Open Astron. 2017; 26: 48–61 DE GRUYTER OPEN

Research Article

Serhii Kyryliuk and Dariia Kholiavchuk*

Geographic envelope of the Moon and the identification of Moon landscapes with the use of the axiomatic method

https://doi.org/10.1515/astro-2017-0010
Received Jun 19, 2017; accepted Aug 25, 2017

Abstract: Three consequent concepts that build up the algorithm of the identification of modern landscapes on the Moon surface are suggested. They are anaglyphonosphere axiomatic and landscape concepts obtained with the use of the axiomatic method. The first concept depicts the geographic envelope of the Moon as an anaglyphonosphere layer (relief) that is a continuum (total environment). The latter becomes the research subject for both a geomorphologist and a landscape researcher. Continuity, dynamics, range (amplitude), and erosion potential determine anaglyphonosphere. Axiomatic concept means constructing the sole scheme (mathematically determined) of the search for the elementary surface units using the geometric interpretation of surface patterns of the Moon and its landscape interpretation. The landscape concept is based on the classical principles of the landscape theory and the axiomatic principles of the previous concept. The synthesis of concepts is implemented in the models of Moon landscapes of four scales: zero, linear, two- and three-dimensional. The paper offers the last two models of Davy Catena.

Proposed concepts with appropriate correction can be used in parallel studies of the natural environment: geological, geomorphological, climatic, etc. The advantages of the axiomatic method consist in the objective approach to the division of the surface into specific units (the landscapes in our case). The proposed method of identifying and displaying the landscape complexes on the lunar surface can be a significant complement for the study and mapping of terrestrial planets, satellites of planet-giants, etc.

Keywords: Moon, surface; planetary formation; cratering; geographic envelope; Moon landscape

1 Introduction

1.1 Geographic envelope of the Earth in comparison to the Moon

The concept of the geographic envelope (GE) introduced by Brounov as the outer sphere has been known since 1910 (Khodyakov and Khodyakov 2002). Earlier, principles related to GE are found in the works of Reclus (1905) and later in the works of Grigorev (1963). The most recent findings on the subject are manifested in the set of studies (Vernadsky 1998; Thomas and Goudie 2000; Grigorev 1966; Isachenko and Massey 1973; Gvozdetskiy *et al.* 1971; Kotlyakov and Komarova 2007; Huggett 1995; Kondratyev *et al.* 2004) with similar objects appeared. The geographic envelope of the Earth is considered to be the Earth surface where the atmosphere lower layers, the lithosphere upper layers, the whole hydrosphere, and the biosphere are in close interaction with each other (Gerenchuk 1980). Figure 1 demonstrates an active and continuous exchange of matter and energy. The permanent input of water into the atmosphere as a result of the evaporation from terrestrial and ocean surfaces, the input of solid particles into the atmosphere as a result of volcanic events, convection and advection flows are all examples of the interactions. Similarly, the water and air come into the lithosphere through the pores of rocks. Atmosphere gases dissolve in the waters of the hydrosphere. Solid particles enter the hydrosphere due to weathering and endogenic processes respectively. Plants absorb carbon dioxide from the atmosphere and release oxygen. Living organisms while dying off, contribute to the soil accumulation. These are only a few examples.

Corresponding Author: Dariia Kholiavchuk: Yuriy Fedkovych Chernivtsi National University, Department of Physical Geography, Geomorphology and Paleogeography, 2 Kotsubynskogo Street, 58012, Chernivtsi, Ukraine; Email: d.kholyavchuk@chnu.edu.ua
Serhii Kyryliuk: Yuriy Fedkovych Chernivtsi National University, Department of Physical Geography, Geomorphology and Paleogeography, 2 Kotsubynskogo Street, 58012, Chernivtsi, Ukraine; Email: s.kyrylyuk@chnu.edu.ua

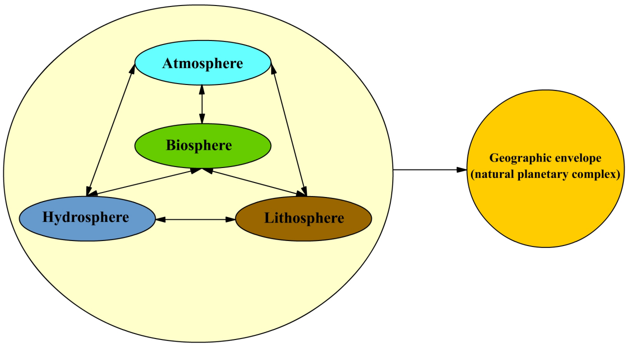


Fig. 1. Geographic envelope of the Earth

In the case of the Moon, the outer sphere becomes different and simpler due to the absence of atmosphere, hydrosphere and biosphere (Khodyakov and Khodyakov 2002). Here, the only component is lithosphere that is determinant for the establishment of the planet GE. As a result, the Moon lithosphere is distinguished by the absence of interactions from other layers common to the Earth and its monolithic structure. Hence, the lower boundary cannot be associated with the core as in the case of the Earth. Vertical boundaries on the Moon are easy to detect in comparison with the Earth GE because of a close and uneven penetration of the components. As a result, on the Earth, vertical boundaries are blurred, but they should be well-defined on the Moon, because there is no such interpenetration.

Taking into account the peculiarities, anaglyphonosphere approach (from the Latin ***anaglyphon*** – relief and ***sphaera*** – sphere) to the detection of the Moon GE is considered for the drawing of the Moon GE. The latter is identified with the anaglyphonosphere layer of the Moon landscape (Figure 2) (Kyryliuk 2012a).

