SOIL-LANDSCAPE PECULIARITIES IN THE NORTH OF CENTRAL SIBERIA (ACCORDING TO INTERPRETATION OF SATELLITE IMAGES)

T.V. Ananko

V.V. Dokuchaev Soil Science Institute, 119017 Moscow, Pyzhevskii 7, bld.2, e-mail: tatyana@ananko.ru

When correcting the sheets of the State Soil Map for the northern part of Central Siberia in electronic format using satellite imagery obtained by SAS Planeta, it seemed possible to specify the boundaries of old soil contours and to identify new ones. Interpretation of satellite images for sloping landscapes within the northern taiga subzone confined to compacted deposits of trappean complex, loose Quaternary rocks and Jura sedimentary non-carbonate rocks, permitted to enlarge the knowledge about the component composition of the soil cover at the above territory.

Keywords: Central Siberia, sheets of State soil map, correction, interpretation of satellite images

INTRODUCTION

Within 1986–2006 the specialists of the V.V. Dokuchaev Soil Science Institute have carrying out the research in compiling the sheets of the State Soil Map for insufficiently known territories, which are difficult of access in Siberia and the Far East. It is worth of note that the method of expert mapping based upon the soil-ecological forecasting was considered as the main method of soil survey for such vast territories [11]. In the last ten years this method remained as a basic one being widely employed instead of labor-intensive and expensive field surveys. Besides, the modern GIS-technologies allowed increasing the objectivity and accuracy of soil mapping with respect to its forecasting [9]. To be able to have the needed accuracy of forecasting maps, it was also possible to use the satellite images that permit to identify new soil contours, to correct the boundaries of old soil contours with the aim at specifying the soils within these contours. However, in that time the remote sensing techniques have been so far applied insufficiently for creating the authors' sheets of the State Soil Map [1, 10].

Objects of research and methods

Paper versions of soil maps compiled by specialists of the V.V. Dokuchaev Soil Science Institute in the 1990s of the 20th century served as a factual basis for these studies. They were corrected in electronic format using GIS-technologies and satellite images obtained by SAS Planeta 90902.

The following materials were used for GIS information layers:

1. Topographic map at a scale of 1 : 1000000.
2. State geological map (1 : 1 mln M) edited by Lungersgausen, 1959.
3. Satellite images obtained by SAS Planeta (http://sasgis.org/sasplaneta).

Under use were also paper versions of the following maps:

1. Topographic maps at 1 : 300 000 scale.
2. The map of Quaternary deposits in the USSR (1 : 2.5 mln M), 1976.
3. The map of vegetation in the USSR (1 : 4 mln M) edited by Karamysheva and Ladygina in 1990.
4. The geomorphological map of the USSR (1 : 2.5 mln M), 1987.
5. The soil map of the RSFSR (1 : 2.5 mln M) edited by Fridland, 1984.
6. Atlas of Agriculture in Yakutsk ASSR, 1989.
7. Atlas of the USSR, 1984.

The sheets of the State Soil Map were corrected by using the data of satellite survey and the above maps.

INVESTIGATION RESULTS

Several sheets of the State Soil Map embrace a vast territory under study. The sheet R-47 “Khatanga” includes the eastern part of Putoran plateau; the elevation of watersheds is varying from 700 to 1100 m being maximal 1400–1500 m. The relief is a plateau dissected by steep slopes and narrow river valleys. The plateau consists of old Precambrian sedimentary deposits of Paleozoic covered by thick volcanogenic Triassic formations including basalt, tuff, tuffite, tuff conglomerates, sandstone, limestone, etc. The upper lava-containing stratum comprises basalts, whose shallow eluvial, deluvial-colluvial and colluvial deposits serve as parent materials for the soil development. In river valleys the thick old alluvial deposits are widely spread. The vertical climatic zonality of oceanic type is represented by three floristic belts in the plateau.

