Creating of a geological GIS database of Eastern Kazakhstan using the Kalba-Narym Zone as an example

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Abstract: *GIS is an indispensable tool for modern geology, allowing efficient management of spatial data, complex analysis and support for important decisions in the geological industry. In the Republic of Kazakhstan, the need for unified collection, analysis and further creation of GIS database, as well as storage in electronic media or publication on the Internet, was expressed as early as the 90s of the last century. In Kazakhstan, one of the topical issues is the creation of a unified or regional (separate for each ore zone) database, which is reflected in the strategic documents for the development of the geological exploration industry of Kazakhstan. The existence of a national, public and relevant geological GIS database is an indicator of involvement and interest in the development of the geological sector of the economy. Today, many countries, mostly developed ones, have a developed GIS. At the same time, the detection and mapping of ore deposits based on remote sensing data using machine learning methods, including artificial intelligence, is of particular importance, which will be a breakthrough to improve prospecting based on remote sensing methods. The object of the study is the Kalba-Narym zone in Eastern Kazakhstan. The geological database of GIS of Kalba-Narym zone of East Kazakhstan is based on 1: 200 000 scale maps, remote sensing data, field survey materials. Data processing and analysis were performed in QGIS software. The key aspect is to bring heterogeneous data to a single coordinate system, which allows to integrate them into a single GIS and conduct complex spatial analysis. On the basis of the conducted research the data structure for creation of GIS of Kalba-Narym zone was developed, the main problematic issues in the development of geological GIS database were identified.*

Keywords: database, GIS, geology, remote sensing

Introduction

Geographic Information Systems (GIS) play an important role in geological investigations by enabling the creation, storage, processing, interpretation and visualization of spatial data obtained from various sources. This technology helps geologists analyze the configuration of the earth's surface, the presence of mineral resources, and other geological characteristics about a site. Geographic information systems integrate information from various sources, such as databases on terrain, climatic conditions, soil cover, groundwater conditions and water processes occurring on the surface, geodetic data on field measurements, space images, and present it on a single digital cartographic base (map). A complete study of the geologic structures of a region helps to identify important areas where minerals may be located. In addition, GIS is needed for geologic hazard classification and disaster risk assessment.

One of the key direction of GIS use in geology is the creation of geological databases. These databases provide collection, storage, processing and visualization of vector and raster maps and other geological data in spatial coordinates. Today, many government organizations, educational institutions, research centers, and private mining companies use GIS to work with geospatial data. Thus, depending on the target user of geological data, bases can be created for educational, analytical, administrative and management purposes. For successful development of mineral resource base of Kazakhstan it is necessary to improve and develop approaches to creation of GIS-base of geological data with updating of tools of replenishment and structuring of data, i.e. introduction of geoinformation support of geological exploration works on the basis of remote sensing data.

Literature Review

GIS databases working with geological and cartographic data can be hierarchically classified by the areas and scales covered. Traditionally, they are divided into global, continental, national and private regional (Naumova, 2004).

An example of a service that displays geologic information in a map format is Mineral Resources Online Spatial Data (U.S. Geological Survey, n.d.). This resource provides various geologic maps and information on mineral deposits worldwide through an interactive map. Geophysical and tectonic maps are also available. However, some researchers have noted possible errors in coordinate accuracy and data relevance outside of North America (Tkachev et al., 2015).

Another significant example of a global geological GIS platform is OneGeology (Laxton, 2017). This project develops an interactive geologic map that works worldwide. The platform optimizes data sharing from different geographic regions and provides access to geological data of interest to researchers and other users. There are no geological maps covering the territory of Kazakhstan on the start page of this platform, but the cartographic catalog of the interactive map contains schematic geological maps at scales of 1: 1,000,000 and 1: 200,000. These materials were uploaded by the Karpinsky All-Russian Research Geological Institute. The interactive map complies with GeoSciML standards and uses the Open Street Map as a basis.

The next category of coverage classification is GIS-based national geological databases. These databases can perform several functions in real time: collecting, storing, processing and customizing data. Currently, many developed countries have their own national platforms, such as Geoscience Australia (Pigram, 2012), the British BGS Geology Viewer (Fellgett & Monaghan, 2024), the National Geological Web Portal of Slovakia (Linkevich, 2021), and the database of state geological maps of Russia. National platforms play an important role in studying the geological environment of a country, assessing natural risks and studying minerals, providing a wide range of maps at different scales, etc.

