Geoheritage (2023) 15:43
https://doi.org/10.1007/s12371-023-00807-y

ORIGINAL ARTICLE

Geoheritage and Geotourism Potential of Kalaruch Old Workings (Ancient Mines) and Satbarren (Archeological Stone) in Kashmir Valley of Himalaya

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Received: 21 September 2022 / Accepted: 13 February 2023 / Published online: 9 March 2023

Abstract

Kashmir Valley besides being famous as a luring destination of tourism and other recreational activities is also rich in diverse geology, geomorphology, archeology, and cultural history. The present study describes the geoheritage and geotourism potential of the Kalaruch old workings (ancient mines) and Satbarren (archeological stone) and highlights its significance for preservation, conservation, and sustainable development. These unique structures are of immense geological, archeological, historical, cultural, educational, and scientific importance. Its surroundings with beautiful topography and geomorphic landforms covered with lush green forests possess the marvelous potential for geotourism development. In this area, more than 8 old workings (OWs) clustered along a major quartz vein of strike length ~3.5 km (from Madmadou-Lashteal-Lainat Top to Gagarnar) and the average width of ~9 m (2–15 m) are present. The quartz vein is hosted within the Lolab Formation of the Lower Cambrian age that represents the oldest lithounits of the Paleozoic succession of the Kashmir Nappe Zone. The Formation shows profuse development of ichno fossils and tentatively marks the Precambrian-Cambrian (P-C) boundary in the area. Prominent sulfide mineralization of pyrite, arsenopyrite, chalcopyrite, malachite, and azurite is present within the main quartz vein, its host rock and on the walls of OWs respectively. Conversely, the Satbarren is an archeological giant slaty rock that is meticulously crafted and half buried in the ground. It comprises 9 shallow carved shelves (doors) that do not represent any distinct route to Russia and other neighboring countries as commonly believed. However, the Kalaruch OWs and Satbarren stone form an important geo-archeological artifact that indicates ancient mining activities by early civilization probably during ~3300–1000 BC in the area. Therefore, developing this place as a geoheritage and geotourism site will help in enhancing the socio-economic status of the local population and conserve it for future geologists, archeologists, researchers, students, and curious tourists. For its geoconservation and sustainable development, certain recommendations are provided in this study.

Keywords Lashteal village · Kupwara district · Kalaruch old working · Satbarren archeological stone · Ancient copper mining · Lolab Formation · Geoheritage · Geotourism · Kashmir Himalaya

Introduction

Globally and as a traditional practice, people visit the natural places with great scenic beauty and mesmerizing landscapes. These landscapes with high geological and geographical value play an important role for tourism development and attraction—aptly called as geotourism (Hose et al. 2011). The geological and cultural heritage has become a primary attractiveness to the visitors and tourists. Concurrently, the geotourism facilitates to acquire an in-depth knowledge of geology and geomorphology of such places and landscapes (Singh and Anand 2013). Additionally, one of the main focuses of geotourism is also to interpret and preserve

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the earthly features for touristic value (Dowling 2011). It also provides ways and opportunities for the maintenance and development of the geo-sites (Hose 2007; Hose et al. 2011). For economical development and conservation, it is very essential to inform and educate the general public, local community, and visitors regarding the importance of geo-sites (Thornbush and Allen 2018; Turner 2019). Within the domain of geotourism, the ancient mining and quarrying activities have also been considered as important and essential sectors for sustainable development. During recent years, a number of studies have attempted to explore the use of mines/or ancient mines and its potential development for geotourism purposes (Goki et al. 2018; GSI 2018).

The Kashmir Valley is endowed with a great diversity of reliefs and picturesque landscapes making it a paradise for geo-tourists, geologists, and geo-conservators (Bhargava 2015; Mir 2018; Mir et al. 2016, 2023). This diversity is greatly linked to its complex geological history modeled since the Precambrian Era by several orogenies and several cycles of sedimentary and magmatic processes with a unique lithological and paleontological richness (GSI 2012). The area also witnesses a very marked climatic diversity playing a large role in the landscape evolution and geomorphological diversity (e.g., diverse reliefs, gorges, waterfalls, valleys). Consequently, the geo-diversity is an asset of remarkable interest from scientific as well as geotourism point of view (Mir 2018). In this regard, the Permian-Triassic boundary section of Kashmir Valley (located in Guryul Ravine, Khunamuh about ~15 km away from the Srinagar city) can be cited as the best manifestation and an excellent example that has long been famous among the most complete fossil sites in the world, with an apparent continuous sedimentation and gradual faunal changes across the boundary (Sheng 1984; Mir 2018; Bhargava 2015; Shah et al. 2022; Mir et al. 2023). Moreover, there are also a number of places and geological sites that have a lot of scope for preservation, conservation, and potential for development as geoheritage and cultural sites in the area (e.g., Mir 2018; Verma et al. 2022; Mir et al. 2023). Among such locations, the Kalaruch caves and Satbarren (a meticulously crafted half-buried archeological giant stone) located in the Kupwara district of the northern Kashmir need special mention and ample attention so that the place can be developed as a geoheritage and geotourism site in the Kashmir Valley. Generally, the place is famous by the name of Kalaruch caves and Satbarren and is locally reported to be one of the most mysterious sites in the area (Pal 2020; Mahjoob 2021). It is believed that these caves/or tunnels have been earlier called as "Qila-e-Roos" meaning "Russian Fort." The Kalaruch village is believed to have derived its name from the myths related to these caves (Pal 2020; Mahjoob 2021). A giant stone called as "Satbarren" depicting seven doors in local parlance is also located at the end of the Lashteal village towards the Khetardor mountain range. It is also believed that these seven doors symbolize seven distinct routes to Russia and other neighboring countries (Fies et al. 2018). It is important to mention that the origin and age of these caves and Satbarren are still unknown as no systematic study into the age of these structures has been undertaken to date. Nowadays, these caves are locally very famous by the name of "Tramkhai" meaning copper pits/or mines due to the existence of crimson-colored copper minerals therein. But, as per our findings, these caves actually represent ancient copper mines called geologically as "old workings" in the area. Chowdury and Banerjee (1957) while finding the presence of copper minerals of pyrite and chalcopyrite also described these caves as old workings. Therefore, in this article, we retain the correct nomenclature of old workings (OWs) here onwards instead of caves/or tunnels etc. as commonly used in literature (Pal 2020; Mahjoob 2021; Mir et al. 2023). The OWs as locally called as "Tramkhai" correctly represent and depict the presence of ancient copper-bearing pits in the area. The presence of these unique geological and archeological features in the area depicts its importance in terms of scientific, historical, cultural, geoheritage, geotourism attraction, sustainable development perspective and understanding.

Nevertheless, the area experiences cold, warm, and temperate climatic regime. It is generally warm and temperate during the summer season (April–October) whereas, during the winter season (November to March), it is very harsh. It experiences a pleasant weather from April to October with scanty rainfall. The snowfall is limited between December and April. Winters are severe with the minimum temperature falling down to below −5 °C, and summers are quite hot with more than 30 °C temperature. Temperature goes below freezing point in December and February. January and February are the coldest months during which the temperature falls down to −6 °C. July and August are the warmest months during which the temperature rises to 35 °C. The longest sunshine hours are in September, October, and November. The higher reaches experience severe winters where the heavy snowfall and rainfall are also very common. Besides this, the rugged areas experience scanty rains during lean spells and result in drought-like conditions also. Snowfall generally commences in October in the higher reaches of the hilly terrain. The annual average temperature is about 14.1 °C, and the average rainfall is about 843 mm. About 600–1100 mm of precipitation falls annually and from July to August, the rainfall is as high as 70%. Precipitation is lowest in November, with an average of about 35 mm. The greatest amount of precipitation occurs in March with an average of about 174 mm (Fig. 1). December has the highest humidity of 80% whereas, May–June has the lowest humidity of 71%. The average annual humidity is about 72.0% (Mir and Akaram, 2022).

Thus, keeping the above discussion in view, the present study highlights the geological, archeological, and historical importance of Kalaruch OWs and Satbarren stone. The study

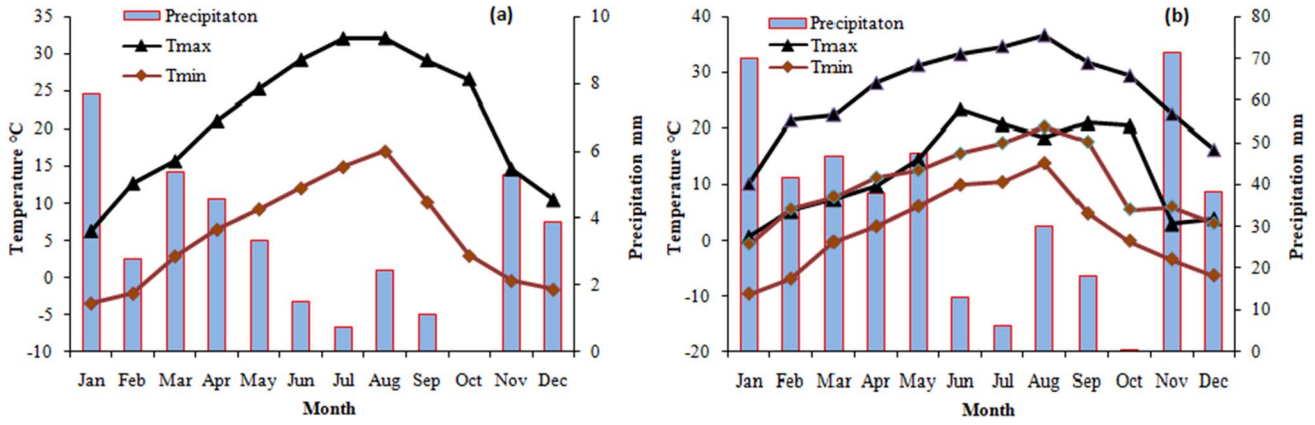

Fig. 1 Plots showing the monthly variation of **a** an average Tmax, Tmin, and precipitation (mm) and **b** maximum monthly range of Tmax and Tmin and total annual precipitation (mm) during 2020 in the study area

attempts to give its significance and potential for development as a geoheritage and geotourism site, for which, few recommendations are also proposed in this study. The site is in dire need of instant attention, conservation, and preservation plans for sustainable development in the area.

Study Area

The study area (Kalaruch old workings and Satbarren archeological stone) lies in the Kalaruch valley of Kupwara district, Jammu and Kashmir, India. It forms a part of the Greater Himalayan Mountain Range (GHMR) of the Kashmir Himalaya. The area falls towards the right side of the metalled road connecting the Lolab valley with the Machhal valley. It is located between the coordinates of 34°34'00"N and 34°35'00"N latitudes and 74°19'00"E and 74°21'00"E longitudes. It is about 130 km from Srinagar and about 10 km northwest from the main town of Kupwara district. The main spots are located in the midway between Lashteal and Madmadou villages on the westerly facing steep slope of a moderately elevated mountain range trending in the N-S direction. The Satbarren stone representing a unique place of ancient architecture is situated on the outskirts of the Lashteal village. The old workings are located towards uphill of mountains about 200 m away from Satbarren stone through a narrow footpath. These sites are connected by metalled roads, partly by unmetalled roads, foot and mule tracks from the above-mentioned villages. In the area, the infrastructure facilities are not much developed in the interior and remote parts towards the foothills and mountainous parts of the area. However, towards the low-lying areas along the foothills and within the plains, the developmental facilities are underway. The inhabitants of the area extensively depend on the agricultural cultivation for their livelihood. The area represents a unique place where the past and the present architecture is seen meeting. The location map of the area is shown in Fig. 2.

Physiography and Geomorphic Setting

The area forms a part of the south-western slopes of the GHMR, and therefore, the entire topography is mountainous with rugged terrains, high elevated steep slopes with very high relief. The undulatory and rugged topography is characterized by high peaks and precipitous slopes indirectly reflecting the control of lithology and its fabrication (texture and structure). The general elevation of the area varies from 1800 m to 3000 m asl (above sea level). The topography is formed by northern towering mountains that are extremely close, irregular, and jammed against each other. In the area (Kalaruch valley), the main drainage pattern is of dendritic type. Generally, the 3rd order streams (Nallas) fed by a number of small tributaries of 1st and 2nd order originating from the surrounding mountains define the drainage system. The small streams draining the high mountain slopes are dominantly of 1st order drainage pattern. The southerly flowing Kalaruch Nalla emerging from the N-NW-W trending GHMR is the main drainage system in the area. The Kalaruch Nalla is joined by Wan-Nar Nalla near Kalaruch village, after which it provides a picturesque view to the whole valley (Fig. 2). These major streams join a 4th-order Lolab stream near Khumbriyal village located towards the south-western side of the study area. There are also a number of springs lying in the low-lying plains along the foothills and valleys of the area.

