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ConsanguinityMapping of Kunjar- Darjing rocks with Upper Brahmani Basin, Odisha

Swarup Ranjan Barik[1], Siba Prasad Mishra [2], Saswat Mishra,[3]Kumar Chandra Sethi [4]
[1],[2],[4]: Geo-informatics Department, Centurion University of Technology and Management, Bhubaneswar, Odisha, India; Corresponding author: E-mail ID: 2sibamishra@gmail.com
[3]:Civil Engineering Dept, Kalinga Institute of Industrial Technology; Bhubaneswar, Odisha

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Abstract:
The Upper Brahmani Basin from Vedvyas to Renagal Reservoir is a lower Gondwana geographic deposit related to the paleo sedimentation of Kunjar Darjing sub-basin rocks along the upper Brahmani Basin of Bonai Granite Phase II. The lithology of the Lineamentis schist, shale, quartzite, gold, uranium, laterite, and banded iron formation, including Banded Hematite Quartzite (BHQ), Banded Hematite Jasper (BHJ), Banded Hematite Shale (BHS), in iron ore deposits like hematite,magnetite, and goethite.

The present study attempts to correlate the Upper Brahmani Basin (UBB) with the Upper Carboniferous (lower Permian) Talchir boulder bed, which has coarse- to fine-grained sandstone and shales of the Iron Ore Group (IOG) banded with quartzite, Jaspar, and shales over Archean granite genesis. The methodology applied during the study includedregular site visits, a literature review, a geographical investigationsystem, and remote sensing technologies using ERDAS software. The ethanol-botanical flora, fauna, and microorganisms are studied, and their medicinal use by the aboriginals is explored.

The Talchir basin exhibits Diamictite, sandstone grains of greenish and buff colour, shale, rhythmite, turbidite, etc. A detailed study is indispensable to find gems and gold deposits, if any.The natural radio-active pollutants discharging to the Brahmani River must be handled.The Bonai block has plenty of minerals and vegetation. But the aboriginals and sons of the soil are poor migrants.

Key Words: Basin, GIS/RS, Lithology, Hematite, Talchir formation, Etheno Botany

Introduction

The Brahmani River valley witnesses various chronologic Homosapiens settlements in the Rukura Valley in various stages. The Brahamani River system in its upper reaches of the Bonaigarh area has waterfalls like Khandadhar and the Darjing group of rocks. Mendaly, 2019[1];Hota et al., 2020[2]). The studyis on the Khandadhar Falls and Darjing group of rocksover the Brahmani River, Bitola Village, Bonai. The Khandadhar Falls is India's ninth-highest waterfall in India and Odisha's second-tallest waterfall after Barehipani within the Similipal area. This is a geology and Stratigraphic study of the Upper Brahmani Basin (UBB)and part of the Baitarani Basin in the Bonai Area (Vedvyas to Barkote), Odisha.The stonesbelong to the Talchir group over the Precambrian basement of the lower Gondwana

formations.

The Brahmani Basin (BRB) is between the Mahanadi (right) and the Baitarani (left), housed in the Chhota Nagpur Plateau(east and south). A ridge separates it, and drains cover 39033 sq. km. area (22576 sq. km. in Odisha), finally debouching to the Bay of Bengal at Nilakantha. The UBB start from the confluence point of Sankh (Right) and Koel (Left)at Vedvyas up to fag end of Rengali Reservoir over Brahamani. The area is tagged with waterfalls, meandered channels, stiff rock cliffs, and valuable rocks but with poorly scheduled aboriginals and financially backward communities.

Study area

The Brahmani River flows over the Chhota Nagpur Plateau, circumscribing the subdivision. Bonaigarh is surrounded by Raigarh andJashipur (Chhattisgarh) inthe North-West, Simdega and Singhbhum in the north (Jharkhand), Keonjhar(east) and Jharsuguda, Sambalpur, Deogarh districtin the south. towards the south the districts are, and Angul. Bonaigarh Subdivision comprises four blocks: i.e. Gurundia, Bonaigarh, Lahunipara and Koira Block.The six revenue circles, Bad Godua, Bonai, Kenaveta, Jhirdapali, Ruguda and S-Balang, covering 118 revenue villages, are in the Bonai Tehsil. The area is covered in Indian old Toposheet No. 73B/16, 73C/13 and 73G1 (New Topo sheet No F45 G 16, F45 M13 and F45 N1)(Fig 1)

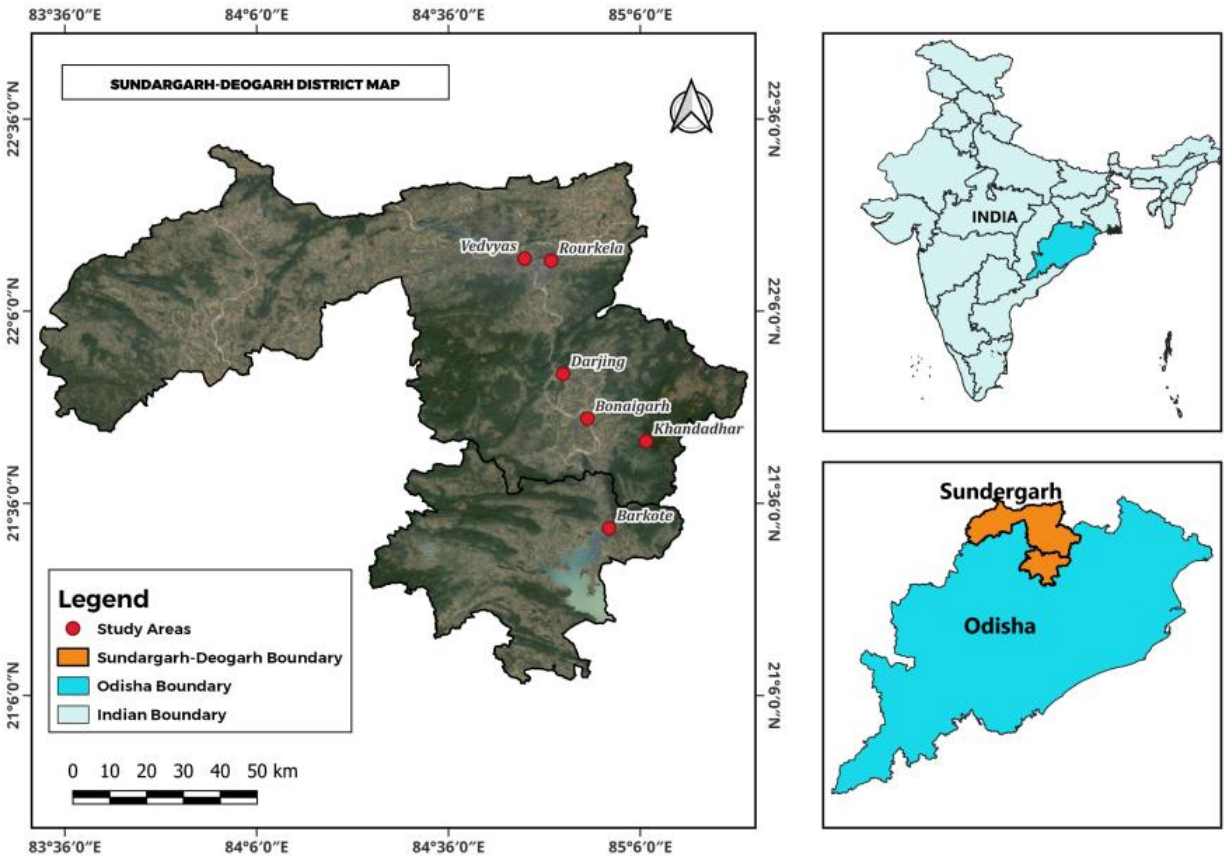


Fig 1: The Kunjar- Darjing Basin in the Upper Brahmani Basin Lower GondwanaFormation

Review of Literature:

The Talchir Formation is the lower Permianstratigraphic unit of the Gondwana Supergroup. It is the assemblage of the Late Paleozoic glaciation comprising of glacial, glacio-fluvial, or glaciolacustrine deposit (Dasgupta 2006;[3]Patel et al., 2021[4], Nance 2022[5], Tripathy 2022[6]).The sedimentation type of Talchir formation belongs to the Gondwanaland

glaciation of the Late Paleozoic period along the Brahmani Basin(Tripathy,1997[8]; Patel et al., 2021[4])

