Master's thesis

The mineralogical and geochemical features of sandstone deposits in Germany

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Declaration of Authorship

„I declare in lieu of oath that this thesis is entirely my own work except where otherwise indicated. The presence of quoted or paraphrased material has been clearly signaled and all sources have been referred. The thesis has not been submitted for a degree at any other institution and has not been published yet."

Preface, Dedication, Acknowledgement

Sandstones are sedimentary rocks, formed millions of years ago by the accumulation of sandy sediments and their subsequent transformation into solid rocks under pressure and time. These rocks have a variety of textures, colors and patterns; and because of their high strength, sandstone combines well with elements of carving, ornamentation and sculpture to create unique works of art.

However, weathering and erosion threaten the preservation of these unique examples of natural and architectural heritage.

In the present study, German sandstones from different deposits were analyzed, since many of them were used in the construction of St. Petersburg. Therefore, it becomes important to pay attention to the research and preservation of the German sandstones.

The research was carried out at the Resource Centers of the St. Petersburg State University (Microscopy and Microanalysis, Methods of Chemical Analysis of Matter, and X-ray-Diffraction Methods of Research) and the Central Laboratory of VSEGEI.

I would like to thank the Saint Petersburg Mining University, Montanuniversität Leoben, TU Bergakademie Freiberg and Saint Petersburg State University for the opportunity to study in this program and have an unforgettable experience throughout my studies.

Abstract

This study is devoted to an in-depth study of sandstones from German deposits and their significance in various fields of industry and cultural heritage.

The aim of the study was to examine the geological features and composition of German sandstones and to identify their characteristics that make them attractive for use in various fields.

The work includes an analysis of the structural-textural characteristics and mineralogical composition of sandstones, as well as the study of weathering processes of this rock in urban conditions.

The main advantages and limitations of the use of sandstones were investigated, and examples of outstanding architectural structures and monuments created with the use of German sandstones were given.

The study provides a better understanding of the geological nature and features of the German sandstones and contributes to the use and conservation of this valuable natural material in various fields of activity.

The results of the study can be useful for geologists, engineers, architects, and restorers in selecting materials for construction and restoration of buildings, as well as in predicting the behavior of sandstones in urban environments. The conclusion emphasizes the importance of studying the properties of materials for creating stable and durable structures.

Zusammenfassung

Diese Studie widmet sich einer eingehenden Untersuchung von Sandsteinen aus deutschen Lagerstätten und ihrer Bedeutung in verschiedenen Bereichen der Industrie und des kulturellen Erbes.

Ziel der Studie war es, die geologischen Merkmale und die Zusammensetzung der deutschen Sandsteine zu untersuchen und ihre Eigenschaften zu ermitteln, die sie für die Verwendung in verschiedenen Bereichen attraktiv machen.

Die Arbeit umfasst eine Analyse der strukturell-texturellen Merkmale und der mineralogischen Zusammensetzung von Sandsteinen sowie die Untersuchung der Verwitterungsprozesse dieses Gesteins unter städtischen Bedingungen.

Die wichtigsten Vorteile und Grenzen der Verwendung von Sandsteinen wurden untersucht, und es wurden Beispiele für herausragende architektonische Strukturen und Denkmäler angeführt, die unter Verwendung deutscher Sandsteine geschaffen wurden.

Die Studie ermöglicht ein besseres Verständnis der geologischen Beschaffenheit und der Merkmale der deutschen Sandsteine und trägt zur Nutzung und Erhaltung dieses wertvollen natürlichen Materials in verschiedenen Tätigkeitsbereichen bei.

Die Ergebnisse der Studie können Geologen, Ingenieuren, Architekten und Restauratoren bei der Auswahl von Materialien für den Bau und die Restaurierung von Gebäuden sowie bei der Vorhersage des Verhaltens von Sandsteinen im städtischen Umfeld von Nutzen sein. Die Schlussfolgerung unterstreicht, wie wichtig die Untersuchung der Eigenschaften von Materialien für die Schaffung stabiler und dauerhafter Strukturen ist.

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Introduction

The architecture of St. Petersburg has had a significant influence on the development of architecture not only in Russia, but also beyond its borders. The Historic Center of St. Petersburg and Related Groups of Monuments was the first Russian site to be inscribed on the UNESCO List in 1990. Today the city is one of the main centers of architecture and cultural heritage of the world.

In the construction of residential buildings and monuments of St. Petersburg a wide variety of decorative natural stone is used. These are various granites, labradorites, marble, limestone, sandstone, quartzite, etc., having a very wide geography of places of their extraction. Sandstone was widely used because of the great variety of colors, high strength and easy processing of the material.

In an urban environment the destruction of stone is much faster than in natural conditions; as a consequence, the weathering of sandstone is a serious problem for the preservation of the cultural heritage of St. Petersburg.

Deposits of a stone of the central Europe have appeared the most territorially accessible for deliveries of sandstone of various colors in St.-Petersburg. A large number of sandstone deposits have made it possible to use this rock in construction, as well as to successfully transport it to other countries, including Russia.

The relevance of the study is determined by the need to identify the features of sandstones and assess its condition in the decoration of St. Petersburg for restoration work.

Purpose of the study: the identification of structural and material features of different types of sandstone from German deposits used in the stone decoration of St. Petersburg.

In order to fulfill the goal the necessary tasks were set:

- studying of the history of the use of sandstones in the decoration of St. Petersburg;

- revealing of structural and textural features of rocks;

- determination of the mineral composition of rocks;

- identifying the geochemical features of sandstones;

- evaluation of the forms of rock destruction in the urban environment.

The following methods were used to solve the set tasks.

1. Photo-documentation and creation of a database

2. Macroscopic description

3. Petrographic analysis

4. Computed tomography

5. XRF - X-ray fluorescence analysis (petrogenic oxides and trace elements)

6. Microprobe analysis (SEM analysis)

7. Study of biofilms from facades of buildings in St. Petersburg.

Scientific novelty. The structural-textural and mineralogical-geochemical features of different types of sandstones from German deposits, which were used in the stone decoration of St. Petersburg, were considered. The characteristic forms of their weathering in the urban environment have been established.

Practical Significance. The data obtained will be useful for making decisions on the use of this rock for the construction of buildings and cladding of houses. The results of the study can be used by geologists, engineers architects and restorers to assess the resistance of the material to external influences and is necessary for the future choice of restoration measures and predictions about the behavior of sandstones in urban environments.

Chapter 1: A brief geological sketch of the area

1.1 Physical and geographical sketch

Geographic position

Germany stretches 876 km from north to south and 640 km from east to west. The total length of the border is 3,876 km. Germany borders with Denmark to the north (a length of 68 km), with Poland to the northeast (469 km), with the Czech Republic to the east (817 km), with Austria to the southeast (817 km, without a border on Lake Constance) and with Switzerland to the south (333 km; with the borders of the exclave of Büsingen, but no border at the headwaters of Lake Constance), southwest with France (455 km), west with Luxembourg (136 km) and Belgium (204 km), and northwest to the Netherlands (576 km; no border at the edge of Ems). Lake Constance has no internationally recognized border.

Germany's land area was 357,050 km² in 2004, 19 km² more than in 2000. The coastal sea, which is under German sovereignty and has a maximum width of 12 nautical miles according to the Convention on the Law of the Sea, covers about 16,900 km², while the North Sea covers 7,900 km² and the Baltic Sea 9,000 km².

Climate

Germany belongs to the temperate climate belt of Central Europe in the area of westerly winds and is in the transition zone between maritime climate and continental climate.

The climate is also influenced by the Gulf Stream, which makes the climatic values unusually mild for the latitude.

Another influencing factor is the currents of heated winds, the fen, which are found in the Ore Mountains and in the foothills of the Alps. The Alpine fen can lead to strong storms with a maximum speed of 150 km/h and is noticeable as far as the Danube. In winter and spring, it can lead to significantly higher temperatures and thus affect the melting of snow. Extreme weather conditions such as prolonged droughts, hurricanes, tornadoes, severe frost or extreme heat sometimes occur. There are regular floods that result in flooding and significant damage after periods of heavy rainfall in the summer or after snowmelt.

The precipitation chart for Germany shows regional deviations from the average. The highest annual temperatures were recorded in the southern part of Baden and in the lowlands of the Upper Rhine and exceeded 11° C, while the average in Oberstdorf was below 6° C. In addition, there is a general trend toward higher temperatures: according to the German Meteorological Service, in 14 of the 15 years since 1990, average temperatures have exceeded the multiyear average of 8.3°C, and in 2000 they even reached 9.9°C. °C. Summers, in particular, have become significantly warmer. In addition, spring came on average five days earlier in each decade.

Hydrology

The most important water bodies of federal importance are the Danube, the Rhine, the Elbe, and the Oder.

Lakes are important sources of drinking water, the largest natural lake is Lake Constance. The Mecklenburg Lakeland with the Müritz and Kimsee as the largest lake in the foothills of the Alps is important.

Large underground groundwater reservoirs can be found in the Upper Rhine graben, in the foothills of the Alps and in the glacial valleys in northern Germany.

The largest reservoir is the Bleiloch Reservoir, which holds 215 million m³ of water. In the German waters of the North Sea, for example, there is the German Bay up to 50 m deep, the Flensburg Fjord, the Kiel Bay and the Mecklenburg Bay in the Baltic Sea.

Major islands in the Baltic Sea are Rügen, Usedom, and Fehmarn. The island of Sylt, belonging to the North Frisian Islands, and the island of Borkum, belonging to the East Frisian Islands, are located in the North Sea. The islands in the North Sea and Baltic Sea serve as coastal protection for the mainland, and therefore the loss of area is compensated for by the prior washing out of the sand.

Because the Wadden Sea is considered a unique habitat and of great importance for fish, plants and animals, national parks have been established there. The Baltic Sea, for example, has species-rich brackish water lakes and tidal flats protected by the West Pomeranian Lagoon National Park.

1.2 Geological sketch

Geological Structure

Based on the surface geology, Germany can be divided into four main regions: the north, which was formed during the glacial period and stretches from the coast to the Middle Canal, the harmful Elbe and upper Lusatian, the low mountain ranges (Rumpfgebirge) and the southern part, which is more strongly influenced by the effects of the Alps. Compared to the other regions mentioned, the Alps constitute only a very small part of Germany's national territory (Litt T., 2008).

The North is geologically relatively monotonous and largely covered by Quaternary glacial and melt deposits. Characteristic, among others, are sandy loose deposits and scree moraine deposits, sometimes with boulders weighing several tons. Boulders and some smaller deposits were transported from Scandinavia to northern Germany along with the inland ice during the cold periods of the Pleistocene.

Central and southern Germany are geologically much more diverse. These are mostly rocks from the Variscan basement and Mesozoic overburden rocks, from which the landscapes of Germany's lowlands have been modeled. The basement consists of Variscan (i.e. Upper Paleozoic) folded rocks, some of which were transformed into metamorphic rocks such as gneisses, mica schists or amphibolites during folding. Above all, these metamorphic parts of the basement are interspersed with large granite bodies which, together with the metamorphic rocks, form what are called crystalline complexes.

Areas of bedrock with actually non-metamorphic folded rocks, such as graywacke, shale or "diabase", in which granite is absent or occurs only in small quantities, are summarized by the term "shale mountains". Such rocks make up the Rhine Shale Mountains (especially the Rothhaar Mountains, Siegerland, Eifel, Hunsrück, Taunus), the Harz, and the Thuringian-Franconian-Fogtland Shale Mountains (Thuringian Shale Mountains, Franconian Forest, West Vogtland). Although the Variscan orogeny took place in the Paleozoic, the renewed uplift of crystalline and shale rock complexes and thus the appearance of today's surface forms only began during the Tertiary period and is associated with the formation of the Alps.

In the later phase of the Variscan folding period (Upper Carboniferous) the coal deposits of the Ruhr region were formed, which were of great economic importance, especially in the 19th and 20th centuries. Hard coal layers and intermediate layers with low coal content are united by the term "Ruhrkarbon". The intermediate layers are eroded material from the Variscan highland system, which accumulated as outer molten rock in the so-called Variscan foreland depression.

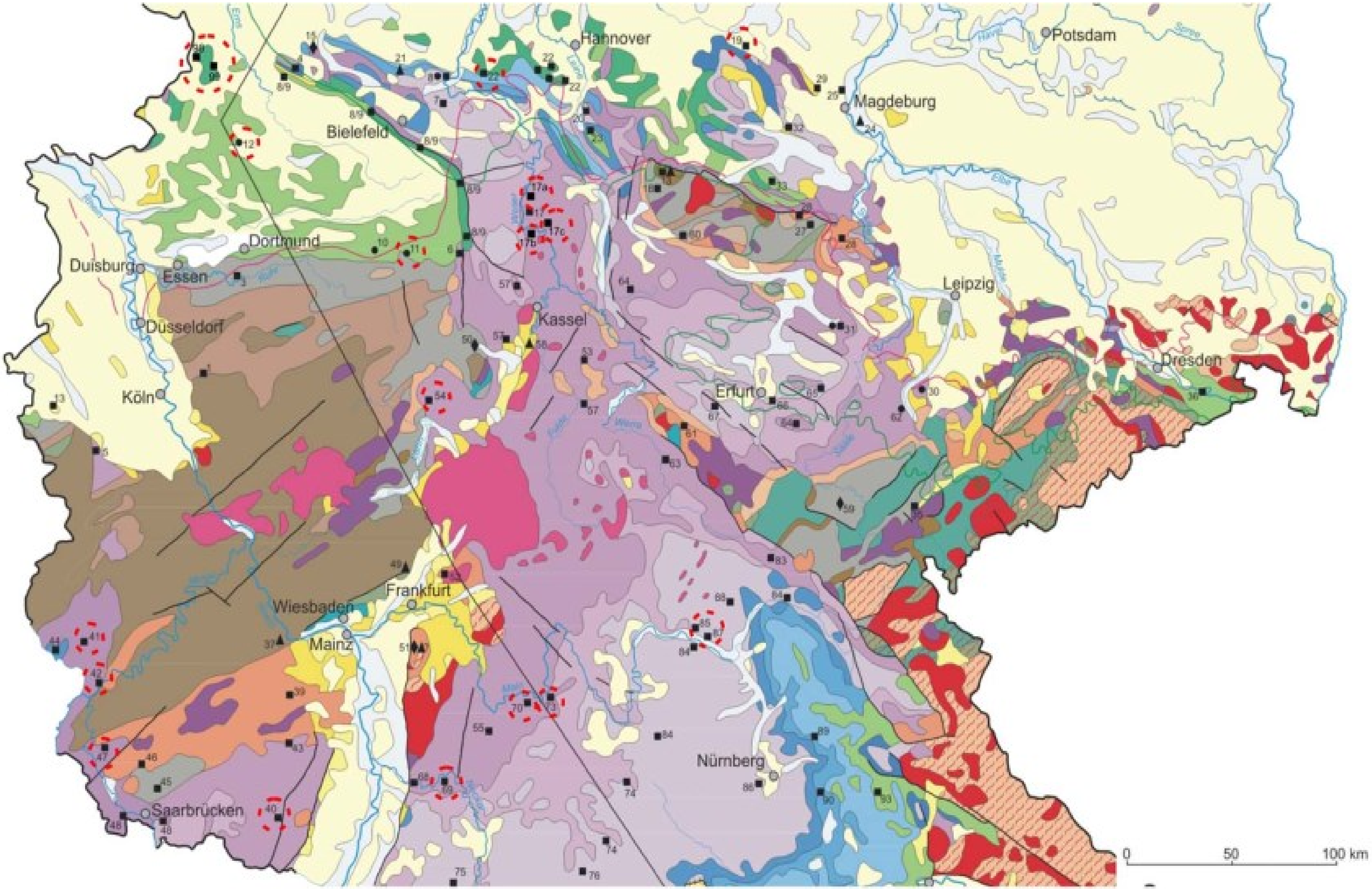


Figure 1. Geological map of central Germany (Savchenok A., 2009)

In southern Saxony-Anhalt, northern and central Saxony and, above all, in the Thuringian Forest and Rhineland-Palatinate, strata similar in age (Upper Carboniferous to Middle Permian) and at least partly similar to the Ruhrian Carboniferous were found. They are largely reversed and also represent the erosional phase of the Variscan Highlands, but they do not represent the deposits of the Forland Basin, as in the case of the Subvarian, but the so-called inner Molasses. Whereas the Carboniferous inner molasse often contains hard coal, the Permian inner molasse (Rotliegend) is characterized by red sediments containing no coal. In addition, the Rotliegend sedimentation was accompanied in many places by intense volcanism. In this respect, rhyolites ("quartz porphyries") are particularly common in the Rotliegend sequence. The Carboniferous and Rothligendian Molasses of the Intraviscan Basin are also united by the term Permo-Silesian Stage and are referred to as a transitional stage (transition from the bedrock stage to the overburden stage).

The surface geology of Thuringia, Hesse, Franconia and Swabia is dominated by non-faulted Mesozoic overlying rocks, especially sedimentary rocks of the Triassic. The Triassic of Central Europe north of the Alps is also called the Germanic Triassic. It consists of the Buntsandstein, Muschelkalk, and Keuper sequences. Swabia and Franconia also have large areas of Jurassic rocks. Of particular importance are the strata of the South German Upper Jurassic, composed mainly of limestones and forming the Swabian and Franconian Jura. Among other things, they contain one of the most famous fossils in the world - the "primeval bird" Archaeopteryx.

The Cretaceous sediments are represented only in northern Germany, especially in the northern part of the Harz (Subherzin), in Münsterland and on the Ruegen, by "chalk" (i.e. special limestone). The Elbe Sandstone Mountains in Saxony and the Franconian Jura are dominated by sandstones in the Cretaceous period (Henningsen D., 2006).

The Sechstein, deposited in the upper Permian (i.e., as early as the Paleozoic Era) and thus still below the Buntsandstein, is also considered part of the overburden. It is of economic significance primarily because of its productive rock and potassium salt deposits, including the salt domes, which were formed in the depths of northern Germany from the zechstein salt that was once stored horizontally.

The Upper Rhine graben and the foothills of the Alps occupy a special position in southern Germany as geologically young dipping areas with their extensive distribution of Cenozoic deposits. Here, as well as in the transition area from the North German lowlands to the low mountain ranges, both Quaternary and Tertiary deposits occur near the surface. The

Tertiary is economically important primarily because of its lignite deposits, which, however, are only exploited in sections, especially in the Rhine lignite mining district, in the Helmstedt area, in the Halle-Leipzig area and in the Lower Lusatian. The Tertiary and partly Quaternary periods of western, central and southern Germany also contain evidence of a second major episode of continental volcanism in Central Europe. In contrast to the Rotliegendian volcanism, Tertiary volcanism left mostly basalt and related rocks, which, for example, cover the Vogelsberg, Westerwald, and much of the Wren. The Eifel is still somewhat volcanically active today, which is reflected in the presence of very high carbon dioxide springs (mofettes) there, for which Geysir Andernach, the highest cold water geyser on earth at 50 to 60 meters. is the most impressive example. Along with Laacher See, Eifel also has one of the youngest volcanoes in Germany.

The rocks of the Alps, like those of the Variscan basement, are folded, but this folding only took place at the end of the Mesozoic and in the Tertiary period. Thus, the Alps, unlike the areas to the north of them, also contain folded Mesozoic and Cenozoic sedimentary rocks. The German Alps are mostly composed of Middle and Upper Triassic limestones (Northern Limestone Alps). These strata were not deposited in present-day Central Europe, but were transported from the south in the form of tectonic cover to their present position during the formation of the Alps. Therefore, they differ as the Alpine Triassic from the Germanic Triassic.

Since Germany is not on a plate boundary, but entirely on the Eurasian plate, it is one of the regions with low seismic activity. However, some areas of Germany are located on active fault lines, and therefore earthquakes are relatively frequent, which can sometimes be relatively strong. This applies in particular to the Lower Rhine graben with the Bay of Cologne and the Upper Rhine graben, as well as to the Vogtland.

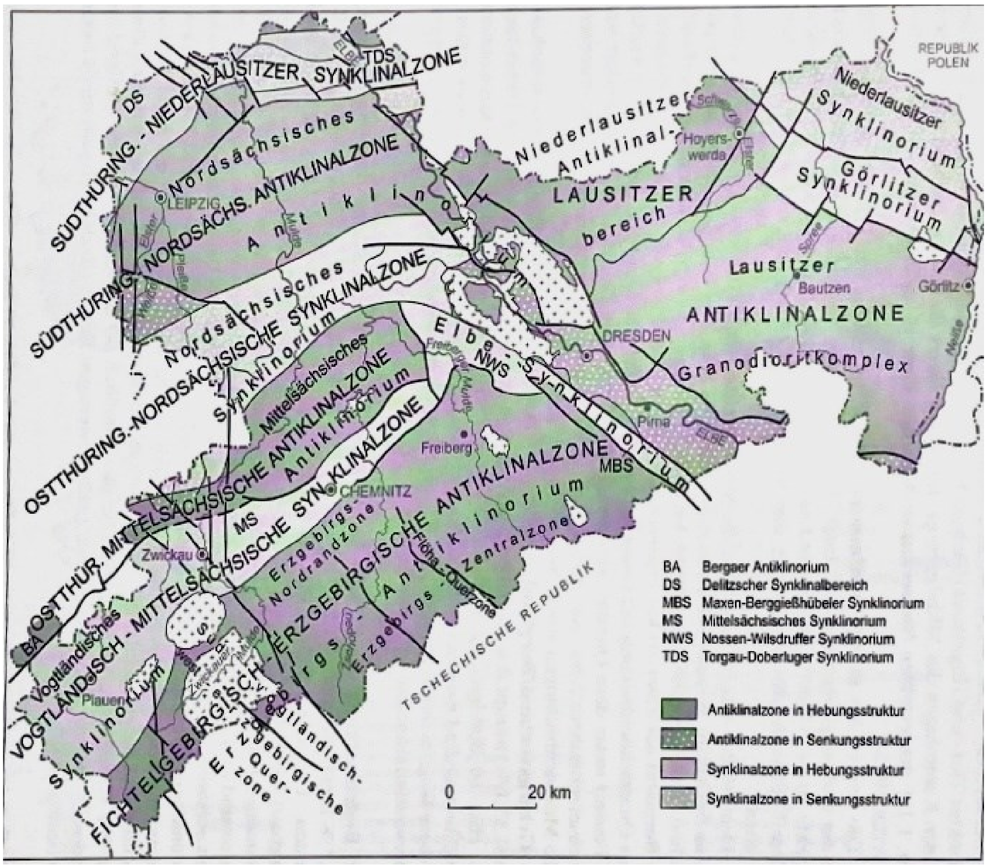


Figure 2. Regional geological subdivisions of the eastern territory of Germany (Linnemann U., 2010)

Geomorphological structure

Germany, located in Central Europe, has several large-scale landscapes that can be divided geomorphologically. Alternatively, the country can be divided into major natural regions.

The North Sea and the East Sea.

