Advances in Biology & Earth Sciences
Vol.2, No.1, 2017, pp.73-84

INDICATOR GEOMETRY OF CRYOGENIC LANDSCAPES

V. R. Alekseev[1,2*]

[1]V.B. Sochava Institute of Geography SB RAS, Irkutsk, Russia
[2]P.I. Melnikov Permafrost Institute SB RAS, Yakutsk, Russia

Abstract. The indicator geometry of cryogenic landscapes (cryogeometry) as a promising scientific direction of geographical research is considered. Examples are provided of the interpretation of geometrical figures on aerial photographs and space images.

Keywords: *indicator geometry, cryogenic landscapes, underground ice, permafrost.*

Corresponding Author: *Prof. Vladimir Alekseev, V.B. Sochava Institute of Geography SB RAS, Irkutsk, Russia, 554033, 1, Ulan-Batorskaya st., Irkutsk, Russia, e-mail: snow@irk.ru*

Manuscript received: *26 January 2017*

1. Introduction

Geometrical characteristics of cryogenic landscapes provide a crucial information resource for geographical permafrotology. Information on the external appearance of freezing earth materials has been widely used in all evolutionary stages of geocryological science, and to date it has steadily high demand among researchers specializing in quite different fields. Landscape regionalization of a territory is thought to form the basis for cryogenic survey. Otherwise it would be impracticable to map the permafrost and seasonally frozen ground as well as accompanying cryogenic-geological formations. However, the term “landscape” does not have an unambiguous interpretation; therefore its use in this paper requires further explanation.

2. On the notions “landscape” and “cryogenic landscape”

The German word *Landschaft* means “scenery” or a general view of a terrain *(Land* **–** a word from Germanic origin, and -*schaft* is equivalent to the more common English suffix –*ship*). The geological-geographical literature uses three main definitions of the term: regional, typological, and general. According to the regional definition, it is a particular, individual natural-territorial complex (NTC) that has its geographical name and an exact location on the map. Typological approach implies that the landscape is a certain taxonomic category combining facies, facies groups, stows, etc. In this approach, one type of landscapes can include units separated from one another. A general definition treats the landscape as the notion not bounded by the taxonomic frames, i.e. as the synonym of NTC. In this case, a natural-territorial complex is considered to mean *”a consistent combination of natural, geographical components (the Earth’s crust with its intrinsic topography, water, air masses, soils, and communities of living organisms) forming an integral material system…. The individual components of* *the natural environment within the NTC are evolving as parts of a single whole"* [1]. Hence, a particular landscape must have a volume, a weight, a shape, definite properties, etc. When this is the case, there arise a number of very important questions, such as: Where is the upper and lower boundaries of the landscape? Can it be weighed and displaced and How can a number of integral physical characteristics be determined? And some other questions.

It is obvious that the notion of the "natural-territorial complex" is not equivalent to the notion of the "landscape" in its original meaning. That is the reason why the word "landscape" is used by many naturalists as an adjective (landscape complex, landscape survey, and landscape indicator), although they share many theoretical statements of landscape science concerning the dynamical processes of interaction of conjugate environments: the ground layer of air, snow cover, vegetation, soils, underlying rocks, etc. [2, 3]. Thus researchers of the Geology Faculty (Moscow State University) and specialists of VSEGINGEO and PNIIIIS used the landscape-indication method of mapping frozen rocks to arrive at the conclusion that the geographical landscape is not a volumetric category of the environment but "an area of the land surface bounded by natural borders within which the natural components (topography, soil, vegetation, water bodies, climate, and fauna), as well as artificial, i.e. anthropogenic (built-up areas, roads, agricultural lands, etc.), are in interaction with an adapted to one another [4]. It is this viewpoint which is reciprocated by us. We believe that the landscape is the interface between lithosphere, atmosphere and hydrosphere which reflects their interaction and evolutionary development; it is a two-dimensional, rather than a three-dimensional, space that has a length and a width but does not have a depth and a height.