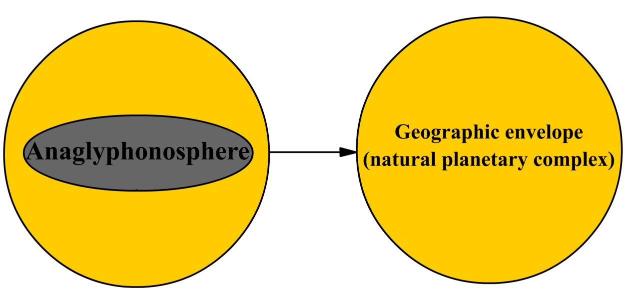


Fig. 2. Geographic envelope of the Moon

1.2 Moon landscape

The Earth landscape studies are of a rather broad and multifaceted context. Still, several branches of the landscape interpretation that are linked to the current research are found. The classical approaches concern studies of Glazovskaya (1963); Victorov (2008); Beruchashvili (1987); Armand (1969); Isachenko (1973); Antipov and Semenov (2006); Andreichuk (2009), in which question of the relationship of "living" and "dead" nature are among the important theoretical preconditions that determine the content and, ultimately, the successful implementation of the complex of landscape studies. The decision of these issues depends on the proper assessment of the role of various factors in the separation and formation of natural landscapes. The thoughts of the listed experts on these issues are largely divergent. Some of them came to the conclusion that in the formation of natural landscapes all factors are equivalent. Others hold the idea of alternating signs, arguing that the leading factor varies depending on the taxonomic rank of the landscape unit. However, most of them give the living matter a leading role in this process. In the case of lunar landscapes, according to the ideas of mentioned scientists, such a role should belong to the upper part of the lunar lithosphere. Pragmatic view– Khagget (1979); Etkins (1987); Kovalov (1999); Merleau-Ponty (1996); Antrop (2000); Kholiavchuk (2015); Luo (2001) – the main idea of these scholars consist in dividing the concepts of "surface of the planet" and "relief". They argue that the surface of the earth-type planet is primarily a material structure, and the relief itself – a consequence of reflection in the human mind of specific features and properties of the planetary surface in the study of landscape complexes on it; aesthetic view – Hrodzynskyi (1998); Buchko (1999) – the aesthetic views on the landscape are reduced to the fact that only Nature, not any artificial objects, including artistic works, is the primary bearer of aesthetic and beautiful. Aesthetic is not laid in any ideal, but in Nature itself, a certain object, the closer it is to Nature (in particular, the territory), the more aesthetic it is. In the case of the Moon, according to these opinions, we are faced with a completely aesthetic body; anthropogenic view– Milkov (1978); Nikolaev (1992); Denysyk (2001) – Anthropogenic Landscape Science is based on four postulates:

1. all natural components that compose the landscape complex are equivalent;
2. the change of any natural component is immediately reflected on all other components and the landscape complex overall;

3. man-made landscapes should be considered as newly created landscapes by human, and all those natural complexes in which radical changes are also made by humans;
4. to anthropogenic complexes should be attributed consciously and intentionally constructed by man to perform certain socio-economic functions and facilities resulting from unintended changes in natural landscapes. It will be suitable to note that the man has already created on the Moon some anthropogenic landscapes – traces of astronauts who visited the Moon, self-propelled vehicles, etc.

Meanwhile, only a few abstract interpretations of the moon surface exist. Geochronologic and lithologic aspects determine joint pathways of the studies in the field. The moon landscapes are insufficiently covered in the recent literature. Gilbert (1893); Baldwin (1949); McCauley (1967); Greeley (1994, 2013); Wlasuk (2000); Bell (2009) offer a specific landscape interpretation. The geochronological dating of the Moon surface including the aspects of landscape diversity is identified in the studies of Green (1962); Hartmann and Kuiper (1962); Quaide (1965); Fielder (1965); McCord (1969); Mackin (1969); Stuart-Alexander and Howard (1970); Ronca and Green (1970); Lowman (1970); Pohn and Offield (1970); Strom (1971). Lithological differences of Moon surface that concern the landscape interpretation of Moon surface are found in the works of Lindsay (1976); Markov (1962); McCallum *et al.* (1975); Kesson and Lindsley (1976); O'Sullivan *et al.* (2011); Nemchin *et al.* (2012).

To come closer to the definition of Moon landscape, it should be compared to the Earth landscape. According to Kovalov (2005), the landscape is not a still image, but alive, permanently changing and unique in every next step. Accordingly, the peculiarity makes a landscape, the reflection of what we cannot cover with eyes or measurements. Hence, giving the description of landscape appears to be senseless. The Earth landscape from we evolve, is the part of our system and we cannot fully understand the system until we are a part of it. On the other hand, the Moon becomes absolutely another system that does not interfere with our life being or interferes with it with a thin and insignificant facet. Moreover, we are able to observe the Moon system from the outside that makes us consider it an alien object. The Earth GE has intense dynamics. The most significant changes can be observed even in a short time span and in separate parts. The same situation is observed within the Moon GE which is the antagonist of the Earth's one. The Moon dynamics is so slow, that the major part of its continuum is found in the homogeneous state in ultralong geological periods. Then, the appearance of new details within its boundaries coexists with the conservation of the old ones. Hence, the landscape definition cannot be applied to Moon landscapes due to the set of differences between the Earth and Moon landscapes. The distinguished details of the Moon surface and its conservation are explained by the lack of atmosphere and hydrosphere that are the most active weathering factors. Besides, the Moon has been tectonically inactive during two-thirds of its functioning that facilitates the conservation of the form and physical state of GE.

The basic idea of the above lays in the particular approach in identifying and interpreting lunar landscapes in relation to earthly landscapes. Given the minimal dynamics of lunar surface changes over a long period of time in models of lunar landscapes, it's possible to ignore the general tendency of the gradual development of landscape, as it occurs on the Earth, where there is always a movement from simple to complex and from lower to higher. Confirmation of this in Earth's condition is the development of landscape complexes in their hierarchical sense: the facies, in the process of development, are transformed into a bigger complex – a complicated facies, then - transformed in the landscape area and, eventually, in the landscape. In the process of development of associated with erosion forms of relief landscape complexes, there is a continuous complication of them until such forms reach the state of maturity. After that, their gradual simplification begins. But this simplification is relative and is not a direct return to the old one. There is no such development on the Moon – the newly created landscape complexes remain unchanged during long geological periods and undergo partial changes, mainly under external influence and as a result of slow morphostructures transformations under the influence of gravitational processes, while retaining a significant part of the primary morphostructure.

1.3 Study Area

To implement the concepts, a Moon area with the typical landscapes of the surface was chosen (Figure 3). Geologic differences of Davy Catena include marine formations that are one of the oldest on the Moon surface apart from the Nectarian Basin and similar to them. In particular, three geologic structures are distinguished in Davy Catena: **1. Formations of Pre-Imbrian time (Nectarian period)** – mostly old craters the prevailing number of which are located under deposits of younger periods. **2. Calie formations** – mare territories of the Imbrian time. They are known for even and flat surfaces that sometimes are disrupted with prolonged ridges and insignificant highlands with the inclusion of clastic and volcanic material. **3. «Cobra head»** – formations of the Copernican period characteristic of young circle structures of meteoritic origin. Their development was mostly connected with volcanic processes.

