

Research on Igneous Rock Lithofacies Identification Methods and Development of Related Software

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Abstract: The identification of lithology and facies forms the foundation of igneous rock logging evaluation. Studies on the logging response patterns of igneous rocks with different lithologies and facies in the study area suggest that: conventional logging data can reflect the chemical composition of igneous rocks, while electrical imaging logging can display the rock structure. By integrating these two, igneous rocks can be named. Additionally, the structures and textures seen in electrical imaging logging have a good correlation with the facies of igneous rocks. Combining this with information on the morphology and amplitude from conventional logging, the facies of igneous rocks can be identified. Based on these works, software engineering methodology has been employed for systematic analysis, overall design, detailed design, and coding to develop a software for lithology and facies identification in igneous rocks. This software can automatically or interactively identify lithology and facies, and has demonstrated good practical performance in the processing of actual well data, confirming its usability.

Keywords: Igneous Rock; Lithological Identification; Rock Facies Identification; Software

1. Introduction

Igneous rocks are formed by the cooling and solidification of magma, and their rock types are very complex. Based on where they form within the Earth's crust, igneous rocks can be divided into two main categories: intrusive rocks and extrusive rocks. According to the depth at which magma intrudes, intrusive rocks can be further classified as plutonic rocks, hypabyssal rocks, and subhypabyssal rocks. Depending on their formation, extrusive rocks can be categorized as volcanic lava, volcanoclastic rocks, and volcanoclastic lava. Based on the chemical

properties of the magma, igneous rocks can be classified into alkaline series and subalkaline series, among others. According to their acidity levels, igneous rocks can be further divided into ultrabasic, basic, intermediate, and acidic rocks^[1-9].

A gas field is located in the Songliao Basin of China, where over a dozen wells have encountered igneous gas layers. The igneous rock formations in this region were formed through multiple eruption phases and exhibit complex lithology with a wide variety of rock types. In terms of rock composition, rocks range from basic to acidic types. From the perspective of rock genesis, they include volcanic lava, volcanoclastic rocks, volcanoclastic lava, and intrusive rocks. To establish a solid foundation for the precise logging evaluation of igneous reservoirs in the study area, methods for identifying igneous rock types and facies have been studied, and corresponding software has been developed.

2. Lithology Identification Method

For igneous rocks with similar mineral compositions but different origins or structures, such as rhyolite, (rhyolitic) welded tuff, (rhyolitic) welded tuff with clasts, (rhyolitic) welded tuff breccia, (rhyolitic) welded tuff breccia clast, (rhyolitic) welded tuff clast breccia, rhyolite porphyry, (rhyolitic) tuff, (rhyolitic) volcanic breccia, rhyolitic lapilli-ash tuff, rhyolitic clast volcanic rock, and rhyolitic crystal-ash tuff, these rock types are all classified as acidic rocks. Acidic magma intruding into the crust (less than 1.5 km deep) cools and solidifies to form rhyolite porphyry; acidic magma overflowing or erupting onto the surface cools and consolidates to form rhyolite. Volcanic debris generated by volcanic eruptions accumulates and solidifies to form volcanoclastic rocks. (Rhyolitic) welded tuff, (rhyolitic) welded tuff with clasts, (rhyolitic) welded tuff breccia, (rhyolitic) welded tuff clast breccia, (rhyolitic) tuff, (rhyolitic) volcanic breccia, and rhyolite

porphyry all belong to the category of volcanoclastic rocks, but they differ in the proportions of volcanoclastic debris of different grain sizes. Volcanoclastic debris, when cemented by magma and then cooled and solidified, forms volcanoclastic volcanic rock, which is a transitional type between volcanic rocks and volcanoclastic rocks. Rhyolitic lapilli-ash tuff, rhyolitic clast volcanic rock, and rhyolitic crystal-ash tuff all belong to the category of volcanoclastic volcanic rocks. Since conventional logging primarily reflects information about the chemical composition of rocks and contains very little structural information, it is necessary to use electrical imaging logging to distinguish between these rocks that have similar mineral compositions and chemical compositions but different geological origins and structures.

