SUTGMK PROGRAMME

Server based Unified Thematic Geological Mapping in Kazakhstan

UNESCO Chair on Coastal Geo-Hazard Analysis
Research Institute for Earth Sciences
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Research Proposal for Tender Number 12879043-1 in Kazakhstan

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To participate in an international tender in geology (Number 12879043-1), here are the main stages of surface and subsurface geological studies to include in a research proposal for preparing a subsurface geological map at a scale of 1:200,000 in an area of ~ 15,000 Km² in the Pavlodar province of Kazakhstan:

1. Preliminary Data Analysis:

- Collection and evaluation of existing geological data.
- Mapping of known resources and geological formations.

2. Field Studies:

- Conducting fieldwork to collect samples.
- Observing outcrops and geological formations at the surface.

3. Geophysical Surveys:

- Utilizing geophysical methods (seismic, resistivity, gravity) to explore the subsurface.
- Determining hidden geological structures.

4.geochemical surveys:

- Investigation the appropriate sampling method for geochemical exploration.
- Designing the sampling network and taking samples at the required speed.

5. Drilling and Subsurface Analysis:

- Performing drilling to obtain soil and rock samples.
- Analyzing samples in the laboratory to determine geological composition and properties.

6. Geological Modeling:

- Developing a geological model by integrating surface and subsurface data.
- Identifying geological layers and their distribution.

7. Mapping:

- Creating the subsurface geological map at a scale of 1:200,000 using a geographic information system (GIS).
- Integrating collected data to illustrate geological formations, resources, and geological risks.

8. Final Report Writing:

- Preparing a detailed report outlining methods, results, and recommendations.
- Presenting conclusions and implications for future studies or exploitation projects.

These stages will facilitate the creation of an accurate and useful subsurface geological map for the Pavlodar province, although as a more detailed outline of the main stages of surface and subsurface geological studies for a research proposal aimed at preparing a subsurface geological map at a scale of 1:200,000 in the Pavlodar province of Kazakhstan:

1. Preliminary Data Analysis

- Objective: To establish a baseline understanding of the geological context of the area.
- Activities:
  - Literature Review: Study previous geological surveys, academic papers, and reports related to the Pavlodar region.
  - Data Gathering: Compile existing maps, geological datasets, mineral exploration reports, and remote sensing data.
  - Geological Compilation: Create a comprehensive database of known geological formations, mineral resources, and structural features.

2. Field Studies

- Objective: To obtain firsthand geological information and validate existing data.
- Activities:
  - Site Selection: Identify key locations for field studies based on preliminary analysis.
  - Geological Mapping: Conduct detailed mapping of surface geology, including lithology, stratigraphy, and structural features.
  - Sample Collection: Collect rock, soil, and sediment samples from outcrops and other geological features for further analysis.

3. Geophysical Surveys

- Objective: To explore subsurface conditions and identify geological structures that are not exposed at the surface.
- Activities:

- Survey Design: Plan the geophysical survey based on target areas identified in field studies.
- Data Acquisition:
  - Seismic Surveys: Use reflection and refraction methods to map subsurface layers and identify faults and folds.
  - Electrical Resistivity: Apply resistivity imaging techniques to differentiate between saturated and unsaturated zones.
  - Gravity Surveys: Measure variations in the Earth's gravitational field to infer subsurface density variations.
- Data Processing: Analyze geophysical data to create subsurface models that complement surface findings.

Using Magnetotelluric (MT) and Audio magnetotelluric (AMT) surveys can be an excellent addition to your geological study for producing a subsurface geological map. Here's how magnetotellurics can be utilized and its benefits:

MT/AMT Surveys: Overview

MT/AMT are electromagnetic methods used to investigate the electrical properties of the subsurface. It measures the natural variations of electric and magnetic fields at the Earth's surface to infer the resistivity structure of the subsurface.

Benefits of Using Magnetotellurics

1. Depth of Penetration: MT/AMT surveys can provide information at significant depths (hundreds to thousands of meters), making it useful for mapping geological structures that are not accessible by traditional means such as drilling.

