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Analysis of the Dynamics of Changes in Soil–eluvial Formations Across the Main Bioclimatic Zones of the Aragats Mountain Massif

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Abstract

The aim of this study is to examine the sequence of soil–eluvial formations using the Aragats Mountain Massif as a representative example. The differentiation of these formations is primarily governed by the influence of bioclimatic factors. Primary soil–eluvial formations, commonly referred to as soil eluvium, are regarded as integrated complexes comprising weathering crusts and soils formed under natural landscape conditions. In Armenia, however, investigating such formations poses a considerable challenge. Owing to centuries of human activity and land use, a substantial proportion of primary soil–eluvial complexes has been either destroyed or significantly transformed. Only in limited areas have soil eluviums retained their original characteristics or remained relatively intact.

Keywords: soil–eluvial formations, bioclimatic factors, weathering crust, belozem, carbonate crust

Introduction

According to B.B. Polynov's interpretation, the term "weathering crust" is a key concept and subject for loose detrital deposits, where primary rocks forming the upper part of the lithosphere continuously change under the influence of weathering processes. According to E. Shantser, weathering crust coincides with the definition of "eluvium." B.B. Polynov called "residual," i.e., unredeposited, referred to the residual weathering crust using this term. The formation of eluvium, the composition of its constituent formations, and its thickness vary depending on climatic conditions (a combination of temperature and humidity).

Currently, principles for classifying agrolandscapes have been formulated, taking into account zonal affiliation, the nature of crop rotations, their biogeochemical structure, and migration processes in catenas (Perelman & Kasimov, 1999; Kasimov, 2013). The simplification of the biogeochemical structure of agrolandscapes compared to natural ones determines their lower stability, and maintaining it requires ensuring the necessary diversity and preserving the ecological framework (Glazovskaya, 1992; Nikolaev & Kopylov, 2004). The effects of the mutual influence of elements depend on the type of crops and migration conditions (Environmental Geochemistry, 1990; Glazovskaya, 2007).

In mountainous terrain (Gevorgyan, 2006), where vertical zonality is strongly pronounced, the distribution of main bioclimatic factors, the development and changes in soil cover occur completely differently compared to lowland areas. Studying all stages of landscape formation makes it possible to understand how certain features (in particular, soil-ground) arose. And, undoubtedly, each landscape component should be studied within a dynamic framework.

In general, eolian processes in Armenia occurred under structural-morphological and hydrothermal conditions that, with active water exchange, contributed to the formation of acidic and slightly acidic solutions, thereby facilitating the rapid migration of chemical elements and oxidation of metallic elements (Balyan, 1982; Balyan & Hayrapetyan, 1979). These processes directly affected the products of primary weathering materials and their redistributed varieties, endowing them with specific geochemical characteristics.

Comparison of the content of chemical elements in primary rocks and, accordingly, in the varieties of the weathering crust showed the degree of their accumulation and redistribution.

The study aims to investigate the sequence of soil-eluvial formations of the Aragats mountain massif under the influence of the bioclimatic factor.

Methods and Materials

To achieve the objectives of this study, relevant published works (Bargagli, 2005; Bashkin & Kasimov, 2004; Vinogradov, 1998; Dobrovolsky, 1979, 1998; Margaryan et al., 2022) were taken as a methodological basis. The Aragats mountain massif is a suitable object for the present study due to the large amplitude of changes in bioclimatic conditions caused by vertical zonality, and the presence of primary soil-eluvial formations or massive crystalline rocks of similar composition.

This allows considering the sequence of primary soil-eluviums from the subnival to the dry subtropical belt, developed on rocks of the Aragats mountain massif of andesite-basaltic and andesite-dacitic compositions, more or less altered by post-magmatic processes.

Here, three main bioclimatic belts with characteristic types of primary soil-eluvial formations are distinguished. Research was conducted along the Ashtarak – Agarak – Byurakan – Mount Aragats profile, as this profile traverses all landscape-climatic belts of the Aragats mountain massif. They are grouped into three main bioclimatic belts, based on the conditions of formation of primary soil-eluviums.

