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Development Model and Quantitative Prediction of Igneous Rock in S Oilfield, the Bohai Sea Area

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Abstract

The structure of S Oilfield of Bohai sea area in China is located in the low uplift slope zone of the Dongwa Laibei area in the Huanghekou depression. The target interval of the oilfield belongs to the Paleogene layered structural oil reservoir under the influence of igneous rocks. Due to the widespread development of igneous rocks, and the diversity of igneous rock types, the structure is complex, and the lateral changes are intense. The differences in volcanic eruption intensity and volcanic materials made the igneous rock masses overlap each other, with rapid changes in lithofacies, and complex seismic reflection structures. Therefore, it was difficult to carry out fine characterization of igneous rocks. Based on the lithofacies model, lithofacies combination types, and seismic response characteristics of volcanic mechanisms, this paper summarized three types of development models of volcanic mechanisms in the study area. At the same time, through technical means such as stratigraphic slicing, seismic attribute extraction, and attribute optimization analysis, the spatial distribution characteristics of various facies zones of igneous rocks at different stages were described in detail, achieving precise prediction of igneous rocks in Bozhong S Oilfield. During the development process of the oilfield, the technical research results guided the optimization of well locations and provided technical support for the efficient development of the oilfield.

Keywords

Igneous Rock, Facies Model, Volcanic Institutions, Seismic Attribute

1. Introduction

With the continuous improvement of oil and gas field development technology, the exploration and development of oil and gas reservoirs related to igneous rocks is becoming increasingly important. The types of igneous rocks are diverse, with complex structures and violent lateral changes. The differences in volcanic eruption intensity and the emplacement environment of volcanic materials make the igneous rocks overlap each other, resulting in rapid changes in lithofacies, and complex seismic reflection structures. Lithological analysis of igneous rocks provides a geological basis for lithofacies identification and volcanic eruption stage division, and is a basic means to depict the spatial distribution of igneous rocks. Through comprehensive analysis of logging, core, and test data, it provides a technical means for lithologic identification, and provides an effective discrimination method for quantitative identification of complex genetic igneous rocks (Wang et al., 2008a). The spatial distribution characteristics of igneous rocks are characterized by the types of igneous facies assemblages and their genetic relationships (Si et al., 2012), based on volcanic stratigraphy, identifying and tracking volcanic eruptive cycles, eruptive periods, volcanic institutions, and igneous rock masses can effectively guide the exploration and development of igneous oil and gas reservoirs (Wu et al., 2011; Liu & Zhang, 2010; Wang et al., 2008b). Different igneous rock facies have different attribute characteristics. The characterization of igneous rocks is mainly based on techniques such as seismic facies, seismic attributes, time slices, and stratigraphic slices, and the distribution of igneous rock facies is predicted on the plane and section, respectively. Igneous rock, as a special lithology of abnormal sedimentation, is difficult to quantitatively describe by conventional methods, which restricts the efficient development of igneous rock oilfield. Based on the lithofacies model, lithofacies combination types, and seismic response characteristics of volcanic mechanisms, this paper summarized three types of development models of volcanic mechanisms in the study area. The spatial distribution characteristics of various facies zones of igneous rocks at different stages were described in detail, achieving precise prediction of igneous rocks in Bozhong S Oilfield. During the development process of the oilfield, the technical research results guided the optimization of well locations and provided technical support for the efficient development of the oilfield.

2. Geological Setting

Bozhong S Oilfield is located on the north side of Laibei Low Rise in Huanghekou Sag, Bohai Bay Basin, with strong tectonic activity and relatively developed large and medium-sized faults. The main structural area is a complex fault block structure. Affected by boundary faults, the oilfield is subdivided into multiple fault blocks by faults. During the sedimentary period of the Paleogene Dongying Formation, volcanic eruptions were frequent in the oilfield, and a large set of igneous rocks developed in the stratum (Guo et al., 2018). This set of igneous rocks overlies the target layer. Due to the shielding effect of igneous rocks on seismic energy, the seismic reflection characteristics of conventional sandstone reservoirs are complex, making it difficult to predict the reservoir using geological data and posing risks to the structure. This study comprehensively utilizes drilling, logging, and seismic data, combined with previous research results on igneous rocks (Tang et al., 2007; Chen, 2003; Pan et al., 2015), detailed research on the prediction of igneous rock facies zones in Bozhong S Oilfield has been carried out, providing technical support for the efficient development of the oilfield.