The history of the Baltic Sea is defined by the melting of a Scandinavian ice sheet 2-3 km thick during the Vistula glaciation some 12,000 years ago. The Baltic Ice Sea was formed first, followed by the Joldic Sea, the Ancilla Sea and, 8000-8500 years ago, the Littorina Sea. In the interaction of land uplift and sea level rise, inland seas and inland seas alternated one after the other. More recently, the southern part of the Baltic Sea sank as a result of land uplift in Scandinavia and the coastal forms of bays and fjords (complete depressions carved out by glaciers) and the Bodden or Bodden compensatory coast (through a stock of material, former moraines connected to each other by narrow land bridges). The North Sea has risen about 33 centimeters per century over the last 7,500 years. After the last ice age, new landscapes were formed on the North Sea coast: the Watt Sea and the marshlands.

The North German Lowlands.

The North German Lowland is a large landscape extending from Emden through Hanover, Berlin, and Frankfurt/Oder, and characteristic of northwestern Poland. Its length from north to south is about 200 km.

In the coastal areas of the Baltic Sea there are a large number of Bodden water bodies, separated from the open sea by promontories. In the northeast of Mecklenburg-Western Pomerania, relatively flat land follows.

Upland areas with many lakes, such as the Mecklenburg Lakeland and the Mecklenburg Switzerland, are mountain ranges with isolated mountains over a hundred meters high. There are other mountain ranges in Brandenburg, and in the very south is the first mountain over 201 meters high, Heidehöhe. The northern ridge, the Baltic Ridge, was formed by glacial debris deposits during the Vistula glaciation, and the southern ridge, the southern ridge, during the Saale glaciation.

On the North Sea coast, dense landscapes alternate with lower marshes. While the marsh was created without any natural elevation at about sea level as a result of gradual silting of tidal banks, the gesso landscapes are forms of the glacial series. The eastern part of the North German Plain contains primarily glacial valleys, terminal moraines, and sandstones, which were formed during the Weixelian glacial period and have a higher relief energy than the glacial forms of the western plain created by older phases. of the Saale glacial period, which are much older and therefore more susceptible to erosion.

The mountains of the low mountain range and the steppe terrain in southwest Germany.

The Lowland Ridge Mountains belong to the low mountain ranges of 500 m to 1,500 m in height. Geologically, they are characterized by the fact that after the Variscan orogeny there were recurring inland seas whose deposits were uplifted during the Alpine orogeny and partly re-elevated by erosion. Mountains such as the Rhine Shale Mountains, the Vogelsberg, the Wren and the Sudetes had volcanic phases when they formed.

The Rhine Shale Mountains are characterized by volcanic craters, massive deposits of pumice and basalt, and maar. The Laher See volcano erupted 13,000 years ago, ejecting about 5 cubic kilometers of magma in four to five days. The most recent volcanic eruption in Germany occurred about 11,000 years ago at Ulmener Maar near Ulmen. In the volcanic Eifel there still appear sources of carbon dioxide (mofettes), the most impressive example of which is geyser Andernach, the highest cold water geyser on earth with a height of 50 to 60 meters.

The Vogelsberg is the largest continuous basalt massif in Europe, covering an area of 2500 km². The Lusatian Mountains in the Sudetes consist mainly of sandstone. Volcanoes have repeatedly burst through this sandstone, creating large deposits of basalt. About 35 million years ago the formation of the Upper Rhine Plain began as a result of plate tectonic processes. There are many extinct volcanoes there, such as the Kaiserstuhl, Hegau, Schwebischer, Katzenbakel and Pechsteinkopf. As a consequence, the areas on both sides of the Graben have grown dramatically, and the Schwarzwald and Odenwald have developed on the German side, which are part of the southwestern German steppe country.

Where marine sediments are exposed, limestone is washed out, resulting in the formation of underground caves, so-called karstification. There, precipitation seeps in almost completely, and this leads to an arid terrain. The Venus of Holefels, the oldest plastic work of art by mankind, was found in the Hohler Fels cave (Swabian Alb). It dates back to the Wurm glaciation.

One of the most seismically active areas is in the area bordering the Czech Republic, in the Egergraben. It runs from the Saxon Vogtland through Northwest Bohemia to the six Bavarian offices. The Egergraben is geologically comparable to the Upper Rhine plain and is known for the massive earthquakes that frequently occur there.

Alpine foothills and the Alps.

The Alps are the largest mountain range in Europe, a climatic and watershed. Within Germany, they gradually fall into the Bavarian foothills of the Alps. Part of the Alps in Germany is part of the Northern Limestone Alps. It consists mainly of limestone that has been advanced from the south.

The mountain formation of the Alps, which is still going on today, was counteracted by weathering, in which rocks were carried northward by glaciers in the form of moraines and rivers. The farthest ice advance occurred during the Riess Glaciation (simultaneously with the Saale Glaciation in northern Germany) and the most recent Forland Glaciation occurred during the Wurm Glaciation (simultaneously with the Weichsel Glaciation in northern Germany). For example, today's Lake Constance was created as a reservoir for the meltwater of the Rhine glacier, which extends to today's Schaffhausen, while Munich's gravel plain is a sandbar with a maximum thickness of 300 meters and a maximum area of 1500 km², which was created over several glacial periods. The foothills of the Alps and the valleys of the Alps are known for their extensive green landscapes. The region is sparsely populated and economically dependent on agriculture and tourism.

1.3 Sandstone deposits in Germany

Germany is known for its numerous deposits of stone building materials, a large part of which are sandstone deposits. They are located in the central and southwestern parts of the country, where the terrain is dominated by plateaus and mountains. The sandstones that have historically been mined in Germany are of various ages, including Carboniferous, Triassic, Jurassic and Cretaceous. Of these, sandstones of the Carboniferous and Jurassic systems were used only for local construction, while sandstones of the Triassic and Cretaceous were more often exported and used in the architecture of other countries (Savchenok A.I., 2009).

Total sandstone production in Germany is about 30 million tons per year, making this country one of the largest producers of stone building materials in the world.

Sandstone mining in Germany dates back to the Middle Ages, and these stone materials have been used in the construction of many historic buildings.

The sandstones quarried in Germany have high strength and durability, making them an ideal material for building houses, bridges, roads, monuments and other structures.

In addition to their use in construction, sandstones are also used in other industries, such as the production of glass, ceramics and powders. The use of sandstones as natural stone for landscape design and landscaping is also of great importance. However, despite its high quality and widespread use, mining sandstone can have a negative impact on the environment, including the soil, water, and air; therefore, Germany is actively working to improve the technology of mining and processing sandstone in order to minimize the negative environmental effects.

Sandstone mining in Germany is currently carried out in accordance with environmental standards and safety requirements, thus preserving the country's natural resource wealth.

There are several sandstone deposits in Germany, some of which are most important for the construction and industrial sectors:

1. The Naumburg deposit in Sachsen-Anhalt is the largest sandstone deposit in Germany. It is known for its high strength and is used in the construction of bridges, dams and other structures.

2. Salzwelverde in Rheinland-Palatinate is a shale-sandstone deposit known for its energy resources. It is used as a raw material for shale gas production.

Ebersdorfer in Sachsen is a sandstone deposit known for its high strength and construction applications. It is used for concrete and other building materials.

4. The Kalteinfeld deposit in Bayern is a sandstone deposit that is also used in construction and building material production.

5. In Germany there are deposits of Bentheim sandstone, which is considered the most famous in the world. It was formed about 125 million years ago, in the Lower Cretaceous period, and has been mined here since the 13th century. Although Bentheim sandstone is not as popular now as it used to be, in the mid-1950s it was in great demand and was very popular, leading to the simultaneous development of nine quarries in the region.

6. One of the largest sandstone deposits in Germany is the Lausitz deposit, which is located on the border between the states of Brandenburg and Saxony. It is the largest sandstone deposit in Europe and one of the largest in the world. Lausitz is renowned for its high-quality stone materials, which are used for many architectural structures.

These and other sandstone deposits are important resources for construction and industry in Germany and abroad. They all have their own unique characteristics and are used to create different types of structures.

Some famous sites created from German sandstone include the Brandenburg Gate and Neuschwanstein Castle in Bavaria. Most sandstone deposits in Germany are owned by private companies that mine and sell the material.

Figure 3. Sandstone blocks in the warehouse of Ziedler & Wimmel in Kirkheim (Bulach A., 2009).

Given the information from the sources, there are 12 areas of studied sandstone deposits in Germany (Fig. 4).

I.
Benthaimer sandstein
Gildehauser sandstein
II.
Wealden Sandstein
Oberkirchen Sandstein
III.
Velpker Sandstein
IV.
Baumberger sandstein
V.
Ruthener Sandstein
VI.
Wesersandstein Arholzen
Wesersandstein Karlshafen
VII.
Niederwaimer Sandstein
VIII.
Udelfanger Sandstein
Kylltaler Sandstein
Vogesen Sandstein
IX.
Schweinstaler Sandstein

Pfälzer Sandstein grün gelb

X.

Neckartäler Sandstein

XI.

Wustenzeller sandstein

Miltenberger Sandstein

Ebenheider Sandstein

Eichenbuhler Sandstein

XII.

Coburger Sandstein

Schonbacher Sandstein

Sander Sandstein (Savchenok A., 2009).

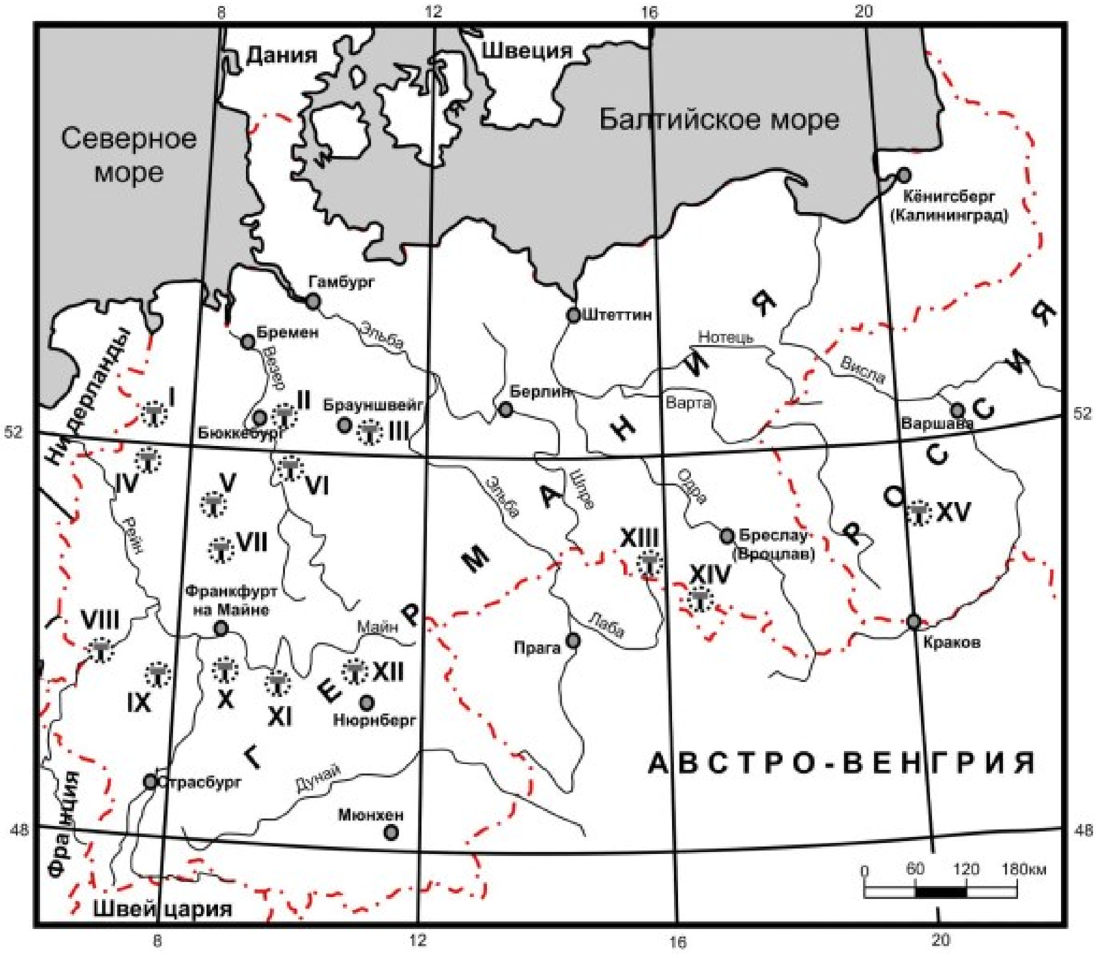


Figure 4. Political map of the central part of Europe in the period 1871-1918, with the areas of the studied sandstone deposits marked on it (Savchenok A., 2009).

Later, a table was compiled, in which the selected samples were correlated with the extraction field and their age (Table 1).

Table 1. Deposits and age of sandstones

№	Deposits	Age
1	Schoenbacher Sandstone	T3
2	Coburg Sandstone	T3
3	Udelphan Sandstone	T1
4	Schweinsteel Sandstone	T1
5	Marburg Sandstone	T1
6	Marburg Sandstone	T1
7	Niederweim Sandstone	T1
8	Niederweime Sandstone	T1
9	Marburg Sandstone	T1
10	Marburg Sandstone	T1
11	Ruegen Sandstone	K2
12	Anrech Sandstone	K2
13	Baumberg Sandstone	K2
14	Baumberg Sandstone	K2
15	Gildehau sandstone	K1
16	Gildehau sandstone	K1
17	Bentheim Sandstone	K2
18	Bentheim Sandstone	K2
19	Ibbenburen Sandstone	C1
20	Port Sandstone	J1
21	Arolsen Weser Sandstone	T1
22	Karlshafen Weser Sandstone	T1
23	Karlshafen Weser Sandstone	T1
24	Karlshafen Weser Sandstone	T1
25	Welpka Sandstone	T3
26	Eichenbuchlian Sandstone	T1
27	Kasheim Sandstone	T1
28	Ebenheide Sandstone	T1

Chapter 2: Saint Petersburg Stone Decoration

2.1 History of Stone in Saint Petersburg

Since ancient times, residential construction and architecture have ceased to be merely a functional element of protection from external factors and began to be regarded as art. In Russia in the 18th century the aims and tasks of architecture were revised and new types of industrial and public buildings appeared, such as theaters and museums, collegiate and chancellery buildings, shipyards for shipbuilding, etc.

In St. Petersburg, which was built during the time of Peter the Great, architecture appreciated rationalism and simplicity, which were combined with baroque plasticity of architectural details. Such methods were characteristic of palaces, public buildings, and residential buildings (Architectural idea: [website]).

New urban planning methods were used in the construction of the new capital, focused on the European canons. According to the plans of Peter I the new city had to resemble Venice or Amsterdam, so all the buildings of those times were built by foreign masters on the image and likeness of the architecture of other countries.

Stone was widely used in the construction of St. Petersburg because of its abundance in the areas adjacent to the city, as well as because of its strength and durability. An important stage in the history of stone use in St. Petersburg was the construction of the Fortress of Peter and Paul in the early 18th century. Stone was used in St. Petersburg to build many other iconic buildings such as the Winter Palace, St. Isaac's Cathedral, the Mariinsky Theater, the Smolny Cathedral, and many others. Some of these buildings, such as St. Isaac's Cathedral and the Admiralty, were built on sites where there had previously been wooden structures.

Stone was used not only to build buildings, but also to reinforce embankments and create foundations for bridges. It was also used for decorations and sculptures on the facades of buildings.

The variety of decorative natural stone in the monuments of architecture of St. Petersburg is considerable. They are various granites, graniteegneisses, gabbro, labradorites, larvikites, marbles, marbleized and organogenic-fragmental limestones, lime tuffs, dolomites, sandstones, quartzites, slates, etc., having a very wide geography of places of their extraction (Savchenok A., 2009).

By orders of Russian and foreign architects, tons of building material were brought to St. Petersburg to erect buildings and clad homes, both from local deposits and from remote ones located in Tver and Moscow provinces, in Karelia, in the Urals, in Siberia, Sweden, Finland, Norway, Germany, Poland, Estonia, Italy, Spain and France (Architectural idea: [website]).

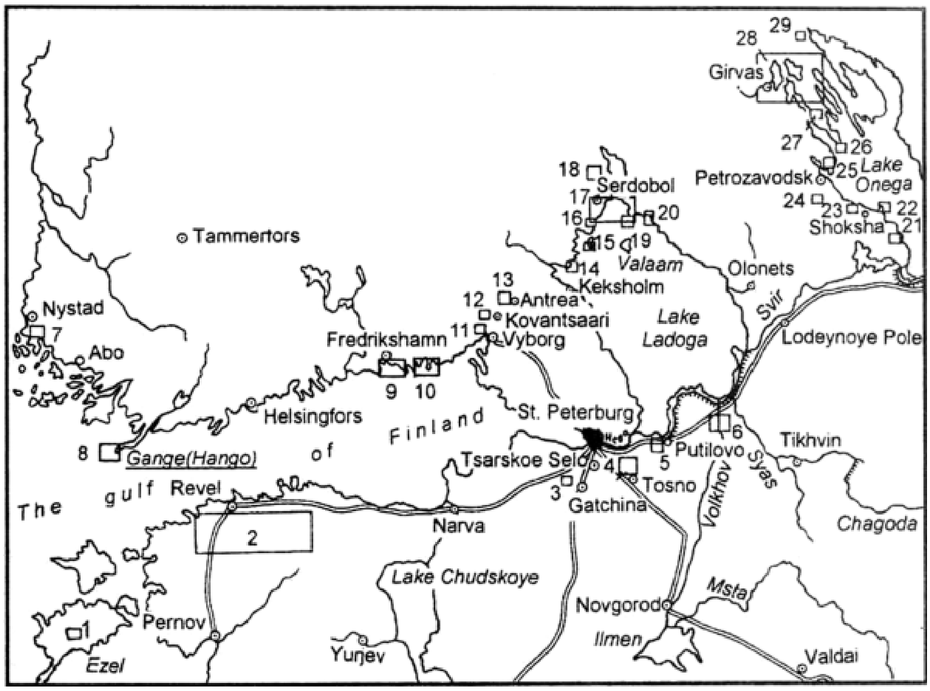


Figure 5. Places of stone mining in the XVIII and XIX centuries (Bulakh, A., 2015)

Deposits in central Europe were the most geographically accessible for the supply of sandstone to St. Petersburg, so it was quite easy to deliver the necessary materials by waterways or railroads. In the 19th and 20th centuries, large shipments of sandstone were transported to St. Petersburg and other cities, as at that time sandstone was one of the traditional materials for construction.

According to archival information, we know that the first "Bremen stone" appeared on the Russian market, a gray sandstone, which was shipped from Bremen, a port city in northern Germany, by sea. This hard, dense rock composed of fragmented quartz grains and siliceous cement was used for making various architectural details and decorations. It was used to make facing slabs, columns, sculptural and carved ornaments (Savchenok A., 2009).

Today sandstone continues to be used in the construction of St. Petersburg, but in much smaller quantities than before. Nevertheless, many of the sandstone buildings of the past continue to adorn the city and serve their original purpose.

The architecture of St. Petersburg has had a significant influence on the development of architecture not only in Russia, but also beyond. Today the city is one of the main centers of architecture and cultural heritage of the world.

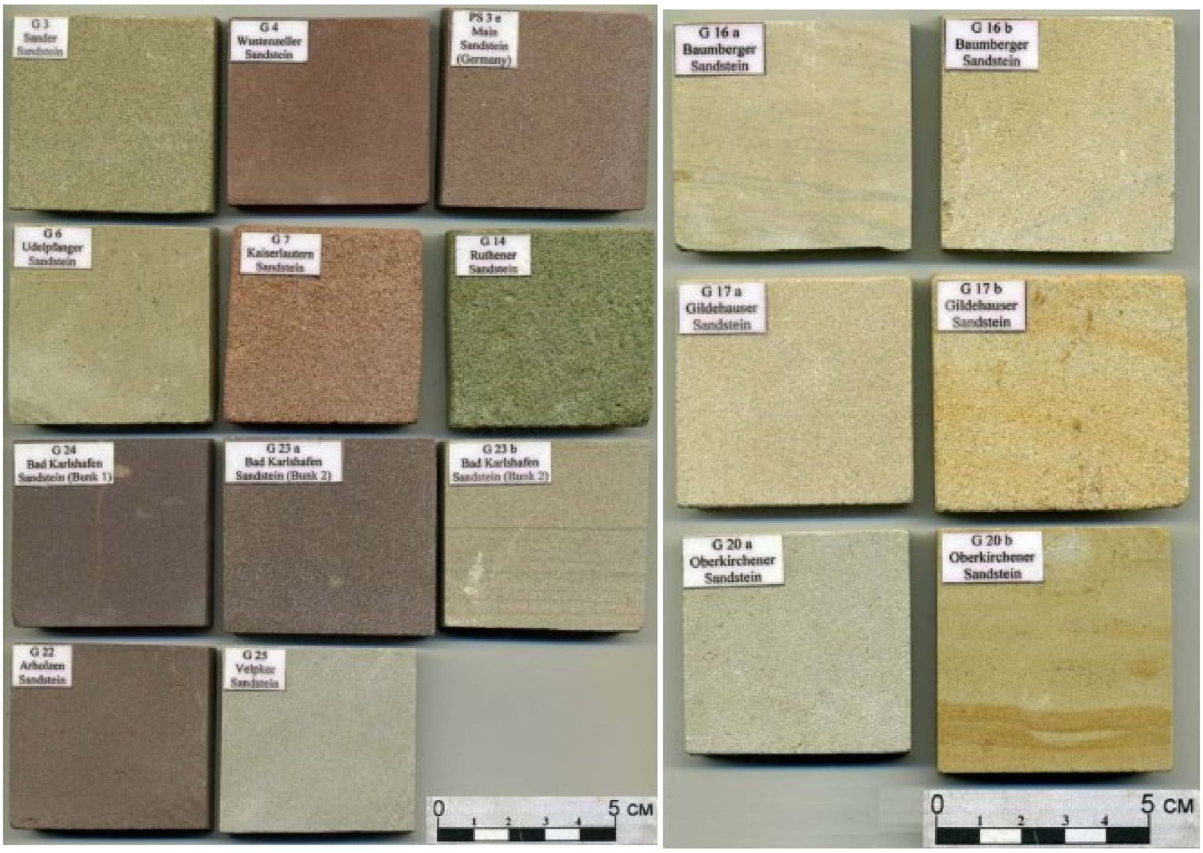


Figure 6. General view of sandstones from German deposits

2.2 Sandstone in the stone decoration of St. Petersburg

In the northern capital there are many objects made of different kinds of stone: mainly granite, but nevertheless sandstone is also widely used. Sandstones are highly durable and easy to polish, making them an ideal material for construction and decoration. They are also generally easier to work than igneous and metamorphic rocks.

Sandstones are used as facade decoration for many buildings in the city, as well as for the construction of bridges, statues and other elements of urban architecture.

For example, one of the most famous sandstone buildings in St. Petersburg is the Winter Palace, the former residence of the Russian emperors. Its facade is lined with sandstone with five portals, which were rebuilt after devastating bombings during World War II. Other sandstone buildings include the Kazan Cathedral, the Admiralty, the Mariinsky Theater, Nevsky Prospect, the Smolny Cathedral, and many others.

A study was conducted in the city which found thirty buildings whose facades were partially or completely lined with various sandstones. All types of sandstone used for cladding belong to four color varieties: gray, yellow, green and red sandstones.