2.1 Rock Composition Classification Recognition

To utilize conventional well logging for lithological classification, the rock types in the study area are categorized into four classes: basaltic class, andesitic class, rhyolitic class, and trachytic class. Rocks belonging to the same lithological class have similar chemical compositions, thus exhibiting similar responses in conventional well logging. In contrast, rocks from different lithological classes have significantly different chemical compositions,

leading to noticeable differences in their conventional well logging responses.

Well log crossplotting is an intuitive and effective method for identifying igneous rock types. It involves plotting two well log parameters on a two-dimensional graph and determining the values and ranges of the desired parameters based on the coordinates of the intersection points. On the crossplot, the boundaries and distribution areas of various rock types can be visually identified, making it relatively straightforward to recognize igneous rocks.

In the study area, nine well logging curves including natural gamma (GR), deep lateral resistivity (RD), neutron porosity (CNL), bulk density (DEN), compressional slowness (AC), photoelectric absorption cross-section index (PE), uranium (U), thorium (TH), and potassium (K), along with two well logging parameters M and N, were used to generate a total of 20 cross-plots.

Among the 20 cross-plots, the GR-TH cross-plot has the best recognition effect, with a recognition accuracy rate of 93.0%, as shown in the left side of Figure 1. However, in some wells in the study area, natural gamma spectroscopy was not measured. In such cases, the GR-DEN cross-plot can be used, with a recognition accuracy rate of 87.3%, as shown in the right side of Figure 1.

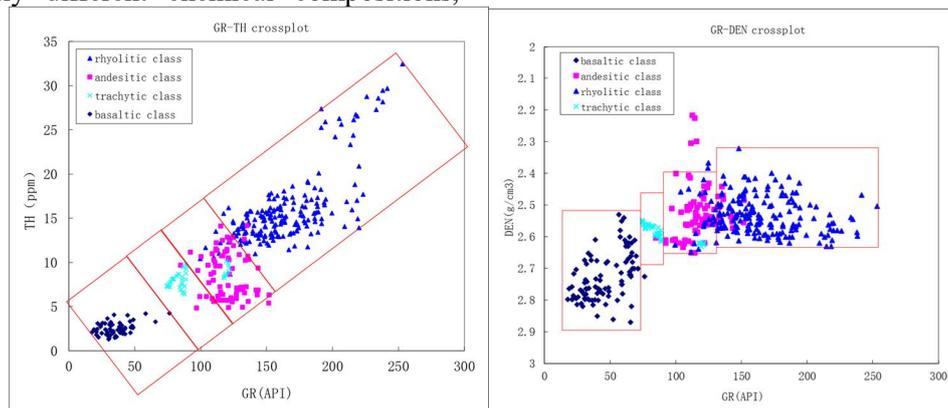


Figure 1. Classification chart of rock components in the study area

2.2 The Comprehensive Identification of Lithology Combines Conventional Logging with Electrical Imaging Logging

Due to the differences in the environment and accumulation conditions formed by volcanic eruptions, each rock type has its inherent structural and textural characteristics. These structural and textural characteristics are crucial

for well logging identification between volcanoclastic rocks and lava, as well as between volcanic rocks and sedimentary rocks. Since igneous rocks have complex compositions, even if the chemical composition of the rocks is the same, different origins and structures can result in different rock types and names. Therefore, it is difficult to distinguish these rocks using conventional well logging curves that only

reflect compositional features. On the other hand, imaging logging images can more intuitively display the rock's structural and textural features. Thus, conventional well logging can be used to identify rock compositions, while imaging logging can be used to identify rock structures and textures, which can then be combined to comprehensively determine the rock type. Figure 2 shows the matching diagram of the conventional logging curves, FMI images, and

core photographs for the coring section of Well XX101. From the conventional logging responses, the GR value is around 160 API, and the DEN value is approximately 2.60 g/cm³. According to the cross-plot chart, this section belongs to the rhyolite category. The FMI images show a lava structure and massive texture, which is identified as rhyolite and is consistent with the actual core conditions.

