

Geological Heritage of the Anthropocene Epoch—A Conceptual Viewpoint

Dmitry A. Ruban ^{1,2} 

¹ K.G. Razumovsky Moscow State University of Technologies and Management (the First Cossack University), Zemlyanoy Val Street 73, Moscow 109004, Russia; ruban-d@mail.ru

² Southern Federal University, 23-ya Linija Street 43, Rostov-on-Don 344019, Russia

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Abstract: The growth of interest in the Anthropocene has coincided with the rise of geoheritage research and these ideas seem to be mutually enriching. However, very few previous investigations were devoted to the Anthropocene geoheritage. The conceptual treatment of the geoheritage classification demonstrates that the majority of geoheritage types and forms are relevant to the Anthropocene. From types, the most relevant are the stratigraphical, economical and geomorphological types, which include, for instance, such unique objects as the Anthropocene global stratotype candidate sections, exploited ore deposits and man-made landforms, respectively. Ex-situ forms (such as museum collections) and many in-situ forms (such as quarries and roadcuts) result from the geological-scale activity of humans. The practical importance of the strong Anthropocene–geoheritage relationship is linked to communication of Anthropocene-related knowledge and better research coordination. Importantly, geosites and geoparks themselves manifest human influence on the global geological environment, that is, their establishment among the Anthropocene-related forces.

Keywords: geopark; geosite; human pressure; mining; tourism

1. Introduction

The Anthropocene has retained a double meaning since its introduction in the 2000s [1,2]. On the one hand, this seems to be a new subdivision of the geological time scale characterizing a particular interval of the Earth's evolution (Figure 1). It has been already formalized as such, although much research is yet to be done [3,4]. On the other hand, the Anthropocene represents a broad idea that stimulates understanding of humans as a full-scale geological agent and facilitates the relevant research. These meanings are not only closely related but indivisible. The accelerating attention to the Anthropocene has triggered many far-going discussions in geosciences. For instance, these are relevant to critical stratigraphical boundaries [5], zoogeomorphological processes [6] and biogeographical patterns [7]. Undoubtedly, some big portions of the geological knowledge must be changed and the relevant classifications, nomenclatures and typologies need updating in light of the growing evidence for the Anthropocene.

It must be stressed that the current idea of the Anthropocene is not so novel. In the beginning of the 20th century, the famous Russian geologist A.P. Pavlov coined the term *Anthropogene*, and this term has been used by several generations of Russian geologists as a synonym of the *Quaternary* [8–10].

System / Period	Series / Epoch	Stage / Age	Ma
QUATERNARY	ANTHROPOCENE		Present
	HOLOCENE	Meghalayan	~0.00007
		Northgrippian	0.0042
		Greenlandian	0.0082
	PLEISTOCENE		0.0117
		Upper	0.126
		Middle	0.773
		Calabrian	1.80
		Gelasian	2.58

Figure 1. Approximate position of the Anthropocene within the Quaternary time scale (the chronostratigraphical basis follows the latest recommendations of the International Commission on Stratigraphy [11]; however, the Anthropocene is not yet formally defined).

Interestingly, the rise of interest in *Anthropocene*-related issues has coincided with the growth of another direction of geoscience research, namely *geological heritage* (geoheritage) studies. The latter have intensified in the past two decades and addressed such topics as geosite and geopark establishment, geoconservation and geotourism. The relevant knowledge has become huge already and it is conceptualized in works by Brilha [12], Brilha et al. [13], Brocx and Semeniuk [14], Bruno et al. [15], Chylinska [16], Dowling [17], Dowling and Newsome [18], Ezquerro and Simón [19], Gordon [20], Gray [21], Henriques and Brilha [22], Henriques et al. [23], Hose [24], Olafsdottir and Tverijonaite [25], Prosser [26], Prosser et al. [27], Purdie et al. [28], Reynard and Brilha [29], Reynard et al. [30], Ruban [31,32], Ruban et al. [33,34], Štrba et al. [35–37], Thomas [38], Wimbledon and Smith-Meyer [39], Wimbledon et al. [40] and Yürür et al. [41]. Some experts tend to pay attention to the “absolute” value of geoheritage and the needs of its proper conservation [12,26,27,29,39], whereas some others focus on its utility [17,18,22,24] or “technical” issues of geoheritage studies [11,27]; the almost philosophical treatment of geoheritage also exists [13,20,21,38]. Generally, geoheritage studies have resulted in the recognition of heritage value of numerous geological features because of their uniqueness and importance for science, education and tourism. In the other words, a geology–human link through heritage has been realized.