Thus, during the erection of the building of the Russian Foreign Trade Bank (32 Bolshaya Morskaya St.) beautifully colored Wurttemberg sandstones in different shades from yellow to red were used, and light gray Bremen sandstone was used to decorate the palace of Prince Vladimir Alexandrovich (Palace emb., 26), where it decorated the central portal and balcony (Fig. 7).

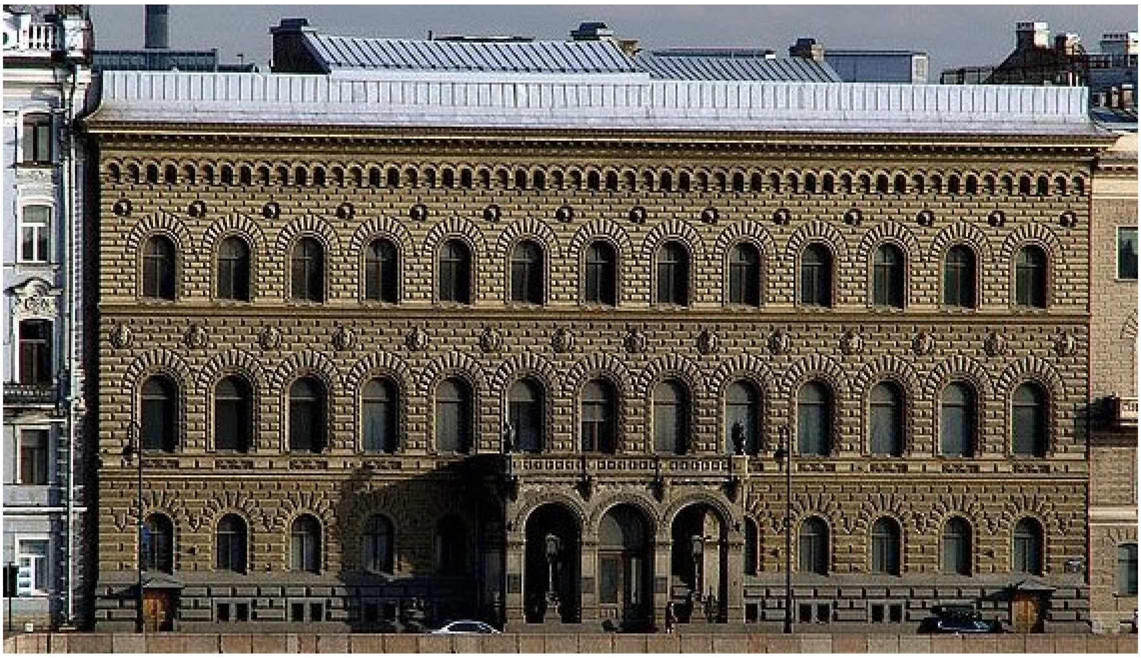


Figure 7. House on the Palace Embankment, 26 (Google:[website])

The central telephone exchange at 22 Bolshaya Morskaya Street (Fig. 8), built to a design by C.A. Baldi in 1903-1904. The facade of the building is distinguished by its rich and complex stone decoration, which uses sandstones of two colors. Red sandstone, worked in different textures (coarse-bumpy, fluted and fine-pointed), is used for the decoration of the ground floor, while gray sandstone is used for the upper floors and stone ornaments, which are supplemented with details in ceramics. On the facade of the building can be found the ornaments above the windows, intricate garlands around the large window in the clock tower and the coat of arms of St. Petersburg, consisting of a crossed scepter and two anchors (Bulakh A., 2009).

Figure 8. House on Bolshaya Morskaya Street, 22

House № 40 on Bolshaya Morskaya Street (Fig. 9). This building was built in 1889-1900, designed by L.N. and Yu. Benua, and served as a residence of the First Russian Insurance Society. The plinth of the building was faced with pink-red Valaam granite, which is well polished and has an irregular spotted or striped structure, and in some places turns into gneiss granite. The upper floors were faced with pink and yellow sandstone and decorated with a complex carved ornament carved from light gray sandstone (Bulakh A.G., 2009).

Figure 9. The house on Bolshaya Morskaya Street, 40

The house of the Joint-Stock Insurance Company "Salamandra" at 4, Gorokhovaya St. (Fig. 10). This apartment building was built in 1907-1909 by N.N. Verevkin together with M.M. Peretyatkovich. Architects used several types of stone for exterior decoration: red Gangut granite, red sandstone and white marble. Relief mascarons decorate the facade of the building and depict the heads of people and animals, pythons and horns of plenty. They were all carved from sandstone, which has a fine-grained structure and a homogeneous coloration, allowing for very fine detailing.

Figure 10. The house on Gorokhovaya Street, 4

There is a museum of Academician Stieglitz on Solyanoy Lane, 15 (Fig. 11). This impressive building, made in the style of Italian palaces of the 16th century. The low socle is lined with large blocks of pink Finnish rapakivi granite, the walls are lined with light gray sandstone. The facing of the lower floor is made of rusticated rock slabs, which alternate with slabs of smooth texture. The doors and windows are decorated with carved garlands of laurel leaves. The upper floor is lined with sandstone slabs, which are also finished in a smooth texture. The windows of the floor are decorated with three-quarter columns. The cladding of the entire building is made of sandstone that was quarried in Silesia.

All the cladding work was carried out by the German company Zeidler & Wimmel, which is a well-known performer of sandstone cladding of the Brandenburg Gate, the Reichstag, the cathedral in Berlin, the Knight's Gate in Konigsberg, as well as many other buildings and pavilions in various countries.

Figure 11. Stieglitz Museum at 15 Solyanoy lane (Google:[website])

Sandstones in St. Petersburg were also used to create many famous statues and monuments. For example, in the center of the city stands the Bronze Horseman, a monument to Peter the Great that was cast in bronze and mounted on a sandstone pedestal. Other famous sandstone monuments include the monument to Alexander III on the Marble Embankment and the monument to Nicholas I on Senate Square.

Thus, sandstones are an important element of the stone decoration of St. Petersburg, and contribute to the beautiful architecture and unique character of this city.

A detailed examination of these buildings, including a study of biofilms and weathering forms, was conducted for all sandstone specimens in later chapters of the paper.

Chapter 3: Structural features of sandstones

A working collection of sandstone samples taken from building facades and from German active and abandoned deposits was established for laboratory studies. A total of 33 samples, 28 of which were taken from quarries and 5 samples from building facades for biofilm studies.

A rational scheme is used for the petrographic study of rocks, which includes the choice of a certain sequence of methods for the study of the substance. These methods range from express, cheap and mass methods to precise quantitative methods.

In the course of the study, rocks are subjected to analyses in this sequence:

1. Photographic documentation and macroscopic description.

2. Examination of rocks and their components in transparent and polished thin sections.

3. Determination of composition and properties in samples without first separating the rocks into their constituent parts.

4. Dividing rocks into clastic part and cement and studying them separately.

4.1 XRF (petrogenic oxides and trace elements) X-ray fluorescence analysis

4.2 Micro-ring-spectral analysis and SEM microscopy

4.3 Computed tomography

5. Investigation of biofilms from facades of buildings in St. Petersburg.

The study of sandy rocks is an important part of geological research, interregional comparisons, and analysis of the composition and structure of the Earth's sedimentary shell as a whole.

The texture of sedimentary rocks and their structure are important petrographic features that are closely interrelated.

The texture of sandstones is determined by the size of the grains and their degree of fineness, as well as the degree of compactness of the grains, which can be loosely separated from each other or tightly packed together. The structure of sandstones describes the different shapes and ordering of the grains.

Sandstones formed under different conditions may have different structures and textures, which may be indicative of different geological processes and past events. For example, rounded grains may be the result of water transport, while angular grains may indicate local rock formation without transport. Layering and other structural features may indicate the ways in which sandstone accumulates in nature, such as deposits on beaches, in river deltas, or in lake basins.

The study of sandstone textural and structural features is important for understanding the history and geologic evolution of different regions and can help establish geologic relationships between different deposits.

In addition, the study of sandstone textures and structures can help determine their engineering and geological properties, such as strength, permeability, resistance to deformation, etc. This, in turn, can be useful in the design and construction of various engineering structures such as dams, bridges, buildings, etc.

3.1 Textures

A sedimentary rock is characterized by its textural features, which are determined by the spatial relationships of its components and their orientation relative to the layering surface and the Earth. One of the main textural features is the layering of the rock.

The texture of rock is formed from the stage of sediment accumulation. The primary textures produced during sedimentation reflect the state of the environment at the time of sediment accumulation and the results of its interaction with the sediment. They can transform into post-sedimentary stages. Secondary textures arise in the already formed rock during catagenesis, metagenesis and hypergenesis (Shvanov V., 1987).

The textural features of sandstones may be related to their genesis and formation history. For example, textures may indicate the processes of sorting, transport, and deposition of gravel, sand, and silt fractions in the rock. They may also reflect diagenesis processes such as cementation, recrystallization, etc.

Textures can also serve as an indicator of the origin of sedimentary material. For example, sandstone textures may indicate that the rock was formed in a river, on an ocean shore, or on the seabed. Studying the textural features of sandstones helps to understand past geological processes and can also be useful in finding new mineral deposits.

Textures significantly affect the physical properties of rocks, such as strength, compressibility, filtration capacity, etc. Textures are mainly studied visually - in outcrops, pits, core samples, sometimes under a microscope (Parmuzina L., 2013).

Optical and electron microscopy techniques are used to study sandstone textures more accurately, especially fine and complex ones. This allows us to see a more detailed structure of the rock, identify microcracks, inclusions, and other elements that may affect its physical properties.

Massive texture is characterized by a disorderly arrangement of rock constituents, which provides the same physical properties in different directions. Fragmentation produces irregularly shaped fragments.

Sandstones with a massive texture have the advantage of their durability and resistance to weathering, as well as their resistance to corrosion, which allows them to serve for a long period of time.

Layered textures are caused by alternating layers of different sedimentary rocks and can be caused by various reasons, such as unequal size of clastic particles, differences in mineral composition, orientation or coloring of particles, differences in the amount and composition of organic residues, etc.

When the texture of a rock is not clearly layered, it may be haphazard, spotty, granular, etc. A disorderly texture is characterized by an irregular arrangement of mineral grains, which can be caused by various factors, such as uneven distribution of clastic particles in the sediment, mixing of different types of rocks due to geological processes such as shear, folds, fractures, etc.

For example, the occurrence of lumpy texture in clayey rocks is associated with the penetration of plant roots into the sediment and a strong alteration of the original material. In addition, the presence of metal oxides or hydroxides in the rock may contribute to this texture.

A mottled texture has small patches or flecks of different colors and sizes caused by the presence of minerals that color the rock or by its uneven distribution.

Granular texture is characterized by the presence of small pieces that may be the same or different sizes and shapes. This texture may be caused by repeated processing of the rock, such as crushing and reorganizing it as a result of high pressure and temperature

The study of sandstone textures is important not only for geology and geological research, but also for industry, including the extraction and use of natural resources such as oil, gas, water, etc.

All sandstones, based on the results of visual macroscopic observations, are characterized by high homogeneity and their proximity of structural-textural features (Annex 1). The study of sandstones revealed only two main types of their textures: parallel-layered and massive homogeneous. It was possible to identify the only significant difference of sandstones for architectural objects - their color (Figs. 12, 13).

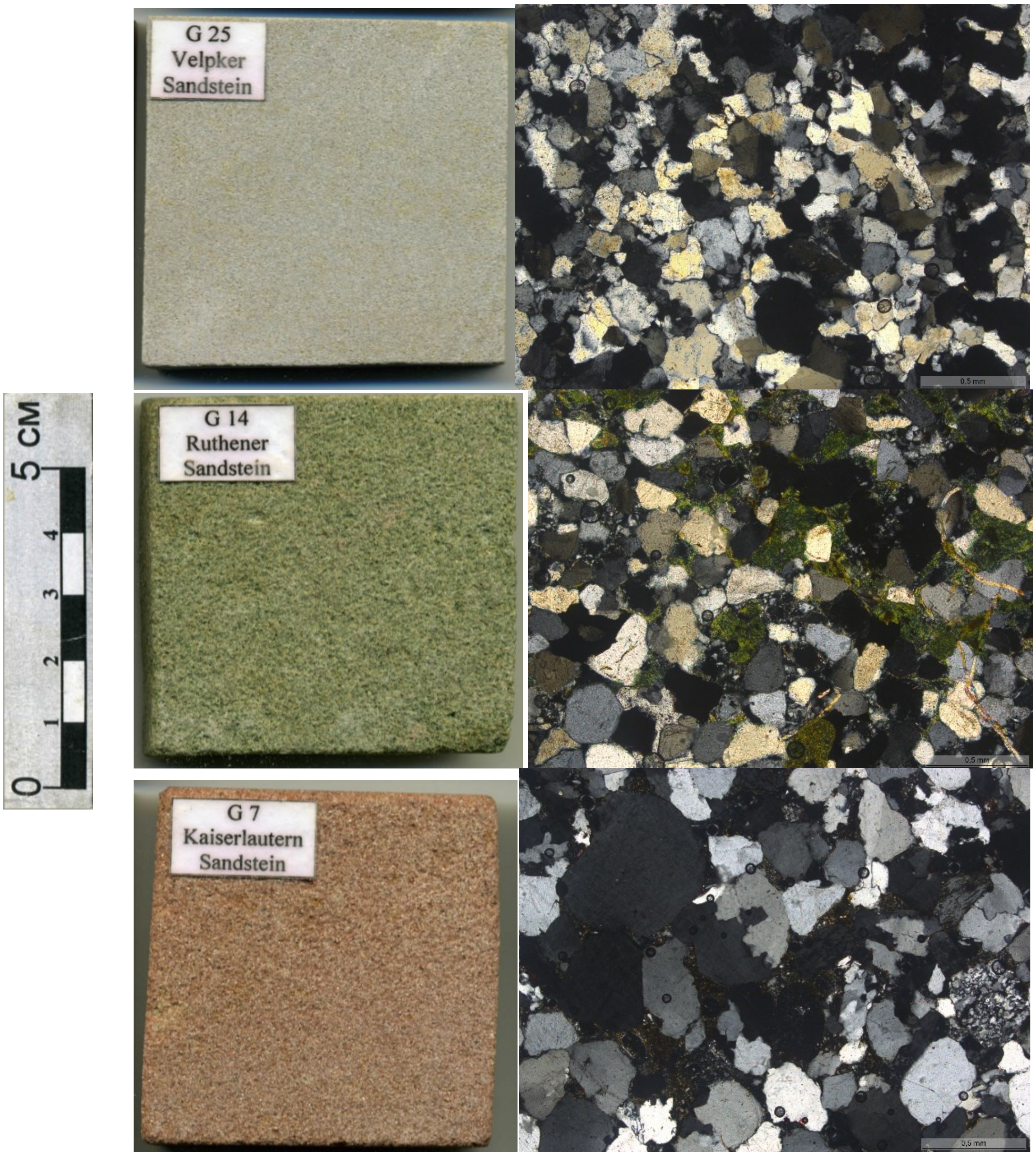


Figure 12: Texture of gray, green, and red sandstones.

The red, gray, and green sandstones have an exceptionally massive texture.

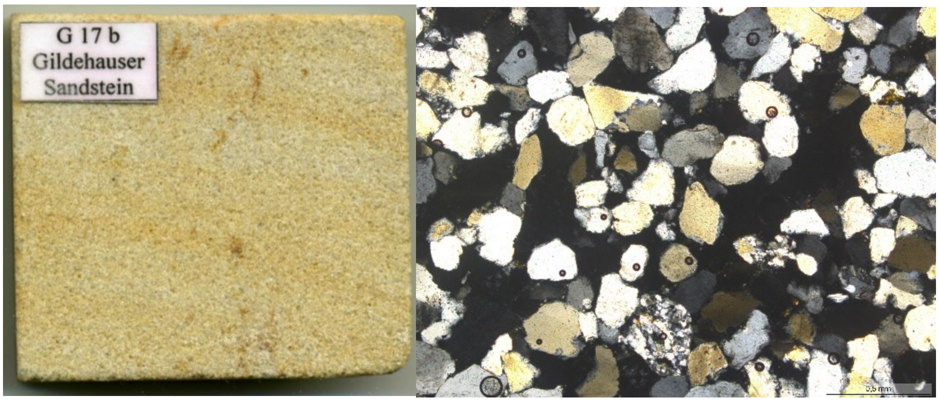


Figure 13. Yellow sandstone texture.

The texture of yellow sandstones is defined by its massive and layered character.

On the architectural structures of St. Petersburg, the texture of all sandstones is massive because it has the highest density, which is most important for the construction of buildings.

3.2 Structures

The structure of rocks is the most important factor in their diagnosis and classification, along with mineral and chemical composition. It is evaluated by the shape, size and grading of the grains that make up the rock. Sandstone structure can vary considerably depending on what minerals and elements bind the sand grains together. In general, the structure of sandstone can be quite complex and varied, and can vary depending on the location and conditions of its formation.

The study of sandstone structure is an important area of geologic investigation that can provide valuable information about the origin, properties, and uses of this rock.

Microstructure analysis allows us to describe the textural features of a rock and provide information about its petrogenesis, formation conditions, deformation, folding, and alteration. Microstructure includes the texture and fine-scale structures of a rock.

Various methods can be used to study sandstone structure, including optical microscopy, X-ray diffraction, spectroscopy, and electron microscopy.

Optical microscopy examines sandstone structure using light waves. This method makes it possible to determine the size and shapes of sand grains, their orientation, and the presence of inclusions and other structural elements.

X-ray diffraction is used to determine the composition and structure of crystalline components that may be associated with sandstones. This allows us to determine which minerals are part of the rock and how they are related to each other.

Spectroscopy is used to study the optical properties and chemical composition of the minerals that make up the sandstone. This method allows us to determine which elements are present in the rock and how they are distributed.

Electron microscopy provides a detailed image of sandstone structure at the micro level, allowing details of the structure, such as grain size and shape, the presence of pores, cracks and inclusions, and their mutual arrangement, to be studied.

Understanding the structure of sandstones can help optimize their use in construction, glass, ceramics and other industries.

Sandstone can contain cracks that form as a result of uneven compression and deformation of the rock. These fractures can be of varying lengths and depths and may be important for recovering oil and gas from sandstones.

Granulometric composition and mechanical analysis data determine the rock's place in the particle size classification. There are several classifications based on particle size distribution.

The particle size distribution of sandstones can vary considerably depending on their place of formation and origin. This can lead to significant differences in their structure, properties, and uses.

For example, sandstones formed from quartz sand generally have a more uniform particle size distribution and better strength properties than sandstones formed from clay or shale rocks.

Also, particle size distribution can significantly affect the properties of sandstone when used in various industries. For example, when sandstone is used in construction, grain size and size distribution can affect the strength of building materials.

Debris size is the main parameter that characterizes the structure of sandstone rocks. Determining the distribution of debris by size fraction is an important aspect of sandstones and other clastic rocks because it allows conclusions to be drawn about the dynamics of material accumulation. From the debris size, it is possible to determine the rate of rock flow (current or wind), facies conditions (marine or fluvial deposits), and the rate of sedimentation.

In Russia, a classification based on the decimal metric system is widespread. According to it, within the psammite (sandy) silty (dusty) and pelitic (clayey) groups of clastic rocks are distinguished the following structural differences in size of fractions:

- psammite (2.0-0.05 mm): coarse-grained (2-1), coarse-grained (1.0-0.5 mm), medium-grained (0.5-0.25 mm), fine-grained (0.25-0.1 mm), fine-grained (0.1-0.05)

- silty (0.05-0.005 mm): coarse-silty (0.05-0.01 mm), fine-silty (0.01-0.005 mm)

- pelitic (<0.05 mm): coarse-silty (0.005-0.001 mm), fine-silty (<0.001 mm) (Platonov M., 2017)

The sandstones belong to the psammite structural dimension. The structural-textural features of sandstone samples are studied by visual inspection and using a petrographic microscope. The number of examined samples is 28 (Annex 1).

The results of the particle size analysis of the sandstone component (Fig. 14) allowed us to draw some preliminary conclusions. All studied sandstone samples are dense with a fine-grained and fine-grained structure. The sandstone in the samples is very well sorted.

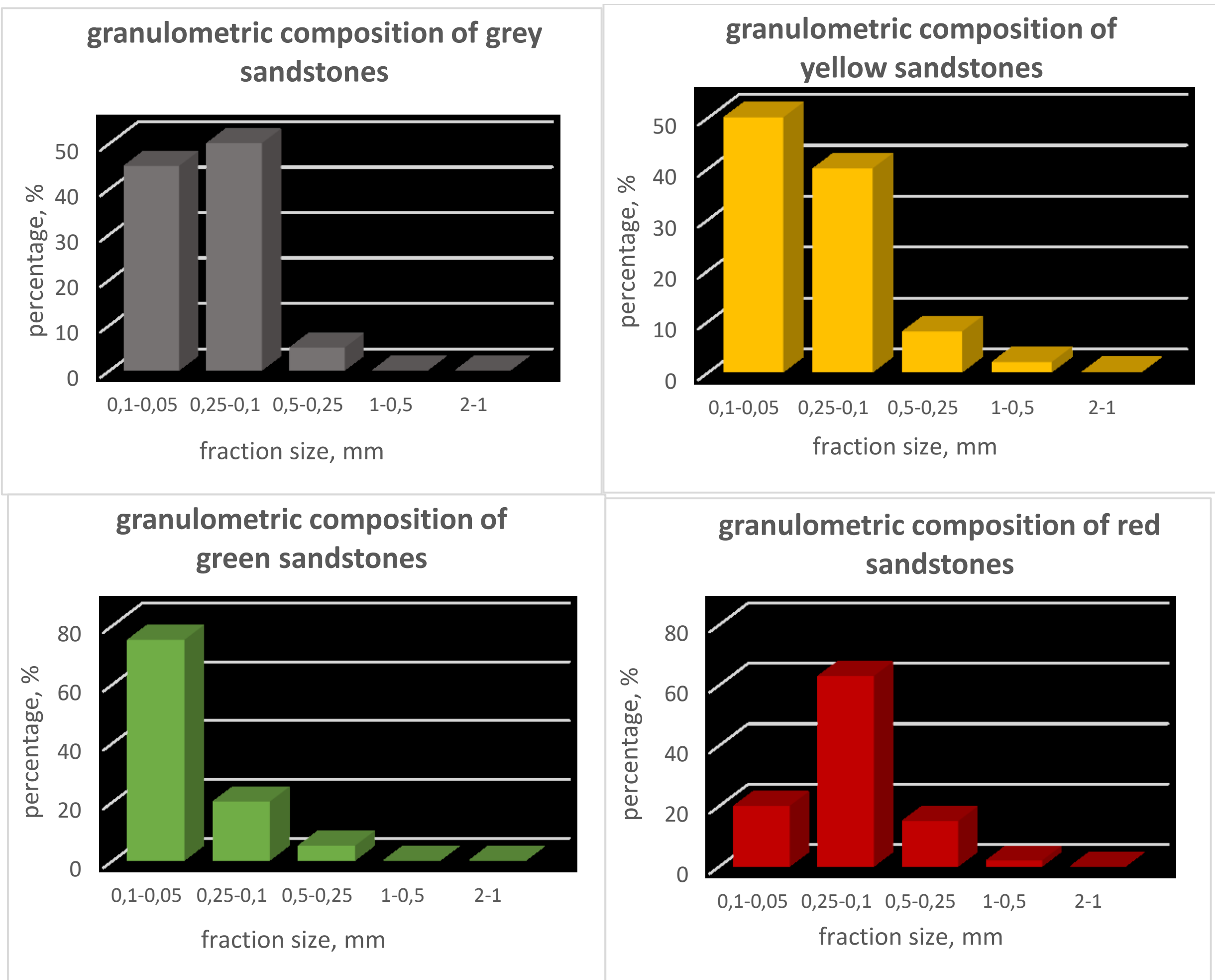


Figure 14 Results of the granulometric analysis of the sandstones.

