Geoheritage (2024) 16:88
https://doi.org/10.1007/s12371-024-00994-2

ORIGINAL PAPER

A Note on Spectacular Geodiversity and Cultural Sites In and Around Gaya-Rajgir Region of Bihar, India: Prospect for Geoheritage and Geotourism

K. Milankumar Sharma[1] · Sapam Ranabir[2] · N. Amardas Singh[3] · Prafull Singh[1]

Received: 1 February 2024 / Accepted: 13 August 2024 / Published online: 2 September 2024

Abstract
The Indian subcontinent is well known for its rich geological and cultural diversity. The Magadh region, with its plethora of heritage sites, stands as a living testament to the rich tapestry of India's cultural and geological history. The geodiversity of the Gaya-Rajgir area of Bihar, India comprises of volcano-sedimentary sequences juxtaposing with Rajgir meta-sediments and volcano sedimentary sequence of Bathani, anorthosite-gabbro and granites suites of Barabar-Nagarjuni area. The present report highlights some of the important geological and cultural sites of this region. The pillow basalt site of Churi Hill, Gaya is proposed to be classified as a geoheritage site which needs immediate conservation in addition to the already classified Barabar caves geoheritage site having been known for its remarkable architectural antiquities, relics and inscriptions of the rich historical past of Mauryan dynasty as engraved in the granite of the cave. The area is also characterized by the presence of its rich natural, geological, geomorphological, and significant historical and cultural heritage especially the Churi hills, Mahabodhi Temple, Vishnupad Temple, Nalanda University relict site, Caves of Barabar Hill, Rajgir area, cyclopean walls, hot water spring of Brahmakund, peace pagoda etc. From the ancient ruins of Nalanda to the spiritual sanctuaries like Vishnupad Temple and Mahabodhi Temple, each site narrates a unique story of the past. The Barabar Caves and Rajgir add further layers to this narrative, offering a glimpse into the diverse facets of the region's history. As we explore and celebrate these heritage sites, it is essential to prioritize their preservation and promote sustainable tourism, ensuring the livelihood promotion of the local indigenous people and also conserving the beauties and significance that endure for generations to come.

Keywords Geodiversity · Geoheritage · Cultural Heritage · Geotourism · Conservation · Gaya-Rajgir-Nalanda · India

Introduction

India is also indeed a land of diversity in terms of geodiversity, topography and cultural landscape. The term 'Geodiversity' covers a wide perspective of the natural inheritance of our mother earth covering almost all the abiotic components of nature, such as minerals, rocks, fossils, soils, landforms, and the active geological processes that give rise to them (see, IUCN 2021, Kuhn et al. 2022; Kaur 2022). It also encompasses the natural range of geological and geomorphological features, including their assemblages, relationships and properties, and we should see the scope for exploring the possibility of promoting geotourism (also see, Insua Pereira et al. 2013; Brilha 2016; Schrodt et al. 2019). The term 'geoheritage' (geological heritage) was first used at the 1st International Symposium on the Conservation of our Geological Heritage at Digne, France, in 1991 where the necessity of protection and preservation of geodiversity were discussed. Semeniuk and Semeniuk (2001) define geoheritages as global to national to state-wide important features of geology, including igneous, metamorphic, sedimentary, stratigraphic, structural, geochemical, mineralogic, paleontologic, pedologic and hydrologic attributes, that offer important information or insights into the formation or evolution of the Earth; or that can be used for research, teaching, or reference.

✉ K. Milankumar Sharma
milankumar.sharma@gmail.com

1 Department of Geology, Central University of South Bihar, Gaya, Bihar 824236, India

2 Regional Centre, Indira Gandhi National Centre for the Arts, Ranchi, Jharkhand 834008, India

3 Department of Geology, Central University of Punjab, Bathinda, Punjab 151401, India

The geodiversity of a place along with other climatic factors is constantly in a direct or indirect relationship with biotic components of the earth and hence the diversification of the biodiversity is also directly or indirectly related to the geodiversity of a region (also see, Bruschi 2007; Pereira et al. 2008). Thus, it brings the foundation of the life around that place. However, the geodiversity of many parts of the country is under serious threat along with the increase of our course of action related to civilisation, development, agricultural activities, mining, construction, etc. The need for conservation and preservation of our geodiversity is arising to protect and safeguard the integrity of relevant geodiversity sites, to minimize the adverse impacts on these sites, to interpret and explain geodiversity to visitors of protected areas, and to contribute to the safeguarding of biodiversity and ecological processes (Sharples 2002; De Lima and Vargas 2014; Santos and Brilha 2023). According to Brilha and De Carvalho (2010), geoconservation is defined as the set of initiatives that involve the inventory and characterization of geological heritage, aiming at conservation and management, to ensure the proper use of geosites for scientific, educational, or tourism purposes. Since 1991 onwards, certain works related to the conservation of 'geoheritage' have been recorded in certain literature (also see, Bradbury 1993; Kozłowski 1999; Semeniuk and Semeniuk 2001; Gray 2004; Brocx and Semeniuk 2007, 2011; Brilha 2002, 2016, 2017). Bruno (2015) described 'Geosites' as geoheritage resources which should be studied, conserved, and developed to ensure that future generations can continue learning the geological history of the Earth. However, 'geomorphosite' is perceived as an important landform with a special value due to human perception or exploitation (Panizza 2001; Reynard and Panizza 2005; Pereira et al. 2008). 'Geoparks' on the other hand are geographically well-defined territories where a sustainable development strategy is carried out, together with the population, based on geoconservation, geotourism, and education, along with other forms of heritage, such as cultural, architectural, ethnographic, and gastronomic heritage, among others (Brilha 2009, 2012).

Looking into the Indian context, even though the country is blessed with a diverse geological setup of different ages, the concepts of geopark, geoheritage, geoconservation and geotourism are relatively new and it need to be popularised especially among the common mass (also see, Kaur 2022; Shitole et al. 2023). In recent time, various Central and State Government agencies including the Geological Survey of India, Birbal Sahni Institute of Palaeoscience Lucknow, many universities,certain State Forest departments, and district administrations, etc. have taken up the lead role to conserve a large number of geologically significant sites including fossiliferous sections, caves, and exclusive geomorphic sites across the country, but there is not yet any UNESCO approved Global Geopark in India. Many workers have emphasised the importance of geoheritage in the recent years and proposed certain new possible geoheritage sites in India which need to be conserved (also see, Bakliwal et al. 2004; Ahluwalia 2006; Mazumdar 2010; Swarna et al. 2013; Phani 2016; Grover and Mahanta 2018; Shekhar et al. 2019; Ranawat and George 2019; Mathur 2020; Chauhan et al. 2021; Bhosale et al. 2021; Ghosh et al. 2021; Singh and Ghosh 2021; Mehrotra 2022; Shitole et al. 2023, etc.).

Gaya-Rajgir-Nalanda region of Bihar, India India is known for its rich cultural heritage and unique geodiversity. The cultural, archaeological and geological heritage of this region serves as the best possible destination for geotourism, cultural tourism and eco-tourism. The region is blessed with the two distinct internationally acclaimed UNESCO heritage sites of Mahabodhi Temple and Nalanda University and certain other important geological, archaeological and cultural spots. The work aims to delve into the rich geological and cultural heritage of this region, focussing on their conservation and dissipating the knowledge through sustainable geo and cultural tourism, and searching of future potential geopark sites of the country.

Study Area Connectivity

The present study area falls in parts of Gaya, Jehanabad and Nalanda districts of Bihar, India. It is mainly occupied by quaternary sediments of the Indo-Gangetic plain where local people are mainly living on agriculture. Some parts of the area are also occupied by open forest areas managed by the Divisional Forest Officer. The region is considered to be of historical and archaeological significance and certain caves and temples of historical and archaeological values of global significance are preserved by the Archaeological Survey of India (ASI). The area is well connected by metal roads and railway lines from major cities like Patna, Varanasi, Ranchi, Kolkata, Delhi, etc. The region is also connected through air transport through the nearest airports situated in Patna and Gaya.

Regional Geological Set-up

In the regional context, the Peninsular Eastern Indian Shield also known as Chotanagpur Gniess Granulite Complex (CGGC) comprising of gneisses and granulitic rocks demarcates the southern edge of the Rajgir Group of Proterozoic Metasediments and Bathani volcanic sequence. The CGGC occupies a vast area covering ~. 80 000 km^2 (Mahadevan 2002; Acharyya 2003; Ahmad et al. 2021) (Fig. 1, Table 1). The quaternary deposits of the Gangetic alluvium marks as the northern boundary of CGGC and on the south it is bound by Singhbum Mobile belt (\ad et al. 2022). The exposure of the rocks of Bihar Mica belts (BMB) and Mungar Group and Rajgir Gaya Subbasins shows a basement cover relationship

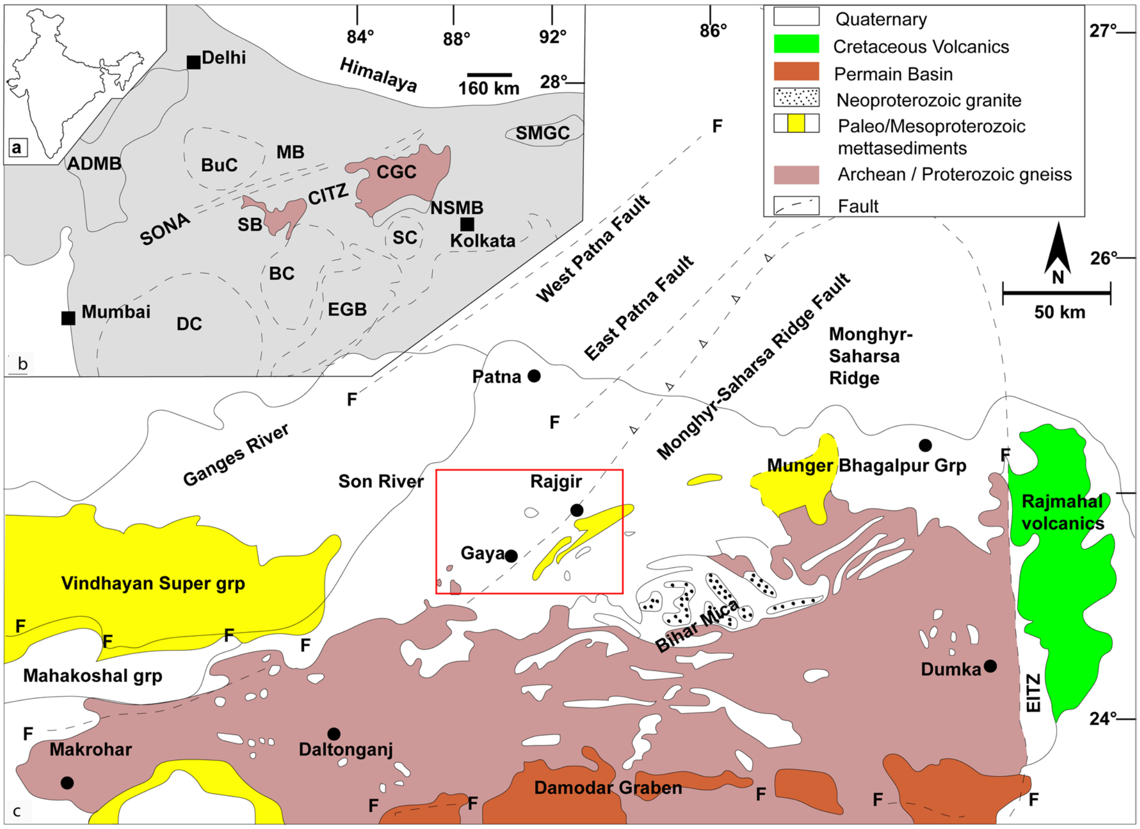

Fig. 1 **a** Map of India. **b,** Regional map of the region showing study area. **c** Regional Geological Map of Chotanagpur Gneissic Complex (CGC), Satpura Belt (SB) and Mahakoshal Belt (MB), SONA and its eastern continuation represented by east Patna Fault and Monghyr—Saharsa Ridge Fault (modified after, Chatterjee and Ghose 2011)

with the CGGC, however, the Gangetic alluviums cover most of the field evidence (Ghosh and Mukherjee 2002). The eastern margin of CGGC is marked by sediments of Bengal Basin, the northeastern side is bounded by Mesozoic volcanics of Rajmahal Trap, and the Gondwana sequences of Permian to Middle Cretaceous marks the western fringe (see Mahadevan 2002; Ahmad et al. 2021). The Gondwana deposits demarcate CGGC from the Central Indian Tectonic Zone (CITZ) which separates the northern and southern Indian continental block after their collision took place during the Proterozoic time (Chatterjee and Ghosh 2011). On the northern side, the CGC is also bounded by the Munger-Saharsa Ridge (MSR) fault which is considered as the southern boundary extension of the Central Indian Tectonic Zone (CITZ) (Mohammad et al. 2022). Vindhyan and Mahakoshal groups of rocks of Proterozoic age mark the northwestern margin of the CGGC. The rocks of CGGC are constituted of late Precambrian gneisses, granites and migmatites of at least three generations (Mukhopadhyay et al. 2011). The migmatites in grunerite bearing quartzite grading to ferruginous quartzite, phyllites and mica schists, grading into mica-gneiss due to granitization, and certain enclaves meta-sedimentary rocks occur in different dimensions (Mohammad et al. 2022). It is considered that the rocks CGGC have suffered metamorphism in the range from middle to upper amphibolite facies with at least P–T conditions ranging from 4–6 Kb and about 680 °C respectively (also see, Mallik 1968; Ahmad et al. 2021). The CGGC is also known for the occurrence of various types of anorthosite-gabbro suite of rocks such as Bela, Hizla, and Chatra, etc. (Das and Mukherji 2001) representing an end-product of differentiated basic igneous rocks (Ahmad et al. 2021).