It should be noted that the identified bioclimatic belts correspond to generally accepted geomorphological altitudinal stages: the near-summit belt, the middle belt, and the lower belt.

In field conditions, profiles were constructed in the most suitable places to identify the interaction of residual and redeposited or buried under effusive weathering crusts, and a sufficiently large number of samples were taken from characteristic sections, mainly from eluvium and their redeposited varieties.

The following methods were used to study the selected samples: comparative, soil-geographical, morphological-genetic, profile, fractional, bulk-chemical, etc.

Mineralogical and morphological analyses were used to process the collected samples, mainly from eluvium and redeposited varieties of rocks and soils. The content of trace elements in the samples was determined by spectral analysis, according to which landscape-geochemical coefficients were calculated: Clarkes of concentrations, ratios of trace elements characterising certain geochemical processes, etc.

Mineralogical and chemical data obtained from X-ray diffraction analyses were subsequently processed.

It should be noted that the general methodological principles for studying landscape geochemistry also include historicism and a dynamic approach, as the formation of the modern landscape (and, in particular, the active agent of the landscape spectrum – the soil cover) is often associated with events of the distant geological past.

Retrospective analysis may further allow predicting the dynamics of development of the investigated soil-eluvial formations in the direction of degradation due to the spontaneous course of natural processes under the influence of the bioclimatic factor.

Studies were conducted in the three identified bioclimatic belts with characteristic types of primary soil-eluvial formations: the near-summit belt, located above 2600–2800 meters; the middle belt, located below, approximately at elevations up to 2000–2500 m; the lower belt, occupying the foothills of the southern and southwestern slopes of Mount Aragats, up to an altitude of approximately 1500–2000 m.

The research results were obtained based on processed samples collected in the field. The obtained materials serve as visual confirmation of the general position on soil-eluvial formations, as well as soils, as a mirror and memory of landscapes, and further, on the weathering crust itself, developed in natural landscapes.

Results and Discussions

As already noted, the three main bioclimatic belts studied are arranged in the following order. The near-summit belt is located above 2600–2800 m above sea level. Weathering and soil formation conditions here are harsh. The climate is cold, with frequent temperature drops below 00 C in all months of the year. Precipitation is about 800–1000 mm or more (Table 1). The middle belt is located below the near-summit belt at elevations up to 1600–2600 m. The climate is moderately cold and cold. Precipitation is approximately 600–800 mm. The lower belt occupies the foothills of the southern and southwestern slope of Mount Aragats up to an altitude of 1500–2000 m. The climate is characterised as continental, moderately warm, dry, with an annual precipitation of 400–600 mm.

Table 1. Values of average monthly and maximum air temperatures at meteorological stations for their entire period of operation

Meteorological station	Elevation above sea level, m	Months											
		I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
		Air temperature, °C											
Aragats H.M. Station	3229	-2,62	-1,82	2,50	8,03	12,2	15,8	18,6	18,4	14,9	9,45	4,05	-0,38
Amberd	2071	-7.2	-6.0	-2.1	4.4	9.6	13.8	18.0	18.2	14.0	7.7	1.2	-4.6
Ashtarak	1090	-4.2	-1.3	4.4	11.3	16.2	20.8	24.7	25.0	20.2	13.6	6.6	-0.5
		Atmospheric precipitation, mm											
Aragats H.M. Station	3229	72.7	78.2	91.9	106.0	105.8	79.7	67.8	47.5	38.5	65.7	77.1	71.6
Amberd	2071	62.5	63.4	66.9	81.2	99.3	56.4	34.4	21.9	23.1	53.8	55.0	60.4
Ashtarak	1090	26.3	28.3	34.8	50.0	55.1	33.5	20.4	12.1	15.0	32.2	29.1	29.2

Soil-eluviums of the near-summit belt. The harsh, sufficiently humid climate, with the absence of a frost-free period and frequent temperature transitions through the freezing point of water in the summer months, leads to the development of mainly frost weathering mechanisms here. That is, the process of rock destruction occurs under the wedging effect of freezing water. It is known that when the temperature drops below 0°C, water located in the system of large rocks freezes first. Water filling capillary, microcapillary cracks during the summer do not have time to freeze completely, and only partially freeze in winter. This contributes to the formation of large blocky and blocky material for eluvium and a relatively small amount of fine-grained material. The absence of a frozen phase in eluvium significantly changes the usual type of moisture migration and stress distribution for other bioclimatic belts, which ultimately leads to the formation of various eluvial-blocky formations here, the so-called "chingil."