2. Identification of Geological Boundaries: The resistivity data obtained from MT/AMT can help identify different geological layers, including aquifers, petroleum reservoirs, and mineral deposits, based on differences in electrical conductivity.

3. Hydrocarbon and Mineral Exploration: MT/AMT can be particularly effective in identifying areas with potential hydrocarbon accumulations due to the different resistivity contrasts associated with oil and gas-bearing formations.

4. Integration with Other Methods: MT/AMT data can be integrated with geological mapping, geophysical surveys, and drilling results to provide a more comprehensive understanding of the subsurface geology.

5. Non-invasive Technique: MT does not require drilling or extensive ground disturbance, making it an attractive option for environmentally sensitive areas.

6. AMT/MT methods can be used in different scale od studies, i. e., from regional scale to deposit scale mapping.

Implementation of Magnetotellurics in Your Study

1. Survey Design: Determine a survey grid based on geological and geophysical targets identified in previous stages of your study. Consider deploying a network of MT stations. Regional studies to cover the whole area (e. g., using a survey grid of 10*10 Km) could be carried out at the initial steps.

2. Data Collection: Use specialized equipment to record electromagnetic field variations over a predetermined period. Ensure that the measurements are taken over diverse geological settings.

3. Data Processing and Analysis:

- Data Cleaning: Remove noise and artifacts from the recorded data.

- **Impedance Tensor Calculation**: Compute the impedance tensor from the electric and magnetic field data to characterize the subsurface resistivity structure.

- Inversion Modeling: Use inversion techniques to create a resistivity model of the subsurface, providing insights into the geological features.

4. Integration with Other Data: Combine the MT data with results from geological mapping, drilling, and other geophysical methods (e.g., seismic and gravity surveys) to refine subsurface interpretations.

5. Mapping and Interpretation: Generate additional sections, maps, and models that highlight the findings from the MT survey and their geological implications.

Incorporating magnetotelluric surveys into your geological study will enhance the depth and accuracy of your subsurface mapping efforts. With its ability to reveal resistivity variations related to different geological materials and structures, MT can significantly contribute to a thorough understanding of the subsurface geology in the Pavlodar province.

4. Geochemical Surface Sampling:

Geochemical surface sampling can play a crucial role in the exploration mining and geological mapping project, complementing other methods like geological mapping and geophysical surveys. Here are some key points to consider regarding geochemical surface sampling in the context of your project:

1.sampling method and designing the sampling network and collection and selection of duplicate samples.

2. Elemental Analysis: Geochemical sampling allows for the analysis of soil, rock, heavy mineral or sediment samples to determine the presence and concentration of elements. This can help identify mineralization, contamination, or geochemical anomalies indicative of specific geological processes.

3. Indicator of Subsurface Conditions: Surface geochemical signatures can often reflect underlying geological formations and guide further exploration efforts, particularly in locating ore deposits or characterizing geological features.

4. Analyzing the results of sample analysis and preparing a map of geochemical anomalies.

5. Mapping Alteration Zones: Geochemical data can reveal alteration zones related to processes such as hydrothermal activity, aiding in the understanding of the local geology and mineral potential.

6. Integration with Other Data: When combined with geological mapping and geophysical data, geochemical results can enhance the interpretation of the subsurface, leading to more accurate geological models.

7. Cost-Effective Exploration: Compared to drilling or other invasive techniques, geochemical surface sampling is generally more cost-effective and can provide a wealth of information that guides more detailed exploration efforts.

Implementation Steps:

1. Design Sampling Strategy: Define a systematic approach to sampling locations, considering factors like accessibility, geological context, and prior knowledge of the area.

2. Sample Collection: Collect soil, rock, or sediment samples at defined intervals or grid patterns, ensuring proper handling to avoid contamination.

3. Laboratory Analysis: Send samples to a laboratory for geochemical analysis, looking for key indicators based on the objectives of the study.