Previous literatures on the structural and geochronological studies of CGC established atleast three phases of deformation events during the Proterozoic time thereby manifesting a distinct superposed fold patterns and structural fabrics (also see Chatterjee et al. 2008 and the references therein).

Geology and Geodiversity of the Study Area

The study area in and around Gaya-Rajgir can be demarcated into two diverse geological set up comprising a) The Rajgir-Gaya volcano meta-sedimentary sequence and b) The variety of magmatic rocks forming Barabar- Nagarjuni hill ranges which is surrounded by Indo- Gangetic alluvium just at the south of Ganga River and east of Son River. The details of

Table 1 The comparative stratigraphy of CGC from Bihar (source: Mukhopadhyay et al. 2011; Raza et al. 2020a, b)

	Stratigraphy by Singh (1993, 1998, 2001)		Compiled geological map of GSI (1:2 million scale)	Shastry (1948–50), Rao (1951–53)
Intrusives	Massive, granite-granophyres, gabbro-anorthosite, ortho-amphiboles			
Rajgir Group	Upper phyllite Formation			Munger Group
	Quartzite Formation			
	Lower phyllite Formation			
	UNCONFORMITY			
Intrusive suite	Rare metal bearing pegmatite, pegmatoid granite and quartz veins, Mica pegmatites, Trondhjemite; Gabbro, Porphyritic granites and augen gneiss, Migmatite and gneisses		Hazaribagh granite and pegmatite/quartz	Pegmatite/quartz veins
Kodarma Group	Kakolat Fm	Massive quartzite, quartz-schist and quartz mica schist	Metamorphics	Metasedimentaries (= enclaves within CGC)
	Dhab Fm	Mica schist, mica gneiss, carbonaceous schist with thin bands of calc-silicate, calcareous quartzite and acid tuff		
	Phulwaria Fm	Quartzite, quartz-schist, quartz-mica schist BHJ, BHQ, amphibolite, hornblende schist, calc-silicate gneiss, crystalline limestone, conglomerate, conglomeratic and pebbly quartz-schist		
	UNCONFORMITY			
Intrusive Suite	Aplo-granite, pegmatite, quartz veins, Jaled Ultramafics: Pyroxenite, peridotite			
Chatra Gneiss Suite	Granite gneisses, tonalite gneisses, Migmatites, Augen Gneiss		Granite gneisses	Granite gneiss
CGGC	Meta-ultramafites-mafites with layers of magnetite & garnet BIF Calc-silicate and skarn rocks; Magnetite-chert, banded magnetite-chert-jasper, banded magnetite-grunerite quartzite		Unclassified Metamorphics	Metasedimentaries (Enclaves with CGC)
Enclave Suite	Chakrabandha Schists; Chlorite schist, mica schist, garnet-biotite schist and gneiss Sillimanite + muscovite + garnet schist and gneiss, quartz-biotite gneisses, meta- quartzite; Dumka Granulites: Charnockite, khondalite, pyroxene granulite, leptinite, etc			
	BASEMENT NOT KNOWN			
	Pre-tectonic mafic- ultramafic intrusive Palaeo- Proterozoic- Late Archaean (≥ 2000 Ma)		Amphibolite (schistose), meta-ultramafics (viz. talc-tremolite schist, tremolite-actinolite schist, chlorite schist, actinolite-cummingtonite schist, hornblende schist, serpentinite etc.) and layered anorthosite	
	Basement Archaean (?) – Palaeo-Proterozoic		Tonalite gneiss, volcano-clastic metasediments, khondalite and leptynite (Granulite Facies, Phase-I)	

both the sequence are discussed in below sub sections. For clarity, they are being described separately.

a) The Rajgir Metasediments and Volcano Meta-sedimentary Sequence

The volcano sedimentary sequence exposed around Bathani village (24°59.5′N, 85°16′E) of Gaya district, Bihar, India exposed bimodal volcanic and volcano-sedimentary rocks. This suite is considered as the eastward extension of the Mahakoshal Mobile Belt associated with CGGC (Saikia et al. 2014). This volcano-sedimentary sequence juxtaposed with the Rajgir metasediments of the Munger-Rajgir Group of rock (Ahmad and Wanjari 2009). The volcano-sedimentary sequence is characterised by the presence of garnet-mica schist, rhyolite, tuff, banded iron formation (BIF) and chert bands with carbonate rocks as enclaves within rhyolite andesite, pillow basalt, massive basalt, tuff and mafic pyroclasts (also see, Ahmad and Wanjari 2009; Saikia et al. 2014) (see, Fig. 2). The volcano sedimentary sequence shows low grade green schist facies of metamorphism in banded formations and tuff indicates very low-grade green schist facies metamorphism (also see, Turner 1968; Saikia et al. 2014; Gogoi et al. 2017). Gogoi et al. (2017) described the intrusive relation between granite with banded chert of volcano- sedimentary sequence as exposed near Ghansura village and granites at the contact zone carry xenoliths of surrounding banded chert and other volcano- sedimentary rocks. Ahmad and Wanjari (2009) classified the lithostratigraphy of these volcano-sedimentary deposits as under:

- (i) Mafic volcanic, comprising pillow basalt and mafic pyroclasts
- (ii) Acid volcanic, comprising rhyolite and
- (iii) Volcano-sedimentary sequence comprising tuff, banded chert and banded iron formation (BIF).

Based on primary sedimentary and volcanic structures it may be established that the volcano-sedimentary sequence is overlain by the differentiated volcanic sequence and there is no remarkable break between the two sequences (Saikia et al. 2014). The metasedimentary deposits of the Munger-Rajgir Group of rocks (also see, Figs. 3 and 4) were deposited at the Proterozoic basement of CGGC. Chatterjee and Ghose (2011) described the basement of these metasedimentary units marked by porphyritic granite (K-feldspar, plagioclase, biotite, quartz) near Gaya (Bihar) and biotite granite in Bhagalpur district (Bihar). In the Rajgir Group, two stratigraphically distinct units of quartzite and phyllites are overlain by the volcano-sedimentary sequence (Raza et al. 2020a, b). The phyllite unit shows both gradational as well as sharp contact relationship with the quartzite. The phyllite is essentially thinly laminated and of variegated colour and ferruginous in nature (Fig. 3a). The alternate quartzite and phyllite units of the Rajgir area have preserved clear evidence of polyphase deformation (Fig. 3b, c). Quartzite and phyllites also show well developed sedimentary structures

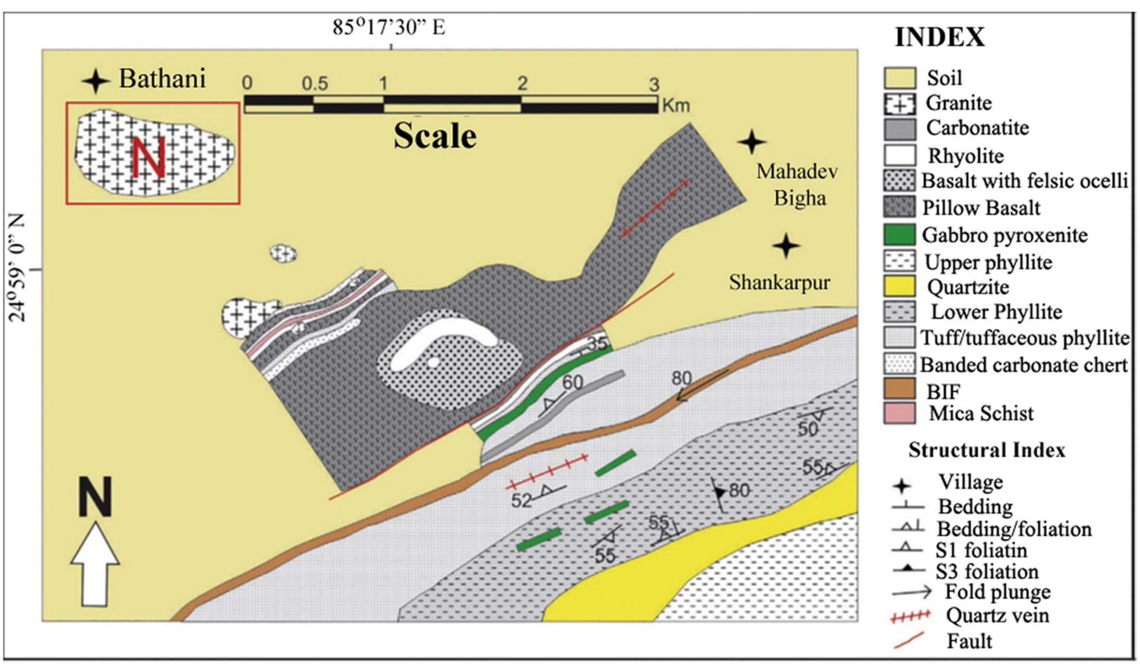

Fig. 2 Geological map of the Bathani volcano-sedimentary sequence showing the location of the Nimchak Granite Pluton (NGP) marked as N (after, Gogoi et al. 2017)

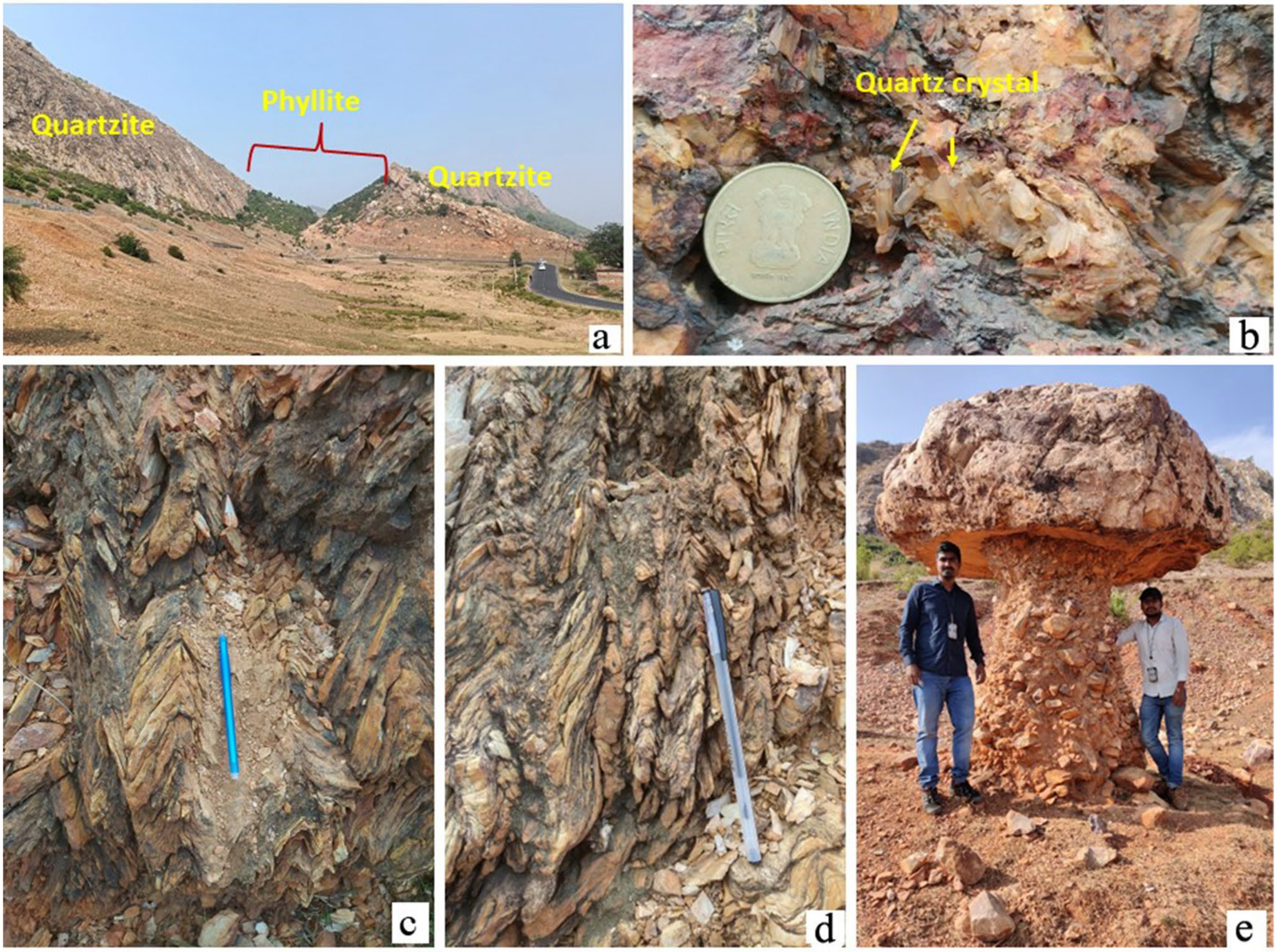

Fig. 3 **a** Photograph of Arai area along Gaya-Rajgir section showing the quartzite-phyllite-quartzite exposure of Rajgir Group of rock. **b** Showing growth of quartz crystal in quartzite Rajgir Group of rock, Arai area. **c**, **d** Showing tighly folded, highly sheared phyllitic rock at Arai area along Gaya-Rajgir section, **e** mushroom shape structure as exposed at Gaya-Rajgir section exposed near Arai area

showing both the compositional and colour banding (S0) in tuff/ tuffaceous phyllite. Phyllite shows three sets of foliations, the refolding of bedding-parallel foliation, and certain rootless isoclinal folds are also observed (also see, Fig. 3c,d). The metasedimentary rocks of the Rajgir Group of rocks show primary structures like ripple marks (Fig. 4d), graded bedding (Fig. 4e), cross-bedding, etc. Mushroom like demoisel formed by the erosion of debris accumulated along the foothill of Atari-Jethian road towards Rajgir (Fig. 3e).