The area is characterized by varied geomorphic landforms also. The main geomorphological features include the high structural hills, colluvial slopes and fans, extensive mounds of Karewas, moraines and alluvial-filled terraced valleys, and broad U-shaped valleys. The high structural hills

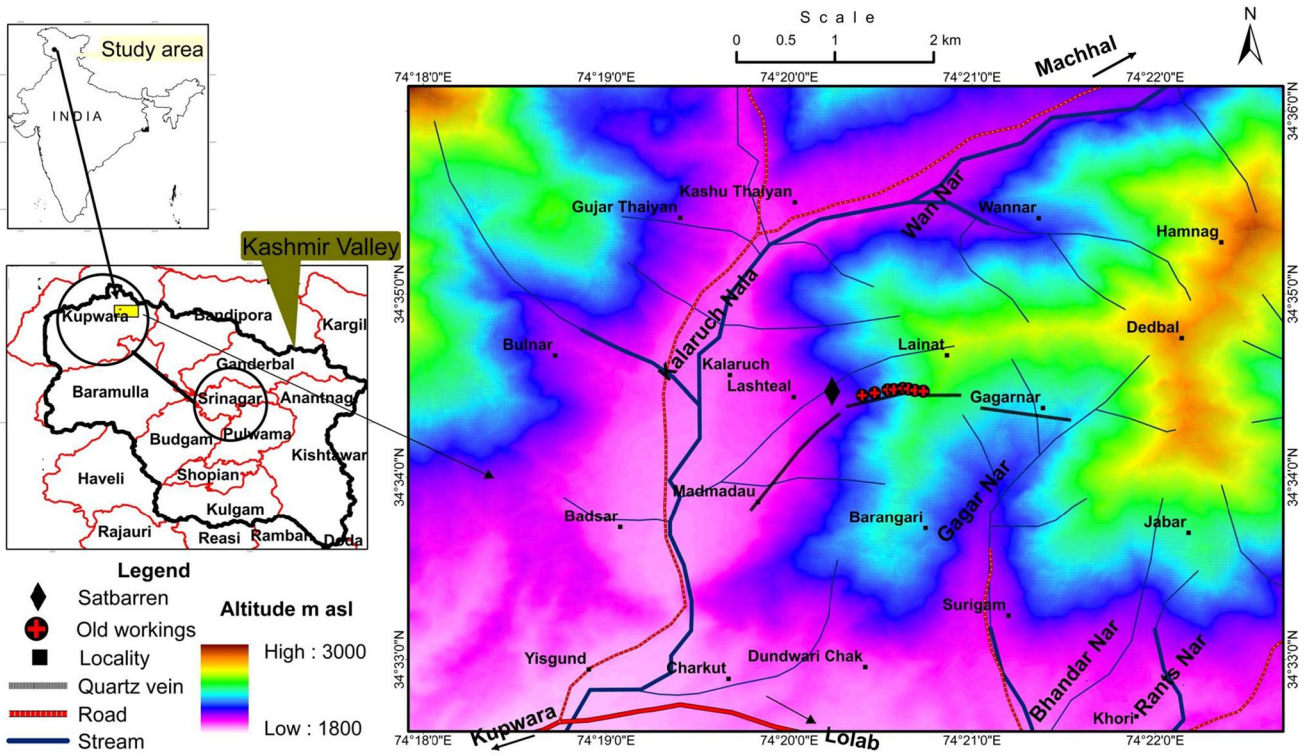

Fig. 2 Map showing the location of Old workings, Satbarren stone, and major quartz vein in the area. Other topographic features are also visible on the map. The background of the map is represented by ALOS DEM (12 m resolution)

towards northern areas are generally high to moderately dissect. The area is thickly forested around the higher reaches with extensive pastures on the highlands. The thick forest cover has developed a thick soil cover also in the area. The pastures are the regular haunts for the cheerful shepherds who bring up their flocks for grazing. The best varieties of pine and deodar are found in these forests. Dense lush green forest cover and rich wildlife make it a significant place for tourist attraction. The forest also lend a blissful charm that is a great factor of healthful fragrance to the atmosphere in the area. The Kalaruch OWs and Satbarren cover the parts of the Khetardor Forest area and lie towards the left side/bank of the Kalaruch Nalla (Fig. 3). The beautiful geomorphic landforms and topography represent a mix of mountains, valleys, and streams that offer tremendous potential for developing scenic and adventure geotourism in the area.

Geological Setting

Regionally, the area forms a part of the Paleozoic basin of the Nappe Zone of Kashmir Himalaya. The area is represented by the rocks of the Salkhala and Machhal Formation of the Hapatnar Group, Pohru Group, quartz veins, basic rocks and granite, Karewa Group, and undifferentiated Quaternary deposits (Raina and Razdan 1975; Sadhu et al. 1983; Sadhu et al. 1984; Raina and Sadhu 1984; GSI 2012). The rocks of the Hapatnar Group are met along the northern areas. The undifferentiated Salkhala Formation of the Proterozoic age (Pre-Cambrian/or Ediacaran age) represents the oldest lithounits and forms the basal part of the succession (Wadia 1934; GSI 2012). The Machhal Formation of the Neo-Proterozoic/or Vendian age has a faulted contact with Salkhala Formation. The rock units of this Formation consist sedimentary structures including ripple marks, load casts, and cross stratification (Sadhu et al. 1983; Sadhu et al. 1984). In ascending order, the Pohru Group has been broadly classified into the Lolab, Nutnus, Trehgam, Waterkhai and Marhama Formations respectively. The Lolab Formation of the Lower Cambrian age represents the oldest litho-unit of the Pohru Group. These strata overlie the youngest member of the Machhal Formation in Kalaruch valley with a gradational contact. The Nutnus Formation of the Middle Cambrian age comprises a lower fossiliferous sandstone member. The Trehgam Formation of the Late Cambrian age comprises partly recrystallized limestone/or marble bands (Mir and Habib 2020). It also contains brachiopod fossils viz, *Dicellomus* sp., *Orthis* sp., *Obolus* sp. The Waterkhai Formation of the Ordovician age comprises purple vesicular tuffs, thin flows of lavas, and conglomerate. The Marhama Formation of the Ordovician to Silurian age comprises a ferruginous sandstone, arenite, and conglomerate. Additionally, a number of quartz veins, doleritic dykes, sills, and

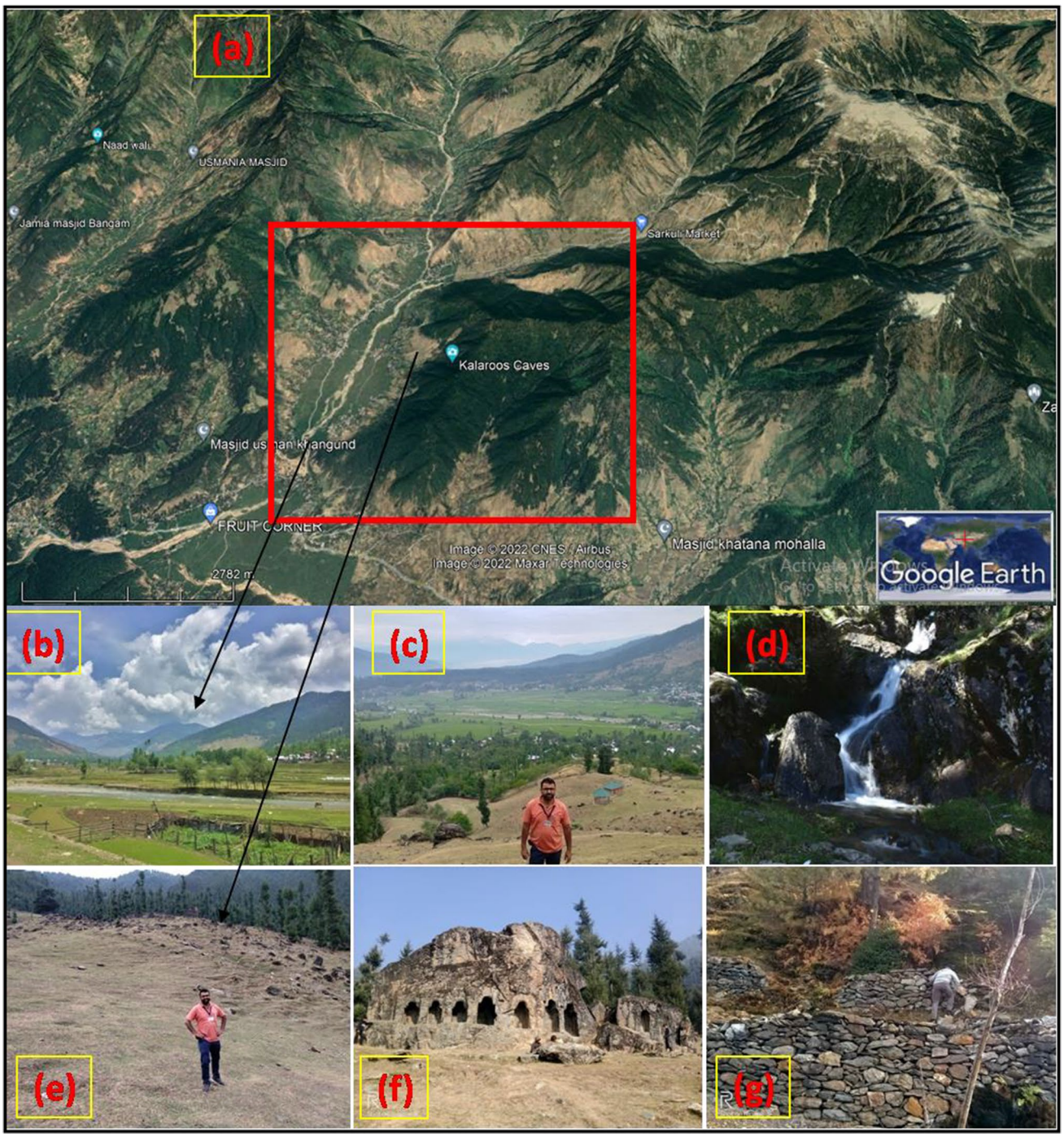

Fig. 3 Google image showing the panoramic view of **a** Kalaruch valley and old workings **b** field photographs of Kalaruch valley and stream **c**, **e** barren foothill near Satbarren stone **d** first-order stream near Tramkhai old working **f** Satbarren giant rock **g** leachate spring near Satbarren in the area

leucocratic granite with feldspar porphyries occur as intrusive in older litho units in the area (Sadhu et al. 1983; Sadhu et al. 1984; GSI 2012; Mir and Habib 2020). The sediments of the Karewa Group of Pliocene-Pleistocene age comprising the Hirpur, Nagum, and Dilpur Formations occur as isolated patches. The undifferentiated quaternary deposits are also present along the river terraces and foothills in the area (GSI 2012).

Structurally, the Paleozoic rock sequences of the Kashmir basin exposed towards north-northeastern areas show a regional trend of NE-SW with moderate dips in either direction. There is however a considerable variation in the dip

and strike of the bedding planes due to folding at different locations (Sadhu et al. 1983; Sadhu et al. 1984; GSI 2012). These rocks are involved in several stages of folding. The folds are generally open type as compared to the isoclinal and close folding reported in the south-southwestern areas of the Kashmir basin along the Pir-Panjal range. A number of minor parasitic folds are very commonly superimposed on the major folds and usually reflect the general attitude of the major folds. In the area, the Machhal anticline and Marhama syncline are the major and commonly known folds (GSI 2012). The rocks are also faulted, sheared, and deformed in the area. The geological map showing the regional stratigraphy is shown in Fig. 4.

The study area around the Kalaruch OWs and Satbarren stone comprises mainly the lithounits that belong to Lolab Formation, Hirpur Formation, and Quaternary deposits (Fig. 5). The Lolab Formation is of large thickness of about 500 m comprising predominantly different variants of slate, phyllite, quartzite, banded greywacke, siltstone, quartz arenite, green slate with occasional thick bands of gray quartz-arenite (Figs. 6 and 7). The Formation is also extensively intruded by several quartz veins of different dimensions (~5 cm to 18 m thick) as well as the dolerite dykes and sills (Fig. 4). The Lolab Formation comprises prominent sedimentary structures like ripple marks, load casts, and micro-lamination (Fig. 8a, b). In the Kalaruch area, ichno fossils including worm tubes and burrow trail fossils commonly filled with siliceous material are profusely present (Fig. 8c, d; Fig. 4). Raina and Razdan (1975) on the basis of *Redlichid* fauna observed near Putshai-Nar in Lolab valley, besides assigning the Lower Cambrian age to these strata, also established that during Early Cambrian times the Kashmir basin has been a part of the Redlichia Sea. The basal zone (50 m) has been reported to yield trace fossils of *Planolites* sp. and *Bergoneria* sp. whereas, the topmost zone (50 m) has yielded trilobite fossils of *Redlichia* sp. and *Brachiopods* sp. (Shah et a. 1980; Raina and Razdan 1975). The trace fossil-bearing basal zone of the Lolab Formation tentatively marks the Precambrian-Cambrian (P-C) boundary in the area (Kumar et al. 1964; Raina and Razdan 1975; GSI 2012). Tewari (1989) based on Pre-trilobite Small Shelly Fossils (SSF) of the Tommotian/Meishutunian stage tentatively placed the P-C boundary in the lower part of the Lolab Formation in the Tethyan sequence of Kashmir Valley. These strata overlie the youngest member of Machhal Formation of Pre-Cambrian in Kalaruch valley with a gradational contact and occupy an outcrop width of about 8 km between Kalaruch-Gagal Nalla and Putshai-Kanthpur Nalla catchment areas respectively to the north and south of Manchhar Nalla (Raina and Razdan 1975; GSI 2012).