The saucer-shaped Brahmani Basin emanates from the Chhotanagpur Plateau and runs 541 kilometres in Odisha, irrigating 39033 sq. km with an upper stretch from Vedvyas from Rourkela to Barkote tail end of the Rengali Reservoir, it has minerals Uranium, quartz, gems stone, gold, coal, iron ore, bauxite, chromite, copper, manganese, limestone,dolomites, lead, fire-clay, and china clay,with Permian paleodiversity(https://odisha.gov.in/odisha-profile/topography, Dash et al., 2021[9];Mishra et al., 2022[10],Mallick S., 2024[11]). The river bed in UBB shows more sinuosity, Levee depositions, channel area variation, and bar area, which shows avulsion and meandering, n (Anand et al., 2022).The geology of the Bonai granite complex tells us the area is under the Chandiposh group, which is older than the Gangpur group but younger than the iron ore supper group, proving the consanguinity with Kunjar Darjing Basin (Mahallick N., 1987[12]; Naik et al., 2006[13]; Chaturvedi et al., 2016[14], Mallick et al, 2015[15])

The paleo-master basin of the Mahanadi system belongs to leftovers of the Gondwana rocks, Which are reported to be groupings datable to the Permian–Triassic Succession and pre-Cretaceous periods, Goswani et al., 2006[16], Hota 2010[2[, Mishra et al., 2020[17], Goswami et al., 2022[18]).The Upper Brahamani basin faced numerous natural and anthropogenic stresses. The rock stratum and drainage course have gone through many transformations with time. Investigating the area's land cover, rock erosions, and mining activity is pertinent.Various modern technologies and model analyses will be applied to learn more about the transformations of lithology, limnology, and geospatial changes as the river beds are interfaces.

Objective:

The objectives of the present study are:

1. Assessing the significant structure zones and their relation with alteration zones.
2. Assessing alteration zone types andmineralisation thereof.
3. Assessing lithology and vegetation in the investigation area
4. Assessing the consanguinity of Kunjar-Darjing basinstratification and UBBrivers..

Methodology:

River beds or drainage channels are the major geological indicators that help to know an area's geology, stratigraphy, and lithology, which goes slowly but continuously, as well as the exposure areas.Rock Formations, lithology, and stratigraphic determination are very important for developing properties and estimating reservoir characterisation. Traditional methods were used to get geoinformation through field surveys, drilling, and analysis of the log cores. Presently, the inaccessible areas are well studied by various models using photometry, GIS/RS, and GPR technology, which is fast, less extensive, and covers the entire area usingthe whole bid data. The steps used to determine the area of the Upper Brahmani basin after the site visit are given below.

Field Survey method:

The field survey method involves (i) field observation, collection of samples, observations and, if required, use of tools (SOI maps, tables, figures, videosand photographs. (ii) study the minerals or ores, shapes, sizes, colour, lustre, etc. (iii)Use an optical microscope or XRF (X-Ray fluorescent spectrometers) using field samples, and finally analyse to identify the rock, lithology, alteration, minerals or stratigraphy Fig 2(a).

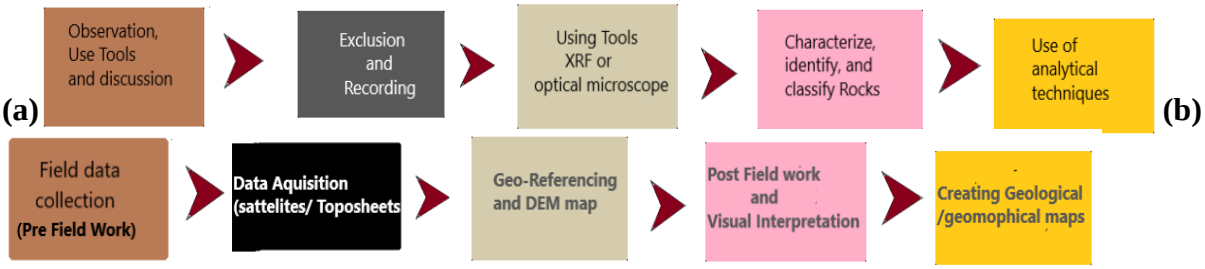


Fig 2 (a and b): Step by Step followed (a) Field survey methods (b) The GIS/RS method

GIS/RS method

Geological maps were made using SOI topographic maps (1:50000 and 1:100000), and Landsat ETM (Enhanced Thematic Mapper) and satellite data were acquired for the study area. After getting the data is georeferenced using ASTER, ETM ETM, and SRTM images, the geological map and ETM images, and finally, the required map Fig 3(b).

The site visit and the Field Study:

Khandadhar Waterfall:

The 244m high waterfallKhandadhar (shaped like the edge of a sword) has coordinates 21 45’ 41” N and 85 52’ 02” E and isconnected through the thick jungles of Nandapani, which is 19km from Bonai. The geological formation belongs to the iron ore formation of the Bonai-KeonjharBelt. The geomorphological characteristics of the area are its topography, hills, mountains, valleys, springs, rapid waterfalls, potholes, cascades, plunge pools, and the drainage pattern present in the area. The topographic elevation of the regionis 514m, bounded by a continuous western ridge and dissected eastern highlands by the central Jamda-Koira valley. Sahoo et al., 2020[19], Fig 5(a).

Kunjar-Darjing Area:

Darjing is a hilly picnic spot over the Brahmani River at 21^0 56’ 53” N and 84^0 52’ 46E”,accessible through NH 143. The Kunjar- Darjing basin hasProtozoic era formationsof metasedimentary rocks, a prominent source of uranium. GIS with Spatial Modeling can be used in Geoscientific Information for Exploration of Uranium over the Kunjar-Darjing Basin, Odisha.The geological succession is given as follows. (Fig 3 and Fig4(a and b))

Itma and Ekma Granite (May contain REE-bearing pegmatite of Jharsuguda-Bamra granite) **Kunjar Basin rocks**
------UNCONFORMITY------
Gangpur Group (mafic/ultramafic sills/dykes) **Darjing Group (mafic/ultramafic sills/dykes)**
------UNCONFORMITY------
Tamperkola Granite and Jharsuguda-Bamra Granite **Bonai Granite Phase II** **Iron Ore Group**
------UNCONFORMITY------

Archean Granite (consisting Bonai Granite Phase I(3.4 Ga) and unclassified granite)

Fig 3: Geological Succession of Kunjar-Darjing Basinin Upper Brahmani Basin

Easterghats Mobile belt (EGMB):

The Upper Brahmani Basin in the Rengali Province (UBB) is seismically active due to the reactivating faults and bends within it. The domain receives mild tremours either due to foliation,Coal miningactivities in the vicinity of Talcher, or theimpounding of the Rengali Reservoir.The Eastern Ghat Mobile Belt (EGMB)possesses the signature of cratonic gravity below the Rengali Province. or the northern boundary of the Talchir Basin. The Post-Gondwana faults are localisedin the UBB, responsible for these mild seismic tremors and have epicentresnear the North Odisha Boundary Fault (NOBF)(Gupta S., 2014[20]).

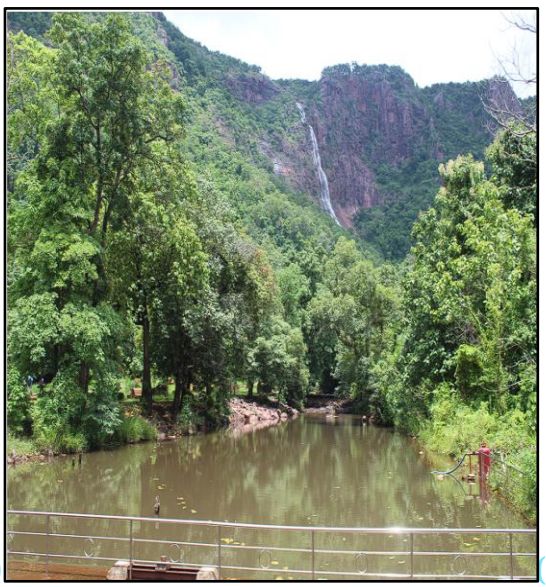
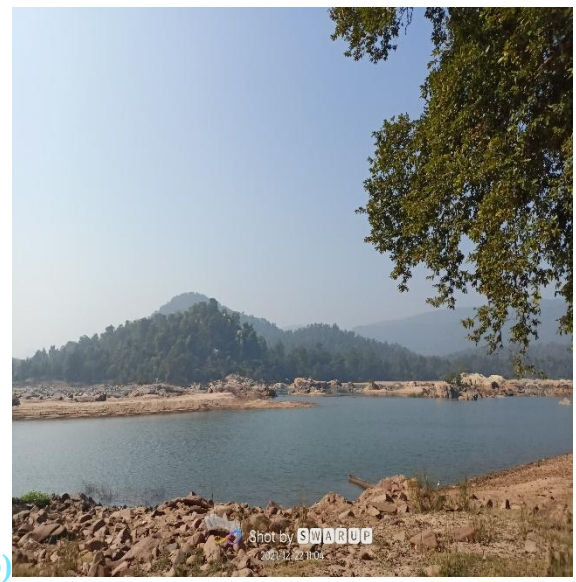
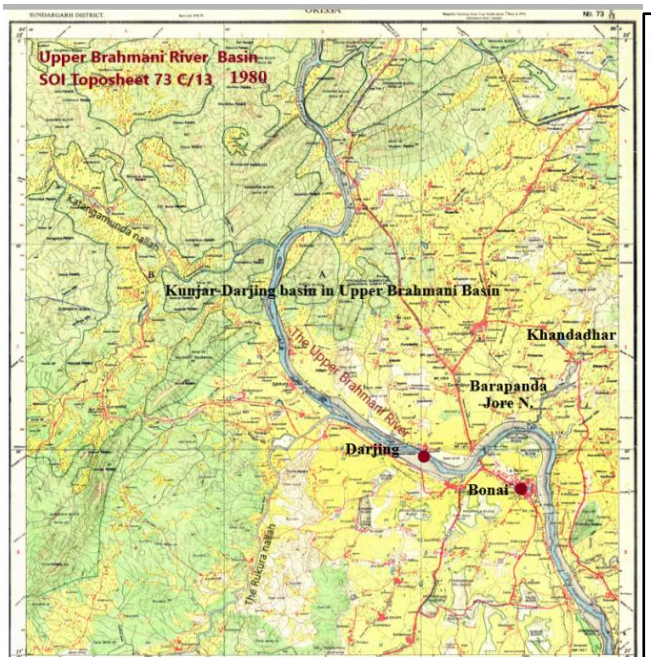
(a)  (b) 