Certain tectonised structures of brittle and brittle-ductile deformation such as brecciation, fault gauge, tension gashes showing en échlon sigmoidal shear sense (Fig. 4a), slicken slide (Fig. 4g), fault (Fig. 4b). The folded volcano-sedimentary sequence of the Rajgir-Gaya area is considered to experienced at least three phases of deformation (Saikia et al. 2017, 2019; Raza et al. 2020a, b). The interference of the two-fold systems has produced a structural basin at Rajgir (Rajgir basin) (see, Sarkar and Basu Mallick 1979, 1982).

Pillow Lava of Churi Hill (N 24^{O}49′44.18″; E 84^{O}55′43.28″ Elevation: 188 m)

The volcano-sedimentary sequences of the Munger-Rajgir Group of rocks which are well exposed at Rajgir are extended over a known ~ 40 km area distance from Bathani to Churi-Jagannathpur in the Gaya District of Bihar (see, Fig. 5a). The age of this area is approximately Mesoproterozoic. Saikia et al. (2017) and Saikia et al. (2019) suggested subduction-related arc magmatism for the formation of the granites of the Bathani volcanic (also see, Fig. 6) and volcano–sedimentary sequence emplaced at approximately approx. 1,700–1,600 Ma. The Churi area is manifested by the well exposure of pillow basalt, which may indicate that sub-marine volcanism occurred in this area (Figs. 5, 7, and 8a). Associated lithologies around the area include granite, gabbro, anorthosite, granodiorite etc. indicating multiple phases of volcanism and plutonism. Chilled Margins

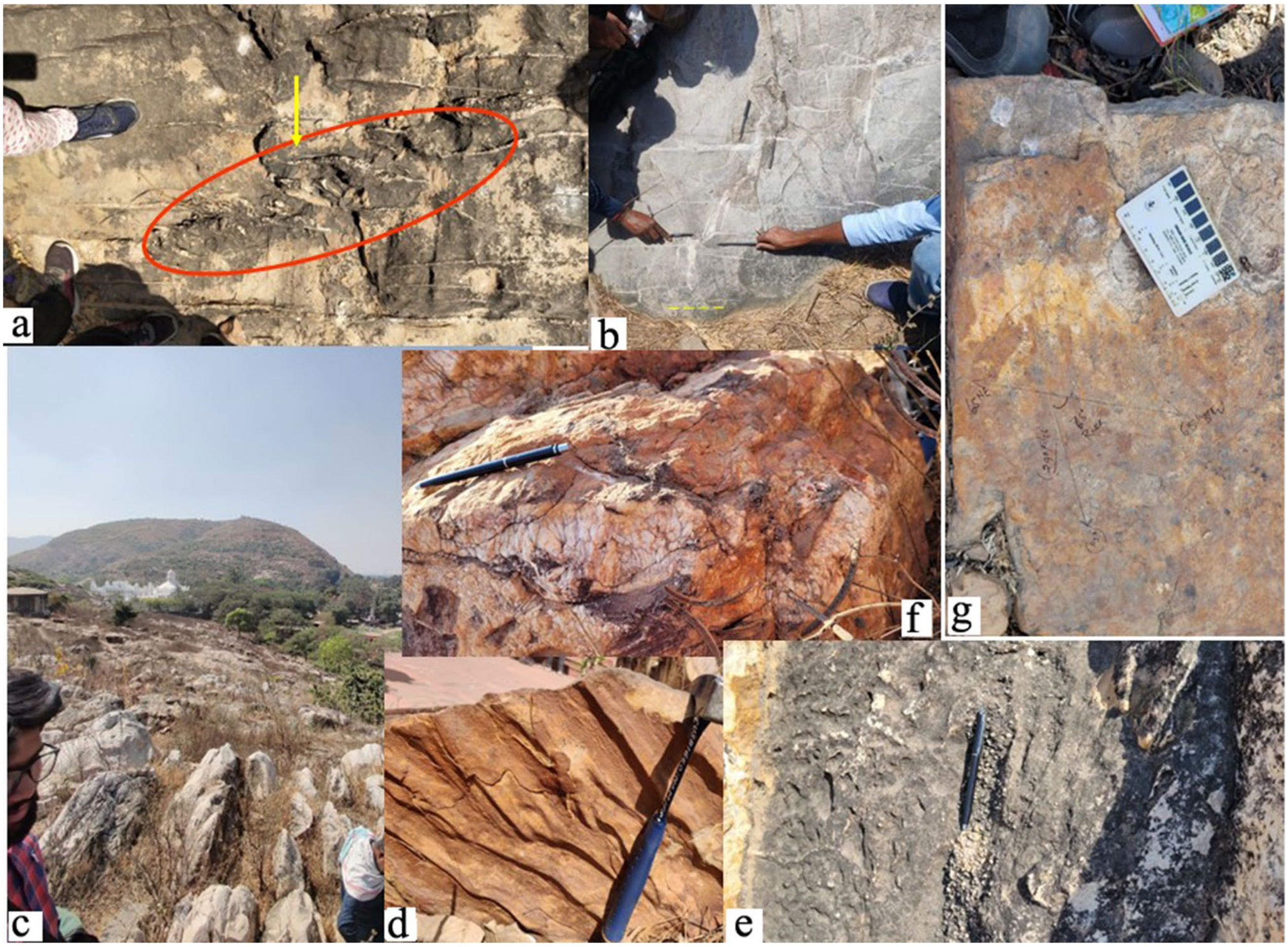

Fig. 4 **a** Tension gash deformation structure developed at Quartzite of Rajgir Group as exposed near Rajgir Brahma Kunj area. **b** Fault at Quartzite of Rajgir Group as exposed near Rajgir Brahma Kunj area. **c** View of Rajgir Hill. **d** Ripple marks at Quartzite of Rajgir Group as exposed near Brahma Kunj area. **e** Graded bed at Quartzite of Rajgir Group as exposed near Brahma Kunj area. **f** Growth of quartz crystal at at quartzite of Rajgir Group of rocks. **g** Slickenslide at Quartzite of Rajgir Group of rocks

are present in Pillow Basalt (Fig. 8a), which are characterized by glassy or fine-grained zones along the margin where the magma or lava contacted air, water or particularly much cooler rock. This is caused by rapid crystallization of melt near the contact with the surrounding low-temperature environment. The pillows are either spherical or elliptical in shape, but they are extended indicating deformation (Fig. 7a, c). The pillow structures exhibit well developed chilled margins, vesicles, cracks, V-up and convex –up features (Figs. 5c and 8a). Cracks are developed due to over cooling. The pillows are tightly packed with less inter-pillow space. In some places, pillow basalts are deformed and highly stretched towards the NE-SW direction indicating the manifestation of the later phase of tectonism.

At the Bathani area, the sequence comprises of pillow basalt, phyllite tuff, mafic pyroclastic rock, tuff, rhyolite, chert and banded iron formations that are well exposed. The preservation of pillow lava structures is also found in the Jaganathpur area near Churi and at certain sites near Mahadev Bigha and Ghansura villages towards the north-eastern extension. However, the exposure of pillows at Churi Hills is very well preserved with different shapes and dimensions (Fig. 7a, b). The size of each pillow varies from < 15 cm to a mega pillow of > 1 m in length on the longer axis. The pillow basalt shows diverse pillow features such as spherical, ellipsoidal, elongated, irregular shape, mushroom, kidney, etc. The preservation of well-developed chilled margins is visible, and other features like rim/rind, cracks, vesicles, V-up and convex-up are also well developed. Features like radial cracks in the pillows are rarely observed and the pillows are tightly packed and suffer deformations as evidenced by the presence of other diastrophic structures in it (Fig. 7b). Pillow breccias are abundant in Jagannathpur area (Ahmad et al. 2021). The petrographic studies of the pillow basalts from the study area show a mineral assemblage typical of lower greenschist facies conditions

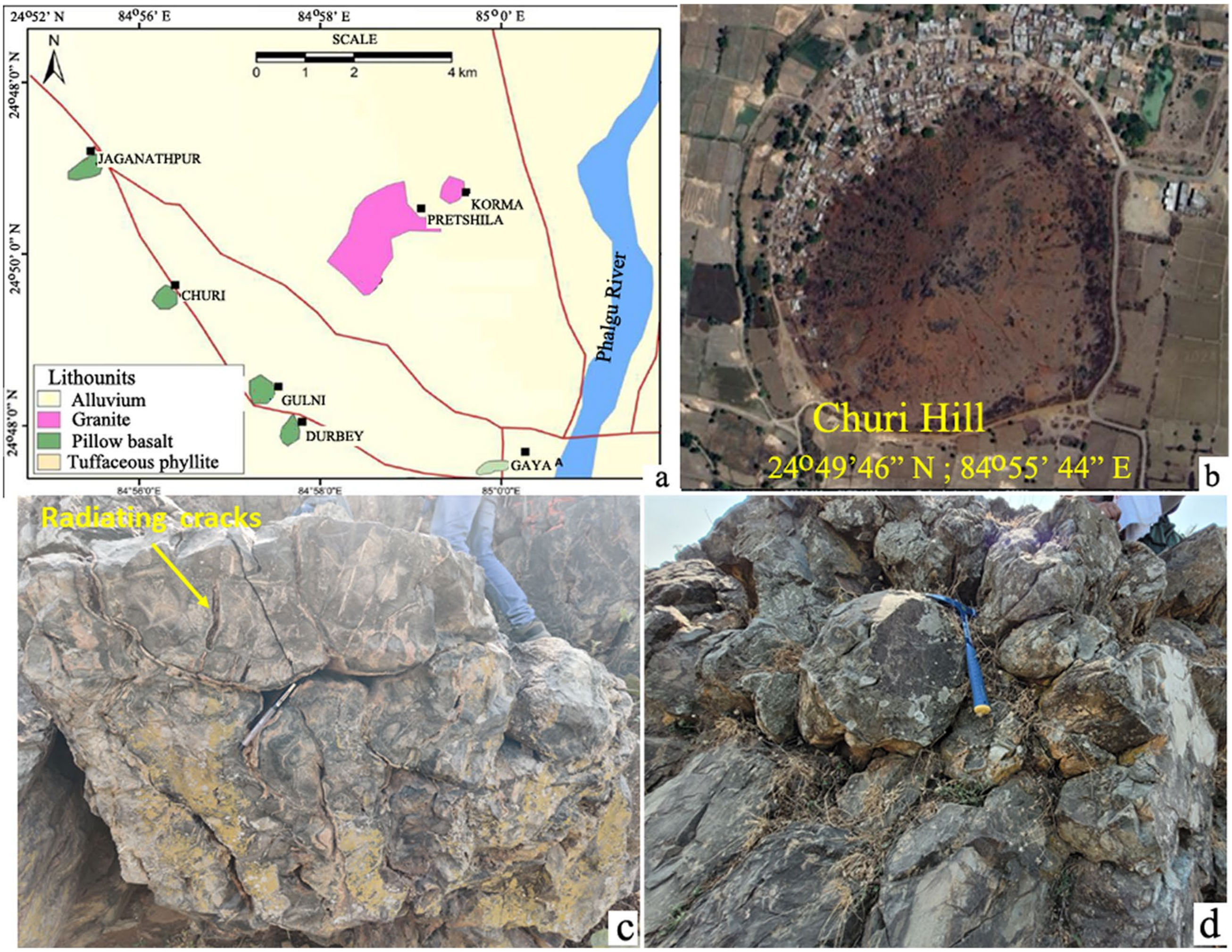

Fig. 5 **a** Geological map around Gaya and Bodh Gaya (GSI, 2020). **b** Google map image of Churi Hill Gaya, Bihar which needs protection (image not is scale). **c** Well developed radiating cracks at pillow basalt of Churi Hill Gaya. **d** Subspherical to subrounded pillow structures of Churi Hill, Gaya

comprising of plagioclase, feldspar, amphibole, chlorite and minor opaque minerals (Fe–Ti oxide) (also see Ahmad et al. 2021; Ahmad and Wanjari 2009).

Gehlaur Passway The Gehlaur Manjhi Passway is a significant spot located at N24052′38.08″ E85014′34.51″ along the Rajgir-Gaya route and it is connected by a metaled road (Fig. 9). Dasrat Manhji, also known as the Mountain man of India from Gehlor village of Gaya, Bihar carved a 110 m-long (360 ft), 9.1 m-wide (30 ft) wide and 7.7 m-deep (25 ft) path through a ridge of hills between Atri and Wazirganj blocks of Gaya district using only a hammer and a chisel. It took 22 years (1960–1982) to build the path at the quartzite hill. His sacrifice gave cheers to the inhabitants of the village and shortened the distance from 55 to 15 km to move the other side of the hill making it much safer and easily accessible. The metasedimentary sequence of quartzite and phyllite (see Fig. 9b, c, d) are exposed along the section passway are very hard, compacted massive and exhibit foliation trend of N58°E and 55°dips towards S30°E. The fault breccia is observed along the section along with slickensides which is evidence of brittle faulting. Department of India Post issued Rs. 5 stamp commemorating Dashrath Manjhi and his sacrifice (Fig. 9d).