2 Theory and methods for the anaglyphonosphere concept

2.1 Detection of the Moon GE as an anaglyphonosphere layer

The space that can be depicted with curved planes stuck to the maximum and minimal points of the profile sets means anaglyphonosphere. Accordingly, anaglyphonosphere is a relief sphere that is defined by the profile sets that are made parallel to each other, are tangent to each other, maximal and minimal points of which are fixed to the curved planes. Anaglyphonosphere is not limited by the altitude field and is not a sole plane (hypsometric), but the layer between the maximum and minimum planes of the surface (Figure 4) (Kyryliuk 2012b).

The most appropriate method for the construction of maximum and minimum surfaces of anaglyphonosphere is the method of tangent profiles. The method is based on the determination of maximum and minimum points within profiles that are put into the plane line that will be tangent to the next analogous line. In the sum, they will form the profile set. The interpolation of maximum points, serves the basis for the construction of maximal curve of anaglyphonosphere plane, interpolation of minimum plane respectively, and the interpolation of its differences – the range model of anaglyphonosphere (Kyryliuk 2012a).

2.2 Selection of maximum and minimum points

Theoretically, maximum points should be congruent to the young relief formations generated by endogenous processes. They are seen as positive forms that have not undergone intensive exogenous processes. Conversely, minimum points should coincide with the negative forms that are prone to the intensive influence of exogenous processes. Still, in practice, the situation with the selection is different. Maximum shapes of relief are formed not only by endogenous but also exogenic processes and are related to the planets of the Earth group too. For example, crater swells are positive relief forms generated by exogenic processes such as the fall of a meteorite or the asteroid body. In the conditions of the Earth, Mars, and some part of Venus, the set of eolian formations like dunes and barkhans refer to such forms. Glacial forms of the Earth and Mars such as drumlins and moraine ridges are also the results of exogenic processes.

Minimum points are also formed not only by the exogenic but also by endogenous processes. For example, the majority of the lunar maria is covered with the system of rifts of different level of complicatedness. They are manifested by negative forms of the endogenous origin in the relief. The latter is due to the cracks of the clinker cover formed during the uneven solidification when the mare basins were being developed, and the apparent movements of separate solidified surface mare blocks over the melting lower layers on the initial stages of their formation. In the case of Earth, Venus, and Mars, such relief forms are effusive volcanoes, young tectonic fractures, some parts of geosyncline belts, epeirogenic zones. These disruptions make anaglyphonosphere layer the inhomogeneous. The latter means the anaglyphonosphere inversion.

The basic characteristics of anaglyphonosphere can be grouped by continuity, dynamics, depth range and erosion potential:

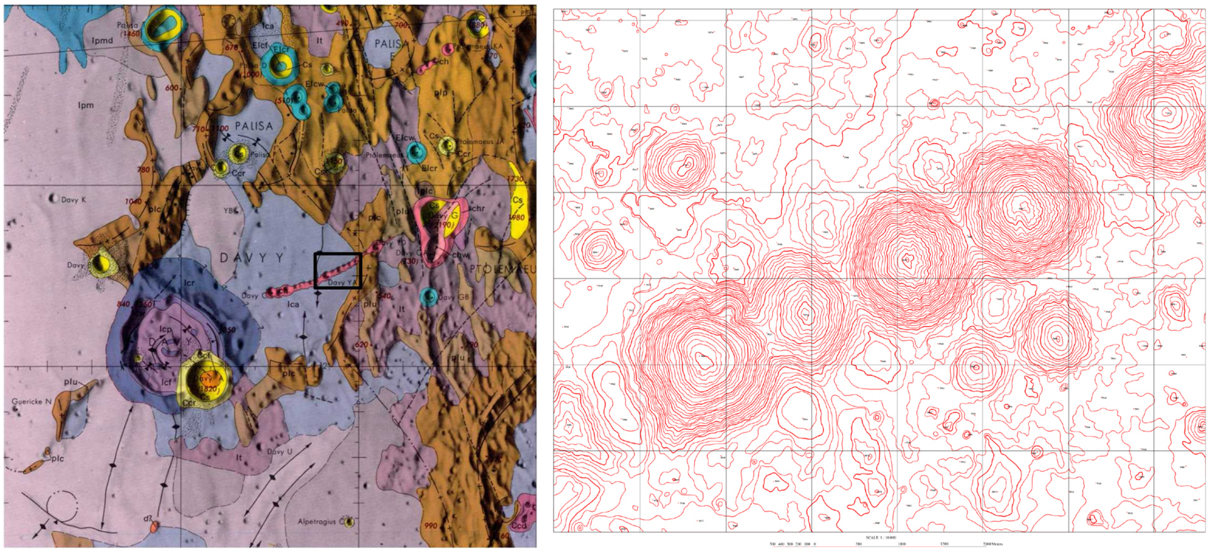
Continuity. Anaglyphonosphere layer is a continuous sphere continuum that covers the entire planet surface disregarding to the dominant sphere on the surface.

Dynamics. The appearance and metric characteristics of anaglyphonosphere are permanently changing under the influence of endogenous and exogenic processes that modify the development of maximum and minimum curves and its structural parts.

Depth capacity (range). The range is a space between maximum and minimum curves of anaglyphonosphere. The range determines the complexity of relief within the typical relief disregarding of its genesis, age, and geomorphological processes. The range remains almost constant within the homogeneous relief.

Erosion potential. The bigger the range, the higher the erosion potential is. Conversely, the smaller the territory, the bigger the denudation is.

