Something more than boulders: A geological comment on the nomenclature of megaclasts on extraterrestrial bodies

Delia E. Bruno, Dmitry A. Ruban

Abstract

Large clasts are common on extraterrestrial bodies, and these are traditionally termed “blocks” and “boulders”. These two terms can easily raise confusion, however, because they are used in a sense that differs from geological definitions. Several classifications of large clasts are currently in use in the Earth sciences, and they differ only in detail. They restrict the size of boulders to 1–4 m; larger particles are called “megaclasts”. The analysis of the published information on large clasts on planet satellites, asteroids, and comets imply that the particles often described as “boulders” actually are megaclasts; boulders, as the term is used in the Earth sciences, are too small to be detected given the limited resolution of most images obtained. It was therefore scientifically preferable if the established geological literature were applied in the modern planetary and space research. It appears sensible to distinguish boulders from megaclasts; the latter comprise bodies that might be subdivided granulometrically into blocks, megablocks, and superblocks. It is also shown that the abundance of megaclasts on extraterrestrial bodies may itself be beneficial for our understanding of such particles, which are rare on Earth.

1. Introduction

Outstanding achievements in the exploration of the Solar System have been recorded since the Sumerian and Assiro-Babylonian cultures, about 2000 years ago, when the cosmic objects were studied for early civilizations needs. Talete of Mileto (624 a.C.), a Greek philosopher, was the first whose whose intuitions led to astronomical hypotheses. Further, observations and then investigations led to major discoveries in the Universe. However, modern planetary and space research employs a lot of knowledge obtained from the Earth.

During the past decades, the development of what can be termed provisionally “planetary geology” (Tanaka and Hartmann, 2012; de Pater and Lissauer, 2015) increased our insight into the age, morphology and structure of extraterrestrial bodies. Some analogies with the Earth have been noted, above all for the nearest planets, their satellites, and some asteroids. It is well demonstrated that the approaches used for geological investigations on Earth can be applied with equal success in studies of other cosmic bodies. A typical example can be found in the work of Pondrelli et al. (2008), who recognized deltaic facies in the Eberswalde crater on Mars. It is worth to add that morphological evidence of fluvial and fluvial-like landforms have been recorded on the surfaces of the inner planets and on some of their satellites (Baker et al., 2015) and also crater size, debris flows, and gullies have been studied in detail (Krishna and Kumar, 2016).

Considering that much of this research has dealt with morphological and structural features, the widespread distribution of large clasts (called ‘blocks’ and ‘boulders’) on extraterrestrial bodies has received close attention (e.g., Lee et al., 1986; Michikami et al., 2008). These large clasts have evident analogues on the Earth’s surface (Fig. 1). Recently, the successful Rosetta mission to comet 67P/Churyumov-Gerasimenko and its flyby asteroid 21 Lutetia has obtained evidence that has increased the interest in both the morphology of these bodies and their ‘sedimentary cover’ (Küppers et al., 2012; Auger et al., 2015; Pajola et al., 2015). Such research requires the use of proper terminology for description of the different clasts constituting this cover.

With regard to the success of extraterrestrial geology (exogeology), it is logical to consider the suitability of the Earth-based clastic rock nomenclature for extraterrestrial bodies. This option has been expressed already, particularly, by the developers of one classification (Blair and McPherson, 1999) and was practically employed by Miyamoto et al. (2007). However, it is evident that these and other classifications are not used widely in the modern planetary and space research. The main objective of the present paper is to discuss the terminology that should be applied to large clasts defined provisionally.
Different classifications of large clasts (grades, i.e., subdivision of classes, are not considered because these appear to be less important for planetary and space science).

