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ABSTRACT

of the dissertation for the degree of Doctor of Philosophy

FLORA, VEGETATION AND PALYNOLOGY OF SOME SPECIES OF MUD VOLCANOES OF SHAMAKHI-GOBUSTAN REGION

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INTRODUCTION

The relevance and the degree of its elaboration of the research topic. Mud volcanoes are found in many countries of the world and are usually confined to young Cenozoic depressions. They have been studied by both foreign[1,2,3] and domestic scientists[4,5,6] as a geological object of study. While the processes occurring on mud volcanoes undoubtedly affect the dynamics of their vegetation, which cannot but cause interest in the need for comprehensive floristic and geobotanical studies.

The study of mud volcanism in relationship with vegetation is still highly specialized and fragmentary. The largest generalizations in this regard were the works of K.A. Korznikov[7], T.M. Ting and A.D. Poulsen[8], who studied the diversity of plants surrounding the mud volcanoes of Tabin and Lipad.

In Azerbaijan, the phenomenon of mud volcanism is observed in Shamakhi-Gobustan and Lower Kura districts, on the Absheron peninsula, in the areas of Baku and Absheron archipelagos. Flora and vegetation of mud volcanoes of Azerbaijan, its peculiarities of

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[1]Лимонов, А.Ф. Грязевые вулканы // Сетевой образовательный журнал, - 2004. №1. - с. 63-69.

[2]Dimitrov, L.I. Mud volcanoes - a significant source of atmospheric methane // Geo-marine Letters, - 2003. № 23, - p. 155-161.

[3]Kopf, A.J. Significance of mud volcanism // Reviews of Geophysics, - 2002. № 2, vol. 40, - p. 1-52.

[4]Алиев Ад.А., Гулиев, И.С., Рахманов, Р.Р. Каталог извержений грязевых вулканов Азербайджана (2008-2019 гг.) / Ад.А. Алиев, И.С. Гулиев, Р.Р. Рахманов. - Баку: Элм, - 2019, - 70 с.

[5]Алиев, Ад.А. Грязевые вулканы Каспийского моря // Геология и полезные ископаемые Мирового океана, - 2014. № 1. - с. 33-44.

[6] Ахмедов, А.Г. Геология и нефтегазоносность Гобустана / А.Г. Ахмедов. - Баку: Азнефтеиздат, - 1957. - 299 с.

[7]Корзников, К.А. Растительные сообщества грязевого вулкана Магунтан (о. Сахалин) // Бюллетень Московского общества испытателей природы. Отдел биологический, - 2015. т.120, вып. 1, - с. 61-68.

[8]Ting, T.M, Poulsen, A.D. Understory vegetation at two mud volcanoes in north-east Borneo // - Journal of Tropical Forest Science, - 2009. №3, vol. 21, - p. 198-209.

formation in conditions of volcanic activity have not been studied so far. There are only fragmentary data on the growth of a particular plant when describing the geological and landscape features of volcanoes[9,10].

There are still open questions such as the species composition of the flora of the dirty volcanoes of Azerbaijan, the structural organization of the vegetation cover, the diversity of plant elements, the patterns of their distribution on the surface of volcanoes, etc. Thus, the vegetation of mud volcanoes in the world has been poorly studied, and serious research in the areas of Azerbaijan has not been conducted. In this regard, we studied the flora and vegetation around some dirty volcanoes of Azerbaijan, and our study is of current importance and, of course, makes a certain contribution to the history of the study of dirty volcanoes of Azerbaijan.

Object and subject of the research. The objects of the study were mud volcanoes Gyzmeidan, Toragay, Pirekyashkul, Dashgil and Kichik Maraza. Flora, vegetation and interrelations in the soil-plant system of mud volcanoes served as the subject of the study.

Purpose and main objectives of the research. The aim of the present study was to investigate the modern flora and features of vegetation formation of mud volcanoes. Based on the goal of the work, the following tasks were solved:

1. Identification of species composition and compilation of an outline of the flora of mud volcanoes;

2. Taxonomic, biomorphological and bioecological analysis of the flora.

3. Study of the peculiarities of formation of plant communities of mud volcanoes and their structural organization;

4. Study of the relations between the chemical composition of some dominant forage species and surface soil layers;

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[9]Зейналова, С.М. Индикационное дешифрирование аридных ландшафтов южного склона Юго-Восточного Кавказа: / дис. канд. геогр. наук / - Баку, 1998. - 185 с.

[10]Керимова, Э.Д. Формирование и дифференциация ландшафтов районов развития грязевых вулканов (на примере Абшерон-Гобустанского района): / диссертация на соискание учёной степени доктора философии по географии. / - Баку, 2010. - 194 с.

5. Study of morphological features of pollen of some herbaceous plants growing on the territory of mud volcanoes;

6. Population and ontogenetic assessment of rare plant species growing on the territory of volcanoes and development of recommendations for their protection.

Research methods. Taking into account the set tasks, floristic, geobotanical, population-ontogenetic, chemical and palynological methods of research were used in the work.

The basic provisions of the dissertation defense:

1. The composition of flora and vegetation cover of mud volcanoes differ from the surrounding phytocenoses, because their formation occurs in specific conditions caused by periodic release of volcanic mud on the surface.

2. The flora and vegetation of each of the 5 mud volcanoes is characterized by its uniqueness, as it is formed under the influence of ecological conditions specific to each volcano and their surrounding environment.

3. Dynamic development of the vegetation cover of mud volcanoes occurs through allogenic and autogenic successions, since the improvement of growing conditions by the vital activity of living organisms is not only influenced by them, but is also caused by the transformation of abiotic factors created by mud volcanoes.

4. In the conditions created by the activity of mud volcanoes it is possible to predict the transformation in the interconnected soil-plant system in the future.

The scientific novelty of the research. For the first time for Azerbaijan the flora of mud volcanoes of Pirekyashkul, Dashgil, Toragay, Kichik Maraza, Gyzmeidan was compiled, which includes 134 taxa belonging to 118 genera and 39 families. Four rare (*Tulipa biflora* Pall., *Pyrus salicifolia* Pall., *Ophrys oestrifera* M. Bieb., *Rosa pulverulenta* M. Bieb.) and an endemic species (*Rosa pulverulenta*) of Azerbaijan flora were found on the studied 5 mud volcanoes.

Bioecological analysis of the mud volcano flora has the following ecogroup ratio: mesophytes 79 species (59%), xeromesophytes 38 species (28%), xerophytes 13 species (10%), mesoxerophytes 4 species (3%); and according to the ratio of life

forms are represented by the following biomorphs: therophytes 51 species (38%), phanerophytes 11 species (8%), chamaephytes 12 species (9%), hemicryptophytes 39 species (29%), cryptophytes 21 species (17%).

Successional series of vegetation units formation were established in the territories of mud volcanoes, as a result of which 24 vegetation units were identified: Pirekyashkul and Kichik Maraza - 3 associations each, Toragay - 2 associations, Dashgil and Gyzmeidan - 1 association each.

In the soil-plant system in the conditions of mud volcanoes, the highest values of the coefficient of biological absorption of metals in some forage species are observed in *Salsola nodulosa* (Moq.) Iljin - 0.04-0.52, the lowest - in *Suaeda microphylla* Pall. - 0.01-0.29, the species *Salsola dendroides* Pall. occupies an intermediate position - 0.03-0.33.