The anaglyphonosphere continuum consists of three components: active, passive and potential anaglynosphere. *Active anaglyphonosphere* is found in the space of the maximum and minimum planes and is filled with the material part of the lithosphere undergoing weathering and transforming into the passive one. The *passive anaglyphonosphere* is located within the space of maxi-



a) b)

Fig. 3. Basic maps: a) geologic structures of Davy Catena (Howard and Masursky 1968) b) Davy Catena topomap (Lunar topophotomap of Davy Catena 1971)

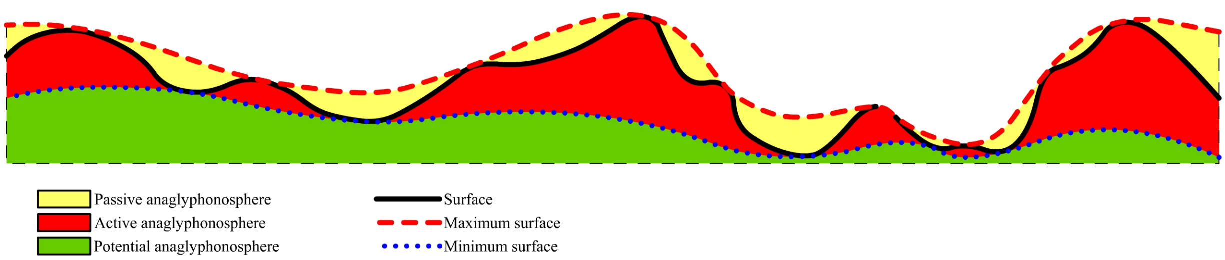


Fig. 4. The scheme of the anaglyphonosphere continuum

mum and minimum planes without the material part of the lithosphere. The sphere is mainly a denudated and a weathered component of anaglyphonosphere. Potentially, the passive component can transform into the active component due to the deposit accumulation, abrupt exogenic and endogenous processes that mix passive and active components. *Potential anaglyphonosphere* lies lower than the average minimum surface and its boundary is defined with the even plane and dynamic in time that coincides with the planet's lowest point (the absolute basis of erosion) and is perpendicular to the normal of planet gravitation.

2.3 Java program

The original Java program was developed for modeling anaglyphonosphere layers (Figure 5). Manual marking process is performed with this program. It minimizes the number of erroneous minimum and maximum points for constructing anaglyphonospheric layers. Automation of the process at this stage leads to a large number of errors in the selection of the maximum and minimum points and needs to be seriously revised. In order to achieve complete automation of the process of marking a basic cartographic image in the future, it is necessarily to involve the relevant highly skilled programming specialists in the work. This program will be the subject of a separate publication. The main purpose of the current application is to create a database of surface points and to construct the interpolation models of maximum and minimum surfaces according to them.

Figure 6 presents the models of the Davy Catena maximum and minimum surfaces built in the mentioned program.

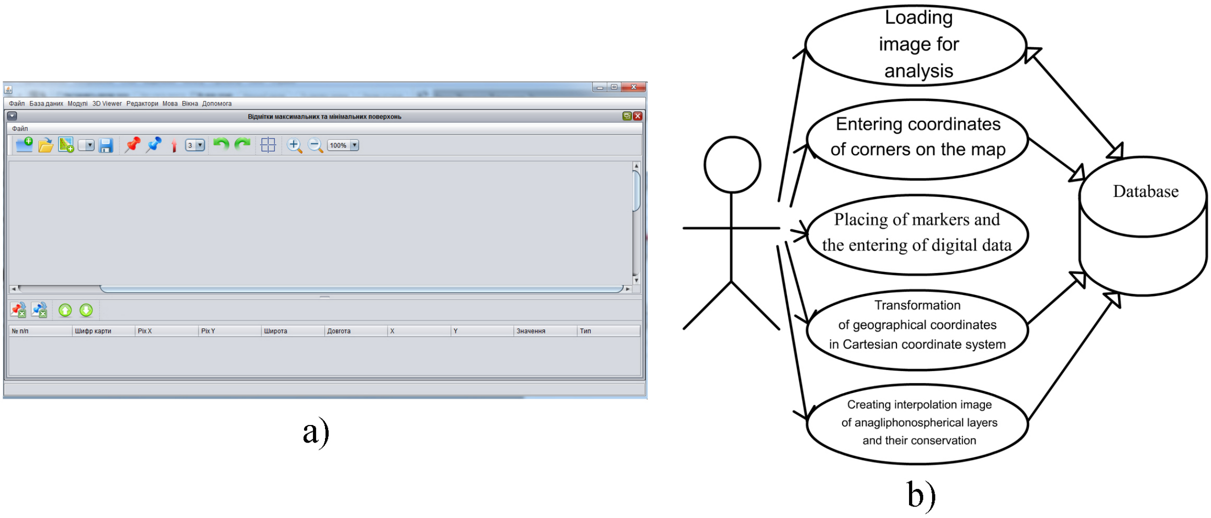


Fig. 5. The Java program for marking maximum and minimum points and synthesis of anaglyphonosphere layers: a) general screen of the software application b) simplified diagram of precedents of functional algorithm

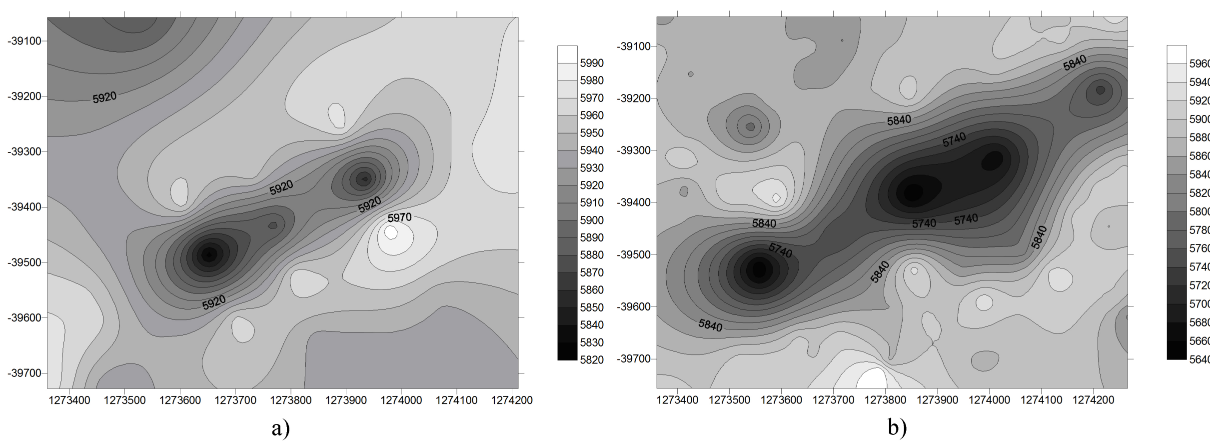


Fig. 6. The Davy Catena anaglyphonosphere surfaces: a) maximum surface b) minimum surface