The presented graphs represent the average granulometric composition of the sandstones in the four main colors. As can be seen from Fig. 14, the presented diagrams are unimodal, i.e., they have one maximum value. The differences between the rocks are determined by the different colors with the ratio of fraction sizes in the rock composition as a percentage, as well as by the genesis of these sandstones.

Sandstones with larger grains are generally considered more stable. This is due to the fact that large grains have a higher resistance to shear and deformation than small grains.

Porosity is also an important characteristic of the structure of a material and determines its ability to store and transport liquids, gases, and other substances. Porosity is defined as the ratio of pore volume to the total volume of the material and is expressed as a percentage. The pores can be of different sizes and shapes and can be associated with different rock formation processes.

Two basic types of sandstone porosity are distinguished, open and closed tomographic porosity.

Open porosity is characterized by connective pores that have open channels to the rock surface. This allows liquids and gases to easily penetrate the rock and propagate through the pores, which can be important for processes such as filtration and transportation. However, open porosity can also contribute to rock destabilization and failure under high pressure and mechanical stress.

Closed porosity is characterized by tightly coupled pores that have no open channels to the rock surface. This means that liquids and gases can have difficulty penetrating the rock and moving through the pores, which can be important for processes such as gas or oil retention in rocks. However, closed porosity can also impair the permeability of the rock and prevent its use for some construction activities.

It is important to note that sandstone porosity can be composite, that is, it can consist of both open and closed pores. Therefore, when studying the porosity of sandstones, it is necessary to consider their types and the relationship between open and closed pores in order to more accurately determine their properties and potential applications in various industries.

An important aspect of porosity is its effect on the physical and chemical properties of the material, such as permeability, capillarity, reactivity and diffusion. Porosity can also be related to the material's resistance to various influences, such as corrosion, wear and tear, and failure.

The porosity of sandstone can be measured by various methods such as gravimetric method, gas porosity method, radiation beam method and others. Each of these methods has its advantages and disadvantages and can be applied depending on the requirements and purposes of the study.

In the present study, the porosity of selected samples was investigated using the computed tomography method on a Neoscan-80 X-ray tomography analytical complex. This method begins with a rock sample being placed inside a special scanner, which then rotates around it and takes a series of X-ray images in different directions. These images are then processed by a computer, which creates a three-dimensional image of the internal structure of the sample.

Using computed tomography to analyze rocks allows you to see internal defects such as cracks, pores and inclusions that can affect the quality and strength of the material.

The results of the analysis are presented in Table 2. Some samples were deliberately excluded from the analysis to avoid repetition.

Table 2. Results of computed tomography of sandstone samples

№		1	3	4	8	9	10	11	12	14	15	17
tomographic porosity, %	open	6,91	23,08	11,92	0,48	13,87	18,2	5,66	0,15	0,46	23,59	17,95
	closed	1,9	0,15	0,29	3,27	0,19	0,41	1,98	3,08	2,74	0,1	0,56
	total	8,67	23,19	12,19	3,73	14,03	18,56	7,53	3,23	3,2	23,07	18,4

continuation of table 2

№		18	19	20	21	22	23	25	26	27	28
tomographic porosity, %	open	8,59	12,41	0,05	0,2	1,22	0,37	1,44	0,52	7,73	5,98
	closed	3,44	1,32	0,55	1,99	3,26	1,37	5,02	3,63	2,08	3,09
	total	11,73	13,56	0,6	2,19	4,44	1,73	6,39	4,13	9,65	8,89

As can be seen, the average total porosity among all samples is 9.5%, the highest value is 23.19% in sample №3, and the lowest is 0.6% in sample №20. Thus, sample № 20 is considered to be the most resistant to external changes (Fig. 15).

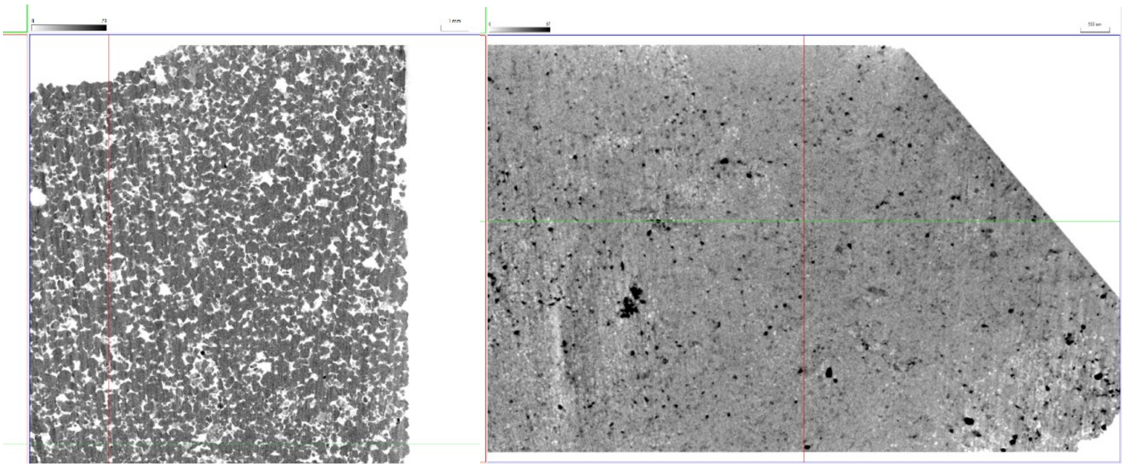


Figure 15. Example of samples with different tomographic porosity: sample № 3 (23.19%) and sample № 20 (0.6%), respectively.

However, it should be noted that the porosity of sandstones can be variable and depends on various factors, such as sandstone type, depth, formation conditions, pressure, and temperature.

The porosity of sandstones is important for various industries. For example, in construction, porosity can affect the water permeability, strength and resistance to frost and fracture of sandstone. In the mining industry, porosity can affect how sandstone is mined, transported and processed.

Rolled debris is a structural characteristic that indicates the degree of wear on the original edges of the debris and reflects the duration of movement and deposition of the sediment. In other words, the higher the roundedness of the grains, the more cycles of redeposition the sediment has experienced or the longer it has migrated from drift sources.

1 - completely uncoated grains with sharp edges;

2 - weakly calcined - retaining their original shape and having only slightly smoothed edges;

3. Moderately dome-shaped, with smoothed corners, but with straight edges still visible;

4 - well rounded, with only a trace of the original cut;

5 - perfectly rounded (Platonov M., 2017).

The gray and yellow sandstones in most samples have different degrees of rounding with the predominance of medium-rounded particles. In the gray sandstone from the German Eichenbuchl deposit (sample № 26), angular and poorly rounded grains predominate.

The study of the shapes of clastic grains in green sandstones showed that quartz grains are medium-rounded and rounded, and glauconite grains are rounded.

The clastic grains in the red sandstones have varying degrees of roundedness with the predominance of angular and weakly rounded particles. By the shape of grains among the red-brown sandstones, it is not possible to distinguish certain types or separate sandstone groups.

Another element of the sandstone's structure are mineral inclusions. These are small particles of minerals that have been incorporated into the rock during its formation. These inclusions can be visible to the naked eye and can have different shapes and colors.

Sandstones can have a variety of mineral inclusions including quartz, clays, gypsum, calcite, pyrite, mica, etc. Quartz is one of the most common mineral inclusions in sandstones.

Mineral inclusions in sandstones can provide important information about the origin and composition of the rock. For example, the presence of crystalline inclusions can indicate the formation of sandstone under high-temperature conditions, and the presence of inclusions of organic material can indicate that the rock was formed under conditions that were suitable for the development of living organisms.

In addition, mineral inclusions can affect the physical and mechanical properties of sandstone. For example, the presence of clay inclusions can reduce the strength of a rock, and the presence of crystalline inclusions can improve its heat resistance. Clays and gypsum can also be found in sandstones and affect their porosity and strength. Pyrite is a mineral inclusion that can lead to oxidation of the rock and deterioration of its mechanical properties.

In general, the structure of sandstone consists of grain size distribution, porosity and mineral inclusions. Each of these elements can affect the properties and use of sandstone, so all of these factors must be considered in the study and application of this rock.

The choice of the more stable sandstone fraction depends on specific conditions and requirements. For example, for construction applications, larger grains may be preferred to create stronger materials, but local conditions such as climatic and geological conditions that can affect the stability of sandstones must be considered.

Consequently, when researching sandstones and their use in various industries, differences in grain size distribution and other characteristics must be considered to select the best material for a particular application.

Chapter 4. Mineral and geochemical features

4.1 Mineral composition of rubble and cement

The standard description of rocks is the initial stage of the study, on the basis of which a more detailed study of the characteristics of individual components and their relationships begins.

The study of minerals in transparent and polished thin sections is an important step in geological and mineralogical research. Polished schlifs studies are used to study the chemical composition of minerals, their structure and texture.

Transparent thin sections are used to study the properties of minerals, such as optical properties, light refraction and birefringence. Various techniques, such as engraving, sandblasting and polishing, are used to produce transparent slides. These are made by treating the surface of the mineral with abrasive materials such as silicon carbide or aluminum oxide.

Petrographic thin sections can also perform chromatic analyses, microchemical reactions, local X-ray spectral and luminescence analyses.

For example, chromatic analysis can be used to identify minerals by color and microchemical analysis can be used to identify the presence of certain elements in minerals. Local X-ray spectral analysis and probe analysis can investigate the microstructure of materials and determine their chemical composition.

Luminescence analysis can also be used to study minerals and rocks. This method is based on measuring the spectrum of light emitted by a material when it is excited by light of a particular wavelength. Different minerals and components have unique luminescence properties, allowing them to be identified and their properties to be studied.

Petrographic thin sections and the methods of analysis used with them are important tools in geological research and can be used to determine the age of rocks, study their history and origin, and search for minerals.

The mineral composition of fragments and cement of sandstone samples (analysis of petrographic thin sections) is studied using a petrographic microscope. The total number of schlifs is 28. The samples from which the thin sections were made, selected from the existing collection, but most of the samples were not used in the study previously.

The mineral composition can tell us what processes took place during the formation of rocks. For example, the high iron content of rocks may indicate their formation in an oxidizing environment, where iron was oxidized and converted to oxides and hydroxides.

In addition, certain minerals may indicate the presence of minerals in the rocks. For example, the presence of bauxite minerals may indicate the presence of bauxite, which is used to produce aluminum.

The schists considered are primarily distinguished by color and can be classified on the basis of their color characteristics, which can be determined by microscopic examination.

Sandstones have a diverse palette of colors, including gray, white, green, red, brown, and yellow, with various shades and overtones. Usually the color of the schliff depends on the mineral composition of the cement, with the exception of green sandstones, where the color is due to the presence of glauconite. The presence of hematite may give a red or brown color, and other iron oxides and hydroxides may give a gray or yellow color.

Based on the data of the slices reviewed, four main categories have been identified that can be distinguished on the basis of their color characteristics.

1. gray
2. yellow
3. green
4. red and brown

Table 3: Petrographic features of sandstones

Number	Deposits	Brief description
	grey	
1	Schoenbacher Sandstone	Medium-grained sandstone with quartz grains of 0.05-0.2 mm, feldspars of 0.1-0.2 mm, mica particles of 0.05-0.15 mm are in small amounts. Cement constitutes a significant percentage of the surface of the thin sections.
2	Coburg Sandstone	Medium-grained sandstone with quartz grains 0.05-0.2 mm, feldspars 0.1-0.3 mm, mica particles 0.05-0.1 mm.
3	Udelphan Sandstone	Fine-grained homogeneous sandstone with quartz grains 0.5-0.1 mm, feldspars 0.05-0.1 mm, glauconite grains 0.03-0.05 mm.
10	Marburg Sandstone	Coarse-grained sandstone with quartz grains sized 0.15-0.5 mm, mica particles 0.03-0.05 mm
13	Baumberg Sandstone	Fine-grained homogeneous sandstone with quartz grains of 0.02-0.2 mm, cement dark
14	Baumberg Sandstone	Fine homogeneous sandstone with quartz grains sized 0.02-0.2 mm, cement dark

15	Gildehau sandstone	Medium-grained sandstone with quartz grains sized 0.1-0.35 mm, mica particles in small amounts sized 0.01-0.03 mm.
16	Gildehau sandstone	Medium-grained sandstone with quartz grains sized 0.05-0.2 mm, mica particles in small amounts sized 0.03-0.05 mm.
25	Welpka Sandstone	Fine-grained sandstone with quartz grains sized 0.05-0.2 mm, small amount of mica particles sized 0.03-0.05 mm.
26	Eichenbuch Sandstone	Fine-grained sandstone with quartz grains of 0.1-0.2 mm, feldspar grains of 0.05-0.15 mm, mica particles of 0.05-0.1 mm.
yellow		
5	Marburg Sandstone	Medium-grained sandstone with quartz grains 0.05-0.2 mm, mica particles 0.03-0.05 mm.
6	Marburg Sandstone	Medium-grained sandstone with quartz grains 0.1-0.35 mm, feldspars 0.1-0.3 mm, mica particles 0.03-0.2 mm.
9	Marburg Sandstone	Coarse-grained sandstone with quartz grains of 0.05-0.4 mm, mica particles of 0.05-0.2 mm
17	Bentheim Sandstone	Medium-grained sandstone with quartz grains of 0.05-0.2 mm, mica particles in small quantities of 0.03 mm.
19	Ibbenburen Sandstone	Coarse sandstone with quartz grains sized 0.1-0.3 mm, mica particles 0.1-0.4 mm
20	Port Sandstone	coarse sandstone with quartz grains of 0.3-0.5 mm, mica particles in small quantities of 0.05-0.1 mm.
23	Karlshafen Weser Sandstone	Medium-grained sandstone with quartz grains sized 0.1-0.2 mm, mica particles 0.1-0.2 mm.
green		
11	Ruegen Sandstone	Coarse-grained sandstone with a dense green coloration due to dissemination of glauconite grains 0.05-0.2 mm, quartz grains 0.05-0.2 mm, mica particles 0.01-0.05 mm, cement in large quantities
12	Anrech Sandstone	Fine-grained sandstone with quartz grains sized 0.01-0.08 mm, feldspars 0.05-0.1 mm, glauconite 0.03-0.1 mm. Cement with glauconite grains sized 0.05-0.2 mm, quartz grains sized 0.05-0.2 mm, mica particles sized 0.01-0.05 mm.
red		
4	Schweinsteel Sandstone	Coarse-grained sandstone, quartz grains 0.05-0.45 mm, rock fragments 0.01-0.03 mm.
7	Niederweiss sandstone	Fine-grained sandstone with quartz grains sized 0.05-0.1 mm, mica particles 0.05-0.1 mm.
8	Niederweim sandstone	Fine-grained sandstone with quartz grains sized 0.05-0.1 mm, mica particles 0.05-0.1 mm.
18	Bentheim Sandstone	Medium-grained sandstone with quartz grains sized 0.05-0.15 mm, small amount of mica particles sized 0.03-0.05 mm.
21	Arolsen Weser Sandstone	Fine-grained sandstone with quartz grains of 0.02-0.1 mm, mica interlayers of 0.02-0.1 mm are present

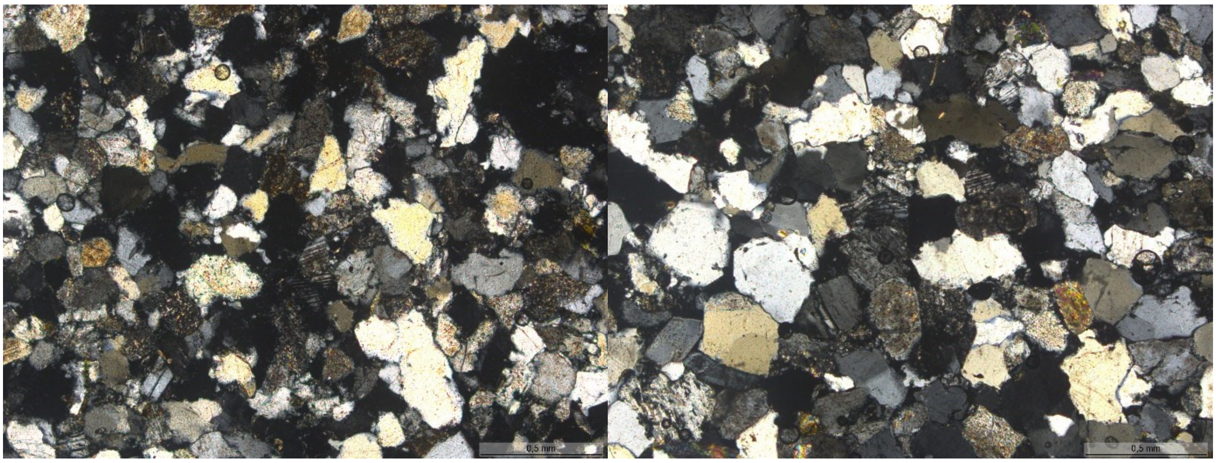
22	Karlshafen Weser Sandstone	Medium-grained sandstone with quartz grains sized 0.1-0.3 mm, feldspar grains sized 0.05-0.15 mm, mica particles sized 0.05-0.1 mm.
24	Karlshafen Weser Sandstone	Fine-grained sandstone with numerous micaceous interlayers of 0.0-0.05 mm.
27	Kasheim Sandstone	Medium-grained sandstone with quartz grains 0.05-0.1 mm, feldspars 0.1-0.15 mm, mica particles 0.05-0.1 mm.
28	Ebenheide Sandstone	Fine-grained sandstone with quartz grains sized 0.05-0.1 mm, mica particles 0.05-0.1 mm. Dark cement

Quartz is the main rock-forming mineral in all sandstones.

Gray sandstones.

The relative content of quartz is about 80-90 % of the total rock volume. Secondary minerals are feldspars (plagioclase and potassium feldspar), mica (biotite, muscovite), and zircon, ilmenite, and rutile. Feldspars are present in the rock in small quantities, about 5-10%. Mica inclusions and evenly distributed ore minerals are present in small amounts (Fig. 16).

Biotite is represented in the rock as lamellar crystals and muscovite as elongated crystals. The relative content of biotite and muscovite may vary, but the total amount does not exceed 2-3% of the rock volume. Muscovite is represented in the rock in the form of elongated crystals. Zircon grains are also present as single inclusions in some samples.



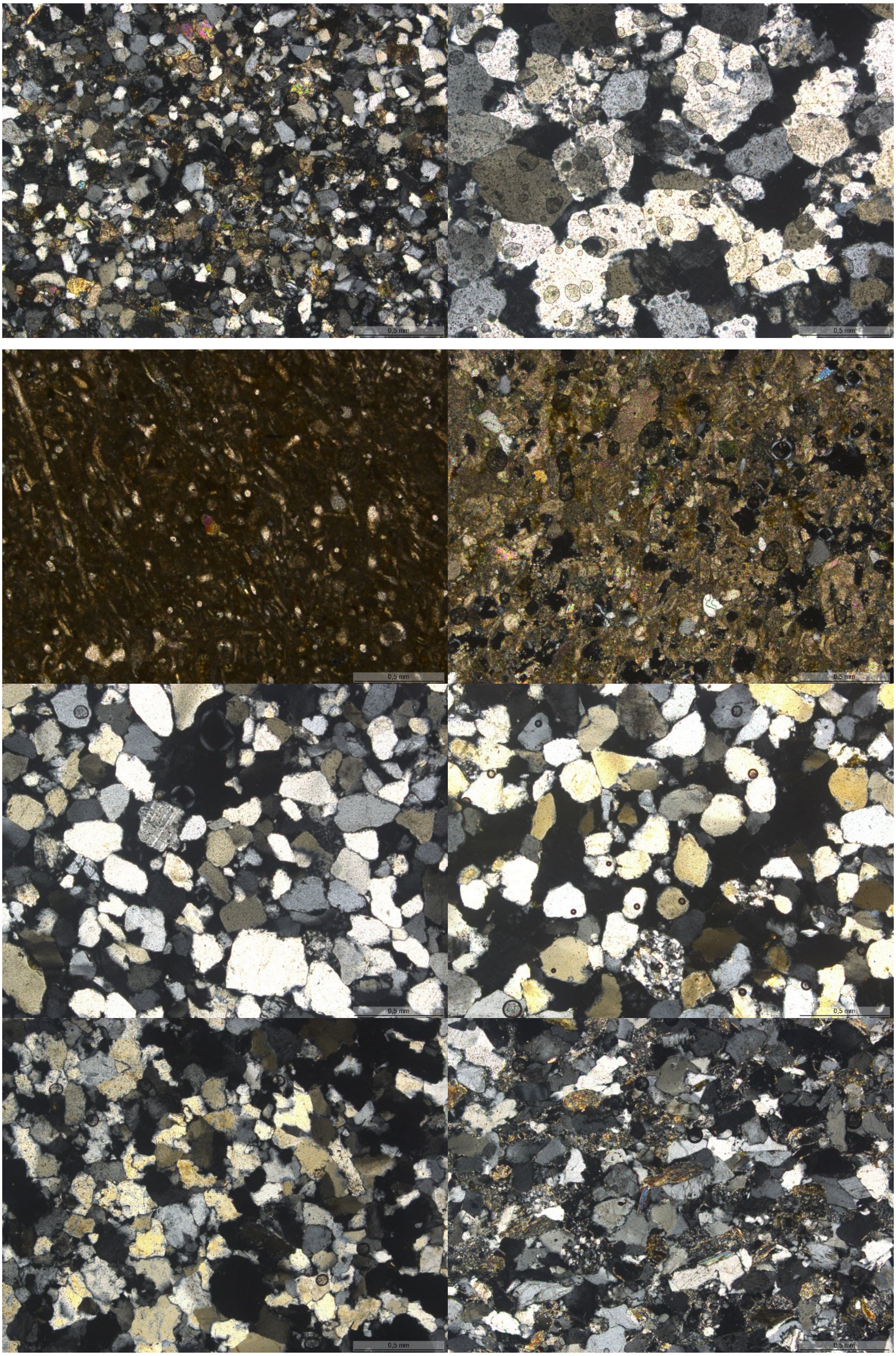
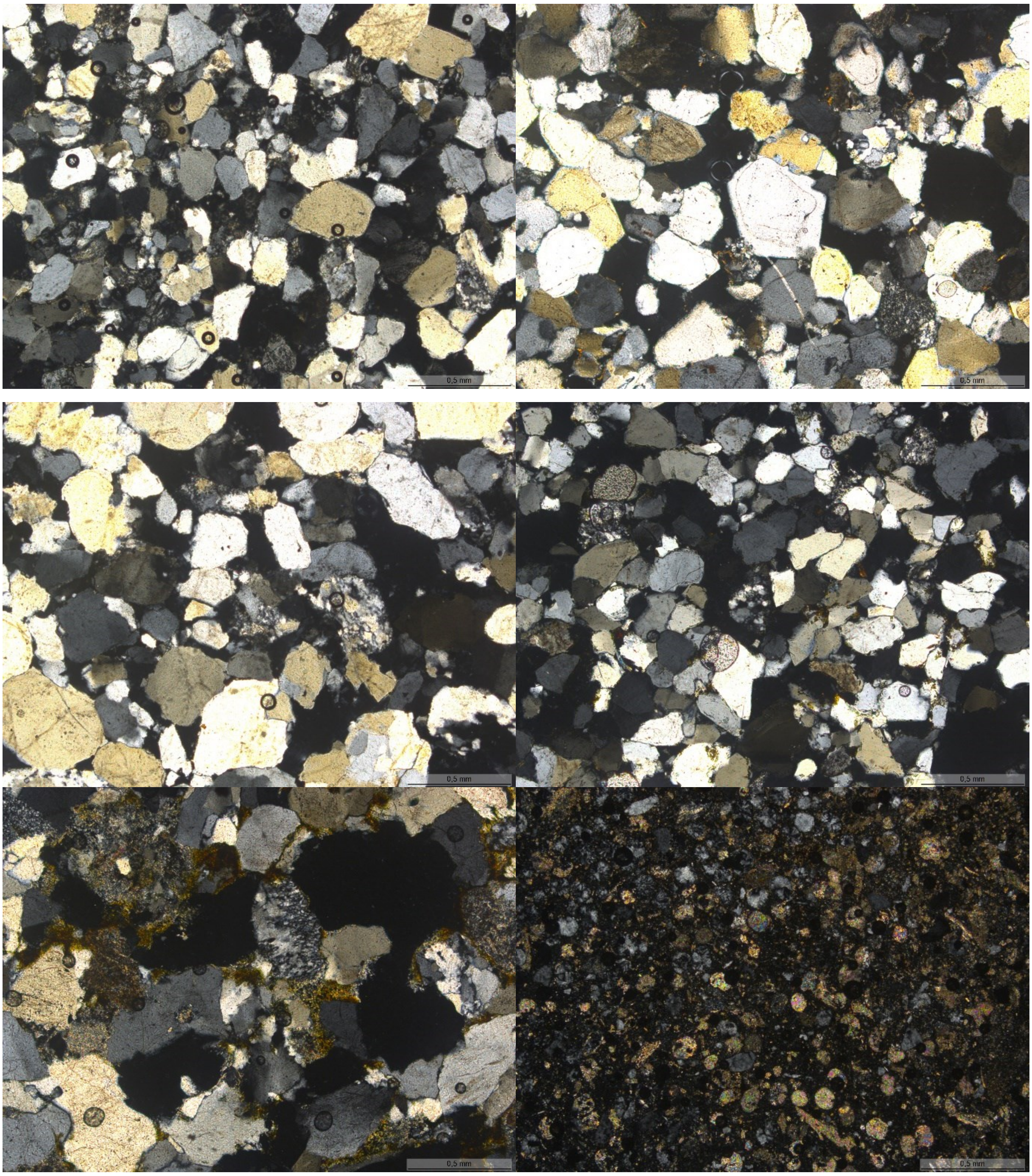


Figure 16. Images of petrographic thin sections of gray sandstone

Yellow sandstones.