3. Analysis of the Development Pattern of Igneous Rocks

Volcanic institutions refer to the accumulation of volcanic eruptions in the vicinity of volcanic vents during the same period, forming various lithological and lithofacies combinations and morphological relationships of volcanic eruptions (Huang et al., 2007). The Bozhong S Oilfield mainly develops a composite layered volcanic structure composed of various igneous rock facies formed by multiple volcanic eruptions. The top of the volcanic structure is generally distributed with main volcanic vents, and the slopes around the volcanic vents are mainly distributed with volcanoes accompanied by volcanic channels. Two types of igneous rock development modes in the study area are identified by integrating data such as core, seismic facies, and stratigraphic slices as follows.

3.1. Central Composite Layered Volcanic Mechanism

The central composite layered volcanic mechanism is composed of multiple types of igneous rock facies superimposed on each other, and the profile shows an umbrella shape. Through the seismic reflection profile, it can be seen that the profile cuts through two volcanic mechanisms, which are interconnected and inlaid with each other, presenting a composite umbrella shape; On the time slice of the variance body, the attribute value of the crater is high, with a planar shape that is nearly circular, and the internal structure usually presents as a ring shape (**Figure 1** and **Figure 2**). Combining the seismic profile and the variance slice

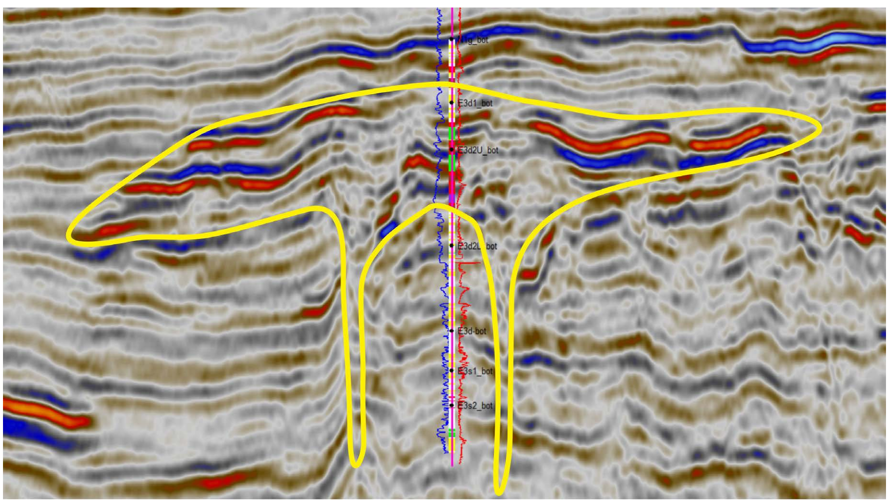

Figure 1. Seismic facies of central composite layered volcanic mechanism.