The Cyclopean Wall of Rajgir Located to the south of Rajgir along National Highway No. 82. (N24°58′48.21″ E85°25′45.32″), the remnant of the fortification of the city of Rajgir by a massive ~ 40-km-long wall is evidenced. All observation points are visible from the metaled road which is well connected from Gaya and Rajgir. The site serves as an excellent geoarchaeological spot for witnessing the advancement of the Maurya empire in the field of architecture and engineering and it is estimated to be built around c. 600 BCE to c. 400 BCE (Walker 2019) (also see, Fig. 10). This

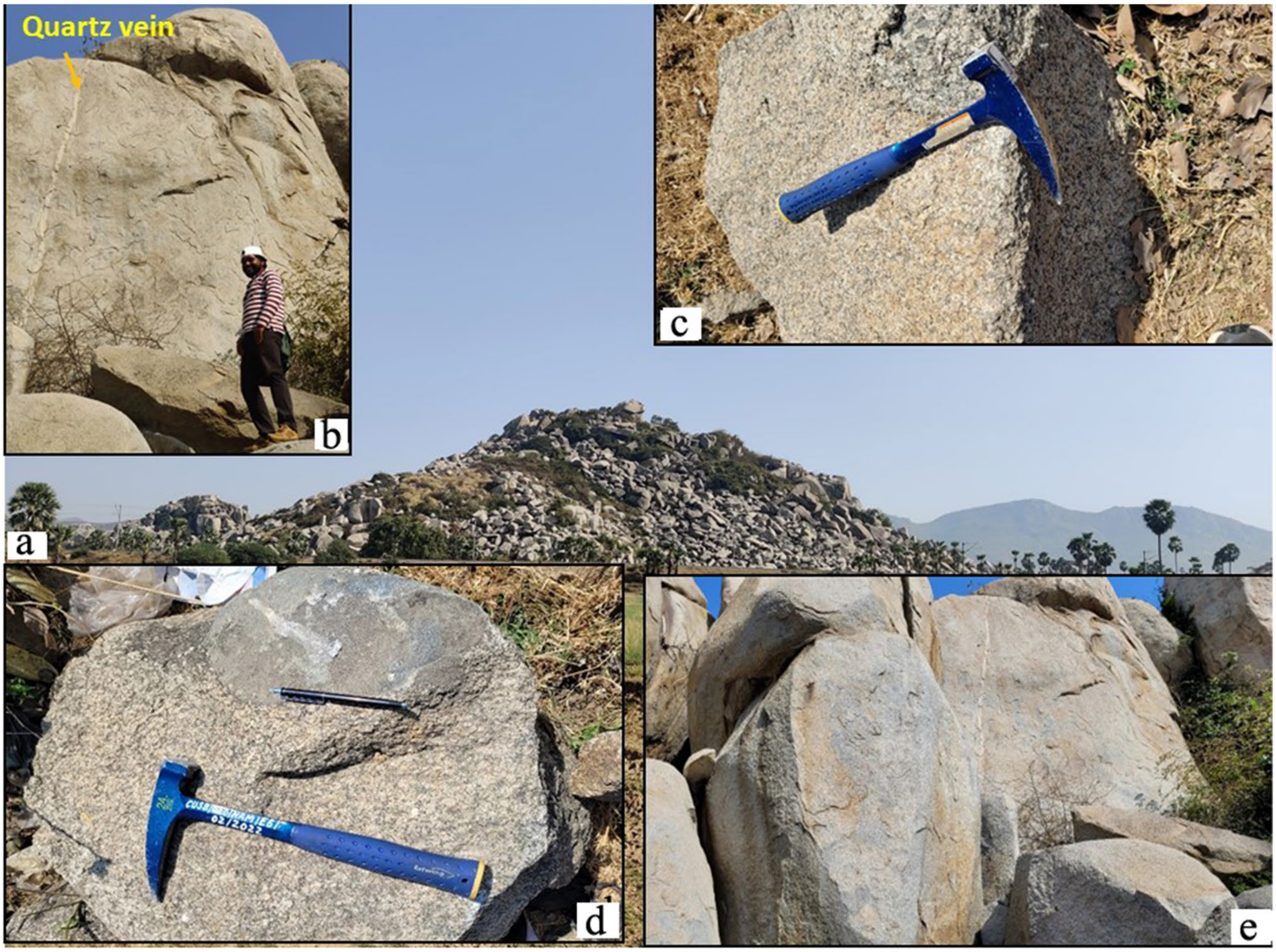

Fig. 6 **a** Panoramic view of the exposure of Bathani Granites (N 24° 58′ 49.34"; E 85° 16′ 48.64") exposed at Gulelwa Hill, Bathani area. **b** Quartz vein at granite exposed at Gulelwa Hill, Bathani area. **c** Porphyritic granite as exposed at Gulelwa Hill, Bathani area. **d** Basaltic Xenolith in Porphyritic Granite as exposed at Gulelwa Hill, Bathani area. **e** Exfoliation and Spheroidal weathering exposed at Gulelwa Hill, Bathani area

wall was built along the trend of Rajgir Hill comprising of metasedimentary sequence of quartzites and phyllites having foliation trends N45°E-S45°W dipping 68° towards SE. The Cyclopean Wall comprised of many gates and outer fortifications meant to secure dual protection of the capital city from external invaders and enemies (Raza et al. 2020a, b).

The stonework remains of the Mauryan period were built with a massive block of rocks mainly comprised of quartzite without the use of mortar. Many of the original structures have disappeared in due course of time. This wall structure is currently designated as one of the national monuments of India and it deserves to be included in the list of UNESCO World Heritage Sites.

b) Magmatic Rocks of Barabar- Nagarjuni-Sapneri Ranges

The Barabar-Nagarjuni-Magmatic complex comprises of magmative intrusion of Gabbro-Anorthosite-Granite series. The area falls at the toposheet number 72G/4 and 72H/1 of the Survey of India under Jehanabad and Gaya district and these magmatic complexes are well exposed at Barabar hills, Nagaruni hills and Sapneri village with an areal extension of about 25.5 sq. kilometers with maximum elevation of the 110 m. Geologically, the area falls under the northernmost portion Chotanagpur-Granite-Gneissic Complex which is again bounded by the Munger-Saharsa Ridge Fault to the

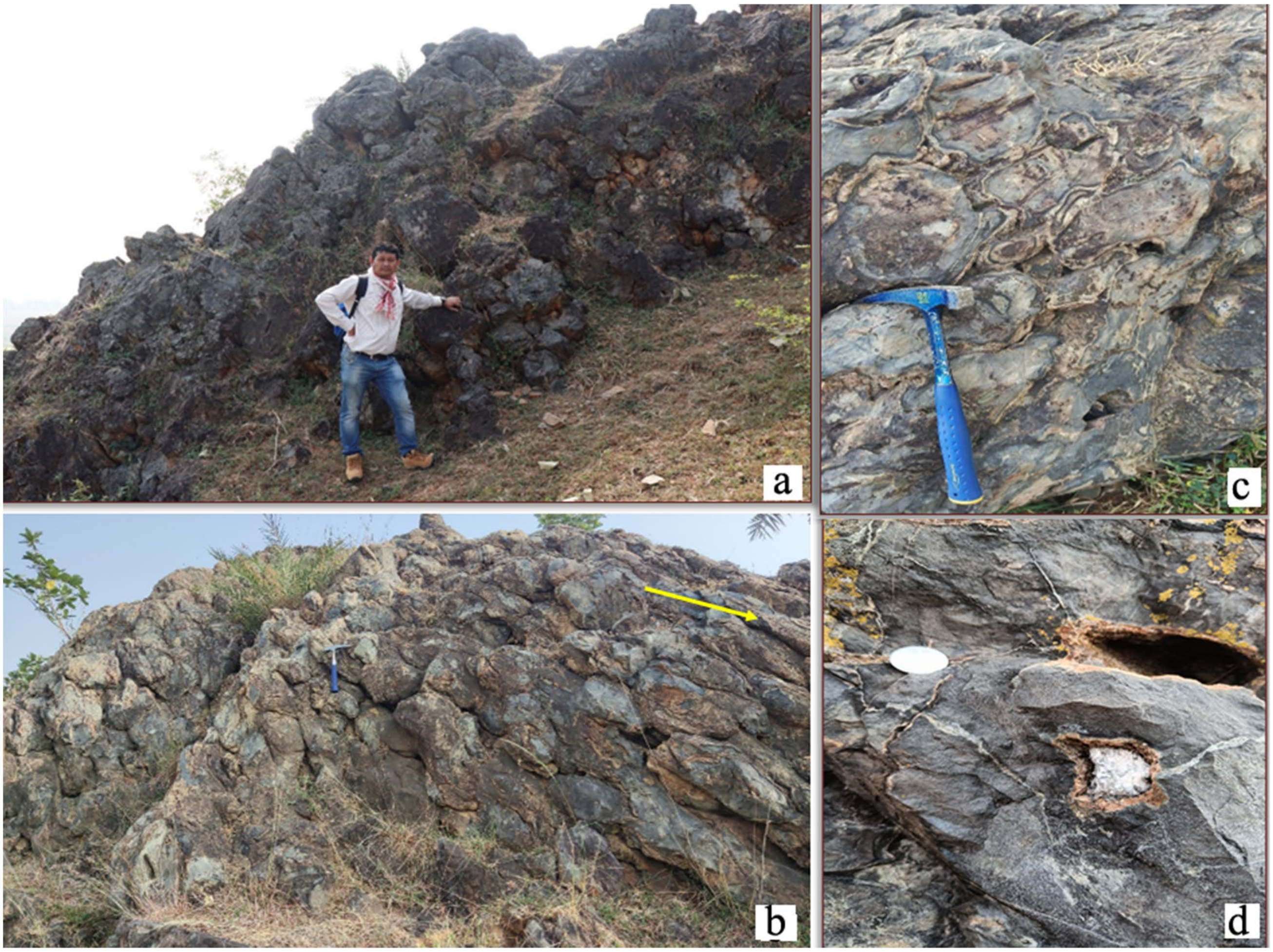

Fig. 7 **a** Exposure of Pillow Basalt at Churi Hill, Gaya. **b** Showing sub-spherical to elliptical shape pillow as exposed at Churi Hill, Gaya. **d** Showing deformation in pillow basalt at Churi Hill, Gaya. **e** Showing quartz infilling at Pillow basalt at Churi Hill, Gaya

north (also see, Mukherjee et al. 2019). The major lithology of these areas includes Anorthosite, Gabbro and Porphyritic Biotite Granite with Titaniferous-Vanadiferous Magnetite ore body mineralization with both lode and lens deposits in the anorthosite body.

Several workers from the Geological Survey of India (GSI) carried out the systematic geological mapping at and around Barabar, Nagarjuni hills and Sudamakund area (also see, Dayal 1983, Mukherjee 2010; Mohammad et al. 2022). The prominent rock types around this area are magmatic suites, comprising of Anorthosite, gabbro and Granitic suites. Major lithology of at Barabar- Nagarjuni hill ranges comprises of two different suites of rocks viz. gabbro- anorthosite suite and granite suite of rocks in which the later one is more prominent and they are surrounded by Indo-Gangetic alluvium deposits. Mukherjee (2010) proposed a tentative litho-stratigraphic succession of this area comprising of recent alluvium deposit and Pegmatite and aplite Porphyritic biotite granite, pegmatic granite and homophanous biotite granite. Gabbro-Anorthosite suite interlayered withtitaniferous vanadiferous magnetite of Proterozoic age.

The rock type manifested in the area exposes a gabbro-anorthosite-granite suite of rocks forming a part of the Chotanagpur Gneissic Complex (CGC) (also see, Mohammad et al. 2022) (Fig. 11). Small pockets of gabbroic-anorthosite lens occur as enclaves within the granitoid country rock. The litho-units from this study area are comprised of amphibolite, talc-tremolite-actinolite schist, metagabbro/gabbro, anorthosite and granite. The different varieties of granite include homophonous biotite granite, porphyritic biotite granite, hornblende granite and silicified granite and the deposit consists of Vanadiferous-Titaniferous Magnetite interspersed with anorthosite and as a xenolith in the granite (for details please see, Mohammad et al. 2022). Quartz veins and pegmatite are also found in small lense. are usually of small dimensions and not very prominent in the area. Quartz veins range from a few centimetres to a few metres in size and they