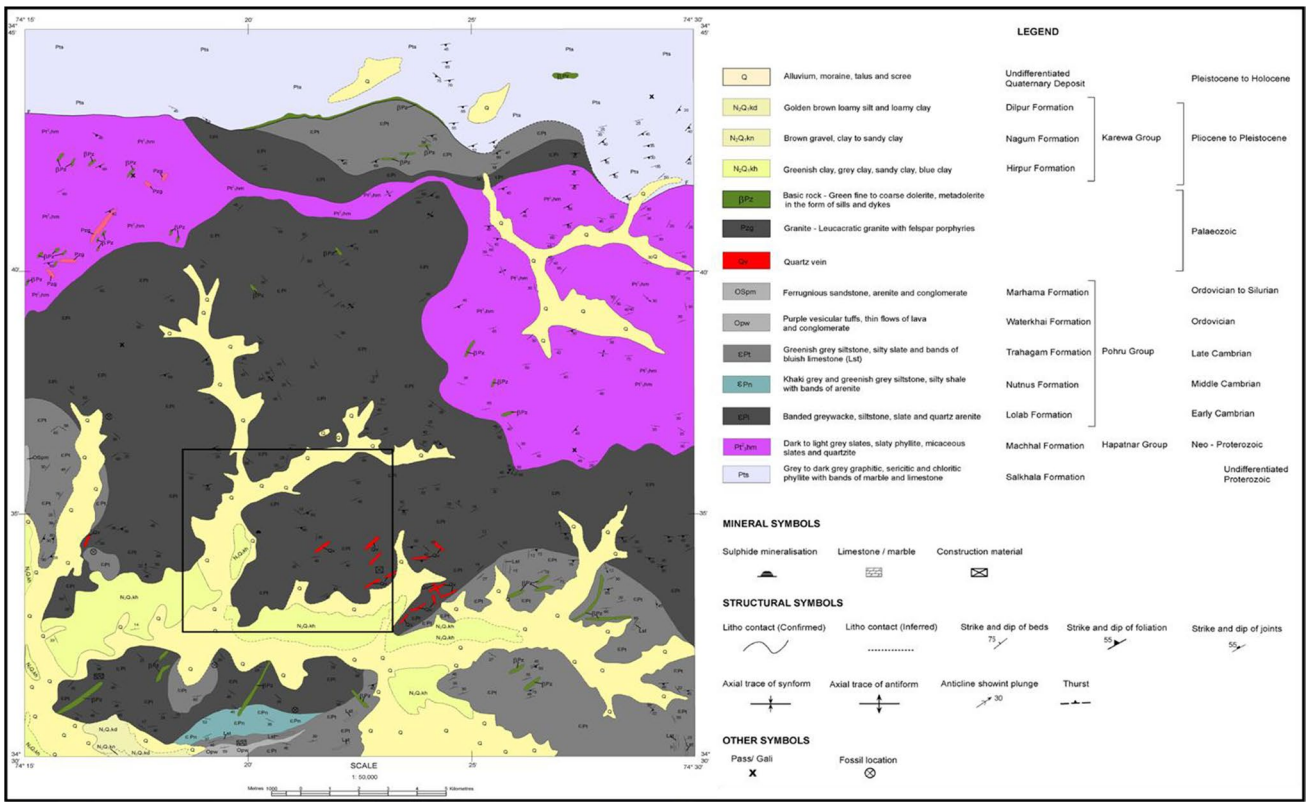

Fig. 4 Regional geological map of the area (after GSI 2013). The black outlined square shows the location of the present study area

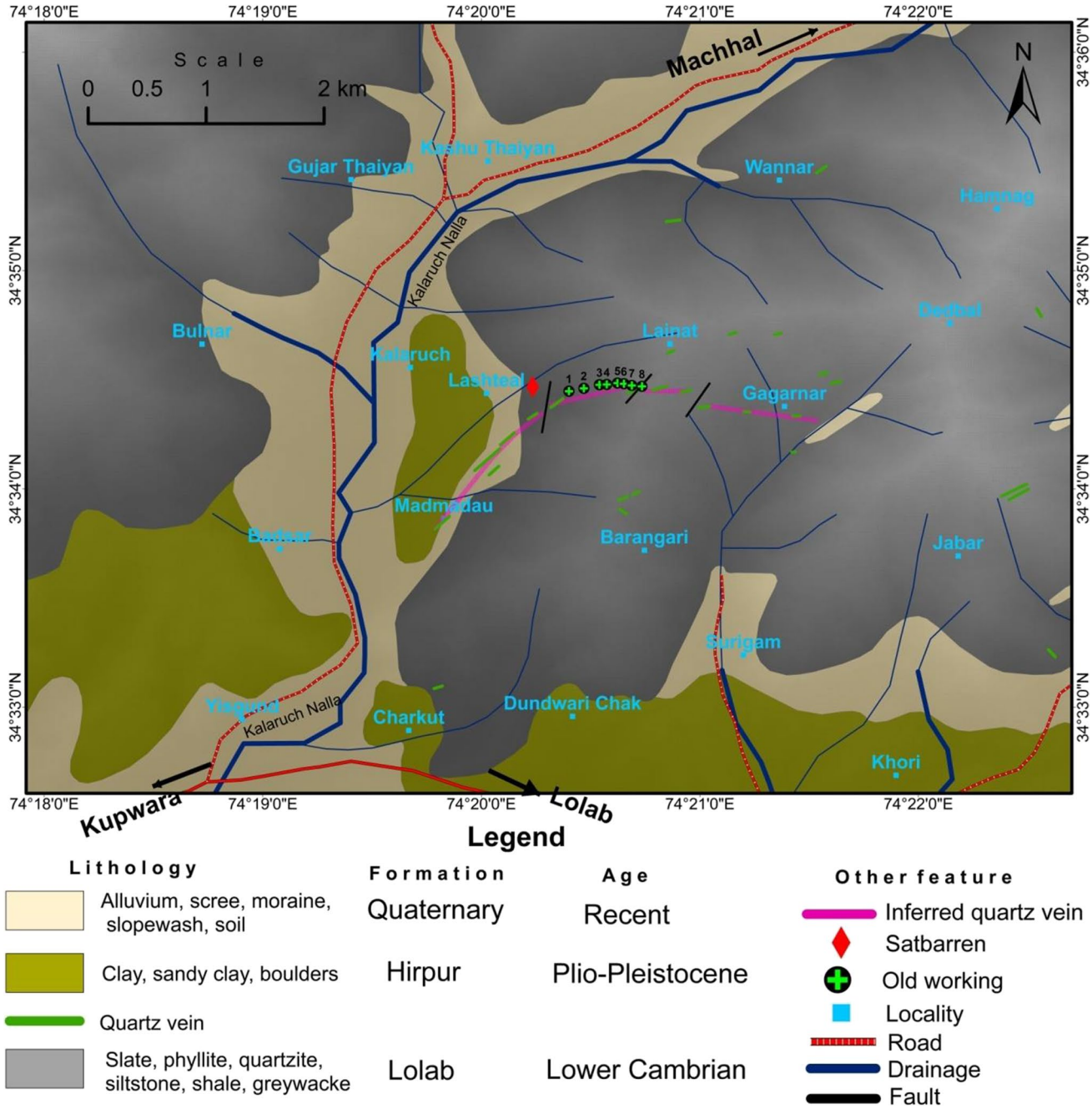

Fig. 5 Geological map of the study area

Towards the lower plain areas of Kalaruch and Lolab valleys, the Lolab Formation is unconformably overlain by the Hirpur Formation of Pliocene-Pleistocene age and Quaternary sediments of the Holocene age. The Hirpur Formation comprises clay, sandy clay and occurs as isolated patches in the area. The recent sediments are represented by alluvium, colluvium, slope wash material, moraines, talus, and scree deposits. The stratigraphic sequence of this area is given in Table 1. Structurally, the area is folded and faulted also (Fig. 9). It forms a part of a broad anticline having a general E-W trend. Its southern limb is exposed in the Kanthpur-Sugam area of Lolab valley, but a portion of its northern limb is noticed in the present area located east of Thaiyen village around Kalaruch valley. There are some minor folds with their axes trending parallel to the axis of the main fold (Fig. 9a, b).

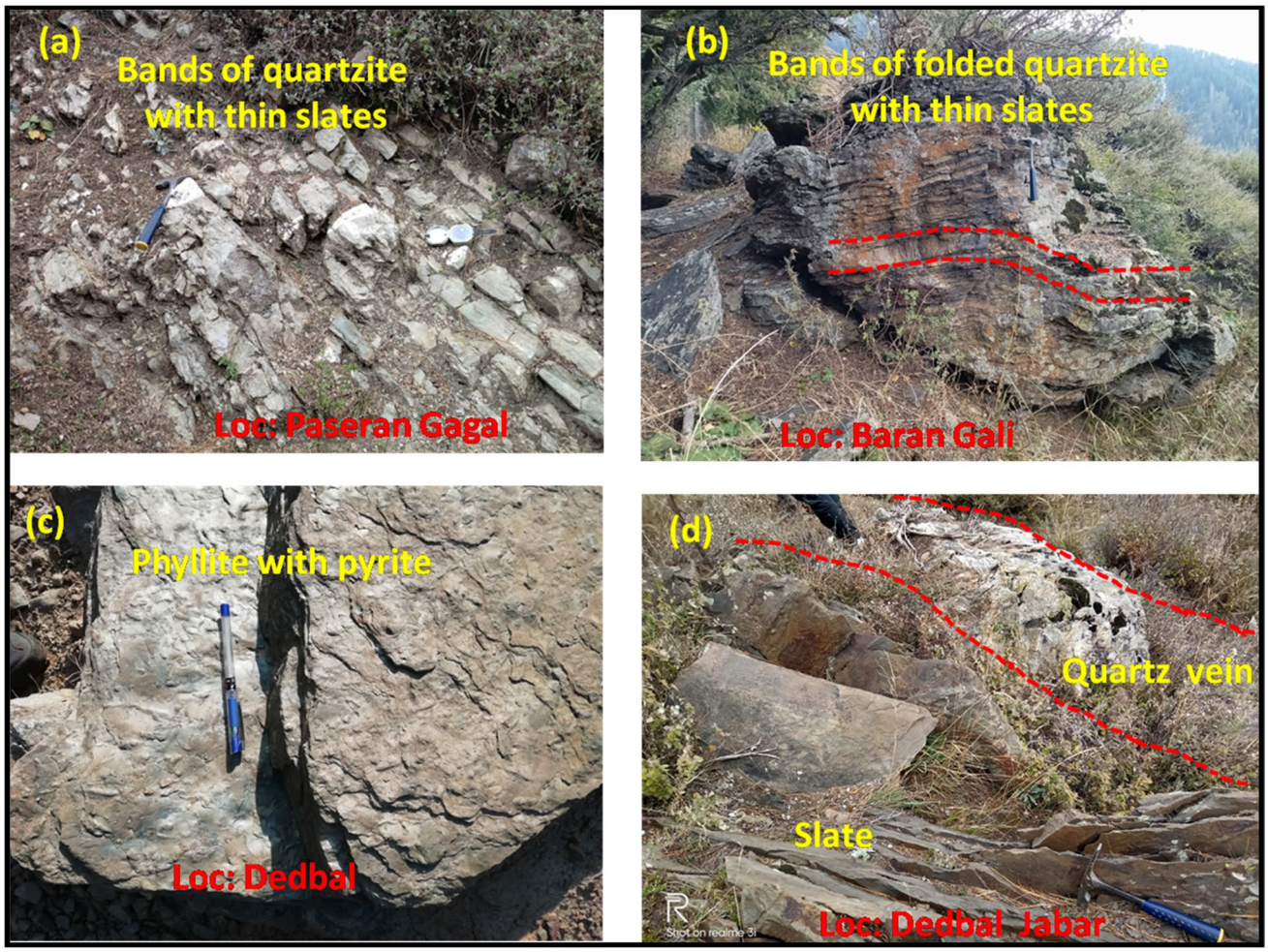

Fig. 6 Field photographs of different lithounits **a**, **b** quartzite with thin slates **c** phyllite with pyrite crystals **d** slates with quartz vein in the area

Mineralization

A major quartz vein intruded into the rocks of the Lolab Formation is present in the study area. The vein is varying in width from ~3–15 m with an average width of 9 m. It runs over a strike length of ~3.5 km from the Madmadou-Lashteal-Lainat-Gagarnar-Sagjepal area (Fig. 5). It is present over a steep topographic slope from Satbarren to Lainat Top to Gagarnar area. The outcrop pattern of the vein is discontinuous in nature (Fig. 10). From Madmadou to Lashteal (Satbarren), it shows an NE-SW strike with a dip of 35–50° towards SE. But, from Satbarren to the Lainat Top-Gagarnar area, its strike direction is almost E-W dipping 70° towards the south. It is steeply dipping from Tramkhai-Lainat Top. Near Tramkhai old working, two small quartz veins (~1 m thickness each) are observed occurring parallel to it. Along its length, the main vein is displaced by several minor cross faults. The field observations indicated that the intrusion and disposition of the quartz vein are dominantly controlled by a fault/or shear zone in the area. A fault-controlled spring (red leachate spring) is also present towards the left southern side near Satbarren stone at the contact of the quartz vein with the host rock (Fig. 9c). The vein is dissected by various deep-cutting Nallas towards lower elevations around Satbarren.