The relative content of quartz is about 80-90 % of the total volume of the rock. Feldspars: acidic plagioclase grains and microcline grains with irregular boundaries are present in the rock in amounts up to 3-5% (Fig. 17).

The main well-detectable and reliable indicators for sandstones of this color variety are their grain size distribution and typical content of petrogenic oxides.



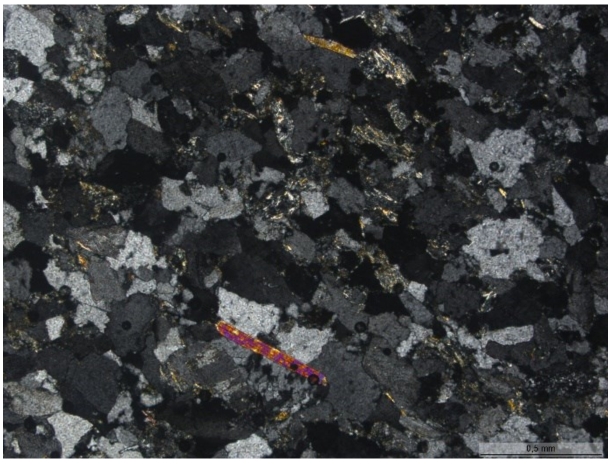


Figure 17. Images of petrographic thin sections of yellow sandstone

Green sandstones.

Quartz grains account for 70-80% of the total volume. In addition to quartz, the clastic portion of sandstones contains glauconite grains, rock fragments, and feldspars. Grains of glauconite are contained in an amount of 10-15 vol.%. Feldspars and rock fragments are found in insignificant quantities and can be classified as minor components. The green color of the rocks is determined by the presence of glauconite and titanite grains (Fig. 18).

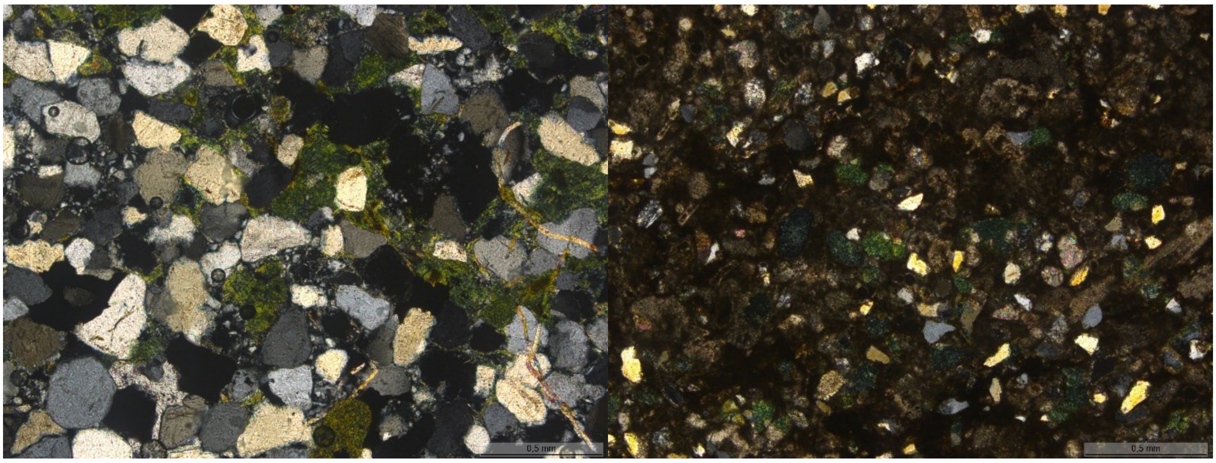
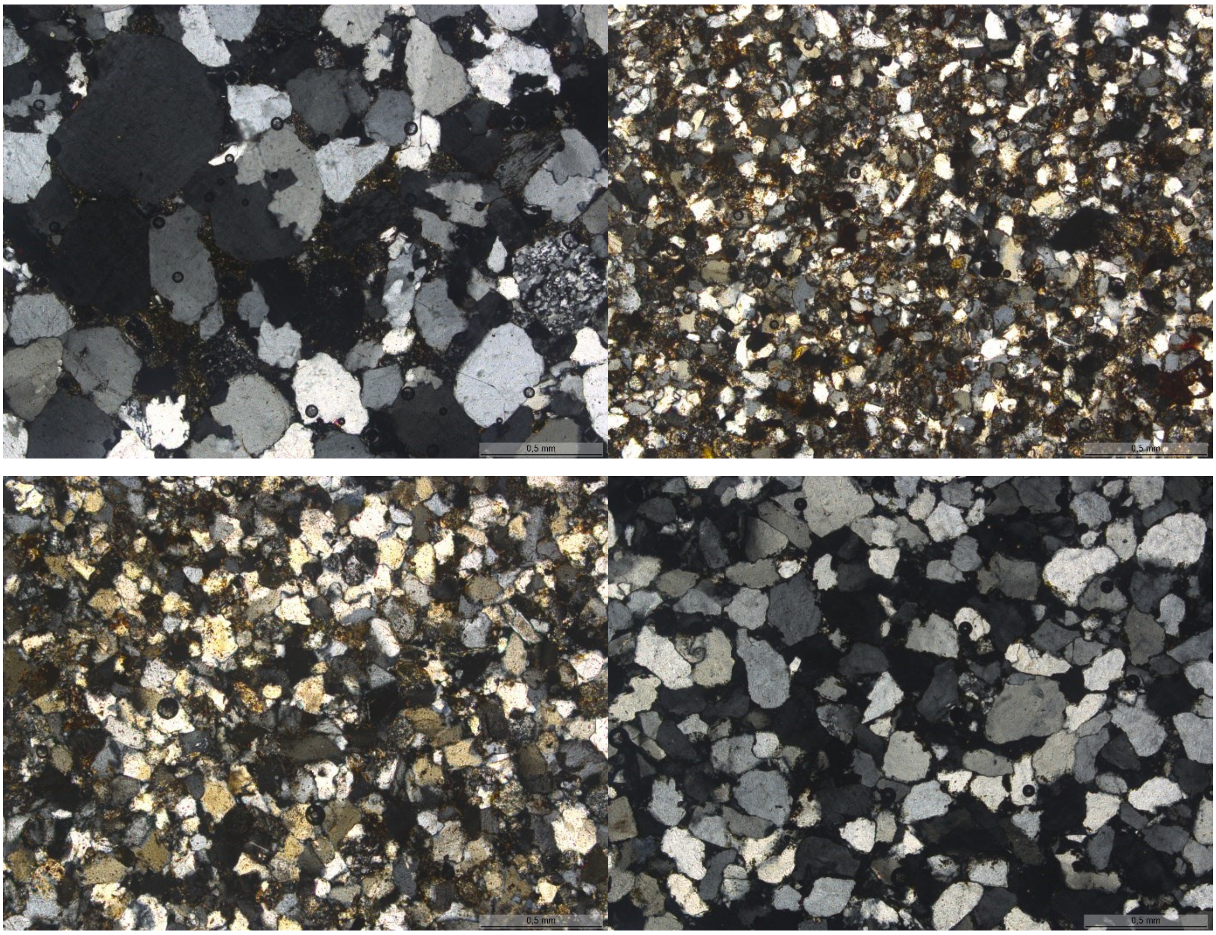


Figure 18. Images of petrographic thin sections of green sandstone

Red and brown sandstones.

Quartz is represented by grains of various sizes, often forming aggregates, but there are also individual grains, its content is on average about 70-80% of the total volume, also present in the composition are fragments of rocks, feldspars, and mica (muscovite, biotite). Feldspars occur in an amount of 10-25 % and are represented by acidic plagioclases and potassium feldspars. Plagioclase is represented by grains of various shapes: there are both large elongated lamellar grains with noticeable cleavage and small grains. Crystals have light colors (white, gray).

Clastic rocks are represented by angular, less frequently rounded grains of microquartzite and comprise the clastic part of sandstones in an amount of 5-10 vol.%. Quartz and feldspars are irregularly distributed throughout the rock, and mica often forms clusters. Rutile, ilmenite, apatite, zircon, and tourmaline were noted as minor minerals in the samples (Fig. 19).



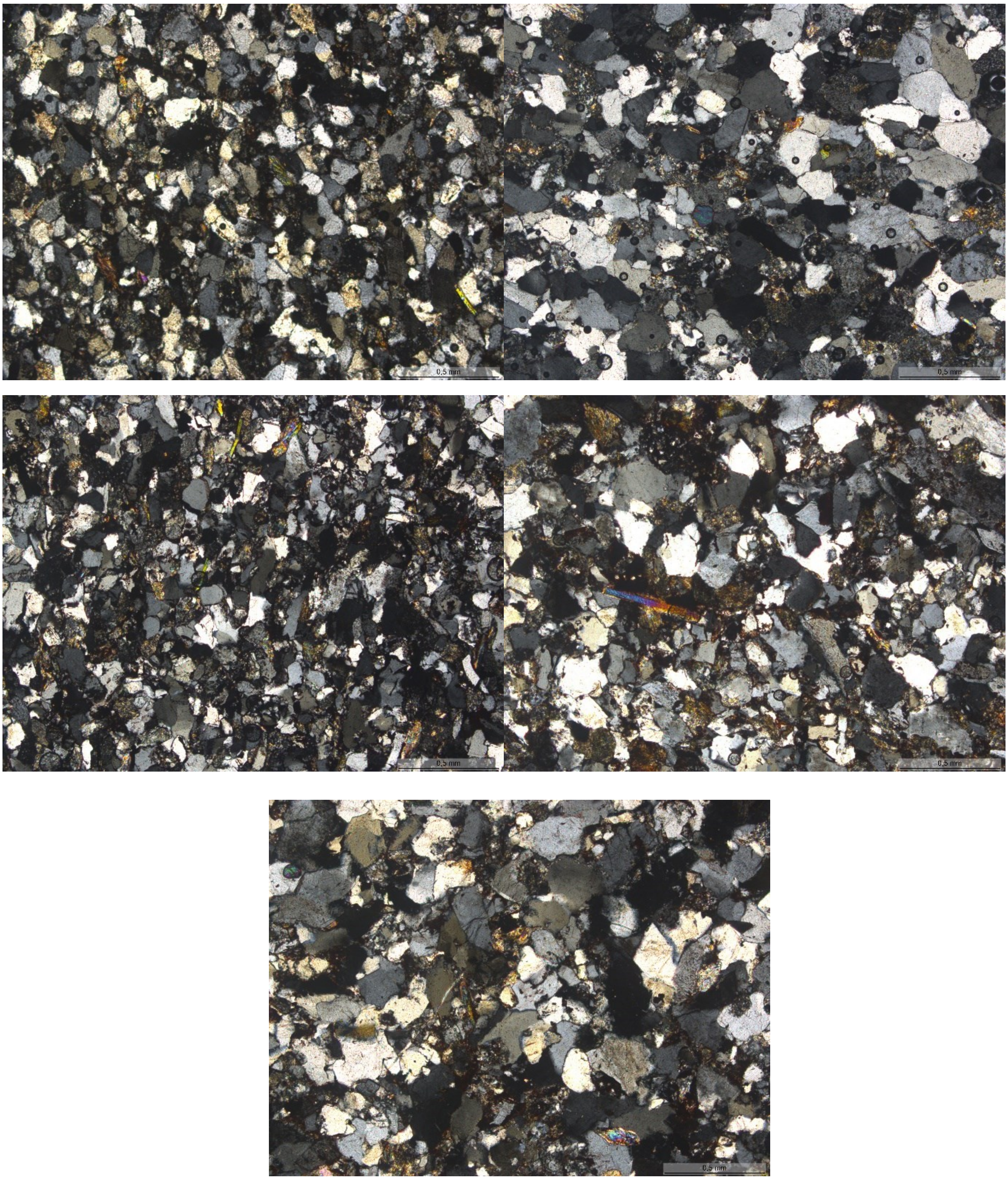


Figure 19. Images of petrographic thin sections of red sandstone

For a more representable result of the petrographic analysis of sandstones, the data of the thin sections were presented on the classification diagram for sand and siltstone rocks by W. Schvanov.

This diagram is a tool used to classify sandstones and other sedimentary rocks. It allows you to visualize the relative content of quartz, feldspars, and rock debris and helps to display rocks on a graph, where each angle corresponds to a particular mineral and the distance to the center of the diagram reflects the relative content of each of the minerals in the rock. The ordinate axis represents the relative content of quartz and the abscissa axis represents the relative content of feldspars and rock fragments.

Quartz typically makes up the bulk of the mineral composition of sandstones, which is reflected in the location of the samples at the top of the diagram. The diagram may also highlight areas corresponding to certain types of sandstones, such as oligomictic and mesomictic sandstones, which contain significant amounts of minerals other than quartz, such as feldspars and clays.

The dots representing individual samples are arranged on the diagram according to their mineral composition. The color of the points corresponds to the color of the sandstone samples (Fig. 20).

Thus, V. Shvanov's diagram makes it possible to quickly determine the mineral composition of sand and siltstone rocks and quantify the relative content of the main minerals in them. This helps in their classification and further geological analysis.

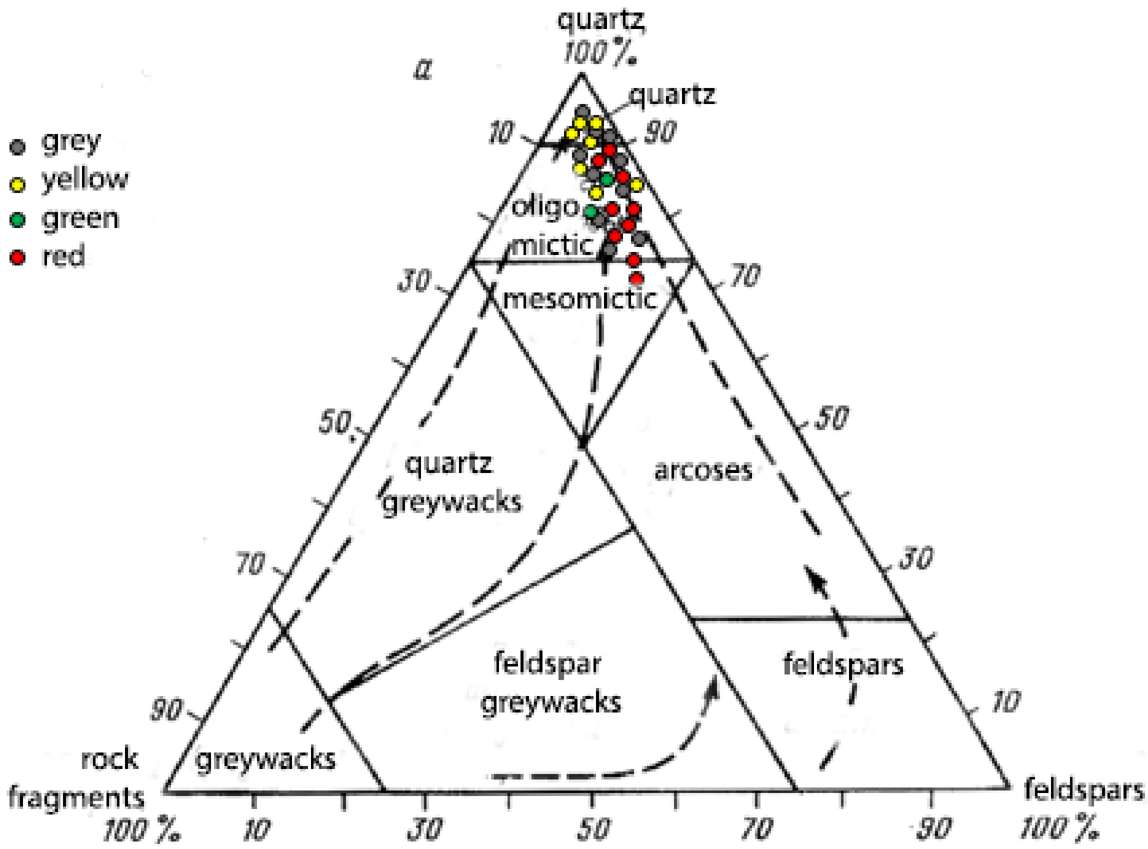


Figure 20. Classification diagram (triangle) for sandy siltstone rocks (according to V. Shvanov, 1987) with the marked samples.

All samples are within three categories: quartz, oligomictic, and mesomictic sandstones. Most of the samples belong to oligomictic sandstones, which contain 75 to 90% quartz grains.

Almost all of the studied samples of gray sandstones belong to the petrographic type of quartz and oligomictic sandstones. The exception is gray sandstone № 26 (German Eichenbuchl deposit), which can be classified as mesomictic quartz-feldspar sandstone.

The yellow sandstones are classified as quartz and oligomitic sandstones in terms of the mineral composition of the clastic component.

Both green sandstones can be classified as glauconite quartz sandstones.

The red sandstone samples studied refer to oligomictic and mesomictic sandstones according to the triangular classification diagram of quartz - feldspars - rock fragments.

Sandstone cement is the material that fills the space between rock grains. The study of the cement of sandstones is important for understanding their formation and properties.

Optical microscopy and X-ray diffractometry are commonly used to study sandstone cements. In optical microscopy, the cement is stained with special dyes to distinguish it from the rock grains. X-ray diffractometry examines the crystal structures of the minerals that make up the cement.

The main components of sandstone cement are quartz, feldspars, clays, carbonates and iron oxides. The study of the cement of sandstones allows us to establish the type and conditions of their formation, determine the age of the rock and identify its geological features. Depending on the conditions of rock formation, the content and composition of the cement may vary significantly. For example, in marine sandstones, glauconite, which gives the rock a greenish hue, often serves as the cement.

Clay cements can be formed by the simultaneous deposition of fine fractions together with sandy material, or by the infiltration of pelitic fractions into a framework of newly deposited sand or into the porous sandy rock by groundwater. In the initial composition of clay cements, the parent rocks and conditions of deposition play a determining role.

Carbonate cements are also widespread, but on a smaller scale than clay cements. They are the opposite of clay cements in the sedimentation zone, as the development of one or the other type characterizes the degree to which sandy sediments are washed away from clay fractions. Carbonate and siliceous cements are opposite to each other at all stages of sedimentation, because directional changes in the factors contributing to carbonate precipitation (T, p, pH and a number of others) simultaneously create conditions for the dissolution of silica. The joint occurrence of carbonate and siliceous cement in the rock implies that they are formed at different times.

Siliceous cement. Silica in the cement can be represented by opal, lussatite, chalcedony, and quartz. The prevalence of cementation by opal, lussatite, and chalcedony is much less than cementation by quartz, because amorphous silica difference is typical only for sediments of young age and transitions to quartz with time. Quartz can be authigenic and represented as crystals dispersed in cement of a different composition, most often clayey, or as regenerative rims that complete the clastic quartz grains.

Oxide-iron cement may be contained in clay cement in the form of iron oxides, oxide hydrates, or flakes located between or enveloping the grains. The shrouds formed can be observed under a microscope in transmitted or reflected light. The color of rocks and strata may be red, which is associated with the presence of iron-oxide cements.

The following conclusions can be drawn from the analysis:

According to the mineral composition of the cement of gray sandstones and its relationship with clastic grains, two groups of sandstones were distinguished:

Sample № 26 belongs to the first group and is represented mainly by a continuous uniform pore cement with the presence of contact cement only in some areas. This cement consists of clay and mica minerals or a mixture thereof in microcrystalline form, which fill the pore space. In addition, siliceous cement was found in some areas of contact of quartz grains.

All other examined samples of gray sandstones were assigned to the second group. Their cement is mainly represented by contact cement, with siliceous cement in some areas, and only occasionally and in some areas was clayey cement found, which consists of clayey and mica minerals or a mixture of them.

Cement in the yellow sandstone samples is predominantly represented by contact cement, the presence of siliceous cement is possible in some sections, and clayey cement is noted rarely and only in some fragmentary sections. Clayey cement consists of clayey or mica minerals or a mixture of these.