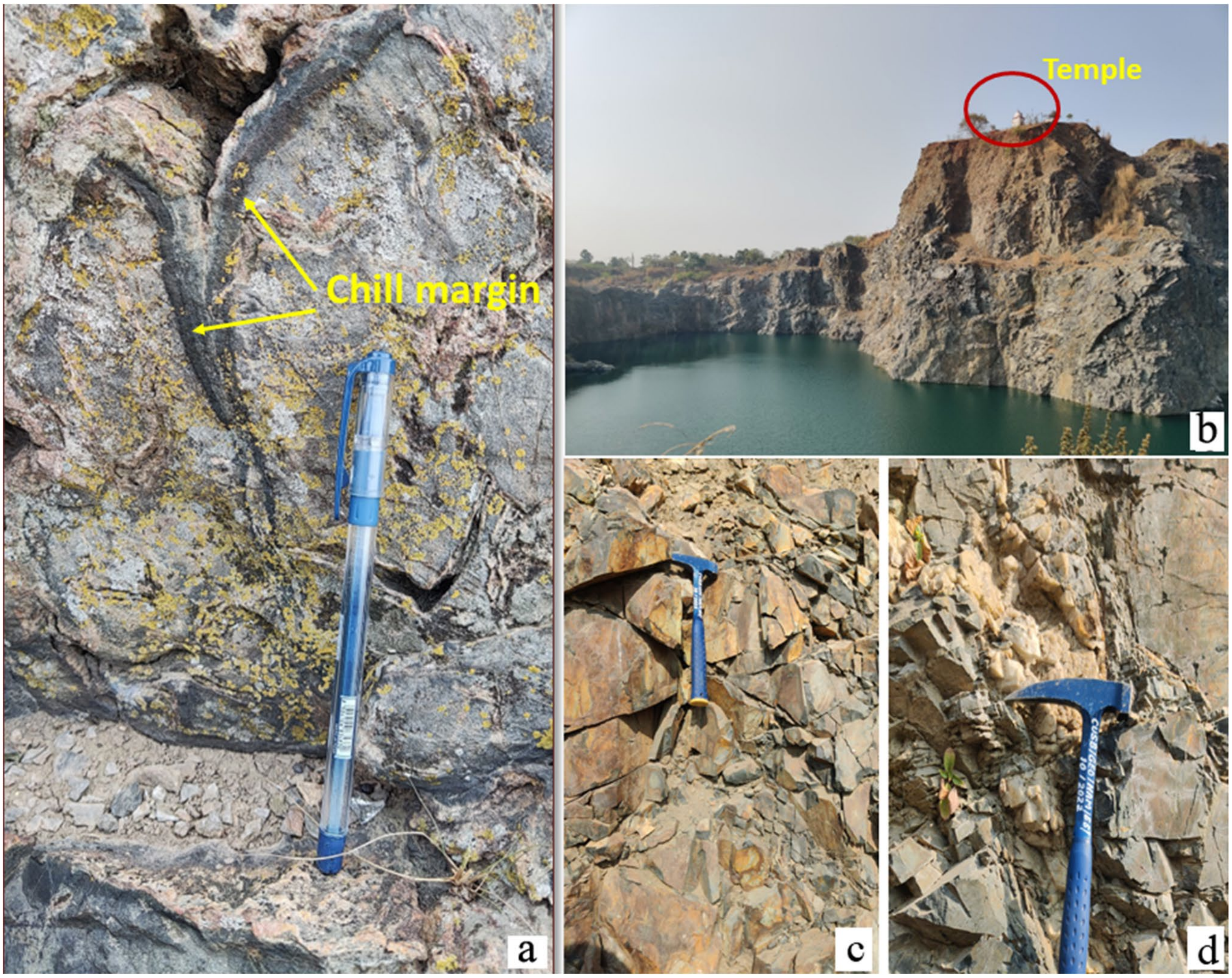

Fig. 8 **a** V shape pillow margin with remarkable chilled margin at pillow basalt of Churi Hill. **b** Mining site of pillow basalt at Jagannathpur area of Gaya. **c**, **d** Photograph of brecciated basaltic rock of Jagannathpur area of Gaya

are not prominent. Pegmatites are found along the shear and joint plane of the granitic body. At Barabar Hills, titaniferous magnetite ore bodies are found associated with anorthosite pockets or as a large pocket within porphyritic biotite granite (Mohammad et al. 2022). The porphyritic granites from Barabar Hills in Gaya contain monazites with a crystallisation date of ~ 1697 ± 17 Ma. and thus a Proterozoic age granitic plutons of Barabar Hill is valid (Chatterjee and Ghose 2011). However, Rb–Sr whole rock isochron of granites from the Paharpur locality near Gaya gives a slightly younger isochron age of 1337 ± 26 Ma (Wanjari et al. 2012).

Geoheritage Site of Barabar Caves: Ancient Rock-Cut Marvels

The Barabar Hills, home to the world's oldest surviving caves, are a historical treasure in Jehanabad district. Dating back to the 3rd century A.D., these rock-cut Buddhist chambers are believed to have been religious centres for Jain monks and even witnessed Gautama Buddha's meditation. Geological Survey of India has recently listed Barabar Hill caves as a national geoheritage site (Figs. 12 and 13). It is located at N25°00′20.62″ E85°03′47.03″ at Barabar Hills and is well connected by a metalled road from Gaya city and Rajgir. The Barabar Caves are considered the oldest surviving man-made caves in India dating from the Mauryan Empire (322–185 BCE) (also see, Cunningham 1871). A total of seven rock-cut caves within massive granite are located in the twin hills of Barabar (four caves) and Nagarjuni (three caves). The four caves of Barabar Hill are namely, Karan Chaupar, Lomas Rishi, Sudama and Visvakarma (Cunningham 1871). Sudama and Lomas Rishi are considered as the earliest examples of rock-cut caves in India with magnificent architectural designs of the Mauryan period

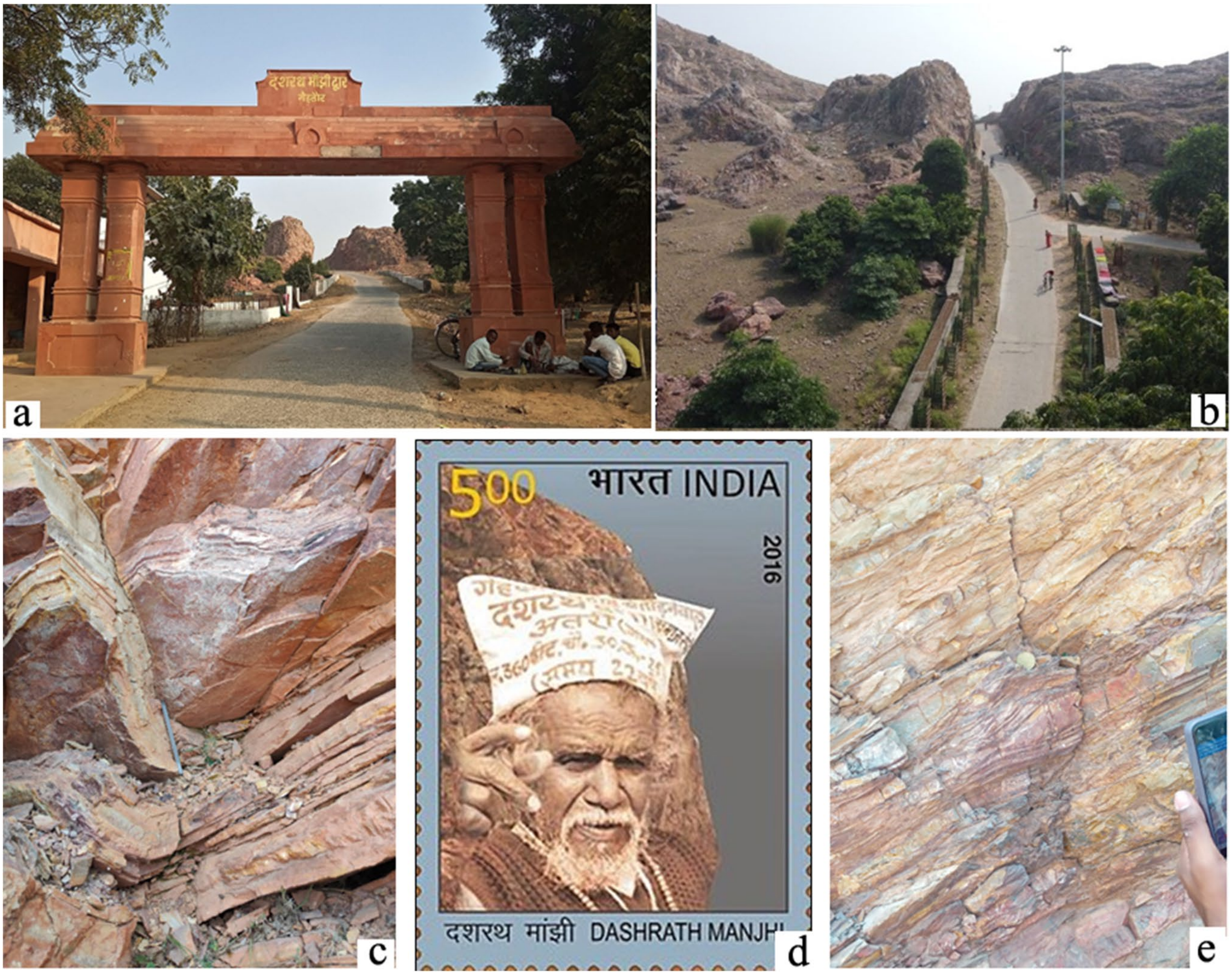

Fig. 9 **a** Gate of Dasrat Manjhi Gehlaur Passway (N 24°52′38.08″ E 85°14′34.51). **b** Photograph of Gehlaur Passway cutting across quartzite hill. **c** Folding at quartzite-phyllite rock exposed at the side of Gehlaur Passway. **d** Department of India Post issued Rs. 5 stamp commemorating Dashrath Manjhi.**e** Pinching and swelling structure at quartzite as exposed at the side of Gehlaur Passway

(Fig. 12d). Ashoka inscriptions are found at Sudama Cave, Karan Chaupar Cave, and Visvakarma Cave, however, cave Romas Rishi has never been completed due to structural rock slide problems and hence has no Ashoka inscription (also see, Le 2010; Lahiri 2015) (also see, Fig. 13c). The Baba Siddharth Temple, located on one of the highest peaks in Barabar Hills, further enriches the historical landscape with its Gupta-period architecture. The four caves of Barabar Hill with its unique historical and architectural significance are briefly highlighted as under:

- **Karan Chaupar Cave:** Karan Chaupar, also known as Karna Chaupar, is located on the northern side of Barabar granite hill. This cave consists of a single rectangular room with polished surfaces, measuring 10.2 × 4.27 m. An inscription dating back to approximately 250 BCE, from the 19th year of Ashoka's reign, is found immediately to the right of the entrance. Initially believed to be dedicated to Buddhist monks, recent research by Harry Falk in 2007 corrected the interpretation, revealing that the cave was indeed dedicated to the Ajivikas. The inscription mentions King Priyadarsin offering the cave to the Ajivikas for shelter during the rainy season.

- **Lomas Rishi Cave:** Lomas Rishi Cave features an arch-like shaped facade mimicking contemporary timber architecture. The doorway displays a row of elephants proceeding towards stupa emblems along the curved architrave. This cave, along with Sudama, represents the earliest examples of rock-cut architecture in India, showcasing Mauryan period detailing. The influence of Barabar caves is evident in the broader tradition of rock-

Fig. 10 **a** View of Cyclopean Wall of Rajgir Hill (Source: https://tourism.bihar.gov.in/en/destinations/nalanda/cyclopean-wall#category-cyclopean-wall). **b** Photograph of the Cyclopean Wall of Rajgir being constructed along the ridge of quartzite hill

cut architecture across the Indian subcontinent. Sudama cave, reachable by Ashoka steps hewn into the cliff, comprises a circular vaulted chamber with a rectangular mandapa.

- **Sudama Cave:** Sudama Cave, part of the Barabar Caves complex, showcases bow-shaped arches and consists of a circular vaulted chamber with a rectangular mandapa. Dedication to the Ajivikas by Mauryan Emperor Ashoka in 261 BCE marks its historical significance. The caves hold a symbolic representation of peace and love, enshrining the relics of Buddha in their foundation and top.
- **Visvakarma Cave**: Visvakarma Cave, accessible via Ashoka steps, consists of two rectangular rooms. Its proximity to Sudama Cave adds to the interconnectedness of these ancient rock-cut marvels.

The caves were carved out of granite, and each cave consisted of two chambers of which the first rectangular hall-like chamber meant assembling the worshipers and the circular to domed-shaped second chamber probably had a stupa-like structure for worshipping. A very smooth and fine finish is visible on the smoothly polished internal surface with mirror image reflection from the polished surface and an exhilarating echo effect is present in the chambers (Cunningham 1871; Lahiri 2015) (Fig. 13a). The unique echo effect within the caves, where any sound persists for three minutes, adds to their mystique. Similar large-scale polish is evocative of the pillars and capitals of the Ashoka pillars on smaller surfaces of the Maurya statuary (Lahiri 2015). These caves collectively contribute to the rich heritage of Barabar Hills, with their historical inscriptions, unique architectural features, and connections to the religious and philosophical traditions of ancient India. The meticulous detailing and craftsmanship evident in these caves have significantly influenced the trajectory of rock-cut architecture in the region. Their preservation and exploration continue to unveil the layers of history embedded in the heart of Barabar Hill.

Caves on Nagarjuni Hill

The caves on Nagarjuni hill, located approximately 1.6 kms east of the Barabar Caves, were constructed a few decades later and consecrated by Dasaratha Maurya, the grandson and successor of Emperor Ashoka. Dedicated to the Ajivikas sect, these caves showcase exquisite craftsmanship and historical inscriptions. The three caves of Nagarjuni Hill namely Gopika, Vadithi-ka-Kubha cave, and Vapiya-ka-Kubha cave were built a few decades later than the Barabar

Fig. 11 **a** Sapneri gabbro-anorthosite suite a panoramic view exposed at Sapneri (25^{0}0′41.5476’’N; 85^{0}8′58.524’’E). **b** Exposure of Grabbro in the Sapneri area. **c** Layer anorthosite at Sapneri area. **d** Anorthosite block at Sapneri area. **e** Magnetite exposed at Sapneri area

caves. and sanctified by Dasaratha Maurya, Ashoka's grandson and successor (see, Cunningham 1871).

The three caves on Nagarjuni hill are as follows:

- **Gopika Cave:** Also known as Gopi-ka-Kubha or Nagarjuni, the Gopika cave is the largest in the Barabar complex. Situated on the south side of the hill, it consists of a single oblong room measuring 13.95 × 5.84 m. Notably, the two ends of the room are circular, setting it apart from the other caves. King Dasharatha, the grandson of Emperor Ashoka, excavated this cave, as confirmed by an inscription above the front door. The inscription, dated around 230 BCE, states that the cave was created as a hermitage for the Ajivikas.
- **Vadathika and Vapiyaka Caves:** These two caves, Vadathika and Vapiyaka, are situated higher on the north side of Nagarjuni Hill. Despite their small size, they are intricately carved and visually stunning. Vadathika cave, located in a crevasse, features a single rectangular room (5.11 × 3.43 m) with a porch at the entrance (1.83 × 1.68 m). Dasharatha Maurya consecrated this cave for the Ajivikas, as indicated by an inscription dating back to around 230 BCE.
- **Vapiyaka Cave:** Vapiyaka Cave, also known as the "Well Cave," comprises a single rectangular room (5.10 × 3.43 m) and was dedicated to the Ajivikas by Dasharatha. The cave boasts a beautifully vaulted hall made entirely of polished granite. Similar to Gopika Cave, an inscription on Vapiyaka echoes the dedication to the Ajivikas, and several short inscriptions from the Gupta era further enhance its historical significance. The dedication of these caves by Dasaratha Maurya serves as a testament to the cultural and religious diversity of ancient India, with each cave standing as a unique expression of devotion and architectural prowess.