In the Republic of Kazakhstan the need for unified collection, analysis and further creation of GIS database, as well as storage in electronic media or publication on the Internet were voiced back in the 90s of the last century (Uzhkenov, 1997). Today, one of the urgent issues is the creation of a unified or regional (separate for each ore zone) database. As stated in the concept of the “State Program of Geological Exploration for 2021-2025”, one of the problems of the geological industry is a weak level of automation and digitalization, which was also touched upon in the previously existing “Program of geological exploration in the Republic of Kazakhstan for 2015-2019”. It analyzed the problems of development of the geological industry in the country, and one of the negative factors was the lack of analytical modules of the Subsoil Data Bank, automated access to work with geological information, low level of filling of databases. It was also noted in the document that the republican geological fund has accumulated over 53,000 titles of geological materials and annually over 300 geological reports are submitted to the republican fund (Government of the Republic of Kazakhstan, 2014; 2022). In this regard, it was necessary to finalize and launch the national database. The resource was to be launched in 2021, however, the work on the project was only 60% completed (Bancikin, 2022).

The existence of a national, public and up-to-date geological GIS database is a marker of government involvement and interest in the development of the geological sector of the economy. Such projects fulfill several functions: 1) a source of information for educational purposes, especially for students of educational institutions and for scientific researchers; 2) a reference resource when performing administrative and inventory activities; 3) a reference and analytical and forecasting tool for potential subsoil users, especially foreign ones. Today, many countries, mainly developed countries, have this category of GIS (Bekishev et al., 2023; Cardoso-Fernandes, J. et al., 2019; Mataibaeva, 2017; Oitseva, T. et al., 2022). At the same time, the recognition and mapping of ore deposits based on remote sensing data using machine learning methods, including artificial intelligence, is of particular importance, which will be a breakthrough to improving prospecting based on remote sensing methods (Rakhymberdina et al., 2022; Rakhymberdina et al., 2021; Safonov et al., 2018; Zaalishvili et al., 2020). Thus, the development and implementation of geoinformation support of geological exploration works in the East Kazakhstan region is of topical importance.

Methodology

The database consists of geologic maps and additional graphical drawings and schematics created by various methods and obtained from a variety of sources. The cartographic materials consist of traditional paper maps, open online web map services (WMS) and raster and vector images found during the survey. Map sources can be categorized by the areas and scales they contain conventionally.

Geological maps at a scale of 1: 1,000,000 cover the Kalba-Narym metallogenic zone and are used for overview purposes (Figure 1). This map is located on the map page under the number M-44. To create the overview map, the primary source maps were imported as WMS from the OneGeology resource. The WMS service is provided by Karpinski University. Also, additional information was obtained from the “geological map of the Zaisan sheets” compiled by O.V. Navozov.

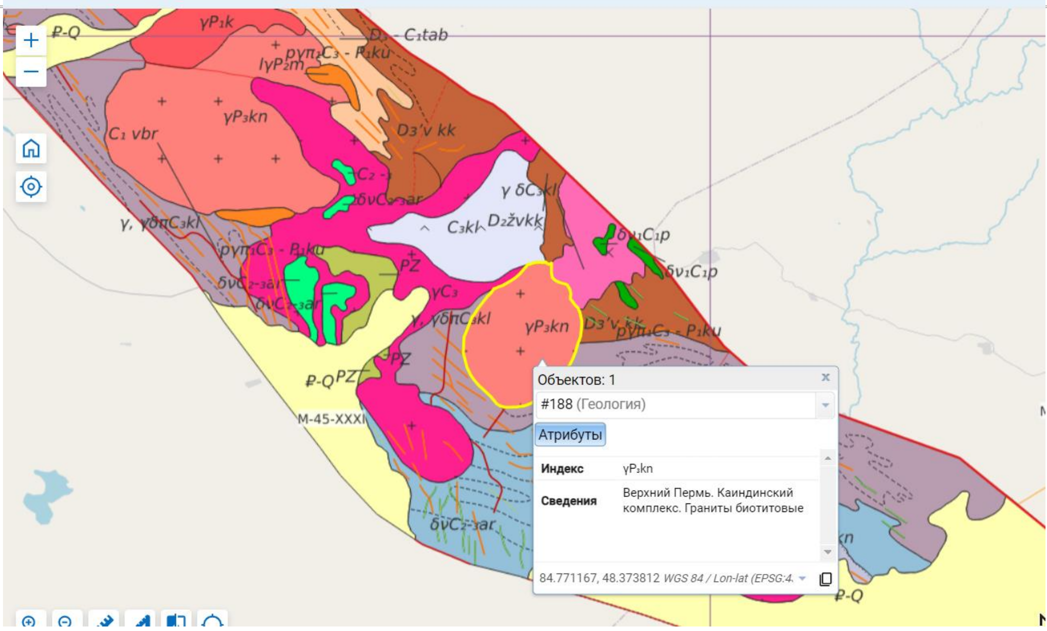


Figure 1: Geologic map 1:1 000 000.