In the aforementioned meaning, the landscape implies an infinite set of modifications among which the cryogenic group of formations stands out in cold regions of the globe. The cryogenic landscape is the type of terrain, the main physiognomic features and properties of which are responsible for subzero temperatures as well as for snow and ice masses. This feature has a clearly pronounced zonality and differs from all the other categories of natural environment by its specific properties and exceptionally important functions. It is highly sensitive to external impacts. A change in its structure, caused by phase transitions of water, gives rise to extremely hazardous and disastrous phenomena, to the extent that the initial NTC disappear. That is why the study of cryogenic landscapes is acquiring a very important practical significance.

The synonym of the term "cryogenic landscape" is the "cryogenic type of terrain". Ranking (classification) of the types of terrain is the subject of geographical landscape science. It received wide acceptance and was used in the series of large-scale World Maps, the territory of the USSR, Russia and separate regions. Many landscape maps contain characteristics of the cold environment, but they are not special models that would provide a thorough insight into the significance of low subzero temperatures, solid precipitation, and snow and ice cover. The sole exception is provided by some publications of the authors from the Permafrost Institute SB RAS for the territory of Yakutia [5, 6], but they are not systemic in character, because a universal classification of cryogenic landscapes has not been developed.

The notion of "landscape" is related to the notion of NTC. A combination of the NTC components ("lithogenic base", soils, vegetation, etc.) and their state is always reflected in the characteristics of the day surface. NTC and landscape are not simply interrelated, but they are genetically conditioned. Neither of them exists separately. Identification of landscapes from quasi-constant classification attributes characterizing the composition, form, orientation and location of units reflects a long-lasting state of territorial complexes, whereas the use of variable indicators (color, reflective power, structure of surface, etc.) fixes a short-period transformation of the properties of the interface (during hours, days or seasons).

The cryogenic landscape possesses a large number of useful attributes and properties which can be used to easily disclose, read and assess the events in the past, determine the current dynamical state of the surrounding space and to make a forecast for the future. Therein lies the outstanding cognitive significance of landscapes in general, and cryogenic landscapes in particular.

3. Principles of indication cryogeometry

Landscape is the mirror of natural phenomena. None of the processes, irrespective of their scale and duration, occur without leaving a trace. Land surface sensibly responds to every internal and external impact. And these impacts are reflected not only in the physiognomic appearance of the landscape but also in the structure, properties and state of NTC. This fundamental property of the material world forms the basis for interpretation of the most intricate and enigmatic patterns of land surface. Landscape indication of natural phenomena is a well advanced scientific area [3, 7, 8]. With the advent of aircraft and space technology, it became widely known and found practical application. The indication properties of cryogenic landscapes were studied by many researchers over the course of the last 70– 80 years. To date they form a reliable information basis for engineering-geocryological explorations and mapping [9, 10]. They are used to determine not only many external features of NTC but also their deceptive (i.e. hidden from direct observation) components and their characteristics. The external appearance of the freezing and thawing earth and of the snow and ice cover is an open book of Nature, and it is easy and simple to read it provided that there are appropriate skills in interpretation of characteristic attributes and properties of cryogenic phenomena. Of special significance in this fascinating and useful process is the observer's ability to see, transform and reflect the multifarious portrait of terrain in a graphical form, i.e. in the form of a drawing on paper, tracing-paper, cloth, monitor screens or on some other recording information medium. In this case, the following main principles of indication cryogeometry should be sued as a guide.

1. Structural elements of a landscape of any complexity category can be represented as a system of geometrically regular figures and lines which can be measured or calculated by using modern instruments and mathematical operations.

2. Geometrical elements of a landscape that produce the pattern of the land surface, snow or ice reflect quite definite processes of interaction of boundary environments, and their internal content and dynamics.

3. The information capacity and indication significance of cryogenic landscapes depend on the type of generalized figures and lines, their number, size, relationship) mosaic pattern), and on the position in the system of geographical coordinates.

4. The reliability of indication is controlled by physical laws of formation and development of cryogenic systems, and by special-purpose observations on reference experimental plots and in representative test areas.

4. Geometrical interpretation of cryogenic landscapes

The characteristic features of landscape are most thoroughly reflected on aerial color photographs and space images. Serial imaging provides a means of studying changes in the properties and structure of land surface, glaciers, aufeis, and ice cover of seas, rivers, lakes and reservoirs. Photographs as products of remote sensing done by human-controlled instruments are always objective. Essentially it is a mosaic pattern of external attributes of NTC.

