Potential Area for A National Geoheritage Site at Injana Area, Himreen South Mountain, Middle of Iraq

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Abstract

The study area is located on both limbs of Himreen South Mountain, approximately 150 km northeast of Baghdad city alongside Baghdad- Kirkuk main road. Injana Geoheritage sites are interesting to consider for this study's geological conservation. It includes five national geological sites. The first interesting site of vertebrate fossils that showed the significance of the evolution of life. It also includes twenty-one species of vertebrate fossils within a pebbly sand bed in the Mukdadiya formation in late Miocene-Pliocene. The second interesting volcanic activity showed the significance of structural features. That involved feature showed volcanic ash deposited in the Mukdadiya formation during the late Miocene–Pliocene. The third interesting depositional environment showed the significance of ancient environments. The third site includes some ancient environments, such as a closed lagoon in the Fatha formation, fluvial in the Injana formation as well as fluvial or lacustrine environments in the Mukdadiya formation. The fourth interesting economic deposit showed the significance of rock types. That contains some industrial rocks and building materials such as gypsum in the Fatha formation and gravel and sand in the Mukdadiya formation and in the Quaternary sediments. The fifth interesting burnt hill showed the significance of surface and subsurface features. That contains unaltered and baked sediments capped by fused rocks. The suggested study areas are perhaps protected as a national geoheritage sites because of the inventory characterizations of geosites criteria, besides it is considered the first study on the national geoheritage in Iraq.

Keywords: Burnt hills, depositional environments, economic deposits, geoheritage, vertebrate fossils, volcanic activities.

1. Introduction

Geology and landscape have influenced society, civilization, and cultural heritage. The world Heritage Convention (WHC) identified the geological sites of world value, but it did not recognize the importance of geological sites at the national or regional level. Many important geological sites are not meeting the criteria of WHC, therefore UNESCOs initiative issued a geopark network to support many countries to protect and enhance the value of geological heritage [1]. The International Union for Conservation of Nature was founded in 1948 and now is the largest organization in the world which provides knowledge of natural resources and has links with more than 1400 members and more than 15000 experts. "International Union for Conservation of Nature (IUCN)" deals with several interested persons, such as NGOs, governments, local communities, scientists, businesses, and other stakeholders to implement solutions to environmental challenges and achieve sustainable development. IUCN, in the last decade, focuses on geo-conservation to conserve, enhance and promote awareness of geodiversity (geological diversity) and geoheritage (geological heritage) [2]. Geodiversity includes the diversity of geology (minerals, rocks, fossils), the diversity of geomorphology (physical processes and landforms) beside the type of soil. In addition to the properties, assemblages, systems, and interpretation relationships [3]. Geologic and physiographic importance can be classified into Global Significance when it is not duplicated anywhere in the world. Regional Significance when it is the best example in the region, national significance when it is the best example in the country, and provincial significance when it is the best example in the province or state [4]. In 2015, all members of UNESCO ratify the formation of a new label for the UNESCO global geoparks, during the general conference. This expresses the government's recognition managing of the outstanding geologic and geomorphic sites in a holistic manner. UNESCO supports member's efforts to establish geoparks all over the world, in collaboration with the Global Geopark Network (GGN), particularly in the Arab states and Africa due to the lack or absence of geoparks [5]. In Iraq, a high number of publications were studied to show the relationship between geodiversity and biodiversity [6-9]. Besides the importance of the natural heritage of Sawa lake [10]. Moreover, many studies on geopark were published that involved geosites in Missan province, southeast Iraq [11], as well as in Makhul mountain, Khanuqa anticline, and north Tikrit city [12]. Finally, the current work highlights the recognition of geoheritage, and the important geosites in Himreen mountain, that is in the middle of Iraq.