3 Axiomatic concept

Axiomatic method is a primary method for the explanation of the Moon landscape diversity. In the case of Moon landscapes, the method suggests generating the sole scheme of search, classification and interpretation of elementary surface units. As early as 1916, Berg suggested that in order to establish the law, one should provide parameters to organize the phenomenon (Berg 1950). The latter means the detection of elementary forms of the Moon surface and the landscape interpretation, while generating an abstract model. Next, it is to distinguish landscapes on the Moon surface in the process of generalization of geometric image. The model relies on the three issues:

1. invariant search,
2. distinguishing the landscape properties from its geometric shape,
3. fundamentalization of the elementary form of surface and its identification with geometric figures of surface.

1) The first step is to prove the constancy of the Moon surface appearance with stable properties of geometric figures on the surface and the formed knots. It means the invariant state of Moon landscapes. Here, the invariance is explained according to the theorem of Fary-Milnor (Fary 1949; Milnor 1950):

let $\mathcal{K}$ be a knot in a three-dimensional Euclidian space, k=k(p) – its curvature in the point p. Then, if

$$\int_{K} kds \leq 4\pi, \qquad (1)$$

the knot K is considered a trivial. As a direct outcome of the theorem, all non-trivial knots concern inequality (1). Alongside, in the case of some trivial ("unknotted") knots the value

$$\int_K kds \tag{2}$$

is an integral curvature of knot and may exceed 4π. To detect invariants, we used the Jones polynomials (Jones 1987; Murakami 1989; Prasolov and Sossinsky 1997; Duzhin and Chmutov 1999). The definitions are mainly used to determine the Jones polynomial (Jones 1987; Duzhin and Chmutov 1999): with Kauffman bracket, firstly, we determine additional multinominal

$$X(L) = (-A^3)^{-w(L)} \langle L \rangle \,, \tag{3}$$

where w(L) – the writhe of the L-diagram, and $\langle L \rangle$ – Kauffman bracket. The writhe is determined as the difference beetwen positive links (L+) and negative (L−). The number isn't a knot invariant: it is not preserved in Reidemeister moves of the first type. Then $X(L)$ will be the knot invariant since being invariant regarding to the three Reidemeister moves of the L-diagram (Alexander and Briggs 1926/27; Reidemeister 1926; Trace 1983; Hass and Lagarias 2001; Hayashi 2005; Hagge 2006). The invariance regarding moves of the II and the III type results from the Kauffman bracket and the writhe number in response to these moves. In the case of the I type moves, the Kauffmann bracket is multiplied by $-A^{\pm 3}$, that is compensated with the change to +1 or −1 of the writhe w(L). While fulfilling the substitution

$$A = t^{-1/4} \tag{4}$$

in $X(L)$, we obtain the Jones multinomial V(L). The Jones polynomial is determined while presenting the group of braids with the operational algebra. Let assume the link L. The Alexander theorem suggests that any link is a result of the closure of a braid with n strings (Alexander 1923; Sossinsky 2002).

Let us define the mirror of the braids' group p with n strings by Bn, using the algebra of Temperley-Lieb (Kauffman 1987; Temperley and Lieb 1971); TL_n with the coefficients with

$$Z\left[A, A^{-1}\right] \tag{5}$$

and

$$\delta = -A^2 - A^{-2}. \tag{6}$$

The standard generator of braids σ_i is equal to

$$A \cdot e_i + A^{-1} \cdot 1, \tag{7}$$

where 1, e_1, e_2, ... e_{n-1} – standard generators of the Temperley-Lieb algebra. Let's consider the σ braid derived from L and define

$$\sigma^{n-1} trp(\sigma), \tag{8}$$

where tr – the Markov's track. It gives $\langle L \rangle$, where $\langle\rangle$ – bracket polynomial. With the skein relation, the Jones polynomial is suggested equal to 1 on any diagram of a trivial knot and the next skein relation:

$$(t^{1/2} - t^{-1/2}) V(L_0) = t^{-1} V(L_+) - t V(L_-), \tag{9}$$

here L_+, L_- and L_0 – three oriented diagrams of bindings that coincide everywhere except of the little region where their behavior is connected with positive or negative crossings and the smooth path without joint knots.

2) To distinguish landscape properties from its geometric form. The latter means to move from the specific to the abstract. On the initial stage of cognition of the Moon landscape structure, the forms and knots are the focus but not the quality of landscapes. In the process of abstraction, there is a transition (climbing) from sensually perceived concrete objects of the lunar surface (with all their properties, sides, etc.) to the abstract representations about them, reproduced in consciousness. Thus, the process of abstraction is deliberately neglecting of less significant properties of the lunar surface. At the same time, neglect is the process of isolating and forming of one or several essential features, properties, connections of objects of the lunar surface. The result obtained during this process is an abstract model. The above convergence from abstract to specific, characterizes the general orientation of scientific and theoretical knowledge, which has the aim to transition from less to more meaningful knowledge. In other words, the scientist receives a coherent picture of the investigated object in all the richness of its contents in the end.

3) To recognize the fundamentality of elementary forms on the Moon surface and identify them with geometric figures (circle, triangle, square) to detect invariants and knots. The holistic images or geosystems, are possible to reproduce while moving figures in the space. According to the theory of symmetry, the number of moves is limited. This contributes to the rapid detection of all the groups of moves and generation of combinations. In the case, the group is a set of elements where the operation of multiplication is given and satisfies next axioms:

1. Closure of a group regarding the operation of multiplication: for any or some two elements the third also exists that is derivative (10).

$$\forall A, B \in G : \exists C \in G A \cdot B = C. \tag{10}$$

Such cases can be observed in the distribution of separate moon landscapes (secondary craters, catenas);

2. Associativity of the multiplication – the order of performance does not matter (11).

$$\forall A, B, C \in G : A \cdot (B \cdot C) = (A \cdot B) \cdot C = A \cdot B \cdot C. \quad (11)$$

Such groups mainly characterize the uniform distribution of Moon landscapes in a given area (mare craters, wavy planes with alternate depressions and highlands);

3. The existence of a single element: specific element E exists in the group. The derivatives of the element in the combination with any element of the group A produce the same element A (12).

$$\exists E \in G : \forall A \in GA \cdot E = E \cdot A = A. \quad (12)$$

These are separate landscapes that do not fit to typical forms (volcanic (effusive) formations, sinuses);

4. Existence of reverse element: for any element of group A there is an element A–1, while their derivatives produce a single element E (13).

$$\forall A \in G : \exists A^{-1} \in G : A \cdot A^{-1} = A^{-1} \cdot A = E. \quad (13)$$

The groups of craters that do not differ in shape but in age are the most appropriate examples (Zhelobenko 1970; Kargapolov and Merzlyakov 1972; Barut and Ronchka 1980; Lyakhovskiy and Bolokhov 1983).