Green: The cement in sandstone samples of this color variety is mostly represented by a continuous uniform pore material, and only in some areas is there a contact cement. In thin sections of the samples, the clayey cement, consisting of clayey or mica minerals or a mixture thereof in microcrystalline form filling the pore space, is clearly distinguishable. Siliceous cements may be found in some areas of direct contact between quartz grains.

Cement in red sandstone samples is predominantly represented mainly by continuous and uniform pore cements, but contact cements are present in places. Two main types of mineral cements can be distinguished according to their composition: clayey and iron-oxide. Clay cement is represented by clay or mica minerals in microcrystalline form filling the pore space. The oxide-iron cement is probably represented by iron oxides and hydroxides, which fill the pore space in the mixture with the clay cement and the space at the grain contact. In addition, siliceous cement may be present in some areas of direct contact between quartz grains.

Microprobe analysis is a method of material analysis based on the measurement of the elemental composition of microscopic samples using a microprobe.

A microprobe is an analytical tool that allows the elemental composition of a sample to be analyzed by bombarding it with an electron or ion beam. Measurement results can then be used to identify minerals and other components of the sample, as well as to study its structure and properties.

Microprobe analysis is a highly accurate and sensitive method of analysis which provides information on the composition of a sample at the micrometer level. It has a wide range of applications and can be used for various scientific and engineering tasks.

The microprobe method is widely used in geological, materials science and other scientific and engineering fields to analyze various samples including minerals, ores, glass, metals and semiconductors. It can also be useful for studying processes occurring at the micro- and nano-levels, such as crystallization, corrosion, oxidation, etc.

As a result, chemical spectra of the minerals that make up the sandstones have been obtained. The accessory minerals in gray sandstones are zircon, rutile, siderite, hematite; yellow sandstones are siderite; green sandstones are titanite, viterite, fayalite, strontianite, celestine, calcite; red sandstones are hematite, ilmenite, phosphorite, zircon, vavellite, rutile (Table 4). Examples of images of the analysis by this method are shown in Fig. 21.

Table 4. Content of accessory minerals in sandstones

The accessory minerals of sandstones:
Gray - zircon, rutile, siderite, hematite
Yellow - none
Green - titanite, strontianite, celestine, viterite, calcite
Red - ilmenite, phosphorite, zircon, rutile

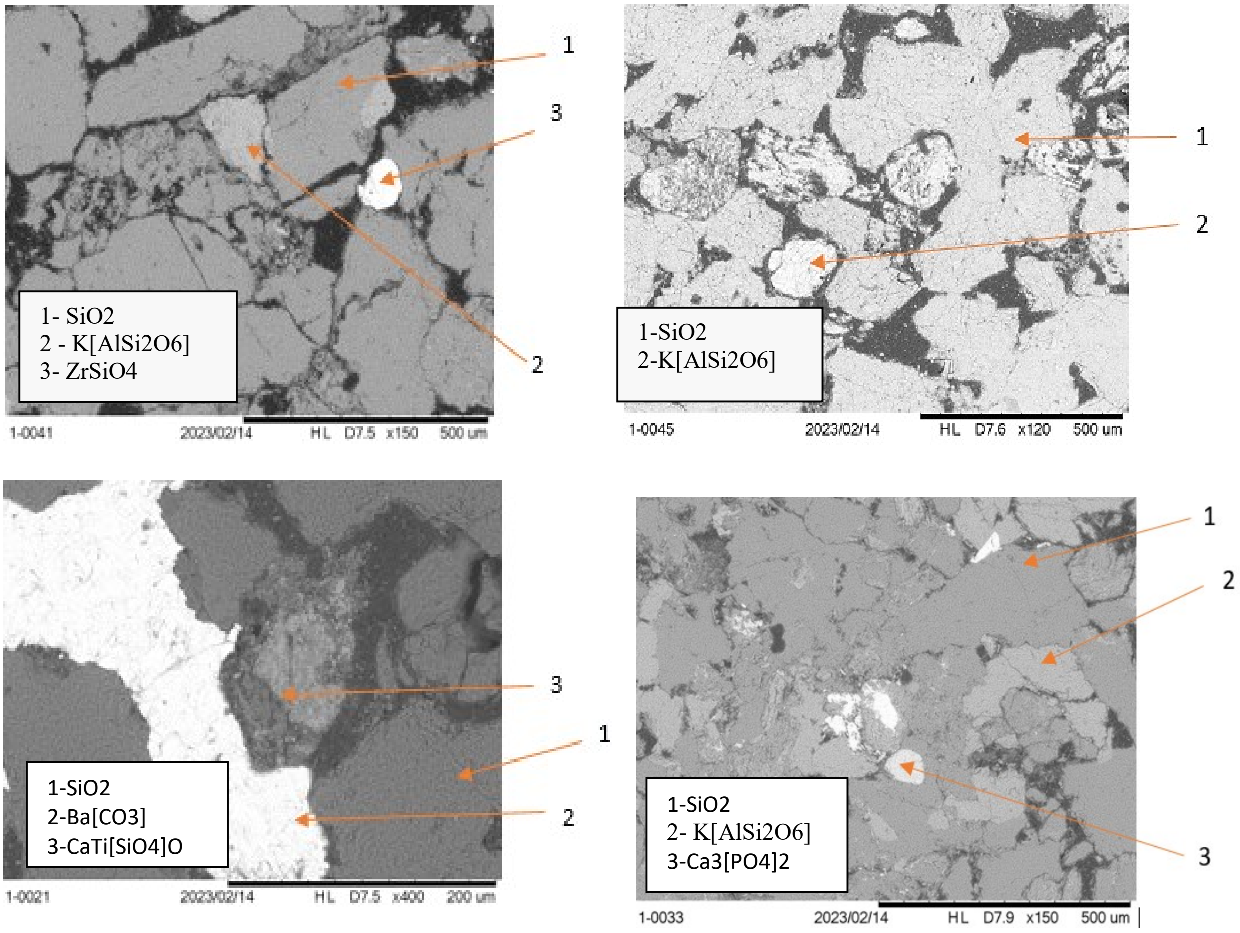


Figure 21: Microprobe results for gray, yellow, green, and red sandstones.

From the data presented, we can conclude that the use of microprobe in the analysis of minerals and rocks is an effective method for obtaining accurate information about the chemical composition and structure of the material. Microprobe allows you to determine the concentration of various elements in very small volumes of material, which makes this method particularly useful for the study of microscopic samples.

4.2 Petrogenic oxides

The X-ray fluorescence analysis method (XRF, XRF, XRF) is used to determine concentrations of elements from Be (№4) to U (№92) in various materials and substances ranging from ppm to 100%. The method is versatile, accurate and fast, and because of its ease of use, it has found wide application in both industry and science. X-ray fluorescence analysis is based on the dependence of X-ray intensity on the concentration of an element in a sample (Techade: [website]).

To perform X-ray analysis, the atoms of the sample must first be irradiated with high-energy photons, using the primary X-ray radiation originating from a radionuclide source or X-ray tube. When the atoms are energized, they go into an excited state, where the electrons move to higher energy levels. After a short period of time, usually a fraction of a second, the atoms return to the ground state. During the return process, the outer shell electrons fill the vacancies and the excess energy is emitted as a secondary photon or transferred to another electron from the outer shells. The energy of the secondary photon lies in the X-ray range, which lies between ultraviolet and gamma radiation in the spectrum of electromagnetic vibrations (Techade: [website]).

Irradiation of the sample with high-energy X-rays from the tube produces fluorescence emission of atoms, which has a characteristic spectrum that depends on the concentration of elements in the sample.

XRF analysis can provide accurate data on the composition of samples and determine the presence and amount of various impurity elements. This information can be useful for understanding the chemical composition of sandstone and its properties as well as for assessing its suitability for use in various industries.

For example, if sandstone contains high concentrations of heavy metals such as lead or cadmium, this may indicate that it is unsuitable for use in construction or other industries involving contact with human health. Fluorescence analysis can also be used to determine the origin of sandstone, which can be useful in the restoration and preservation of historic buildings constructed from this material.

The X-ray fluorescence analysis resulted in percentage values of the elements. Further, for representativeness, the data were converted into a table of petrogenic oxides (Table 5).

Petrogenic oxides are compounds of metals with oxygen and can be found in various rocks, such as granites, basalts, diabases, gabres, as well as in metamorphic and sedimentary rocks.

They constitute a significant portion of the minerals that make up rocks and can be various chemical compounds such as iron oxides (FeO, $Fe2O3$), aluminum oxides ($Al2O3$), titanium oxides (TiO2), silicon oxides (SiO2) and many others. Petrogenic oxides are an important source of many chemical elements, such as iron, copper, aluminum, etc.

Petrogenic oxides are widely used in various industries and are also important for science and geology. Their composition and structure can provide information about the formation processes and age of rocks.

The interaction of oxides with water, oxygen and other chemicals in the environment can lead to changes in rock structure and properties, which in turn can cause rock degradation. For example, iron oxides can oxidize and dissolve in water to form rust and acid solutions that can penetrate pores and fractures in the rock, destroying its structure.

Table 5. Content of petrogenic oxides, %

№	**SiO2**	**Al2O3**	**P2O5**	**K2O**	**CaO**	**TiO2**	**MgO**	**MnO**	**Fe2O3**	**CL**	**total**
grey											
1	85,83	10,34	0,46	0,46	0,36	0,11	0,41	0,02	0,74	1,28	**100,00**
2	88,22	8,25	0,65	0,35	0,19	0,12	0,68	0,03	0,61	0,90	**100,00**
3	96,42	1,08	0,49	0,15	0,00	0,18	0,76	0,04	0,05	0,83	**100,00**
10	96,15	1,77	0,33	0,61	0,00	0,11	0,58	0,03	0,04	0,37	**100,00**
13	92,65	2,55	0,32	0,59	0,83	0,12	0,70	0,02	1,51	0,73	**100,02**
14	92,99	1,83	0,31	0,88	0,74	0,08	0,50	0,04	1,90	0,73	**100,00**
15	98,16	1,37	0,42	<0,03	<0,01	<0,01	<0,05	<0,01	0,04	0,00	**100,00**
16	97,62	1,60	0,37	<0,03	0,31	<0,01	<0,05	<0,01	0,10	0,24	**100,24**
25	97,68	1,62	0,44	<0,03	<0,01	0,09	<0,05	<0,01	0,17	0,00	**100,00**
26	90,85	7,32	0,45	<0,03	0,07	0,17	<0,05	0,02	1,12	0,00	**100,00**

№	**SiO2**	**Al2O3**	**P2O5**	**K2O**	**CaO**	**TiO2**	**MgO**	**MnO**	**FeO**	**CL**	**total**
yellow											
5	95,84	2,39	0,47	0,33	<0,01	0,04	0,32	0,01	0,10	0,49	**100,00**
6	96,20	2,05	0,41	0,32	<0,01	0,05	0,21	0,03	0,15	0,57	**100,00**
9	97,23	1,23	0,35	0,23	<0,01	0,20	0,42	0,06	0,05	0,23	**100,00**
17	93,70	2,78	0,46	0,17	0,15	0,16	0,66	0,03	0,86	1,04	**100,00**
19	90,52	5,87	0,40	0,53	<0,01	0,10	0,20	0,03	1,40	0,95	**100,00**
20	89,29	3,56	0,28	0,29	1,65	0,20	0,63	0,04	3,20	0,85	**100,00**
23	90,11	7,07	0,46	0,31	0,33	0,13	0,22	0,03	0,88	0,46	**100,00**

№	**SiO2**	**Al2O3**	**P2O5**	**K2O**	**CaO**	**TiO2**	**MgO**	**MnO**	**FeO**	**CL**	**total**
green											
11	90,76	4,05	0,69	<0,03	0,60	0,62	<0,05	0,05	3,23	0,19	100,19
12	87,18	2,49	2,08	0,57	0,83	0,11	0,49	0,06	5,60	0,59	100,00

№	SiO2	Al2O3	P2O5	K2O	CaO	TiO2	MgO	MnO	Fe2O3	CL	total
red											
4	97,16	1,93	0,51	<0,03	<0,01	<0,01	0,10	<0,01	0,30	0,00	**100,00**
7	86,86	9,08	0,60	0,16	0,21	0,30	0,23	0,12	2,32	0,13	**100,00**
8	91,42	5,78	0,49	0,30	0,09	0,17	0,39	0,05	1,07	0,25	**100,00**
18	92,84	2,99	0,59	0,45	0,06	0,18	0,26	0,05	1,68	0,90	**100,00**
21	90,18	6,04	0,67	<0,03	0,20	0,47	<0,05	0,02	2,42	0,00	**100,00**
22	92,63	5,47	0,53	<0,03	0,25	0,20	0,00	<0,01	0,92	0,00	**100,00**
24	88,99	6,79	0,53	<0,03	0,20	0,38	<0,05	<0,01	3,10	0,00	**100,00**
27	88,49	7,45	0,50	0,33	0,18	0,30	0,37	0,01	1,76	0,60	**100,00**
28	91,77	5,74	0,45	<0,03	0,30	0,32	<0,05	<0,01	1,42	0,00	**100,00**

Based on the results of the analysis of petrogenic oxides, we can conclude that silicon (SiO2) and aluminum (Al2O3) oxides predominate in the composition of sandstones, iron content is superior in green sandstones. These oxides account for more than 95% of the total mass of sandstones. In addition, smaller amounts of calcium (CaO), magnesium (MgO), potassium (K2O), and phosphorus (P2O5) oxides are present.

The content of silicon oxides indicates that the sandstones are siliceous rocks, which is characteristic of this type of rock.

The content of iron and calcium oxides (CaO) varies depending on the color of the sandstones. The aluminum and iron oxides content is related to the presence of minerals such as glauconite and hematite. In green samples, the content is much higher due to the presence of glauconite, which forms glauconite phenocrysts that determine the characteristic greenish color.

The presence of calcium, magnesium, potassium, and phosphorus oxides indicates the presence of minerals such as calcite, leucite, and plagioclase. In addition, we can observe that the green sandstones have a higher TiO2 content than the gray, yellow, and red samples. This may indicate the presence of the minerals titanite and ilmenite, which are rich in TiO2.

Thus, analysis of the table of petrogenic oxides of sandstones allows us to conclude about the chemical composition of these rocks and the presence of various minerals present in them.

For clarity, a diagram of petrochemical modules was compiled based on the tables of petrogenic oxides.

Petrochemical modules are artificial constructs created on the basis of previously known facts. For example, it is known that SiO_2 and Na_2O are removed and Al_2O_3 accumulates during the weathering of substances, so the modules Al_2O_3/SiO_2 and Al_2O_3/Na_2O should grow as they weather and can be used to determine the "chemical maturity" of a deposit.

Two basic modules are mainly used: the hydrolysis module (HM) and the iron module (IR). Other modules such as aluminosilica (AM), femic (FM), titanium (TM), potassium (KM), sodium (NM), normalized alkalinity module (NAM), alkalinity module (ALM) and souring module (SM) are also used to further characterize sedimentites. Each module has its own range of values, which should be divided into three parts corresponding to "normal", "reduced" and "elevated".

To describe these sedimentites, only one petrochemical parameter, the hydrolysis module ($HM = (Al_2O_3+TiO_2+Fe_2O_3+FeO+ MnO) / SiO_2$), is needed to quantify two important hypergene processes - leaching and hydrolysis. These processes occur during infiltration of meteoric waters, which remove mobile components from rocks, including silica and hydrolysis elements that form hard-soluble hydroxides. High GM values indicate severe rock weathering and deep leaching, while low GM values indicate more mature sedimentary rock.

The aluminum-silica module ($AM = Al_2O_3/SiO_2$), which duplicates the GM, also indicates the maturity of the sediment. However, the presence of mica increases the AM value and the presence of feldspars decreases it, so lower AM values may indicate the presence of feldspars in the rock.

Maximum values of titanium modulus ($TM = TiO_2/Al_2O_3$) are associated with epochs when intense chemical weathering occurred in humid conditions, and TiO_2 content in clays in continental areas decreased continuously toward the open sea. In terrigenous rocks, TM should correlate with at least two parameters: with HM (inverse correlation in clastic lithogenic rocks) and with FM (less often with LM) - direct correlation in petrogenic and pyrogenic rocks.

The iron module ($IM = (Fe_2O_3+FeO+MnO)/(Al_2O_3+TiO_2)$) expresses the ratio between the ferrous and aluminous hydrolysis products. The FM value is of service value for hydrolysate rocks, setting genetically similar classes, but it is much more important for syallites, since highly ferruginous rocks of moderate hydrolysates are not typical of normal sedimentary rocks.

The femic module (FM = ((Fe2O3+FeO+MnO)/SiO2) + FeO + MnO + MgO) / SiO2) is useful for determining petro- and pyrogenic sedimentites.

Table 6: Gradation of rock lithotypes according to petrochemical modules (Yudovich. Y., 2000)

Class	GM	AM	TM	IM	FM
Hypo-	<0,05	<0,05	<0,02	<0,20	<0,03
Normo-	0,05-0,10	0,05-0,20	0,02-0,08	0,20-0,70	0,03-0,10
Super-	0,10-0,20	>0,20	0,08-0,12	0,70-1,00	0,10-0,15
Hyper-	>0,30	-	>0,10	>1,00	>0,15

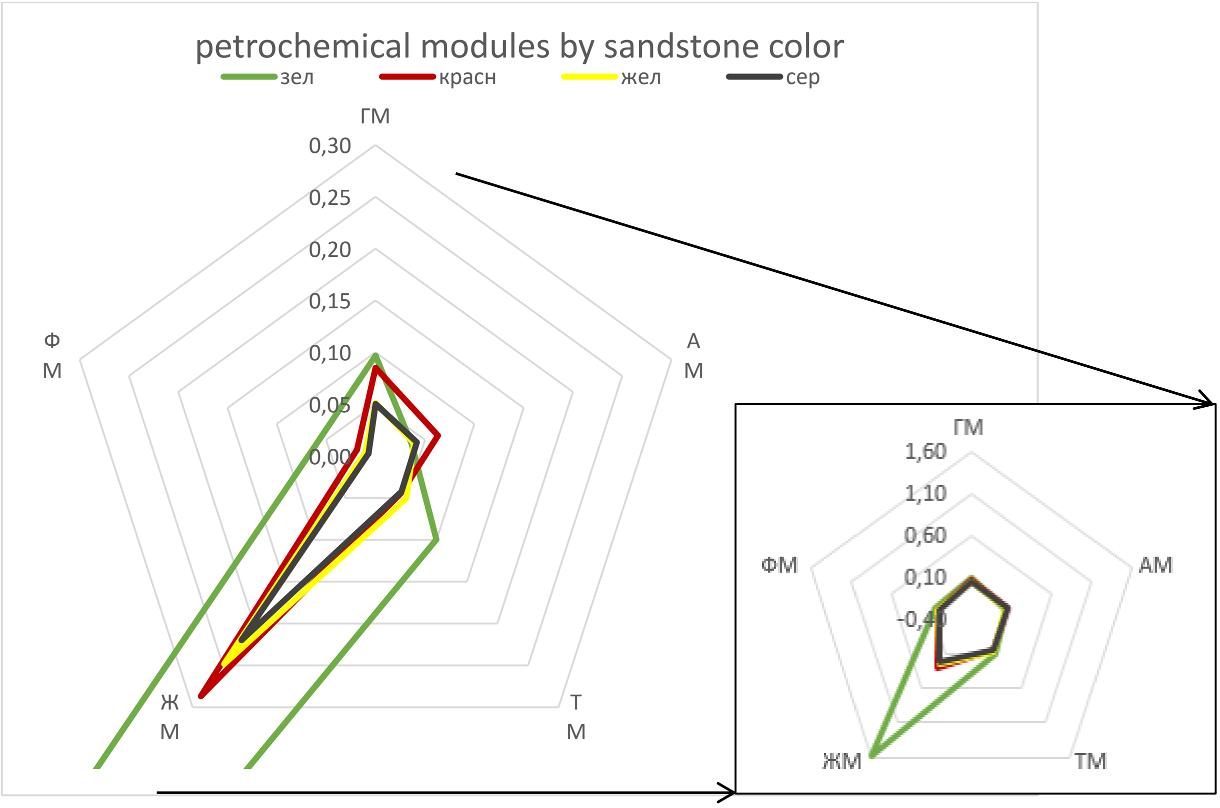


Figure 22. Petrochemical modules by sandstone colors

GM - hydrolysis module ((Al2O3+TiO2+Fe2O3+FeO+MnO)/SiO2);
AM - aluminosilicon module (Al2O3/SiO2);
TM - titanium module (TiO2/Al2O3);
FM - iron module ((Fe2O3+FeO+MnO)/(Al2O3+TiO2));
FM - femic module ((Fe2O3+FeO+MnO)/SiO2)

Concluding from the diagram, we can see a similarity in the moduli values of gray and yellow sandstones.

A strong difference in the value of IM in the green sandstones is characterized by the presence of glauconite. According to the value of this modulus, the gray, yellow, and red sandstones belong to the normosilites, and the green ones to the hypersilites. A high value of this module means that the rock is less resistant to weathering.

The hydrolysis modulus is responsible for the rock's resistance to external influences. The highest value has the green sandstone, but the value of HM for this species reduces its strength. Therefore, when choosing a material for construction, it is necessary to pay attention to the values of the petrochemical modulus. According to the value of this modulus, gray and yellow sandstones belong to hyposilites, and green and red sandstones to normosilites.

Based on all, the most stable are the gray and yellow sandstones, the red and green sandstones are considered less stable because of the high values of FM.

4.3 Elemental impurities

Impurity elements are minor components that are present in rocks, ores and minerals, replacing major components or represented by micro-extractions of independent minerals. If their content is low (less than 1%) or extremely low (<0.01%), these elements may be of industrial importance and economically extracted from the main ore minerals to improve their quality or obtain independent concentrates during beneficiation.

In addition, sandstones may contain impurities of metals that can change their color and texture. For example, iron can give sandstones a reddish hue and copper can give them a greenish hue.

Some of these elements can hinder mineral processing, interfere with equipment, or have a negative impact on the quality of the final product, making them a harmful by-product.

Therefore, research and analysis of these elements are important tasks in the field of mining and geology. One method of analyzing impurity elements in rocks and minerals is fluorescence analysis.

The analysis was performed using a portable X-ray fluorescence analyzer Omega Innov-x. The results of XRF analysis are presented in Table 7.

Table 7. Average content of impurity elements in sandstones, in %

element	Ba	Mn	Zr	Cr	V
grey, n=10	0,07	0,04	0,007	<0,0056	<0,0024
yellow, n=7	0,05	0,05	0,004	<0,0056	<0,0024
green, n=2	0,051	0,07	0,010	<0,0056	0,13
red, n=9	0,14	0,08	0,009	<0,0056	<0,0024

Based on the table obtained, we can conclude about the content of impurity elements in the average composition of sandstones, which allows us to better understand their chemical composition and origin. According to the table, in the gray, yellow, and green sandstones, the Ba content prevails, and in the green sandstones, the V content prevails.

Chapter 5. Weathering of sandstones in urban environments

The mechanical bonds between rock particles are destroyed by water, wind, and temperature variations. This causes rock-forming minerals such as feldspars, mica, pyroxenes, amphiboles, and others to become clay minerals that are washed out of the rock. Harmful gases and substances in the air and water also have negative chemical effects. Carbonic acid, formed when carbon dioxide dissolves in rainwater, causes acidic leaching. Oxygen causes oxidation and the transition of chemical elements to acidic forms. Wind erosion also has a biodegradative effect on stone when dust and seeds of lower plants (mosses and lichens) enter the pores and cracks of stone.

