalites and Tidal rhythmites – tide generated depositional feature.

Plate 7: Geoheritage sites

Surajkund (hot spring), temperature more than 85°C

Mahabodhi Temple at Bodh Gaya.

Great Buddha statue – 80 feet tall near Mahabodhi temple.
Chapter IV: Summary and conclusions

Summary

On completion of field tour in all these traverses, the delegates will obtain a comprehensive idea on the transitional nature of the glacial-fluvial-marine interactive systems in the frame of post-glacial transgressive-regressive (T-R) setup. Such T-R cycles during the late Paleozoic Lower Gondwana sedimentation will be explained in terms of prograding and retrograding successions, sediment-organism interaction pattern, sea level fluctuations, sediment supply and basinal tectonisms. The participants will be enlightened about such regressive-transgressive systems in the frame of changing net accommodation space due to base level fluctuations caused by post-glacial isostatic adjustments of the crustal blocks under significant climatic amelioration.

Conclusions

1. Basal part of the Gondwana Supergroup represented by Talchir Formation (Permo-Carboniferous) is dominantly glaciogenic followed by abrupt change over to glacio-marine to terrestrial fluvio-lacustrive depositional environment.

2. The glacio-marine Talchir Formation has disconformable contact with fluvial coal bearing Karharbari Formation.

3. The fining upward cyclic sequence of Barakar Formation stores commercial coal deposited under largely fluvial environment with intermittent marine influx.

4. The Barren Measures Formation (middle Permian ~ 271–260 ma) is a non-coaliferous unit characterized by tidalites, tidal bundle, mud drapes, tidal rhythmites manifest sedimentation in a shallow subtidal to inter tidal transgressive settings.

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BIBLIOGRAPHY


Cover: Convolute structures and seismites in post-glacial, fluvio-marine sediments, Lower Gondwana.