Both ideas, namely the Anthropocene and geoheritage, characterize the relationship between humans and the geological environment that can be traced on planetary, country and local scales (cf. [20]). If so, why not relate these ideas? Although some discussions have been undertaken (see literature review below), the Anthropocene geoheritage is a very novel issue needing conceptualization. This is not because the Anthropocene is a new epoch but because it reflects the action of a new geological force. Moreover, the Anthropocene as an idea is much wider and deeper than the only human activity, and, therefore, the previous consideration of the man-made features as geoheritage needs extension in regard to the Anthropocene itself. The objective of the present contribution is to propose such a theoretical treatment of the Anthropocene geoheritage. Undoubtedly, such a proposition can be only tentative and subjective in somewhat because a broad discussion within the international research community is the only method to shape the full understanding of this complex issue (this discussion requires idea exchange, “negotiations” and formal ratifications via voting). However, this proposition is necessary to put the Anthropocene geoheritage on agenda of the modern research, that is, to start the noted discussion. In the present paper, the relevance of the Anthropocene to types and forms of geoheritage is emphasized as an essential approach to demonstrate the geological activity of humans through the prism of heritage value.

2. Literature Overview

The publications that directly link geoheritage to the Anthropocene remain very few [42–47]. Some articles focus on specific issues and others relate two ideas in an occasional manner. These pioneer works have formed a basis for further deeper analysis and conceptualization. These articles are indicated below in a systematic way.

Three works explain that geoheritage itself can provide sufficient evidence for the *understanding of the Anthropocene* and this evidence strengthens heritage value to the relevant sites. Ansari et al. [42] paid attention to several UNESCO World Heritage Sites that inform about the geological-scale activity of humans. This evidence is suggested to be used for a better definition of the Anthropocene. Pica et al. [43] stressed a still limited interest of Anthropocene researchers in urban geomorphological heritage, although the latter provides excellent evidence of characteristic features such as specific deposits of the newly proposed epoch. Brown et al. [44] reviewed the alluvial record of the Jurassic Coast World Heritage Sites and concluded that some landforms and sediments reflect human activity in the Anthropocene and, thus, this globally-ranked geoheritage site can contribute to the knowledge of this interval of the geological time.

Two works are linked to *archaeological records*. Evidently, the latter form a kind of “bridge” between geology and humans. Solli [45] explored possible changes in the meaning of archaeological heritage in the Anthropocene environment. Riede [46] discussed connections between archaeological findings and interpretations, heritage management and current environmental concerns, linking which has become so urgent together with the growing interest in the Anthropocene. Importantly, this specialist paid attention to the geological dimension of the above-mentioned connections.

Finally, one work considers *soils* as the other “bridge” linking geology and humans. Ibanez et al. [47] focused on soils as a geobiological substance that has evident biological and geological heritage value. This substance is not only formed in the Anthropocene but its heritage value can be heavily affected by human activities that are typical for the Anthropocene.

Indeed, there are numerous publications that are strongly related to the Anthropocene geoheritage, although do not consider the Anthropocene. First of all, these are the works devoted to urban geoheritage and urban geotourism [48–54]. Growth of cities always leads to significant perturbation of their geological environment and, thus, the relevant heritage represents activity of humans as a powerful, geological-scale force. Additionally, it is worth to note that some works pay attention to geoheritage as a source of climate change knowledge [34,55,56]. Evidently, the global climate change is one of the most characteristic phenomena of the Anthropocene.

3. Evidence from Geoheritage Classification

A significant gap in the available knowledge (see overview above) is linked to the absence of clear understanding of how the Anthropocene-related unique features are represented by geoheritage. In other words, the place of these features in classifications (typologies, nomenclatures) of geoheritage is yet to be defined. Various classifications and their elements were proposed, particularly by Bradbury [57], Bruno et al. [15], Fuming et al. [58], Migoń and Pijet-Migoń [59], Prosser et al. [27] and Ruban [31]. This information has been re-considered by Habibi et al. [53] who have proposed the detailed, double-sided classification of geoheritage. This classification distinguishes *geoheritage types* on the basis of the geological essence of unique features (e.g., palaeontological, mineralogical, geomorphological, etc.) and *geoheritage forms* on the basis of how such features look physically (e.g., natural outcrops, roadcuts, building stones, etc.). The relevance of these types and forms to the Anthropocene is explained below.