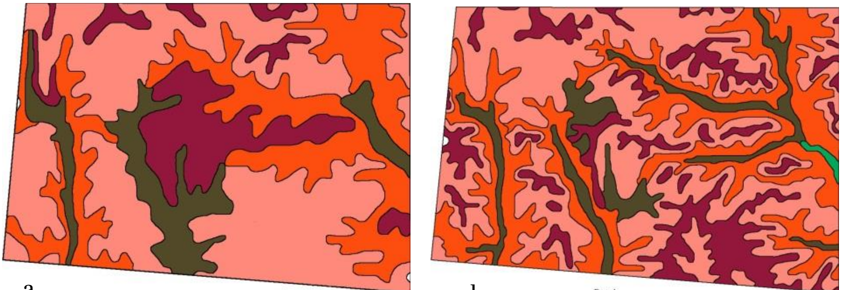
At a height of 700 m in the north and 1100–1200 m in the south the arctic belt is represented by cristose and foliose lichen, moss, alpine flowering plant species combined with tundra communities and stone placers. The tundra belt is a shrubland covered by moss and lichen in combination with shrubby plants and stone placers. The taiga belt includes scrub and larch thin forests. The conception of soil-landscape interrelations presented on the State Soil Map was not changed, only the soils being specified at the studied territory obtained new names. Within the belt of larch and thin forests the modal soils are dry frozen shallow soils – ocherous podburs on steep slopes and ice-frozen non-gley hydromorphic soils – peaty-humus cryozems on terraced slopes (on the State Soil Map they were named as frozen-taiga soils). Within the tundra belt the podburs are recognized although they have been named as tundra podburs on the State Soil Map; in the arctic belt – stone placers. In the paper version of the above sheet the boundaries of contours dominated by rock outcrops, tundra and ocherous podburs as well as peaty-humus cryozems have been conditionally identified by using the vegetation and topographic maps – the highly elevated watersheds with stone placers were identified as contours characterized by dominant rock outcrops. The boundaries between the contours covered by podburs in the tundra belt and ocherous podburs in the taiga belt have been shown according to the topographic map based upon slightly expressed differences between tundra and taiga belts; the contours prevailed by peaty-humus cryozems had no links with the vegetation cover and were recognized according to the lower parts of gentling slopes including the river terraces where the increased depth of the fine earth stimulated the formation of ice-frozen hydromorphic soils.

The use of GIS-technologies and interpretation of satellite images allowed increasing the accuracy of boundaries between the soil contours in different floristic belts and identifying new contours with the due account of soils and non-soil formations. Interpretation of satellite image was carried out at the territory with the same relief and parent materials that is why the vegetation was considered as a basic indicator of the soil cover pattern. In arctic and tundra belts the exposed surfaces and those covered by arctic-alpine shrubby vegetation were clearly interpreted in the color mosaic of the satellite image (Fig. 1). It made

Fig. 1. Vertical belts in the Putorana plateau. Alpine belt covered by different stony showers and scanty tundra vegetation, a – rock outcrops are dominant; b – stony showers and soils under vegetation occupy approximately the same area.

possible to identify contours dominated by coarse-grained stone placers (their amount proved to be higher as compared to the paper version of the map) and to divide them into those occupying 90% of the surface and those, where the soils under scanty vegetation and rock outcrops occupy identical surfaces. Thanks to the satellite image the boundary between podburs and ocherous podburs was specified more exactly by transition of the light-green color of tundra vegetation into the more intensive green color of forest vegetation. At last, the dark-green color of forest vegetation prevailed in slope piedmonts and river valleys in combination with thermokarst depressions permitted to outline a more exact boundary between ocherous podburs and peaty-humus cryozems (Fig. 2).

In sheets Q-49-50 “Udachny” and R-49-50 “Olenek” of the State Soil Map the Olenek-Anadyrskiy and Olenek plateaus are presented as composed of different-aged sedimentary carbonate bedrocks with varying composition and density, including limestone, dolomite, sandy and clayey limestone, marl, conglomerates, etc. The soil-landscape interrelations in the northern taiga of this plateau have been shown on the



a b

Fig. 2. Fragments of soil maps in paper version (a) and in electronic format (b) compiled by using satellite images.

State Soil Map in the following way. The watersheds are occupied by gley peaty-humus soils but the slopes – by humus-carbonate soils. Taking into consideration new materials obtained by field surveys [2, 12, 6] the paper version of the map displayed the soil cover of this plateau part consisting of gleyic cryozems and residually carbonate soils in complex with peaty soils in cracks and humus-carbonate soils on steep slopes. However, the satellite images showed a significant heterogeneity of this soil cover. Their interpretation according to vegetation [8] combined with the analysis of relief forms and geology of this territory permitted to identify different sloping landscapes on carbonate bedrocks and to show in detail the soil cover in electronic format.

