International Journal of Energy
ISSN: 2957-9473 | Vol. 3, No. 3, 2023

Application of Different Logging Techniques in Uranium Exploration

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Abstract: With the depletion of energy, nuclear energy as a new type of clean fuel has attracted much attention, and its main resource is uranium, so the exploration of uranium resources has become a key point and hot spot in the global mining field. Uranium exploration methods are varied, based on the current situation to find a fast and cost-effective means of uranium exploration is particularly important, appropriate logging technology can not only improve the efficiency of the search for minerals, but also save costs. This paper mainly introduces the principle of different uranium logging technology and the characteristics of uranium-rich areas, combined with the research results of previous people, explains in detail the advantages and disadvantages of different logging technology in exploration, as well as analyzing the problems they have, and finally the prospect of uranium exploration technology.

Keywords: Uranium Mine; Logging Technology; Uranium Enrichment Characteristics; Outlook.

1. Introduction

Logging technology originated at the beginning of the 20th century and has been used for more than a hundred years [1]. In mineral exploration, geophysical logging can intuitively reflect the changes in geophysical properties in the longitudinal direction, so that people can better understand the deep part of the earth, understand the internal structure, the environment and other geological events, especially in the identification of sandstone-type uranium mines has an important guiding role.

The type of uranium ore in China is characterized by many types, wide range, shallow burial, large reserves, etc. The main type is sandstone-type uranium ore, with the scarcity of available energy and the increasing demand for energy, at this stage, China's uranium mining is gradually transferred from shallow to deep, the original logging method is gradually not applicable to the current stage of mining, so we need to understand the advantages and disadvantages of different logging techniques, enhance the practicality of logging technology, combine with the actual local mine site, choose the best logging technology, and select the best logging technology for the mine. Combined with the actual situation of local mines, we can choose more economical and effective logging exploration methods to improve the efficiency of uranium mining, obtain higher quality uranium resources, and increase China's own uranium resources reserves.

2. Overview of Logging Techniques

Before 1991, there was only one method of gamma logging (radioactive logging)[2]. With the continuous research now there are resistivity logging, natural potential logging, gravity logging, natural gamma logging, instantaneous neutron logging, sonic logging, seismic logging and electromagnetic logging (Table 2-1). Different logging techniques have different adaptive range and advantages and disadvantages, in the prediction of unknown minerals, often rely only on one is not desirable, are combined with each other, the prediction accuracy will be higher, we step by step on each logging technique is briefly introduced.

To determine the location, thickness, grade and radioactive elements (U, K, Th) of the deposit, we usually use gamma logging, natural gamma logging and instantaneous neutron logging, of which gamma logging is the earliest proposed method of logging, belongs to the indirect logging, is the use of a radiometer to measure the intensity of natural gamma rays of the rock and ore along the borehole, according to the distribution of the gamma field to determine the deposit of the logging method, has the advantage of not being disturbed by the core taking and mineralization unevenness, but the sample analysis period is long, and the interpretation of the data is a big workload[3]. The advantages of core taking and mineralization inhomogeneous interference, but the sample analysis cycle is long, logging data interpretation workload . With the continuous evolution, transient neutron logging was gradually developed, which is a direct uranium logging technique developed independently by China, and plays a very important role in the study of uranium, which can directly determine the original uranium content in the formation[4]. The use of coreless drilling technology reduces the cost and improves the work efficiency, but the field application is less, we still need to combine with the field deposits continue to improve, and will be extended to different mineral research.