During the palynomorphological study of some species of the flora of the mud volcano, it was found that pollen of the studied species belonged to 5 pollen types: 3-colpate *Brassicaceae* Burnett, *Convolvulaceae* Juss., *Fabaceae* Juss. (*Hedysarum sericeum* Kitam.), *Lamiaceae* Martinov, *Linaceae* DC. ex Perleb), 3-colporate (*Asteraceae* Giseke, *Cistaceae* Juss., *Hypericaceae* Juss., *Euphorbiaceae* Juss., *Fabaceae*, *Rosaceae* Juss.), stepanocolporate (*Polygalaceae* Hoffmanns. & Link), 6-heteroaperturate (*Boraginaceae* Juss.) and pantoporate (*Ranunculaceae* Juss.).

Scientific and practical significance of the research. Rare taxa found on volcanoes and assessment of their condition are used in writing a new 3rd edition of the Red Book of Azerbaijan[11]. The compiled outline of the flora of mud volcanoes can be used in writing a new edition of Flora of Azerbaijan. The ability to increased and high accumulation of a number of metals in the above-ground parts of halophyte plants can be used in phytoremediation of soils polluted with heavy metals. The obtained data will serve both in the present and in the future for effective development of environmental protection measures. The material collected in the course of the study can be used

[11]Azərbaycan Respublikasının Qırmızı Kitabı (Flora) / Red. hey. həmsədrləri İ.Ə.Həbibbəyli, M.B.Babayev. Bakı: İmak, - Üçüncü nəşr. - 2023. - 507 s.

in lectures of educational secondary and higher educational institutions.

Approbation and degree of validity of the results. The main results and provisions of the work were reported at scientific-practical conferences and symposiums held in the republic and abroad:

«International Conference Innovative Approaches to Conservation of Biodiversity» (Baku, 2016); «Innovation and traditions in modern botany» (Baku, 2019); «Multidisciplinary approaches in solving modern problems of fundamental and applied sciences. Second International Scientific Conference of Young Scientists and Specialists» (Baku, 2020); «2nd International Symposium on Biodiversity Research» (Turkey, 2020); «New directions for the development of agriculture and environmental protection» (Baku, 2021); «Integration of Education, Science and Business in Modern Environment: Winter Debates: Proceedings of the 3rd International Scientific and Practical Internet Conference» (Ukraine, 2022); «Science and education in the modern world: challenges of the xxı century» (Kazakhstan, 2022**);** «International Scientific Journal Global Science and Innovations 2023: Central Asia» (Astana, 2023); «Modern approaches in the study of the plant kingdom» (Baku, 2023); «International autumn school» (Baku, 2023); «Role of National Leader Haydar in the Improvement of the Environment in Azerbaijan» (Baku, 2024); X International Symposium «Steppes of Northern Eurasia» (Orenburg, 2024).

It was published 18 scientific papers (6 articles, 12 abstracts) on the materials of the dissertation work, of which 2 in peer-reviewed journals (Web of Science, Scopus, RINC).

Name of the organization where the dissertation was performed. The work was performed at the Department of Biomorphology and Phytointroduction of the Institute of Botany of the Ministry of Science and Education of the Republic of Azerbaijan.

Structure and volume of the research. The dissertation is set out on 243 pages, includes 16 tables, 44 figures. The total number of characters is 234336 including introduction – 7910 characters, 8 chapters (Chapter I – 38900 characters, Chapter II - 7507 characters, Chapter III – 6558 characters, Chapter IV – 54300 characters, Chapter

V – 58984 characters, Chapter VI – 21389 characters, Chapter VII – 23068 characters, Chapter VIII – 12284 characters), conclusions – 2607 characters, practical recommendations – 829 characters, conclusions, list of abbreviations and list of used literature of 232 sources and an appendix.

CHAPTER I. LITERATURE REVIEW OF THE STUDY OF MUD VOLCANOES

1.1. Historical review of mud volcanoes investigation

This chapter clarifies the meaning of the terms “mud volcanoes” or “mud sopka” and provides literature on the history of mud volcano studies and large fiery eruptions.

1.2. Peculiarities of formation, distribution, morphology and current state of mud volcanoes

Literature material concerning the issues of formation and distribution of mud volcanoes on the continents, as well as in the seas and oceans is analyzed, the issues of classification of mud volcanoes and their geomorphological features are touched upon. In the course of the general study, heavy metals are studied as one of the main abiotic stresses leading to dangerous consequences for plants because such area of volcanoes study as toxicity of heavy metals contained in volcanic rocks affects the vegetation cover. The literature on ecological palynology was analyzed because pollen is a part of the life cycle of plants and changes in the basic characteristics of pollen grains can significantly affect the reproductive biology of the whole plant.

1.3. History of the study of flora and vegetation of mud volcanoes

Analytical review of the main sources of literature on the study of flora and vegetation of mud volcanoes has been made. Some information on vegetation of mud volcanic formations of Azerbaijan and the world is presented in them. Much attention is paid to the study of plant communities of young mud fields of Maguntan volcano. Mud

volcanoes and landscapes resulting from their activity are important and widely discussed[12].

CHAPTER II. NATURAL CONDITIONS IN THE LOCATIONS OF MUD VOLCANOES

In this chapter, based on the literature data, the natural and climatic conditions of the studied territories are characterized. To characterize the soils and vegetation of the studied territories the materials of scientific data from a number of publications[13,14].

CHAPTER III. OBJECTS, MATERIALS AND METHODOLOGY OF THE STUDY

3.1. The objects of research

The objects of the research are mud volcanoes Gyzmeidan, Toragay, Pirekyashkul, Dashgil and Kichik Maraza (Fig.1).

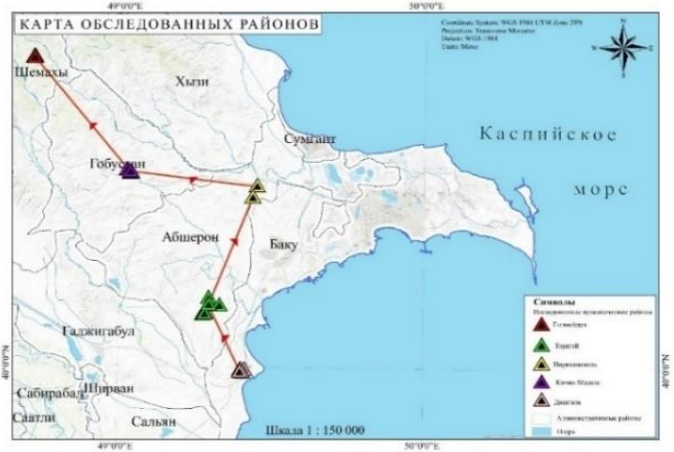

Figure 1. Map - scheme of the trajectory of the study mud volcanoes of Shamakhi-Gobustan region (Azerbaijan)

[12]Korznikov, K.A. Vegetation cover at the Maguntan mud volcano (Sakhalin Island, Russia): species composition and spatial distribution // Phytocoenologia, - 2015. №1-2, vol. 45, - p. 125-134.

[13]Алиев Ад.А., Гулиев, И.С., Дадашев, Ф.Г., Рахманов, Р.Р. Атлас грязевых вулканов мира [Карта] / - Bakı: Nafta-Press, - 2015. - 322 с.