The 1: 200,000 scale maps mainly cover the Asubulak and Belogorsk Ore Node from various geological aspects. These maps show geological, geophysical, geochemical and mineral information as part of sheet m-44-XXIX of the Soviet map printing system located in the UTM 44 area (Figure 2, 3). They consist of the following maps: geologic map, anomalous magnetic field (DT)a, ΔZ map, residual gravity fluctuation map, mineral map and patterns.

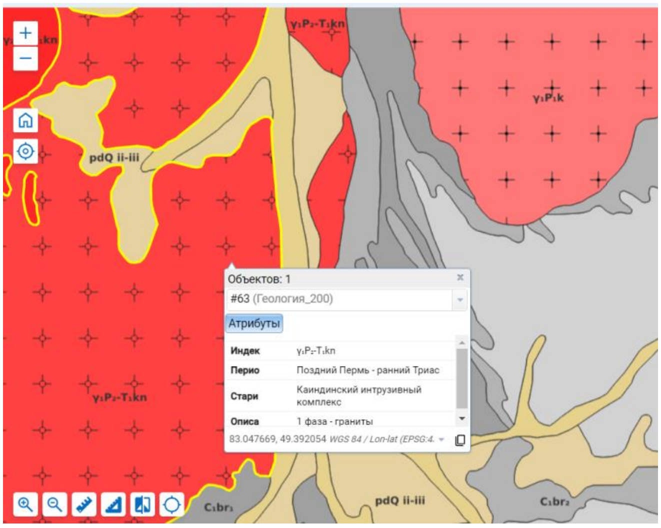
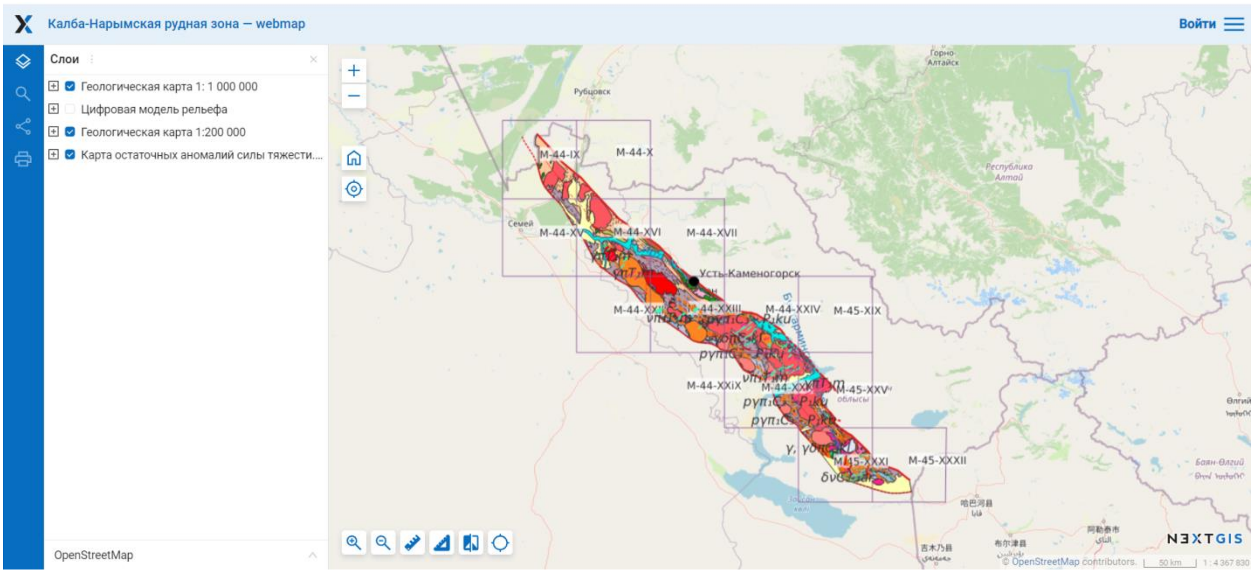


Figure 2: Geologic map 1-200 000.

Figure 3: Gravimetric map 1-200 000.

The 1:100,000 and 1:50,000 scale maps mainly show the Asubulak deposit, respectively, M-44-95-A and M-44-95-B contains cartographic pages. The cartographic materials are collected from drawings and maps compiled by the authors Lopatnikov V.V., Nechaev A.V., Nikolenko A.. E., N.P. Mayorova, Y.G. Azovsky, V.F. Kashcheev and R.R. Vvedensky. The following maps were used at a scale of 1: 100 000: structural-tectonic scheme, schematic geomorphologic map. On a scale of 1: 50 000 the following maps were used: geological map, mineral map, map of residual gravity anomalies, secondary scattering and map of anomalous points (Be, Nb, W, Sn), secondary scattering and map of anomalous points (Li, Cs).

In addition, additional materials rather than traditional geologic materials were provided to compile the geologic GIS database. Among them are remote sensing data, digital terrain model and elevation map (Figure 4).