Table 1

<table>
<thead>
<tr>
<th>Based on the Udden-Wentworth classification principles</th>
<th>Based on the traditions of Russian sedimentology</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Blair and McPherson (1999)</strong></td>
<td><strong>Blott and Pye (2012)</strong></td>
</tr>
<tr>
<td><strong>Class of clasts</strong></td>
<td><strong>Size (m)</strong></td>
</tr>
<tr>
<td>megalith</td>
<td>33600–107500</td>
</tr>
<tr>
<td>monolith</td>
<td>1048.6–33600</td>
</tr>
<tr>
<td>slab (megablock)</td>
<td>65.5–1048.6</td>
</tr>
<tr>
<td>block</td>
<td>4.096–65.5</td>
</tr>
<tr>
<td>boulder</td>
<td>0.256–4.096</td>
</tr>
</tbody>
</table>

^\(^1\) this classification offers both the Russian and the English terminology.

^\(^2\) see also discussions in Lubova et al. (2013) and Ruban (2015).

^\(^3\) as updated by Blair and McPherson (2009).

2. Theory: megaclast classifications

Clastic sedimentary rocks are widespread in the geological record of the Earth. The development of their classification was critical to the development of sedimentology as an individual discipline. The Udden-Wentworth grain-size classification, proposed more than a century ago (Udden, 1898; Wentworth, 1922), is still widely used and accepted (e.g., Boggs, 2006; Nichols, 2008; Tucker, 2011). According to this scheme, all clasts (particles) larger than 256 mm (~0.25 m) in size are boulders (cf. Dutro et al., 1989). Other classifications used in sedimentological, soil, and geomorphological research place the lower size of boulders in the 60–200 mm range (UIFPA, 1961). In the planetary and space sciences, boulders are understood as apparently intact rocks or rock fragments lying on a surface, regardless of emplacement mechanisms (e.g., Krishna and Kumar, 2016). However, such a simple definition is less useful for geologists, especially those dealing with tsunami- and storm-formed deposits where clasts measured by meters and even dozens of meters are common. As a result, several classification systems emphasizing these larger clasts have been proposed since the end-1990s. These classifications can be divided into two “branches”. The majority of the systems have arisen from the Udden-Wentworth classification. The alternative point of view is rooted in the ideas of the Russian school of sedimentology (Logvinenko, 1980; Shvanov, 1998). This alternative view is based on different scaling of clast size. For instance, sand particles are 0.1–1 mm in size, not 0.0625–2.0 mm as in the case of the Udden-Wentworth classification.

The Udden-Wentworth scheme's derivatives differ. The most famous of them was developed by Blair and McPherson (1999), who limited the biggest size of boulders to 4 m and proposed four new classes for larger clasts (Table 1). Their classification provides exact names for clasts as large as 100 km in diameter (see also Blair and McPherson (2009)). Blott and Pye (2012) proposed another classification system for large clasts. Their system limited the biggest size of boulders to 2 m and defined all larger clasts as megaclasts (Table 1). Terry and Goff (2014) adopted new names for the same size classes, proposed initially by Blair and McPherson (1999). The term 'megaclast' was reserved for all clasts larger than 4 m (Table 1). A comparison of these schemes (Table 1) shows clear differences, but it also shows that the only smallest large clasts are defined as boulders.

Ruban et al. (2013), see also Lubova et al. (2013), Ruban (2015) extended the traditional Russian classification. They limited boulders to 0.1–1.0 m, called larger clasts “megaclasts”, and subdivided megaclasts into blocks and megablocks (Table 1). This classification system is essentially similar to the proposals of Blair and McPherson (1999), Blott and Pye (2012), and Terry and Goff (2014), viz. in that it restricts the size of boulders and includes megaclasts.

Generally, large clasts can be effectively classified with the available methods.
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mentological schemes (Table 1). This is important for studies of tsunami deposits, rockfalls, geohazard evaluation, etc. on the Earth’s surface. And these classifications will also be useful outside the Earth. On cosmic bodies, large clasts can be linked to processes such as impacts, slope angles and conditions, weathering, etc. The information on extraterrestrial large clasts allows their reconsideration using the available data from planets, planet satellites, asteroids, and comets. First, the published descriptions of such objects can be used to specify the classes to which these large clasts belong according to different classifications. Second, it is possible to evaluate the relative abundance of representatives of each class on the basis of quantitative data summarized on size-frequency distribution diagrams. This relative abundance reflects proportions of the established clast classes at each given location.