[14]Прилипко, Л.И. Растительный покров Азербайджана / Л.И. Прилипко. - Баку: Элм, -1970. - 170 с.

The study of flora and vegetation at mud volcanoes started with reconnaissance observations, which were conducted in different seasons from 2016 to 2024. The reconnaissance surveys of volcanoes were of primary introductory nature. In the course of these surveys, model sites were selected, sample sites were laid out, where semi-stationary studies and observations were carried out with the collection of necessary material, and the necessary research methodology was selected.

3.2. Materials and methods of research

As the material of research served the flora, vegetation, pollen grains and soil from mud volcanoes.

Taking into account the set tasks, floristic, biomorphological, geobotanical, population-demographic, chemical and palynological methods were used in the work. The collected material underwent cameral and statistical data processing.

3.2.1. Methodology for conducting floristic-taxonomic research

The analysis of the flora of mud volcanoes was carried out according to generally accepted methods of floristic research. When establishing the taxonomic affiliation and nomenclature of species, we adhered to the Flora of Azerbaijan[15], the conspectus of the Flora of Azerbaijan[16], with consideration of the The WFO Plant List'[17]. Also, the geographical elements of the flora of volcanoes were taken into account using the classification of elements of the Caucasian flora developed by A.A. Grossheim[18,19].

The identification of endemic species in the flora was carried out taking into account the Analysis of the endemism of the flora of

[15]Флора Азербайджана - Баку: Изд-во АН Азерб. ССР, - т. I-VIII. – 1950-1961.
[16]Əsgərov, A.M. Azərbaycan florasının konspekti / A.M.Əsgərov. - Bakı: Elm, - 2011. - 204 s.
[17]https://wfoplantlist.org/
[18]Гроссгейм, А.А. Анализ флоры Кавказа / А.А. Гроссгейм. - Баку: Изд. Азерб. филиала Акад. наук, - 1936. - 260 с.
[19]Гроссгейм, А.А. Растительный покров Кавказа / А.А. Гроссгейм. - Москва: МОИП, - 1948. - 264 с.

Azerbaijan[20,21] and the Red list of the endemic plants of the Caucasus Region[22].

3.2.2. Methodology for conducting geobotanical, population-demographic and biomorphological research

Geobotanical descriptions were carried out using generally accepted methods. Based on this, the study was carried out using the method of sample plots and linear transects according to the generally accepted methodology of field studies[23]. In this case, the abundance of species was estimated using the generally accepted Braun-Blanquet[24] cover-abundance scale. When analyzing the patterns of plant distribution, schematic mapping of plant placement on transects was carried out. When studying ontogenesis and demographic structure of populations, we used the principles and methods accepted in modern plant population biology and developed by T.A. Rabotnov[25], L.B. Zaugolnova[26], R.M. Ishkinin and M.M. Ishmuratova[27].

Demographic structure was defined as the ratio of different ontogenetic (age) groups[28]. The type of coenopopulation (CP) was

[20]Əsgərov, A.M. Azərbaycan florasının subendemləri // - Bakı: AMEA Xəbərləri, Biologiya və tibb bölməsi, - 2014. - №1. - s. 81-91.

[21]Аскеров, А.М. Анализ эндемизма флоры Азербайджана // - Баку: Докл. НАНА, - 2014. №1, - с. 51-55.

[22]Schatz, G.E. Red list of the endemic plants of the Caucasus Region (Armenia, Azerbaijan, Georgia, Iran, Russia and Turkey) / G. E. Schatz, T. Shulkina, J. C. Solomon, - St. Louis, US: Missouri Botanical Garden Press, - 2014. - 451 p.

[23]Сукачев, В.Н. Главнейшие понятия в фитоценологии // Сов. Ботаника, - 1942. №1-3, - с. 5-17.

[24]Braun-Blangued, J. Pflanzenosociologie / J. Braun-Blangued. - New York: Wien, - 1964. - 830 p.

[25]Работнов, Т.А. Изучение флюктуаций (разногодичной изменчивости) фитоценозов // - Ленинград: Полевая геоботаника, - 1974. т.4, - с. 95-136.

[26]Ценопопуляции растений (очерки популяционной биологии) /Л.Б. Заугольнова, Л.А. Жукова, А.С. Комаров [и др.] - Москва: Наука, - 1988. - 184 с.

[27]Ишкинина, Р.М., Ишмуратова М.М. Онтогенез любки двулистной (*Platanthera bifolia* (L.) L. C. Rich.) / Р.М. Ишкинина, М.М. Ишмуратова. - Йошкар-Ола:Онтогенетический атлас растений, - 2007. - 372 с.

[28]Животовский, Л.А. Онтогенетические состояния, эффективность и классификация популяций растений // Экология, - 2001. №1, - с. 3-7.

determined on the basis of the Δ-ω (delta-omega) classification of A.A. Uranov[29].

Life forms were analysed using the life form classification system of C.C. Raunkier[30] and the physiognomic system of life forms of I.G. Serebryakov[31].

3.2.3 Chemical analysis of plants and soils

The contents of Cd, Co, Cr, Cr, Cu, Fe, Mn, Al, Ni, Pb and Zn were determined by inductively coupled plasma optical emission spectroscopy (ICP-OES) in the laboratory of R.T. Erdoğan Institute (Rize, Turkey). All analyses were performed in 3-fold repetition with control of measurement accuracy using standard samples. To determine the translocation of the studied metals from the surface soil layer to the dominant plant species, the biological absorption coefficient (BAC) was calculated, which is the ratio of the element content in the plant to its content in the soil[32].

Statistical processing of the obtained results of chemical analysis of plants and soils included methods of descriptive statistics and ANOVA using the Excel 7.0 and Statistic 64 software packages. Mean values, standard deviation, and standard error were calculated.

3.2.4. Methods of light (LM), scanning (SEM) and transmission (TEM) electron microscopy for the study of pollen grains

To study the general morphology of pollen grains were used the methods of light-optical (LM) and scanning electron microscopy (SEM). For the light-optical study, the classical acetolysis method of

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[29]Уранов, А.А. Возрастной спектр фитопопуляций как функция времени энергетических волновых процессов // Биологические науки, - 1975. №2. - с. 7 - 34.

[30]Raunkiaer, Ch. Plant life forms / Ch. Raunkiaer. - Oxford: Clarendon Press, - 1937. - 632 p.

[31]Серебряков, И.Г. Жизненные формы высших растений и их изучение // - Москва: Полевая геоботаника, - 1964. - с. 146-202.

[32]Серебряков, И.Г. Жизненные формы высших растений и их изучение // - Москва: Полевая геоботаника, - 1964. - с. 146-202.

[32]Перельман, А.И. Геохимия / А.И. Перельман. - М.: Высшая школа, - 1989. - 527 с.

Erdtman was used[33]. The study of preparations and photofixation of pollen grains were carried out using oil immersion with a Micmed-6 light-optical microscope (LOMO, St. Petersburg, Russia) and a Canon EOS 20D digital camera. Specific features of pollen grain surface structure (sculpture) were studied using a JEOL JSM-6390 scanning electron microscope and the ultrastructure of pollen grain was studied using a scanning electron microscope and ultrathin sections using a Hitachi-600 transmission microscope at the collective use center of the V.L. Komarov Botanical Institute (St. Petersburg, Russia).