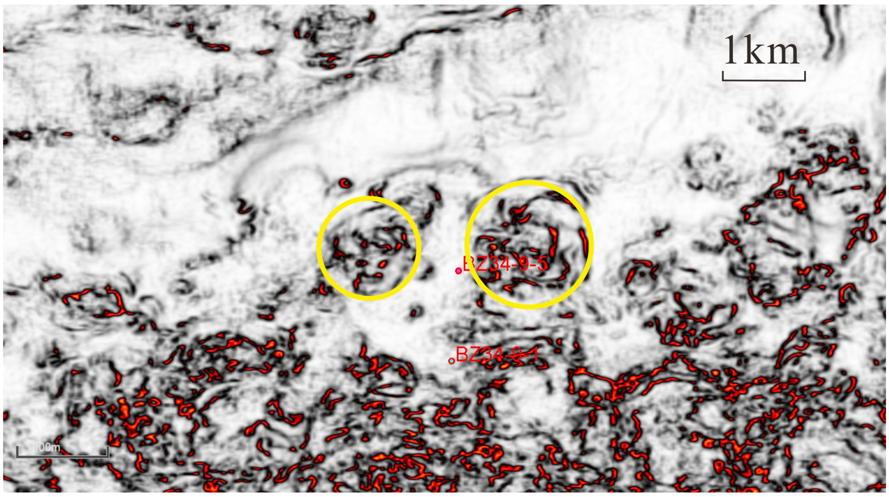

Figure 2. Central composite layered volcanic mechanism Seismic facies Central composite layered volcanic mechanism Variance slice.

with the geological model, a central composite layered volcanic development model is summarized (**Figure 3**). The volcanic mechanism profile is umbrella-shaped, and the volcanic channel is inverted cone shaped. The volcanic eruptive material develops on the top of the volcanic channel and pinches out in all directions, volcanic crater, explosion facies, and effusion facies are mainly developed. Volcanic sedimentary facies are usually developed near volcanic vents and filled to form a negative terrain. Sedimentary facies and igneous rock facies are in unconformable contact, and sedimentary facies are overlying the entire volcanic structure. During the condensation process of acidic magma, the development of intrusive facies is generally accompanied by the development of intrusive facies, which develops near volcanic vents. The igneous rocks developed in Bozhong S Oilfield are mainly basic basalt, and the intrusive facies are relatively undeveloped.

3.2. Central Hydrothermal Volcanic Mechanism

Unlike the central composite layered volcanic mechanism, the central hydrothermal volcanic mechanism emits very little solid matter, mainly gas and liquid. There is no developed oblique structure around the volcanic channel, presenting an inverted cone shape. The reflection inside the channel is relatively continuous, which is caused by the relatively slow deposition of broken surrounding rock. The overlying strata receive the invasion of gas and liquid, changing the physical properties of the rock, and the rock interface has a relatively large wave impedance, A highly continuous high amplitude reflection event is developed at the top of the channel; On the time slice of the variance volume, the attribute value of the crater is high, and the plane shape is nearly circular (**Figure 4** and **Figure 5**). Based on the geological model, a central hydrothermal volcanic development model is summarized (**Figure 6**). Under the action of tensile stress, the volcanic mechanism has an inverted conical shape, with heat supply veins

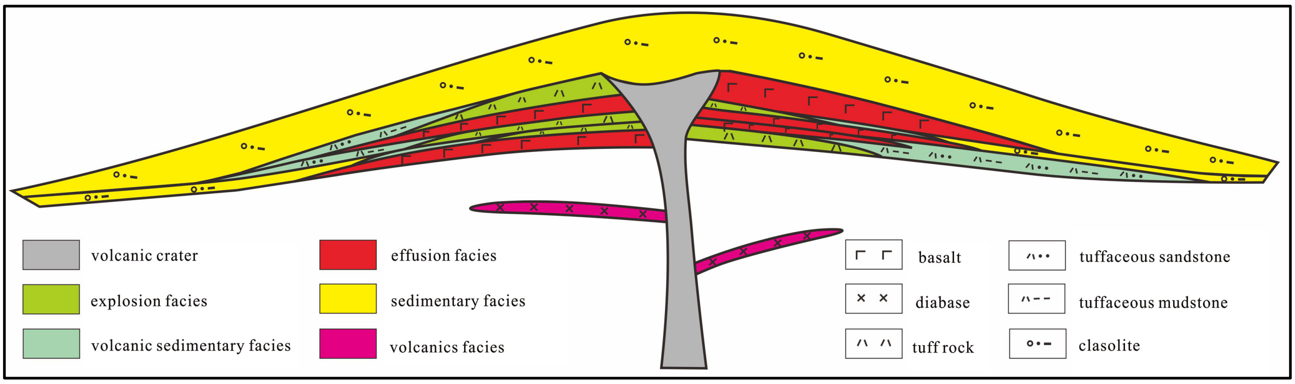

Figure 3. Central composite layered volcanic mechanism model.