Fig 4 (a): The Khandadhar Falls Fig 5(b)Blue stone Recreation area at Darjing (UBB)

Formation Darjing Kunjar basin

The Paleozoic sediments of Darjingand Kunjar sediments are favourablefor unconformity type of uranium mineralisation settings. Thus, contacts of Darjing or Kunjar sediments with the Tamaparkola granite dominatethe mineralisation process(Chaki et al., 2005[21]). The geomorphology of the Kunjar Darjing basintalks about its relief, mountains, Vallie's, Goerges, rivers, drainage patterns, and topography. The topography talks about landform variations in elevation between ≈149m and ≈600 above MSL. The hillocks are at Barghat-Champajharan, Purunapani, Narsinghnath, Dhangarh, Phooljharin, Budhikutuni,etc..The river bed at Talcher hasa sedimentary air rock cut in sandstone of 15.5m of Anantasayan of lord Vishnu that belongs to the Gangapur block Fig 5(a), Fig 5(b).



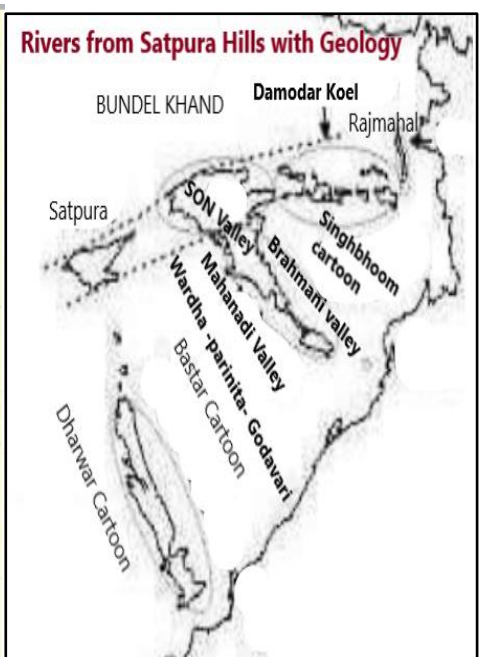
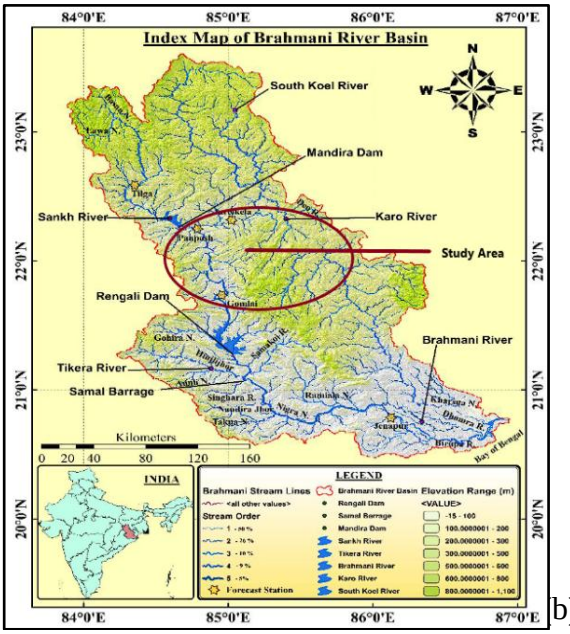


Fig 5 (a): SOI Toposheet 73C/13 showing UBB (1980) Fig 5(b): The UBB and its allied valleys

Upper Brahmani Basin:

The Brahmani Basin (BRB) is a congregation of six sub-basins such as Tilga, Gumla, Noamundi, Gomlai, Angul, and Jenapur,covering Chhattisgarh, Jharkhand, and Odisha. The upper reachis the South Koel, comprised of various plateaus at diverse heights with maximum heights ranging between 600–700 meters. The Brahmani River has an average annual peak flow of 18000 cumec to 20000 cumec at Jenapur downstream of Samal Barrage Fig 6 (a)

(a)



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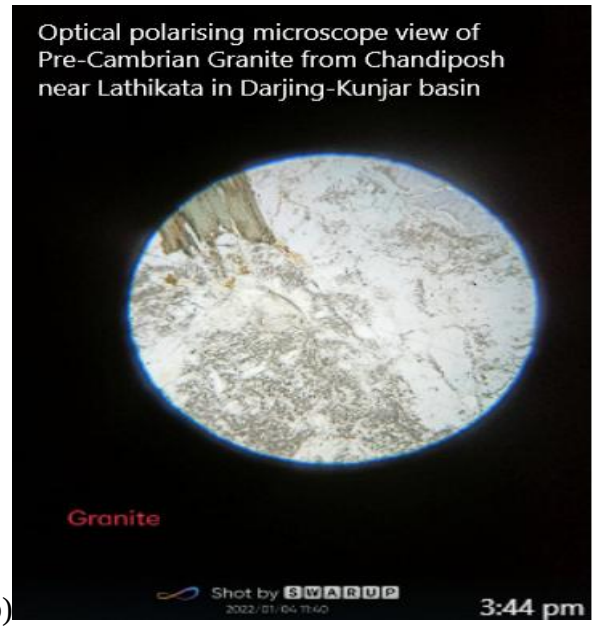


Fig 6(a and b). The Brahmani Basin (b)UBB between Barkote and Vedvyas; Fig (b): Optical Microscopic view of exposed granite onthe river bed of UBB

At higher MSL, the basin is saucer-shaped. The major river emanates from Nagri village near Ranchi as south Koel, collecting water through Sankh, Tikira, Samakoi, and Karo as main tributaries. It runs for 799km, forming a vast delta and finally debouching in the Bay of

Bengal at Nilakantha. The Upper Brahmani Basin (UBB) covers Chhattisgarh, Jharkhand, and Odisha.

The basin has a series of plateaus at different elevations (149m to 600m), branded by undulations and dissected. It slopes towards the southeast, passing through the Bonai—Keonjhar belt. Deodhar and Kurudhi are the two Goerges, and several valleys are formed due to fluvial action and cause for drains (nullahs) like Rukura, kantangMunda nallah, Champajharan, Bhulikuch, Bhulikuchi nallah, Kulijhar Nallah etc in the right bank and the Champajharan, Kurudhi, Kumbhardiha, Phulchuei Nallah and Amsari nallah as tributaries from left. The middle basin is from Barkote to Jenapur, where the tributaries are the Samakoi, Tikira, Mankada River (Bansipani Hills), and bada Jore (Fig 7).

Demography:

The Sundergarh district is geographically 9712 km2 (1762 villages), which is 6.24% of the area and 4.97 % of the population living in 1762 villages of Odisha. The total population of Sundergarh is 2080664 (2011 census). Bonaigarh is a subdivision of three subdivisions of the Sundergarh district in Odisha, India, located in hilly areas that dominate the ST and SC people, with an average elevation of 243 meters. The people of the minesare financially backward, running with poverty. Instead of alleviating poverty, mining exacerbates the backward region (Mishra et al., 2018[22],).