Fig.3a demonstrates light and dark strips alternated along gentle slopes (1.5°–3°) composing of carbonate bedrocks unstable to weathering: marl, bituminous, sandy or clayey limestone (fan-shaped picture). The loamy-clayey Quaternary soil-forming rocks on these slopes are characterized by insignificant detritus, a higher ice amount (40–50%) and thickness of 0.7–1.5 m. Cryogenic and denudation processes lead to the formation of a dense network of dells. The light strips are gentle slopes with permafrost, 70–90 cm thick, the dark strips - dells, where the fine earth was partially washed out and the icy permafrost is close to the surface (<50 cm). The coarse-humus or humus-gleyic residually carbonate cryozems are found under moss-lichen and shrubby thin forests, the gleyic peaty-humus or peaty residually carbonate cryozems - under wet conditions of dells. The soil cover structure on such slopes is represented by *cryozems of different hydromorphism degree*. Fig. 3b shows more steep slopes (5°–8°). The alternation of narrow dark-green

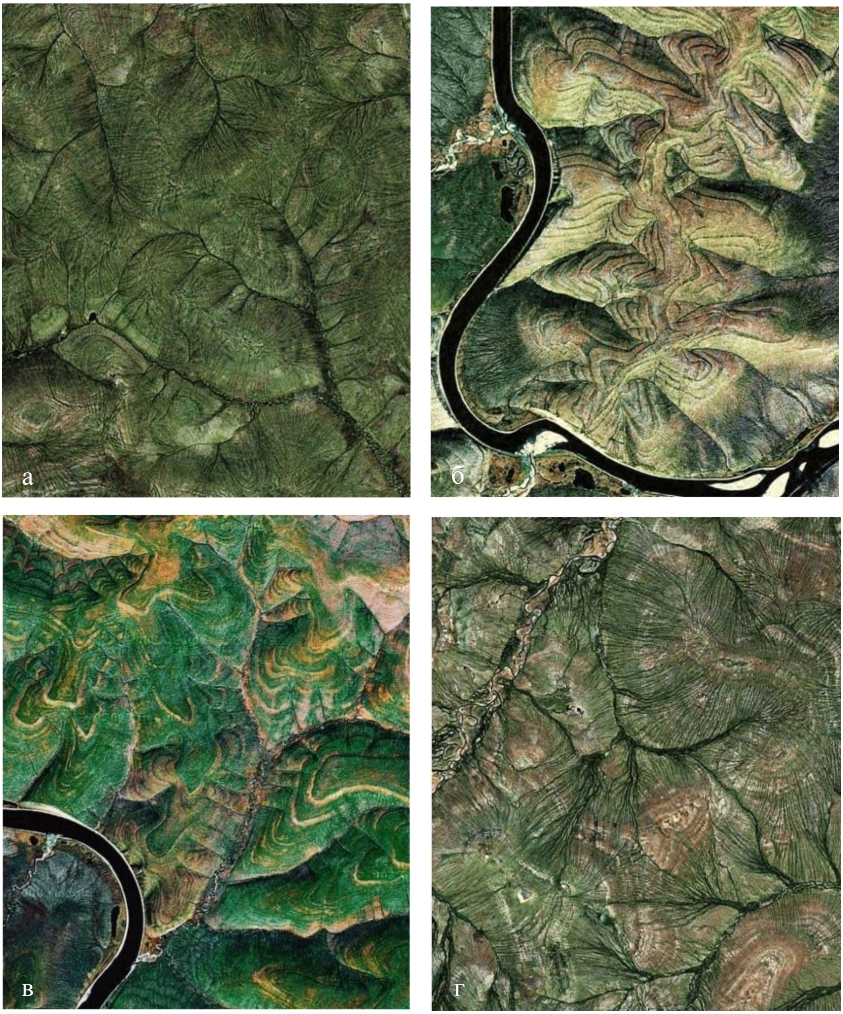

а
б
в
г

Fig. 3. Landscapes on slopes and in watersheds of the north-taiga part of the Olenek plateau derived from carbonate bedrocks: а – gentle slopes; б, в– steep stepped slopes; г– combination of stepped and solifluctional slope parts; д, е– steep slopes with different amount of rock outcrops and stony showers; д, ж – different-drained watersheds; з – stony tundra confined to elevated watersheds within the northern taiga.