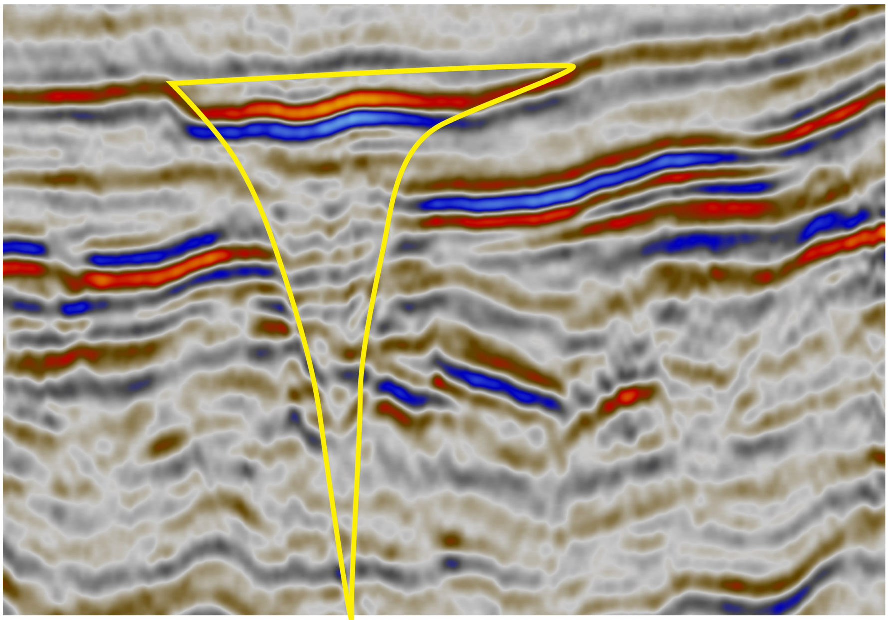

Figure 4. Seismic facies of central hydrothermal volcanic mechanism.

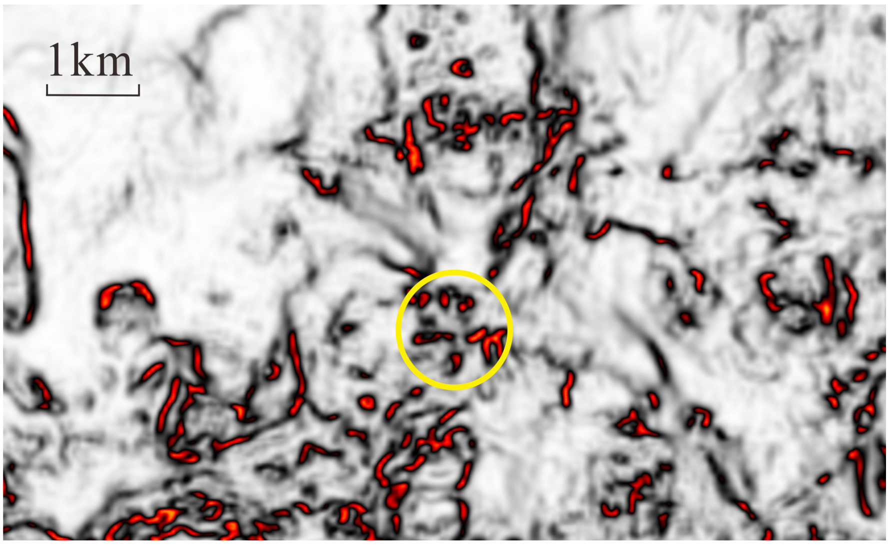

Figure 5. Central hydrothermal volcanic mechanism variance slice.