CHAPTER IV. FLORA AND VEGETATION OF THE STUDIED MUD VOLCANOES

4.1. Characteristics of the flora of the mud volcanoes Pirekyashkul, Dashgil, Kichik Maraza, Toragay, Gyzmeidan

Studies have shown that the species composition and vegetation of mud volcanoes is largely determined by the flora and vegetation of the surrounding areas. For example, the vegetation cover of the Dashgil and Pirekyashkul mud volcanoes is characterized by the presence of surrounding desert and semi-desert plants adapted to arid, hot climates, as well as shrubs, subshrubs and representatives of the synusia of ephemerals and ephemeroids. Plants from meadow and shrub communities of Gyzmeidan area are found on the Gyzmeidan volcano. Of the five mud volcanoes submitted for flora analysis, four - Pirekyashkul, Dashgil, Toragay, Kichik Maraza are located in the lowland and foothill desert and semi-desert regions of Azerbaijan and one - Gyzmeidan belongs to the mountain shrub-meadow zone. Taking into account these differences, the floristic analysis was carried out for each mud volcano separately.

4.1.1. Taxonomic composition of the flora of mud volcanoes

During the research period (2016-2024), 134 taxa of higher vascular plants belonging to 118 genera and 39 families were identified in the flora of mud volcanoes. The leading place in the number of species is occupied by the families *Asteraceae*, including

[33]Erdtman, G. Pollen morphology and taxonomy / G. Erdtman. - Stockholm: Angiosperms, - 1952. - 539 p.

16 genera and 20 species (15%), *Poaceae* Barnhart - 15 genera and 18 species (13%), *Brassicaceae* - 9 genera and 11 species (8%) and *Fabaceae* - 8 genera and 9 species (7%).

The flora of vascular plants of the Pirekyashkyul mud volcano is represented by 6 families, 15 genera and 18 species of higher plants. Accordingly, 11 species of higher plants belonging to 10 genera and 6 families were found in the flora of the Dashgil mud volcano, 44 species belonging to 43 genera and 20 families in Toragay, 39 species belonging to 37 genera and 17 families in Kichik Maraza, and 90 taxa belonging to 81 genera and 33 families in Gyzmeidan.

4.1.2. Biogeographical analysis

Biogeographical analysis of the flora of mud volcanoes showed that in the studied communities the largest number of species are represented by the xerophile type of habitat, comprising 56% (75 species) of the total number of plant species, where species of the families *Poaceae*, *Brassicaceae* and *Amaranthaceae* predominate.

4.1.3. Biomorphological analysis

In the flora of Pirekyashkyul volcano 2 species (11%) of hemicryptophytes, 12 species (67%) of therophytes were recorded, Dashgil volcano respectively 2 species (18%) and 3 species (27%); Toragay - 8 species (18%) and 24 species (54%); Kichik Maraza - 9 species (23%) and 20 species (51%); Gyzmeidan - 29 species (32%) and 32 species (36%). The proportion of chamaephytes and cryptophytes (the latter are absent at Pirekyashkyul and Dashgil mud volcanoes) is as follows: at Pirekyashkyul volcano chamaephytes - 4 species (22%); Dashgil - 5 species (45%); Toragay - 4 species (9%) and 5 species (11%); Kichik Maraza - 4 species (10%) and 5 species (13%); Gyzmeidan - 4 species (4%) and 17 species (19%), respectively. The proportion of perennial woody species - phanerophytes in Gyzmeidan mud volcano is 8 species (8%), Dashgil and Kichik Maraza - 1 species (respectively 9% and 2%), Toragay - 2 species (4%) (Fig. 2).

A similar ratio is observed in the spectrum of life forms according to I.G. Serebryakov.

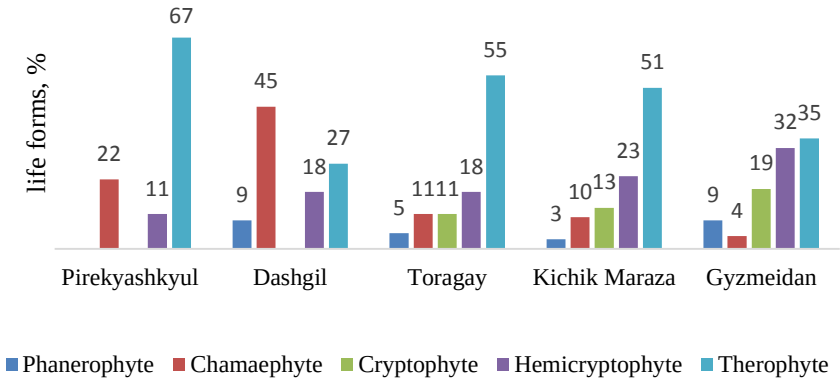

Figure 2. Biomorphological spectrum of life forms
in the flora of mud volcanoes according to C. Raunkier

4.1.4. Bioecological analysis

Bioecological analysis of the conformity of plants in terms of their impact on the moisture regime showed that the xerophyte group is mainly distributed on the Dashgil mud volcano (more than 50%), and the mesophyte group is most common on the Gyzmeidan and Kichik Maraza mud volcanoes. The Toragay mud volcano is dominated by transitional group from the mesophytic to the xerophytic (45%), series is plants that need moisture, but have adapted to the harsh xerophytic conditions of deserts and semi-deserts (Fig. 3).

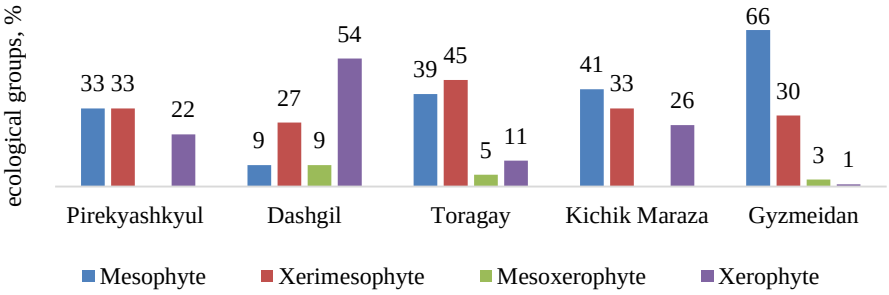

Figure 3. Spectrum of ecological groups
in the flora of volcanoes in relation to hydration

A rather wide range of groups is observed in relation to salinity (Fig. 4).

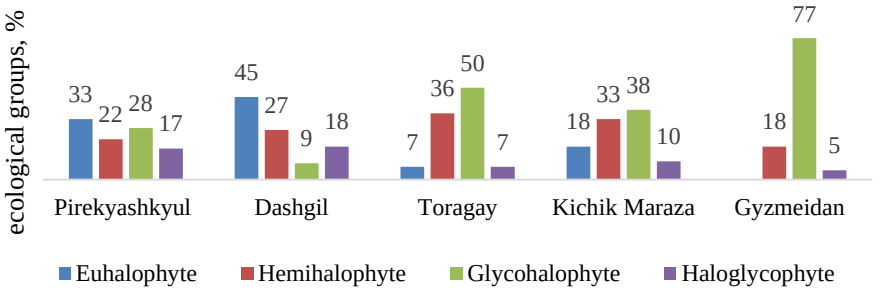

Figure 4. Spectrum of ecological groups
in the flora of volcanoes in relation to salinity

According to the method of obtaining moisture from soil horizons (Fig. 5), two background groups were identified. On the one hand, these are species with root system located in 0-10 cm soil horizon, and on the other hand – plants, root system of which goes into deep soil horizons, providing themselves with moisture due to deep groundwater. The predominant group are ombrophytes, i.e. therophytes, annuals, and from the phytocenotic point of view - representatives of ephemeral-ephemeroid sinusia of volcanoes. The phreatophyte group includes all dominant and price-forming plants - representatives of saltwort vegetation.

