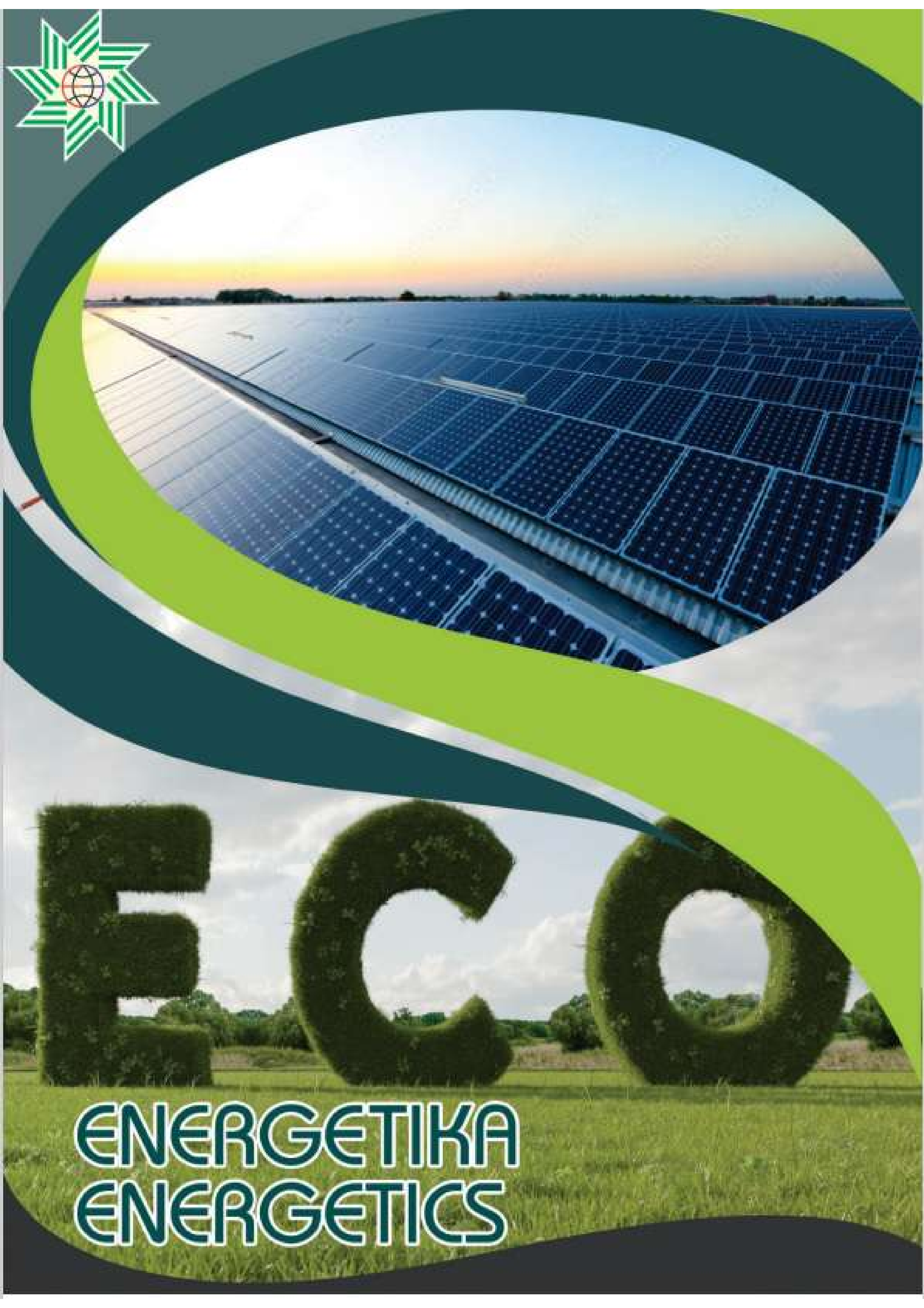

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Artificial Intelligence and Geology