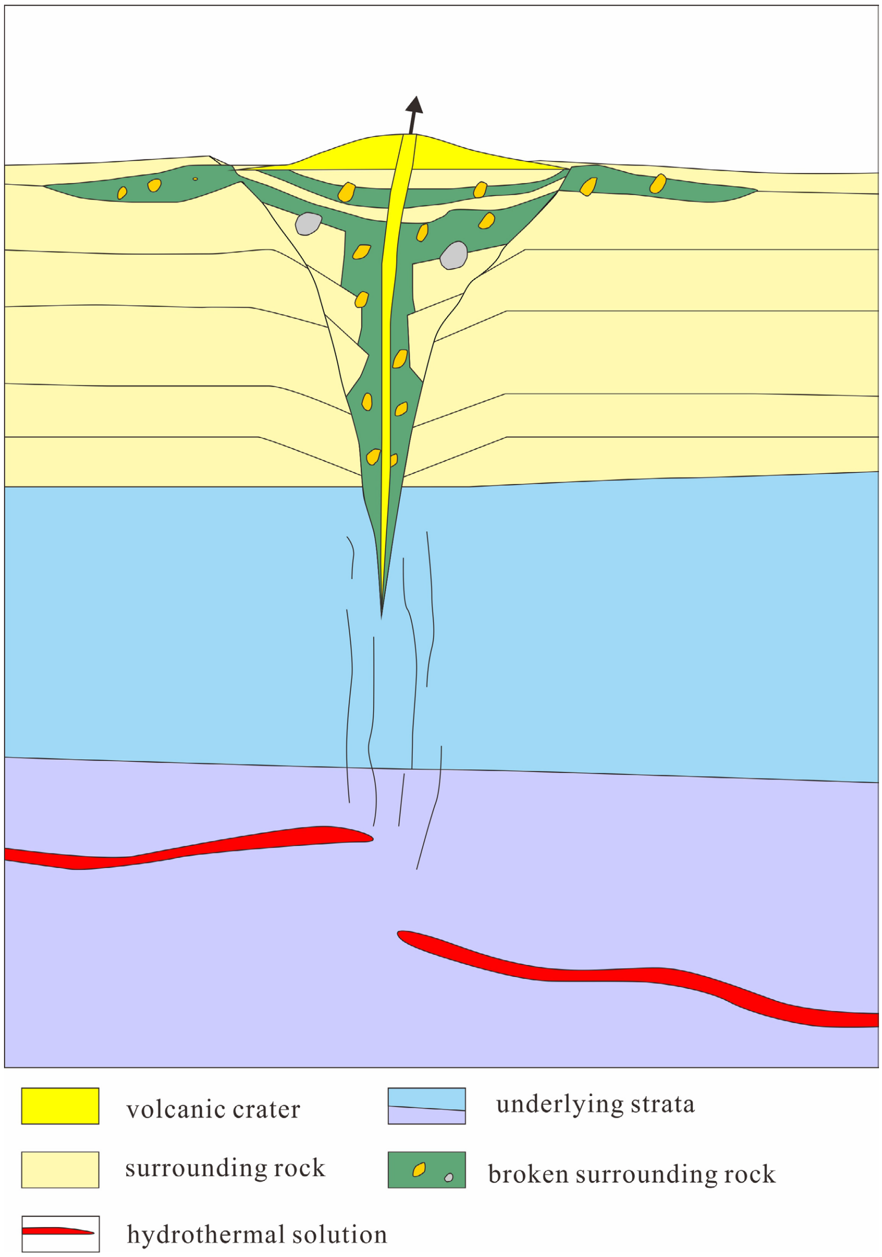

Figure 6. Central hydrothermal volcanic mechanism model.

developed at the bottom, generating high energy gas liquid upwelling and erupting out of the surface. The central fissure hydrothermal volcanic mechanism has the characteristics of episodic eruption. When the energy decreases, the eruption stops, the overlying sediment is compacted, and the bottom continues to generate high pressure, brewing the next eruption. When the accumulated energy is large enough to break through the overlying rock layer, another gas-liquid eruption begins.

4. Methods and Results

Based on a clear understanding of the development pattern of igneous rocks, a series of time slices and stratigraphic slices are used to predict the igneous rock facies on the plane. Multiple attribute extraction is used to optimize the attributes that respond well to the igneous rock facies. The combination of plane and profile analysis is used to establish planar identification indicators for volcanic crater, effusion facies, explosion facies, and volcanics facies. After identifying the plane identification signs of different igneous rock facies, predict the plane distribution characteristics of igneous rock facies.