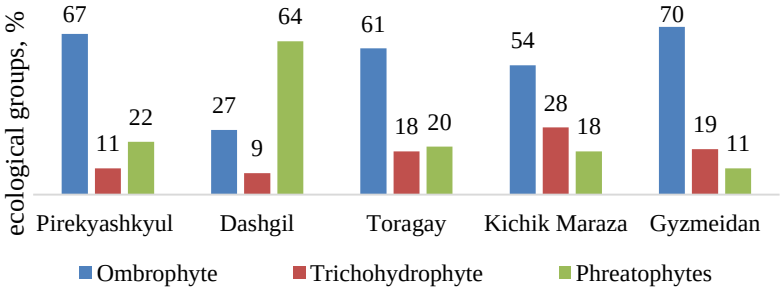

Figure 5. Spectrum of ecological groups in the flora of volcanoes according to the depth of the root system and the way of moisture absorption of soil horizons

4.2. Characteristics of the vegetation of mud volcanoes

The formation of vegetation on the surface of a mud volcano is a long-term process involving primary (emergence of pioneer plants) and secondary (vegetation change with repeated eruptions) short- and long-term successions. Despite the fact that almost 80% of these eruptions occur beneath the oceans, terrestrial volcanic phenomena are quite common and can affect nearby vegetation. The main impacts of volcanic activity on vegetation are lava formation, pyroclastic flows, avalanches of debris, mudflows, deposits of tephra and ash. A general geobotanical description of vegetation was carried out at each volcano during the period of mass flowering, which included noting the species encountered at the volcano, their distribution, and specifying the vertical and horizontal structure of vegetation.

4.2.1. Vegetation cover of the Pirekyashkyul mud volcano

In terms of vertical zoning, the volcano is located at an altitude of 315 m above sea level. The species composition of the vegetation surrounding the Pirekyashkyul mud volcano includes up to 18 plant species belonging to 15 genera and 6 families.

In the vegetation cover of the Pirekyashkyul mud volcano, 6 vegetation units have been identified, of which 3 are associations (№4-6) and the rest are in the stages of aggregation and semi-aggregation, i.e. continue to form:

1. Aggregation of small shrub saltwort desert (S*uaeda microphylla)*;

2. Semi-aggregation of small shrub saltwort desert (*Salsola nodulosa + Salsola dendroides – Ephemerae)*;

3. Semi-aggregation of small shrub saltwort desert (*Suaeda dendroides + Suaeda microphylla – Ephemerae*);

4. Association of small shrub saltwort desert (*Suaeda dendroides + Suaeda microphylla – Ephemerae*);

5. Association of small shrub saltwort desert (*Salsola nodulosa + Salsola dendroides – Ephemerae*);

6. Association of annual saltwort desert (*Petrosimonia brachiata + Climacoptera crassa + Ephemerae*).

4.2.2. Vegetation cover of the Dashgil mud volcano

The Dashgil mud volcano is located in the landscape in the zone of wormwood, small shrub saltwort desert, at an altitude of 124 m above sea level. The species composition of the vegetation on the volcano is extremely poor - 11 species belonging to 10 genera and 6 families.

There are 3 vegetation units on the mud volcano:

1. Aggregation of small shrub saltwort desert (*Suaeda microphylla)*;

2. Semi-aggregation of small shrub saltwort semi-desert (*Salsola dendroides – Ephemerae*);

3. Association of small shrub saltwort semi-desert (*Salsola dendroides + Artemisia fragrans – Ephemerae*).

4.2.3. Vegetation cover of the Kichik Maraza mud volcano

The surveyed area of the mud volcano location (677 m a.s.l.) is dominated by semi-desert small shrub, shrub wormwood-ephemeral-ephemeroidea-saltwort-forb foothill semi-desert.

The species composition includes 39 species belonging to 37 genera and 17 families. In the vegetation cover of the mud volcano in the vicinity of Maraza, 5 vegetation units have been identified, two of which are an aggregation and an agglomeration, and the rest are associations:

1. Aggregation of small shrub saltwort desert (*Suaeda microphylla*);

2. Agglomeration of small shrub saltwort semidesert (*Suaeda microphylla + Artemisia fragrans*);

3. Association of annual saltwort desert (*Petrosimonia brachiata + Ephemerae*);

4. Association of small shrub saltwort desert (*Salsola nodulosa + Artemisia fragrans – Ephemerae*);

5. Association of ephemeral-ephemeroid-wormwood (*Artemisia fragrans + Reaumuria alternifolia – Ephemerae*).

4.2.4. Vegetation cover of the Toragay mud volcano

The Toragay mud volcano, like the previous mud volcanoes, is located in a semi-desert zone, at an altitude of 155 m above sea level. The species composition of the vegetation surrounding the Toragay

mud volcano includes up to 44 plant species belonging to 43 genera and 20 families.

At the Toragay mud volcano, 4 vegetation units are identified, of which 2 (№3, 4) are full-fledged associations:

1. Aggregation of small shrub saltwort desert - *Salsola dendroides*;

2. Semi-aggregation of small shrub saltwort semi-desert - *Salsola dendroides* - *Ephemerae*;

3. Association of small shrub saltwort desert (*Salsola nodulosa* + *Salsola dendroides* – *Ephemerae*);

4. Association of small shrub saltwort semi-desert (*Salsola nodulosa* + *Artemisia fragrans* – *Ephemerae*).

4.2.4. Vegetation cover of the Gyzmeidan mud volcano

The Gyzmeidan mud volcano is located in the mid-mountain shrub-meadow belt (1250 m above sea level).

The species composition of the mud volcano includes 90 taxa belonging to 81 genera and 31 families. The geobotanical description of the vegetation of the volcano allowed us to identify the following vegetation units:

1. Semiaggregation of diverse herbaceous-juniper-wormwood (*Artemisia alpina* + *Juniperus communis* var. *saxatilis* - *Bromus japonicus*);

2. Semiaggregation of diverse herbaceous (*Herbosa*);

3. Association of diverse herbaceous-tree-shrub (*Juniperus communis* var. *saxatilis* + *Pyrus salicifolia* – *Herbosa).*

4.2.6. Features of the formation of the vegetation cover of volcanoes

Phytocenotic description of vegetation of mud volcanoes showed the dependence of spatial organisation of plants on the volume of clay mud ejection, its direction and character of flowing from the centre of the mud volcano. In places of its greatest ‘accumulation’ plants are absent or species composition is sharply reduced. Thus, in the horizontal structure of the vegetation cover of mud volcanoes the distribution of vegetation takes a mosaic character. Ejection and runoff of ‘mud clay lava’ do not allow full-fledged settlement by plants demanding to the ecotope. Such areas are either not populated at all,

or spontaneously populated by solanaceae genetically related to clay saline soils.