2. Materials and Methods

The current study depended on the geological survey of Himreen mountain in the Injana area and surroundings. Samples collection and identification of the collected samples are extensively studied and compared with previous studies which are dealing with vertebrate fossils, volcanic activities, depositional environments, economic depositions, and burnt hills. Moreover, the study area is in Himreen Mountain (Himreen South Anticline), on both sides of the Baghdad-Kirkuk main road, approximately 150 kilometers north-eastern Baghdad city as shown in figure 1, with coordination's of (Long. 44° 38' 10" E), and (Lat. 34° 32' 00" N)

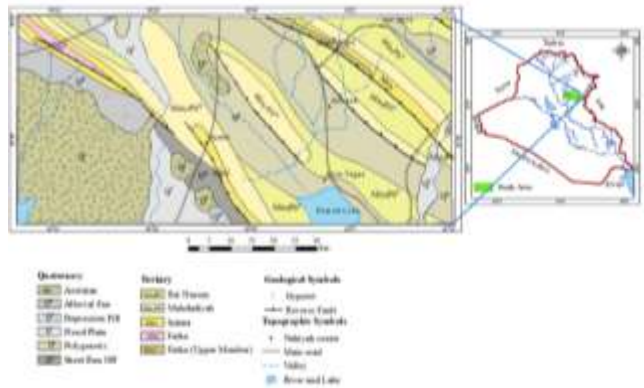

Figure 1: The study area geological map and location [13].

3. Results

3. 1. Geologic setting

Arabian and Iranian plates collision during L. Miocene – Pliocene caused the close of marine and end of carbonate and evaporite depositions of Fatha formation (L. Miocene) and the beginning of the folding, shortening and changed the sediments from marine to fluviatile continental clastic (detrital) sediments [14]. The clastic or detrital sediments include rock bed units within Injana (L. Miocene), Mukdadiya (L. Miocene- Pliocene), and Bai Hassan (Pliocene) formations. The previous formations covered wide areas and their sediments had high thickness. Authors noticed that the Alpine Orogeny caused the folding of the clasitic and other sediments [15]. The basin of Injana, Mukdadiya, and Bai Hassan during the late Miocene –

Pleistocene is considered a part of the subsided Zagros Foreland Basin (ZFB). ZFB resulted from the Zagros Thrust-Fold Belt (ZTFB) that is formed on the Arabian Plate (AB) [16].

Many vertebrate fossils were found in some formations such as Injana formation [17,18] in addition to the Mukdadiya formation [19-24]. Documentations of the "Natural History Museum, University of Baghdad" besides the natural field surveys by the current authors had recorded many bones in the Mukdadiya formation in the study area. The vertebrate bones layer of the Mukdadiya formation, which is exposed on the rock bed units, more than 30 kilometers and is found on the northeast side of the Himreen South Anticline. Most fossil bones have appeared in a grey pebbly sandstone layer [25]. The main exposed rock bed units in the study area belong to the Fatha, Injana, Mukdadiya, and Bai Hassan formations as demonstrated in figure 2.

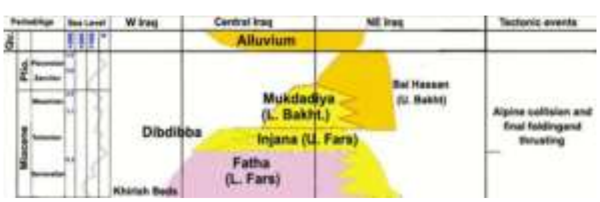

Figure 2: Tectonic events, occurrence, and distributions of some formations in the study area, middle of Iraq [16].

Fatha formation (Middle Miocene) includes comprises marl, greenish grey or reddish-brown marls, limestone, and gypsum. These rocks were deposited in evaporate marine basins which were separated from the open sea during rising ridges [26]. The thickness is approximately 445 meters. The conformable underlain formation is Jeribe formation. Gradational and conformable contact of the Injana formation overlain it [27,28]. Injana formation (Late Miocene) contains sandstone enriched by carbonate materials, siltstone, claystone, and marl beds [22,28]. The upper part of the Injana formation was deposited in the fluvial environment [30] while, the lower part was deposited in marine-continental (transitional environment) [14]. The expected thickness is nearly 620 meters, while in the type locality reaches 2000 meters in other sections. However, it is underlain by Fatha formation and overlain by Mukdadiya formation [28].