Source: created by the author

Figure 4: GIS database of geological data.

Satellite images were acquired to perform geologic mapping using remotely sensed data. The proper selection of satellite imagery is critical for geological mapping for several reasons: data accuracy and detail; spectral characteristics; seasonal and temporal variations; and interference reduction.

The resolution of satellite imagery (spatial, spectral, radiometric and temporal) directly affects the ability to detect and characterize geologic features. High resolution allows for detailed examination of small structures, while low resolution may not capture important features. Different geologic features (e.g., rock types or mineral associations) can be well distinguished in certain spectral bands. Using images that capture the desired spectral bands increases the likelihood of correctly detecting and classifying geologic features. Geologic mapping often requires consideration of seasonal changes such as snow, vegetation, or precipitation. Selecting imagery taken in the right season and time period will help avoid distortions and increase the accuracy of the analysis. In addition, the availability of satellite imagery is a very important factor. Taking into account the above factors and criteria, space images from artificial satellites of different countries were analyzed (Table 1).

Table 1: Analysis of space images for the territory of Kazakhstan.

Satellite name	Spectral range, nm	Number of channels	Spatial resolution, m	Accessibility
Landsat 8	450-2350	9	30	free
ASTER	520-2430	14	15	paid
Sentinel-2	443-2190	13	10-20	free
SPOT-5	490-1780	4	10-20	paid
Worldview-2	400-1040	8	1,85	paid
IKONOS	450-850	4	3,2	paid
KazEOSat-1	450-750	4	4	paid
KazEOSat-2	440-850	5	6,5	paid

Source: Compiled by the authors based on data from open sources

Several criteria have been established for satellite images: number of channels, spectral range, spatial resolution and accessibility. The spectral range is critical for distinguishing geologic objects from space images. Many minerals and rocks appear unusual in the visible and near-infrared ranges. Shortwave infrared rays are required for their classification. Therefore, unfortunately, Kazakhstan's KazEOSat series of satellites have not found application (Kurczyński et al., 2016). The IKONOS and Worldview-2 satellites also operate only in the visible and near-infrared bands.

Aster images are used for geologic mapping purposes, but are distributed for a fee. Therefore, space images from Landsat-8 and Sentinel-2 satellites were used in this research.

Landsat-8 is the eighth satellite in the Landsat series designed for Earth observation. Since its launch, Landsat-8 has provided valuable data for scientific research, natural resource management and environmental change monitoring (Chaves et al., 2020).

Sentinel-2 is a mission consisting of two satellites (Sentinel-2A and Sentinel-2B) launched by the European Space Agency (ESA) under the Copernicus program. The mission aims to monitor the surface and provides data for various applications including agriculture, forestry, water resources, land management and environmental monitoring (Phiri et al., 2020).

Establishment of a digital foundation for the development of a GIS database

In order to convert cartographic materials from various sources into vector maps, several steps are necessary: scanning, georeferencing (landing in a coordinate system), and input of geometric and attribute information.

In the first step, traditional paper maps were scanned. The scans are uncompressed with an accuracy of 300 dpi. In addition, a descreening operation was performed so that there would be no moiré traces through additional devices.

In the next step, the scanned maps were converted to a coordinate system in the QGIS program, through the Georeferencer Plugin. Most of the maps were created according to the global geographic coordinates of Pulkovo-1942, which were used in the Soviet Union. They were converted to the most used today WGS-84 coordinate system. Geographic referencing was performed using polynomial method, and the final marginal error is 1-2 pixels.

Before introducing geometric information, a separate map layer was created for each geologic feature and section. Each layer, in turn, is made based on some geometric shape. For example, polygonal method is chosen to mark geologic boundaries, and linear method is chosen to build networks. Vectorization is performed in QGIS program by semi-automatic method, i.e. with the help of special plug-ins working on the basis of artificial intelligence. For example, Raster Tracer.

Rule-based symbolization was used to change the visibility properties of layers. Working with this type of symbolization requires the use of expressions for filtering. This is accomplished using QGIS Expression Language, a SQL-like query language designed to work with attributes and object geometry. Expressions have been created using the values of the attribute tables of fields and layers.

After creating and processing spatial data, the next step was to add attribute information. In this GIS, the relationship between spatial and attribute data is accomplished using the georelational method. This means that spatial (geographic) data are created and stored separately from attribute data, which are also organized separately but linked through identifiers (IDs) (Yin & Su, 2006). Attribute data are organized as relational tables for each map layer (Figure 5).