CHAPTER V. MORPHO-BIOLOGICAL CHARACTERISTICS OF THE FLORA OF MUD VOLCANOES

During the field studies, in addition to geobotanical descriptions, attention was paid to some phytocoenotic (occurrence, phytocoenotic status, phenology) and biomorphological (life form, structure of main organs, height) characteristics of plants. It was found that the height of ephemera and ephemeroids sinusia in volcanic conditions is characterized by lower height and generally poorly expressed vitality, which is certainly a consequence of difficult soil conditions. The analysis of the obtained results showed that species distributed on mud volcanoes differ significantly from plants of other habitats by such morpho-biological characteristics as height, size, leaf shape, as well as intensity of phenological phases (active early spring vegetation).

CHAPTER VI. STUDY OF THE SOIL-PLANT SYSTEM INTERRELATIONS IN CONDITIONS OF MUD VOLCANOES (ON THE EXAMPLE OF DASHGIL)

Mud volcanic waters and breccias are enriched with trace elements and toxic metals (Hg, As, Li, B, Mo, Sr, Yb, Pb) with concentrations higher than the clarke concentrations. As the salt solutions reach the surface, they lead to the formation of lithogenic base with high salt content and more intensive development of halophytic vegetation on it compared to the surrounding areas[34].

6.1. Chemical composition of mud volcano soils

To study the chemical composition of plants and surface soil layer (0 - 20 cm), key areas (KA) were established from the eruptive center down the slope, key area 4 - uncontaminated area, control. At the key areas we sampled dominant plant species *Salsola dendroides*, *Suaeda microphylla*, *Salsola nodulosa* in 4-fold repetition and surface

[34]Ахмедов, А.Г. Грязевые вулканы и окружающая среда / А.Г. Ахмедов. - Баку: Общ-во «Знание» АЗ.ССР, - 1985. - 50 с.

soil samples in 3-fold repetition. As can be seen from the data in Table 1, even the maximum concentrations of most metals do not exceed their background content in the Earth's crust, with the exception of Zn, Pb, Cd and Cu at key area 4.

Table 1

Content of heavy metals (mg/kg) in soils of key areas of the mud volcano Dashgil

Metal	KA1	KA2	KA3	KA4	Earth's crust *	H (p)
Fe	21730-32485	20025-36675	29930-36645	28475-34985	50000	1.50 (0.68)
Al	10815-14790	8510-51800	11945-55270	8510-19390	n.d.	6.96 (0.07)
Mn	405-700	334-810	473-641	500-811	950	2.52 (0.47)
Zn	148-164	86-221	78-201	79-221	70	1.15 (0.77)
Cr	51.2-72.5	48.0-89.6	60.5-80.3	73.2-79.3	100	3.18 (0.36)
Pb	43.5-56.2	29.8-63.9	27.0-60.0	26.0-63.9	13	0.83 (0.84)
Cu	28.2-47.1	24.0-49.4	37.5-46.5	40.6-79.3	55	0.53 (0.91)
Ni	28.2-39.2	22.7-41.2	35.8-43.1	33.9-44.7	75	5.57 (0.13)
Co	10.2-14.0	9.1-14.6	10.5-17.1	12.4-15.3	25	6.11 (0.11)
Cd	1.3-2.7	0.7-3.3	0.7-2.7	2.0-3.3	0.2	0.66 (0.88)

Note: KA – key area; * – background content in the Earth's crust; H – the Kruskal–Wallis criterion; p – significance level; n.d. – no data.

In soils of key areas, the content of zinc on average 2 times, lead almost 3.5 times, and cadmium 10 times exceeds their values in the earth crust. Analysis of soils of the key areas of the mud volcano revealed a high degree of variation of this indicator depending on the nature of the metal.

Based on the coefficient of variation and the ratio of maximum to minimum value, the degree of variation of heavy metal content in soils of key areas was assessed. It was found that for the studied metals the expression of variation varies greatly. The highest values of the

coefficient of variation and the ratio of maximum to minimum content are observed for Al and Cd, and the lowest - Cr, Ni, Co, respectively.

Thus, it can be concluded that the concentrations of metals in the surface layer of soil in key areas along the slope of the Dashgil mud volcano are arranged in a decreasing series: Fe>Al>Mn>Zn>Cr>Pb>Cu>Ni>Co>Cd. The highest average content values are observed for iron, and the lowest for cadmium and the differences in the content of the first and the last metal reach 14000-16000 times.

6.2. Chemical composition of the soil in the rhizosphere of plants

Concentrations of metals in the soil of the rhizosphere zone along the slope of the Dashgil mud volcano are arranged in a similar descending order: Fe>Al>Mn>Zn>Cr>Pb>Cu>Ni>Co>Cd.

The conducted analysis by non-parametric Mann-Whitney criterion did not reveal reliable differences in the content of all studied metals in soil samples of key areas and in the root-inhabited layer of soil. It follows from the above that the chemical composition of soil did not influence the growth of dominant plant species at the key areas of the Dashgil mud volcano, and it is not associated with the change of dominant species along the volcano slope.

6.3. Comparative analysis of metal content in soil and volcanic mud

A comparative analysis revealed both similarities and differences in the content of a number of elements. The maximum differences are noted for Pb and Al: volcanic mud contains 6 times more aluminum and 10 times less lead in relation to the soils we studied.

6.4. Chemical composition of mud volcano plants

Metal concentrations in all studied plant species are located in a descending order: Al>Fe>Mn>Zn>Cu>Cr>Ni>Pb>Cd>Co.

Suaeda microphylla has the lowest content of almost all metals (Fig. 6), while *Salsola nodulosa* has the highest content, which led to such significant differences in the total content of all metals studied.

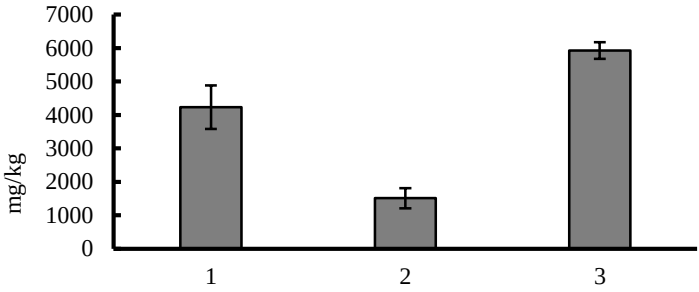

Figure 6. Total content of the studied metals (mg/kg) in dominant plant species of the mud volcano Dashgil:
1 - *Salsola dendroides*; 2 – *Suaeda microphylla*; 3 - *Salsola nodulosa*

6.5. Adaptation of halophyte plants to salinization and increased metal content in soils

The identified dominant species of the Dashgil mud volcano accumulate rather low concentrations of metals in the aboveground part of plants, which, in general, do not exceed their normal content in plants, except for Cd and Cr. The enrichment of the studied plant species with cadmium does not exceed the threshold of its toxicity, while the content of chromium in *Salsola dendroides* and *Salsola nodulosa* is already 2 times higher in relation to the minimum toxic value.

6.6. Interrelations in the soil-plant system

The highest values of the coefficients of biological absorption of all the studied elements are observed in *Salsola nodulosa* (0.04-0.52), the lowest - in *Suaeda microphylla* (0.01-0.29), the species *Salsola dendroides* (0.03-0.33) occupies an intermediate position (Fig. 7).