The application of axiomatic method using mathematic set results in the models of Moon landscapes of four levels: zero, one-dimensional or linear; two-dimensional, three-dimensional. Three-dimensional models are the most appropriate for the study of Moon landscapes. The generation of models of the relief curvature is based on the measure of sinuosity of the isolinear model of relief and geometric generalizations of the surface image. The curvature is determined by calculating the areas of geometric figures. This areas are calculated in the case of deviation of specific isoline while the mean line is drawn between the utmost points of the isoline in the given area and the geometric figures of the surface identified with the specific nature system are positioned. L. Eyler's method (1956) is suggested to obtain the values of sums. The method is designated to approximate the final sum with an integral. In most cases, it enables to obtain the approximation with any accuracy level (Figure 7.). The final formula of summation by Eyler and the detailed derivation is mentioned in several works (Knut 2006; Kyryliuk 2012a).

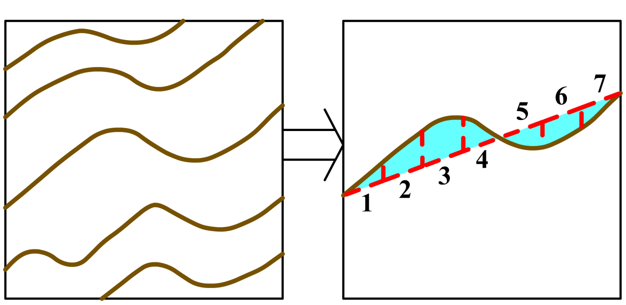


Fig. 7. Approximation of a sum with an integral in relation to the specific isoline

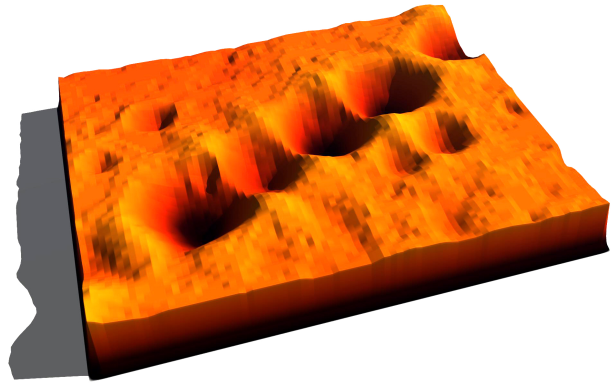


Fig. 8. Three-dimensional model of Davy Catena

The three-dimensional model of Davy Catena produced with the help of the axiomatic and Eylor's methods is shown in the Figure 8 (Eyler 1956; Kyryliuk *et al.* 2015). The model is basically for the landscape mapping of the region.

4 Landscape concept with the use of the axiomatic method

Geometric generalisations for distinguishing landscapes on the Moon are directly connected with the system approach. The generalisations synthesize into their body the set of axiomatic principles of the general theory of systems by Urmantsev:

1. existence (fundamental philosophical characteristic that covers space, time and movement taken separately and altogether,
2. multiplicity (the set of natural formations of the one level of organization due to which the system is formed,
3. totality (single properties that are common to the system elements),
4. unity (structural relations between elements and parts of the system that facilitate the system unity),

5. sufficiency (certain number of elements and structural relations that enable the system existence) (Urmantsev 1972, 1978, 1981; Smirnov 2016).

Consequently, the axioms are involved in constructing abstract images. The construction of images for real natural bodies is senseless. Sokolov and Targulyan (1977) suggested three statements for axioms in soil studies:

1. soil is an independent natural and historical body,
2. soil is a result of the interaction of rocks, climate, living species, relief, and time,
3. all the factors of the soil genesis are equal.

These axioms can be successfully applied to the construction of abstract models of Moon landscapes. There is no significant difference in the application of the earlier mentioned principles to all the nature bodies in the Earth, as well as the Moon, within a single geosphere or in the complex of geospheres:

1. landscapes of the Moon are independent natural and historical formations,
2. landscape of the Moon is a result of the interaction of rocks, climate, relief, exogenesis and time;
3. all the factors of genesis and evolution of Moon landscapes are equal.

The existence of the system of Moon landscapes and its elements contributes to the search for boundaries between the components. The contact of any bodies and natural in particular, is fundamental in mathematics and is closely connected with discreteness and continuity. Armand (1975) considers that the discrete space can be divided into boundaries only by natural measures cutting the space everywhere. The continuous space can be divided in different ways. It is a fundamental fact that the nature of geographic space is continuous. Hence, there is no difference what geographic space is taken into account (geographic envelope of the Earth, the Moon, and the Solar system). Meanwhile, the “paradox of contours” appears that means drawing boundaries where they are absent (Rodoman and Ekkel 1982; Miller and Petlin 1989; Kolomyts 1996; Grodzinskiy 1991).

The boundaries determine elements and its systems. Fridland (1972) considers an elementary area to be the extremely small territorial unit. It is a characteristic of the specific level of organization of the complex system. Perelman (1977); Solntsev (1981) identify “elementary landscape” in the broad spectrum of sizes that are in the directed relations with them.

General beliefs about the element as a main component of a system in the Earth sciences are manifested in the concept of an elementary grid (Dragunov 1965; Shafranovskiy and Plotnikov 1975; Zabrodin 1981). Landau and Lifshits (1976) show the grid to be distinguished with crystallographs. Here, the elementary grid is a parallelepiped built on the mutually perpendicular vectors. In the case of the landscape organization other figures that form knots (triangle, square) can be applied.