Also, the physical characteristics that have been studied in the previous chapters, such as porosity, fineness of grains, and chemical composition, affect the weathering and erosion of rocks. For example, the porosity of a rock can facilitate the penetration of water and other chemicals that can cause its degradation. Chapter 3.2 found that a higher percentage of tomographic porosity has a negative effect on stability.

Grain calcination can also determine the resistance of a rock to mechanical wear and fracture. For example, sand grains that are more rounded may be less vulnerable to chemical weathering failure than more angular grains. This is because angular grains may have sharp edges that may be subject to more weathering as a result of the surface area being under greater stress.

In addition, the shape and roundness of the grains can affect their density and porosity, which can also affect the rate and mechanisms of weathering. For example, denser and less porous grains may be more resistant to weathering than less dense and more porous grains.

The quartz-feldspar ratio is directly related to the weathering resistance of sandstone. Quartz is the most weathering-resistant mineral, and therefore sandstones with high quartz content are generally more resistant to weathering than those with lower quartz concentrations. All of the sandstones studied contain between 85 and 95% quartz grains on average (Fig. 20). At the same time, feldspars are less resistant to weathering, and therefore sandstones containing more feldspars are prone to weathering (Table 8).

Other minerals, such as calcite, can be very sensitive to acids and other chemicals that can cause them to degrade and dissolve; the inclusion of pyrite can lead to oxidation of the rock and degrade its mechanical properties; the presence of clay inclusions can reduce the strength of the rock.

However, if the sandstone grains are round and rounded, even sandstones with higher feldspar content may be more resistant to weathering than those with fewer feldspars but more angular grains.

The interaction of oxides with water, oxygen, and other chemicals in the environment can change the structure and properties of rocks, which in turn can cause them to erode. For example, iron oxides can oxidize and dissolve in water to form rust and acid solutions that can penetrate pores and cracks in the rock, destroying its structure.

Table 8. Resistance of minerals to weathering (Bulakh A., 2015)

very stable	stable	unstable	very unstable
Quartz (zircon, rutile, corundum, anatase)	Potassium feldspar, acidic plagioclases, muscovite (monazite, xenotime, cassiterite, fluorite, magnetite, ilmenite)	Medium plagioclases, pyroxenes, amphiboles (apatite, hematite, garnet)	Basic plagioclases, biotite, chlorite (pyrite, pyrrhotite)

The petrochemical moduli analyzed in Chapter 4.2 also establish a relationship with stability. A high value of the iron modulus means that the rock is less resistant to weathering. From the whole analysis, the most resistant are the gray and yellow sandstones, the red and green sandstones are considered less resistant because of the high iron modulus values.

The degradation of stone in urban environments is much faster than in natural conditions due to the complex influence of abiogenic (physical chemical effects), biogenic and anthropogenic factors, which are closely interrelated (Table 9).

Table 9. Rock weathering in urban environments (Bulakh A., 2015)

Abiogenic (physical and chemical) effects	Biogenic effects	Anthropogenic impact
- surface roughness - depressions and depressions - flaking - cracks - chipping and loss of fragments - chemical weathering	- biofilms - lichen encrustations - higher vegetation	- atmospheric mud deposits - cementation of stone defects - salt deposits - iron hydroxide deposits - deformations - vandalism - catastrophic failures

Studies show that before biocolonies begin to develop, the rock undergoes damage caused by abiotic factors that prepare the surface for subsequent biological colonization. This occurs through changes in surface structure and the appearance of cracks, caverns, and other inhomogeneities that can serve as sites for microbial accumulation and development.

Physical weathering is a process in which a rock breaks down without changing its composition. This type of weathering is mainly caused by various factors, such as changes in temperature, freezing/thawing of water, crystallization of salts, and wind exposure. Physical weathering can manifest itself as surface coarsening, formation of depressions and depressions, flaking, cracks, chipping and loss of fragments (Bulakh A., 2015).

In large cities, the role of abrasive dust is particularly important, which accelerates the process of destruction of rock. Dust, penetrating into cracks, is trapped in heterogeneous cracks, reacts with moisture and participates in chemical fracture reactions. Sandstones with a high percentage of porosity are more prone to pore invasion by microorganisms and dust.

The dust particles, settling on the already weathered surface of the stone, can change its chemical composition. The following chemical elements (average, g/t) are established in St. Petersburg dust: Zr - 515, Zn - 458, Sr - 388, V - 172, Cr - 151, Rb - 135, La - 82, Pb - 65, Ni - 45, Cu - 42, As - 13. For a number of chemical elements, their content in the dust exceeds their content in the lithosphere by 2-13 times. Geochemical spectrum of dust element concentrations clarks in general for St. Petersburg is as follows: As-Zn-Pb-Zr-La-V-Cr. The distribution of chemical elements is not the same for different areas of the city. Zn, P, Z are typical for the dust of the central regions, As is typical for the southern and northern regions (Bulakh A., 2015).

Figure 23: Examples of physical weathering from the facades of buildings in St. Petersburg

Chemical weathering, in turn, is a process of chemical transformation of minerals and rocks under the influence of various agents such as water, coal, sulfuric, nitric and organic acids, oxygen, hydrogen sulfide, methane, ammonia and others. Biochemical processes can also influence the process of chemical weathering (Bulakh A., 2015).

Figure 24. Examples of chemical weathering from the facades of buildings in St. Petersburg

Biogenic weathering occurs due to the impact of living organisms on rocks. Biofouling is the development of living organisms on a solid substrate, which often leads to the destruction of this substrate. This process is often referred to as "biological colonization". Biodegradation is a specific type of destruction of rocks and materials caused by living organisms or their products. Microorganisms such as bacteria, microscopic algae and fungi, lichens, spores and higher plants have a high destructive activity and, according to most researchers, are the main source of damage to stone structures (Bulakh A., 2015).

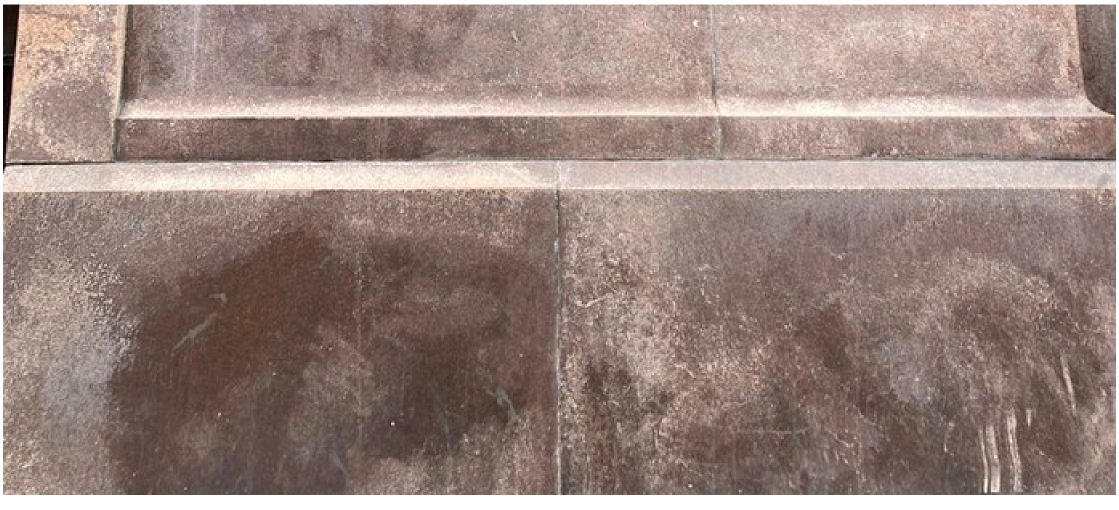


Figure 25. Example of biodegradation on a building facade

There are several types of anthropogenic weathering, including atmospheric mud deposits, cementation of stone defects, salt deposits from interlocking cement failure, deposits from oxidation of metal structures, stone deformations, and paint and graffiti inscriptions. Virtually all of these types of weathering result in accelerated mechanical and chemical failure of the stone. For example, siltation and surface formations create an environment that promotes the penetration of chemicals deep into the rock. Deformation of the slabs also accelerates the process of mechanical destruction. In addition, the application of various inscriptions and signs on the surface of the stone not only spoils its aesthetic integrity, but can also contribute to its more rapid destruction (Bulakh A., 2015).

Figure 26. Anthropogenic Impacts on Buildings

The climatic conditions of St. Petersburg are the main cause of weathering of sandstone from buildings, which poses a serious problem for the preservation of cultural heritage.

The weathering of sandstone is a serious problem for the city, as many buildings in the city were built from this material. The study of sandstone degradation and weathering processes in the ecological environment of St. Petersburg was carried out by means of an on-site inspection of architectural objects and laboratory analysis sampling.

Sandstone used in the construction of buildings in the city has high strength, durability and aesthetic qualities, but due to high humidity and severe frost, weathering occurs, which reduces its strength and aesthetic properties. Weathering of sandstone occurs due to the effects of frost, melting snow, wind, sand and other abrasive materials, which leads to the destruction of its structure and surface.

Most often used in the lining of facades of St. Petersburg German sandstone gray, yellow and red.

Gray sandstone is used in constructions where not only durability, but also aesthetic design is important. It has a soft shade, which allows you to create more exquisite decorative elements.

Sandstone yellow is also often used in the facing of facades of buildings in St. Petersburg. This stone has a brighter and richer color, which makes it an excellent choice for buildings that need to stand out against the background of the surrounding buildings.

Red sandstone has high density, strength and resistance to external factors such as humidity, frost and wind. It also has a beautiful reddish coloring, which gives buildings lined with this material a unique and attractive look. In addition, red sandstone is easy to work with and can be used to create a variety of decorative elements and architectural details.

Green Sandstone is the least used in the facing of residential buildings of St. Petersburg, not only because of its small halo mining, but also because of its strength characteristics. This makes it less suitable for use as a building material that must withstand considerable load and ensure the durability of the structure.

The following signs of weathering were identified during the field inspection of sandstone on St. Petersburg buildings: discoloration due to chemical weathering of minerals; contamination by atmospheric particles forming a dark-colored crust, which was analyzed by microprobe analysis; appearance of colonies of microorganisms such as fungi, algae, lichens and bacteria, which were also analyzed by microprobe analysis; presence of spalling caused by human impact; presence of surface capping and tem

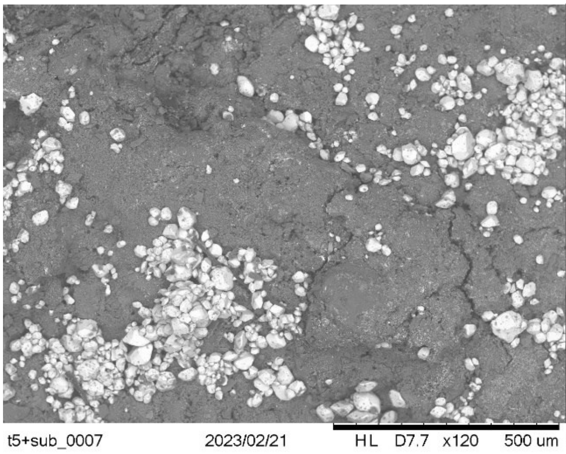
The development of cyanobacteria is associated with the appearance of dark films that can be observed in areas of constant increased moisture. Cyanobacteria secrete mucus, which protects them from drying out, and the intense development of cyanobacteria creates conditions for the development and accumulation of saprotrophic bacteria and diatom algae (Bulakh A.G., 2015).

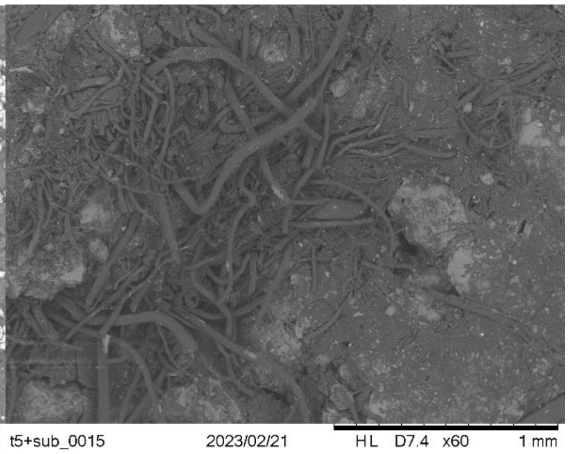
Samples of sandstones with dark crusts were selected for laboratory analysis as part of the study of the mineral composition of crusts. Microprobe analysis was used for the study, and samples were taken from the sites listed below.

PG4 - Admiralteyskaya Nab. 8

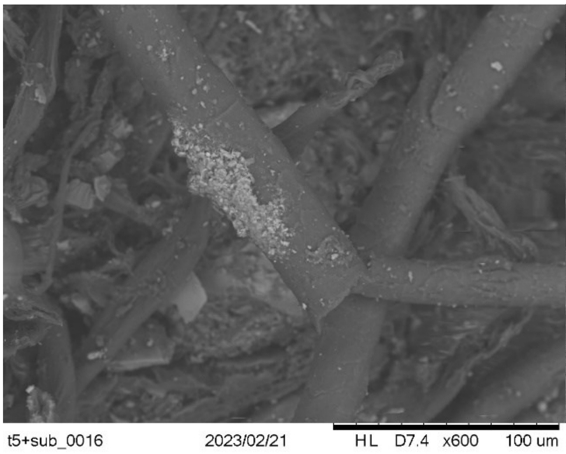
PG21 - Solyanoy per. 15

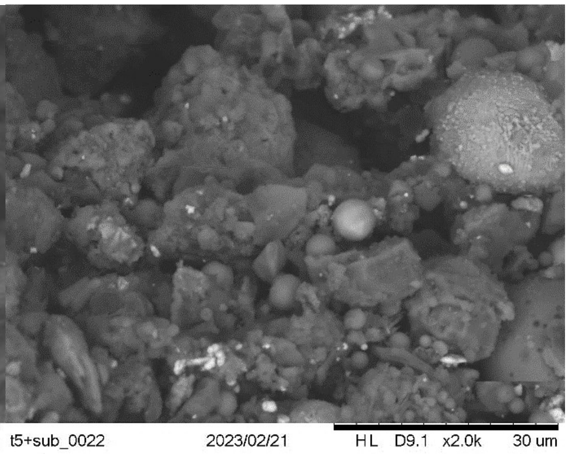
PG19 - Monument at Socialistheskaya ul.





PG4 PG21





PG21 PG19

Figure 27. Images of biofilms from the facades of buildings in St. Petersburg.

In the presented photos according to the results of microprobe analysis it is possible to observe hyphae of fungi, dust particles.

Modern architects, designers and stone companies are very interested in the problem of destruction of stone. They ask the following questions: how to assess long-term changes in the color and structure of stone, how durable stone is, how it can be used for construction purposes, how to assess damage to stone from temperature variations and air quality, what is the mechanical strength of stone, what type of stone is subject to biodegradation and how it depends on the type of stone, and how grouting material for joints affects the mechanical, chemical and biological destruction of stone (Bulakh A., 2015).

There are several methods and techniques for dealing with sandstone weathering on buildings in St. Petersburg. One of these methods is regular cleaning and preservation of the surface of sandstone to preserve its aesthetic qualities and protect it from further degradation. For conservation use special solutions and materials that strengthen the structure of the stone and protect it from negative influences.

Damaged areas of sandstone can also be repaired with various restoration techniques, but this requires care to preserve the historical value of the buildings.

Some experts suggest replacing sandstone with more sustainable materials such as granite or marble. An important step is to choose the right material when constructing and restoring buildings, taking into account their durability and resistance to climatic conditions.

Conclusion

A study of the mineralogical and geochemical features of sandstones from German deposits has provided valuable information on the composition and origin of these rocks.

A study in St. Petersburg identified 30 buildings whose facades were partially or completely lined with various sandstones from different parts of Germany. The samples taken from the collection belong to the Carboniferous, Triassic, Jurassic and Cretaceous ages.

1. 4 colors of sandstones were distinguished: gray, yellow, green, red. The gray, yellow, and red German sandstones are most commonly used in the architecture of St. Petersburg because of their strength characteristics and wide mining halo in Germany. Greens are mined only in two areas and do not have sufficient stability characteristics against external influences, so they can be found quite rarely.

2. In general, sandstones are similar in composition and structural-textural features. Depending on their color, sandstones are dominated by various impurity elements and petrogenic oxides that affect mechanical properties, including the rock's resistance to external influences. The greater volume of pore space determines the possibility of increased moisture and invasion of pores by biota, which leads the rock to rapid degradation. Thus, green sandstone with an average of 5.38% is considered the most resistant; gray sandstone with an average of 12.47% is considered the least resistant.

3. In terms of mineral composition, sandstones fall into three categories: quartz, oligomictic, and mesomictic. In the gray sandstones, siliceous and clayey cements were distinguished; in the yellow sandstones, siliceous cement is present; the color is determined by the presence of iron oxides. Grains of glauconite in the clay cement determine the color of green sandstones. Red sandstones contain clayey and iron oxide cements, the color being determined by the presence of iron oxides.

4. Data on petrogenic oxides allowed us to assign them to the following varieties according to the classification of J. Yudovich and M. Ketris: gray and yellow sandstones belong to hyposilites, green ones - to normo- and hypersilites, red ones are defined as normisilites.

The elements Ba, Mn, Zr, Cr, and V were identified among the impurity elements. The Ba content prevails in the gray, yellow, and green sandstones and the V content in the green ones.

As a result of the textural and structural studies, we can formulate the main criteria of stone stability in an urban environment.

5. The forms of mechanical (delamination, cracks, loss of fragments), chemical (secondary iron oxides-hydroxides), biological (biofilms, lichens and higher plants) and anthropogenic (cementation, graffiti) weathering are identified.

The analysis of the mechanisms of destruction of natural stone requires a comprehensive approach, involving the use of a wide arsenal of modern analytical methods and the application of professional skills of specialists in various fields.

In conclusion, the study of mineralogical and geochemical features of sandstones has an important practical value for geologists, architects, restorers and builders, as these rocks are widely used in construction. The results of the study of damage processes of sandstones in the urban environment can be the basis for a science-based system of measures aimed at protecting stone structures from destruction. And the study of sandstones from German deposits is an important step in the study of the geological structure of this country and provides new opportunities for the use of these rocks in various industries.

List of references

1. Betekhtin A. Course of mineralogy: textbook. - MOSCOW: KDU, 2007. - 721 p.
2. Broad overview of mining and exploration. - Report number: Infact deliverable D2.3, December 2018. - 72 p. URL: https://www.researchgate.net/publication/329656228_BROAD_OVERVIEW_REPUTATION_OF_MINING_AND_EXPLORATION#pf28 (accessed 20.04.2023) - Text: electronic.
3. Bulakh A. Evaluation of granite in monuments of architecture / Edited by Panova E., Vlasov D. - St. Petersburg: Nauka, 2015. - 190 p.
4. Bulakh A. Stone Ornamentation of Petersburg. - SPb.: Tsentrpoligraf, 2009. - 320 p.
5. Burley. S. Sandstone Diagenesis: The Evolution of Sand to Stone / Burley. S., Worden R. - Sandstone Diagenesis: Recent and Ancient, Chapter: 1, 2009. - 44 p. URL: https://www.researchgate.net/publication/230488606_Sandstone_Diagenesis_The_Evolution_of_Sand_to_Stone (accessed 04.04.2023). - Text: electronic.
6. Glaser R. Geologie und Landschaften Deutschlands / Glaser R., Frank N. - Primus in Wissenschaftliche Buchgesellschaf, 2007. - 280 p.
7. Henningsen D. Einführung in die Geologie Deutschlands / Henningsen D., Katzung G. - Spektrum Akademischer Verlag, 2006. - 244 p.
8. Krivoshchekov S. Experience of application of X-ray computer tomography to study the properties of rocks / S. Krivoshchekov, A. Kochnev - Perm: Vestnik PNIPU. Geology. Oil, gas and mining, № 6, 2013. - 11 p. - URL: https://cyberleninka.ru/article/n/opyt-primeneniya-rentgenovskoy-kompyuternoy-tomografii-dlya-izucheniya-svoystv-gornyh-porod (date of reference: 01.05.2023). - Text: electronic.
9. Linnemann U. Pre-Mesozoic Geology of Saxony-Thuringia: From the Cadomian Active Margin to the Variscan Orogen. - Schweizerbart Science Publishers, 2010. - 488 p.
10. Litt T. The Geology of Central Europe / Litt T., Schmincke, H.U., Frechen, M., Schlüchter, C. - Geol. Soc. London, 2008. - 701 p.
11. Logvinenko N. Petrography of sedimentary rocks (with the basics of research methods): Moscow: Vysshaya Shkola Publishing House, 1987. - 416 p.
12. Parmuzina L. Studying the textures of sedimentary rocks: textbook. - UGTU, Ukhta, 2013. - 86 p.

13. Platonov M. Petrography of clastic and carbonate rocks: tutorial. Platonov M.V., Tugarova M.A. - St. Petersburg: St. Petersburg University Press, 2017. - 80 p.

14. Ponomarev A. Experimental field studies of the deformability of argillite-like clays and sandstones / Ponomarev A., Sychkina E. - MSCU Bulletin. T. 13. Vol. 6, 2018. - 10 p. URL: https://cyberleninka.ru/article/n/eksperimentalnye-polevye-issledovaniya-deformiruemosti-argillitopodobnyh-glin-i-peschanikov (accessed 17.04.2023). - Text: electronic.

15. Rajaoalison. H. Determination of mechanical properties of sandstone by non-destructive method / Rajaoalison. H., Zlotkovsky A., Rambolamanana J. - Notes of the Mining Institute, 2020. 241 p. URL: https://cyberleninka.ru/article/n/opredelenie-mehanicheskih-svoystv-peschanika-nerazrushayuschim-metodom (date of reference: 24.03.2023). - Text: electronic.

16. Savchenok A. Mineralogical and lithological features of sandstone and its degradation processes in urban environment (by the example of Stieglitz Museum facade) / A. Savchenok, A. Bulakh, R. Kryza, A. Ehling. - Vestnik (Herald) of Saint-Petersburg University, Ser. 7, Vol. 1, 2009. - 13 p.

17. Savchenok A. Mineralogy of decorative-facing stone in the architectural objects of St. Petersburg, its composition, properties and behavior in the environmental conditions of the city: Ph.D. in Geology and Mineralogy. - SPb., 2009. - 238 p.

18. Shvanov V. Petrography of sandy rocks (component composition, systematics, and description of mineral species). - Leningrad "Nedra", 1987. - 270 p.

19. Thalheim K. Die geologische Literatur über Sachsen 2011-2015. - Schriften des Museums für Mineralogie und Geologie Dresden, 2021. - 503 p.

20. Tucker M. Sedimentary Petrology: An Introduction to the Origin of Sedimentary Rocks. - Wiley-Blackwell: 3rd edition, 2001. - 271 p.

21. Yudovich Y. Fundamentals of lithochemistry / Yudovich Y., Ketris M. - SPb: Nauka, 2000. - 479 p.

22. Zalischak B. Determination of rock-forming minerals in thin sections and immersion preparations / Zalischak B., Burilina L., Kiparenko R. - M. "Nedra", 1981. - 153 p.