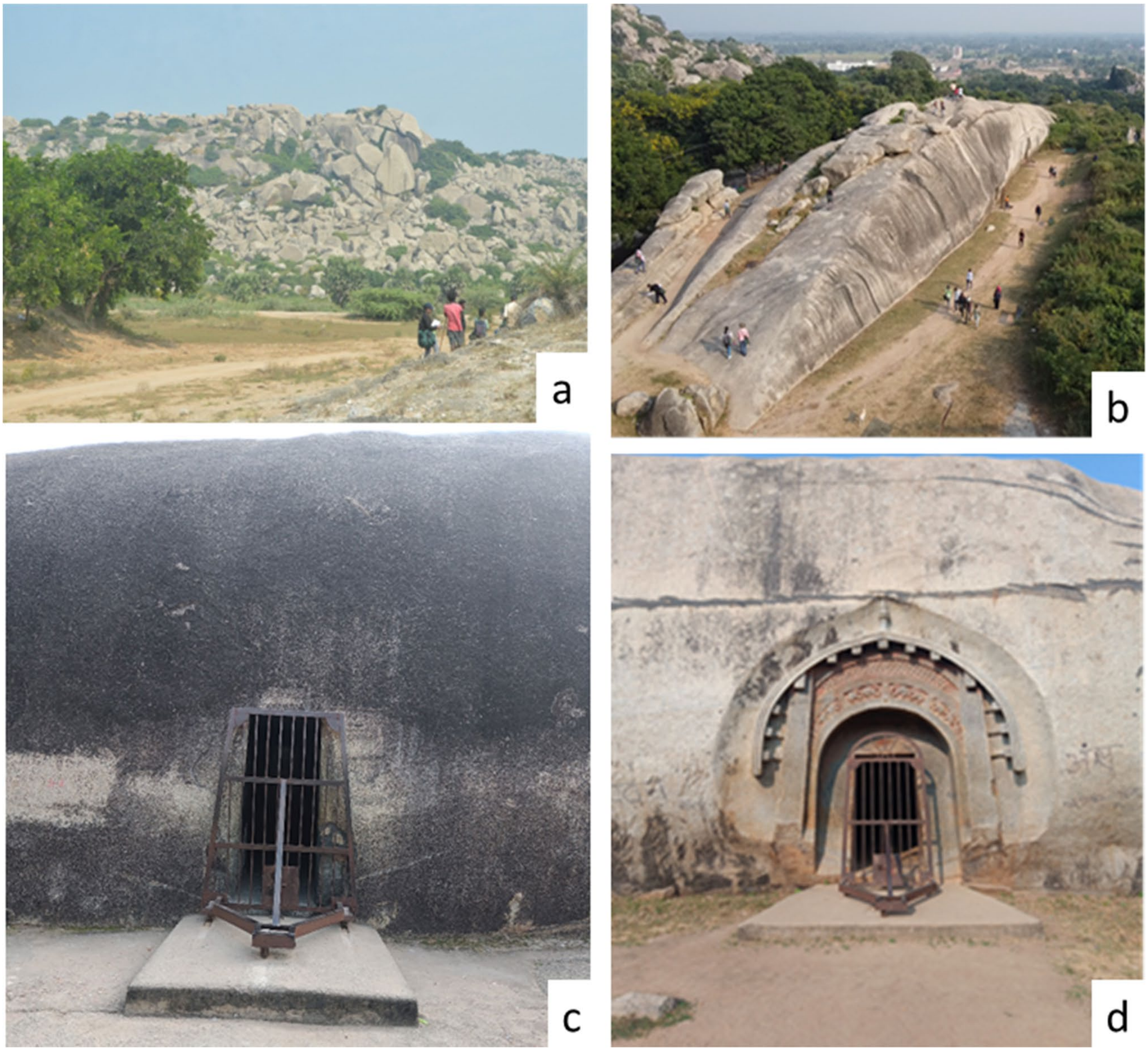

Fig. 12 **a** Spectacular view of Barabar Hills; **b** Granitic block from where Barabar Cave is carved out. **c** View of Karan Chaupar cave, Barabar Hill. **d** The well carved entrance of Lomas Rishi cave, dated to approximately 250 B.C

Significant Cultural and Heritage Sites In and Around Gaya-Rajgir-Nalanda

The Magadh region of Bihar stands as a testament to the convergence of cultural, archaeological, and geological heritage, making it an ideal destination for geo-tourism, cultural tourism, and eco-tourism. This region, encompassing areas like Gaya, Rajgir, and Barabar Hills, is bestowed with internationally acclaimed UNESCO heritage sites such as the Mahabodhi Temple and Nalanda University which attracts national and international tourists from all over the globe. It is also well known for its religious and cultural sites for Buddhist, Hindu and Jain temples (also see, Hastimalji Maharaj 1971), Muslim tomb and certain other important archaeological spots in and around Rajgir, Gaya and Barabar Hills. Rajgir was a royal city surrounded by seven hills, which served as the capital of the Magadh empire from the time of Mahabharata to the 5th Century BC. The city was prosperous till the Magadh King Ajatshatru decided to shift the capital of Magadh to Pataliputra. It was here that Gautam Buddha spent his summers meditation on the peak of the Gridhakuta (Vulture Peak), and the First Buddhist Council was held under Maha Kassapa. Lord Mahavira spent 14 years of his life in Rajgir and Pavapuri, the place where he attained nirvana is not far from here.

Fig. 13 **a** Mirror image reflection at the polished surface inside Lomas Rishi cave, Barabar Hill. **b** Mauryan Sculpture carved in granite, Barabar Hill. **c** Structural problem due to the development of joints inside Lomas Rishi cave. **d** The Brahmi script inscription at Visvakarma cave, Ashoka inscription (c.258 BCE)

Two Chinese scholars Heuen Tsang and Xuanzang were also known to have visited Rajgir, Nalanda University.

Nalanda: Cradle of Ancient Wisdom

Nalanda, a Buddhist monastery dating back from the 3rd century BCE to the 13th century CE, serves as a remarkable archaeological site in the ancient kingdom of Maghada, present-day Bihar (Fig. 14). The remains include stupas, shrines, and viharas, showcasing the evolution of Buddhism into a religion and the flourishing of monastic and educational traditions. The pedagogy, administration, planning, and architecture of Nalanda were foundational for later Mahaviharas, making it a crucial centre for the development of Buddhism in the Indian subcontinent.

Vishnupad Temple: Spiritual Sanctuary in Gaya

Situated in Gaya, the Vishnupad Temple holds great spiritual significance for Hindus (Fig. 15). Legend has it that the temple marks the spot where Lord Vishnu pressed his feet on Gayasura's body, leaving an indelible imprint on the rocky surface. Built-in the Nagara style of temple architecture with a towering Vimana, the temple stands tall on undulating rocky ground, reflecting the sanctity of Gayasur's petrified form. The complex houses various shrines adorned with sculptures depicting Navagrahas, Ganesha, Vishnu, Shiva, and Durga, offering a glimpse into the historical layers of the sacred space. The Vishnupad Temple is an important spiritual site for the Hindus located in Gaya. The river Phalgu flows on the east of the temple.

Fig. 14 **a**, **b**, **c**, **d** View of relics of Nalanda University sites in different views

Mahabodhi Temple Bodh Gaya: Epitome of Enlightenment

The Mahabodhi Temple Complex (Fig. 16), one of the four holy sites associated with the life of Lord Buddha, is a testament to spiritual enlightenment. Built-in the 3rd century B.C. by Emperor Asoka, the present temple stands as one of the earliest brick structures from the late Gupta period. The complex, located in Bodh Gaya, features the sacred Bodhi Tree (Fig. 16a), Vajrasana (Diamond Throne), and various shrines representing the different weeks of Buddha's enlightenment. This iconic site provides exceptional records of events related to Buddha's life and has significantly influenced architectural development over the centuries.

Rajgir – The Abode of Kings: A Royal Haven

Rajgir, known as the "abode of Kings," served as the capital of the Magadh empire before Pataliputra. It witnessed significant events in Buddhist history, including Gautam Buddha's meditation on the Gridhakuta peak and the First Buddhist Council. Lord Mahavira also spent 14 years of his life in Rajgir, and the Son Bhandar caves, shrouded in myth, have intrigued scholars and treasure hunters. The Vishwa Shanti Stupa (Fig. 17a), built in collaboration with the Japanese in 1969, stands on the Ratnagiri hill, symbolizing world peace and overlooking Buddha's favourite Gridhakuta hill. Some of the tourism spots such as Ghora Katora lake (Fig. 17b) and hot water of Brahmakund are also culturally and geologically significant (also see, Raza et al. 2020a, b).

Bodh Gaya Archaeological Museum The museum located at Bodh Gaya (N 24° 41′ 41″ and E 84° 59′ 14″ near the Mahabodhi Temple was established in the year 1956 and it is currently taken care of by the Archaeological Survey of India. This museum preserves rich historical antiquities of ruins and excavated remains collected from the region related to Buddhism and Jainism. Several Hindu and Buddhist relics, miniature pots, stone sculptures, terracotta items, copper antimony rods, Lord Buddha images, coping stones, etc. are well preserved and displayed. The general attraction of the museum comprises the display of the Dasavatara (Incarnation) of Lord Vishnu in the second gallery, sculptures associated with the Buddhist and Brahmanical faith of the Pala

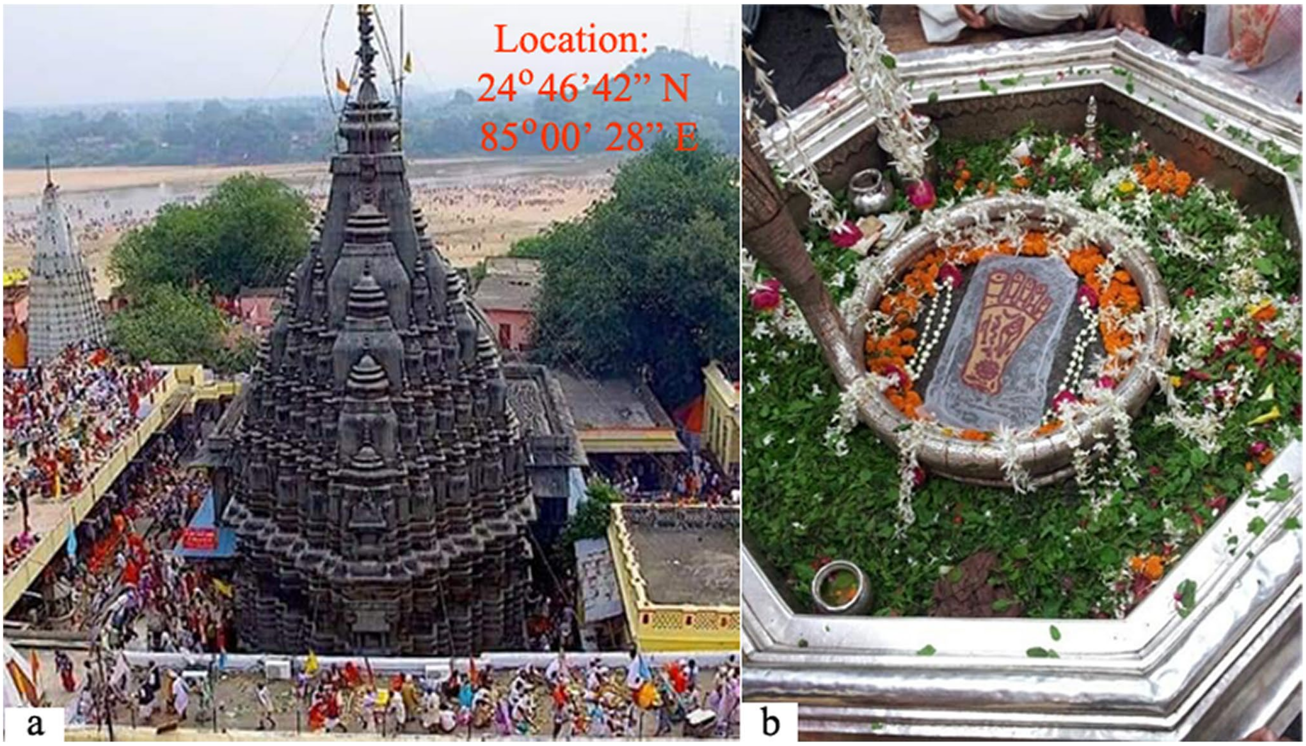

Fig. 15 **a**. View of Vishnupad temple during Pitru Paksha (Source: https://templeyatri.in/places-to-visit-near-gaya-bihar/), **b**. Showing footprint of Lord Vishnu at Vishnupad temple, Gaya (Source: https://www.tripadvisor.in/Profile/Pinddaaningaya/Photo/74456946)

period, huge idols of Lord Buddha in "abhayamudra" position, etc. Certain antique relics and monuments belonging to the Mauryan and Gupta periods, coins of the Mughal era, are also displayed for the visitors.