Eluvial blocks and rubble bear no visible traces of hypergene alteration. The fine-grained material in the cracks between the blocks consists of fragments and mechanically fragmented minerals of parent rocks: feldspars, glass, micas, etc. Clay minerals are present in the clastic grains. Based on optical observations and physical methods data, the clay component of eluvial fines consists mainly of associations of montmorillonite, hydromicas, and kaolinite.

As already noted, the main agent of change in parent rocks is frost weathering. The principal source of sodium (Na), most likely, is groundwater, i.e., the rate of weathering of Na-containing minerals is exceptionally low. Alkaline elements from this landscape belt are mainly removed, as low evaporation prevents their concentration. Considering that in the Quaternary period, Mount Aragats underwent twofold glaciation, the denudation products of which cover quite extensive areas in the form of seas, it should be assumed that in the composition of the eluvium of the near-summit plateau of Mount Aragats, a certain proportion of the aforementioned minerals are products of glacial denudation from the summit zone. It is interesting to note that outcrops of powerful red-yellow hydrothermally altered andesite-dacites are traced in the crater (glacial cirque) of Mount Aragats. Due to the denudation of these rocks on the near-summit plateau, powerful accumulations of Middle Quaternary moraines were formed, in the composition of which, along with undecomposed gray-violet loams, representing products of denudation of weakly decomposed dacites of the summit zone, there are interlayers of ocherous and dirty-yellow loams, which, obviously, represent products of redeposition of hydrothermal rocks or, possibly, exarational denudation of ancient crust. In the Middle Pliocene, intense crust formation processes developed on the Armenian volcanic highlands under hot climatic conditions. In confirmation of this, the fact of pollen of Cimmerian appearance (magnolia, etc.) discovered by him in the weathering crust of the Vardenis highlands is cited. Apparently, similar conditions existed on Mount Aragats, and the redeposited ocherous layers may belong to this ancient crust or are a product of the denudation of the hydrothermal zone of the summit belt of Mount Aragats.

Answers to these questions can be obtained by a detailed study of the spatial position and vertical section of the moraines of the near-summit plateau.

In the composition of the modern soil-eluvium of the near-summit plateau, the presence of highly decomposed minerals (kaolinite, metahalloysite, etc.) indicates to some extent that the formation of soil-eluvium on the near-summit plateau of Mount Aragats developed not on fresh parent rocks of andesite, andesite-dacite compositions, but on a deep Middle Quaternary exarational cut, which preserved in the rock fissures an ancient allochthonous crust, or products of hydrothermally altered rocks brought by glaciers from the summit zone.

Soil-eluviums of the middle belt. Within the middle belt, on the slopes of Mount Aragats with a steepness of up to 20–25°, the weathering crust has significant differences from the weathering crust of the previous belt. Here, primary soil-eluvial formations are formed by chemical and biochemical weathering mechanisms. In the structure of the weathering crust itself, two zones are clearly distinguished: the lower, saprolite zone, the thickness of which, according to drilling data, does not exceed 10 m. On the slopes, due to deforestation, soil and the upper loose parts of the saprolite zone are usually eroded. A typical example of this type of weathering crust can be found on the southern slope of Mount Aragats, at an altitude of about 2300 m above sea level, somewhere near the village of Voskevaz nomad camp. Under conditions of a weakened periodic leaching moistening regime, a significant part of the elements is removed. Active migrants include alkaline and alkaline-earth elements. They are carried beyond the described belt of the weathering crust and can serve as an additional source of carbonates for the illuvial horizons of the lower belt. Iron, aluminium, and silicon remain in the eluvium and participate in the construction of synthetic hypergene neoformations. Carbonates are practically absent or occur in the lower horizons of the weathering crust of subordinate landscapes. In the saprolite zone, hypergene neoformation elements are represented by silicified iron hydroxides, as well as metahalloysite. Newly formed products fill primary and secondary pores and cracks in the eluvium. Their distribution is uneven. Judging by experimental materials, neoformations of this type are found throughout the weathering crust profile. Active migrants are alkaline and alkaline-earth elements, as well as silica. And here, hypergene mineral neoformations appear: halloysite-metahalloysite minerals in the lower parts of the soil-eluvium and montmorillonite in the upper parts.