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Abstract. The article provides information on the direct application of artificial intelligence (AI), which has come to the aid of science and economy in recent years, directly in geological science. Artificial intelligence has repeatedly proven its usefulness, productivity and effectiveness in various fields - in industry, healthcare, agriculture, scientific research. Processing of large volumes of geological data, automatic detection of anomalies, creation of geological maps and construction of geodynamic models through AI systems have already become a reality. In the modern world, the integration of artificial intelligence technologies into geological science has become a strategic necessity for the sustainable and efficient use of natural resources, environmental protection and management of geological risks. The continuous development of these technologies and their application to geological research will be an important step towards building a more sustainable and safe world for future generations.

Keywords: Artificial intelligence, geology, geodynamic models, modeling, computer systems, intelligent behavior, machine learning, neural networks, convolutional neural networks.

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1. Introduction

Geology is one of the rapidly developing sciences in modern times. This development has been accelerated, especially over the last 50 years, by the influence of technological progress. The integration of space technologies, satellite observation systems, digital methods and algorithms into scientific fields has also marked the beginning of a new stage in geology. These technological achievements are not limited to geology alone, but have also given a strong impetus to the sustainable and comprehensive development of the economy and other sciences [1,2]. In recent times, one of the main directions of the scientific and technological revolution in the world has been the rapid development and application of artificial intelligence (AI) technologies. The use of artificial intelligence in various fields - in industry, healthcare, agriculture, scientific research, and including geology - has repeatedly proven its usefulness, productivity, and effectiveness. Processing of large volumes of geological data, automatic detection of anomalies, creation of geological maps, and construction of geodynamic models through AI systems have already become a reality. This has brought completely new forms of approach to geology. Artificial intelligence offers powerful opportunities in terms of accelerating research processes in geology, which studies the structure, geological composition and geodynamic evolution of the planet Earth, increasing the accuracy of analyses and optimizing the decision-making process. These technologies are particularly effective in areas such as analyzing large volumes of data, integrating various data sources and modeling complex geological processes [3]. Analyses that require a long time with traditional methods can now be carried out in a shorter time and with higher reliability with the application of artificial intelligence. For example, processes such as automatic classification of rock types through machine learning algorithms, detection of underground structures from seismic data, and monitoring of landscape changes based on satellite images are carried out rapidly [4]. It is important to note that artificial intelligence technologies have fundamentally changed the research approaches of many fundamental and applied sciences, not only in geology, but in general in recent decades. In geology, these changes are manifested both at the theoretical and practical levels and form the basis of a new generation of research [5]. In a broad sense, artificial intelligence is the intellectual behavior and thinking ability demonstrated by machines, especially computer systems. In other words, this technology aims to automate and simulate the functions of human intelligence - processes such as perception, analysis, learning and decision-making. Artificial intelligence systems are tuned to complex perception and analysis of the environment. For this purpose, special software, machine learning algorithms, deep learning models and the use of large data sets - especially geological and geographical databases - play a key role [6].

2. Experimental detail

The data used in geological surveys are collected from various sources and are highly diverse. These include seismic signals, analyses of the chemical-mineralogical composition of rocks, satellite and aerial imagery, geophysical measurements, drilling data, and even historical geological reports. Artificial intelligence allows processing this diverse and voluminous data on a single platform and detecting patterns, correlations, and anomalies in it more quickly and efficiently [7].