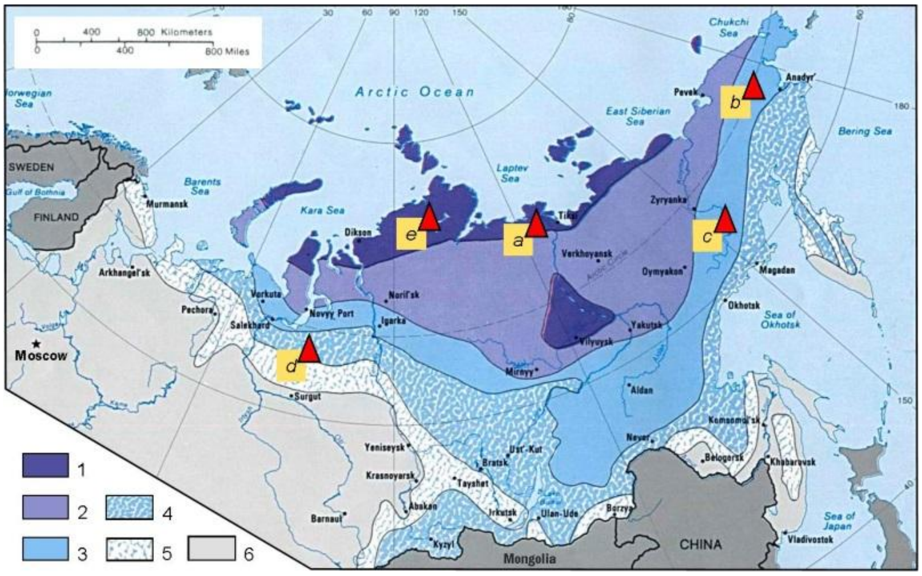

Fig. 1. Distribution of permafrost and geometrical figures in cryogenic landscapes of Russia.

1– continuous permafrost more than 500 m in thickness; cryogenic geometrical figures are universal in occurrence; 2– continuous permafrost 300 to 500 m in thickness; cryogenic geometrical figures occur on mountain slopes, on watershed planation surfaces, and in river valleys; 3– discontinuous permafrost 100 to 300 min thickness; cryogenic geometrical figures occur in intermontane depressions and on flat watershed spaces; 4– permafrost islands; cryogenic geometrical figures only rarely occur in wide valleys and intermontane depressions; 5– sporadic permafrost up to 25 m in thickness; geometrical figures only very rarely occur on flat mountain summits; 6– no permafrost; there occur only relict forms cryogenic landforms. Study areas of the territory: *a*– Lena river delta; *b*– Chukotka Peninsula; *c*– Kolyma river basin; *d*– West Siberian Plain; *e*– Taimyr Peninsula.

For obtaining geometrical characteristics of the features in images, it is necessary to designate, at least virtually, their boundaries, which is not always possible. It is easier and more reliable to prepare a drawing of the feature by creating its graphical image and removing unnecessary details and "noise" as well as bringing the resulting image to the system of very simple geometrical figures – they can be measured and described by using the known mathematical formulas.

This open up an "unexpected" possibility of putting in order the complicated picture of cryogenic and post-cryogenic phenomena, determining their quantitative indicators, gaining insight into the regularities of the distribution, the characteristic properties of conjugation and transformation, and, above all, constructing characteristic geocryological profiles or volumetric block models, which is particularly important in engineering development of a terrain. There are excellent results of a mathematical modeling of the morphological structure of landscapes and methods of calculating quite diverse characteristics of selected contours – their complexity, form, dissection, orientation, mutual location, neighborhood, etc. In order to formalize a mathematical modeling and calculations, A.S. Viktorov [11, 12] suggested a unified classification of landscape patterns in which he identified three systems of images (homogeneous, quasi-homogeneous, and inhomogeneous), each of which is divided into three classes: diffuse, banded and polygonal structures. The classes are subdivided into a set of more fractional taxonomic categories: uniform, nonuniform, tortuous-banded, polygonal-fan-shaped, and others (totaling more than 50). The suggested typization and the methods of quantitative analysis of geometrical figures are, in full measure, also applicable to features of cryogenic and glacial origins.