Mukdadiya formation (Late Miocene- Pliocene), comprises pebbly sandstone, siltstone, and mudstone beds [26]. Depositional cycles are recognized by Fining upward which refers to a fluvial depositional environment [28]. Rock bed units of this formation crop out near the foothill of north and northeast Iraq with thickness approximately 1411 meters. Furthermore, Mukdadiya formation overlain by the Bai Hassan formation. Bai Hassan formation (Pliocene) includes coarse conglomerates, sandstone, siltstone, mudstone, and claystone beds [26]. Bai Hassan formation thickness is approximately 638 meters. Moreover, Bai Hassan formation overlain conformably by the Quaternary sediments (conglomerates, sandstone, and siltstone beds) and fluvial deposits [28].

3. 2. Geoheritage

Individually Geopark should have a range of geosites of global, national, and regional importance. Geosites determine according to the geological history of the study area, events, and natural processes which have formed the earth's surface. The sites may include the importance from the point of view of science, education, rarity, and aesthetics [30]. The purpose of a geosite is to protect the values of geoheritage to be involved. Geosites are protected for many purposes, such as scientific, educational, aesthetic, geotourism, cultural, and ecological values. Geoheritage may have eight types of interesting geosites [31]. Earth's history stages, structural and tectonic features, categories of minerals and their formations, kinds of rare rock and their structures, the evolution of life, recent earth processes, important surface and subsurface features and ancient environments [2]. According to José Brilha [32], the inventory of geosite should include name, ownership, geographical location besides GPS coordination's, accessibility, present statutory protection, fragility and vulnerability. In addition to geological descriptions, geological features and processes, potential educational features and geotourism uses, distinguish features justifying a geosites, limitations on scientific use, links with cultural and ecological assets, safety status for different visitors, and finally limitation of number of visitors as shown in table 1. Graeme L. Worboys and co-authors stated that the study are geosites should include vertebrate fossils (evolution of life), volcanic activities (structural and tectonic features), diverse depositional environments (ancient environments), and economic deposits (types of minerals and their formation). Moreover, José Brilha listed the inventory of eleven common characterization criteria in the geosites is presented in table 1.

Table 1: Inventory of the study area Himreen geosites.

Inventory of study area (Himreen geosites)					
Name of Himreen geosite in (Iraq)	Vertebrate fossils	Volcanic activities	Depositional environments	Economic deposits	Burnt hills
Geographic location with GPS coordination's	34° 32' 00" N 44° 38' 10" E				
Ownership	Federal Iraqi Government (public not private).				
Present statutory protection	No protection				
Accessibility	Near the main road between Baghdad and Kirkuk				
Fragility and vulnerability	None				
Potential educational and geotourism uses	Bone of vertebrate fossil	volcanic ash sediments (Mukdadiya Fn.)	Lithofacies change from marine to fluvial environment	Economic minerals can used by all visitors	Burnt hills, hills capped by fused rocks
Links with ecology and cultural assets	None				
Limitations on scientific use	field work after ISIS is removed				
Limitations on visitor numbers	10 – 20 visitors per each group				
Safety conditions for all visitors	geosites can be used by visitors and students but currently not save				

3. 2. 1. Himreen Vertebrate Fossils Geosite (HVFG).

The main geological features and processes of Himreen study area shows identification of twenty-one species of vertebrate fossils that were collected from a bed of pebbly sandstone with extension of approaching 30 km. The Geological description of the study area comprises pebbly sandstone, siltstone and claystone beds of the Mukdadiya formation [33, 28]. Moreover, distinguishable features justifying a geosites as fossiliferous unit contains various vertebrate fauna representing twenty-one species. The most important fossiliferous layer exposed within Mukdadiya formation, and its extensions increased more than thirty kilometers. It is also found on the northeastern part of southern Himreen mountain that all of bone fossils come from pebbly sandstone bed [25]. The direction of the fossiliferous layer is 135° with a mean dip of about 15° towards the northeast. The involved layer includes more than twenty-one species of phylum Chordata, and class Mammalia [23] as shown in table 2.

Table 2. Showed vertebrate fossils discovered within South Himreen Mountain.