3. Results

Large clasts, termed “blocks” (Lee et al., 1986; Thomas et al., 2000; Basilevsky et al., 2014), “boulders” (Basilevsky et al., 2013; Kickapoop Lunar Research Team and Kramer, 2014; Krishna and Kumar, 2016), or “clasts” (Wilson and Head, 2015), are reported from the Moon, Mars, and the satellites of Mars. The resolution of the analyses is relatively high, and the smallest particles that can be distinguished as individual pieces are a few meters in size. The number of clasts is large. For instance, about 250,000 “boulders” have been noticed in the Censorinus crater of the Moon (Basilevsky et al., 2013). Usually, such “blocks” and “boulders” were formed by impacts. Using revised classifications of large clasts from the craters of the Moon and Deimos implies that only part of them, although a significant part, can be called “boulders”. Depending on the scheme (Table 2), many would be classified as megaclass, blocks, mesoboulders, or megablocks. Interestingly, in the classifications of Blott and Pye (2012) and Ruban et al. (2013) boulders would not be present among those clasts that provisionally were termed “boulders” in the original works. The largest clast on Deimos recognized by Lee et al. (1986) was called “block”, but its size (200 m) implies this is neither a block, nor a boulder; this is a slab, megablock, or macroboulder according to the different classifications (Table 1). Clasts up to 150–200 m in diameter have been recorded on Phobos, where several “boulders,” 30–60 m in diameter, have also been observed (Lee et al., 1986).

Large clasts have been frequently observed on asteroids (Lee et al., 1996; Miyamoto et al., 2007; Michikami et al., 2008, 2010; Küppers et al., 2012; Massironi et al., 2012; Jiang et al., 2015). These are commonly called ‘boulders’, although earlier publications (Lee et al., 1996) use the term ‘block’. The resolution of the analyses is chiefly moderate and limited to several dozens of meters. For instance, asteroid 25,143 Itokawa has ~400 clasts larger than 5 m (Michikami et al., 2008), and several hundreds have been found on asteroid 21 Lutetia (Küppers et al., 2012). Many of asteroid “boulders” are of ejecta origin, although this is not the only explanation (see Jiang et al. (2015) for a brief review). Reconsideration of large clasts reported from asteroids implies that none of them belong to the class of boulders (Table 3). Of course, this does not mean true boulders do not exist on asteroids, but these are below the analyses resolution. The majority of identified objects are megaclass, chiefly blocks/mesoboulders (Table 3). Slabs/macroclasts are found in large numbers on 243 Ida and 21 Lutetia. Using the classification of Ruban et al. (2013), “boulders” described on asteroids are usually megablocks, whereas blocks are not recognized because of insufficient resolution; 25,143 Itokawa is the only exception – true blocks (sensu Ruban et al., 2013) dominate there (Table 3). Some ejecta “blocks” on 243 Ida reach 150 m in size, where they would fall into slabs, megablocks, or macroboulders, depending on the system used (Table 1). On the asteroid 433 Eros, ~330 forms attributable to slabs/macroclasts, blocks/mesoboulders, megablocks, or megablocks depending on the classifications (Table 3).

### Table 2
Renaming of large clasts from planet satellites.

<table>
<thead>
<tr>
<th>Classes of clasts</th>
<th>Location</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Moon – 12 craters (Basilevsky et al., 2013)</td>
</tr>
<tr>
<td>Minimal diameter (resolution)</td>
<td>2 m</td>
</tr>
</tbody>
</table>

### Table 3
Renaming of large clasts from asteroids.

<table>
<thead>
<tr>
<th>Classes of clasts</th>
<th>Location</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Toutatis (Jiang et al., 2015)</td>
</tr>
<tr>
<td>Minimal diameter (resolution)</td>
<td>20 m</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Combined classification of Blair and McPherson (1999) and Terry and Goff (2014)</th>
<th>megalith</th>
<th>macrolith</th>
<th>monolith</th>
<th>mesolith</th>
<th>slab</th>
<th>macroboulder</th>
<th>block</th>
<th>mesoboulder</th>
<th>boulder</th>
</tr>
</thead>
<tbody>
<tr>
<td>Classification of Blott and Pye (2012)</td>
<td>++</td>
<td>++</td>
<td>+</td>
<td>++</td>
<td>++</td>
<td>++</td>
<td>++</td>
<td>++</td>
<td>++</td>
</tr>
<tr>
<td>Classification of Ruban et al. (2013)</td>
<td>+</td>
<td>+</td>
<td>++</td>
<td>++</td>
<td>++</td>
<td>++</td>
<td>++</td>
<td>++</td>
<td>++</td>
</tr>
</tbody>
</table>