From Satbarren (near Lashteal) to Lainat hill Top, the quartz vein is highly mineralized. Surface indication of mineralization is marked by brown, green, and yellow alteration zones due to ferrugenisation, chloritization, and limonitisation respectively (Figs. 11 and 12). Copper carbonates including malachite and azurite staining in the quartz vein and along the contact zone with country rock and on the walls of old workings is commonly present (Fig. 11a). Gossan zone (- an iron-containing secondary deposit, largely consisting of oxides of typically yellowish or reddish color occurring above a deposit of a metallic ore) is present near Tramkhai old working (Fig. 12c, d). Near Sagjepal (Gagarnar areas), a small outcrop (~1–2 m) showing meager development of gossanisation was also found. Sulfide mineralization of dominantly pyrite along with rare arsenopyrite has

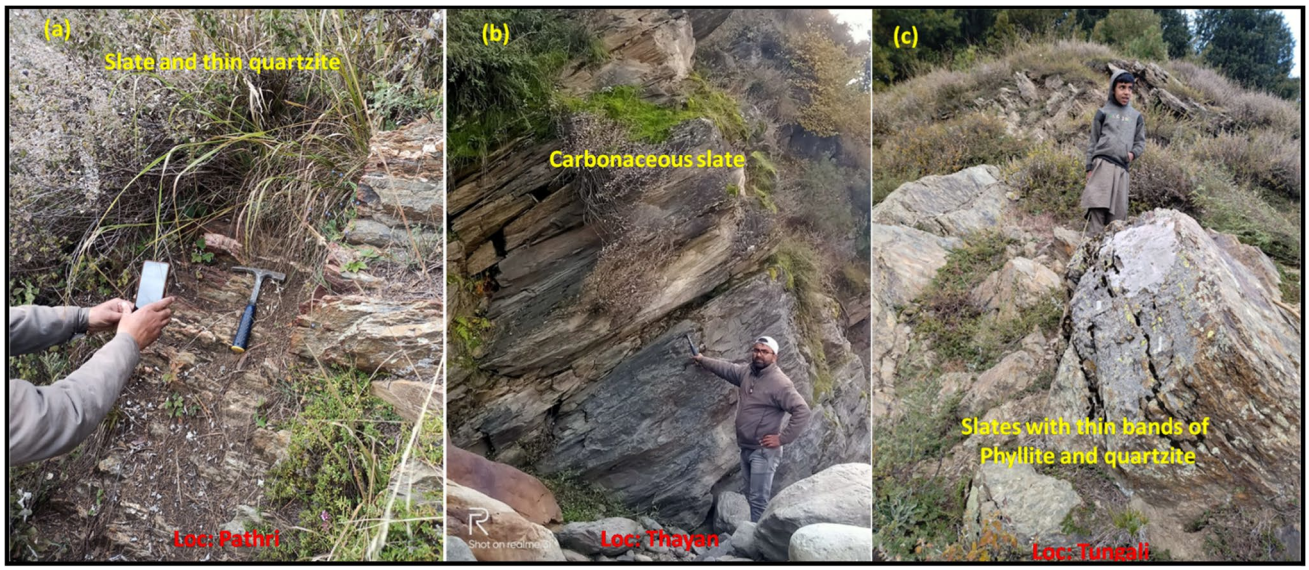

Fig. 7 Field photographs of **a** slates with thin quartzite beds **b** carbonaceous slates **c** slates with thin quartzite and phyllite bands in the area

been noticed within the vein and along its contact zone with host rocks (slate and phyllite). The prominent sulfide minerals observed includes the pyrite, chalcopyrite, arsenopyrite, azurite, bornite, covelite, goethite, and hematite (Mir and Vaseem 2022). These minerals occur as disseminations and as impersistent thin stringers in the old workings. But, on the surface, only limonite and pyrite and occasional arsenopyrite are noticed. Honeycomb or cleavage box work structures are abundant (Fig. 12a, b). The cross ribs are well jointed and the pattern seems to be controlled by the cubic structure of the pyrite crystals. Box work pattern with leached-out pyrite minerals (pits) are seen in abundance and occasionally the quartz appears to be spongy owing to the preponderance of voids. Some syngenetic pyrite minerals are also present along the bedding planes of the slate and phyllite in the unaltered wall rock. The geophysical investigation including Self-Potential (SP) and Electro-Magnetic (EM) studies from the Lashteal to Gagarnar area on a narrow strip of the vein have revealed negative SP centers due to sulfide mineralization (Dutta 1966). However, analytical studies have indicated that the vein is comparatively richer in its copper content from Lashteal-Lainat Top, where as further east and west wards (i.e., towards Gagarnar and Madmadou areas) from this zone, only traces of copper sulphides are present (Bhat 1967). The sulfide mineralization in the vein, in the altered wall rock and silicified phyllites is attributed to hydrothermal activity in the region (Banerjee 1958; Bhat 1965; Dutta 1966; Bhat and Alam 1966; Mir and Vaseem 2022). As per the Wadia (1934), the quartz vein and its associated mineralization are also attributed to the acid intrusive in the area (Fig. 4).

Materials and Methods

The motivation behind this study was to explore in detail, the geo-historical account of Kalaruch OWs and Satbarren stone and to understand the reality behind the mysterious statements and stories pertaining to its origin and age, structural disposition, and continuity. To fulfill this objective, a five-step procedure (Fig. 13), as described briefly below, was followed.

1) First, the Survey of India (SoI) topographic maps, high-resolution Google Earth images, and land use land cover maps (LULC) and ALOS-PALSAR DEM (Digital Elevation Model) were used to understand the topography, physiography, geomorphology, and accessibility in terms of scenic beauty and tourism development of the area. The metrological data from Kupwara station was used for understanding the climatic/ or weather regime in the area.
2) Secondly, an extensive literature survey was carried out to understand the geological setting and mineralogical significance of the area. The existing geological and other related maps were collected from different sources as available. From the detailed review and consultation of this literature, it was found that the quartz vein along with Kalaruch OWs are mineralized and preserve low-grade copper minerals. Extensive consultation of all the scholarly literature available related to the historical and archeological significance of Satbarren stone and other structures found in the area was also carried out. No solid and clear evidence was found existing pertaining to the age, period of construction and builder etc. of these unique structures in the area.

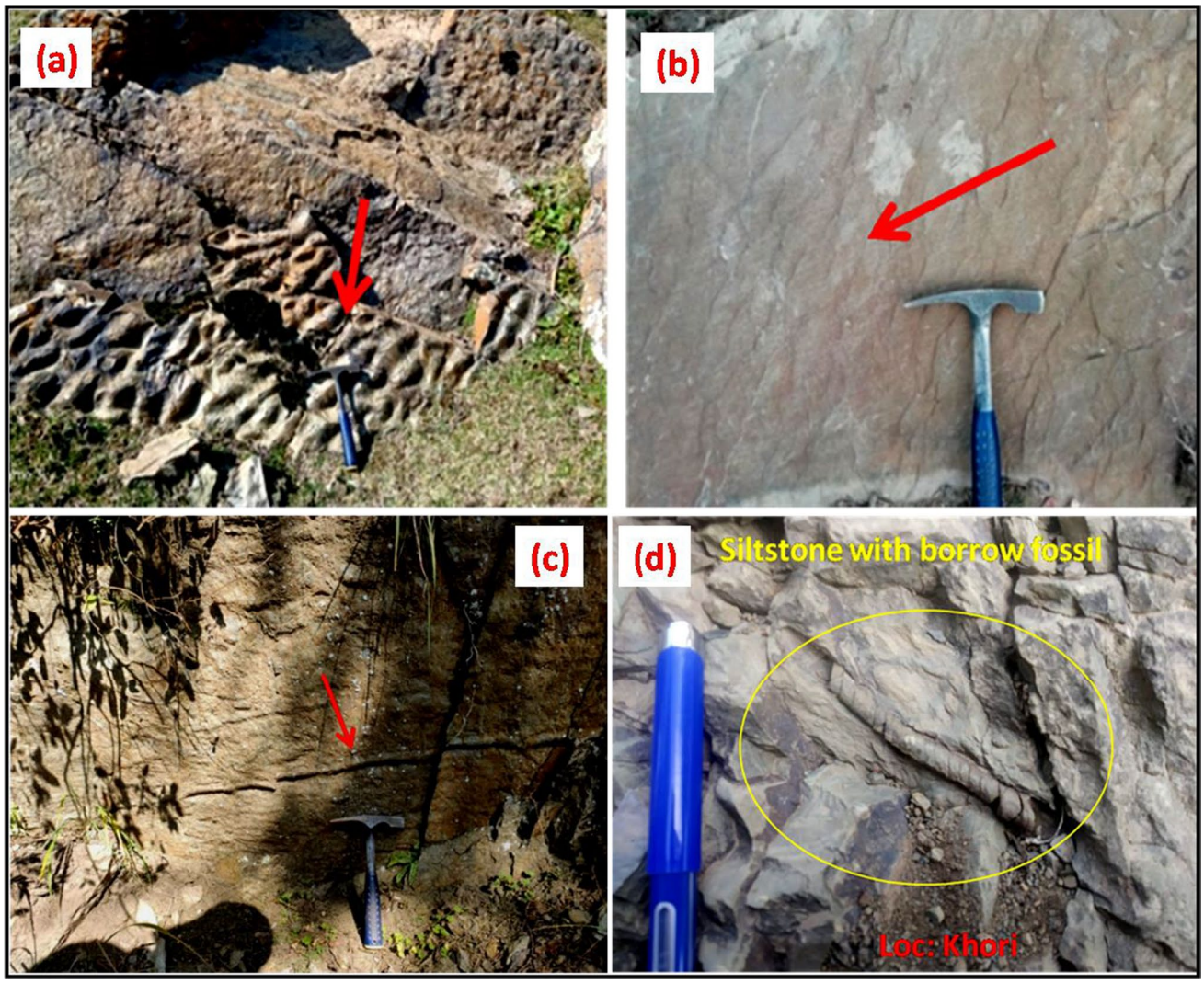

Fig. 8 Field photographs of **a** load cast structure in quartz arenite **b** asymmetrical ripple marks **c** long rod-shaped worm tube in quartz arenite **d** burrow trace fossil in siltstone in the area

Table 1 Stratigraphic sequence of the study area

Formation	Litho units	Group	Age
	Alluvium, moraine, scree, and soil cover		Recent
Hirpur Formation	Clay loam, sandy silt and gravel and pebble beds	Karewa	Plio-Pleistocene
-----Unconformity-----			
	Dolerite dykes, sills and quartz veins		Permian (?)
Lolab Formation	Slate and phyllite, carbonaceous slate, thin quartzite, greenish colored siltstone and silty shale, arenite bands, greywacke	Pohru	Lower Cambrian (Tomotian) (---P-C boundary---)
Machhal Formation	Arenite, phyllite, slate, sandstone, greywacke, calcareous slate and lenticular limestone with penecontemporaneous lava flows	Hapatnar	Neoproterozoic (Vendian/or Ediacaran)