The principles of system functioning should be found after obtaining the system of elements. Eynshteyn (1965) was convinced, that the responsibility of a researcher is to find principles of elementary laws. The idea of the utilization of principles in the Earth Sciences was introduced by Kedrov (1983). He considers any scientific problems should be resolved with the methods of structural axiomatic studies but not only with the methods of genetic analysis, which means that a researcher is faced with the formalized and abstract concepts.

The concepts of abstraction and idealisation are widely used in the Earth sciences. For instance, Dokuchaev (1949) built an idealized soil surface, Glazovskaya (1964) and Afanasev (1977) generated an ideal zonality of soils, Ryabchikov (2001) constructed an ideal hypothetical continent, Stepanov (1986) built a model of soil environment with the invariant and group properties. Hladitsyn worked on the mathematic methods in geography while using the law of closed space and methods of statistics and balances as well as harmonical analysis to characterize the rhythmic phenomena (Armand 1989). Similar abstract and idealized models can be built to explore the landscape environment of the Moon. Based on the abstract and idealized concepts in physical geography, the widely-used term «geographic structure» is introduced by Kalesnik (1970). Sochava (1978) proposed the term «geosystem». Yermolaev (1975) offered the term «geographic space» that was later identified with «soil and geographic space» mentioned by Zolnikov (1970). The outcomes of theoretical assumptions on geographic space and its symmetry are manifested in the work of Solntsev (1981).

Hence, the abstract and idealized models contribute to the search for the discrete and continuous features in the landscape environment. As earlier mentioned, Armand (1975) is convinced in the continuous character of “landscape environment”. Since the Moon GE with the landscape environment is significantly different from that of the Earth, the Moon surface should be continuous too. Conversely, Solntsev (1949); Lidov (1949); Yermolaev (1962); Solntsev (1973) argue the landscape environment of the Earth to be discrete. We propose that continuality or discreteness of the landscape environment are distinguished in the case of addressing specific hierarchical levels of the landscape environment or in the case of a semicontinuum when the discrete is interwoven with the continuous (Khain 1973). The plicated and block structures of the lithosphere serve the examples.

5 Results and discussion

In the case of the Davy Catena landscape complexes, the authors built the series of morphometric and geomorphologic maps (types and genesis of relief) using classical methods of geomorphologic mapping taking into account the Moon surface peculiarities and axiomatic method with geometric generalisations of the day surface (Kyryliuk 2012c; Kyryliuk and Kostiuk 2014a,b; Kyryliuk and Kyryliuk 2014).

The set of landscapes is distinguished in the chosen area (Figure 9.):

1. Mare surface. The landscape is similar to the depression and positive sections. The difference with the latter manifests in the absence of the closed relief forms. The primary peculiarity concerns the presence of the wavy and flat surface shapes that are rarely disrupted by other forms.

2. The slightly wavy depression sections of mare surface. They are found on significant areas and are presented by the concave and elongated surface forms.

3. The slightly wavy positive sections of mare surface. Morphometry is identical to the depression forms. The difference is in a positive relief. The alternation of forms is explained by the uneven lava spreading in Imbrian period when the surface was formed. The nature of weak folding is probable, but needs further approval.

4. Inner crater slopes. In contrast to the big Moon craters, the small ones do not have the system of terraces and differ in steepness only.

5. Crater bottoms. The bottoms are mainly fulfilled with a colluvial material that periodically slides down from the inner crater slopes.

6. Inter-crater saddles. They look like the Earth saddles between two neighbouring peaks. In this case, they are noticed in the places between two craters and are developed only in the crater catenas or in the craters located close to each other. The presence of these relief forms points to the similar or identical age of objects.

7. Convex peaks of ascending swells. The peaks have the rectilinear geometric form that is very seldom disrupted with the linear scree depressions.

8. Ascending swells. They are similar in morphometry with the Earth watersheds and are characterized with the slightly wavy system of distribution. As a rule, they are located on the peripheries of craters. Still, there are areas where they are absent because of the weak manifestation of a crater formation or small asteroids and the dislocation of the fall vector of a striker that was different from the parallel. Accordingly, the swells are formed on the side of the crater where the vector of deviation is dislocated to more than 90°; conversely, when the angle is smaller, the swells are not fully developed.

9. Slopes of ascending swells. They are the same in the morphometric parameters with the inner crater walls. The difference concerns a genesis.

10. Outer crater slopes. The slopes are less steep but with a more significant curvature in comparison to the inner slopes. The situation points to the longer time of final establishment of the landscapes.

11. Small craters. They are mainly secondary and tertiary with small sizes (up to 200 m). The craters do not have a strict crater structure besides of a circle depression.

12. Linear scree depressions. They resemble river systems of the Earth. The difference is in the genesis, since depressions are of scree nature. They are observed only within the inner walls and slopes of ascending swells. These landscapes are found in the big craters with the big areas of manifestation, where the character is not only by scree, but also scree with cones of the take-off and large moving bodies.

The proposed method has been applied to other regions of the Moon: lunar craters Pomortsev (Dubiago P), Yerkes, Picard, Menelaus, Timocharis and Lambert; Montes Apenninus and Mare Serenitatis, where it proved to be effective in identifying and further landscape interpretation of the lunar surface. It should be noted, that the proposed method was also tested on the Earth, where it showed significantly lower results, except for the geomorphological component of the interpretation. We believe that poor results are due to the multicomponent structure of the earth's surface, which is characterized by a sharp surface dynamics, such as the season of vegetation changes, hydrological phenomena of different genesis, geodynamic processes, etc. Such a situation reduces the number of proposed positions of the axiomatic method, for example fundamentalization of the elementary form of surface and its identification with geometric figures of the surface.