Relative abundance of clasts: +++- high, ++- moderate, +- low.

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these can be classified as megaclasts. The reconsideration of large clasts from different cosmic bodies presented above permits several general conclusions. First, there is inconsistency in the application of terms such as boulders or blocks. Second, these large clasts are rarely true boulders and only sometimes blocks in the light of the modern sedimentological classifications. Third, the low resolution of the surface images of planets, planet satellites, asteroids, and comets often does not allow recognition of boulders as understood in the Earth science. Fourth, large clasts of several classes exist on the considered extraterrestrial bodies, and the relative abundance of these various classes may be significant. These conclusions lead to several implications for the future use of Earth science terminology in planetary and space science.

First of all, preference for the term “boulder” in space research developed over the last quarter of the 20th century. This was a period when the Udden-Wentworth classification was used in its traditional form, with boulders as the class of the largest clasts. The later appearance of more detailed megaclast classifications (Blair and McPherson, 1999; Blott and Pye, 2012; Ruban et al., 2013; Terry and Goff, 2014) occurred after planetary and space researchers had started to use simple, less precise, terminology for clast naming. This is why it is unreasonable to criticize the authors of the works with descriptions of extraterrestrial clasts cited in the present paper. Their analyses and descriptions were as accurate as was permitted by the extant terminology. Curiously, the frequent use of the term “block” in the earlier research on extraterrestrial bodies seems to be more compatible with how large clasts should be classified nowadays.

The conclusions given above imply that the Earth-based detailed megaclast nomenclature is suitable also for the description of large clasts on planet satellites, asteroids, and comets. The schemes summarized in Table 1 permit easy, but not simplistic, naming of large clasts with a clear distinction of the larger and smaller objects. This is especially important because slabs/mesoboulders may be found in the quantities comparable to those of smaller clasts (Tables 2–4). The use of any detailed classification of megaclasts permits adjustments of the resolution depending on the scope of an investigation. If available equipment allows a focus on clasts larger than 7 m, it may be sensible to reduce the resolution to, for example, 10 m, which is the limit between blocks and megablocks using the classification of Ruban et al. (2013). In the other case, when the maximum possible resolution is limited to, for example, 3 m, it may be sensible to reduce it to 4 m, which is the boundary between boulders and blocks/mesoboulders in other systems (Blair and McPherson, 1999; Terry and Goff, 2014). Moreover, the equipment and the analytical procedures may be designed initially to reach a resolution appropriate for distinguishing classes of clasts. Planetary and space studies evolve with a strong tie to the traditional geology. As such, the adoption of Earth-based terminology is a logical extension of the tradition. A boulder on the Moon should be a boulder on the Earth, and vice versa.