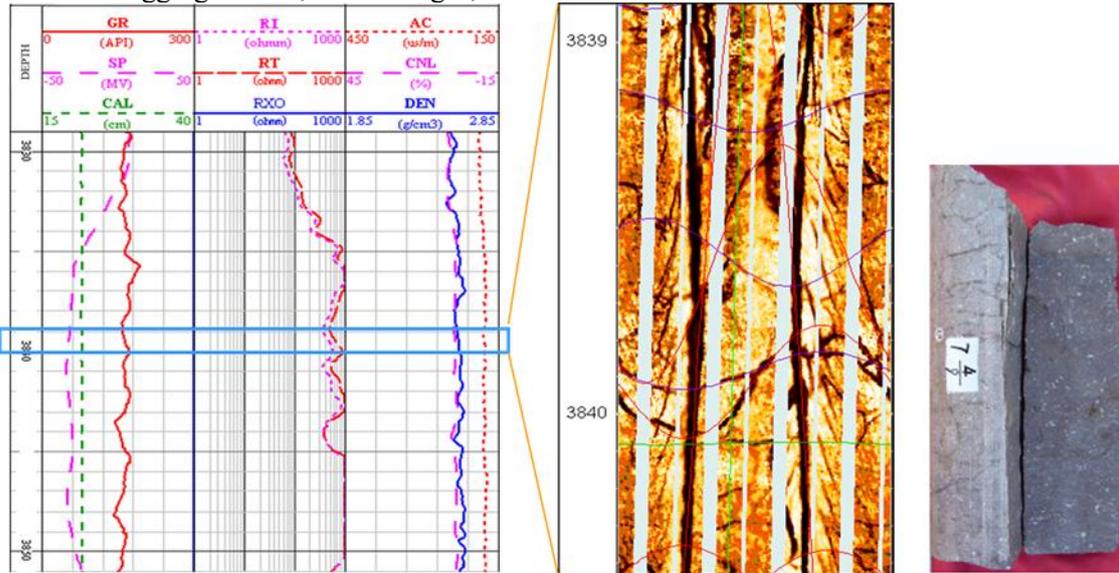


Figure 2. The Comprehensive Identification of Lithology Combines Conventional Logging with Electrical Imaging Logging

3. Facies Identification Method

In the study, igneous rocks were classified into 5 phases and 15 subphases. After analyzing the geological data of the study area, it was determined that the area develops 4 phases and 7 subphases, including: fall-out subphase, pyroclastic flow subphase, lower subphase of overflow, middle subphase of overflow, upper subphase of overflow, transported volcanoclastic sedimentary rock subphase, and subvolcanic rock phase. By summarizing the conventional logging response characteristics and the electrical imaging logging response characteristics of different subphases, it was found that there is a good correspondence between the igneous rock subphases and the logging response characteristics: the rock structure and texture displayed by electrical imaging can indicate the igneous rock phase (Figure 3), and the shape, amplitude, and other information from conventional logging curves can also reflect the rock phase to a certain extent. Therefore, a method for identifying igneous rock facies using logging data was established.

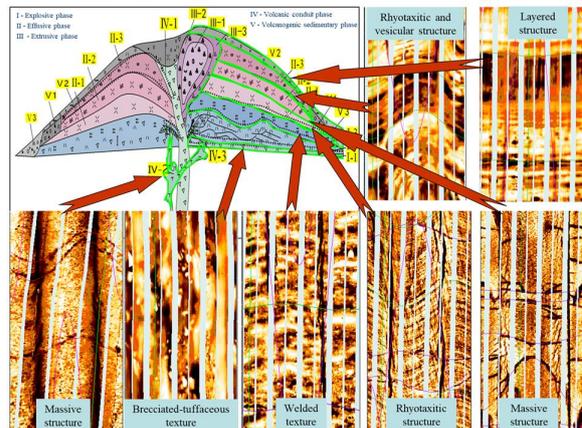


Figure 3. The Correspondence Between Rock Facies and Imaging Logging Characteristics

4. Related Software Development

In accordance with the principles of software engineering^[10], the software for identifying the lithology and facies of igneous rocks has undergone systematic analysis, overall design, detailed design, coding, and testing. The main functions of the software include: loading well logging data, displaying well logging curve charts, automatic recognition and

standard display/editing, displaying and managing electrical imaging libraries, automatic lithology identification, human-computer interactive recognition, and outputting identification result files. Based on problem definition, feasibility study, and requirement analysis of the software, functional analysis is conducted, dividing the software into modules. The sub-modules are refined step by step to form

several programmable modules. The internal details of the program modules are designed, including algorithms, data structures, and detailed interface information between each module. Figure 4 is the software data flow design diagram. The software is then coded, unit tested, and integrated tested based on the design, ultimately completing the development of the igneous rock lithofacies identification software.