4. Data Interpretation: Analyze the results in the context of the geological framework, integrating them with other data sources to inform interpretations and decisions.

5. Regular Updates: Consider the need for ongoing sampling to monitor changes over time and refine geological models.

Incorporating geochemical surface sampling into your geological mapping project will enhance the overall understanding of the study area by providing critical data on elemental composition and geochemical processes. It should be viewed as a vital component of a multi-faceted approach, alongside geological and geophysical methods, to create a comprehensive geological map and inform exploration strategies.

5. Drilling and Subsurface Analysis

- Objective: To obtain direct samples from the subsurface for detailed analysis.

- Activities:

  - Drill Site Planning: Identify strategic locations for drilling based on geophysical survey results and geological mapping.

  - Drilling Operations: Conduct rotary or core drilling to extract subsurface samples.

  - Sample Preparation: Prepare samples for laboratory analysis through methods such as crushing, grinding, and splitting.

  - Laboratory Analysis:

    - Petrographic Analysis: Use thin sections to study mineralogy and texture.

    - Geochemical Assays: Analyze samples for elements of interest, assessing resource potential.

    - Physical Property Testing: Determine properties such as porosity, permeability, and strength.

6. Geological Modeling

- Objective: To synthesize all collected data into a coherent geological framework.

- Activities:

  - Data Integration: Integrate surface and subsurface data into a 3D geological model using specialized software (e.g., GIS or geological modeling tools).

  - Layer Identification: Characterize and delineate subsurface layers, including stratigraphy, structural features, and hydrogeological units.

- Resource Assessment: Analyze resource potentials and risks associated with geological formations.

- Structural cross sections and 3D geological mapping.

7. Mapping

- Objective: To produce a high-quality geological map that accurately represents the subsurface geology.

- Activities:

- Map Design: Decide on key features to be included (e.g., faults, mineral deposits, water resources).

- Map Production: Use GIS to create the subsurface geological map at a scale of 1:200,000, ensuring that data visualization is clear and informative.

- Verification and Validation: Cross-check the map with field observations and analyses to ensure accuracy.

While utilizing machine learning and AI can enhance the geological mapping process, it should not replace traditional methods and human expertise. A hybrid approach, combining advanced technologies with field validation, is recommended. So, the approach developed by Nazari et al. in 2022 and 2023, which extensively utilized machine learning and AI for preparing Server-based Unified Thematic Geological maps, could be effectively applied to surface geological mapping in the proposed Kazakhstan project. Here are a few reasons supporting this:

1. Advanced Data Processing: The use of machine learning and AI can enhance the processing and analysis of large datasets, which is crucial for effective geological mapping, especially in extensive areas like those in Kazakhstan.

2. Pattern Recognition: Machine learning algorithms can identify complex geological patterns and trends that may not be apparent through traditional methods, potentially leading to more accurate mapping.

3. Automation and Efficiency: Implementing AI can streamline the mapping process, reducing the time and resources needed while increasing the overall efficiency of data collection and analysis.

4. Customization: The approach can be tailored to accommodate the specific geological conditions and data availability in Kazakhstan, ensuring relevance and applicability.

5. Integration of Diverse Data: AI can integrate various data types (geological, geophysical, geochemical) into a unified model, providing a comprehensive view of the geological framework.

In summary, adopting the approach of Nazari et al. for the Kazakhstan project would likely provide significant advantages due to its innovative use of machine learning and AI, making it a promising strategy for producing high-quality surface geological maps. Therefore, the approach developed in the SUTGM programme, as applied in the Lut and Makran projects in Iran, could likely be adapted for surface geological mapping in the proposed project in Kazakhstan as the SUTGMK programme, because:

1. Scalability: The approach is designed to handle large-scale projects, making it suitable for the extensive geological mapping required in Kazakhstan.

2. Proven Methodology: Its successful implementation in the Lut and Makran projects demonstrates its effectiveness in different geological settings, which could be relevant to Kazakhstan's geological context.