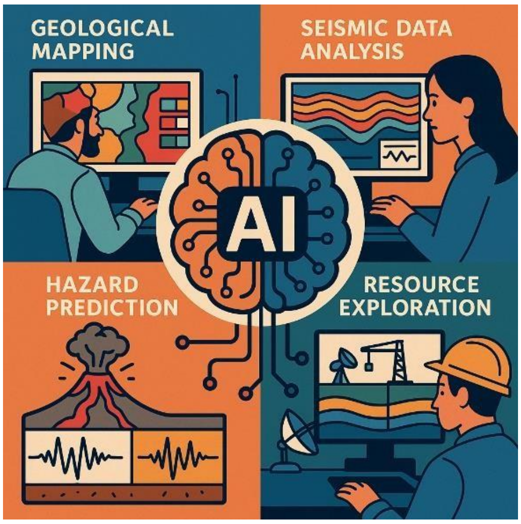

Figure 1. Applications of Artificial Intelligence in Geology: From Mapping to Disaster Forecasting

For example, AI models combined with satellite imagery for analyzing the spectral characteristics of rocks can be used to make preliminary predictions of mineral resources. At the same time, fault and fracture systems can be localized more precisely thanks to neural networks that generate subsurface structural maps based on seismic data. Thus, artificial intelligence has become an intelligent analysis tool in geology based on both spatial and temporal big data [8]. Learning methods of computer systems – in particular, machine learning and deep learning technologies – allow us to efficiently process large volumes of geological data and identify complex and sometimes difficult to detect patterns within them. These approaches allow us to obtain results with higher accuracy by taking into account nonlinear relationships and interactions between multiple variables [9]. For example, in seismic data processing, automatic segmentation, clustering and classification methods are used using artificial intelligence algorithms. These techniques provide effective results in determining the boundaries of various rock layers, predicting their physical and mechanical properties and detecting potential resource zones [10]. In particular, clustering algorithms such as K-means and DBSCAN are used to separate seismic traces into zones with similar characteristics, which allows geologists to build more accurate structural models. On the other hand, methods such as SVM (Support Vector Machines) and Random Forest for classification are successfully applied in distinguishing rock types and analyzing their lithological properties. Thus, such artificial intelligence tools not only save time and labor, but also increase the objectivity and repeatability of studies - which is one of the main indicators of reliability in geological research. On the other hand, regression models - in particular, multiple linear and nonlinear regression methods - allow predicting the physical and mechanical properties of subsurface rock layers based on geophysical measurements. These models are widely used to estimate parametric variables such as rock density, porosity, and elastic modulus values based on field observations or seismic attributes. This approach is especially important in obtaining initial and reliable information about the area before drilling. In addition, deep learning-based neural networks — especially convolutional neural networks (CNNs) — play an important role in the automatic interpretation of complex geological images (maps, cross-sections, seismic slices, etc.). These technologies allow for the automated visual analysis of rock layer boundaries, faults, structural dislocations, and other geological features. CNNs analyze satellite or seismic images presented in different spectral ranges, learn patterns in them, and can recognize the same structures in future images [11].

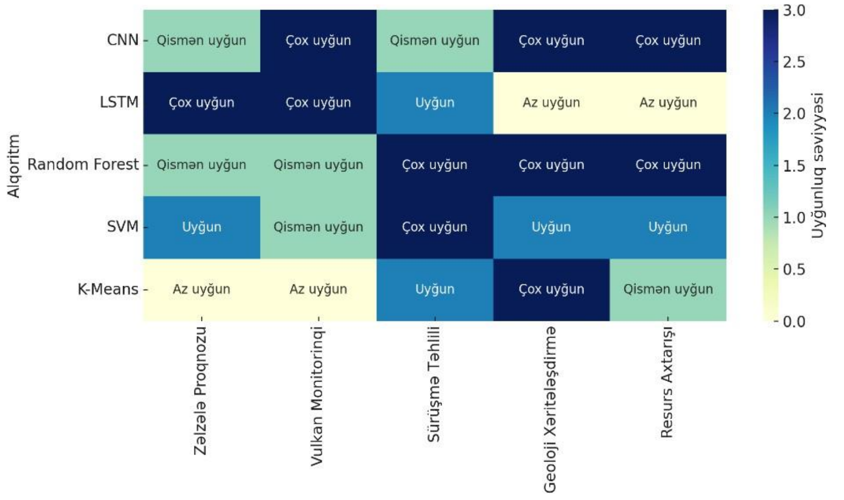

Figure 1. Relevance of Artificial Intelligence algorithms across geological application areas