The Anthropocene geoheritage exists in the majority of the established geoheritage types, from which three types are very important, namely the stratigraphical, economical and geomorphological types (Figure 2).

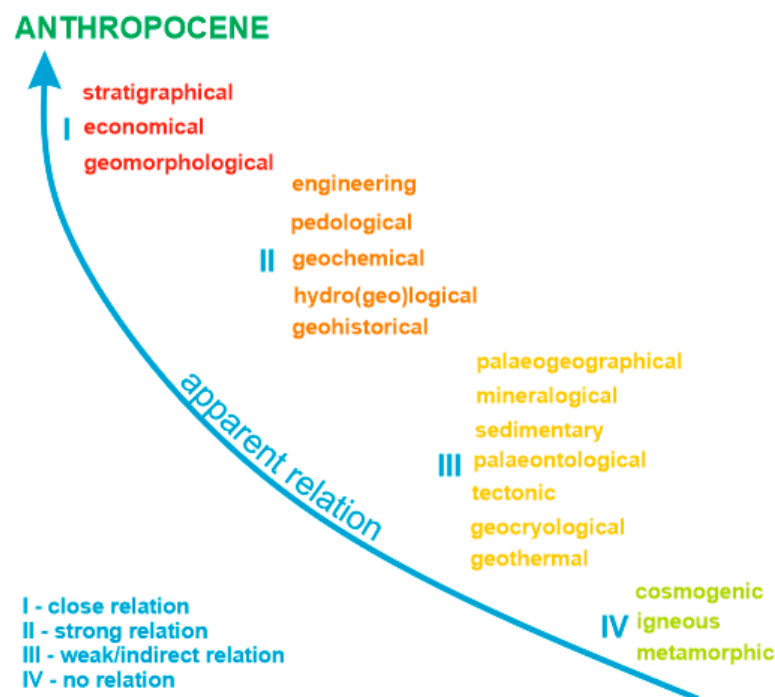


Figure 2. The relevance of geoheritage types to the Anthropocene (the classification [53] is adopted with small modifications).

The *stratigraphical* type includes unique phenomena of rock relationships and geological time. Essentially, the Anthropocene is a unit of the geological time scale of a series/epoch rank [3,4]. If so, it should be traced in geological sections. The latter are unique when fixing the presence of the Anthropocene in a given region or geological domain. But the most unique are the globally-important sections and, particularly, the Global Stratotype Section and Point (GSSP) that fixes the lower boundary of the Anthropocene. Currently, several GSSP candidate sections are discussed for different localities (e.g., the Santa Barbara Basin in the USA, the Clyde Estuary in the UK and the Ernesto Cave in Italy) on the basis of various proxy signals (e.g., heavy metals, radiogenic fallout, etc.) [6]. Moreover, efforts in the Anthropocene formalization have raised two directions of debate. First, the subdivision of the entire Quaternary needs attention [60], especially because of the finished formalization of the Holocene and its stages [61]. Second, the very approaches of the Anthropocene stratigraphical treatment are questioned [62,63]. The relevant debates need field data and, thus, some key sections displaying the Anthropocene interval are of outstanding uniqueness. All this evidence implies that the unique Anthropocene-related features can be found among the stratigraphical geoheritage type.