A geometrical study of cryogenic landscapes is possible at any scale beginning with 1:1000. At a large scale, it is possible to excellently reflect the structure, size and development stages of cryogenic-geological and glacial features. A medium scale makes it possible to fix the boundaries and configuration of massifs and frozen and unfrozen rocks, the outlines of glaciers, aufeis, avalanches and snow patches. On small-scale maps (1:1 000 000 and smaller) the boundaries of natural zones (tundras, forest-tundras, forest-steppes, and steppes) can be used to identify the distribution of continuous and discontinuous permafrost, and permafrost islands as well as the thickness of the layer of seasonal freezing and thawing of ground. Experience of cryogenic mapping on the landscape basis as accumulated by Russian, American, Canadian, Japanese, Polish and other researchers for the last 50– 60 years is unique [13, 14-21]. It was partly summarized in co-authored publications (Moscow State University, PNIIIIS and VSEGINGEO) [9, 10, 13], a great deal of the published procedural manuals and recommendation is largely outdated, because there appeared new data of the Earth's aerospace sensing with high resolution and in different spectral regions. Instruments and methods of large-scale aerial photography have been improved, electronic information media appeared, the possibilities for computer processing and conversion of data have expanded, and many other developments. Nowadays, it is possible ("without leaving the house") to download via Google or some other Internet web search engine the image of any part of the planet Earth and use it where needed, including to obtain information on cryogenic processes and phenomena.

As an example of the geometrical interpretation of cryogenic landscapes, we provide the description of some areas of the permafrost zone of Russia as shown in Fig. 1. The descriptions are made on the basis of interpreting a high resolution space image and photographs taken from a helicopter and a hang glider. By interpreting the space image (Fig. 2), it was possible to determine the number, the morphogenetic characteristics and the spatial distribution of the lakes within an area of 45 thou km^2, construct a hypothetical profile of permafrost containing of wedge-vein ice as well as suggesting the possible position of suprapermafrost taliks and their configuration. The space image suggests the conclusion about the dynamics of thermokarst basins, a contemporary reduction in the area of the lakes, and their influence on the position of the upper boundary of permafrost and on the depth of the thawing of earth materials.

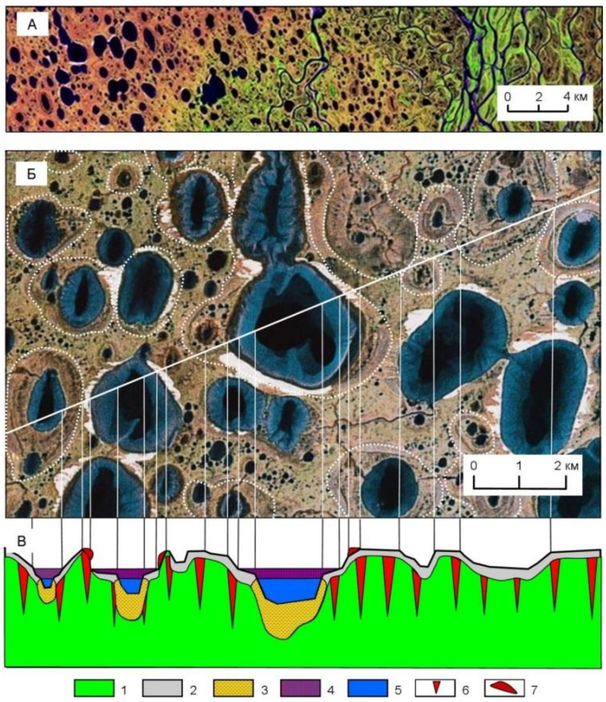

Fig. 2. Geometrical interpretation of the cryogenic landscape of the Lena river delta. Space image from Yandex website Fotki…1303825287_nasa_earth-1015.