The system of landscape division, obtained by applying the axiomatic method, contains, on the one side, all morphological categories of the surface and on the other, it includes several special units and significantly differs from the set of units found in the works of other authors. Attempts to compare representations on this issue suggest that the removal of the agenda of the axiomatic method development for the identification of lunar landscape com-

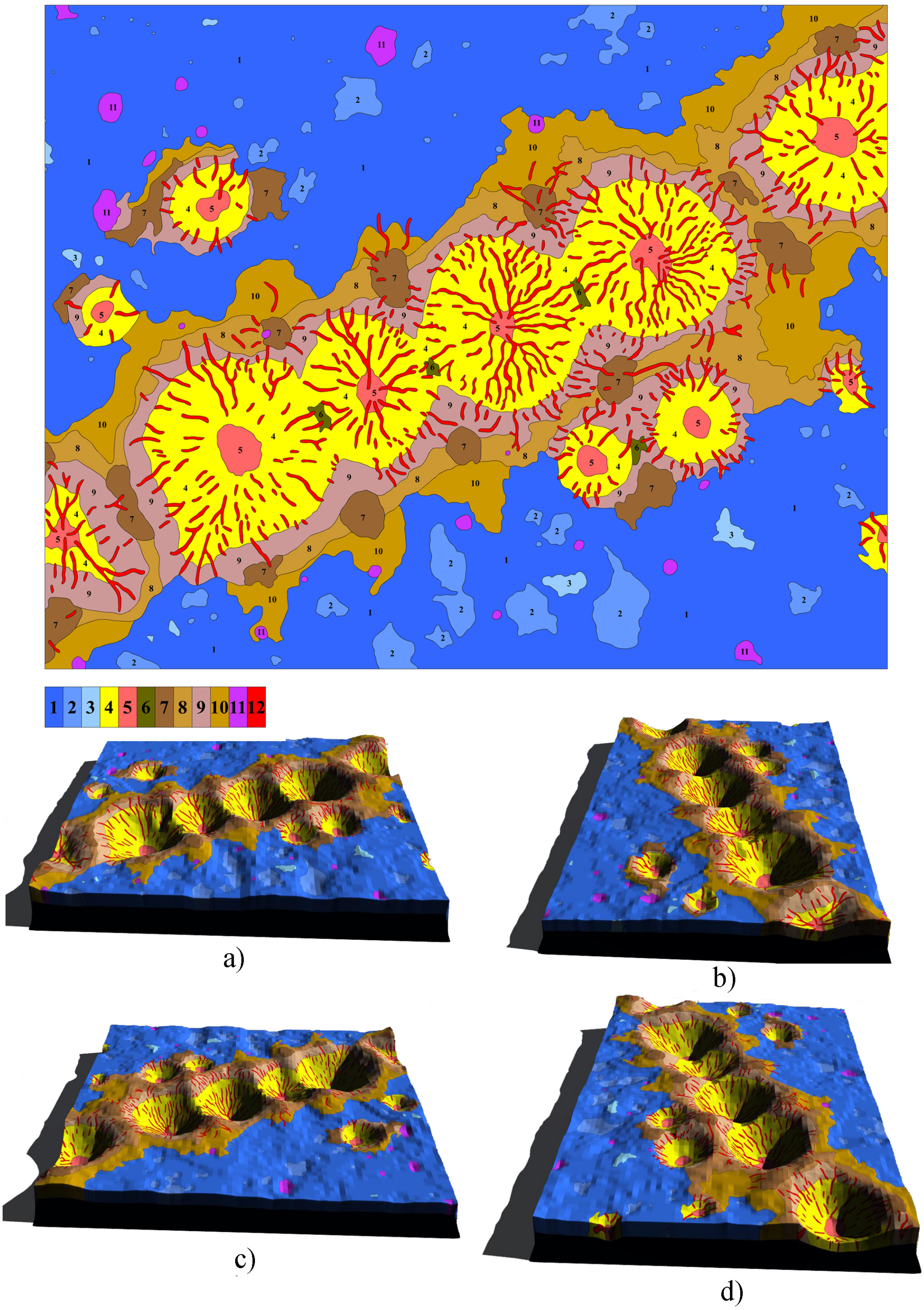


Fig. 9. Landscapes of Davy Catena and its three-dimensional interpretation: 1. Mare surface, 2. The slightly wavy depression sections of mare surface; 3. The slightly wavy positive sections of mare surface; 4. Internal crater slopes; 5. Bottoms of craters; 6. Inter-crater saddles; 7. Convex peaks of ascending swells; 8. Ascending swells; 9. Slopes of ascending swells; 10. Outer crater slopes; 11. Small craters; 12. Linear scree depressions;
Three-dimensional images of Davy Catena: a) view to the north; **b)** view to the east; **c)** view to the south; **d)** view to the west.

plexes is premature since, in our opinion, it is still insufficiently developed and requires a much larger empirical base. Nevertheless, the existing evident successes, provide an opportunity to anticipate positive changes in the development and improvement of the proposed method and the highlighted concepts with optimism.

6 Conclusions

1. In comparison to the Earth envelope, the geographic envelope of the Moon is not polyspherical, is represented with one component of anaglyphonosphere, and is homogeneous all the way through.
2. The maximum surface reflects in some way the primary surface that was formed under the influence of the set of relief-driven processes. Minimum surface points to the relative base of erosion and the lowest point of a potential anaglyphonosphere is supposed to the absolute basis of erosion.
3. The relief range determined by the difference of maximum and minimum surfaces is an essential parameter, since it is characteristic of territories with the most activated processes of weathering. The level of denudation is also defined by the range that is perspective for supplementary studies developing the scheme of relief-driven and relief-destroying processes and events.
4. The implementation of the range coefficient into the geomorphological and landscape studies will contribute to the comparison of the relief forms and natural complexes of different genesis not only within a specific planet and one genetic group but also within the group of planets with a solid surface, different genetic types of relief and natural complexes in general.
5. Axiomatic concept consists of three fundamental positions:
   - search for invariance;
   - abstraction;
   - fundamentalisation.

   The application of symmetry in the third block is aimed at detecting all the groups of moves and generation of its combinations that serve the landscape model and the structure of landscape organization of a territory. The latter is identified with four aspects:
   - closure of groups;
   - associativity of the group;
   - existence of a single element in the group;
   - existence of a reverse element in the group.
6. Landscape concept with the use of the axiomatic method manifests in the algorithm:
   - geometric generalizations
   - construction of abstract images
   - search for boundaries
   - formation of elements
   - determination of fundamental principles
   - establishment of the continuous and the discrete
   - building of the Moon landscapes' models.

The order of operations for landscape studies of the specific territory is objective and is parametrically described according to the sequence of axiomatic concept. In turn, the latter is mathematically proved.

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