Геология — объектов всего: 190, отфильтровано: 190, выбрано: 0

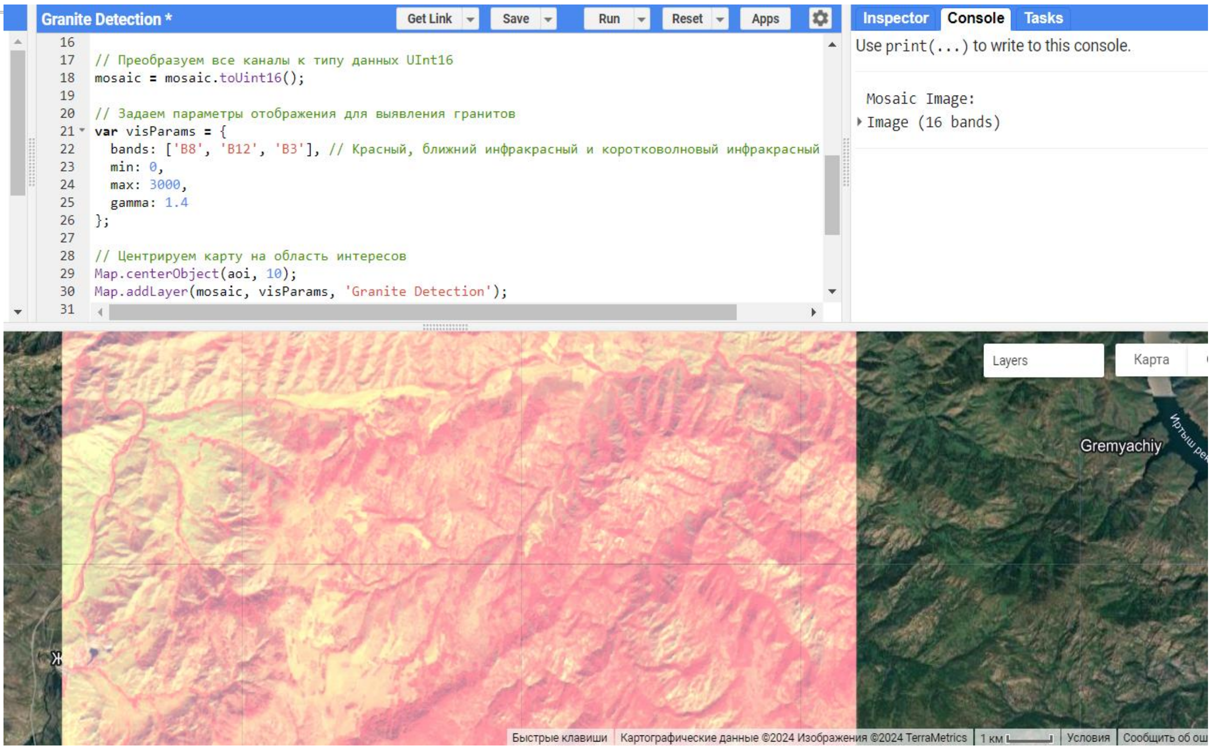
	Индекс	Перио	Стари	Описа
10	C_1br_1	Ранний Каменноугольный	Бурабайская свита	Нижняя подсвита - полимиктовые песчаники, углисто-глинистые алевролиты
11	C_1br_1	Ранний Каменноугольный	Бурабайская свита	Нижняя подсвита - полимиктовые песчаники, углисто-глинистые алевролиты
12	C_1br_1	Ранний Каменноугольный	Бурабайская свита	Нижняя подсвита - полимиктовые песчаники, углисто-глинистые алевролиты
13	C_1br_1	Ранний Каменноугольный	Бурабайская свита	Нижняя подсвита - полимиктовые песчаники, углисто-глинистые алевролиты
14	C_1br_1	Ранний Каменноугольный	Бурабайская свита	Нижняя подсвита - полимиктовые песчаники, углисто-глинистые алевролиты
15	C_1br_1	Ранний Каменноугольный	Бурабайская свита	Нижняя подсвита - полимиктовые песчаники, углисто-глинистые алевролиты
16	C_1br_1	Ранний Каменноугольный	Бурабайская свита	Нижняя подсвита - полимиктовые песчаники, углисто-глинистые алевролиты
17	C_1br_1	Ранний Каменноугольный	Бурабайская свита	Нижняя подсвита - полимиктовые песчаники, углисто-глинистые алевролиты
18	C_1br_1	Ранний Каменноугольный	Бурабайская свита	Нижняя подсвита - полимиктовые песчаники, углисто-глинистые алевролиты
19	C_1br_1	Ранний Каменноугольный	Бурабайская свита	Нижняя подсвита - полимиктовые песчаники, углисто-глинистые алевролиты
20	C_1br_1	Ранний Каменноугольный	Бурабайская свита	Нижняя подсвита - полимиктовые песчаники, углисто-глинистые алевролиты
21	C_1br_1	Ранний Каменноугольный	Бурабайская свита	Нижняя подсвита - полимиктовые песчаники, углисто-глинистые алевролиты
22	C_1br_1	Ранний Каменноугольный	Бурабайская свита	Нижняя подсвита - полимиктовые песчаники, углисто-глинистые алевролиты
23	C_1br_1	Ранний Каменноугольный	Бурабайская свита	Нижняя подсвита - полимиктовые песчаники, углисто-глинистые алевролиты
24	C_1br_1	Ранний Каменноугольный	Бурабайская свита	Нижняя подсвита - полимиктовые песчаники, углисто-глинистые алевролиты
25	C_1br_1	Ранний Каменноугольный	Бурабайская свита	Нижняя подсвита - полимиктовые песчаники, углисто-глинистые алевролиты
26	C_1br_1	Ранний Каменноугольный	Бурабайская свита	Нижняя подсвита - полимиктовые песчаники, углисто-глинистые алевролиты
27	C_1br_1	Ранний Каменноугольный	Бурабайская свита	Нижняя подсвита - полимиктовые песчаники, углисто-глинистые алевролиты
28	C_1br_1	Ранний Каменноугольный	Бурабайская свита	Нижняя подсвита - полимиктовые песчаники, углисто-глинистые алевролиты
29	C_1br_2	Ранний Каменноугольный	Бурабайская свита	Верхняя подсвита - углисто-глинистые алевролиты, алевропелиты с прослоями песчаников
30	C_1br_2	Ранний Каменноугольный	Бурабайская свита	Верхняя подсвита - углисто-глинистые алевролиты, алевропелиты с прослоями песчаников
31	C_1br_2	Ранний Каменноугольный	Бурабайская свита	Верхняя подсвита - углисто-глинистые алевролиты, алевропелиты с прослоями песчаников
32	C_1br_2	Ранний Каменноугольный	Бурабайская свита	Верхняя подсвита - углисто-глинистые алевролиты, алевропелиты с прослоями песчаников
33	C_1br_2	Ранний Каменноугольный	Бурабайская свита	Верхняя подсвита - углисто-глинистые алевролиты, алевропелиты с прослоями песчаников