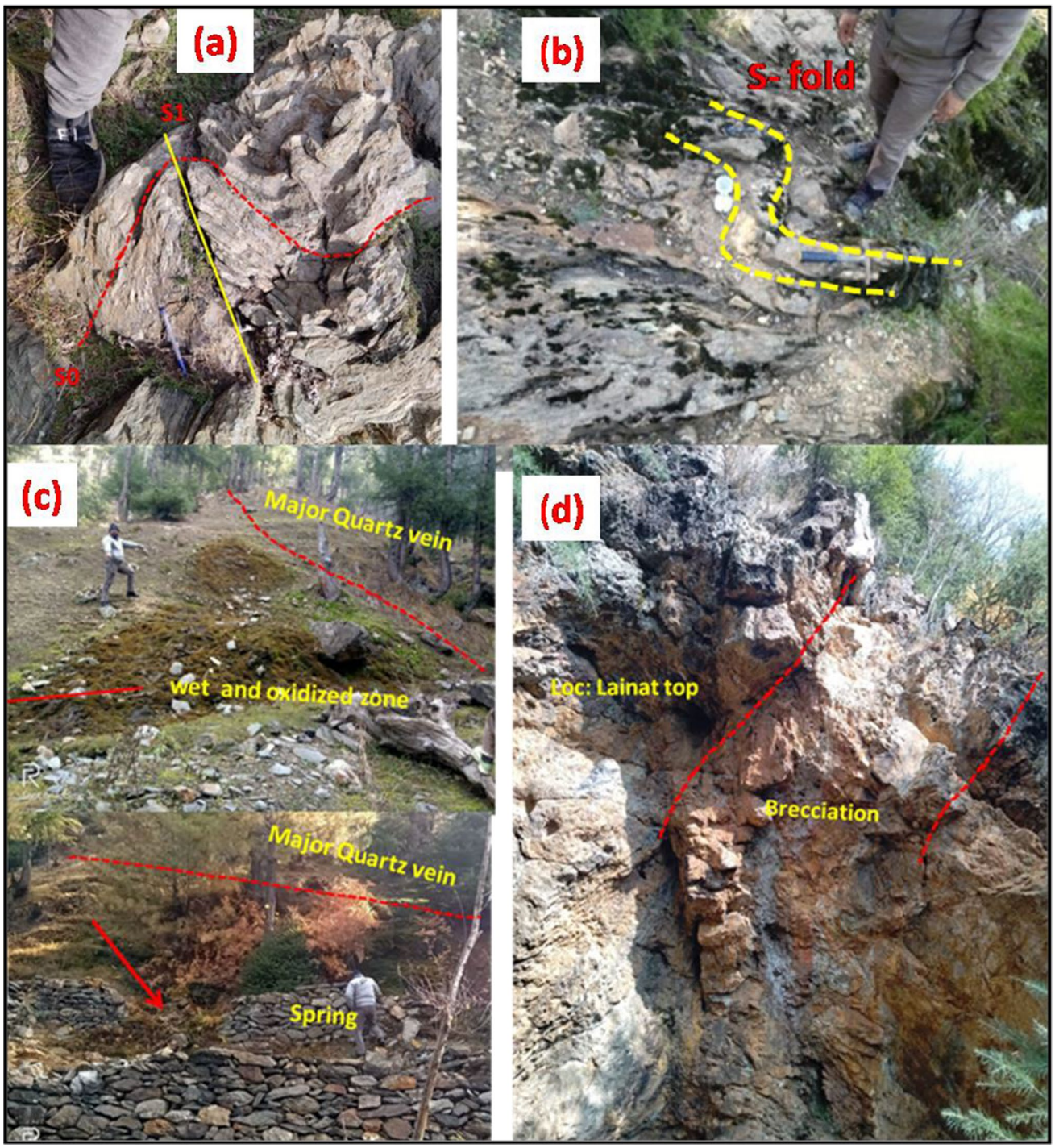

Fig. 9 Field photographs of **a**–**b** open and drag folds **c** leachate springs near Satbarren **d** alteration zone and brecciation along the major quartz vein near Lashteal old working in the area

3) Thirdly, a comprehensive field survey was carried out to collect the ground data and information of the geological setting, copper mineralization as well as the archeological importance of the site. During the field survey, identification and recording of every structural feature such as dimension, shape, pattern, design, and architect of Satbarren archeological stone was carried out. The architectural features present within, outside or near the Kalaruch OWs were identified and recorded during the survey. The precise location of the OWs was collected using a calibrated hand held global positioning system (GPS). The field survey was carried out in and

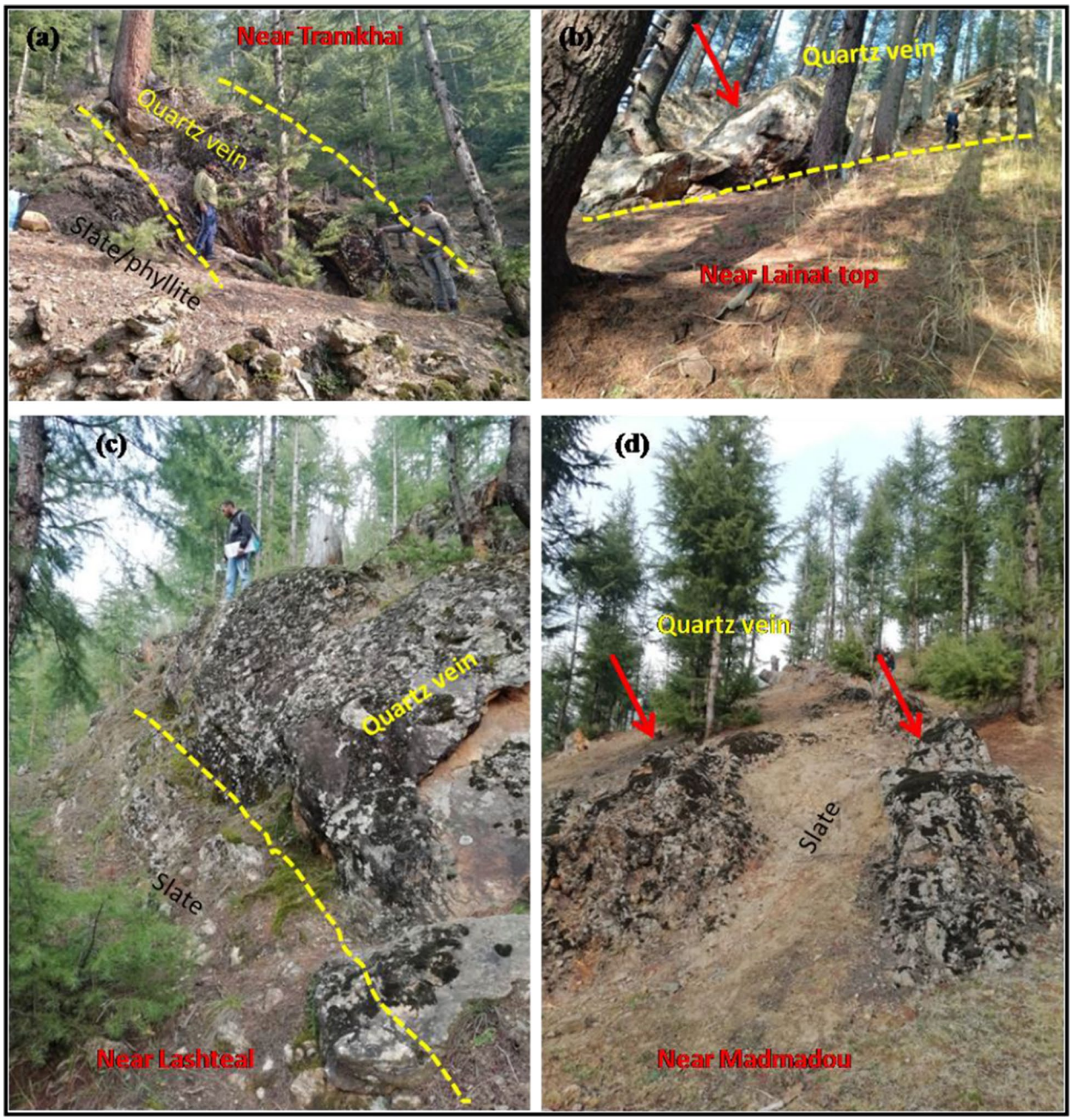

Fig. 10 Field photographs of outcrop pattern and mode of occurrence of the major quartz vein in the area, e.g., **a** quartz vein intrusion into the slate and phyllite **b** vertical disposition of the quartz vein **c** thick and massive quartz vein in contact with slates **d** two parallel 1 m thick quartz veins/off shoots in the area

around Lashteal and Madmadou villages, OWs, Satbarren archeological stone, Lainat Top, Gagarnar and its surrounding areas.

4) The geological and archeological field information/data thus collected was integrated, analyzed, and interpreted in detail accordingly. The findings were correlated with other existing and related information (based on literature) to relatively assign certain possible age to the copper ore mining and archeological construction in the area.
5) Finally, the information/data was analyzed to observe the potential and suitability of the site to be declared as geoheritage, geotourism, an esthetic, and educational spot in the area. A proposal comprising a list of recommendations has been given for its conservation, preservation, and sustainable development.

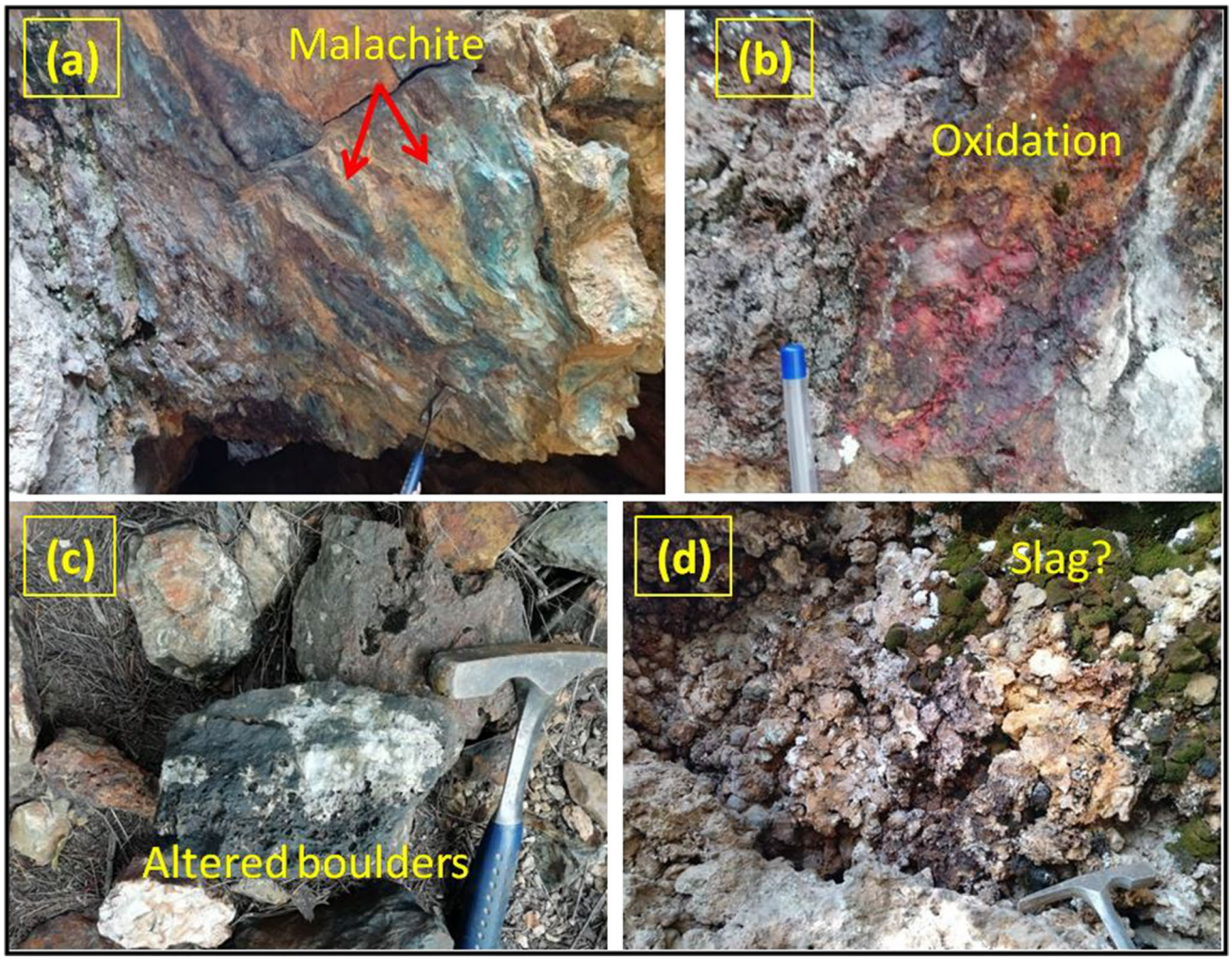

Fig. 11 Field photographs showing surface indication of mineralization **a** malachite and azurite staining **b** oxidation and feruginisation **c** altered boulders of alteration zone (Gossan) **d** heaps of partially preserved slag along major quartz vein in the area

Results

Kalaruch Old Workings (Ancient Mines)

Near Lashteal village from Satbarren to Lainat Top, more than 8 old workings (OWs) and many small pits in the form of adits, winzes, shafts, and inclines are observed (Fig. 14a–i). Out these, 4 adits are very prominent. In addition, broad channel like open caste mines having a width of (20 m) and length of (60 m) are also observed below OW-1 and in between OW-3 and OW-4 (Fig. 15a). A similar open caste mine which is partially disrupted by the collapse of side walls is also present between OW-7 and OW-8 towards higher elevation. The adits commonly driven in the mineralized quartz vein and the altered wall rock are aligned E-W parallel to the strike of the major quartz vein. The adits, 1 and 2 comprise a number of galleries and are connected by a vertical shaft. In adit no. 2 four such galleries are observed that are interconnected by narrow passages (Fig. 16a–i). No OW posses any passages going beyond and across the moutain ranges. The OWs terminate and do not move beyond ~50 m. No signs of recent human passages are found except the presence of Himalayan porcupines in the OWs. The occurrence of OWs along the quartz vein indicates that the quartz vein, which had a good economic concentration of copper minerals, was targeted for exploitation whereas; the open cast mining represents the bulk rock extraction during the ancient mining activities. The mineralization indication features such as box work structures, pyrite pits, malachite, azurite, limonite staining, and ferruginised zones are commonly present on side walls of OWs and main quartz vein (Fig. 15c, d). Gossan zone is observed around lower elevations below OW-1 near Satbarren (Fig. 12d). Dispersed and highly weathered slag heaps (- stony waste matter/or gangue separated from metals during the smelting or refining of ore) are also observed at certain locations around the OWs in the area (Fig. 11d). A prominent set

Fig. 12 Field photographs showing **a**, **b** box work alteration and oxidation in quartz vein **c** altered and leached boulders **d** gossan zone in the area

of joints striking in NNW-SSE is exposed in the adit section. This might have played some role in the control of mineralization. It is because the ancient miners seem to have followed these strcutures for extraction of ore in the area. The presence of old workings and partially preserved slag heaps are the clear evidences of ancient mining activities and extraction of copper ore in the area near Lashteal village (Bhat 1965). Detail characteristics of the OWs are given in Table 2. A brief description of OWs is given below.