A – fragment of the small-scale space image. Lacustrine-alluvial plain complicated by the braided by-channels of the Lena river. The total area is 45 thou km^2. It is composed of permafrost material with high ice content 250– 300 m thick. The upper 10– 15 m horizon is penetrated by ice wedges and veins. Within the delta there are 30 thousand lakes, most of which have a thermokarst origin. B – an enlarged portion of the space image. The system of thermokarst lakes that formed the melting of ground ice (the alases are highlighted by a discontinuous white contour). Within the portion of the territory thus highlighted there are 366 and 18 lakes with an area less and larger than 1 km^2, respectively. Shallow lakes freeze completely to their bottoms, and suprapermafrost water-bearing taliks lie beneath large lakes. C – geocryological profile. Rocks : 1 – permanently frozen, 2 – seasonally frozen, 3 – unfrozen, 4 – freezing part of water bodies (lake ice), 5 – unfreezing water layer, 6 – wedge ice, 7 – snow patch.

All this provides evidence for an exceptional complexity of the conditions for engineering development of the Lena river delta.

Fig. 3 presents the geometrical figures of bog landscapes characteristic for different natural-climatic zones of Northern Asia.

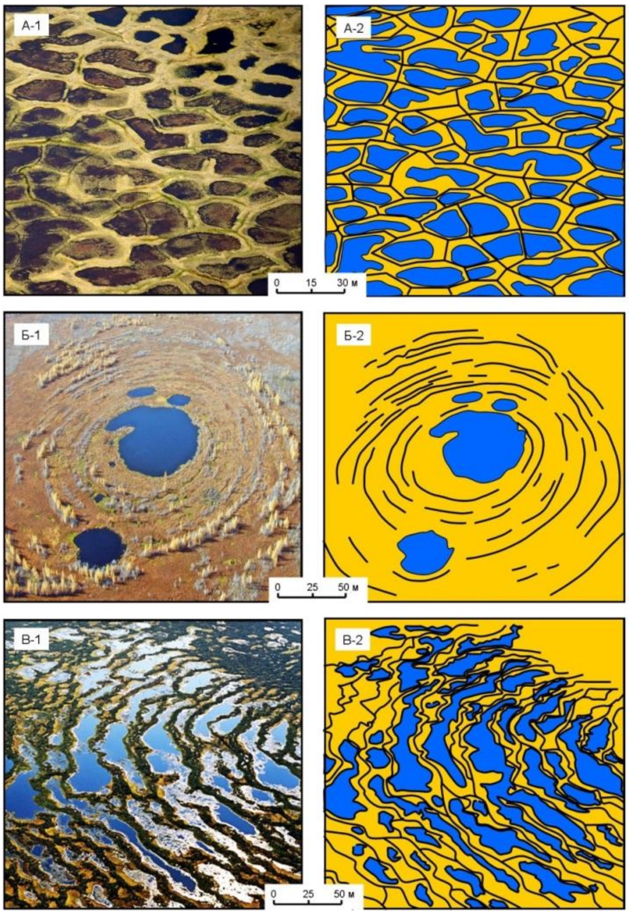

Fig. 3. External appearance of the characteristic natural-territorial complexes of permafrost zone: Chukotka (A), Kolyma Lowland (B), and Western Siberia (C).

A-1, B-1 and C-1 – aerial photographs; A-2, B-2 and C-3 – landscape patterns. For explanations, see the text.

Graphs A-1 and A-2. Chukotka. Region of continuous permafrost up to 500 m in thickness. The maritime lake-bog plain, composed of alluvial deposits with thick wedge ice layers. The polygonal type of geometrical structure of landscape. The territory with an area totaling 14 400 m^2 is divided into a network of quadrangles, pentagons and hexagons 8 to 35 m in diameter. The total number of polygons is 81. Their area averages 177 m^2. The parameters of the ice veins forming the polygons are: the mean width above is 3 m, the thickness is 12 m, the total length is 2 km, the area of the horizontal projection is 6000 m^2 (42% of the area of the territory), and the volume of the ice is 36 000 m^3. The volume of the part of permafrost with the highest ice content (to a depth of 12 m) is 173 000 m^3. The volume of permafrost without wedge ice is 137 000 m^3. The volume of ground ice with 30% average ice content of rocks enclosing wedge ice is 41 000 m^3. The total volume of wedge ice in the permafrost layer is 77 000 m^3 (43.5% of the volume of the calculated part of permafrost). The volume of the mineral mass of permafrost without ground ice is 100 000 m^3.