Bonaigarh has a Geographical areaof 2,322 Sq. Km., population 277001 persons (2011 census), Population Density is 119 persons/ sq. Km, Blocks arefoursuch as Bonaigarh, Lahunipada, Koida and Gurundia, living in 574 villages. The demography is male, 139336, and 137665 females, dominated by ST, witha total population of 187471. The dominating tribes are Kisan (28.45%), Bhuyan (25.15%), Oraon (19.80%), Gond (13.72%), Kolha (7.05%),and Mundari (5.83%) of the total Tribes living in the subdivision.The tribal population distribution of more than 50% claims that Homosapiens have primitive habitation from the prehistoric era, (Mishra et al., 2021[23]).

Gondwana Basin of Odisha:

The Permian–Triassic Succession PTS belonging to the Gondwana Sequence of India was consideredfluviatile-lacustrine deposits. The fossil proxies of marine origin in Odisha's Gondwana basins are found in the Early Permian Talchir basin, extending up to Upper Kamthi, which is of Triassic origin (Goswami, 2008[24]).

Lower Gondwana Formation:

The Talchir Formation is India's lowest Gondwana succession (early Permian) rock, with a 3000m extension outcropping ≈465 sq km exposed at Manendragarh in Chhattisgarhfound with marine fossils,muddy conglomerates (Fluvial), glaciolacustrine sedimentand coastal faunal assemblage, (Ghosh et al, 2019[25];Choudhury et al., 2023[26]). The Geological Survey of India has established a National Geological Monument of 2.5km comprising Marine fossilsas the Lower Permian Marine bed. The lower Gondwana rock formations and characteristic field photographs from the Talchir and Barakarof the Talchir FormationFig 8

Geological geochronology:

The Gangpur Schist Belt (GSB) 's geochronological and metamorphic construction is sandwiched between the Bonai Granite pluton and granite gneisses of the Chhotanagpur Gneiss Complex (CGC). The Precambrian origin of the Bonai Granite is 3,370 ± 10 Ma, whereas the CGC is of c. 1.65 Ga. The sediments in the southern part of the Gangpur basin (a part of UBB) are from the Singhbhum craton, but the northern part is CGC-dominating and is

of late formation (1.45Ga).

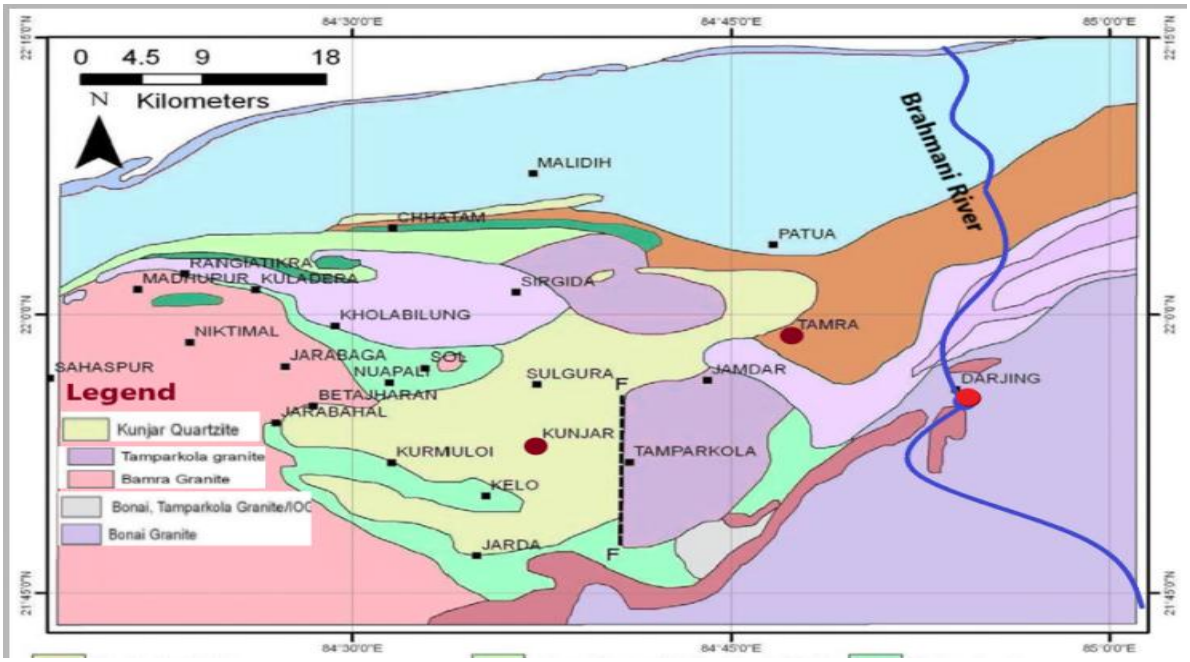


Fig 7: The lithological Kunjar- Darjing group of formation (modified: Chaturvedi et al, 2015[14]) along the Upper Brahmani basin.

.The Upper Brahamani Basin and Bonai-Darjing Group of rocks were metamorphosed between c. 1.56 and c. 1.45 Ga. In contrast, the Gangpur Group of rocks were metamorphosed at c. 1.45 and c. 0.97 Ga, comprising quartzites, schist of quartz, mica, amphibole chlorite, and the younger formations of the Bonai granite are slate, phyllite, quartzite and amphibolite extending uptoRajbasa within Bonai granite showing strikes, dips, faults, and folds in the bedrocks of Brahmani river in upper reaches with the formation of synclinal structure (Chakraborty et al., 2018[27]; Mishra et al, 2021[28]; Mallick et al., 2023[29]).

Climatology:

The upper Brahmani basin enjoys a Tropical (wet and dry) or savanna climate (Aw). The average (AV.) annual maximum and minimum temperature are 34.36ºC and 22.71ºC, respectively. The subdivision has an average annual rainfall of 1647.6mm and maximum and minimum temperatures of 48 C and 6 C. The subdivision has a total forest area of 146061 Ha and a cultivable net area of 257927 Ha during Kharif and Rabi. The surface irrigation Projects (flow) and groundwater flow are 15425 Ha and 1358 Ha, respectively, Mishra et al., 2023[23h], https://weatherandclimate.com/india/odisha/sundergarh.

Geo-Physiography

Bonai geophysical stratigraphy is a mountainous, hilly expanse with dense forests (particularly the Eastern part) at a higher elevation of more than 150m. The area has bald forest hills crisscrossed by a few passes or gorges interconnected. After the settlement, the Rourkela steel Plant, population growth and impounding of Rengali and Rukura reservoirs have made the land fertile by the rise of the water table (GWT), and asignificant portion of Bonaigarh has developed. The mines have enhanced the economic status, agricultural and societal practices.The left flange and side banks of the River Brahmani between Bonaigarh and Kamarposh Balang (K-Balang) and Koida areat high elevation. The geomorphology of the Birtola-Darjing area is divided into northern hilly lands and southern flat terrainAshokan et al., 2021[30].

The Mountainous Range:

The principal peaks are Mankad Nacha (1117mt.) and Badamgarh (1074m), both on the Keonjhar boundary, Kumirital or Kunsiter (1065m), the Biehakani (903.5m) at Khandadhar (914.5m) along with numerous smaller peaks like Rengalbeda, Baghabindha, Raipiri and the Kantamunda under Gurundia Block in Bonaigarh. The other peaks of the Koida block are Ballia and Karasapani. The southeast has bald hills intersected by gorges (Deodhar etc)and narrow valleys of the Brahmani River and its tributaries, Rukura (Fig 8 a-d).

(a) 

(b) 

(c) 
(d) 

Fig 9: (a) Deodhar Gorgeat Kunjar- Darjing basin (b) the Upper Brahmani basin (UBB) (c) Celt debris mounds at Sulabhdih (Lunga Hills) (d) Banded shales (Slopes of Brahmani R. marine origin)

Land use and land cover:

The categories are mountainousrocky laterite, which originates in red soil. Available vegetative covered forest areas are Sal, Piasls, Mahul, Assan, Mango, jackfruit and Kendu trees. Bonai Forest Division has ild animals found in the forest: elephants, bears, foxes and wild bears. The tiger and poisonous snakes are also found in deep forests. Rugda (Astraeus hygrometricus) is a type of wild mushroom that fights against malnutrition and food insecurity for the financially backward people of the area. For collecting Rugda (Astraeus hygrometricus) mushrooms, the tribal caught fire to the forest, so it is essential to develop awareness among the indigenous people to avoid Podu-Cultivation for collecting Ruguda mushrooms (Local name: Phutka, Sargi or Boda) and save the forest from fire. Aboriginals

should be trained in Ruguda Mushroom farming (Sanath et al., 2024[31]) (Table 1).

