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Quantification of geodiversity and its loss

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ABSTRACT

Geodiversity, i.e., a diversity of geological heritage sites, can be quantified with an account of geosite types, type counterparts, and their ranks. Higher numbers of geosite types represented within a given territory and their higher ranks indicate a higher geodiversity. Two additional characteristics, namely geoabundance and georichness, allow measure of the quantity of geosites and the diversity–quantity relationship respectively. Geodiversity loss can be evaluated with an accounting of decreases in geosite type ranks linked to the damage of geosites. A calculation of relative and multi-dimensional geodiversity helps in quantitative assessment of the regional geological heritage.

1. Introduction

Geodiversity is a new, but already well-developed concept, which is essential to understand the geological heritage of particular regions and the entire Earth and to coordinate its efficient conservation (see reviews by Gray, 2004, 2008; Scott et al., 2007). Generally, it may be defined as a broad range of geological phenomena constituting the geological heritage. Scientists need to understand the geological heritage to provide a baseline for their studies, whereas the general public needs it to enlarge their environmental knowledge, to be prepared for natural hazards, and to have a new opportunity for outdoor recreation. While a descriptive version of geodiversity is helpful for geoconservation, the total range of relevant management activities require a numerical expression of geodiversity. We need a clear approach to evaluate where it is greater and where smaller, which regions are rich and which are poor in it. A sustainable use of geological resources for scientific, educational, or recreational/tourism purposes makes necessary an understanding of geodiversity damage, either by natural or anthropogenic causes. Despite its urgency, the problem of quantification of geodiversity and its loss is yet to be solved. For example, Gray (2008) specifies 4 kinds of areas that may bear geodiversity hotspots (which itself is a great achievement!), but emphasizes significant difficulties in numerical evaluation of the geological heritage. Ruban (2007) attempted to find a suitable quantitative approach, but his suggestions remained very preliminary and needed corrections.

In its broadest context, this paper aims to demonstrate that geodiversity can indeed be quantified. A more specific aim is to provide a framework for the quantification of geodiversity. The proposals are based on some obvious considerations about geological heritage sites, which provide rationales for utilizing a numerical approach to the geoconservation practice.

2. Definition of key terms

Geoconservation theory and practice are characterized in a comprehensive form by Prosser et al. (2006), whereas Black (1985), Barettino et al. (1999, 2000), Wimbledon (1996, 1999), Wimbledon et al. (1995, 1998, 1999), Ellis et al. (1996), Gray (2004, 2008), Ruban (2005, 2006, 2009, in press), and Scott et al. (2007) summarized some of their essentials. *Geosite* (=geological heritage site, geological monument, and geological heritage object) is the most principal term. It means geological objects or fragments of the geological environment exposed on the land surface, and, thus, accessible for visits and studies (cf. Ruban, 2005). In this case, accessibility means that the object is not buried in the Earth's interior. A broad range of earth-related phenomena necessitates the proper classification of geosites. The Earth Science Conservation Classification (see Prosser et al., 2006) specifies geosites to include quarries and pits (active and inactive), coastal cliffs and foreshore locations, river and stream sections, inland outcrops, underground mines and tunnels, roads, railroad and canal cuttings,

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static (fossil) geomorphological exposures, active geomorphological exposures, caves, karst features, mineral, fossil or other geological deposits, mine dumps, underground mines and tunnels, and some others. When the above-mentioned classification can be suitable for some managerial purposes, it does not represent the natural variety of earth-related phenomena. There are also other classifications (e.g., Lapo et al., 1993; Wimbledon et al., 1995, 1998, 1999). On the basis of information on composition, structure, and evolution of our planet, which can be obtained potentially from geosites, Ruban (2005, 2009) distinguished 21 *types of geosites*, namely stratigraphical, palaeontological, sedimentary, igneous, metamorphic, mineralogical, economical, geochemical, seismical, structural, palaeogeographical, cosmogenic, geothermal, geocryological, geomorphological, hydrological and hydrogeological, engineering, radiogeological, neotectonical, pedological (soil), and geohistorical. Some of these types were also recognized by the earlier workers (e.g., Lapo et al., 1993; Wimbledon et al., 1995, 1998, 1999). However, many, if not most, of geosites are complex and represent several kinds of information. For example, one geosite can be stratigraphical, palaeontological. geomorphological, and geohistorical. Thus, we need to introduce the term *type counterpart*, which describes a portion of any given type among other types of the same geosite. Depending on their importance, geosites of different *ranks* can be distinguished (Lapo et al., 1993; Wimbledon, 1999; Ruban, 2005) (Table 1). Ranks may differ for type counterparts. In this case, one may assume that a complex geosite has a rank corresponding to the maximum rank observed among its type counterparts. For example, if the palaeontological importance is just local, whereas that stratigraphical is global, the entire geosite has a global rank.