OW-1: It is the first adit reached beyond Satbarren stone at 1980 m elevation. The first 50 m is a narrow up-trending passage that is pinched down in some areas. This leads to a 15 m shaft that opens to a small room/pit. Malachite and limonite staining is present on either of the side walls of it.

OW-2: It is a slightly down trending passage of about 5 m. Beyond 5 m is a 5 m up-trending passage that leads to a narrow horizontal passage terminating within 15 m. The OW-1 and OW-2 are connected through a 10 m incline/shaft, which opens to this room. Also OW-1 is upward trending whereas; the OW-2 is downward trending, with little difference in azimuths and elevations. Malachite and azurite staining is present on the side walls of it.

OW-3: It is located higher up on the mountain side at 2020 m (6627 feet) elevation. It has the largest entrance of the three adits. The main passage is down trending and terminates in 50 m. It looks to have been filled by debris inside from a landslide or years of weathering and erosion therein. Malachite and azurite staining is present on the side walls of it also.

OW-4: It is located higher on the mountain side at 2080 m (6627 feet) elevation. It is a small adit and terminates at 5 m. The passage is horizontal and is locally called as Cheir-Gof meaning (a pit in which lamb/sheep are sheltered). It is highly ferruginised and minor malachite staining is present.

OW-5: It is located higher up on the mountain side at 2090 m (6640 feet) elevation. It has the small open caste cave type adit extracted on the side wall of the mineralized quartz vein. It is very shallow. The main passage is horizontal and terminates in 2 m. It is highly ferruginised, and minor malachite staining is also present.

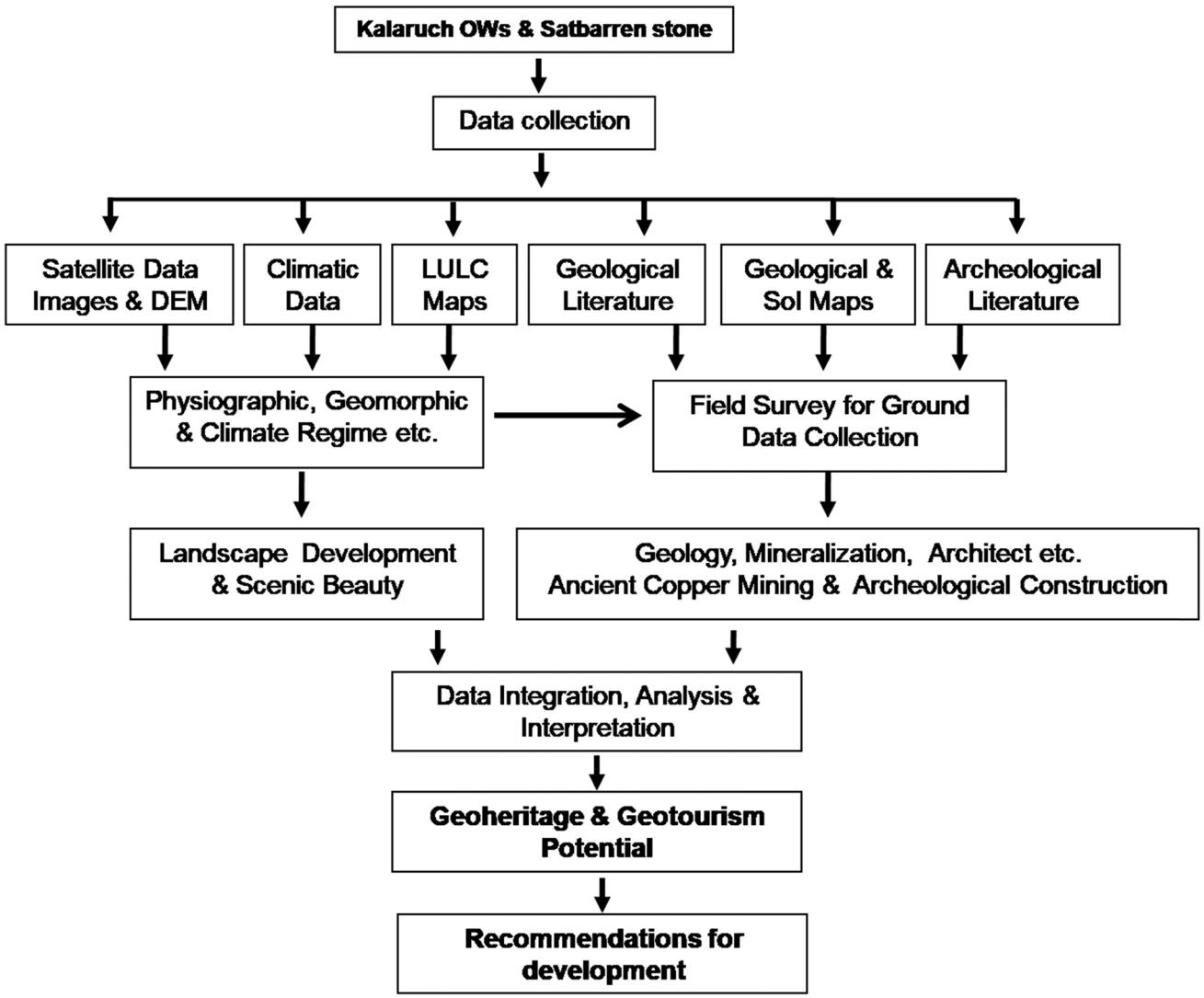

Fig. 13 Workflow of the methodology adopted in this study

OW-6: It is located more higher up on the mountain side at 2100 m (6627 feet) elevation. It is also down trending passage from where it terminates after 5 m through a horizontal shaft. It is also called locally as Cheir-Gof. Minor malachite and azurite staining is present on its side walls.

OW-7: This OW sits at a highest elevation of 2260 m on the steep mountain slope and is also called as Hapatkhai (- Hapat meaning bear in Kashmiri parlance who use to live and shelter inside it) in local Kashmiri language. There is a 40 m down trending passage. It also leads to a pinched horizontal passage that terminates at a distance of 20 m. Signs of being occupied by Himalayan porcupine were observed at its entrance during field visit. Malachite and azurite staining is very prominently present on the side walls of it.

OW-8: This OW also sits at highest elevation of 2280 m on the mountain cliff. It is about 40 m above Hapatkhai towards Lainat Top. There are three small adits almost horizontal, about 2 m deep and 1 m wide. Minor malachite and azurite staining is present on the side walls of it.

Satbarren (Archeological Stone)

Satbarren is a giant carved stone of light greenish to dark gray slate rock with thin phyllite bands meticulously crafted and half-buried in the ground. It is located at the outskirts of the Lashteal village at the foothill of the N-S trending mountain range at an elevation of 1900 m asl (6234 feet). In addition to this giant stone, a relatively small (crafted) and partly dislodged stone is also present towards the left side of this giant stone. The front face of the Satbarren stone is about 18 m in length whereas the right face is about 3 m wide. The

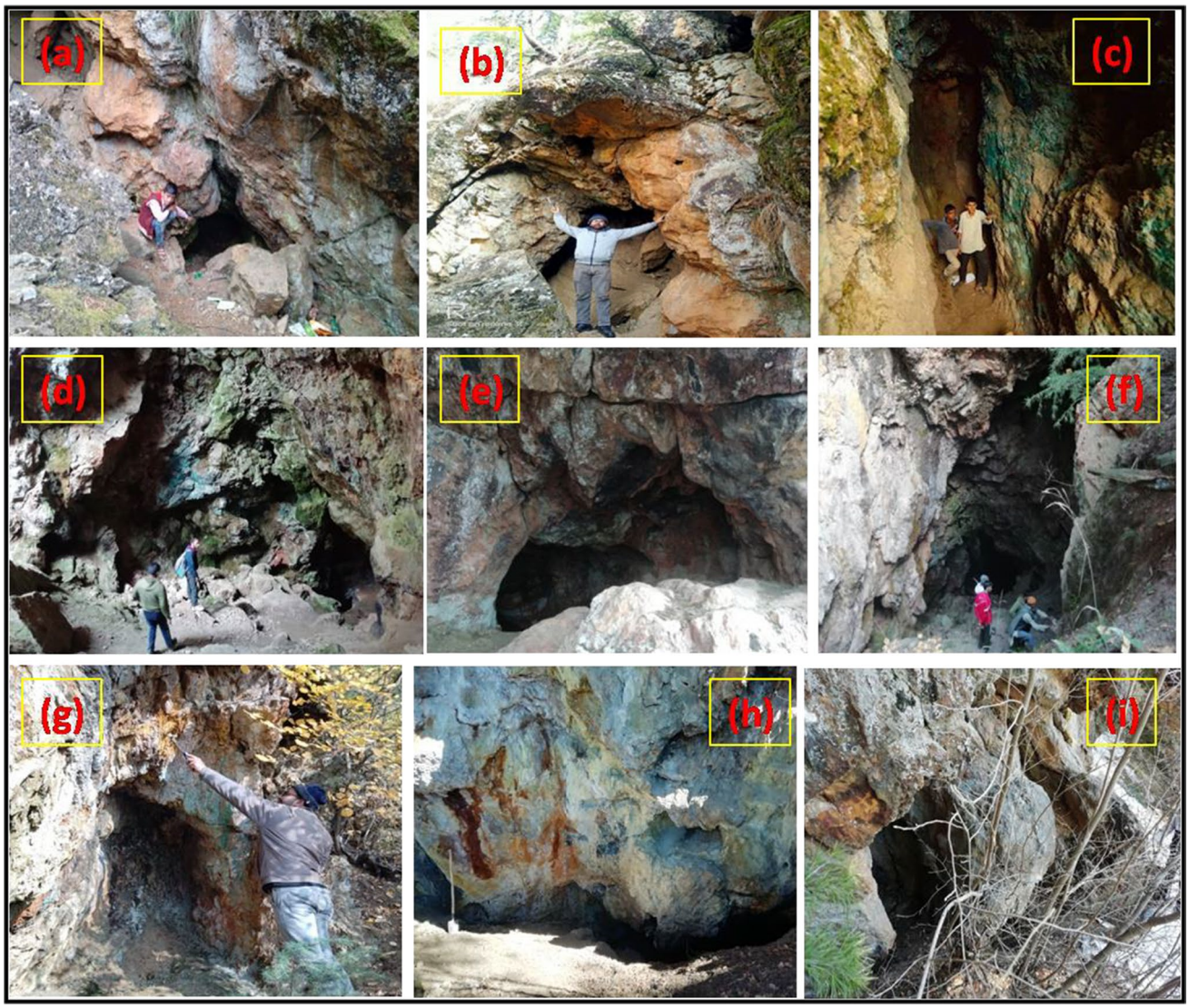

Fig. 14 Field photographs of the adits of the old workings **a**, **b** OW-1, **c** OW-2, **d** OW-3, **e** OW-4, **f** OW-5, **g** OW-6, **h** OW-7, and **i** OW-8 in the area. The limonitisation and malachite, azurite staining is also visible on the surface walls of the old workings

back face is about 14 m, and the left face is about 4 m wide. There are 8 carved shelves (doors) in the giant stone and one carved shelf/opening on the small stone all oriented generally in southwest direction. Out of 8 doors, 7 doors are relatively well preserved on the giant stone, and hence, it is locally called as "Satbarren". The top side (dome) of the 8th door is partially damaged and eroded away. The small carved stone preserves only a single door/or shelf with a different design than the doors on the giant stone. Thus, it is worth to mention that the Satbarren stone actually comprises 9 doors instead of 7 doors (Fig. 17). The doors are of very shallow depth of less than half meter (0.2 m to 0.5 m). The common design of all these doors is generally a dome shape with side shoulders. Salient features of these doors are shown in Fig. 17e–g. After visual analysis of design of Satbarren, it has been observed that the door 7 has a dome shape pattern and a triangular carved collar/or shoulder with an outline grooved outside the periphery of the shelf. The door on small stone has however only a dome shape design (Fig.17a). The door 5 is a central door relatively large sized with a different design and architect pattern as compared to other doors carved on the giant stone. It also contains an outlet/small hole at the right, bottom corner probably used for drainage of water (Fig. 17f). The door also contains iron hooks/nails on the right and left, upper side corners probably used for hanging the curtains. On either side of the door 7, a cubit pit is also noticed. This cubic pit resembles a similar type of cubic pit noticed on the side wall at the entry point of OW-1 (Fig. 17g). However, the pit near OW-1 has a triangular shelf like boundary/outline that is similar to outline of door 7. On comaprision, both