The number of lakes occupying the depressions of the polygons between banks is 78. The maximum diameter of the lakes (when the polygons merge together) is 35 m, averaging 12 m. The water layer at a low-flow period is 0.6 m in thickness. The area of the water bodies averages 150 m^2, the total area of the lakes is 120 000 m^2, and the total volume is 7200 m^3. The volume of the lake ice for the spring period is 8000 m^3.

Taking into consideration the characteristics of the water bodies, the volume of seasonally thawing ground (with the depth of thawing averaging 0.8 min the inter-lake space, and 0.2 m beneath the lakes) is 4500 m^3. With the ice content of 40%, it produces 1800 m^3 of seasonal ground ice every year. Thus the dynamical reserve of the ground ice in the study reference area reaches 78 800 m^3, which is equivalent to 69 000 m^3 of water. In the event of permafrost degradation to a depth of 12 m, the volume of the layer of ground will decrease by 7700 m^3. If there is no outflow of melt water, the land surface will lower by 1.9 m; if natural or artificial drainage systems are available, there is a possibility that the level of land surface would lower by as much as 7.2 m. In any case the thermokarsting process will result in flooding of large spaces adjoining the sea and freshwater reservoirs and river systems.

Graphs B-1 and B-2. Kolyma Maritime Lowland, composed of frozen lacustrine-alluvial deposits 300– 400 m in thickness. Concentric-banded type of geometrical type of landscape. It is distinguished by a boundedness of characteristics. A relatively homogeneous surface of the forest-tundra exhibits three main elements of NTC: saucer-shaped lake basins with an area of 95, 100, 1000 and 2500 m^2 (blue spots on the photograph), a subshrub sedge-sphagnum bog (background of the photograph), and discontinuous parallel ridges 0.3– 0.5 m in height covered by a sparse larch forest with the shrub layer of yernik dwarf birch (highlighted by black lines). The ridges 3 to 10 m in width delineate the shoreline of the water body with an area of about 35 000 m^2 which some time ago occupied almost the entire territory under consideration. The lake was underlain by a closed talik which was gradually decreasing in its volume with a change in the water area; also, it separated into four unequal parts. Ten stages of the lake dynamics can be identified. By dating the absolute age of the ridges using the methods of dendro-indication, lichenometry, radiocarbon analysis and other techniques, it was possible to reconstruct the causes and time interval of the transformation of the cryogenic landscape and the geocryological conditions of the territory as a whole.

Graphs C-1 and C-2. The West Siberian Plain, composed of sand-clay alluvial deposits. Region of deep (1.5– 2.5 m) seasonal freezing of rock and permafrost islands. Vasyugan lake-swamp complex. Undulating unparallel-banded type of geometrical structure of landscape. The territory with an area of 0.04 km^2 consists of alternating tortuous bands of sodded peat mass 3 to 15 m in width, covered by a sedge-moss mantle with a thick shrub layer, and with singly occurring strongly stunted trunks of Scots pine. The ridgy bands 0.3– 0.5 m in height and the (separating them) elongate lakes with an area of the water surface 100 to 1500 m^2 freeze to a depth of 1.0– 1.2 m. Conceivably they are underlain by permanently frozen peat. The ridges vary from 5 to 200 m in length; in places, merging together, they produce a polygonal network with cells 10– 15 m in diameter. Most of the ridges are in unstable equilibrium: during a warm season the thawed peat mass, together with the vegetation cover, slowly slides down the slope to form a characteristic (warped) landscape pattern. The total area of the ridges and lakes is 16 000 and 19 000 m^2, respectively. In the wintertime, the ridges transform to an ice-peat monolith with a total volume of about 20 000 m^3. In the spring period, the volume of the lake ice is 23 000 m^3. During this period the territory turns into a continuous ice reservoir. The lake-swamp complex is virtually impassable in the summertime.

Fig. 4. Geometrical structure of a polygonal bog on Taimyr Peninsula during summer snowfall. Photo taken from Sergei Fomin's hang-glider. "Flight over Russia" project (big_port54). For explanations, see the text.