Table 1: The stratigraphy having rare flora and fauna in Bonai subdivision, Sundergarh

#	Type	scientific name	Local name	Uniqueness
I	**Flora**	Utricularia stariatula	Striped Bladderwort	insectivorous plants of high altitude (Carnivorous)
	Orchid	Epipogiumroseum	Ghost orchid	White, Saprophytic ground orchid
	Epiphyte	Dendrobium regium	Royal Dendrobium	600 meters as a medium-sized, warm-growing epiphyte
		Exacumpaucisquamum	KanaPoondu or Klack	Wild leafy vegetables in the moist deciduous forest of Bonai,Santaliesfood
	Teridophyta	Astraeus hygrometricus	Rugda mushrooms	Nutritious and encourages Podu-Cultivation
II	**Fauna**	East Indian leopard gecko	Kalakuta Sapa,	Harmless but Near Threatened (NT) by Int. Union for the Conservation of Nature (IUCN)
	Animal	Leopard	Chitta-Bagha	Large feline in forests has a tawny coat with black spots
		Rusty-spotted cat	Fishing Cat	smallest wild cat weighing 0.8-1.6 kg, 35 to 48 cm in length without tail
	Bird	Malabar pied hornbill	Kuchila Khai	Common inBonaiforests but poaching for medicine wiped them off
	Lizard	Banded geckos	Chitra Jitipiti	A harmless lizard in forests
	Bird	Imperial pigeon	Duculaaenea	Large bird with greenish-brown upperparts and grey underparts. in deciduous forests Shy bird,.

Source: Goswami, 2012[32], Sanath Ku. Et al, 2024[31], Kumar SN et al., 2022c[33]; Kumar et al., 2021a; Kumar et al., 2024b[35].

The faunal diversity of Bonai Forest Division(BFD) has been enumerated as species of plants (102 types), creepers and climbers (37 numbers), 41 species and shrubs, herbs and grasses of 41, 39 and 13 species, respectively. The insect diversities are dragon/damsel flies (56 types) and butterflies of 136 species belonging to the *Odonata order*. The aqua fauna (31 types) and amphibians (snakes, lizards, turtles) (58 types), and mammals (39 species), Palei et al., 2016[36].

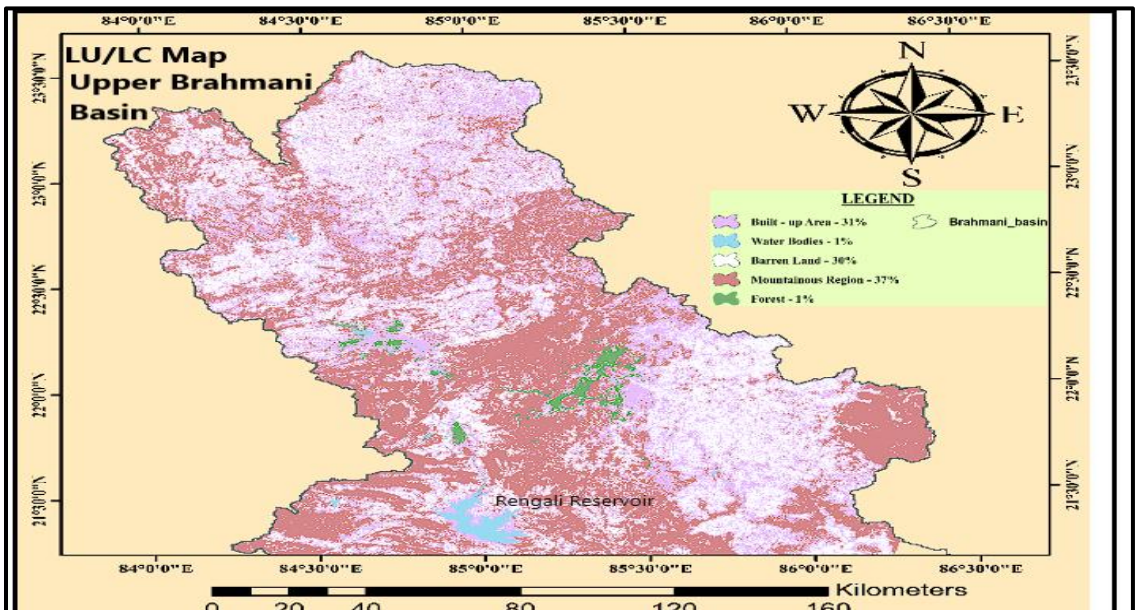


Fig 9: The Land use and Land cover map of the Upper Brahmani Basin

Agriculture:

The inaccessible areas were fearful of wild beasts except for a few hilly roads and sparse agricultural fields with traditional agricultural practices and *Podu*-Cultivation in terraces of the forest.The highest land cover is barren land of area Barren Land of 51864ha. The netarea of the sown and irrigated land of Bonaigarh is 41185 and 7099 ha, respectively.

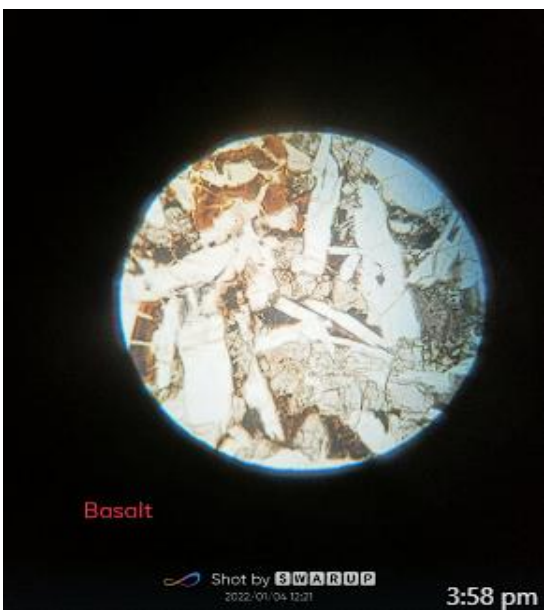
The lands under cultivation are classified as*panibahar (no water scarcity as stabilised from ponds and reservoirs), Berna or pani Berna or Mal (drains pass through the land), gada (rainfed completely),* and bari-bagait (Kitchen Garden or fruit-bearing plants).In the past, all the lands were rainfed, but at present, 3.18% of the total cultivated area is irrigated through the Rukura irrigation projects and the Karachi irrigation project (Koida block).

Irrigation status

The primary drainage system and tributaries that contribute to the Upper Brahmani basin from its basin are the Brahmani River (26190 sq km), Siudhi nallah (18.5 sq km), Kuradi nalla (32 sq km), Amruti nallah (42 sq km), Sapalata nallah (22 sq km), and Rukura nallah D/S (32 sq km). The discharge enters the Rengali reservoir at Rengali, in Talcher District.The basins of all these rivers are part of the Talchir basin and possess Kunjar Darjing formation.The drainage system in the Bonai subdivision has 21 irrigation project drains of 458.97 ha., a catchment area, and an irrigation potential of 6178.12 ha.It is found that the polariser and the analyser are kept in overlapping slots, so they are crossed. The amount of Basalt above the Renagali Rengali dam site is sparse. There is widespread Granite, hematite and dolerite beds are visible.

Mines and minerals:

The Bonai-Kendujhar beltin Odisha, India, is known for its economic exploration of iron ore from deposits of Hematite, where mining activities were rampant in the 20th century. MGM Minerals Ltd extracts iron ore from the Patabeda mine, which contains 55–67% iron, phosphorus at a low percentage, and sulfur content suitable for sponge iron. Bichakani Mines, Barsuan quarry,is used for the smelting at the Rourkela steelplant (RSP).The microscopic samples from Basalt dykes near the Rengali Dam site were tested by optical polarising microscope (a) Without crossed (b) When the polariser and analyser were crossed. The basalt rocks are rarely available in UBB (Fig 6 (b) and 11).