Phylum	Class	Order	Family	Genus	Species
Chordata	Mammalia	Carnivora	Felidae	*Machairodus* (Kaup, 1833)	
		Proboscidea	Gomphotheriidae	*Ghoerolophodon*	*Pentilici* (Gaudry and Lartet, 1917)
			Deinotheriidae	*Dintherium* (Koup, 1829)	-
		Perissodactyla	Equidae	*Equuus* *Hipparion*	*E.Primigenius* (meyer, 1829) *H. Mediteraneum* (Roth and Wagner, 1855)
			Rhinocerotidae	*Brachypotherium* (Roger, 1904)	
		Artiodactyla	Giraffidae	*Palaeotragus* (Gaudry, 1861)	*P. coelophrys* (Rodler and Weithofer, 1890)
				Bohlinia	*B. attica* (Lydekker, 1886)
				Samotherium	*S. poissieri* (F. Major, 1888)
			Bovidae	*Boselaphus* (Blainville, 1816)	
				Miotragocerus (Stromer, 1928)	
				Prostrepsiceros (Major, 1891)	
				Gazella (Blainville, 1816)	
				Gazella	*G. gaudry* (Schlosser, 1904)
				Ovis (Linnaeus, 1758)	
	Reptlia	Squamata	Boidae (Gray, 1825)		
			Erycinae (Ponaparte, 1831)		
		Testudines	Trionychidae	*Trionyx* (Sanit, Hilaire, 1809)	*T. amyda* (Hay, 1908)
			Testudinidae	*Testudo*	*T. geochelone* (Fitzinger, 1835)
			Pelomedusidae		
		Crocodylia (Owen, 1842)	Gavialidae (Adams, 1854)	*Gavialis* (Oppel, 1811)	
	Aves	Struthioniformes	Struthionidae	*Struthio* (Linnaeus, 1758)	

3. 2. 2. Himreen Volcanic Activities Geosite (HVAG)

The main geological features and processes are volcanic ash sediments exposed in the Mukdadiya formation refers to volcanic activities of Late Miocene–Pliocene. Involved sediments can be subdivided into three main facies. The primary pyroclastic facies, the secondary glassy pyroclastic facies, and the secondary pyroclastic facies. The geological description also includes volcanic ash sediments that involved three lithofacies. The primary pyroclastic facies comprise glass shards of about 85 % and pyrogenic minerals of about

15 %. The secondary glassy pyroclastic facies comprise glass shards of about 65 % and pyrogenic minerals of less than 10 %. Such facies comprise clayey tuff stone, muddy tuff stone, and sandy tuff stone. The third kind is the secondary pyroclastic facies which comprises detrital clasts of more than 85 %, and pyrogenic material of less than 15 %. Such facies comprise tuffaceous claystone, tuffaceous mudstone, and tuffaceous sandstone [34]. The distinguishable features justify geosites of volcanic ash sediments deposited in fluvial and lacustrine sediments within Mukdadiya formation (L. Miocene- Pliocene). The Mukdadiya formation (L. Miocene – Pliocene) comprises volcanic ash layers. Those layers were deposited from fluvial environments besides the lacustrine environments and have lenticular shapes [35]. The volcanic ash sediments found within Mukdadiya formation were referred to as volcanic activity processes during L. Miocene – Pliocene. Moreover, the involved sediments can be subdivided into three main facies, besides those eight subdivisions based on Muhammad Al-Hassan, and Ali AL-Zaidy [34] as shown in table 3.