The *economical* type is the other geoheritage type, which is tied strongly to the Anthropocene; it includes unique mineral resources (ores, hydrocarbons, salts, building materials, etc.) and unique places of their current mining. On the one hand, the special meaning of these geological phenomena is determined by their significance to humans. Ore is nothing more than a peculiar mineral association or rock if economically insignificant. On the other hand, extraction of mineral resources and fossil fuel exploitation are among the most important reflectors of the geological activity of humans, that is, this is a sufficient basis for the very definition of the Anthropocene [64–66]. Apparently, the entire economical type can be related to the Anthropocene geoheritage. Unique deposits that were exploited centuries ago, that is, before the start of the Anthropocene Epoch, are better to attribute to the *geohistorical* type (*sensu* [53]; this can be also called the *geoexploration* type). This type characterizes the history of geological exploration of the planet and includes the relevant unique features such as historical places of major discoveries, mining and so forth. This is a question for further discussions of whether unique but pre-Anthropocene geohistorical features representing the geological-scale activity of past civilizations should be related to the Anthropocene geoheritage. Nonetheless, it is evident that some

modifications of geological environment in the historical and even prehistorical times were comparable to those of the 20th–21st centuries.

The *geomorphological* type is also of special interest. It includes unique landforms and processes on the Earth's surface. It is shown clearly that the geological-scale activity of humans has led to significant denudation, as well as new landforms (artificial caves, hills, etc.) have been created actively [67–71]. When man-made landforms and man-triggered geomorphic processes are unique (e.g., because of their scale or very typical appearance), these constitute the Anthropocene geomorphological heritage. Similarly, some other geoheritage types bear the Anthropocene-related component (Figure 2). For instance, this is the case of the *mineralogical* type because human activity produces new substances (e.g., plastic-based) and triggers their preservation in geological records [72]. It is worth noting that features related to active mining can be interpreted as human burrows and erosional surfaces. The former are related to the *palaeogeographical* type [15] and the latter are related to the *stratigraphical* type [53]. Even the types that cannot be attributed directly to the Anthropocene geoheritage (Figure 2) can be linked to human activity. For instance, volcanic ashfalls preserve the evidence of the past civilizations and, thus, create human-related records associated with the *igneous* type [73].

The geoheritage forms are very diverse and the majority of them can be related to the Anthropocene (Figure 3). This is the case of all ex-situ forms, as these represent unique geological features moved and/or installed by humans. For instance, building, decorative and ornamental stones are among very typical geoheritage of this sort [53,74–77]. Although these can be essentially natural (e.g., granites, limestones or sandstones), their occurrence in a given construction reflects human activity and sometimes such an occurrence increases heritage value.

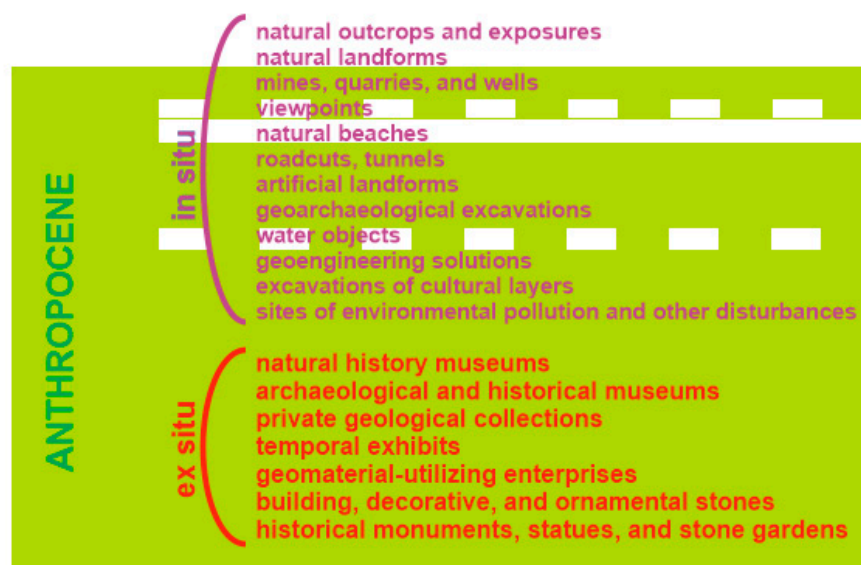


Figure 3. The relevance of geoheritage forms to the Anthropocene (the classification [53] is adopted with small modifications); the man-made forms are shaded in lightgreen colour, a few forms (bold dashed line) can be both natural and artificial.