(a) 

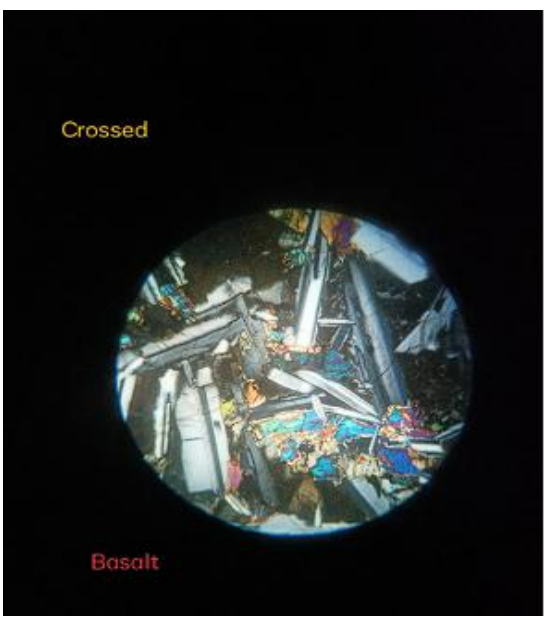
(b) 

Fig 10: The microscopic samples from Basalt dykes near Rengali Dam site tested by optical polarising microscope (a) Without crossed (b) When the polariser and analyser are crossed

Geography and stratigraphy

The present investigation comprises the distribution of stratigraphy of rocks in the middle reach of the basin, which is of geographical importance.The Khandadhar waterfall is located in the Nandapani area, Lahunipada block, Bonaigarh Subdivision, Mayurbhanj District, Odisha.It is 801 feet (244 meters) high and is said to be the tallest waterfall in Odisha.The Korapani Nala, a perennial al rivulet, created the Falls Directorate of Geology, Government of Odisha, and explored the Khandadhar area from 2002 to 2005 (present Topo Sheet No F45N1 (Old 73G1).

The Bonai-Keonjhar belt is a significant iron ore formation group that includes Odisha's Archean supercrustal iron ore group (IOG). This belongs to the Mesoarchean IOG, disposed of in a horseshoe-shaped synclinorium structure in the western part of the Singhbhum Craton. The rocks of the Khandadhar region belong to the western limb of this horseshoe synclinorium(Fig 12)

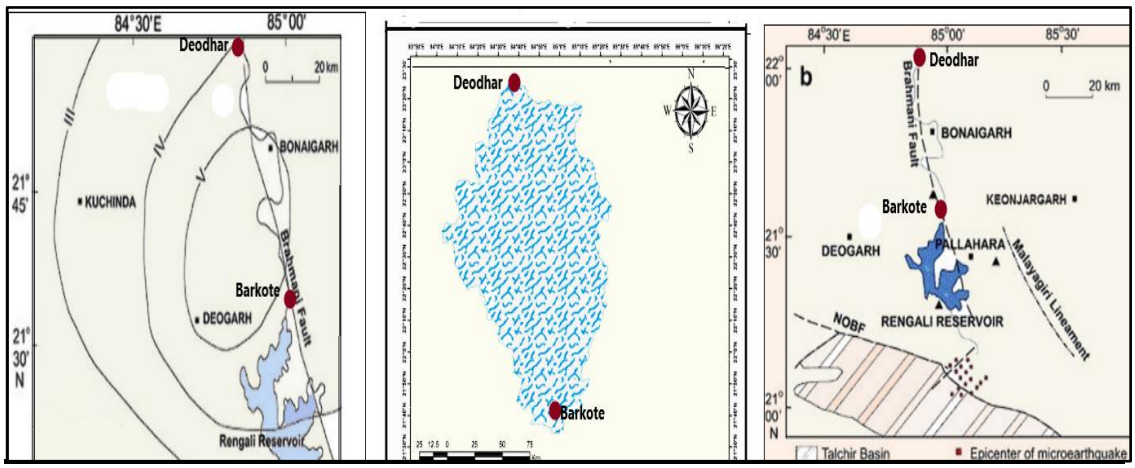


Fig12: The geology features in UpperBrahamaniBasin (UBB) (Source modified:Gupta et al., 2014[20]; Rao et al., 2023[37]; Sanjib Kumar, 2023[38])

Geomorphology Kunjar-Darjing fabric:

In Khandadhar, awaterfallfrom a cliff of the mountain of the height of 244mtrs,they were flowing through a perennial rivulet called Korapani Nalaflowing from east to west through a narrow rocky path forming some cascades.The Korapani nallah, emerging from a dense forest area over a high mountainous range, debouches to the river Brahmani, which flows from north to south. The Khandadhar releases waterthat flows over a series of vertical steep drops due to uneven erosion ofrock beds. All the waterfalls have alternate bands of horizontal beds of exposed harderandsofterrocksduetodifferential erosion. Fall across river beds with steep slopeswithhigh water currentsdownstream areRapids.

Lithology

The Bonai basin consists of metamorphosed volcanic and sedimentary rocks of the Precambrian age of the Koira group. It is an iron ore basin, part of the Bonai-Keonjhar Iron Ore Basin (BKIOB). It has multiple lithological units, such as Laterite, Schist, Cherty quartzite, Tuff, Local dolomite, Banded hematite jasper (BHJ), Banded hematite shale (BHS), Banded hematite quartzite (BHQ), Phyllite, Shale, and Mafic volcanic rocks. However, significant rocks are granite and granite gneiss. However, massive walls of dolerite, used as raw material for mass

production of axes, adzes and chisels in southern Bonaigarh, datable to the Neolithic period (CGWB 2013[39], Mishra et al, 2020; Behera et al., 2020)Fig 11 (a-d).

(a) 

(b) 

(c) 

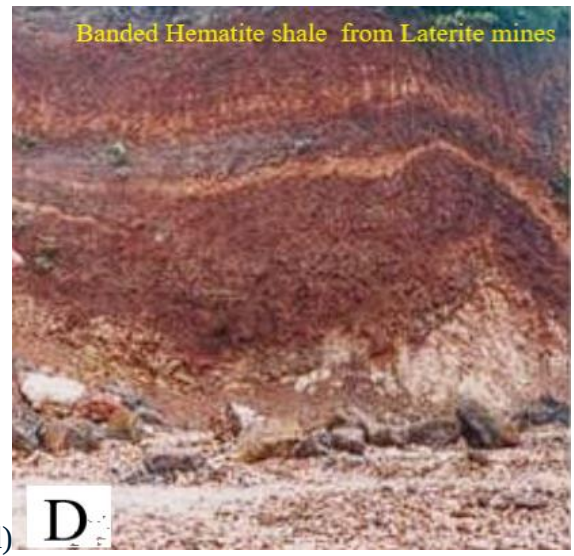
(d) 

Fig 11: (A) Banded Hematite Jaspar (B) Alternation of Hematite to Limonite (C) Banded hematite and quartzite (d) Banded Hematite shale in Laterite mines in SulabhadihaKunjar Darjing area (Indication marine formation)

The Bonaigarh has major lithology types. The area is schist, tuff, phyllite, shale, laterite and banded iron formation, including Banded Hematite Quartzite (BHQ), Banded Hematite Jasper (BHJ), Banded Hematite Shale (BHS), Banded Shale, and iron ore bodies. Iron deposits comprise iron minerals like hematite,magnetite, martite, specularite and goethite. Chert, jasper and quartz constitute the silica-forming bands that alternate with iron minerals. The iron ore found in different forms such as Magnetite (Fe_3O_4, 72.4% Fe), Hematite(Fe_2O_3, 69.9% Fe), Goethite (FeO(OH), 62.9% Fe), Limonite ($FeO(OH)\cdot n(H_2O)$, 55% Fe) orSiderite ($FeCO_3$, 48.2% Fe).

Plunging Pool:

A plunge pool is a deep depression (basin) generally formed at the bottom of a waterfall by the scouring action of water falling from a cliff. The size and depth of a plunge pool usually depend upon the volume and height of falling water. In Khandadhar, water falls from a height of 244mtrs and forms a plunge pool at the bottom by erosion.

Potholes:

ThegeologicalworkofwaterflowingfromKhandadharwaterfallforms potholes in the bedrock exposed on its path. The development of potholes is based on abrasion due to the position and geometric configuration of the channel. However, the shape depends on the bedrock mechanismsand channelhydraulics, which are generally cylindrical.Potholes are erosion features that influence the rock's age where they occur. The abrasion occurs due to rotary currents inside the potholes and the water's vibration of pebbles and stones. The initial force is the fractional force towards the downstream; the potholes are gently sloped towards the upstream direction and times in the flow or the paleocurrent direction where deposits of precious metals like gold can occur (Fig 12 a-d).