Primary soil-eluvial formations of the lower belt are characterised by relatively weak chemical, physical, and physicochemical processes due to a sharp weakening of moistening. As an example, we can consider the weathering crust and the soil developed on it on andesite-basalts 2 km from the village of Agarak (along the Ashtarak–Byurakan road). Two genetic horizons are distinguished in the weathering crust: an eluvial rubbly-loamy horizon with plant roots 0.5–0.6 m thick and an illuvial blocky horizon with abundant white carbonate material excretions along the cracks (thickness 2–3 m). The upper loamy-rubbly horizon of the soil-eluvium is usually destroyed by erosion, and illuvial whitish carbonate horizons, which received the local name "belotsvetnaya" (white-colored), emerge to the surface.

Fractured andesite-basalts within the lower illuvial-carbonate horizon of the soil-eluvium show no visible traces of chemical destruction on the surface. This excludes the assumption of an autochthonous origin of carbonate accumulations. Carbonate excretions are found in the lower parts of the loamy-rubbly horizon, where it has been preserved. Further down the profile, the amount of carbonate substance increases. Dense and powdery carbonate crusts occur, and areas of carbonate cementation appear.

Thus, the clearly expressed contact of the carbonate crust with completely fresh effusives indicates not an eluvial, but rather an allochthonous origin. In addition, the very fact of the development of such powerful carbonate deposits (0.5–3.0 m) of various generations on effusives excludes the possibility of assuming their formation solely at the expense of andesite-basalts, which do not contain so many carbonates in their composition.

The question of the genesis of the so-called "belozems" is analysed and highlighted in detail in the author's work (Balyan et al., 1975), as these light-colored carbonate soils, developed on effusives of the entire Armenian volcanic highlands, have long been a subject of discussion. It is known that the carbonate crust and its products are developed mainly in arid and semi-arid regions on low slopes and foothill plateaus.

However, at the same time, they do not show a direct genetic connection with the parent effusives. Given that they are significantly older formations, their genesis may be related to the period of intense development of Quaternary volcanism, with the release of huge masses of carbon dioxide from numerous eruptive apparatuses abundant around the Mount Aragats massif. The saturation of surface waters with aggressive carbon dioxide contributed to the deposition of carbonate flowstone crusts on effusives.

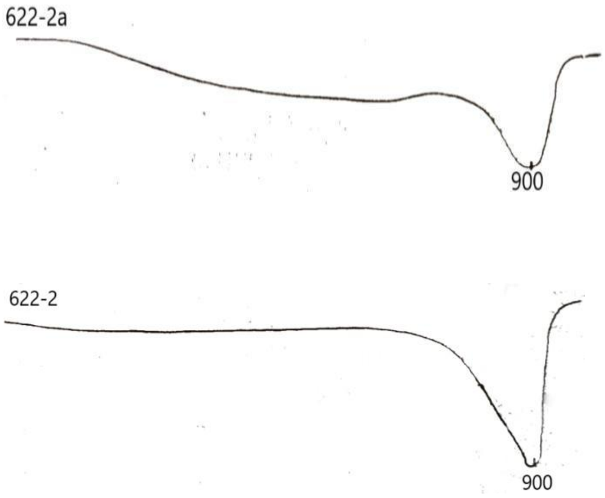

Figure 1. Thermograms of material from the weathering crust of andesite-basalts in the lower belt of Mount Aragats. 1-2 carbonate segregations, white powdery and grey porcelain-like areas, respectively. 1-2 – bulk samples

1. 2.