and wide light-green strips in the satellite image makes it possible to interpret clearly expressed slope steps confined to Cambrian carbonate bedrocks of different density. These slope steps are identified as a bench, edge and sloping bench. The bench is covered by dry thin forests, on the sloping bench – native plant species and accumulation of stony placers in the footslope. As to hydrothermic conditions this slope part is more dry and thoroughly warm. It is interpreted by wide light-colored strips in satellite images. The closed larch forests with juniper grown only on edges are interpreted by narrow dark-green strips [8]. The soil cover structure of such slope steps is represented by *detritus humus-carbonate soils and rock outcrops as spots of carbonate deposits and stony placers.* As seen from Fig. 3в, the slope steps are presented by a contrasting combination of wide dark-green and narrow light-green strips across the slope. In the gentle sloping part under the larch forest the hydromorphic soils are developed, whereas on steep slopes - more dry soils [8]. In this case the soil cover structure is represented by *hydromorphic coarse-humus gleyic residual-carbonate cryozems with peaty soils in cracks as well as mesomorphic humus-carbonate soils with rock outcrops.* If the slope steps are not clearly expressed in the satellite image, the slopes are covered by deluvial-soliflual deposits and the coarse-humus or humus-gleyic residual-carbonate cryozems are formed under the thin larch forests. Fig. 3г shows gentle slopes composing of calcitic dolomites, stable to weathering. The upper part of the slope interpreted by a white color in the satellite image is a bare surface resulted from solufluction – mottles of the exposed ground. Around them the plant species of xerophytic type are abundant because the soils on soliflual slopes become dried in the vegetation period. The horizontal strips are interpreted as the steps in the upper part of slopes, the vertical fan-shaped strips – in the lower part of slopes. The combination of light-colored mottles of bare surface, light-green mottles of thin forests and dark-green mottles of spruce-larch forests in middle and lower parts of slopes permits to identify sloping landscapes covered by *coarse-humus gleyic residual-carbonate cryozems, humus-carbonate soils and rock outcrops.*

According to intensive homogeneous green color the great areas of shrubby and thin larch forests are interpreted in satellite images (Fig. 3д). They are confined to steep slopes (7°–10°) and narrow drained watersheds on dolomites [8]. The good drainage, favorable temperature conditions and the close depth of carbonate bedrocks serve as evidence that *the humus-carbonate soils* are developed there. A comprehensive analysis of satellite images and topographic maps at 1: 300 000 scale made it possible to specify the boundaries of soil contours, in which the surface without vegetation or stony placers occupy significant areas, and those, where the full-developed soils are practically absent (Fig. 3д, 3е). The component composition of such landscapes is represented by *rock outcrops and primitive soils sometimes combined with cryozems or humus-carbonate soils.* At the same time, topographic maps show steep slopes (10°–15°) covered by rock outcrops, whereas the satellite images indicate larch forests on *humus-carbonate soils.*

Thus, in sheets of the State Soil Map the slopes on carbonate bedrocks in dependence on their steepness, forms and the rock density are covered by (1) cryozems, (2) cryozems combined with humus-carbonate soils and rock outcrops, (3) humus-carbonate soils sometimes in combination with rock outcrops, (4) rock outcrops combined with primitive or humus-carbonate soils. The picture of satellite images is more monotonous in watersheds because the vegetation is represented by larch or spruce-larch thin forests on fine earth and icy platforms and larch shrubby forests on shallow dry frozen eluvial carbonate bedrocks. In the first case the soil cover of watersheds is represented by coarse-humus gleyic residual-carbonate cryozems and peaty soils in cracks; in the second case the humus-carbonate soils are developed (Fig. 3д, 3ж). However, there exist some small areas of elevated watersheds with steep slopes on dense carbonate rocks, where the native bedrocks are exposed as resulted from solifluction and the vegetation is rather scanty and represented by tundra groups of plants to be changed into shrubby tundra and larch forests in the middle part of the slope. The soil cover in such landscapes comprises rock outcrops, soddy-and humus-carbonate soils and gleyic peaty-humus residual-carbonate cryozems (Fig. 3з).