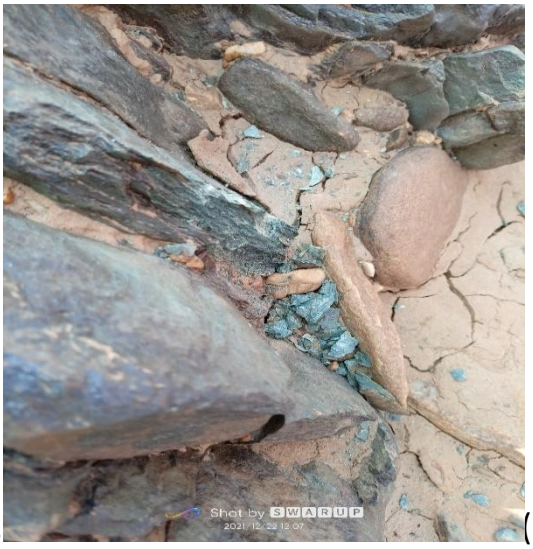
Fig 12(a) The Khandadhar Waterfall (b)The plunge-pul of Khandadhar waterfall (c) The pothole formed near Darjing (d) Cleavage showing in the rock Lithology of the Upper Brahmani R. bed over the Kunjar Darjing fabric.

Joints fractures and veins:

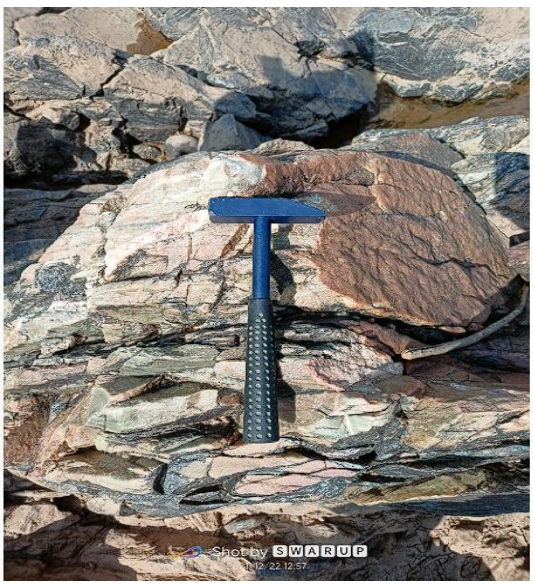
Joints, fractures, and veins also help develop potholes. Water picks up these weak fragments and makes depressions, whichfurtherleads totheformationof potholes.

Petrology and Stratigraphy

From Deodhar to Barkote,the river Brahmani's upper reaches have been thoroughly explored with all tributaries, forests, mountainous ranges and other topographic features as a staff to the Rengali dam project for 12 years.

a. 

(b) 

c. 

d. 

Fig 13(a-d) : (a)Dolerite at Darjing; (b) Green schist with quartz vein(c) BHQ Banded hematite quartzite (Leptua Hills), cross-stratified fine sandstone–siltstone facies association, Talchir Formation(d)Green schist at Areaaat Deodhar.

The entire riverbed was observed to be rocky in all reaches, with alternate ridges, depressions, and more potholes in granite regions than in the quartzite area. Other rocks like Green Schists, greenschist with quartz vein, BHQ Banded hematite quartzite, Hematite with Limonite, Quartzes, etc., are found on river beds, and at some places, laterite, hematite and dolerite are found (Fig 14).

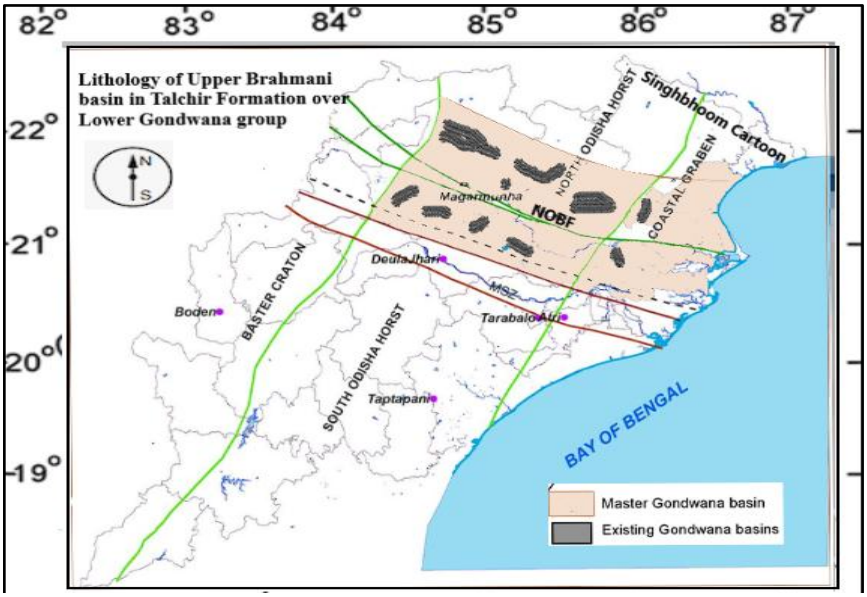


Fig 14 : Geology and stratigraphy of Upper Brahmani Basin of Talchir formation (Modified: Pattanaik et al., 2019[42])

Petrology

Petrology is the branch of geology that studies rocks, aggregation of minerals, heterogeneity in colour,chemical composition, atomic structure, and the formation process in nature. Mineral rocks likedunite,quartziteandmarble have one colour.The igneous, sedimentary and metamorphic rocks, depending on origin, reflect their identification by texture such as crystallinity, granularity, the shape of the grain (igneous rocks),grain size, the roundness of grain, clastic, matrixor cement arrangement (sedimentary rocks). Metamorphic rocks are identified by crystallinity, elongation shape or granularity, schistose, gneissose, granulose, and others that are helpful to characterisemetamorphicrockinthefield.The mountains area and river beds are good sites for rock exposure.

(a) 

(b) 

c) 

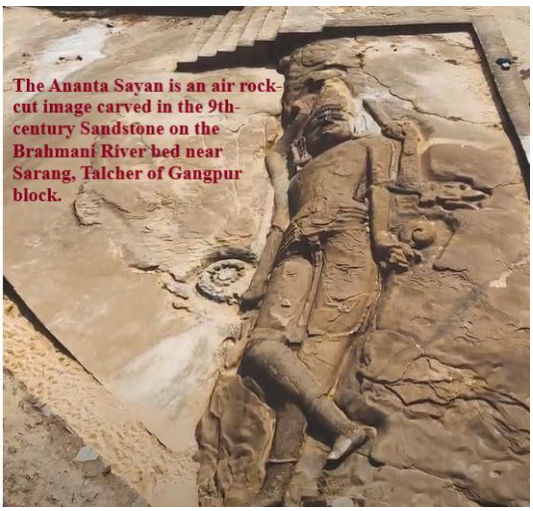
(d) 

Fig 15 (a-d) : (a) Quartz vein with the parent rock (b) Dykes with Dolerite rock(R. bed)(C) Banded hematite Jaspar in the UBB River bed (d) Lord Vishnu's sculpture at Talcher, Brahmani R. bed,at Sarang (Talchir Formation)

The rocks are distinctly observed at the mountain slopes and streambeds.Intheserockysurfacestreams, water forms cascades like waterfalls.Differenttypesof geomorphic features are formed in the rock exposed in the streambed dueto the differential weathering of rock. The streambeds havevariousrock sizes like pebbles, boulders, sand, silt, etc. These are ill-sorted and transported from upstream.TheessentialrocktypesareBHJ,BHQ,Granite, Limonite, Laterite, Manganiferrous shale, etc. Mainly, BHJ and BHQ aremajorrocktypesin this area that belong to the iron ore formation of the Bonai-Keonjhar belt. Banded iron formations are distinctive sedimentary rock units of alternating iron oxides and iron-poor chert layers.Theironbandsintheseoresaremade of hematite,andthesilica bands arequartzorreddishjasper.The Gangapur rocks are yellow, buff, and light brown sandstones and conglomerates in clayey interbeds generally available nearTalcher or the Pranhita-Godavari Basin (Fig 15 a-d).

Discussion:

The Proterozoic Kunjar-Darjing Basins is Singhbum Uranium Province (SUP in the west), Odisha. There is unconformity related to uranium mineralisationand the unconformity between Kunjar-Darjing sediments and the S-type per-aluminous Tamparkola granite housed in the Upper Mahanadi basin. Thegeological,lithological, mineralogical, geophysical, and geochemical aspects of a GIS environment help target locations for uranium exploration. The places targeted to have uranium deposits areKelo, Tamra, northeast of Kunjar, Nuarali and Betajharan in the Upper Brahmani basins.