Electrical method exploration is used by P. Fox in 1835 in the metal ore exploration, until the beginning of the 20th century, large-scale application in the search for minerals, including the natural electric method, resistivity and electromagnetic logging, mainly used to delineate the stratigraphy, permeability layer, lithology and determine the fracture structure and its production characteristics. In uranium exploration, uranium mineralization is mostly distributed in the high and low transition parts of the natural electric field, and the natural potential method can better circle the redox transition zone, so as to find out the uranium anomaly area[5]; electromagnetic logging is based on the distribution law of magnetism, to find out the underground

tectonic features and mineral distribution, which has obvious reference value for the pre-processing of uranium exploration; resistivity logging is based on the resistivity curve, to obtain some geological information, combined with the permeable layer, non-permeable layer, rock properties and determine the fracture structure and its production characteristics. Resistivity logging is a kind of logging method to calculate the ore body reserves based on the resistivity curve, obtaining some geological information, and combining the permeable layer, non-permeable layer and the location of the top and bottom plates[6].

Density logging and gravity logging are often used as auxiliary markers to analyze mineral geological problems. Regarding density logging, it mainly carries out the delineation of stratigraphic sequences and the identification of the location of ore layers[7], but due to the strong radioactivity of uranium-rich layers of uranium mines, the density logging is easily interfered with by it, which affects the results of the logging; in the prediction of the potential of uranium resources, gravity logging is mainly based on the gravity data of the mining area as a support, and according to the gravity anomalies, the gravity anomalies can infer the depth of tectonic fractures and basins. Tectonic fracture and basin depth, and it has significant achievements for the determination of the location of hidden bumps and ancient river channels[8]. However, it cannot be used for direct uranium resource evaluation, so it is generally applied as an auxiliary curve.

In recent decades, as we deepen the study of logging curve and combine it with computer more and more closely, seismic logging slowly comes into people's view. It mainly uses an artificial seismic source to excite seismic waves to the underground or the movement of underground geological bodies to generate seismic waves, people receive seismic wave signals on the ground, and finally identify underground anomalies through the processing and interpretation of seismic wave data[9].In the early 1970's, it was firstly applied in the survey of sandstone uranium ore, and with the continuous field combination, the micro-motion bathymetry technology has been invented now, which gets rid of the artificial seismic source, and the error becomes smaller, and the efficiency is higher[10]. However, in general, seismic logging is expensive compared to the rest of the logging, and multiple considerations are needed to adopt this technology.

Table 1. Statistics of advantages and disadvantages of different logging techniques

serial number	Logging category	Year	Advantage	inadequate	Application
1	gamma (γ)	Early 20th cent-ury	Accurate, fast, efficie-nt and cost-effective	Influenced by the cha-nge of uranium-radium balance, weak discrimi-nation of uranium cont-ent in deep layers	Ore layer thickness, gr-ade and content
2	natural ga-mma (GR)	1940s	No interference from pore space, groundwa-ter, shielding from lo-wenergy gamma scatt-ering rays	Vulnerability to minera-lization of drilling flui-ds and radioactive min erals, heavy workloads	Understanding the dep-ositional environment, determining the mud c-ontent, and determining the location, thickness, and content of the de-posits
3	Electrical resistivity (RD)	1920s	Strong applicability, High working efficie-ncy, good safety, low cost	Shallow detection dept-h, current interference	Lithologic determinatio-n, stratigraphic delineat-ion, pore structure
4	Densities (DEN)	1950s	Work more efficiently and with fewer work constraints	radioactive interference	Distinguishing sandsto-ne and mudstone form-a-tions, determining str-atigraphic porosity, and identifying gas layers
5	Sonic(AC)	1950s	Low cost, time effici-ent, reliable character-ization and thickness determination of rock formations	Restricted measurement depth, low resolution of thin layers	Determination of form-ation porosity, compari-son of formations, stra-tigraphic age
6	natural po-tenti al(SP)	1930s	Low cost, fast efficie-ncy, no power supply required	Many influencing facto-rs and low logging eff-iciency	Obtaining mud content, differentiating between permeable and imperm-eable for mations
7	well diam-eter (CAL)	1950s	High applicability and precision	Higher impact of bore-holes and cracks	Aids in delineating sandstone and mudstone properties and permeab-ility, checking casing
8	earthquake	1970s	Deep exploration dep-th,high efficiency and strong resolution	expensive	Identification of fractur-es and other typical g-eologic units

In summary, the study analyzes that a single logging technique often fails to accurately identify the degree of uranium enrichment and layers, and that each logging technique has significant limitations, so we need to synthesize each technique according to its respective scope of application as well as their strengths and weaknesses in order to more quickly, economically, and accurately identify the potential of uranium resources.