Sometimes the carbonate bedrocks are discontinued by trappean intrusions, thus forming table-like tops of 150–200 m in height. In satellite images they are locally interpreted by stony placers of light-brown color in combination with scanty tundra vegetation of light-green color. As a rule, such isolated tops are surrounded by dark-green forests on slopes confined to carbonate bedrocks (probably in admix-

Fig. 4. The stony tundra on trappean intrusions combined with the north-taiga forests on steep slopes derived from carbonate bedrocks.

Fig. 5. Combination of solifluctional landscapes on slopes confined to carbonate bedrocks and those situated in watersheds being boggy and covered by clays.

ture with trappean debris) and rock outcrops (white mottles) on steep slope benches (Fig. 4). The soil cover in these landscapes is represented by rock outcrops, primitive and pale soils on trapps and humus-carbonate soils, rock outcrops and residual-carbonate cryozems on carbonate bedrocks [3, 4, 14, 15].

In watersheds of Olenekskiy plateau the satellite images demonstrate clearly expressed specific landscapes confined to heavy-loamy- and clayey deposits 5–10 m thick, the peculiar feature of which is a higher ice accumulation near the upper boundary of permafrost-affected rocks (above 60%). The vegetation composes of ledum shrubs, larch thin forests and sedge-cotton grasses on bogs. In combination with shallow thermokarst depressions they show a specific “variolic” picture differed from that presented by larch and thin forests on compact carbonate rocks at a depth of 0.7–1.5 m (Fig. 5). The soil cover structure is represented by gley peat and peaty-humus soils under grass vegetation and peat-gley boggy soils under sedge swamps around the thermokarsts. The soil cover on Jurassic deposits in northern taiga is represented by pale-cryozems and thixotropic humus cryozems together

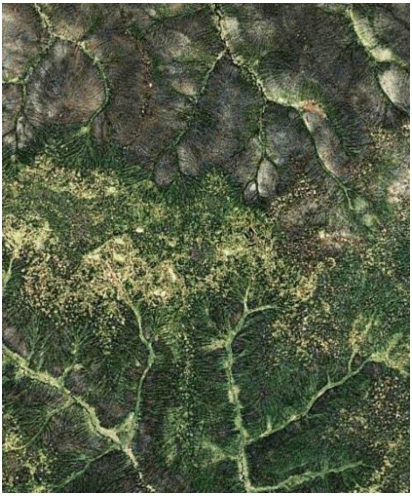


Fig. 6. Combination of slope landscapes confined to carbonate bedrocks and the landscapes in watersheds recovered by Jura sedimentary rocks.

Fig. 7. The weakly dissected watersheds and gentle slopes confined to carbonate bedrocks and recovered by fluvio-glacial loam-sandy and loamy deposits.

with peaty soils in cracks of drained watersheds and slopes, gley peaty-humus soils, gleyic and swampy peaty and peat soils in swampy watersheds with abundant thermokarst likes (Fig. 6).

In the interfluves between Anabar and Olenek (sheets R 49-50) the significant areas of the carbonate plateau are covered by shallow loamy sands and loams of fluvioglacial genesis in watersheds and on slopes. They are confined to the smooth weakly dissected plateau, where thermokarst and solifluction are slightly developed. In the plant cover of watersheds and gentling slopes the larch and thin forests are dominant [8], the soil cover is represented by humus and peaty-humus cryozems as well as pale-cryozems in watersheds and on slopes (Fig. 7). A gradual transition to zonal tundra landscapes is clearly interpreted by light-gray sites of stony tundra and green sites of larch thin forests on slopes in river valleys. Fig.8a shows the taiga vegetation, Fig. 8b – larch forests only in river valleys, the tops of convex watersheds are covered by tundra vegetation including shrubby tundra on slopes.