3. Flexibility: The methodology likely includes adaptable elements that can be tailored to the specific geological, geographical, and logistical conditions present in Kazakhstan.

4. Holistic Integration: The approach may incorporate various data sources and techniques, which can enhance the comprehensiveness of the geological mapping in Kazakhstan.

SUTGMK programme
Server based Unified Thematic Geological Mapping in Kazakhstan

The SUTGMK program is an international, multidisciplinary geological initiative funded by the Kazakhstan government. Launched in 2024, this one-year program unites geologists, remote sensing experts, programmers, and AI specialists to utilize advances in cloud computing and machine learning, with the goal of creating 1:200,000-scale thematic geological maps for approximately 15,000 km² of Kazakh territory.
The main objectives are to provide modern information on integrated geological maps and to evaluate and develop the use of machine learning and AI in geological mapping. The programme also provides for the transfer of knowledge and technology between Iranian and Kazakhstan specialists within the framework of the UNESCO Chair on Coastal Geo-Hazard Analysis (UCCGHA).
The way of working relies on server-based topic mapping and cloud computing to efficiently manage large geological datasets. The use of Object-Based Image Analysis (OBIA) allows for the precise identification of geological formations. SUTGMK products include integrated thematic geological maps that allow for rapid surveys, integration of legends and geological units, and a significant reduction in instrumental analysis. This method allows for national coverage with superior accuracy and speed, while significantly reducing costs compared to traditional methods.
The scientific program details the diverse geology of Kazakhstan, including landscapes formed over millions of years. The geology of Kazakhstan is diverse and rich due to its size and location at the crossroads of several geological regions. The country is home to various geological features, including mountain ranges, deserts, and vast expanses of steppe. One of the main geological features of Kazakhstan is the Tien Shan Mountain range in the southeast, which contains high peaks, deep valleys, and glaciers. The country also has the Altai Mountains to the north and the Kazakh highlands to the west.

Kazakhstan has significant mineral resources, including oil, natural gas, coal, iron ore, copper, and gold. The country is a major producer of oil and gas, with the Caspian Sea region being a particularly important area for energy production. Overall, Kazakhstan's geology reflects a complex history of tectonic activity, sedimentation, and erosion, shaping the country's landscape diversity and mineral wealth.
About 80 per cent of Kazakhstan's land area is vast steppes, while mountainous areas make up about 14 per cent of the country. The remaining percentage is covered by deserts, lakes and other diverse terrains. The vast steppes are characteristic of the country's geography, providing a unique landscape important for agriculture and nomadic traditions. Mountainous regions, such as the Tien Shan and Altai ranges, offer diverse ecosystems and natural beauty.
Kazakhstan has undertaken extensive geological mapping efforts to better understand its geology and natural resources. The country has created detailed geological maps that highlight the distribution of different types of rocks, mineral deposits, and other geological features. These maps are crucial in guiding exploration and development activities in the country, particularly in the energy and mining sectors.

The main scientific lead, Hamid Nazari, holds the UNESCO Chair in Coastal Geohazard Analysis and has extensive experience in the field of geology with a focus on geohazards, geoarchaeology, paleoclimatology, and machine learning applied to geological mapping.

The main objective of the SUTGMK program in terms of geological mapping is to provide new modern information on thematic integrated geological maps of the Kazakh domain in collaboration with regional specialists, and to develop and evaluate the use of machine learning and artificial intelligence in different aspects of geological mapping. As part of the SUTGMK program, artificial intelligence (AI) and machine learning technology is used to improve the efficiency and accuracy of geological mapping. AI and machine learning can process large geological datasets, integrate information from different sources, and identify patterns and trends that might not otherwise be visible. More specifically, the program uses machine learning algorithms, such as Random Forests, to extract relevant features from various remote sensing datasets. This approach allows for a more accurate classification of rock units and a more detailed mapping of geological formations. Using Object-Based Image Analysis (OBIA) in a cloud computing environment helps distinguish between different geological features, which improves the accurate identification of formations.