Facies (A) the primary pyroclastic facies were formed after volcanic eruptions and transported by air, then deposited either at fluviatile or lacustrine environments. Facies still pure without mixing with detrital materials with thickness may reach three meters. Facies composed of coarse particles of ash sediments (0.45 – 0.063 mm) and fine particles of ash sediments (0.063 – 0.005 mm) as well as comprised glass shards and pyrogenic minerals. Facies (B) the secondary glassy pyroclastic facies, include Tuffaceous rocks. The facies represented the eruptions of volcanic ash and gases in the air and deposited on the earth's surfaces then. After they were run transported and redeposited many times within multicycles of reworking sediments which caused the mixing of pyrogenic minerals and clastic materials. The thickness of these facies may range from one to two and half meters and contains tuffaceous claystone, tuffaceous mudstone, besides sandy tuff stones. Facies (C) the secondary pyroclastic facies deposited in the same environment of facies (B) but during low concentration of volcanic clasts supply. The thickness ranged from 0.3 to 0.5 meter and includes tuffaceous claystone, tuffaceous mudstone, besides tuffaceous sandstone. The presence of both facies (A) and (B) mostly referred to volcanic eruptions during Late Miocene – Pliocene when the Mukdadiya formation was deposited. Gases and vapors emissions, such as CO_2, SO_2, and H_2S in addition to HCl, resulted from volcanic eruptions. Such gases and vapors caused suffocation and hard breathing [36]. Moreover, mass extinctions of enormous types of animals happened in the study area during L. Miocene- Pliocene [37].

Table 3: The Lithofacies, facies, and thickness of volcanic eruptions deposits within Mukdadiya formation rock bed units (L. Miocene – Pliocene) [34].

Lithofacies	Facies	Thickness (m)	Sub-facies	descriptions
1. (Tuffstone), primary Pyroclastic Facies: glass shards 85 % and pyrogenic minerals 15 %.	A	3	A. 1 A. 2	Fine grain tuffstone Coarse grain tuffstone
2. (Reworked sediments), secondary Glassy Pyroclastic Facies: glass shards 65 % and pyrogenic minerals < 10 %.	B	1 to 2.5	B. 1 B. 2 B. 3	Clayey tuffstone Muddy tuffstone Sandy tuffstone
3. (Reworked sediments), secondary Pyroclastic Facies: detrital clasts > 85 % and pyrogenic material pyrogenic minerals < 15 %.	C	0.3 to 0.5	C. 1 C. 2 C. 3	tuffaceous claystone tuffaceous mudstone tuffaceous sandstone

3. 2. 3. Himreen Depositional Environments Geosite (HDEG)

A high amount of research revealed the ancient depositional environments of rock bed units of study area and showed that the Fatha formation was deposited in restricted lagoon environments. Moreover, the Injana formation was deposited in marine to continental environments at lower part and in fluviatile environments at upper part. Besides, Mukdadiya formation was deposited in fluvial environments; and Bai Hassan formation was deposited in fluviatile to lacustrine environments. Furthermore, the depositional environment of the Fatha formation was a closed lagoon environment of hypersaline conditions. The lower part of the Injana formation was deposited in the transitional environment (marine-continental). On the other hand, the upper part in the fluvial continental environment.

The depositional environments of Mukdadiya formation were in fluvial environments in rapidly collapsing foredeep basins. Also, the depositional environments of the Bai Hassan formation were in a fluvial to lacustrine in a rapidly collapsing foredeep of typical fresh-water detrital sediments.

Various depositional environments contemporaneous to the collision of the Arabian and Iranian plates. The exposed formations in the study area are Fatha, Injana, Mukdadiya, and Bai Hassan. The environment of deposition of the Fatha formation was a closed lagoon environment of hypersaline conditions. In certain areas where the closed lagoon environment of the Fatha formation was undifferentiated, the lagoons have direct contact with the open sea [15]. The lower beds of the Injana formation have been interpreted as a sub-continental environment or shallow marine water according to the limestone-bearing gastropods, pelecypods as well as ostracods in the lowermost beds of the formation, or maybe a supratidal environment due to algae and amiloride, which are found in the lower beds [33]. The lower beds of the Injana formation seem to be transitional between the environment of marine closed lagoon environment and the fluvial environment [38]. However, Mukdadiya formation was deposited in fluvial depositional environments in a rapid subsiding foredeep basin, which is indicated by the facies analysis of sedimentary rocks, cycles of deposition and fossil remains [33]. Where, Bai Hassan formation was deposited in a fluvial to the lacustrine environment in a rapidly sinking foredeep in typical fresh-water molasses sediments [27]. Moreover, alluvial fans environment may be originated from the Zagros suture zone and the high folded zone [16].