The adoption of a consistent terminology in studies of extraterrestrial bodies may be beneficial for our knowledge of the Earth-based megaclasts because of two reasons. First, large numbers of megaclasts are not common on the Earth. Although examples of such clasts can be found (e.g., on the Hawaiian rocky shore (Felton, 2002) or in the Caucasian canyon (Lubova et al., 2013)), megaclast fields on planets, planet satellites, asteroids, and comets are more impressive, while clasts with a size of dozens of meters are abundant on extraterrestrial objects (Tables 2–4). This permits “cumulative” investigations of megaclasts belonging to different classes, which is difficult to undertake on the Earth. Second, research into extraterrestrial megaclasts is often linked to studies of craters, from which megaclasts originated. On the Earth, megaclasts related to an impact crater are extremely rare. Research on other cosmic bodies can extend our knowledge concerning the different mechanisms of megaclast formation. Third, the experience of research into extraterrestrial “boulders” allows consideration of the use of the different classifications now available (Table 1). Many planetary and space researchers have studied megaclasts with size-frequency diagrams, construction of which has become a standard procedure (Lee et al., 1986, 1996; Michikami et al., 2008; Küppers et al., 2012; Basilevsky et al., 2013; Auger et al., 2015; Jiang et al., 2015; Pajola et al., 2015; Krishna and Kumar, 2016). The size of the clasts is shown there along either a linear or a logarithmic scale, but this scale is based on a factor 10 in both cases. Apparently, such scales were chosen by the specialists intuitively as the most suitable (“comfortable”) for data representation and further interpretation. It is noteworthy that these choices are the best compatible with the megaclast classification proposed by Ruban et al. (2013) and linked to the Russian school of sedimentology (Table 1). Of course, this reduces the importance of the schemes derived from the Udden-Wentworth classification, although the wide use of the latter would require certain reconsideration of the

### Table 4

Renaming of large clasts from comets.

<table>
<thead>
<tr>
<th>Class of clasts</th>
<th>Location</th>
<th>Minimal diameter (resolution)</th>
</tr>
</thead>
<tbody>
<tr>
<td>67P/Churyumov-Gerasimenko – Imhotep region (Auger et al., 2015)</td>
<td>2 m</td>
<td></td>
</tr>
<tr>
<td>67P/Churyumov-Gerasimenko (Pajola et al., 2015)</td>
<td>7 m</td>
<td></td>
</tr>
</tbody>
</table>

Combined classification of Blair and McPherson (1999) and Terry and Goff (2014)

- megaclast
- macrolith
- monolith/mesolith
- slab
- macroboulder
- block/
- mesoboulder
- boulder

**Classification of Blott and Pye (2012)**

- megaclast
- boulder

**Classification of Ruban et al. (2013)**

- megablock
- block
- boulder

Relative abundance of clasts: +++- high, ++- moderate, +- low.
method of construction of the size-frequency diagrams.

The occurrence of very large clasts ( > 100 m in diameter) on some extraterrestrial bodies suggests that the sole distinction of only blocks and megablocks among megablocks may not be sufficient to characterize these larger sized objects. If so, an additional class can be added to the classification of Ruban et al. (2013), although its name should not be confused with those proposed earlier by Blair and McPherson (1999) and criticized by Ruban et al. (2013) and Terry and Goff (2014). We propose to call this class 'superblocks', and a full-scale classification of what can be called provisionally "large clasts" can be suggested (Fig. 2). Its usefulness should become a matter for further debates. This classification is rooted in the one developed by Ruban et al. (2013), but some considerations presented above and the principle of naming used in the Udden-Wentworth classification are taken into account. It should be stressed that the preference of the clast size in the new classification is based on the analysis of scales used by the authors of all main sources where "large clasts" on extraterrestrial bodies are characterized. The proposed classification provides easy use of a proper terminology. For instance, the size of clasts resulted from mass wasting in the Imhotep region of 67P/Churyumov-Gerasimenko comet (Fig. 1B) allows the assignment of the two largest clasts to the grade of medium megablocks, and another clast visible there can be assigned to the grade of fine megablocks. Moreover, the same classification can be used for finding proper terrestrial analogues of such extraterrestrial clasts. For example, the gigantic Maiden's Stone in the Caucasus (Fig. 1C) is a medium megablock, and its view permits understanding of how large are clasts of the Imhotep region on an Earth scale.

Generally, the suitability of the Earth-based clastic rock nomenclature for extraterrestrial bodies is an important topic for further discussions, and it requires close and immediate attention of the international research community. Large clasts are reported from many cosmic bodies in addition to those considered in the present paper (e.g., on Mars – see Pondrelli et al. (2008), Orloff et al. (2013), Dundas et al. (2014)), and these also require a consistent, Earth-based classification system. Future missions to planets, asteroids, and comets need to be planned with an eye towards the accurate, consistent classification of megablocks, allowing an integrated investigation of these objects.

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References