Все объекты

Source: Created by the author

Figure 5: Table of geologic map attributes (Index, Period, Stratigraphic Division, Rock Description).

In addition, it was noted that processed remote sensing (RS) image types had been added to traditional geologic cartogarphic materials. General SAR materials are widely used in geologic mapping and mineral exploration. For example: gold deposits (Bolouki et al., 2020), colliery (Ali-Bik et al., 2020), copper porphyry deposits (Beygi et al., 2021) during exploration. RGB combinations and band ratio methods were used to process the KZ data (Figure 6). The research utilized certain combinations and ratios in the literature (Table 2).



Source: Created by the author

Figure 6: 8-12-3 Sentinel-2 channel combination for granite detection in Google Earth Engine

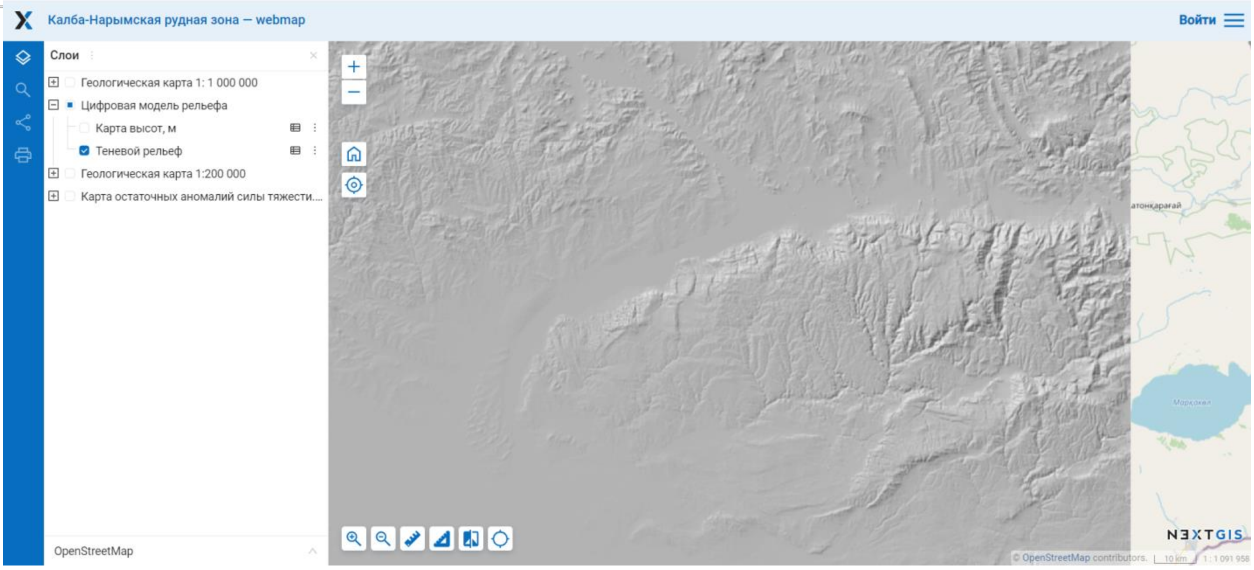
Table 2: RGB combination and channel ratio (Band radio).