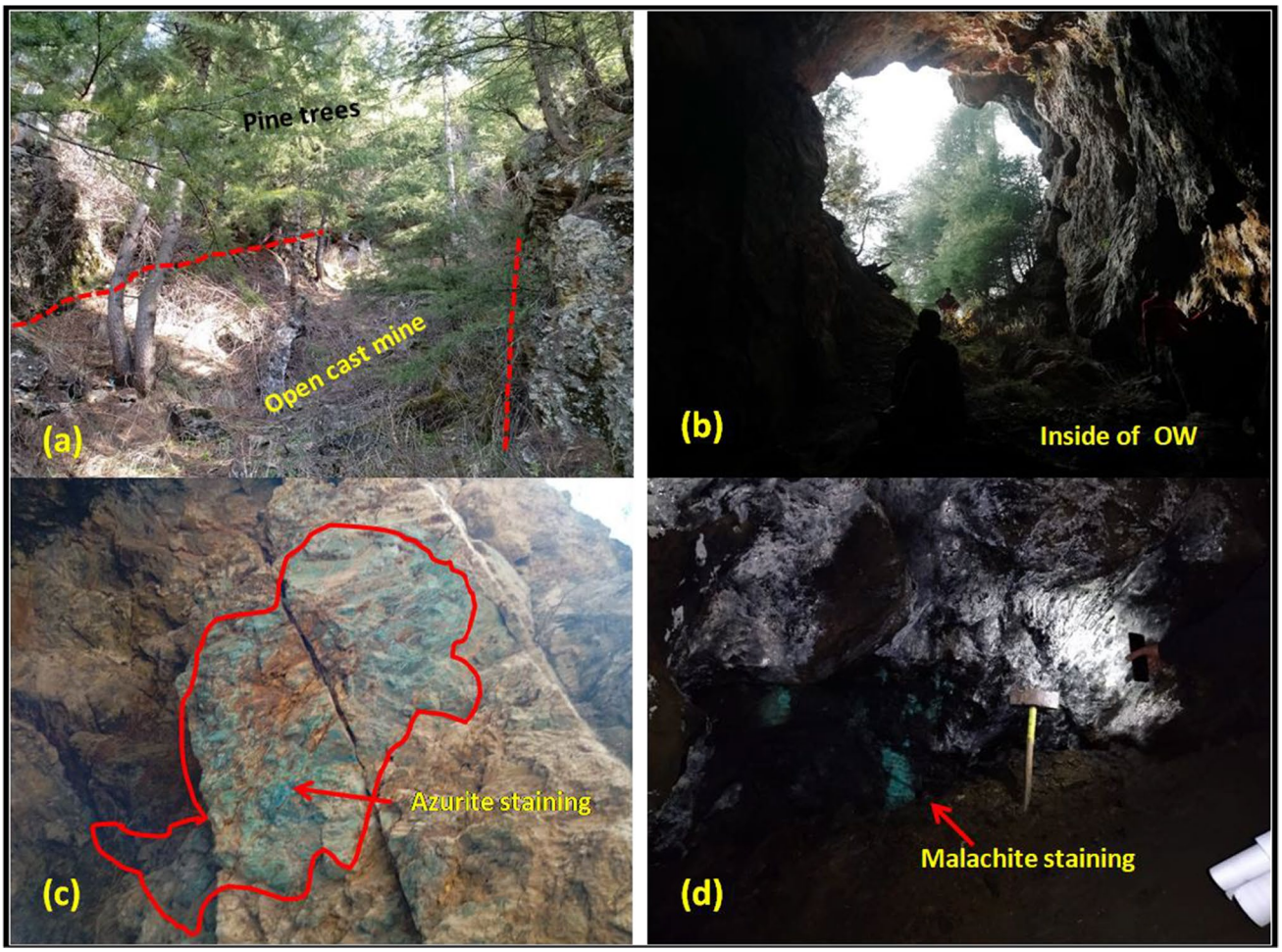

Fig. 15 Field photographs of **a** open cast mine/old workings **b** view from inside/or entrance of OW-3 **c**,**d** Malachite (OW-1) and azurite staining inside old workings in the area

of these architectural features/or patterns match very well and therefore, indicated that the construction of Satbarren and rate holes/OWs for copper mining might have been done probably during the same time period under the reign of a single kingdom/or dynasty (Fig. 18). But, it is pertinent to mention that the Satbarren archeological stone along with OWs may be considered an important evidence and relict of ancient mining civilization in the area. The detail description of the dimensions of the Satbarren doors is given in Table 3.

Discussion

The Kalaruch OWs near Satbarren stone have been first discovered by the local people of Lashteal village in the year 1871, according to the local reports. Since then, the OWs have been used as a place of refuge by the people during the Kashmiri Era (Fies et al. 2018). But, till date, no accurate and scientifically verified data is available regarding the true age of Kalaruch OWs and Satbarren stone. Moreover, it is also practically not correct and factually true to believe that these structures/or doors symbolize distinct routes to Russia and other neighboring countries lying far away at a distance of more than ~3000 km beyond and across the huge and extensive Himalayan terrain. In addition, contrary to popular belief and what is inferred in the literature, the shallowly engraved trefoil doors on the Satbarren stone don't point to any tunnels (Pal 2020; Mahjoob 2021; Mir et al. 2023). Therefore, to find out its true age of Satbarren carvings and OWs of ancient copper mining in the area and to solve the long pending myth about its origin is an important research gap required to be filled. We here provide an overview of the previous studies and attempt to relatively bracket the age and origin of these structures in the area. For instance, according to Jammu and Kashmir Law (2008), the Neolithic people of Kashmir (Neolithic period spanning from 10,000–4500 BC is the final period of Stone Age) might have mined lead ore, steatite (i.e., soapstone) and alabaster (i.e., Onyx marble) from the area and then transported that to

Fig. 16 Field photographs of **a–f** internal as well as **g–i** external adits of the old workings in the area

Harappan Communities by migratory agro-pastoral groups. In the Kashmir Valley, the Neolithic sites generally date from the beginning of the 4th to mid - 2nd millennia BCE (Kak 2002). As per Law's (2008) provenance research, the Kashmir Valley (Lashteal) has been considered as a source for Harappan copper also that is spanning from 3300–1300 BCE (Indus Valley Civilization). In Ancient Era, a large temple is believed to have existed in the area where Pandava dynasty spanning from 3083 to 1752 BCE used to worship the idols placed on all doors of the Satbarren stone (Banerjee 1958). Another theory believes that the Satbarren stone might have been a part of a large structure (possibly a temple) during ancient period which either collapsed or was intentionally destroyed later on (Masood 2018; Fies et al. 2018). The art and architecture has also been under the influence of Hinduism during the period spanning from 2300 to 1500 BC (Kak 2002). The Kalaruch architecture design is also considered an outcome of the Gandhara Art. The Gandhara Civilization existed from the middle of the 1st millennium BCE to the beginning of the 2nd millennium CE in the region. The art and architecture of the Kashmir Valley was greatly influenced by Ghandhara School of thought during ancient times (Kak 2002). A unique type of art and architecture was also developed during the Buddhist period spanning from 6th century to early 4th century BCE in the Kashmir Valley (Kak 2002). Reedy (1997), however, examined the OW shafts and reported that the copper mining in this area has probably originated during the Medieval Era spanning from 8th to 18th century AD.

As per the local archeologists, the Kashmir had historically strong trade relations and ties with the former Soviet Union going back to 2000 years (Mahjoob 2021). During that period, the Kashmir exported minerals such as copper,

Table 2 Detail characteristics of the Kalaruch old workings in the area

S. No.	Old working	Latitude (N)	Longitude (E)	Elevation (meters)	Mineralization	Description
1	OW-1	34°34'25.6"	75°20'24.7"	1980	Malachite and limonite staining	Constructed along the contact zone of mineralized quartz vein and the host rock in the form of almost a horizontal adit.
2	OW-2	34°34'25.9"	75°20'25.0"	1990	Malachite and azurite staining	Constructed along the contact of mineralized quartz vein and the host rock in the form of an incline.
3	OW-3	34°34'25.9"	75°20'27.8"	2020	Malachite and azurite staining	Constructed along the mineralized quartz vein and the host rock in the form of almost a horizontal winzes with two adits.
4	OW-4	34°34'26.8"	75°20'30.7"	2060	Ferruginised and minor malachite staining	Constructed along the mineralized quartz vein in the form of down trending wide incline and contains two adits at the bottom. Also contains water pond inside.
5	OW-5	34°34'26.9"	75°20'36.7"	2070	Ferruginised and minor malachite staining	Constructed along mineralized quartz vein in the form of shallow horizontal shallow adit.
6	OW-6	34°34'28.2"	75°20'38.5"	2090	Minor malachite and azurite staining	Constructed along the mineralized quartz vein in the form of down trending almost as incline. It is blocked by fallen rock mass.
7	OW-7	34°34'28.5"	75°20'39.6"	2260	Malachite and azurite staining	Constructed along the mineralized quartz vein in the form of down trending incline. It is blocked by fallen rock mass.
8	OW-8	34°34'28.6"	75°20'40.5"	2280	Minor malachite and azurite staining	Constructed along the mineralized quartz vein in the form of three shallow pits.

limestone, zinc, and bauxite to the erstwhile Soviet Union. Besides copper ore, the area is also known to posses good quality marble deposits known as "Kupwara Marble" in the area (Mir and Habib 2020). Kashmir and the Soviet Union share cultural and linguistic similarities as well (Mahjoob 2021). However, the locals of the area also believe that this deposit has been worked during the reign of Badshah (1421–1474 AD) nearly 600 years back (Bhat 1965). Banerjee (1958) on the basis of stone statuette of bullock found in slag heaps in the vicinity of Lashteal hamlet (- the statue was left in the original site without any dating) indicated the influence of Hindu culture during the mining period in the Kalaruch area (Fig. 19). The occurrence of slag heaps also indicated that the smelting has been carried out probably for copper during ancient times in the area (Bhat 1965). However, during our field survey, we found no traces of any such artifacts/or statues in the area. Furthermore, as per local people, the Kalaruch OWs were reported to witness hand paintings of the Stone Age and posses a peculiar aura (Masood 2018). Similarly, deep inside one of the OWs, an old discolored board having some unknown and unreadable Foreign Language writings was also reported to exist (Mahjoob 2021). But, during our field surveys in the area, we could not trace such paintings and languages inside the OWs. Overall from these observations, we presume that the approximate age of these geo-archeological structures shall relatively fall between ~3300–1000 BC. It is because, the theory of Harappan copper source (~3300–1300 BCE), idol worshiping placed on Satbarren doors by Pandava dynasty (~3083–1752 BCE), bullock statue indicating Hindu culture influence (~2300–1500 BC) and wide influence of Gandhara architecture (~1st and 2nd millennium CE) correlat relatively well with copper ore mining and Satbarren architecture present in the area. This is also supported by the fact that in the Indian subcontinent too, the age of ancient mining and old workings commonly dates back to ~2000 BC from present day times (GSI 2012).