From in-situ geoheritage forms, some (if not many) are also relevant to humans. For instance, these are *quarries* and *roadcuts*. These are not simply artificial rock exposures but these represent human activity as a geological force (landscape modification and voluminous material extraction). Sometimes, the size of quarries and their importance as sources of raw materials make them very unique. Margiotta and Sansò [78], Parkes and Gatley [79], Prosser [80] and Todaro [81] demonstrated the geoconservation importance of quarries. Generally, geoheritage forms either result from geological activity of humans (i.e., these are “consequences” of the Anthropocene) or themselves retain the Anthropocene-linked heritage value or both. However, there is a problem that requires special investigations and debating in the future. Some man-made geoheritage forms were created before

the beginning of the Anthropocene, that is, before the mid–20th century. For instance, these are Prehistoric megalithic constructions, Roman quarries, Medieval stone buildings and so forth. Do these belong to the Anthropocene geoheritage? A definite answer is unavailable for now but, nonetheless, all geoheritage forms attributed to the Anthropocene geoheritage (Figure 3) include representatives with the age matching the timeline of the Anthropocene.

4. Discussion and Conclusions

The evidence presented above implies that a significant portion of geoheritage can be related to the Anthropocene. Many geoheritage types and forms represent this idea either fully or partly (Figures 2 and 3). This relationship is not only of ‘purely’ conceptual importance. First, the already known and yet-to-be-identified geoheritage can provide important evidence for the Anthropocene-related debates and the very promotion of the relevant knowledge among the broad public. For instance, geotourism has a climate change literacy function [34], which permits use of geosites and geoparks for increasing the awareness of the geological-scale human activity and risks linked to global climate change (this will also contribute to the growth of a regional environmentally-oriented economy [82]). On the one hand, geoheritage features themselves can represent evidence of climate change and/or its negative consequences. On the other hand, these can inform society about climate-related catastrophes of the “Deep Past” or, second, the close relationship between the Anthropocene and geoheritage implies an important direction for inventory of the latter. Special search and further designation of geosites representing Anthropocene phenomena, as well as establishment of the same geoparks is necessary to make the entire geoheritage really comprehensive. Particularly, the GSSP candidate sections [6] that are very unique by definition require recognition as global geosites.

The relationship between the Anthropocene and geoheritage has yet another dimension. Unique geological features are often designated as geosites, which is necessary for their inventory and promotion, legalization and conservation management. Sometimes, this requires some maintenance, including vegetation and slope debris cleaning for better visibility, infrastructure construction (viewpoint places, explanatory panels, trails, etc.) and even restoration (in the case of any natural or human damage). These geoconservation practices are reviewed, particularly, by Prosser et al. [27]. Generally, such maintenance aims at better exposure and accessibility of geosites and reflects human modification of the geological environment. Large areas with several unique features or one big feature can be used for the creation of geoparks, from which the UNESCO Global Geoparks are the most important [22]. Geoparks usually require even more significant human “intervention” into the geological environment and, particularly, massive infrastructural development for tourism purposes. Visitor attraction to geosites and especially geoparks increases human pressure on the environment. For instance, this is the case of the Langkawi Global Geopark in Malaysia [83–85]. If even this pressure is minimal, geosite and geopark maintenance changes aesthetic properties of the relevant geological landscapes. Moreover, the latter receive new meaning when uniqueness and heritage value are realized. The number of geosites in the world is measured by thousands (see Reference [39] for tentative lists of geosites in the European countries), the number of the UNESCO Global Geoparks is close to 150 [86], the European Geopark Network includes ~75 members [87] and there are also many national and other geoparks, as well as the other protected areas that are geosites and geoparks de facto but designated as national monuments or national parks. Taken together, this evidence means geosites and geoparks themselves reflect the human influence on the global geological environment, that is, these are manifestations of the Anthropocene.

Conclusively, the majority of geoheritage types and forms can be related to the Anthropocene and the strong relationship between the Anthropocene and geoheritage ideas is of practical importance. Moreover, geoheritage identification and management for the purposes of conservation and tourism constitute the human influence on the global geological environment and this can be understood as a typical Anthropocene force. Further investigations of the Anthropocene geoheritage are necessary in order to characterize its specific features at particular geosites. Moreover, the present paper reveals

a kind of paradox when the typically Anthropocene geoheritage can be older than Anthropocene in its age. Irrespective of how this paradox will be resolved in the future, it is evident that the Anthropocene–geoheritage relationship challenges the stratigraphical delineation of this new epoch.

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