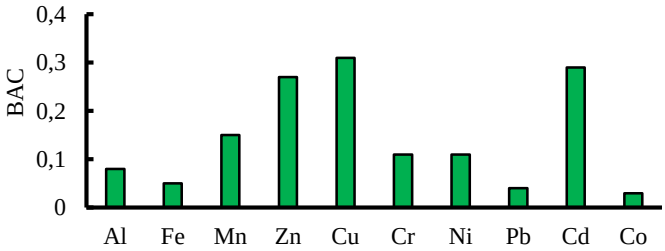

Figure 7. Average coefficients of biological absorption of the dominant plant species of the mud volcano Dashgil

CHAPTER VII. MORPHOLOGICAL CHARACTERISTICS OF POLLEN OF SOME HERBACEOUS PLANTS OF THE MUD VOLCANO FLORA

7.1. Pollen morphology of taxa growing in the territory of Gyzmeidan mud volcano

An important morphological indicator of the functional state of pollen is the percentage of deformed pollen grains in a sample (flower, stamen or anther). A reduction or complete destruction of the cellular contents leads to the appearance of various dents on the surface, disruption of the grain shape, i.e. to its deformation. Underdeveloped, very small (compared to normal) pollen grains are also considered deformed. Deformation of pollen grains can be caused by various factors. Sometimes, sharp disruptions in the conditions of existence of the species can lead to severe deformation.

To study pollen, pollen grains were selected from 20 species from 13 families, widely represented in the phytocenosis and were blooming masse at the time of collection of the material: *Asteraceae* - *Anthemis fruticulosa* M. Bieb., *Artemisia alpina* Pall. ex Willd., *Xeranthemum cylindraceum* Sm., *Jurinea arachnoidea* Bunge; *Brassicaceae* - *Rapistrum rugosum* (L.) All.; *Boraginaceae* - *Lappula barbata* Gürke; *Cistaceae* - *Helianthemum salicifolium* (L.) Mill.; *Hypericaceae* - *Hypericum linarioides* Bosse; *Convolvulaceae* - *Convolvulus lineatus* L.; *Euphorbiaceae* - *Euphorbia seguieriana* Neck.; *Fabaceae* - *Astragalus bungeanus* Boiss. - *Hedysarum sericatum* Kitam., *Medicago minima* (L.) L.; *Lamiaceae* - *Scutellaria orientalis* L., *Teucrium polium* L.; *Linaceae* - *Linum corymbulosum* Rchb., *Polygalaceae* - *Polygala anatolica* Boiss. & Heldr.; *Ranunculaceae* - *Thalictrum simplex* L.; *Rosaceae* - *Filipendula vulgaris* Moench, *Potentilla recta* L. (Fig. 8).

Most of the studied species growing on the mud volcano are characterized by a low percentage (no more than 1%) of deformed pollen. *Rapistrum rugosum* had 2% of deformed pollen grains, *Euphorbia seguieriana* and *Linum corymbulosum* - 3%, and *Hedysarum sericatum* - 5%.

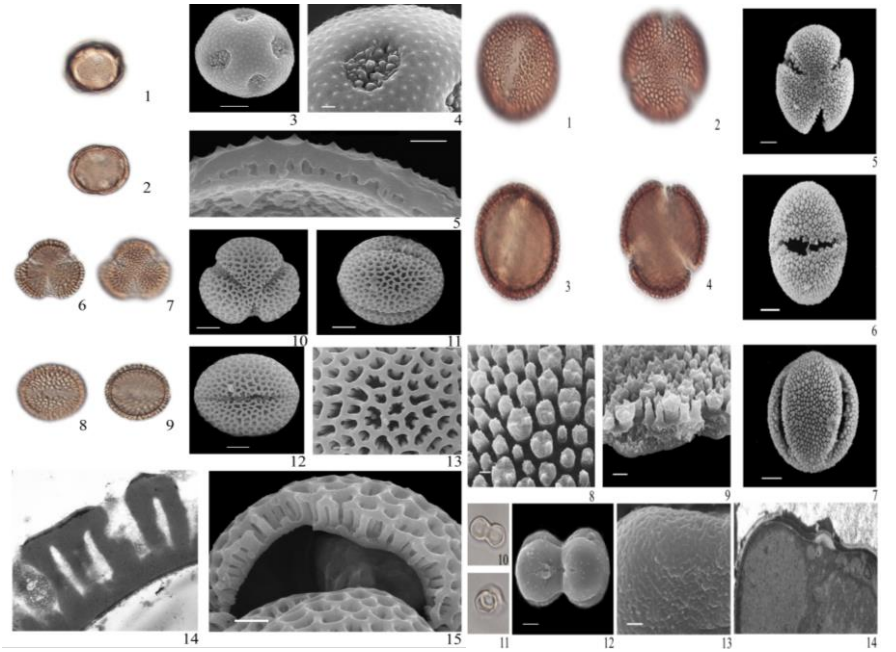

Figure 8. Pollen morphology of the species from the Gyzmeidan mud volcano: A) 1-5 - *Thalictrum simplex*; 6-15 - *Rapistrum rugosum*. 1-5 - view of pollen grain; 6, 7, 10 − polar view of pollen grain; 8, 9, 11, 12 − equatorial view of pollen grain; 4, 13 − detail of ornamentation; 5, 15 − broken pollen wall (exine); 14 − ultrathin section of sporoderm. Scale bar, μm: 1, 2, 5, 6−9, 14, 15 – 1; 3, 10−12- 5 B) 1-9 - *Linum corymbulosum;* 10-14 - *Lappula barbata*. 1, 3, 6, 7, 10, 12 - equatorial view of pollen grain. 2, 4, 5, 11 - polar view of pollen grain. 8, 13 - detail of ornamentation. 9 - broken pollen wall (exine). 14 - ultrathin section of sporoderm. Scale bar, μm: 1-4, 8-14-1; 5-7-5

Comparative analysis of pollen in plants from the volcano and plants from other habitats showed that the percentage of deformed pollen grains does not depend on the place of plant growth (Table 2).

Slight differences were observed in *Euphorbia seguieriana, Linum corymbulosum,* and *Hypericum linarioides*. It should be noted that some plants growing outside the mud volcano have slightly higher numbers of deformed pollen compared to the same species from the flora of the volcano.