3. 2. 4. Himreen Economic Deposits Geosite (HEDG)

The current study areas contain various types of minerals and industrial rocks, such as gypsum in the Fatha formation, gravel and sand in the Mukdadiya and Bai Hassan formations, also in the Quaternary sediments. The low folded zone contains primary gypsum deposits as beds in the lower part of the Fatha formation. Where, gypsum was found either bedded or nodular from 44 to 46 % of SO_3. Besides, sand and gravel were found in quaternary sediments (Pleistocene-Holocene) as alluvial fan and river terrace deposits in addition to older beds of Injana (Late Miocene), Mukdadiya formation (Late Miocene–Pliocene), and Bai Hassan formation (Pliocene-Pleistocene). Gypsum, native sulfur, gravels, and sands are recognized as geosite for their economic value. The study area contains various types of minerals, and industrial rocks, such as gypsum, in the Injana and Fatha formations, bentonite in the Mukdadiya formation, as well as gravels and sands aggregate in the Bai Hassan formation, also in the quaternary sediments.

Gravel and sand are found in quaternary sediments as an alluvial fan and river terrace deposits and in the Mukdadiya formation (L. Miocene–Pliocene) and in the Bai Hassan formation (Pliocene–Pleistocene) in addition to valley-fill deposits. Moreover, a great number of mudrocks in the Injana formation are exposed in the study area. Involved mudrocks, may be suitable for cement and brick industries. The main problem of the mud bricks is the excess lime, which can be reduced by mixing it with high silica silt or sand [39].

3. 2. 5. Himreen Burnt Hills Geosite (HBHG)

Main geological features and processes in the Injana area, south of Himreen, that there are six prominent hills located along a major reverse fault. These hills were studied by Basi M. A. [29] and termed “Burnt Hills”. They are capped by fused rocks and their lower and middle parts are composed of unaltered and baked sediments, respectively. Moreover, Himreen burnt hills are composed of unaltered and baked sediments and capped by fused rocks. The fused rocks are composed mainly of pyroxene and calcic plagioclase with a low percentage of glass. The estimated temperature of these minerals was more than 1100 °C and less than 1370 °C. Therefore, these hills could be formed by the combustion of a hydrocarbon in numerous pits along the reverse fault plain. In the Kirkuk area approximately 200 km north of these burnt hill’s hydrocarbon combustion is noticed in numerous locations at the present time and confirmed the hydrocarbon combustion as an origin of these Burnt Hills. Finally, the distinguishable features justifying a geosites is the capped, dark fused rocks exhibit a resemblance to volcanic rocks, and field and petrographic evidence excluded the igneous origin of these hills.

4. Conclusion

In conclusion the study area includes five national importance geological sites. Vertebrate fossils site or evolution of life that includes twenty-one species of vertebrate bone fossil in the pebbly sand bed among the Mukdadiya formation (Late Miocene-Pliocene). The current study areas contain volcanic ash deposited among the Mukdadiya formation that are referring to volcanic activities during Lower Miocene–Pliocene. Moreover, the study areas also contain some ancient environments such as a closed lagoon in the Fatha formation, fluvial environment in the Injana formation, and fluvial to lacustrine environments in the Mukdadiya formation, and in the Bai Hassan formation. The studied areas contain some types of industrial rocks, such as gypsum, in the Fatha formation and building materials such as gravel and sand in the Mukdadiya formation and in the

Quaternary sediments. In addition to unaltered and baked sediments capped by fused rocks. Finally, the current study suggested that the study area may be protected as a national geoheritage site because it agrees with the inventory characterizations of geosites criteria. Besides it is the first study area on the national geoheritage in Iraq.

Moreover, it's important to indicate that the Injana area has significant geological features for students besides the visitors as a national geoheritage site because it is characterized by the following criteria. Injana is the border area between the Mesopotamian plain and low folded zone. Injana area is also close to Diyala, Baghdad, Kirkuk, and Tikrit Governorates, which include the department of geology in their universities. In addition, many geologic papers have been published on the current study area. Injana area was also visited by a high number of geologists, researchers, geologic students, and visitors because of the geodiversity. Moreover, the current study areas were selected as fields for training courses in geology for the students.

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