Nevertheless, it is important to note that these ancient wonderful archeological ruins clearly demonstrate that the ancient dynasties in Kashmir had splendid architectural art and ore mining skills. To this, the Kalaruch OWs with

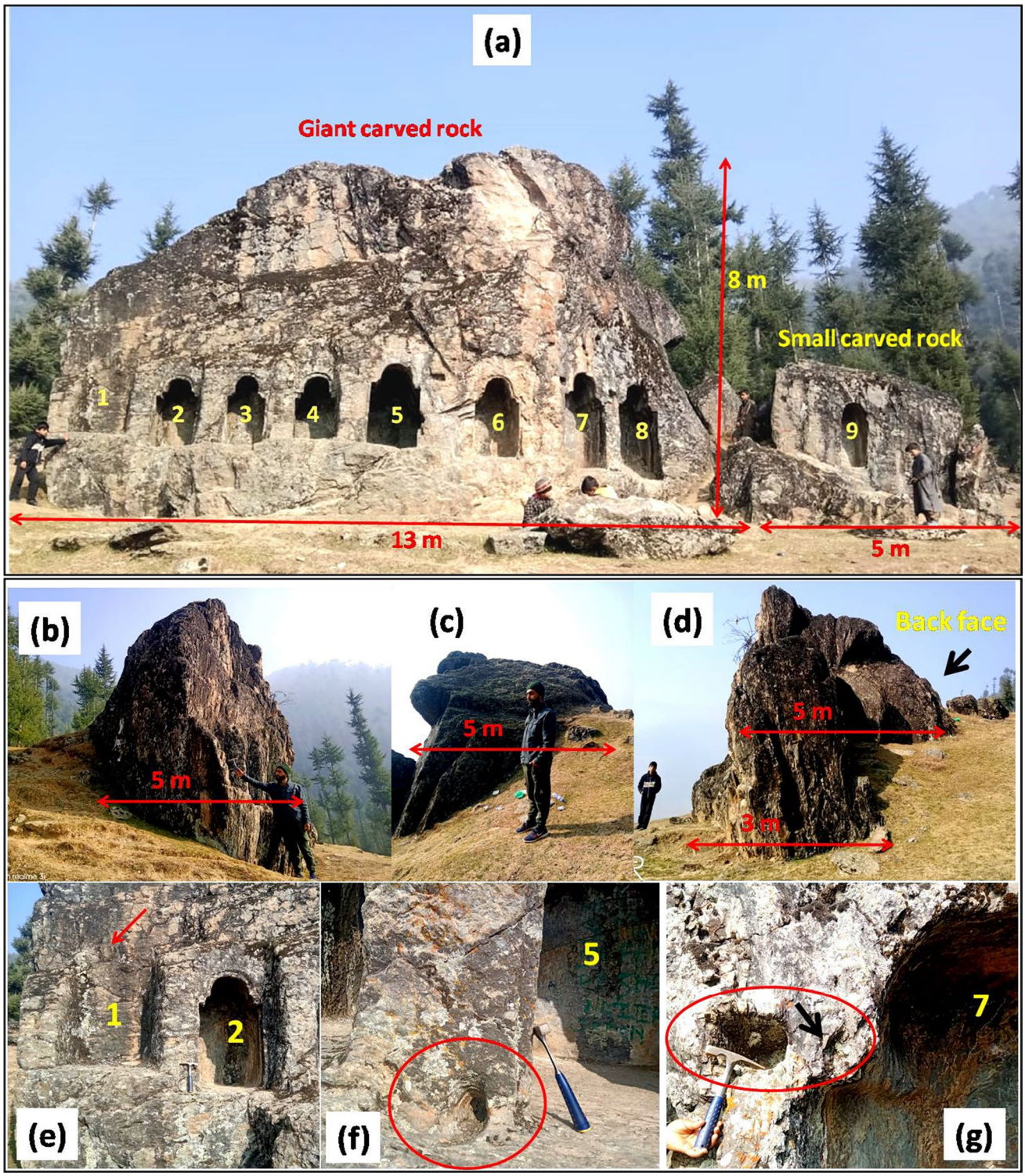

Fig. 17 Field photographs showing the **a** front face **b** right face **c** left face **d** back face **e** tomb less (broken) door 1 **f** outlet drain in door 5 **g** cubic pit and iron hook in the door 7 of the Satbarren rock in the area

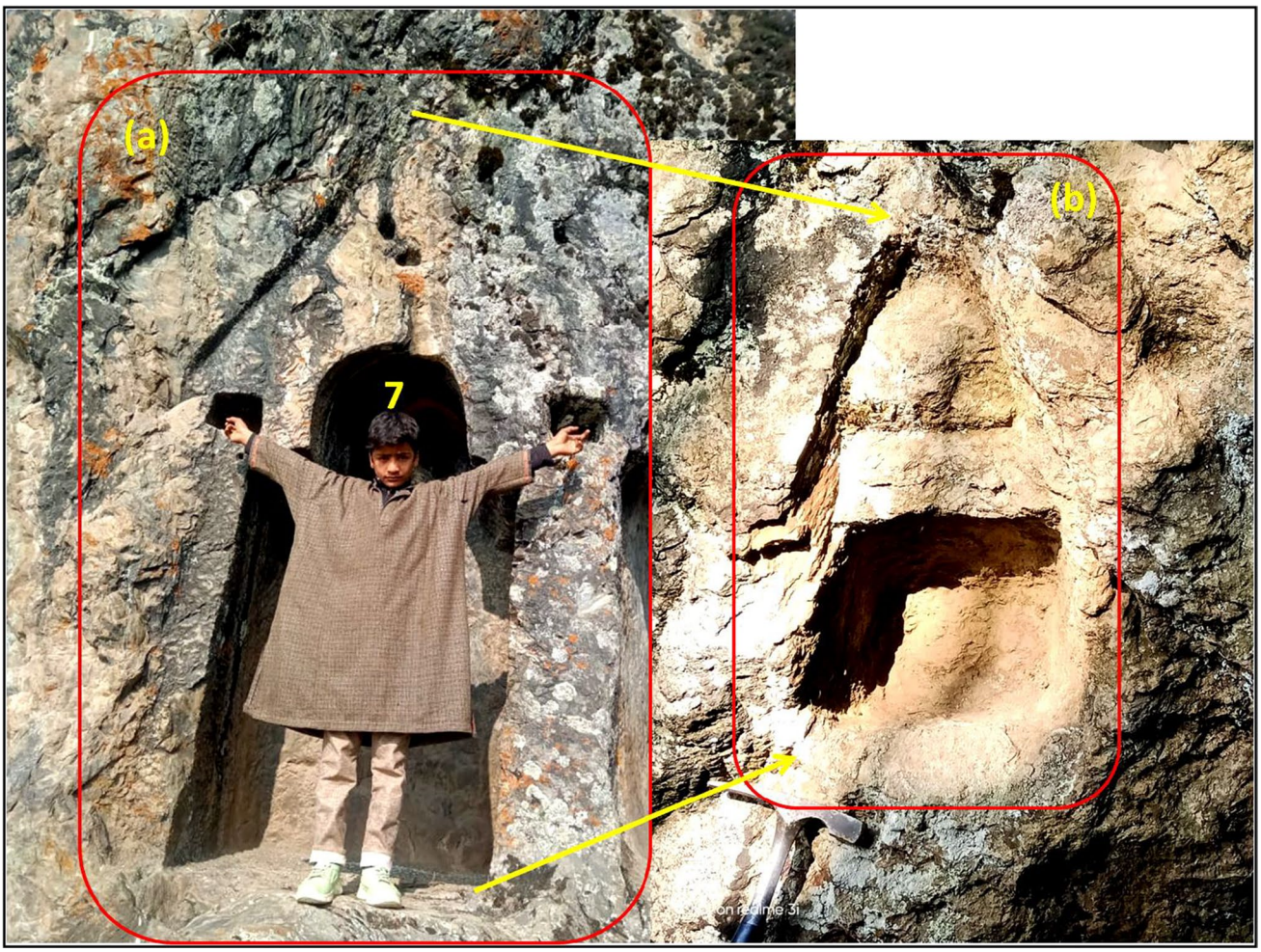

Fig. 18 Field photographs showing similarity between the archeological pattern of **a** door 7 of Satbarren and **b** a small shelf carved on the entrance wall of OW-1 in the area

several adits and interconnected galleries bear a clear testimony to the ingenuity of the ancient workers. Like the architectures of other parts of the world, they had been producing beautiful and impressive architect with distinct designs in the area. The Satbarren stone with 9 trefoil type openings/shelves (doors) clearly indicates the artistic interests of the people during ancient times in the area. But, as far the literaure on history of ancient Kashmir is concerned, there is not any single mention of this place, its age and original creators. Therefore, a detailed geo-archeological study and excavation to locate any artifacts for chronological and absolute dating shall be taken up in the area.

Table 3 Detail characteristics Satbarren archeological stone in the area

S. No.	Door/or shelf No.	Height inch	Width inch	Depth inch	Height tomb inch	Width tomb inch
1	1	47	23	16	Broken	Broken
2	2	76	38	34	20	26
3	3	74	39	28	23	16
4	4	56	31	19	13	19
5	5	60	32.51	63	13	24
6	6	47	27	36	16	18
7	7	50	25	22	13	15
8	8	47	26	35	12	18
8	9	43	36	20	-	-

Fig. 19 Old photograph of a bullock statue found near Lashteal hamlet in the area (ref: Banerjee 1958)

Conclusion

The conclusion drawn out of this study is to emphasis on the need and scope for development of this particular spot as a geoheritage, esthetic, and geotourism site. It is because geological, archeological, and cultural heritage development is an important and central base for its sustainable development and tourist attraction. From this point of view, a lot of scope exists for preservation and development of Kalaruch OWs and Satbarren stone as a geoheritage and geotourism site in the valley of Kashmir. Its development will uplift and enhance the socio-economic status of the local population and conserve it for the concerned researchers and curious tourists. The conclusions are described under two subheadings below:

Geotourism and Esthetic Significance

The Kalaruch OWs and Satbarren stone in the Kalaruch valley will provide obviously a gorgeous destination for tourism attraction and other recreational activities. Firstly, it is because these sites have great importance in terms of its geodiversity and archeological heritage demonstrated by their rich geological, archeological, historical, and cultural heritage. Secondly, it posses huge economic potential that can also be raised in a sustainable and eco-friendly manner. These spots can be developed in an easy way for geo-educational knowledge enhancement and vacation destinations, as these sites are already quite popular in Kashmiri oral and textual traditions as the Kalaruch caves and Satbarren. Additionally, the surrounding areas around these sites posses diverse scenic beauties with fresh and clean environment like many other spectacular places of Kashmir Valley (such as Srinagar, Pahalgam, Gulmarg, and Sonamarg) that can be easily accessed from capital city of Srinagar through the main town of Kupwara district.

Potential for Development as Geoheritage Site

To recognize the Kalaruch OWs and Satbarren stone as geoheritage and geotourism site, a lot of scope exists in the form of its geological, archeological, historical, cultural, tourism, educational, and scientific importance. Previously, the Lolab Bungus Drangyari Development Authority has initiated and communicated to the Directorate of Archaeology and Museums, Jammu and Kashmir to identify and declare these sites as protected monuments and heritage sites (Mahjoob 2021), on which, the Deputy Director of the department has claimed to have commenced work to preserve these sites in the area. The Government of Jammu and Kashmir has declared these sites as state protected monuments. These sites are also included in the tourism pamphlets and brochures (Mahjoob 2021). However, further concrete steps and efforts are again required for its conservation, preservation, protection, and sustainable development. Restoration work and further research on these sites will boost its geo-archeological and geotourism importance in the Kashmir Valley.

Recommendation

Following recommendations are given for the conservation, preservation, and sustainable development of Kalaruch OWs and Satbarren stone in the area.

1. Installation of proper signage boards along with cleaning activities should be promoted.
2. Proper fencing and demarcation of the site and creation of eco-parks around the site should be done by the concerned Government with the help of Geological Survey organizations.
3. Basic civic amenities like road connectivity, proper water supply system and toilet facilities around these sites should be constructed for the convenience of the visitors.
4. Proper foot tract network and accessibility tracts should be constructed to reach up to every old working on the steep mountain slopes.

5. The description of the mineralization (ore) and other geological features should be promoted through erection of suitable sign boards.
6. The sign boards should also describe archeological and historical importance of the ancient mining activities (if any).
7. Disposal of any wastage or garbage around these sites shall be prohibited and regularly monitored.
8. Expansion/or construction of local settlements should be a little away from around this site for its sustainable preservation and development.
9. The area that leads up to this site should also be maintained and cleared of any blockages.
10. Local educational institutions and all higher education institutions in the valley shall promote educational tours and visits to promote its awareness and importance in the public.
11. Various social media platforms should promote its digital marketing and creation of awareness among the masses.
12. The Local Government and concerned authorities need to work out a comprehensive developmental plan for its geoconservation and geotourism attraction.
13. Nonetheless, a sense of care and preservation with regard to the geological and archeological features existing around this place is required to be induced in the individuals of the local society for its sustainable geoheritage and geotourism development.

Acknowledgements The authors are grateful to the Geological Survey of India, UT: Jammu and Kashmir, UT: Ladakh, Jammu/Srinagar for providing opportunity to work in this area during its Field Season Program FSP: 2021-22. The authors are sincerely thankful to the Senior Officials of the Geological Survey of India for providing constructive inputs during the course of work and field survey in the area. The authors are grateful to the local people who assisted during the field work. The authors are also acknowledging the USGS for using its freely available satellite data.

Author Contributions RAM conceived the idea and took the lead in writing and drafting the manuscript with the support from SAA. VA helped and supported during fieldwork and survey in the area. VK supervised and helped in editing of the manuscript.

Declarations

Competing Interests The authors declare no competing interests.

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