Chariot Mark An exceptional geoarchaeological spot is located to the south of Rajgir along National Highway No.82 (N24°59′05.05″ E85°25′52.54″) and the spot is well connected from Gaya and Rajgir by metalled road. It shows an excellent preservable of anthropogenic activities in the historical past in the form of pounding marks along with grooves resembling the chariot wheel marks (Fig. 18). It is believed that the marks were created by the chariot marks of Lord Krishna during during Mahabharat times. The two parallel channel-like grooves run along the NE-SW trend with a width of around 1ft and extending for about 50 ft. The grooves are smooth and have a deep of 9 to 21 cm. The structure is created at phyllite of the Munger-Rajgir Group of rocks. The light purple colour phyllite shows a foliation trend of N55E-S55W dipping 58 towards SE and certain Z-shaped micro-folding plunging 15°to 20° towards SW are also observed. Pounding marks along the grooves are observed which points towards human activities (mineral exploration) sometime in the past. Geologically, the grooves coincide with the two parallel master joints with a space of about 1 m running for a kilometre. The grooves occurring at quartzite and phyllites are more pronouncedly deepened by later anthropolical activities which are further smoothened by fluvial runoff in the stream along the grooves. Thus, the structure might have closely resembled the impression of a groove created by the movement of a Chariot.

Discussion on Conservation and Sustainable Tourism

In recent years, the relationships between geoheritage and cultural heritage have been increasingly explored all over the world for geotourism, environmental conservation purposes and public outreach of geology (also see, Rocha-Vargas et al. 2019; Freire-Lista et al. 2022b, Halbouni et al. 2022; Pijet-Migoń and Migoń 2022; Freire-Lista et al. 2023). Subsequently, geosites have progressively involved many important aspects of local cultural, historical and archaeological, natural resource management, land management, research, education and tourism (Frey et al. 2001; Ibrahim 2003; Brocx and Semeniuk 2007; Burek and Prosser 2008). The conservation of geosites, and cultural sites in a developing country like India is a big challenge owing to its negative factors comprising of large-scale unemployment of youths, illiteracy, low income, lack of sensitisation and awareness of geoheritage conservation.

Fig. 16 **a** Bodhi Tree Maha Bodhi Temple, Bodha Gaya (Photo Source: https://natureforall.global/blog/the-restoration-of-the-holy-bodhi-tree-at-bodhgaya-india), **b** Footprint of Buddha under Bodhi Tree Maha Bodhi Temple, Bodha Gaya (Photo source: https://commons.wikimedia.org/wiki/File:013_Siripada_%28Buddha%27s_Footprints%29_%289222192156%29.jpg) **c** A view of Mahabodhi temple, Bodha Gaya (Photo source: https://timesofindia.indiatimes.com/travel/destinations/all-about-bodh-gaya-and-its-mystic-mahabodhi-temple-complex/articleshow/69372683.cms)

Thus, the concepts of geodiversity, geotourism and geoconservation should be in the syllabus curricula of schools and colleges at all educational levels so that the entire society can safeguard this natural resource in a sustainable way (also see, Kubalíková et al. 2021; Salameh et al. 2021; Crofts et al. 2021; Kaur 2022). As education plays an important role to promote and protect the geological environment, widespread sensitisation to the civilians thereby giving necessary awareness for the conservation of geoheritage, geosites, and cultural sites and promoting them for geotourism, cultural and ecotourism is required.

It is the right time for us as an informed society to appreciate these values and protect the geoheritage, which is part of the essence of local culture and society (also see, Azman et al. 2010; Khoukhouchi et al. 2018; Freire-Lista and Fort 2019) which will also serve as a niche area of the local tourism economy. These geological and cultural sites need to be preserved and cared for the future generations. The geodiversity of Gaya and the adjoining area are associated with its rich cultural, historical, archaeological value and hence the area serves as a great prospect for an ideal destination of geotourism for national and international tourists. Thus, geotourism also serves as a route for public outreach (Freire-Lista et al. 2017, 2022a; Freire-Lista 2020) and can include archaeological, natural and cultural sites as historical quarries which attract many tourists and economic prosperity (Kozłowski 2004; Reynard and Panizza 2007; Citiroglu et al. 2017; Medina-Viruel et al. 2019; Hall and Zeppel 1990a, b).

Conclusion

The study area is characterized by the presence of rich historical background, geological, geomorphological significance and cultural heritage especially the Churi hills, Mahabodhi Temple, Vishnupad Temple, Nalanda University relict site, Caves of Barabar Hill, Rajgir area, cyclopean walls, hot water spring of Brahmakund, Vishwa Shanti Stupa, etc. The preservation of these geological and cultural heritage of the Magadh region is a paramount importance for our future

Fig. 17 **a** Showing Vishwa Shanti Stupa (Peace Pagoda) at Ratnagiri hill, Rajgir. **b** Ghora Katora lake of Rajgir (Photo source: https://tourism.bihar.gov.in/en/destinations/nalanda/ghora-katora). **c**, **d** Brahma Kund hot water spring of Rajgir

generations. The Pillow basalt site of Churi Hill is a unique geological site which need special attention to be taken care for conservation and steps may be taken in the future to list this site as the third nation geoheritage sites from Bihar, the other two being Barabar Caves and Koshi Megafan. Efforts must be directed towards sustainable tourism practices that respect and safeguard these invaluable sites. Conservation initiatives should be focussed on maintaining the structural integrity of temples, caves, and monuments while ensuring the protection of geological formations. Education and awareness programs can play a pivotal role in promoting responsible tourism and fostering a sense of pride and ownership among local communities. Taking into consideration of the prospects for geo, cultural and ecotourism, it is

Fig. 18 **a** Showing an overview of the Chariot Mark in the Rajgir area. **b** Image showing two parallel channel-like marks within phyllite resembling the wheel marks of the chariot. **c** Undeciphered shell Inscriptions at the phyllites

required to prepare a layout plan and tourist route to allow local, national and international travellers to gain exposure to these areas. Roads, railways, infrastructure and other transport connectivity towards the geosites and cultural site are needed to be upgraded to facilitate geotourism and strengthen the employment generation of local people. It is of utmost importance to integrate the geosites with cultural, sacred pilgrimage sites and other tourist places of the nearby area to make a sustainable geotourism at and around the Gaya region of South Bihar, India. Beyond these well-known landmarks, the region boasts other significant archaeological spots and geological formations, providing a promising foundation for potential UNESCO Geopark sites. It also further required to undergo more research on highlighting the suitability putting the geoheritage region of the Gaya region of South Bihar, India for developing a Geopark based on UNESCO norms. The region serves as a highly prospective site for our country for proposing it under the Geopark sites for future research, geo and cultural tourism of international significance.

Acknowledgements Corporation from Dr. Priti Rai (Assistant Professor, Department of Geology, CUSB, Gaya) and M.Sc. Geology students Department of Geology, CUSB Gaya is highly grateful.

Authors' Contribution All authors have equally contributed in this manuscript.

Funding The work was not funded by any organization.

Declarations

Conflict of Interest The authors declare that there are no conflicts of interest.

References

Acharyya SK (2003) The Nature of Mesoproterozoic Central Indian tectonic zone with exhumed and reworked older granulites. Gondwana Res 6:197–214

Ahluwalia AD (2006) Indian geoheritage, geodiversity: Geosites and geoparks. Curr Sci 91(10):1307–1307

Ahmad M, Wanjari N (2009) Volcano-sedimentary sequence in the Munger-Rajgir metasedimentary belt, Gaya district, Bihar. Indian J Geosci 63:351–360

Ahmad M, Paul AQ, Negi P, Akhtar S, Gogoi B, Saikia A (2021) Mafic rocks with back-arc E-MORB affinity from the Chotanagpur Granite Gneiss Complex of India: relicts of a Proterozoic Ophiolite suite. Geol Mag 158:1527–1542. https://doi.org/10.1017/S0016756821000078

Azman N, Halim SA, Liu OP, Saidin S, Komoo I (2010) Public education in heritage conservation for Geopark community. Procedia-Soc Behav Sci 7:504–511. https://doi.org/10.1016/j.sbspro.2010.10.068

Bakliwal PC, Grover AK, Kaura SC (2004) Earth Science related features for Geotoursim in Arunachal Pradesh, Northeastern India. In: Workshop on Geotourism in NE India with special emphasis on Meghalaya, Shillong. Geol Surv Ind, pp 37–38

Bhosale S, Chaskar K, Pandey DK, Lakhote A, Thakkar A, Chauhan G, Bhandari S, Thakkar MG (2021) Jurassic geodiversity and geomorphosite of Kanthkot area, Wagad, Kachchh, Western India. Int J Geoheritage Parks 9(1):51–68. https://doi.org/10.1016/j.ijgeop.2020.12.008

Bradbury J (1993) A preliminary geoheritage inventory of the eastern Tasmania Terrane. A report to Park and Wildlife Service, Tasmania

Brilha J (2002) Geoconservation and protected area. Environ Conserv 29:273–276

Brilha JBR (2009) A importância dos geoparques no ensino e divulgação das Geociências. Geol USP 5:27–33

Brilha J (2016) Inventory and quantitative assessment of geosites and geodiversity sites: a review. Geoheritage 8:119–134. https://doi.org/10.1007/s12371-014-0139-3

Brilha J (2017) Geoheritage and Geoparks. In: Reynard E, Brilha J (eds) Geoheritage: assessment, protection, and management. Elsevier, Amsterdam, pp 323–335

Brilha J (2012) A Rede Global de Geoparques Nacionais: um instrumento para a promoção internacional da geoconservação. In: Schobbenhaus C, Silva C (Org.) Geoparques do Brasil: propostas. Rio de Janeiro: CPRM-Serviço Geológico do Brasil, pp 29–37

Brilha JBR, De Carvalho AMG (2010) Geoconservação em Portugal: uma Introdução. In Ciências Geológicas: Ensino, Investigação e sua História Volume II Geologia Aplicada. Publicação Comemorativa do "Ano Internacional do Planeta Terra" (Org. Cotelo Neiva JM, Ribeiro A, Victor M, Noronha F, Ramalho M). Associação Portuguesa de Geólogos Sociedade Geológica de Portugal

Brocx M, Semeniuk V (2007) Geoheritage and geoconservation–history, definition, scope, and scale. J R Soc West Aust 90:53–80

Brocx M, Semeniuk V (2011) Assessing geoheritage values: a case study using the Leschenault Peninsula and its leeward estuarine lagoon, south-western Australia. Proc Linnean Soc NSW 132:115–130

Bruno DE (2015) Concept of geosite. In: Tiess G, Majumder T, Cameron T (ed) Encyclopedia of mineral and energy policy. Springer, Berlin, pp 1–5. https://doi.org/10.1007/978-3-642-40871-7_6-1

Bruschi M (2007) Development of a methodology for the characterization, evaluation and management of geodiversity resources. University of Cantabria, León, p 355

Burek CV, Prosser CD (2008) The history of geoconservation: an introduction. Geol Soc Lond 300(1):1–5

Chatterjee N, Ghose NC (2011) Extensive early Neoproterozoic high-grade metamorphism in North Chotanagpur Gneissic Complex of the Central Indian Tectonic Zone. Gondwana Res 20:362–379

Chatterjee N, Crowley JL, Ghose NC (2008) Geochronology of the 1.55Ga Bengal anorthosite and Grenvillian metamorphism in the Chotanagpur gneissic complex, eastern India. Precambrian Res 161(3–4):303–316. https://doi.org/10.1016/j.precamres.2007.09.005

Chauhan G, Biswas SK, Thakkar MG, Page KN (2021) The unique geoheritage of the Kachchh (Kutch) Basin, Western India, and its conservation. Geoheritage 13:1–34

Citiroglu HK, Isik S, Pulat O (2017) Utilizing the geological diversity for sustainable regional development, a case study-Zonguldak (NW Turkey). Geoheritage 9(2):211–223. https://doi.org/10.1007/s12371-016-0196-x

Crofts R, Tormey D, Gordon JE (2021) Introducing new guidelines on Geoheritage conservation in protected and conserved areas. Geoheritage 13:33. https://doi.org/10.1007/s12371-021-00552-0

Cunningham A (1871) Four reports made during the years, 1862–63–64–65. Government Central Press, pp 43–52

Das S, Mukherji S (2001) Mineralogy and geochemistry of V-Ti magnetite deposits of Mayurbhanj basic igneous complex, Orissa. Indian Mineral 35:134–150

Dayal N (1983) Report on the systematic geological mapping in parts of Gaya District, Bihar; Geological Survey of India. Kolkata, India. Unpublished Report

De Lima FF, Vargas JC (2014) Geoconservação, geoturismo e geoparques. In Universidade Federal de Santa Catarina. Departamento de Engenharia Sanitária e Ambiental. Centro Tecnológico. Florianópolis: [s. n.]