RGB combinations			
Landsat-8	Sentinel-2	Speciality	Reference
2-5-7	2-8-12	Iron oxides and clay minerals	Ali and Pour, 2014
6-7-4	11-4-12	Lithological contrasts	Mwaniki et al., 2015
5-7-3	8-12-3	Hydrothermal alteration of rock	Mia and Fujimitsu, 2012
Band ratio			
6/7	11/12	Hydrothermal alteration of rock	Sabins, 1999

Source: publications in open sources

Results and discussion

Based on numerous paper and raster maps, a geological GIS database of Kalba - Narym metallogenic zone and its structural part Asubulak pegmatite area was compiled. The database complex includes as a component the following set of maps: geological, geophysical, geochemical, geomorphological, geotectonic and mineral maps. In addition, there are images created from remotely sensed data and DEM images showing terrain relief created with SRTM (Figure 7).



Source: U.S. Geological Survey, a.n.d. created by the author

Figure 7: Digital terrain model of the study area.

This set of maps is in different scales: 1,000,000, 1:200,000, 1:100,000 and 1:50,000.

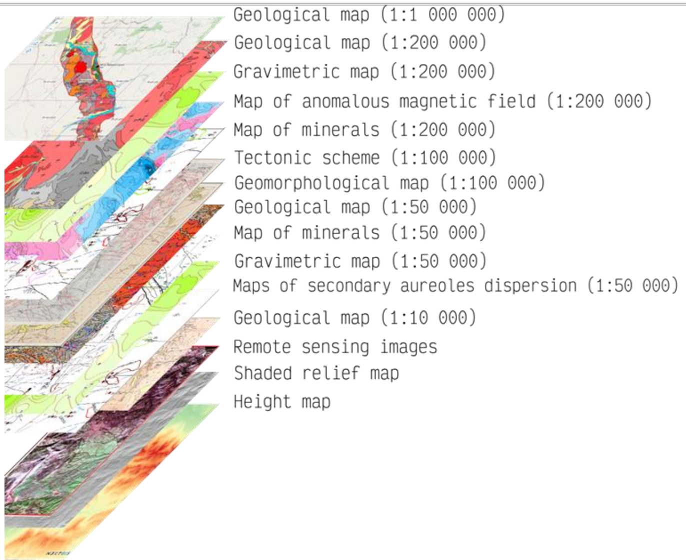
Initially, paper and raster maps were collected from different sources. Using QGIS, all maps were digitized and structured. The digitization process included the following steps: scanning and georeferencing. Paper maps were scanned with high accuracy. The raster images were georeferenced in a coordinate system in the QGIS program using the “georeferent” module.

During the raster quantification process, geologic units, tectonic faults, mineralization contours, and other features were vectorized using the vectorization tools in QGIS. Attribute data containing characteristics of ore bodies, lithologic units, geochemical anomalies and other parameters were added to the appropriate layers.

All data are structured and placed on thematic layers. The database was organized so that each layer had a clear thematic structure and attribute information.

To ensure easy visualization and analysis of the data, an interactive map was created in NextGIS WEB. This resource provided powerful tools for interacting with the data and analyzing geologic information.

All digitized data were exported from QGIS and uploaded to the NextGIS web platform. The interface of the interactive map is customized for easy and intuitive use. There are functions for switching layers, zooming, and filtering data by attribute characteristics (Figure 8).



Source: Created by the author

Figure 8: Map layout in Web GIS.