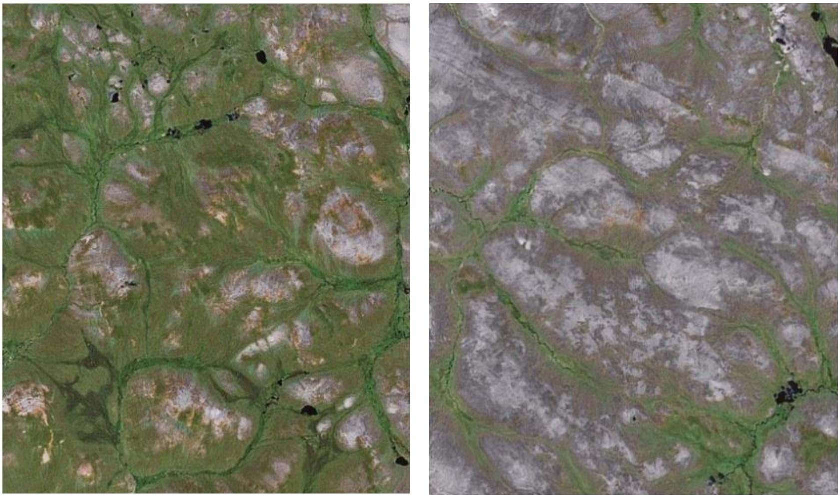


Fig. 8. Typical landscapes of the forest tundra in the Maimecha-Kotuy plateau.

The interpretation of such landscapes permits to outline contours prevailing by residual-carbonate cryozems, humus-carbonate soils under thin forests as well as the contours, where modal soils are represented by mottled tundra.

Within the tundra zone of Central Siberia the expert estimation indicated a character of soil-landscape interrelations represented by humus-carbonate tundra soils in watersheds and on slopes as well as rock outcrops on steep slopes. The new materials obtained in field showed that the tundra landscapes on carbonate plateau reveal a great diversity of the vegetation and the component composition of the soil cover [7]. This is evidenced by satellite images of areas in sheets R-47-51 “Khatanga”, “Olenek” and “Tixi”. In the tundra zone of these sheets the following soils are shown: humus-carbonate, shallow soddy-carbonate and carbonate soils in some places, humus soils in cracks, coarse-humus cryozems and primitive humus residual-carbonate soils. Fig. 9a and 9b demonstrate the highly dissected plateau with steep slopes elevated by 350–450 m and composed of compact limestones, dolomites and carbonate shales of middle and lower Cambrian. In satellite images the light-gray and almost white tones in the coloring mosaic of watersheds and slopes interpret the bare surfaces. The vegetation is confined only to the lower parts of slopes being represented by

Fig. 9. The stony tundra on compact carbonate rocks: a – Fomich-Koty plateau; b – Kotuy plateau.

shrubs, lichens and green moss, its projecting cover accounts for 10–30% [7]. Such landscapes on sheets of the State Soil Map are reflected by polygonal complexes of carbonate soils and humus soils in cracks combined with rock outcrops – in watersheds, the rock outcrops and primitive soils in complexes – on slopes and the humus-carbonate soils and coarse-humus cryozems – in river valleys and adjacent footslopes under shrub vegetation. The above landscapes are typical for the plateau situated northwards the Fomich river, Kystyk plateau in the upper Olenek river as well as the vast territory of Kotuisk plateau.

The second typical tundra landscape is confined to the plateau composing of sandy-carbonate bedrocks of Sinian complex. It is widely spread in watersheds with thermokarst depressions and gentle slopes, covered by the vegetation of lichen, moss-lichen, cowberry-bilberry tundra [8]. This landscape is interpreted by the light-green color in watersheds and by the darn green color on gentle slopes (Fig. 10). Depending on the soil drainage degree the soil cover is represented by coarse-humus cryozems, humus residual-carbonate soils in combination with peaty or peaty-humus soils in cracks as well as soddy- or humus-carbonate soils. Sometimes the elevated stony watersheds and gentle slopes are identified by light-colored spots of scanty vegetation. Due to the solifluction process the mottled tundra soils are developed there.

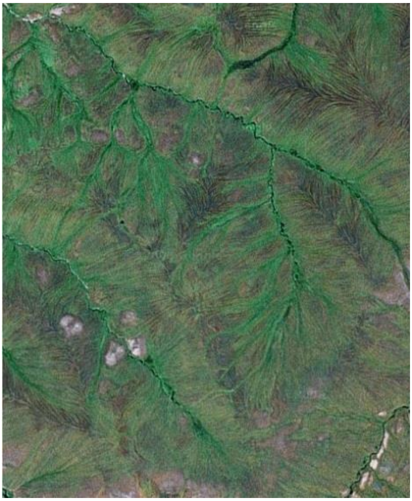


Fig. 10. The moss-lichen shrubby tundra on the easy weathered carbonate rocks in Fomich-Kotuy plateau.