Freire-Lista DM (2020) Geotourism from Fuente de Cibeles of Madrid. History, Building Stones and Quarries. Cadernos do Laboratorio Xeolóxico de Laxe. Revista de Xeoloxía Galega e do Hercínico Peninsular 42:69–94. https://doi.org/10.17979/cadlaxe.2020.42.0.7286

Freire-Lista DM, Fort R (2019) Historical city centres and traditional building stones as heritage: the Barrio de las Letras, Madrid (Spain). Geoheritage 11(1):71–85. https://doi.org/10.1007/s12371-018-0314-z

Freire-Lista DM, Fort R, Varas-Muriel MJ (2017) Ruta Geomonumental por Manzanares el Real (Madrid). Geogaceta 62:107–110

Freire-Lista DM, Campos BB, Sanjurjo-Sánchez J, Costa R (2022b) Heritage Stone of São Tiago de Folhadela Romanesque church (North of Portugal). Petrography, glyptography, construction phases and deterioration of its historic ashlars by pyrite oxidation. Constr Build Mater 350:128904. https://doi.org/10.1016/j.conbuildmat.2022.128904

Freire-Lista DM, Campos BB, Ramil MP, Rego A, Lopez Díaz MJ (2023) Building Granite characterisation, construction phases, mason's marks and glyptography of Nossa Senhora de Guadalupe

Church, Mouçós e Lamares, Galicia-North Portugal Euroregion. Geoheritage 15:24. https://doi.org/10.1007/s12371-023-00790-4
Freire-Lista DM, Becerra Becerra JE, Simões de Abreu M (2022a) The historical quarry of Pena (Vila Real, north of Portugal): associated cultural heritage and reuse as a geotourism resource. Resour Policy 75. https://doi.org/10.1016/j.resourpol.2021.102528
Frey ML, Martini G, Zouros N (2001) European Geopark charter. In: Frey ML (ed). EuropeanGeoparks magazine 1:28
Ghosh AR, Mukherjee A (2002) Arsenic contamination of groundwater and human health impacts in Burdwan District, West Bengal, India. Geol Soc America (Abstracts) 34(2):107
Ghosh A, Mukhopadhyay S, Chatterjee S (2021) Assessment of geoheritage and prospects of geotourism: An approach to geoconservation of important geological and geomorphological sites of Puruliya district, West Bengal, India. Int J Geoheritage Parks 9(2):264–283. https://doi.org/10.1016/j.ijgeop.2021.03.001
Gogoi B, Saikia A, Ahmad M, di Mineralogia P (2017) Titanite-centered ocellar texture: a petrological tool to unravel the mechanism enhancing magma mixing. Periodico Mineral 86:245–273
Gray M (2004) Geodiversity – valuing and conserving abiotic nature. Wiley, Chichester
Grover AK, Mahanta BN (2018) Geotourism potential in Arunachal Pradesh—a preliminary appraisal. Indian J Geosci 72:345–360
Halbouni D, AlRabayah O, Rüpke L (2022) A Vision on a UNESCO Global Geopark at the Southeastern Dead Sea in Jordan—Geosites and Conceptual Approach. Land 11:549. https://doi.org/10.3390/land11040549
Hall CM, Zeppel H (1990a) Cultural and heritage tourism: the new grand tour? Historic Environ 7(3/4):86–98. https://doi.org/10.3316/informit.870765828978406
Hall CM, Zeppel H (1990b) History, architecture, environment: cultural heritage and tourism. J Travel Res 29:54–55. https://doi.org/10.1177/004728759002900212
Ibrahim K (2003) Conservation geology – protecting hidden treasure of Malaysia. Academy Science of Malaysia Inaugural Lectures 2003. Academy Science of Malaysia and Lestari UKM Publications. Bangi 51:27–36
Insua Pereira D, Pereira P, Brilha J, Santos L (2013) Geodiversity ASSESSMENT of Paraná State (Brazil): an innovative approach. Environ Manag 52:541–552. https://doi.org/10.1007/s00267-013-0100-2
IUCN (2021) Geodiversity, World Heritage and IUCN. https://www.iucn.org/theme/world-heritage/our-work/global-world-heritage-projects/geodiversity-world-heritage-and-iucn. Accessed 03 Jun 2021
Kaur G (2022) Geodiversity, geoheritage and geoconservation: a global perspective. Journ Geol Soc India 98(9):1221–1228
Khoukhouchi M, Errami E, Hassou N, Irzan M (2018) The geomorphological heritage of the Oualidia and Sidi Moussa lagoons: assessment and promotion for a sustainable human and socioeconomic development. J Sci Res 5(4):73–87
Kozłowski (1999) Programme of geodiversity conservation in Poland. Pol Geol Inst Sp Papers 2:15-18
Kozłowski S (2004) Geodiversity. The concept and scope of geodiversity. Przegl Geol 52:833–837
Kubalíková L, Bajer A, Balková M (2021) Brief notes on geodiversity and geoheritage perception by the lay public. Geosciences 11:54. https://doi.org/10.3390/geosciences11020054
Kuhn CES, Santos FRP, de Jesuz CR, de Andrade KA, Augusto Gomes Vieira Reis F (2022) Public policies for geodiversity in Brazil. Geoheritage 14:74. https://doi.org/10.1007/s12371-022-00705-9
Lahiri N (2015) Ashoka in ancient India. Harvard University Press, Harvard
Le HP (2010) Buddhist Architecture. Book Publication, Grafikol
Mahadevan TM (2002) Geology of Bihar & Jharkhand. Geological Society of India, Bangalore
Hastimalji M (1971) Jain Dharma ka Maulik Itihas Part-1, ed., Jain Itihas Samiti, p 739–742
Mallik AK (1968) Mineralogy and Temperature of Formation of Titaniferous Magnetite Ores Associated with Gabbro in the Moulabhanja Parbat Area, Dhenkanal District, Orissa; Geological Survey of India. Unpublished Report, Kolkata
Mathur S (2020) Concept of geoheritage: a review in Indian context. J Water Clim Chang 7:1–17
Mazumdar MK (2010) Sustainable use of lanscapes through geoconservation promotion: The Geoparks approach with particular reference to Northeast India. In: Islam S, Barua P, Das KC (eds) Biodiversity Conservation and Sustainable Development. Commerce College, Guwahati, pp 137–166
Medina-Viruel MJ, Fuentes Jiménez PA, Pérez-Gálvez JC, González Santa Cruz F (2019) The role of gastronomy in trips: types and motivations. J Soc Sci Res 5(512):1758–1767. https://doi.org/10.32861/jssr.512.1758.1767
Mehrotra N (2022) Why India needs UNESCO global geoparks. In: Land, water and people, the society of earth scientists. Lucknow, India, pp 39–42. http://earthses.org/?page_id=1988. Accessed 23 Aug 2024
Mohammad A, Prasad AK, Wetsah K-u, Azad M, Aryan V, El-Askary H (2022) Titaniferous-vanadiferous, magnetite-ilmenite mineralization in a mafic suite within the chhotanagpur gneissic complex, Bihar, India. Minerals 12(7):860. https://doi.org/10.3390/min12070860
Mukherjee D (2010) Report on tectono-magmatic evolution of gaya-sudamakund area in Gaya and Jehanabad districts, Bihar and Associated Magnetite-Ilmenite Mineralization; Geological Survey of India, Kolkata, India
Mukherjee S, Dey A, Sanyal S, Sengupta P (2019) Proterozoic crustal evolution of the Chotanagpur granite gneissic complex, Jharkhand-Bihar-West Bengal, India: Current status and future prospect. In: Mukherjee S (ed) Tectonics and structural Geology: Indian context. Springer Geology International Publishing AG, Cham, pp 7–54
Mukhopadhyay P, Ray S, Saran R, Huin AA (2011) Status Report on the Geology, Structure, Metamorphism, Petrology, Mineral Chemistry, Petrochemistry, Geochemistry and Geochronology and Economic Potentiality of the Major Units of Chhotanagpur Gneissic Complex in West Bengal, Jharkhand and Bihar, Eastern India (SER/ER/HQ/2008/013); Geological Survey of India. Kolkata, India.
Panizza M (2001) Geomorphosites: concepts, methods and examples of geomorphological survey. Chin Sci Bull 46(Suppl 1):4–5. https://doi.org/10.1007/BF03187227
Pereira P, Pereira D, Caetano Alves MI (2008) Geomorphosite assessment in Montesinho natural park (Portugal). Bol AGE 47:397–399
Phani PRC (2016) Geological Excursion to Eparchaean Unconformity at Namalagundu, Anantapur District, Andhra Pradesh, India. J Earth Sci India 1:1–8
Pijet-Migoń E, Migoń P (2022) Geoheritage and cultural heritage—a review of recurrent and interlinked themes. Geosciences 12(2):98. https://doi.org/10.3390/geosciences12020098
Ranawat PS, George S (2019) Potential geoheritage & geotourism sites in India. Int J Sci Res 9(6):9016. https://doi.org/10.29322/ijsrp.9.06.2019.p9016
Raza MA, Shareef M, Badireddi V, Suryavanshi H, Baswani SR, Dora ML, Meshram T, Akhter P, Kumari S, Panda B, Saha SK (2020b) Multiple sulfur sources for the volcanic hosted massive sulfides in Betul Belt, Central India: evidence from the sulfide ore chemistry and sulfur isotope geochemistry. Geochemistry 80(4):125632
Raza AA, Awungshi R, Bishwapriya A (2020a) Rajgir-Bodh Gaya-Barabar Geotourism Spots: A Unique Geological and Historical Heritage of Bihar. ER004 pre-congress Field Trip guide, 36 International Geological Congress, Delhi (NCR), p 1–52

Reynard E, Panizza M (2005) Geomorphosites: definition, assessment and mapping. An introduction. Géomorphologie 3:177–180
Reynard E, Panizza M (2007) Geomorphosites: definition, assessment and mapping. An introduction. Géomorphologie 3:177–180. https://doi.org/10.4000/geomorphologie.337
Rocha-Vargas DC, Becerra- Becerra JE, Benavente D, Cañaveras JC, Gilberto-Costa A (2019) Estudio preliminar de las características petrográficas, petrofísicas y comportamiento mecánico de rocas naturales tipo "piedra bogotana" y "mármol royal bronce" utilizadas en construcciones patrimoniales y recientes en Colombia. Rev UIS Ingenierías 18(3):203–222. https://doi.org/10.18273/revuin.v18n3-2019021
Saikia A, Gogoi B, Ahmad M, Ahmad T (2014) Geochemical constraints on the evolution of maficand felsic rocks in the Bathani volcanic and Volcano-sedimentary sequence of Chotangpur Granite GneissComplex. J Earth Syst Sci 123:959–987
Saikia A, Gogoi B, Kaulina T, Lialina L, Bayanova T, Ahmad M (2017) Geochemical and U-Pb zircon age characterization of granites of the Bathani Volcano Sedimentary sequence, Chotanagpur Granite Gneiss Complex, eastern India: vestiges of the Nuna supercontinent in the Central Indian Tectonic Zone. Geol Soc Spec Publ Lond 457(1):233–252
Saikia A, Gogoi B, Ahmad M, Kumar R, Kaulina T, Bayanova T (2019) Mineral chemistry, Sr–Nd isotope geochemistry and petrogenesis of the granites of Bathani volcano-sedimentary sequence from the Northern Fringe of Chotanagpur Granite Gneiss Complex of Eastern India. In: Mondal MEA (ed) Geological evolution of the Precambrian Indian shield. Springer International Publishing, Cham, pp 79–120
Salameh MM, Touqan BA, Awad J, Salameh MM (2021) Heritage conservation as a bridge to sustainability assessing thermal performance and the preservation of identity through heritage conservation in the Mediterranean city of Nablus. Ain Shams Eng J. https://doi.org/10.1016/j.asej.2021.07.007
Santos PLA, Brilha JA (2023) Review on tourism carrying capacity assessment and a proposal for its application on geological sites. Geoheritage 15:47. https://doi.org/10.1007/s12371-023-00810-3
Sarkar AN, Basu Mallick S (1979) Study of palaeodynamics in Bandhuwa- Jethian – Rajgir area, Gaya, Nawada and Nalandadistricts, Bihar. Unpublished Report. Geol Surv India FS: 1972–73
Sarkar AN, Basu Mallick S (1982) Study of palaeodynamics inthe Rajgir metasedimentary belt, Bihar: stress system crustalshortening and deformation patterns. Rec Geol Surv India 112(3):25–32
Schrodt F, Bailey JJ, Kissling WD et al (2019) Opinion: to advance sustainable stewardship, we must document not only biodiversity but geodiversity. Proc Natl Acad Sci USA 116(33):16155–16158. https://doi.org/10.1073/pnas.1911799116
Semeniuk V, Semeniuk CA (2001) Human impacts on globally to regionally significant geoheritage features of the swan coastal plain and adjoining coastal zone, southwestern Australia. Gondwana to greenhouse: Australian environmental geoscience-The Australian environment. Aust J Earth Sci 21:181–199
Sharples C (2002) Concepts and principles of geoconservation. Retrieved from: file:///C:/Users/c04qx/Downloads/Sharples2002_ConceptsPrinciplesOfGeoconservation_v3.pdf. Accessed 23 Aug 2024
Shekhar S, Kumar P, Chauhan GM, Thakkar G (2019) Conservation and sustainable development of geoheritage, geopark, and geotourism: a case study of cenozoic successions of W. Kutch, India. Geoheritage, pp 1–14
Shitole AD, Gupta V, Gidwani L, Verma V, Rajora S, Anand S, Tripathi SC (2023) Bagh Dinosaur National Park Region, Dhar District, Madhya Pradesh: a Potential UNESCO Global Geopark. Geoheritage 15(4):116
Singh RS, Ghosh P (2021) Geotourism potential of coal mines: anappraisal of Sonepur-Bazari open cast project, India. Int J Geoheritage Parks.https://doi.org/10.1016/j.ijgeop.2021.02.007
Swarna K, Biswas SK, Harinarayana T (2013) Development of Geotourism in Kutch Region, Gujarat, India: an innovative approach. J Environ Prot 4:1360–1372
Turner FJ (1968) Metamorphic petrology. McGraw Hill, New York
Walker B (2019) Hindu world: an encyclopedic survey of Hinduism. In Two Volumes. Volume I A-L. Routledge, p 62
Wanjari NR, Chaturvedi R, Mahanta DN (2012) Specialised thematic mapping in Munger–Rajgir Group of rocks to examine structural and stratigraphic set up in and around Gaya–Rajgir areas in parts of Gaya, Nawada and Jahanabad districts of Bihar; Unpublished report, GSI (F.S.: 2008–09, 2009–10)