Two pilot programs conducted in the Lut Desert and Makran zone in Iran successfully used this methodology to achieve an accuracy rate of above 85% in mapping rock units, demonstrating the effectiveness of integrating AI and machine learning into the geological mapping process.

The SUTGMK program covers 15000 km2 of the territory of Kazakhstan. In combination with sub-surface surveying, the program aims to create integrated thematic 3D geological maps for this entire area, at scales of 1:200000.

The main outputs and expected results of the SUTGMK programme are as follows:

1. Integrated thematic geological maps: The programme aims to produce thematic geological maps at a scale of 1:200000 for certain parts of the Kazakh territory in Pavlodar province, NE

Kazakhstan. These maps are designed to provide a quick and comprehensive understanding of geological data, making it easy to analyze and update information to a global standard.

2. Integration of geological data: The program will allow for the integration of different geological datasets from various sources, which contributes to the creation of more complete and accurate maps.

3. Identifying new patterns: The integration of data and the use of advanced analytical tools can identify new patterns and trends in geological data, which can be useful for mineral exploration, environmental management, and land use planning.

4. Real-time access to data: Geologists can access and analyze geological data in real-time, speeding up the decision-making process during geological surveys.

5. Advanced data analysis: Geologists can use analytical tools to identify relationships between different geological features, such as rock formations and faults.

6. Cost and time savings: The program provides substantial cost and time savings compared to traditional geological mapping methods.

7. Training and knowledge transfer: The program includes training workshops and knowledge and technology transfer activities between Iranian and Kazakh specialists.

8. Hardware and software platforms: The program provides for the equipment and implementation of parallel processing systems and drones for high-precision coastal mapping.

9. methodologies and results of the research carried out within the framework of SUTGMK.

Summary

The SUTGMK program, a Kazakh government-funded initiative, integrates cloud computing, machine learning, and modern geological data to create large-scale thematic 3D maps, revolutionizing the accuracy and cost-effectiveness of geological mapping. Key aspects of the program include the application of machine learning and artificial intelligence in generating comprehensive maps, as well as leveraging mixed object-based image analysis and cloud computing. Kazakhstan's diverse geology, from the Tien Shan Mountains to extensive mineral resources, are the focal points of development, where the new approach has successfully enabled nationwide mapping at reduced costs with significantly enhanced precision.

8. Final Report Writing

- Objective: To compile findings and present them in a professional manner.

- Activities:

  - Report Structure: Organize the report into sections: introduction, methodology, results, discussion, and conclusions.

  - Data Presentation: Include maps, charts, and tables to support findings visually.

  - Recommendations: Provide suggestions for further studies, potential resource exploitation, and implications of the geological findings for local development.

  - Peer Review: Before submission, have the report reviewed by experts in the field to ensure accuracy and clarity.

- Conclusion

The proposed stages will collectively contribute to a comprehensive understanding of Pavlodar province's subsurface geology, resulting in a valuable geological map that will aid in exploration and resource management decisions. This map will facilitate informed decision-making, identify potential mineral and hydrocarbon deposits, and enable more effective resource extraction and management strategies, contributing to the province's sustainable economic growth.

The geological map will also serve as a framework for ongoing research and academic studies, integrating data from various sources and disciplines to provide a comprehensive understanding of the region's geological evolution. The project's successful completion will have far-reaching implications for the region's future development, from optimizing resource extraction to mitigating environmental risks. Regular updates and refinements will be essential to reflect new data and emerging trends, ensuring the map remains a vital resource for stakeholders and decision-makers. Kazakhstan has leveraged modern technologies, including satellite imagery, GIS, and remote sensing, to enhance its geological mapping capabilities and support sustainable natural resource management. The SUTGMK programme involves information gathering, base map preparation, field operations, sampling, and satellite image modelling as well as sub surface data. Upon receiving approval from the Kazakh side, the project will present its schedule, budget, participant details, and estimated costs.