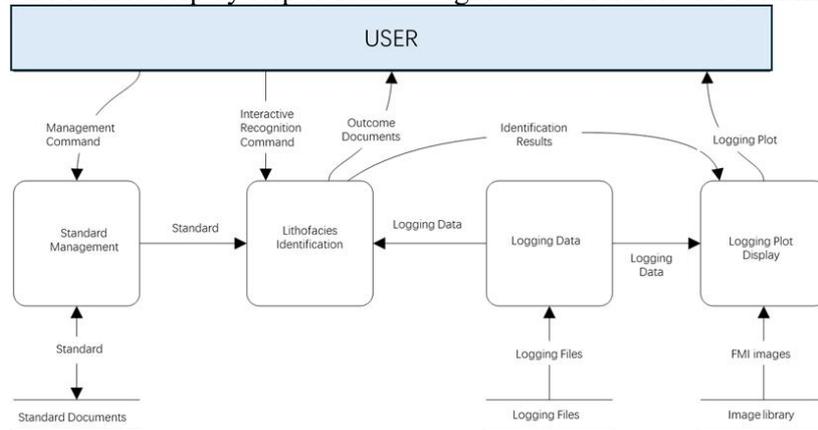


Figure 4. Data Flow Design Diagram of the Software

Applying the software to the processing of actual well data (Figure 5), the routine well logging data is loaded. Based on the recognition criteria in the software (using cross-plot methods), automatic identification of major rock types is performed. Users can compare the electrical imaging well logging graphic features with typical structural and tectonic examples in the software's image library to identify rock

structures and tectonic characteristics. By combining the display of routine well logging curves, shapes, amplitudes, and other features shown in the software's curve diagrams, users can complete the identification of igneous rock types and facies. The results can be displayed in the software and can also be exported as outcome files, confirming the usability of the software.

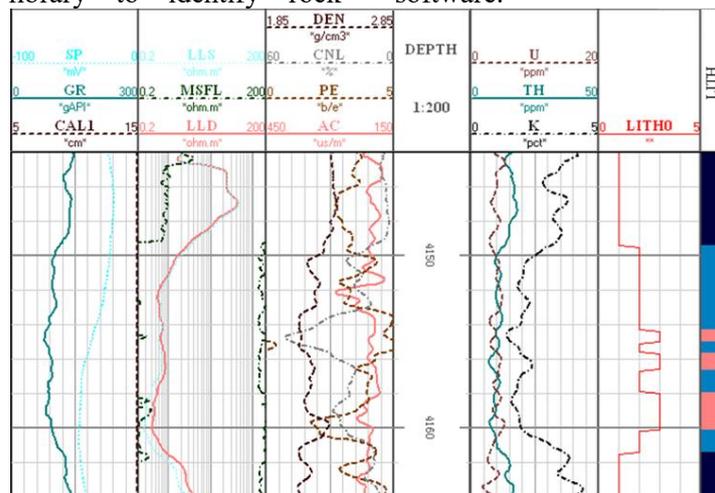


Figure 5. The Effect of Software Application

5. Conclusions

(1) The igneous rocks in the study area are classified into four categories based on their rock composition. Conventional well log parameter crossplot charts can be used to differentiate major rock types, with GR-TH and GR-DEN

crossplot charts showing particularly good results. Combining the information on rock structure displayed by electrical imaging logs, the rock lithology can be identified.

(2) The rock structures and formations indicated by the electrical imaging logs in the study area provide good indications of the igneous rock

facies. By combining the amplitude and shape characteristics of conventional logging curves, the igneous rock facies can be comprehensively identified.

(3) By developing the software according to the principles of software engineering and applying the completed software to the processing of actual well data, the required functions can be accomplished, thus verifying the practicality of the software.

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