23. Architectural idea [electronic resource] // History of architecture. - Architecture of Russia 1700 - 1750s - URL: https://architecturalidea.com/architecture-history/arkhitektura-rossii-1700-1750-kh-godov/ (access date: 30.04.2023) - Text: electronic.

24. Google [electronic resource]. URL:https://www.google.com/ (date of reference: 25.04.2023) - Image: electronic.

25. Technoanalytpribor- X-ray fluorescence spectrometry. URL: https://techade.ru/stati/rentgenofluorestsetnaya-spektrometriya (accessed 30.04.2023) - Text: electronic.
26. Virtuellen kartenforum [electronic resource]. URL: https://kartenforum.slub-dresden.de/?oid=oai:de:slub-dresden:vk:id-10006815 (accessed 16.04.2023) - Image: electronic.

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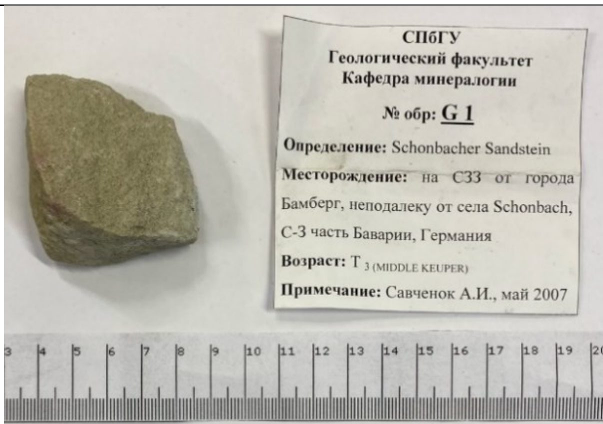
1	G1	T3	
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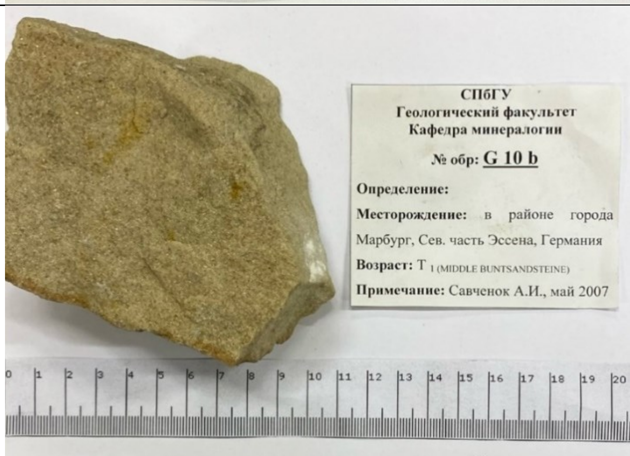
<tr><td>6</td><td>G10b</td><td>T1</td><td>
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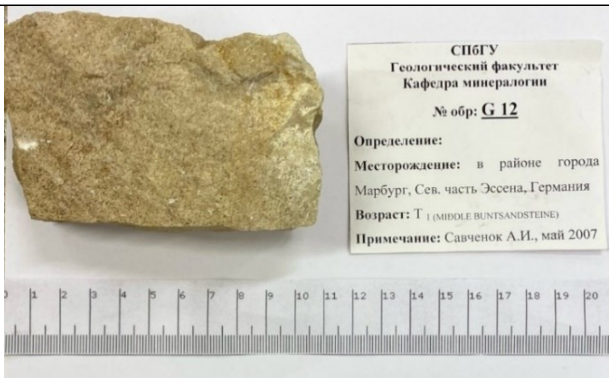
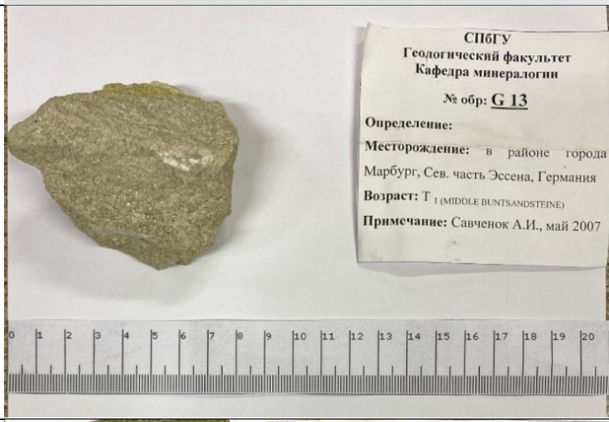
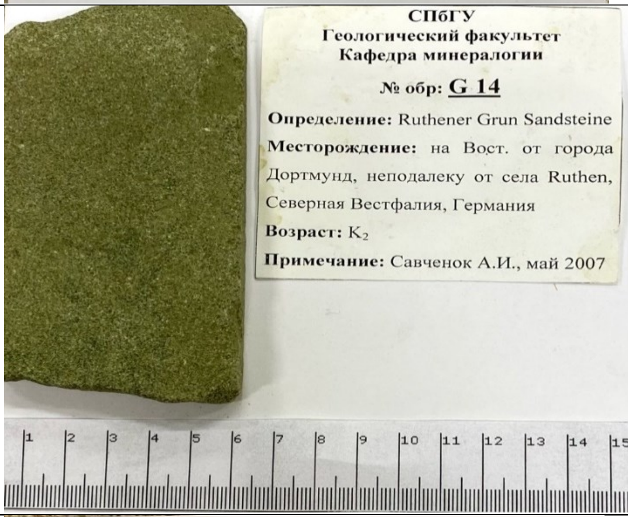
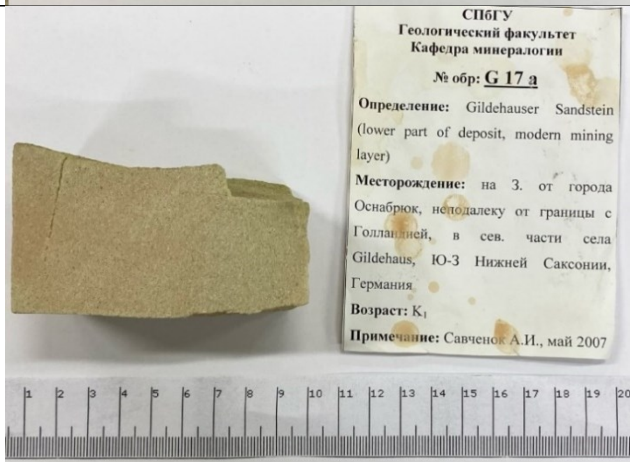
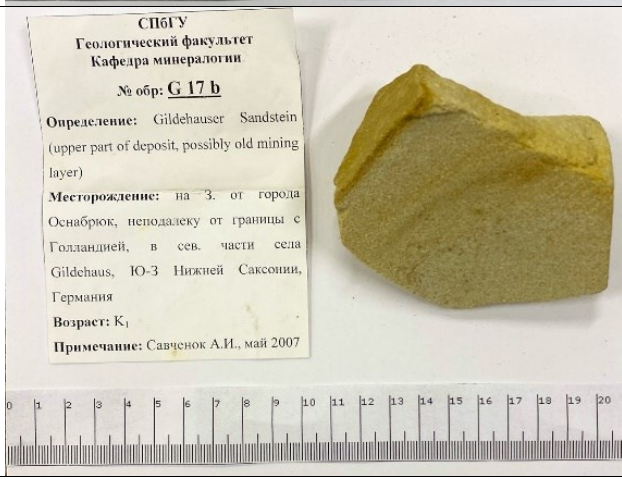
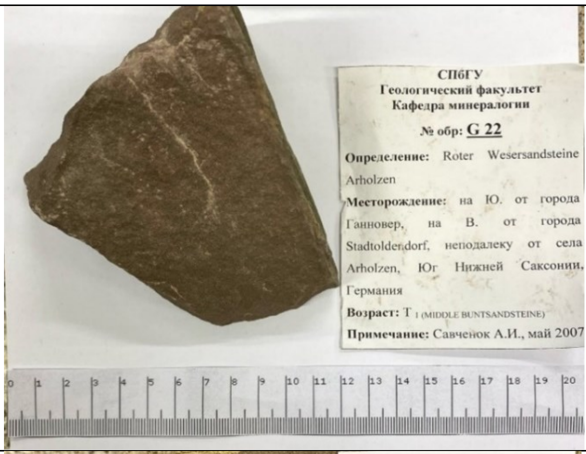
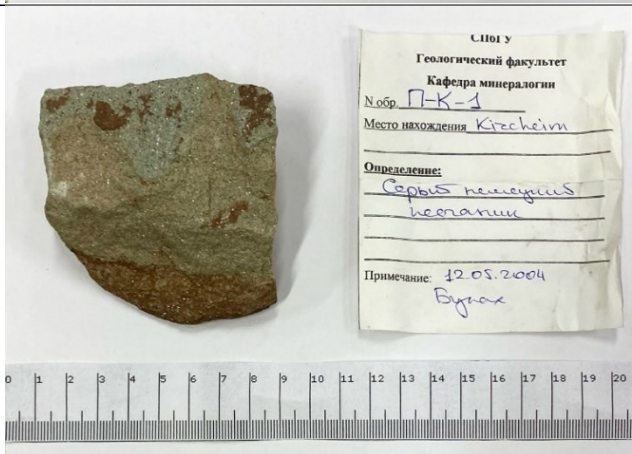
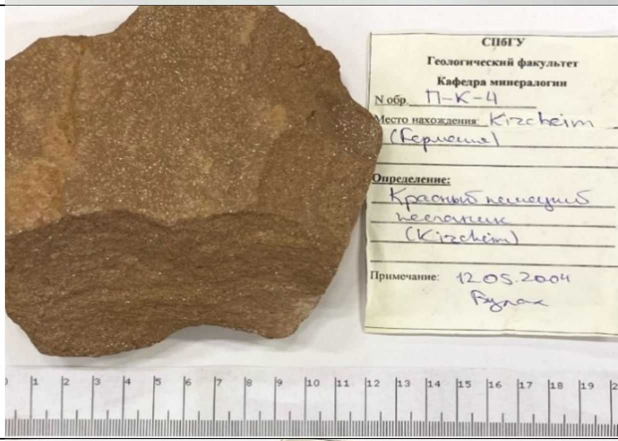
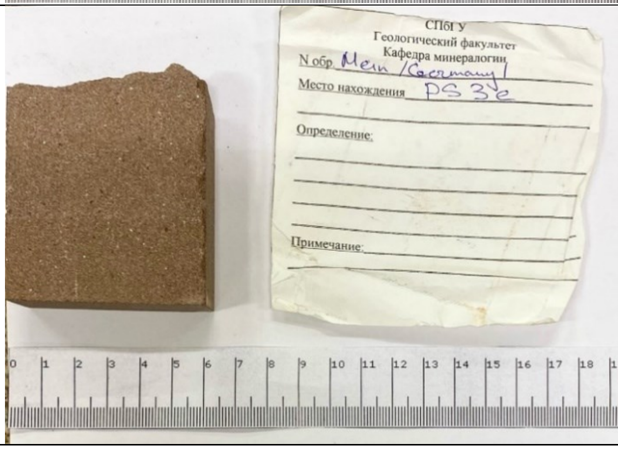
9	G12	T1	
10	G13	T1	
11	G14	К2	
12	G15	К2	

13	G16a	К2	
14	G16b	К2	
15	G17a	К1	
16	G17b	К1	

17	G18a	К2	
18	G18b	К2	
19	G19	С1	
20	G21	J1	

21	G22	T1	
22	G23a	T1	
23	G23b	T1	
24	G24	T1	

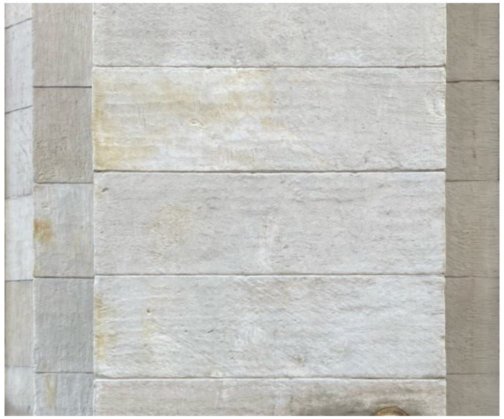
25	G25	T3	
26	ПК1	T1	
27	ПК4	T1	
28	Ps3e	T1	

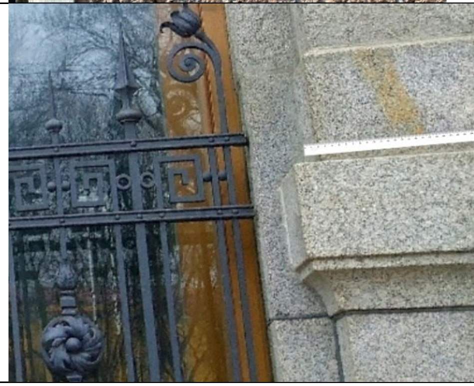
Annex 2. List of addresses of buildings clad in sandstone.

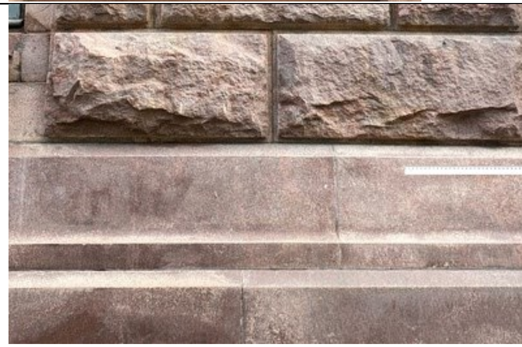
№	Address	Architects and years of construction	Purpose
1	Bolshaya Konyushennaya st., 21-23	E.F. Wirrich 1908 - 1909	Trading House of the Guards Economic Society
2	9 Bolshaya Konyushennaya st.	L.F. Fufaevsky 1899, 1902	V.A. Sleptsov's mansion
3	Dvortsovaya emb. 26 / Millionnaya st. 27	A.I. Rezanov 1867 - 1872	Grand Palace of Vladimir Aleksandrovich
4	Nevsky Prospect, 1 / Admiralteysky Prospekt, 4	V.P. Zeidler 1910 - 1911	Saint-Petersburg Private commercial bank
5	Gorokhovaya St., 4	M.M. Peretyatkovich, N.N. Verevkin 1908 - 1909.	Salamander Insurance Salamander Association
6	Bolshaya Morskaya St., 22	N.E. Efimov, K.V. Baldi 1844	Police Officer House (telephone station)
7	Bolshaya Morskaya st. 32	V.A. Schroeter 1887 - 1888	Building of the Russian Foreign Trade Bank
8	40 Bolshaya Morskaya st.	L.N. Benois 1899	House of the First Russian Insurance society
9	37 Bolshaya Morskaya st.	L.N. Benois, Z.Y. Levy 1898-1899	House of the Insurance Society "Russia"
10	47 Bolshaya Morskaya st.	M.F. Beisner, B.F. Gusisty 1901 - 1902	House of E.I. Nabokova. House where the writer was born and lived V. V. Nabokov (1899-1917)
11	48 Nevsky Prospect	S.S. Kozlov 1901 - 1902	Passage
12	62 Nevsky Prospect	B.I. Hirshovich, A.K. Spiegel 1896 - 1898	The building of the St. Petersburg Azov Commercial Bank
13	15 Solyana st.	M.E. Mesmaher 1885 - 1896	A.L. Stieglitz Museum
14	Tchaikovsky st., 28	V.I. Chene, V.I. Chagin. 1896 - 1897 changed facades	A.F. Kelch's mansion (I.M.Alexandrov)
15	34 Mokhovaya st.	Y.Y. Benois, A.I. Vladovsky. 1902 - 1907	N.V. Bezobrazova's mansion
16	42 Liteiny pr.	L.L. Bonstedt 1852 - 1858	Z.I. Yusupova Palace

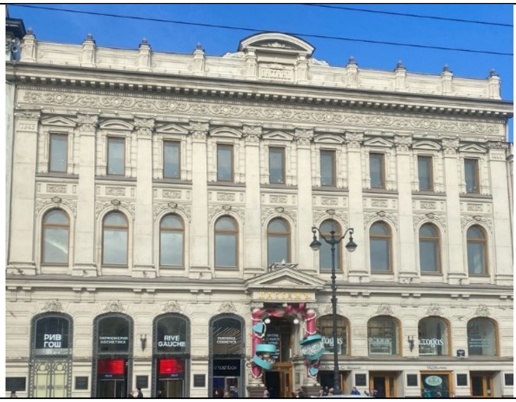
17	20 Stremyannaya St.	G.G. von Goli, G.D. Grimm 1899 - 1901	House of the Society for the Dissemination of Religious and Legal Enlightenment
18	Grafsky Lane, 10/11	I.Y. Moshinsky 1900	Apartment House House where lived F.M.Dostoevsky (1842 - 1846) and D. Grigorovich (1843 - 1845)
19	14 Socialistskaya st.	No information	The building of the printing house where the the first issue of Pravda newspaper was printed May 5, 1912
20	Pravdy st., 13	A.N. Pomerantsev 1898 - 1900	The building of the School Board of the Synod with the Church of St. Prince Alexander Nevsky and the school
21	7a Izmaylovsky pr.	V.P. Stasov 1828 - 1835	The Cathedral of the Holy Trinity of the Life Guard Izmailovsky Regiment
22	Stachek pr. 48	V.A. Kosyakov 1901-1906	Church of St. Nicholay and St. Martyr Alexandra
23	8 Angliyskiy pr.	V.J. Johansen 1901 - 1902	House of H.G. van der Pals
24	Poshtamtskaya st, 23/ Konnogvardeyskiy lane, 8	No information	No information
25	Birzhevaya Line, 1	J.J. Ketcher 1920s	Building of the Library of the Academy of Sciences
26	Birzhevaya Line, 4	S.S. Korvin-Kruschwein 1913-1915 rebuilt	The building of the candy factory; House where physicists lived D.S. Rozhdestvensky (1939-1940) and S. Vavilov (1941, 1945-1946)
27	Admiralteyskaya nab. 8	M.E. Mesmacher 1885 - 1891	Palace of the Mikhail Mikhailovich
28	Ostrovsky Square, 1-3	E.S. Vorotilov 1896 - 1901	Imperial Public Library
29	Fontanka Embankment, 78	R.P.Golenischev 1898 - 1900	State Bank savings bank
30	Kamennoostrovsky Prospect, 44b	S.S. Krichinsky 1913	Emir Bukhara House

Annex 3: Database of photographs of sandstone-clad facades of buildings in St. Petersburg

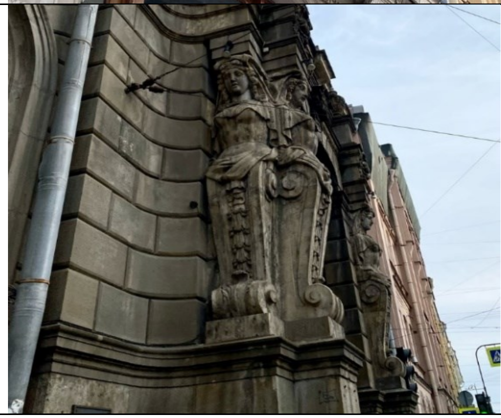
№	Address	General view	Details	Structure of the stone
1	Bolshaya Konyushennaya st., 21-23			
2	9 Bolshaya Konyushennaya st.			

3	Dvortsovaya emb. 26 / Millionnaya st. 27			
4	Nevsky Prospect, 1 / Admiralteysky Prospekt, 4			
5	Gorokhovaya St., 4			

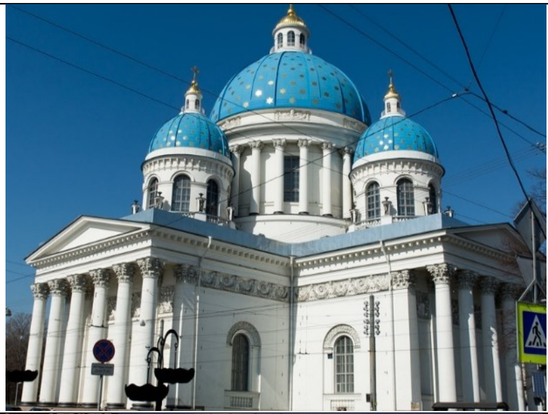
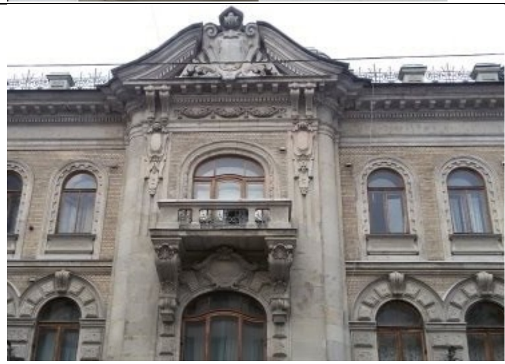
6	Bolshaya Morskaya St., 22			
7	Bolshaya Morskaya st. 32			
8	40 Bolshaya Morskaya st.			

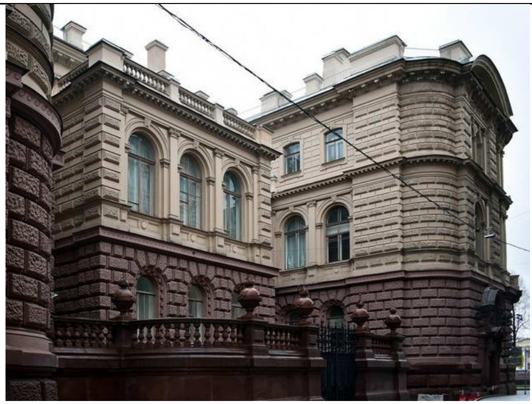
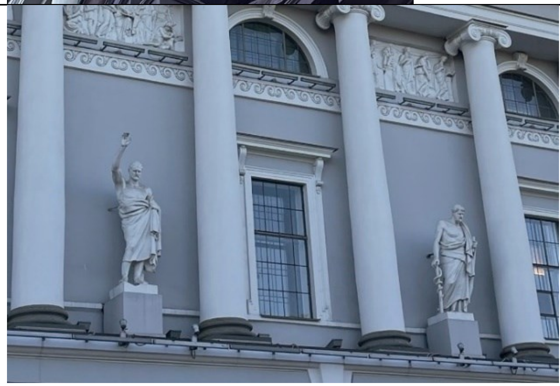
9	37 Bolshaya Morskaya st.			
10	47 Bolshaya Morskaya st.			
11	48 Nevsky Prospect			

12	62 Nevsky Prospect			
13	15 Solyana st.			
14	Tchaikovsky st., 28			

15	34 Mokhovaya st.			
16	42 Liteiny pr.			
17	20 Stremyannaya St.			

18	Grafsky Lane, 10/11			
19	14 Socialistskaya st.			
20	Pravdy st., 13			

21	7a Izmaylovsky pr.			
23	8 Angliyskiy pr.			
24	Poshtamtskaya st, 23/ Konnogvardeyskiy lane, 8			

25	Birzhevaya Line, 1			
27	Admiralteyskaya nab. 8			
28	Ostrovsky Square, 1-3			

29	Fontanka Embankment, 78			
30	Kamennoostrovsky Prospect, 44b