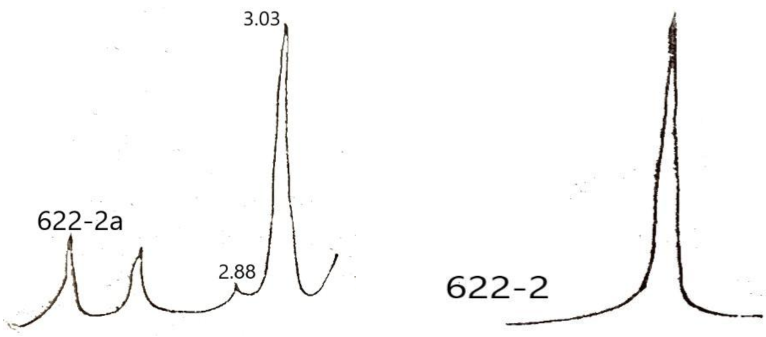

Figure 2. Diffractograms of material from the weathering crust of andesite-basalts in the lower belt of Mount Aragats. 1 – white powdery carbonate. 2 – grey porcelain-like carbonate

Based on thermal (Fig. 1, curves 1 and 2) and X-ray (Fig. 2, curves 1 and 2) analyses, the carbonate segregations are represented by calcite. The X-ray method detected a clay phase of montmorillonite with a small amount of hydromica and chlorite in the insoluble residue. Already below 2-3 m from the surface, carbonate segregations, as well as other products of supergene alteration of the rock, practically disappear.

According to X-ray and thermal analyses (Fig. 1, curves 1 and 2 and Fig. 2, curves 1 and 2), the eluvial crusts mainly contain a complex of minerals characteristic of the parent rock. The absence of any relict soil-eluvial formations of a different composition and structure in the described landscapes suggests that "white-colored" soil-eluvians developed over a very long period, at least for most of the Quaternary period.

Figure 3. Salinization

The system of primary soil-eluvial formations of Mount Aragats and the adjoining Ararat plain represents an area of salt accumulation with a progressively increasing series of salinisation (Fig. 3), occurring due to the weathering of basic massive-crystalline rocks rich in alkali and alkaline earth elements and infiltration of groundwater.

Conclusion

In the summit bioclimatic belt of Mount Aragats, eluviums are mainly dominated by coarse blocky material, and an independent soil zone is not distinguished. The main agent of parent rock alteration is frost weathering.

The clay phase is inherited from hydrothermal alteration of rocks and is represented by the association: hydromica-montmorillonite.

The principal source of sodium (Na) is most likely groundwater, as the weathering rate of Na-containing primary minerals is extremely low.

In the middle belt, primary soil-eluvial formations are formed by chemical and biochemical weathering mechanisms. They consist of two distinctly expressed zones: saprolite and soil. Hypergene mineral neoformations appear here: halloysite and metahalloysite minerals in the lower parts of the soil-eluvians and montmorillonite in the upper parts.

The primary soil-eluvial formations of the lower belt are characterised by relatively weak chemical and physicochemical processes. The thin blocky soil-eluvium has a differentiated profile with a leached and carbonate horizon.

A number of signs of the mineral part of the soil-eluvians, as well as historical and archaeological data, suggest that weathering and soil formation on the slopes of the middle and lower belts of Mount Aragats occurred under forest communities, which are primary here. This is one of the positive factors ensuring the prospects for planned reforestation work in the republic.

The results indicate that in the landscapes of the summit belt, Na is an active migrant, supplied by infiltrating groundwater, as chemical and physicochemical weathering is not developed. The sodium supplied with the water does not linger in the soil-eluvians of this belt. This element does not affect the soil-eluvians of the underlying landscapes down to the lower belt. Unlike calcium, the bulk of which is formed in the middle belt. Along with calcium mobilised in situ, it forms carbonate neoformations here.

The system of primary soil-eluvial formations of Mount Aragats and the adjoining plain represents an area of salt accumulation with a progressively increasing series of salinisation.

Competing interests

The authors declare that they have no competing interests.

Authors' contribution

All authors provided critical feedback and helped shape the research, analysis and manuscript.

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