Many ethnobotanical plants and local faunal diversities are available in the Upper Brahmani Basin bed, which the aborigins use as medicine for many diseases. Some unique practices in UBB areas are:

1. Deposits at Sulbhadiha stone scraps used as celts representthe presence of the Stone Age in the upper Brahmani Basin
2. There is variation in lithology between the upper and lower Brahmani basin.
3. The upper/lower basin has a variation of stratigraphy and mineralogy (UpstreamofRenagli Dam and downstream below Samal barrage; the 22km is the transition zone with hematite and coal deposits).
4. Catching fish using sonication techniques

5. Human-elephant conflicts are common in the UBB
6. Tadi is one of the significant locally-made liqueurs used commonly
7. Rugda powder is used with coconut oil to fight skin infections.
8. Resin of Kusum used as a colouring agent
9. Bulb of Bulbophyllum orchid is consumed as a food.
10. Resin of Sal with honey is used in diarrhoea

Cognition of the stratigraphy

The lithic celt production sites (mostly chisels and adzes) are located in the village of Sulabhdih in the Bonai subdivision. They are presumed to have later spread to other state regions (Behera et al., 2020). The lithology, variations of rock units, climate conditions, etc., are the significant factors that cause changes in weathering under the same conditions.

The UBB is included in the Darging-Kunjar fabric, a part of the Bonai-Keonjhar belt of IOG. The deposits vary in trend from NE-SW to NW-SE and in the E-W direction. When transported by fluvial action within the river, banded iron formation and iron ores create pebbles due to abrasion. After the impounding of the Rengali Reservoir in 1984, the pebble's creation processes were dominated by the sediment transport phenomenon. The Brahmani River bed has been dominated by two main litho-units, such as banded hematite-quartzite (BHQ) and banded hematite jasper (BHJ), covering the other BIF disposition of banded chert and ferruginous shale,etc. The iron ore deposits are found in varieties (mainly epigenetic and syngenetic), the dominant being the hematite (Beuria et al., 2018[43]; Behera et al., 2020[41]).

The river bed from Barkote to Deodhar possesses varying rock strata similar to UBB. The tributary bed or the Brahmani R. bed forms gorges due to differential weathering in the granites or quartzites. The rocks have cliffs, and waterfalls are formed.

LATERITE:

Laterite, common in the transition of Bonai and Keonjhar (Khandadhar), is mainly formed due to intense leaching caused by tropical rains and high temperatures. Thelaterite ores with lime, $FeCl_3$, Al_2O_3, and silica leached away after forming hydroxides, leaving behind soil rich in oxides and aluminium compounds.

Quartzites: Patches of white to bluish quartz in bedding planes or banded veins are found in the bed of the river Brahmani in extended patches. The trend is east to west and dipping at a high angle Northwest. They are found in river beds where sinusoidal meandering of the river occurs (i.e. near Darjing). The bluish quartzites are standard on the upper reaches of the Brahmani river bed in uniform characteristics and colour. They are distinguishable from marbles due to their grain size, compactness, hardnessand absence of porosity.

BANDEDHEMATITEQUARTZITE(BHQ):

Banded hematite quartzite is a banded iron ore depositlike BHJ.Here,alternatinghematite(brown) and quartzite (white) layers arepresent.BHJ is unevenly banded with alternating layers of hematite and jasper. The thickness of individual bands varies (a few mm to about 2cm). The bands also vary from grey to red and brown or black. These rocks occur in the hanging wall of the mountain.

LIMONITE:

Silica bands occur with alternating bands of yellowish-browncolour and are limonite. The

hydration of iron-rich minerals like hematite forms Limonite. In these areas, stream water weathers hematite and produces a hydrated oxide form of hematite,i.e. limonite.

Basic Dolerite Rock: These igneous rocks aredark in colour, holocrystalline, medium grains, and coated with plagioclase feldspar. These exposed greenish hard massive rocks exist in the upper Brahmani river bed like large walls with fractured cleaves. Later, in the flow through the steep bed and falling within the route of the Brahmani River, the large boulders fragment into pebblesafter reachingthe reservoir.

Conglomerate boulders:

The Brahmani river bed and basin have fragmented rocks, pebbles, sands, and clay, which form the conglomerate, which is composed of rounded quartzites, pebbles, BHJ, shales, and even celt stones of sedimentary origin. These stonesproxy the geological deposition cycle and are consanguineous with the Kunjar—Darjing rocks.

Riverbed Placer deposits or alluvial placers:

The river runs through a sloppy bed, and variation of current causes the river to meander, and alternate deposition layers of placers, pebbles, boulders, alluvial soils and sand are sorted systematically. During the construction of the Rengali Dam, the people nearby have the practice of collecting gold flakes/grains or gems stones collected from the river bed after passing floods.The presence of gold flakes suggests that a gold-bearing horizon existsin the UBB catchment. The fact demands a proper geological study to find these gold deposits.

Granite bed:

It is worth noting thatduringthe investigation, especially from Darjing to Bonai (from Gumulai to Tala Dhipa), the river bed meanders due to exposure to the Precambrian Bonai granite complex. The cracks and fractures found of feldspar grains in the riverbed establish the catalytic structure of metamorphism, which is enhanced with biological weathering.

Stratigraphic studies:

During the field visits, it was observed that the quartzites are intruded by granite. The intrusion of the primary rocks intoquartzites and floated tells that the intention was prior to foliation. The intrusion of dolerite into granite without quartzite suggests later-stage insertion.Stratigraphy Hierarchy. It may be concluded that the hierarchy of stratigraphy of rocks on the beds of the Brahamani River is in its UBB hierarchy (Fig 16)

Fig 16 : Stratigraphic Hierarchy of the UBB bedrocks

Theexcavation of the bed of the Brahmani River in Dam,the site near the gorge at

Rengali,exhibited paleo sedimentation similar to the Kunjar Darjing basin sediments and the availability of traces of gold grainand Talchir basal boulder. (Table 2)

Stratigraphic studies Lower Gondwana Talchir Supergroup with the UBB

Table 2 : Stratigraphic Growth of early Lower Gondwana Talchir Supergroup with the UBB

Age	Group	Formation /depth	Lithology/ stratigraphy	Reference
Early Lower Permian	Lower Gondwana	Talchir Rock (130m)	Greenish sandstones with spread clasts, rhythmites with groove casts, fine-grained ripple laminated sandstones, and olive/ chocolate-coloured needle shales.	Rajarao 1982[44]
Early Lower Permian	Lower Gondwana	Talchir formation	Greenish sandstone, Boulder bed, needle shale, marl, rhythmites	Pandya 2006[45]
Early Lower Permian	Lower Gondwana	Talchir formation (170m)	Diamictites, rhythmites, turbidites, conglomerate, greenish sandstones, olive-coloured needle shales, turbidite, tiliets and tilloids	Goswami et al., 2012[32]
Archian Bonai Granite	overlying Iron Ore Group (IOG) rocks	Quartz-pebble conglomerate (QPC)	QPC has adsorbed uranium over goethite and infiltrated ferruginous material (limonite), with grains of monazite, zircon, allanite and rare xenotime	Kumar et al. 2009[46]
Early Lower Permian	Lower Gondwana	Talchir formation	Pale-green splintery shale	Hota et al. 2010[2]
Bonai granite pluton	Iron Ore Group (IOG)	Archean (QPC)	Presence of Au, REE, Ag and PGE in Iron Ore Group (IOG) equivalent	Ajay Kumar 2017[47]
Bonai granite Phase I & II	Noamundi-Koira Iron Ore Group (IOG)	Bagiyabahal and Birtola areas	The siliciclastics comprise Th/U and Au-bearing quartz-pebble conglomerate (QPC) and quartzite succession.	Jena et al, 2021[48]
Bonai Granite complex	Kunjar Darjing rocks	Brahmani River basin	Cognition and Consanguinity of Kunjar- Darjing rocks with Upper Brahmani Basin	***Present study***

CONCLUSION

Ridges, anastomosis of drains, dissected highlands and waterfalls can represent the geomorphology of an basin..Therocktypeandstreamflowareresponsibleforsuchtopography. The major drainage is Brahmani, which flows from north tosouth. The study team directly observed the geomorphic feature in the stream.They have developed an accurate concept of the formation of potholes, plungepools,and waterfalls,as well as their characters and geologicalimportance.Potholesarethespottocollectheavymineralslikegold.Thestudyteamvisit edandobservedthepresentgeomorphicfeaturesofKhandadhar.Thepresentgeomorphic stratigraphy of UBB, exposed cliff in the slope, exposed drainsand the riverbedshave

formations of Hematite (mostly), schist, shale, quartzite, laterite, and banded iron formation, including Banded Hematite Quartzite (BHQ), Banded Hematite Jasper (BHJ), Banded Hematite Shale (BHS), in iron ore deposits like hematite,magnetite, and goethite. More intensive geographic and scientific studies are essential to locate the places wheregold, gemstones and uranium are concentrated. So that such mines can be explored to augment the economic status of the local people and the nation.

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