3. Uranium Identification Characteristics

3.1. Logging response characteristics

In the preliminary survey of uranium resources, it has been found that the closely related measurements are radioactivity, natural gamma, density and resistivity, and their characteristics in uranium-enriched areas are introduced one by one below:

(1) Abnormally high and natural gamma values

In the uranium anomaly area, due to the large amount of radioactive element U, the radioactivity value is often larger than that in other areas, and the positive correlation between the content of U element and the natural gamma amplitude is more significant, while the correlation between the content of Th and K elements and the natural gamma amplitude is weaker. It can be seen that the radioactive anomalies in the study area are mainly caused by the U element, and the gamma and natural gamma logging curves in this area are obviously more prominent than those in other locations, which is conducive to the distinction of other minerals and is an important factor in the judgment of uranium resources.

(2)Lower density values

Uranium ore tends to be enriched in "mud-sand-mud structures" and "sand-mud interbedded structures"[11]. There is no big difference between the density values of conglomerate and sandstone, and the density value of mudstone is lower than that of conglomerate and sandstone, i.e., the density decreases with the increase of mud content. So the density curve has a smaller trend in this structure, which helps to determine the location and thickness of the uranium layer, so we use the density as an auxiliary marker of uranium enrichment in sandstone-type uranium ores.

(3)Slightly higher electrical resistivity

Visual resistivity is more effective in distinguishing lithology, and its value becomes smaller as the rock grain size becomes smaller, previous research is often used for lithology identification, and it is not linked to uranium enrichment, and the resistivity of conglomerate, sandstone, and mudstone becomes smaller with the gradual reduction of rock grain size[12]. Uranium deposits are generally enriched in sandstones and conglomerates, so the resistivity values are generally relatively high in the uranium-enriched areas, which can be used as an auxiliary factor to more accurately identify the location of the deposits.

3.2. Geological features

It is often not enough to predict uranium-rich areas simply by logging curve characteristics, we should also fully understand the law of uranium mineralization, generally from the source of uranium, ore-bearing lithology - petrographic characteristics, hydrogeological conditions, paleoclimatic evolution, tectonics and other aspects of the consideration of the two, which will be more convincing when the two are combined.

With regard to the source of uranium, on the one hand, it is believed that the mineralized material originates directly from the peripheral orogenic belt, and is formed into ore through leaching, migration and accumulation; on the other hand, the deep fluids bring in deep uranium-bearing material, which is enriched and formed into ore in the geologic body with conditions. In terms of lithology and petrography, uranium ore is usually dominated by sandstone conglomerate with complete sand-mud interbedded structure, and pyrite is often accompanied by pyrite output in the uranium-enriched areas, which is also one of the signs of its search for minerals, and the unconformity and its intersection with the faults, the slope zones at the periphery of the basin and the tectonic monopoly zones, etc., can provide storage space for the uranium ore. In terms of hydrology, the complete replenishment-runway-discharge system can provide sufficient power for the migration of uranium elements. The alternating wet and dry climatic environment accelerates the formation of uranium ore.

To summarize, uranium exploration itself is a very comprehensive and difficult technical work, and there are many factors affecting uranium enrichment, relying on the information obtained by a single mineral search method to evaluate the prospect of mineralization is often one-sided. Only by comprehensively analyzing the relationship between different logs and uranium mineralization, combined with the geological conditions of the study area, can we finally determine the uranium anomaly areas and provide sufficient basis for the next step of mining.