Such technologies are already being applied in the fields of geological mapping, identification of mineral zones, and even prediction of potential landslide or seismic risk areas. This is driving the development of geological science in a more accurate, objective, and technologically based way. Artificial intelligence is not limited to resource exploration and geological mapping, but also plays an important role in predicting and modeling dangerous geological processes - including natural disasters such as tsunamis, earthquakes, and volcanic eruptions. In this field, AI-based algorithms and deep learning technologies enable disaster risk assessment and approximate time-space coordinates by learning complex relationships between multiple geophysical indicators. For example, data collected from real-time seismological networks for earthquake prediction can be analyzed with artificial intelligence models to detect anomalous vibration patterns (seismic precursors). Deep neural networks and time series models (e.g., RNN or LSTM) are successfully applied in this field [12]. At the same time, ocean floor pressure sensors, sea level satellite observations and meteorological data are used to model the propagation trajectories of tsunami waves. This data is analyzed using artificial intelligence algorithms and timely and accurate wave direction prediction is carried out. In addition, AI systems are also applied for long-term analysis of the speeds and directions of movement of tectonic plates. This is also very important in terms of mapping potential seismic zones and identifying risks in advance. Thus, artificial intelligence technologies have begun to play a strategic role not only in data processing, but also in ensuring the safety of life and infrastructure. One of the main tasks of geological science is to predict the probability of occurrence of various natural disasters of geological origin - earthquakes, volcanic eruptions and landslides - and to manage risks. Since these processes are highly dynamic, their modeling and the establishment of early warning systems pose special challenges. Artificial intelligence in this field allows for more accurate predictions through the analysis of historical data and the automatic identification of seismic or geodynamic signs (for example, micro-earthquakes, stress changes, deformation of the earth's surface, etc.) that occur before events. These systems are pre-loaded with large volumes of archival data (training datasets) and models are trained on the basis of this data. As a result, AI algorithms can perform an early warning function by analyzing possible development scenarios of similar events that may occur in the future [13]. However, it should be noted that artificial intelligence does not replace traditional geological forecasting methods. On the contrary, these technologies provide more effective results when applied in conjunction with approaches based on the experience of geologists and classical methodologies. Artificial intelligence methods serve to increase the overall reliability and accuracy of forecasts by revealing interactions and nonlinear patterns between multiple variables. This is especially important in building multidisciplinary risk analyses and complex models. Thus, artificial intelligence acts as an important complementary tool that improves the forecasting and monitoring systems of geological science for natural disasters. Forecasting volcanic eruptions is one of the most difficult and at the same time critical areas of geology. These processes are accompanied by numerous geophysical and geochemical indicators, and various changes are observed in the pre-eruption stage. Artificial intelligence technologies play an effective role in terms of time series analysis of such complex data and automatic feature detection. To monitor the behavior of volcanoes, seismic activity indicators, changes in the composition of gases (e.g., SO_2, CO_2), surface deformation measurements (using InSAR technology), temperature anomalies and other parameters are collected in real time. This multi-channel data is analyzed using artificial intelligence models - in particular, recurrent neural networks such as LSTM (Long Short-Term Memory) and GRU. These models can predict potential eruption scenarios by learning relationships between time-varying indicators [14]. In addition, clustering methods, such as k-means and hierarchical clustering, are used to identify anomalous activity zones and active craters based on the similarity of seismic signals. Thus, artificial intelligence-based systems continuously monitor the activity of volcanoes, increasing the effectiveness of early warning systems. This serves to prevent potential dangers not only for scientists, but also for the population and infrastructure living in nearby areas. In volcanic hazard management, these technologies create significant advantages in reducing risk and making operational decisions [15]. Landslides are one of the most dangerous processes of geological origin, and their prediction is of strategic importance for both human life and infrastructure. These processes are affected by numerous factors - the mechanical composition of the soil, the angle of inclination of the slope, the intensity and duration of precipitation, vegetation, the level of water saturation of