Photography from a hang glider (Fig. 4) provides important information on a small area of terrain with characteristic cryogenic landforms. The photograph of a Taimyr bog covered with a thin mantle of snow displays the structure of the upper layer of frozen rocks broken by a network of frost fissures with thick (10– 12 m) layers of wedge ice. Some time ago, in one of the nodes o the displayed cryogenic system there emerged a small lake which was gradually expanding to occupy a considerable part of contiguous polygons composed of peatified loam. The roundish water body was about 20 m in diameter, and its depth did not exceed 1.2– 1.5 m. The lake basin was being covered by snow, which produced the condition for formation of the bowl of a suprapermafrost talik. For some period of time, during alternating warm and snow-abundant winters, it was in a quasi-stable state, but there occurred an abrupt decrease in winter air temperatures, the snow cover decreased in depth, the wind velocity dropped, and the talik froze throughout its depth. Also, the lake developed a fissured frost mound, and a clay-peat slush was ejected from its interior and froze. In the summertime, the frost mound thawed and subsided, and around it there arose a small bank composed of the downward moving grassy turf about 1 m in width and 0.5– 0.8 m in height. During a next winter the moistened heaving mass of earth material, under the effect of hard frost, "shrank" and cracked; the cracks developed ice wedges of frozen snowmelt. And the exposed voids of the first generation coincided with the network of incompletely formed microdepressions of the surrounding bog thereby fitting into the primary polygonal structure of terrain. The upper part of the ice wedges thawed away but, with the onset of a cold weather, it built up again by moving apart the enclosing earth materials. In a warm dry weather, the exposed earth materials was losing moisture due to intense evaporation; the surface developed angular cracks and drying polygons 0.8– 1.0 m in diameter. Such is the information that is "read" from the photo portrait of a ocal area on Taimyr Peninsula.

The above descriptions were compiled on the basis of photographs selected from the Internet in a random fashion, without referencing to a particular terrain. They are largely subjective, because they are based on personal experience and on this author's knowledge of the general regularities of evolution of cryogenic phenomena; moreover, they are not supported by ground-based observations. Nevertheless, the resulting characteristics provide insight into many important features of morphological structure of definite areas in the permafrost zone as well as determining the ways for their further investigation whenever this is required by the scientific or practical interests.

More valuable and comprehensive information can be obtained through integral investigations where image interpretation is accompanied by routine observations of the dynamics of processes, and by a study into plan and soil cover, surface and subsurface runoff, micro- and mesoclimatic conditions, etc. By interpreting the geometrical characteristics of structural elements of cryogenic landscapes, it is possible to solve many problems of engineering permafrostology, namely to lay out line structures, determine the depth of foundations, specify the types and size of culvert aqueducts, asses the snowdrift extent of a territory in winter and trafficability in summer, calculate the surface runoff and its transformation, substantiate measures for fire, thermal erosion, oil spills control, etc. On the basis of cryogeometry of landscapes, it is possible to deal with some issues of nature management, such as tentative assessment of water and biological resources, peat reserves and building materials, planning of melioration measures, and others.

The methods and results of interpretation of photo portraits of a terrain cannot be identical – the natural landscapes of the permafrost zone and their state are far too varied in different seasons. Furthermore, of significant importance is an operator's level of informational training and practical experience. In each particular case, an individual approach is required, the specific character of which is determined by the geographical location of the study area, and by the goal of work. The practical implementation of the aforementioned principles of the cryogeometry of landscapes needs the development of procedural manuals and recommendations having regard to the morphological characteristics, formation regularities and evolutionary development of the natural-territorial complexes in the permafrost zone of Siberia and of other regions of the globe.

3. Conclusion

Interpretation of the geometrical figures of landscapes on the terrain or on aerospace images provides a reliable avenue for an understanding of the present state and historical development of the poorly explored areas on the Earth and on other planets of the Solar System. Indication geometry of cryogenic landscapes (cryogeometry) can be recognized as a promising scientific area of geographical research for obtaining a large body of data, and for using them in engineering explorations and territorial development.