Table 2

Quantitative characteristics of pollen of the plants growing on the mud volcano and beyond

Studied sample	Quantitative characteristics									
	1	2	3	4	5	1	2	3	4	5
	Mud volcano					Other habitat				
Asteraceae										
Anthemis fruticulosa	32.7-43.3	32.5-44.0	0.9-1	4.5-5.5	<1	32.4-43.5	32.4-43.6	0.9-1	4.5-5.4	<1
Artemisia alpina	28.5-31.4	30.0-34.5	0.9-1	4.0-5.0	<1	26.5-29.8	27.2-29.8	0.9-1	4.3-4.9	3
Convolvulaceae										
Convolvulus lineatus	51.3-57.5	51.0-60.2	0.9-1	5.1-5.5	5	57.6-64.0	53.8-63.1	0.9-1	5.2-5.7	1
Euphorbiaceae										
Euphorbia seguieriana	40.0-50.0	41.0-50.0	0.8-1.1	4.0-4.5	3	38.9-49.7	40.7-49.8	0.9-1.1	4.0-4.5	5
Rosaceae										
Filipendula vulgaris	21.0-24.3	20.0-24.3	1	1.5-1.8	10	19.0-23.7	17.4-21.7	1-1.15	1.5-1.7	32
Potentilla recta	22.7-26.8	23.5-24.8	0.97-1.1	1.8-2.0	56	23.0-25.1	21.6-23.0	1-1.2	1.5-1.9	88
Boraginaceae										
Lappula barbata	13.4-16.5	6.7-8.0	1.7-2.4	1.0	1	14.8-17.4	7.1-9.0	1.7-2.4	1	1
Linaceae										
Linum corymbulosum	56.8-66.0	59.5-69.8	0.8-1	5-5.4	3	54.8-62.0	54.9-59.0	0.9-1.0	4.7-5,4	9
Clusiaceae										
Hypericum linarioides	19.0-20.0	16.4-18.5	1.1-1.2	1.3-1.6	1	25.8-27.1	20.3-23.6	1.1-1.3	1.3-1.6	5
Polygalaceae										
Polygala anatolica	44.2-50.0	40.2-50.0	0.97-1.2	2.8-3.4	<1	40.0-45.5	40.0-45.6	1	2.5-3.0	1

Note: 1 − polar axis length (P, μm); 2 − equatorial axis length (E, μm); 3 – P/E; 4 − exine thickness (μm) (LM); 5 – percentage of deformed pollen grains.

The highest percentage of deformed pollen grains was found in representatives of the *Rosaceae* family (*Filipendula vulgaris* and *Potentilla recta*). Thus, 10% of deformed pollen was found in *Filipendula vulgaris* plants growing on a mud volcano, while 32% was found in control plants. In *Potentilla recta*, 56% and 88%, respectively.

The obtained data are not indicators of environmental influence on the pollen morphology of these plants, since many genera of the *Rosaceae* family and, in particular, the genus *Potentilla* are always characterized by a large number of deformed pollens, which is traditionally associated with a high degree of hybridization of representatives of this taxon. The revealed insignificant differences concern only the size of pollen grains. However, in all cases, the difference in the sizes of pollen of the studied species from different habitats (volcano and other habitats) corresponds to the range of intraspecific variability and always remains within the size group according to the classification of G. Erdtman.

CHAPTER VIII. POPULATION-DEMOGRAPHIC ASSESSMENT OF THE STATUS OF RARE SPECIES

Three rare taxa were found on the territory of the Gyzmeidan mud volcano - *Pyrus salicifolia, Rosa pulverulenta, Ophrys oestrifera*, and in the Toragay and Kichik Maraza mud volcanoes - *Tulipa biflora*.

CP 2 (*Ophrys oestrifera*), 3 (*Rosa pulverulenta*), 4 (*Tulipa biflora*) are young, which means that the prospects for their development are assessed by us as positive. As for CP 5 (Tu*lipa biflora*), we assess the condition of this CP as satisfactory, since adult individuals still dominate here, which means the nature of renewal is weaker than in previous CP.

In the five CP studied, the highest number of pre-generative individuals is in CP 4, the lowest in CP 5. The highest proportion of generative individuals was found in CP 5, the lowest in the population of CP 3. The maximum values of individuals in the post-generative age class were found in the population of CP 5 and were absent in the population of CP 2.

RESULTS

1. For the first time for Azerbaijan the flora of mud volcanoes of Pirekyashkul, Dashgil, Toragay, Kichik Maraza, Gyzmeidan was compiled, which includes 134 taxa belonging to 118 genera and 39 families.

2. The leading role in the studied 5 mud volcanoes belongs to the *Asteraceae* family, which includes 20 species and 16 genera, *Poaceae* - 18 species and 15 genera, *Brassicaceae* - 11 species and 9 genera, *Fabaceae* - 9 species and 8 genera, *Amaranthaceae* - 8 species and 6 genera, *Rosaceae* - 7 species and 6 genera, *Lamiaceae* - 6 species and 6 genera. The remaining families are represented by 1-3 species.

3. Four rare (*Tulipa biflora*, *Pyrus salicifolia*, *Ophrys oestrifera*, *Rosa pulverulenta*) and an endemic species (*Rosa pulverulenta*) of Azerbaijan flora were found on the studied 5 mud volcanoes.

4. The flora of mud volcanoes has the following ratio of ecogroups: mesophytes 79 species (59%), xeromesophytes 38 species (28%), xerophytes 13 species (10%), mesoxerophytes 4 species (3%); and according to the ratio of life forms, they are represented by the following biomorphs: therophytes 51 species (38%), phanerophytes 11 species (8%), chamephytes 12 species (9%), hemicryptophytes 39 species (29%), cryptophytes 21 species (17%).

5. As a result of the vegetation cover analysis, 24 vegetation units were identified: Pirekyashkyul - 3 associations, Dashgil - 1 association, Toragay - 2 associations, Kichik Maraza - 3 associations, Gyzmeidan - 1 association. All other formations are classified as aggregation, agglomeration and semiaggregation. The largest number of fully formed communities are found in the mud volcanoes Pirekyashkyul, Toragay and Kichik Maraza.

6. It was found that in the soil-plant system in the conditions of mud volcanoes the highest values of the coefficient of biological absorption of metals in some forage species are observed in *Salsola nodulosa* - 0.04-0.52, the lowest - in *Suaeda microphylla* - 0.01-0.29, the species *Salsola dendroides* occupies an intermediate position - 0.03-0.33.

7. During the palynomorphological study of some species of the

mud volcano flora, it was established that pollen of the studied species belonged to 5 palynotypes: 3-borough (species from the families *Brassicaceae*, *Convolvulaceae*, *Fabaceae* (*Hedysarum sericeum*), *Lamiaceae*, *Linaceae*); 3-borough-oral (*Asteraceae*, *Cistaceae*, *Clusiaceae*, *Euphorbiaceae*, *Fabaceae*, *Rosaceae*); 6-heteroborough (*Boraginaceae*); multi-borough-oral (*Polygalaceae*) and multi-borough-oral (*Ranunculaceae*).

8. Assessment of the status of the rare species found, that the CP of *Ophrys oestrifera*, *Rosa pulverulenta* and *Tulipa biflora* are characterized by successful adaptive capabilities in volcanic conditions. The CP of *Pyrus salicifolia* with a shift to generative maturity and poor representation of pregenerative specimens indicates an ambiguous position.

PRACTICAL RECOMMENDATIONS

1. Forage plants are recorded on the studied volcanoes, which makes them vulnerable to factors such as grazing of small cattle by local people. Taking into account that the volcanoes are also home to rare, endemic plants, which are trampled, damaged and eaten by cattle, we consider it necessary to organize conservation measures on the territory of mud volcanoes.

2. The ability to increased and high accumulation of a number of metals in the above-ground parts of halophyte plants can be used in phytoremediation of soils polluted with heavy metals.

3. In recent years, active mud volcanoes have been experiencing significant recreational pressures associated with tourism, littered with rubbish from the local population, which negatively affects soil formation and the formation of vegetation cover. In this regard, special protection of the territories of these mud volcanoes is required.

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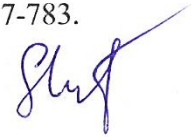

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