4. Conclusion

At this stage, uranium resources is one of the manifestations of the comprehensive national strength, but also an important guarantee of national security, China's uranium resources are obviously in short supply, which requires us to further improve the quality of uranium exploration, different logging methods have different advantages and limitations, which requires us to continue to go to the field to study, and its logging methods continue to improve, a variety of logging technology joint surveys, in order to better adapt to the requirements of the new situation to look for uranium, I believe that as we continue to improve, we will certainly make breakthroughs in the exploration of uranium in China.

(1) There are many kinds of factors affecting enrichment, logging technology is only one aspect, in the field investigation, the source of the survey site, paleoclimate, tectonics, hydrogeology, lithology, lithology and other metallogenic conditions should be taken into account, and then combined with the experimental analysis of the core taken by the drilling and logging, to overcome the external influence of logging, and to find out the uranium-enriched areas more effectively.

(2) The new technologies we have introduced are often not very mature in field application and are subject to many constraints, such as instantaneous neutron logging, CO_2+O_2 method in ground leaching, etc. Often the technology is not fully mastered, which requires us to do more research in the future in this area, and to study the new technologies for the status quo of our country based on the characteristics of the sandstone-type uranium mines of our country with large depths and low grade in the present stage.

(3) In recent years, the application of computers in China has become more and more widespread, and the combination of computer technology and logging technology applied to the search for minerals has the advantages of accuracy, rapidity, high efficiency, low cost, etc., and research efforts in this area should be increased.

References

[1] Lu Junyi. Research on oil-based drilling fluid with drilling lateral resistivity logging technology based on C~4D technology [D]. Zhejiang University, 2018.

[2] Wang Dengxue, Yu Shuiquan, Huang Xiaoxiao. Review and prospect of the development of γ logging technology in China[J]. Uranium Mining Geology, 2023,39(01):124-132.

[3] Tang Xiaochuan, Guan Shaobin. Application of radioactive logging methods in sandstone uranium mines: 2019 Annual Conference of the Chinese Nuclear Society[C]. Baotou, Inner Mongolia, China, 2019.

[4] Tang Xiaochuan, Guan Shaobin, Hu Mingkao, et al. Uranium reserve estimation based on natural gamma logging method[J]. Modern Mining, 2015,31(11):141-143.

[5] Xu Shushan, Yu An, Tang Hongzhi. Application of natural potential method to sandstone-type uranium ore in interlayer oxidation zone[J]. Western Prospecting Engineering, 2017,29 (01):82-84.

[6] Li Qiang, Zhang Xuefen, Wu Xinmin. Application of geophysical logging in the construction of uranium ground leach process holes[J]. Journal of Donghua University of Science and Technology (Natural Science Edition), 2016,39(01):53-58.

[7] Yang Xing, Li Na, Zhao Xu. Study and application of calibration of density logging curves in sandstone-type uranium exploration[J]. Xinjiang Geology, 2021,39(03):497-501.

[8] Wang Yanguo, Liu Peng, Nie Fengjun, et al. Application of heavy magnetic exploration method in sandstone uranium mines[J]. Journal of Donghua University of Science and Technology (Natural Science Edition), 2017,40(01):42-46.

[9] Zheng Xiaojie, Yu Changqing, Nie Fengjun. Application of seismic-logging joint inversion in sandstone uranium exploration[J]. Science, Technology and Engineering, 2020,20 (30): 12342-12348.

[10] Xu Guilai, Mei Ruwu. Comprehensive technical services of seismometers[J]. Physical and Chemical Exploration, 2001 (06):436.

[11] Kang Qiankun. Application of random forest algorithm for anomaly identification in sandstone uranium mines based on logging data[D]. Jilin University, 2020.

[12] Zhao Xianling, Wang Guiwen, Zhou Zhenglong, et al. Review of lithology interpretation methods for geophysical logging[J]. Advances in Geophysics, 2015,30(03):1278-1287.