References

1. Great Soviet Encyclopedia, Sovetskaya Entsiklopediya, Moscow, 1969– 1978. http://dic.academic.ru/dic.nsf/bse/123892/%D0%9F%D1%80%D0%B8%D1%80%D0%BE%D0%B4%D0%BD%D1%8B%D0%B9
2. Beruchashvili N.L. (1990) Landscape Geography, Vysshaya Shkola, Moscow, 287p.
3. Viktorov S.V., Chikishev A.G., (1990) Landscape Indication and Its Practical Uses, Moscow Univ., Moscow, 197 p.
4. Dictionary on Landscape Design. http://www.onlinedics.ru/slovar/land/l/landshaft.html.
5. Vasiliev I.S., (2012) The contrast of Yakutia’s landscape caused by the influence of climatic factors, *Nauka i Obrazovanie*, 2, 32– 39.
6. Samsonova V.V., (1999) Cryolandscape Mapping of Forested Territories of Yakutia Using Remote Sensing Data, *Extended Abstract of Cand. Sci. (Geogr.) Dissertation*, Yakutsk, IMZ SO RAN, 22 p.
7. Alekseev V.R., (2005) Landscape Indication of Aufeis Phenomena, Nauka, Sibirskoe Otdelenie, Novosibirsk, 364 p.
8. Obukhovsky Yu.M., (2008), Landscape Indication, Manual, Minsk, 299 p.
9. Methods of Comprehensive Cryogenic-Hydrogeological and Engineering-Geological 1:200000 and 1:500000 Surveys, Moscow Univ., Moscow, 1970, 354 p.
10. Methods of Cryogenic Survey, V.A. Kudryavtsev, Ed., Moscow: Moscow Univ., 1979, 358 p.
11. Viktorov A.S., (2006) The Main Problems in the Mathematical Morphology of Landscape, Moscow, Nauka, 252 p.
12. Viktorov A.S., (1986) The Landscape Pattern, Moscow, Mysl’, 179 p.
13. GIS Maps of Yamal and Prospects of Future Research of IEC SB RAS. Second Yamal Land-Cover Land-Use Change Workshop-1010. D.S. Drozdov, S.E. Grechishchev, G.V. Malkova, and Yu.V. Korostylev. Presentation of the Institute of the Earth’s Cryosphere SB RAS. http://www.geobotany.org/library/talks/DrozdovDS2010_yamal_tal100308.pdf

14. Tumel N.V., Khoroleva H.A., Mikljaeva E.S., (2009) Feature of landscape indication cryogenic conditions at zone, regional and local levels at engineering-ecological researches, *Engineering geology*, 2, 24-29.
15. Olszewski A., (1982) Icings and geomorphological significance exemplfild from Oscar II Landand Prins Karls Forland, *Acta Universitetis Nicolai Copernici, Geographia*, 16, 91-122.
16. Hauber E., Reiss D., Ulrich M., et al., (2011) Landscape evolution in Martian mid-latitude regions: insights from analogous periglacial landforms in Svalbard, *Geological Society, London, Special Publications*, 356(1), 111-131. doi: 10.1144/SP356.7
17. French H.M., (2007) The Periglacial Environment, 2nd Ed., John Wiley & Sons, Ltd., England, 458 p.
18. Washburn A.L., (1988) The World of Cold, Geocryological Studies, Moscow, Progress, 382 p.
19. Jones B.M., Amundson C.L., Koch J.C., Grosse G., (2013) Thermokarst and thaw-related landscape dynamics- an annotated bibliography with an emphasis on potential effects on habitat and wildlife, U.S. Geological Survey Open-File Report 2013-1161, 60p. http://pubs.usgs.gov/of/2013/1161
20. Grosse G., Jones B.M., (2011) Spatial distribution of pingos in Northern Asia, *Cryosphere*, 5, 13-33. http://www.the-cryosphere.net/5/13/2011/tc-5-13-2011.pdf
21. Yoshikawa K., Hinzman L. D., Kane D.L., (2007) Spring and aufeis (icing) hydrology in Brooks Range, Alaska, *Journal of Geophysical Research*, 112(G4). doi:10.1029/2006JG000294