The following satellite images demonstrate the landscape of Maimecha-Kotuisk plateau at a height of 400–600 m composing of carbonate Ordovician and Cambrian deposits penetrated by trappian intrusives, the latter being reached 700–800 m about the sea level (Fig. 11). The soil cover is characterized by a higher sod formation being represented by lichen and moss-lichen tundra soils in watersheds and slopes. On moderately steep slopes the soils are developed on different substrata including carbonate bedrocks with the high content of dark-colored ferruginous minerals, carbonates on trapp enriched with carbonate detritus and the "pure" trapp [7].

The dominant watersheds derived from trapp reveal different combinations of stony showers, primitive and pale soils or podburs at the bare or exposed surface as well as at the surface covered by scanty tundra vegetation. The pale and peaty-humus soils under tundra vegetation are interpreted by the light-green and greenish-brownish color in satellite images. The stepped slopes are covered by soddy-(humus) – carbonate soils, rock outcrops and the humus residual-carbonate cryozems in admixture with trapp fragments; they are interpreted by horizontal white-colored strips of rock outcrops and the light-green strips of the tundra vegetation at the flat surface. The steep slopes are covered by stony showers and the riffle hollows – by peaty hydromorphic carbonate soils.

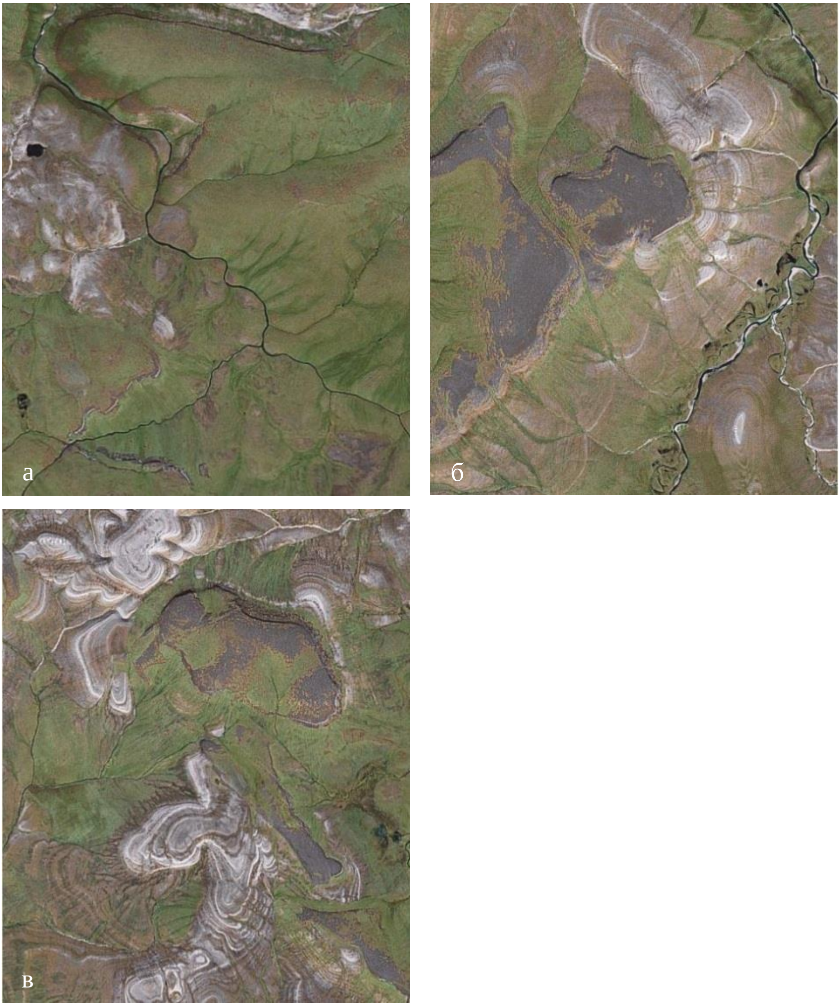


Fig. 11. Alpine-tundra landscapes on carbonate rocks and trappean intrusions in Fomich-Kotuy plateau: a – tundra landscapes on trappean intrusions are dominant; б – alpine landscapes on trappean intrusions combined with slope tundra landscapes on carbonate rocks; в – alpine-tundra landscapes on trappean intrusions and polygonal mottle stony tundra in watersheds and on slopes derived from carbonate bedrocks.