rocks, anthropogenic impacts, etc. [16]. Artificial intelligence, especially machine learning algorithms, play an important role in predicting landslide probability by identifying the interactions between these complex factors. For example, Random Forest, Support Vector Machines (SVM), Gradient Boosting and Neural Network models are widely used to identify landslide-prone zones based on various relief and ecological parameters. These models can be trained based on field observations and historical landslide events to identify new potential risk zones. In addition, indicators such as soil moisture, slope morphology, NDVI (Normal Difference Vegetation Index) and LST (Land Surface Temperature) are automatically extracted and incorporated into the models based on satellite images and remote sensing data. This enables spatial-temporal mapping of landslide risk and the establishment of early warning systems [17]. Thus, the application of artificial intelligence both increases the accuracy of landslide prediction and creates a solid scientific basis for risk management. Artificial intelligence technologies have led to revolutionary changes in the process of creating and updating geological maps. While traditional mapping methods require long-term field research and manual data analysis, modern computer learning (machine learning) and image recognition algorithms allow this process to be significantly accelerated and automated. In particular, it is possible to automatically determine the geological structures, rock types, soil types and morphological characteristics of the area based on satellite images and remote sensing (Remote Sensing – RS) data. For this purpose, algorithms such as convolutional neural networks (CNN), Random Forest, SVM and K-means are used. These algorithms can analyze multispectral and hyperspectral images and group, classify and visualize rock and soil types with similar spectral signatures on digital geological maps [18]. Additionally, AI also helps map lithological divisions and structural elements (faults, anticline/syncline structures, etc.) based on geomorphological indicators — slope angle, aspect, relief height, drainage density, etc. This approach reduces survey costs by minimizing the need for fieldwork and acts as an alternative survey method, especially in difficult or dangerous areas. As a result, AI technologies not only automate the creation of geological maps, but also significantly increase the accuracy and analytical potential of these maps. Use. The application of artificial intelligence in the field of oil and gas exploration has grown rapidly in recent years and has fundamentally changed the research, analysis and decision-making processes of energy companies. One of the most widely used technologies in this field is deep learning methods, which are especially applied in areas such as automatic interpretation of seismic data, identification of potential sedimentary structures and prediction of reservoir selection. Leading energy companies – for example, ExxonMobil, Shell, BP, TotalEnergies and Chevron – analyze thousands of terabytes of seismic images using artificial intelligence algorithms. The positions of potential hydrocarbon reservoirs are determined in these images based on parameters such as depth, amplitude, wave speed. These structures are more accurately modeled and optimal locations for drilling are determined using convolutional neural networks (CNN) and 3D seismic image analysis. In addition, these technologies are also applied to operations such as pre-simulation of drilling results, prediction of the productivity of layers and detection of dangerous zones. This both reduces the exploration time and requires fewer financial and technical resources than traditional geophysical methods. As a result, the application of artificial intelligence makes a significant contribution to accelerating strategic decisions in the energy sector, reducing risks and increasing investment efficiency.

3. Conclusion

The application of artificial intelligence in geology is not limited only to the analysis of existing data, but also opens up completely new opportunities for deep modeling of processes, explanation of complex geodynamic phenomena and early prediction of natural disasters. Thanks to these technologies, it has become possible to more accurately simulate the behavior of geological systems, reduce uncertainties and more reliably support the decision-making process. Artificial intelligence accelerates research processes, optimizes the demand for field and laboratory analysis, and significantly increases the objectivity of results. Through AI systems, it is possible to conduct large-scale analyses, from the evolution of the Earth's crust to the spatial distribution of natural resources, which makes a significant contribution to deepening our knowledge of the Earth. In the modern world, the integration of artificial intelligence technologies into geological science has become a strategic necessity for the sustainable and efficient use of natural resources, environmental protection, and geological risk management. The continuous development and application of these technologies to geological research will be an important step towards building a more sustainable and safe world for future generations.

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