Geosites of several types may occur on any given territory, and the entire range of geosite types occurs on the planet. This is a reason to tell about *geodiversity*. Two different definitions of this term are proposed. Gray (2004, 2008) defines geodiversity in a material sense, i.e., as the diversity of geological, geomorphological, and soil features with an account of "their assemblages, relationships, properties, interpretations and systems" (Gray, 2004, p. 8, 2008, p. 287; cf. Lapo, 1999; Stanley, 2000). However, Ruban (2007) treats it just as the numerical expression of geosite diversity. While somewhat different these two definitions are not mutually exclusive and should both remain in use. Geodiversity was introduced similarly to biodiversity (Gray, 2004, 2008) and as with the latter, *geodiversity* may have some *loss*, which can be generally defined as a reduction in the number of geosite types.

In addition to diversity, modern ecology and palaeoecology operates with such terms as abundance and richness (different from species richness!) (e.g., Buzas, 1979; Mosbrugger, 1992; Thomas and Packham, 2007; Townsend et al., 2008). This is a good reason to describe *geodiversity*, *geoabundance*, and *georichness*. Accounting the common (palaeo-) ecological definitions we may propose explanations of these new terms as follows. Geodiversity measures the quantity of geosite types, geoabundance measures the quantity of geosites, and georichness measures both (Fig. 1). Three noted characteristics should be evaluated for a geological heritage of every given territory.

3. Quantification of regional geodiversity, geoabundance, and georichness

3.1. General considerations

3.1.1. Geodiversity

By definition, geodiversity can be quantified as a simple sum of geosite types, i.e.,

$$\text{Geodiversity 1} = \text{total quantity of geosite types occurring on a given territory.} \quad (1)$$

The Mountainous Adygeja geodiversity hotspot is located in the Western Caucasus (southwestern Russia) and exhibits a very diverse geological heritage (Fig. 2 and Table 2). Ruban (in press) recommends this area for establishing the first national geopark in Russia. Principal geosites known from the Mountainous Adygeja are complex, and their type counterparts are igneous, metamorphic, palaeogeographical, stratigraphical, palaeontological, sedimentological, geomorphological, hydrological and hydrogeological, engineering, structural, and geohistorical (Table 2). Thus, Geodiversity1 of this area can be quantified as 11, which is equal to the quantity of the above-mentioned geosite types.

One may assume that higher ranks of geosites make the entire geological heritage more important and, thus, contribute to the geodiversity. In order to account a difference of geosite ranks within a given territory it is necessary to weigh up each rank with a definite score. Linear or logarithmic scales of rank scores can be proposed (Table 1). Logarithmic scale is more appropriate because the importance of geosites with regional and national ranks differs and attracts the attention of unique groups of people. Meantime, rank scores should be chosen by specialists in geoconservation by a deliberative procedure. We may evaluate a geodiversity with a use of maximum rank scores:

$$\text{Geodiversity 2} = \text{Sum of maximum rank scores of each particular type of geosites within a given territory.} \quad (2)$$

Note that the rank score is evaluated for every type counterpart at complex geosites. Maximum rank scores are preferred to average or median rank scores, because a presence of even one higher-ranked geosite of a particular type among many others lower-ranked suggests a higher importance of the entire regional geological heritage, and, therefore, a higher geodiversity.

In the case of the Mountainous Adygeja geodiversity hotspot, the maximum rank scores are as follows (geosite(s) with the maximum score are indicated in parentheses): igneous – 0.01 (Granite Gorge), metamorphic – 0.001 (Granite Gorge), palaeogeographical – 0.1 (Lago-Naki Plateau, Raskol Cliff), stratigraphical – 1 (Raskol Cliff), palaeontological – 1 (Raskol Cliff), sedimentological – 0.01 (Khamyshki Section), geomorphological – 0.1 (Lago-Naki Plateau, Granite Gorge), hydrological and hydrogeological – 0.01 (Granite Gorge), engineering – 0.001 (Khadzhokh Canyon, Granite Gorge, Khamyshki Section, Rufabgo Canyon), structural – 0.01 (Khadzhokh Canyon, Rufabgo Canyon, Sakhraj Canyon), and

Table 1
Geosite ranks and their scores (partly adopted from Ruban, 2005).

Rank	Limits of geosite importance	Suggested scores	
		Linear scale	Logarithmic scale
Local	Important for districts, counties, etc.	0.25	0.001
Regional/Provincial	Important for states, provinces, regions, historical regions, etc.	0.5	0.01
National/Federal	Important for countries	0.75	0.1
Global/International	Important for the world community	1	1