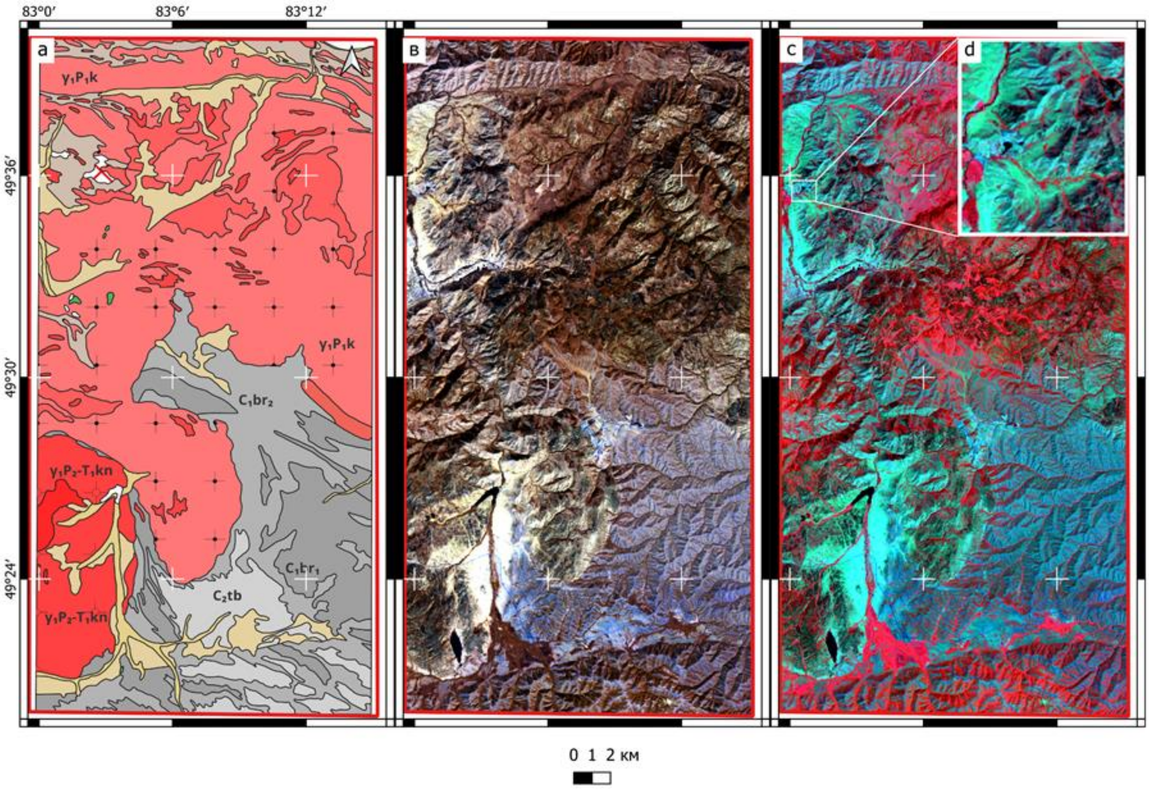
In terms of map functionality, the web map allows users to view and analyze geologic features at several zoom levels, from large details (1:50,000) to regional overviews (1:1,000,000).

Attribute data such as mineralogical composition, tectonic characteristics, geochemical anomalies and geophysical measurements are available for each feature on the map. The creation of an interactive geological database and map has provided a number of important benefits for the study of the Kalba-Narym Ore Region and the Asubulak pegmatite field: increased accuracy and availability of data; integration of different types of data; and improved analysis and forecasting methods;

The digitization and organization of historical maps made it possible to combine different data into one system. The interactive map has improved data access, visualization and simplified the analysis process.

The ability to combine geological, geochemical, geophysical and other data on one platform allows for comprehensive analysis and the identification of patterns that might otherwise go unnoticed.

In terms of remote sensing data, some of the processed combinations of Landsat-8 and Sentinel-2 space images can allow geologic features to be distinguished from one another. For example, a 6-7-4 combination of Landsat-8 space image can create a geologic contrast (Fig. 9-b). Intrusive complexes predominantly composed of granite can be distinguished from sedimentary rocks and Quaternary deposits. In addition, another 5-7-3 combination distinguished rocks near the quarries among the garnet complexes. Additional spectrometric laboratory work is required to investigate this feature.



Source: Created by the author

Figure 9: Geological map and images of Landsat-8: a) geological map (1:50,000); b) image of Landsat-8 with a combination of RGB 6-7-4; c) image of Landsat-8 with a combination of RGB 5-7-3

Conclusion and Recommendation

The results of this research emphasize the importance and effectiveness of using GIS and remote sensing technologies to create comprehensive geological databases and interactive maps. These tools not only improve data availability and accuracy, but also contribute to a more complete and thorough understanding of the geologic processes and resources of the study regions.

The creation of the database needs to be continued, i.e. for a full-fledged improvement, the missing map set needs to be found, digitized and incorporated into the web map. In addition, it is necessary to take into account the possibility of expanding the interactive map in the regional context. It is necessary to replenish the database on the basis of vectorization of cartographic information on other areas of the Kalba-Narym ore zone.

Remote sensing data has provided basic fundamental data, but it needs to be used to conduct detailed AI based research. Therefore, future work needs to include spectroradiometric studies of rock and mineral samples, the creation of a spectral library of a specific study area, and the use of space imagery from high-precision commercial satellites.

A key aspect of the research was the reduction of heterogeneous data to a single coordinate system, allowing integration into a single GIS and comprehensive spatial analysis. On the basis of the conducted research the data structure for creating GIS of Kalba-Narym zone was developed, the main problematic issues in the development of geological GIS base were identified.

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