CONCLUSIONS

When redacting the sheets of the State Soil Map for the North of Central Siberia in electronic format by using satellite images, it seemed possible to specify the boundaries of soil contours recognized earlier and to identify new ones. As a result of correcting the above sheets, the obtained information permitted:

– to enrich the knowledge about the diverse soil cover of landscapes on slopes and in watersheds of the plateau confined to carbonate deposits in dependence on geomorphological peculiar features of relief and the density of carbonate rocks;

– to identify the peculiarities of the soil-vegetation cover in landscapes derived from carbonate deposits and the trappian rocks, carbonate deposits and loose Quaternary different-originated covers;

– to o specify the boundaries of areas covered by non-soil formations (stony showers, solifluctional outcrops) on different compact deposits and the component composition of alpine and tundra floristic belts in mountains.

REFERENCES

1. Andronikov V.L., Shishov L.L., Tereshenkov O.M. Sostavlenie listov Gosudarstvennoi Pochvennoi karty SSSR s ispol'zovani emkosmicheskikh snimkov, *Aerokosmicheskie metody v pochvovedeniii I khispol'zovanie v el'skomkhozyaistve*, Moscow, 1990, pp. 82–88.

2. Elovskaya L.G., Petrova E.I., Teterina L.V. *Pochvy Severnoi Yakutii*. Novosibirsk,1979, 301 p.

3. Ershov Yu.I. Zakonomernosti pochvoobrazovaniya v predelakh Srednesibirskogo ploskogor'ya, *Eurasian Soil Science*, 1995,No.7,pp. 805–810.

4. Ershov Yu.I. Mezomorfnoepochvoobrazovanie v taezhno-merzlotnom semigumidnom sektore Srednei Sibiri, *Eurasian Soil Science*, 1994,No.10.

5. *Klassifikatsiya I diagnostikapochv Rossii*. Smolensk, 2004, 341 p.

6. Konyushkov D.E. *Pochvoobrazovanie na karbonatnykh porodakh v kontinental'noi subarktike (naprimeresevera Srednei Sibiri),* Extended abstract of candidate's thesis, Moscow, 1991, 253 p.

7. Konyushkov D.E. Struktura pochvennogo pokrova severo-vostochnoichasti Sredne-Sibirskogo ploskogor'ya, *Eurasian Soil Science,* 1992, No. 1, pp. 61–73.

8. Lukicheva A.N. *Severo-taezhnaya rastitel'nost' Sibirskoi platformy v svyazi s geologicheskimstroeniem*, Leningrad, 1972, 52 p.

9. Savin I.Yu. Komp'yuternaya imitatsiya kartografirovaniya pochv, *Tsifrovaya pochvennaya kartografiya, teoreticheskie, ieksperimental'nyeissle-dovaniya*, Moscow, 2012, pp. 26–33
10. Simakova M.S. O soderzhanii, printsipakh i priemakh oformleniya poch-vennykh kart, *Bulletin of V.V. Dokuchaev Soil Science Institute,* No. 61. pp. 3–11.
11. Sokolov I.A. *Rabochaya programma po sostavleniyu listov gosudar-stvennoi pochvennoi karty SSSR masshtaba 1:1000000*, Moscow, 1986 (rukopis').
12. Sokolov I.A. O Raznoobraznom proyavlenii gidromorfnogo negleevogo pochvoobrazovaniya, *Eurasian Soil Science*, 1980, No.7, pp. 5–19.
13. Sokolov I.A. Gidromorfnoe negleevoe pochvoobrazovanie, *Eurasian Soil Science*, 1980, No. 1.
14. Sokolov I.A. Palevye pochvy Srednesibirskogo ploskogor'ya,*Eurasian Soil Science*, 1986, No. 8, pp. 5–18.
15. Sokolov I.A., Bystryakov G.M. Palevye pochvy severnoi taiga Vostochnoi SibiriiDal'nego Vostoka, *Moscow University Soil Science Bulletin*, Ser. 17,*Soil Science*, 1980, No. 1, pp. 30–37.
16. *Pochvennaya karta RSFSR. Masshtab 1:2.5 mln*, Ed. V.M. Fridland, Mos-cow, 1988.