4.1. Plane Characterization of Volcanic Crater

The volcanic crater is mainly formed by the magma retention and volcanic backfill of the volcanic channel, which differ greatly from the seismic response characteristics of the surrounding rock. The seismic reflection characteristics are inverted cone shaped chaotic reflections, and the planar shape is circular on the time slice of the variance body. The seismic facies are parallel sub parallel reflection surrounded chaotic reflections. Due to the conical shape of the volcanic channel, the internal lithological combination is complex, and the peripheral area is usually developed with continuous effusion facies, On the root mean square stratigraphic section, generally circular and elliptical low amplitude areas are presented, and on the variance section, circular and elliptical high abnormal values are presented, or lumpy distribution is presented, with a variance value greater than 0.4. Using the variance attribute section can better identify volcanic crater (Figure 7 and Figure 8).

4.2. Plane Characterization of Effusion Facies

The overflow phase is formed at the bottom of a volcanic eruption cycle, and is

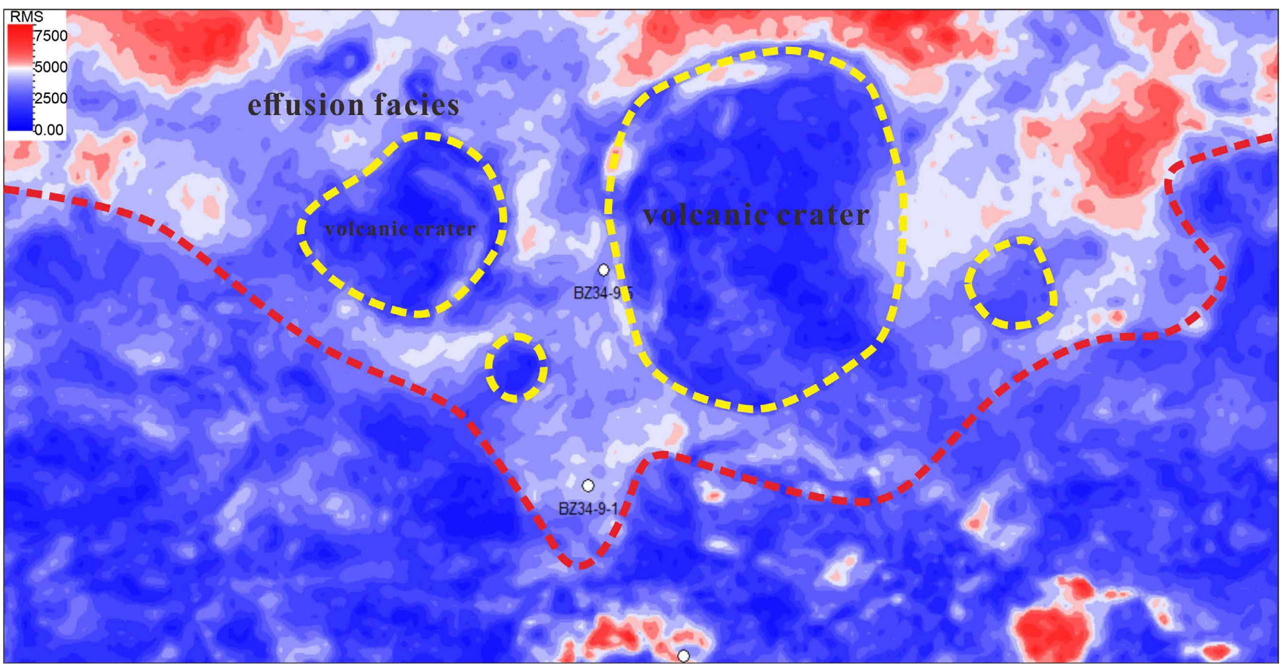

Figure 7. Root mean square amplitude attribute stratigraphic slice.

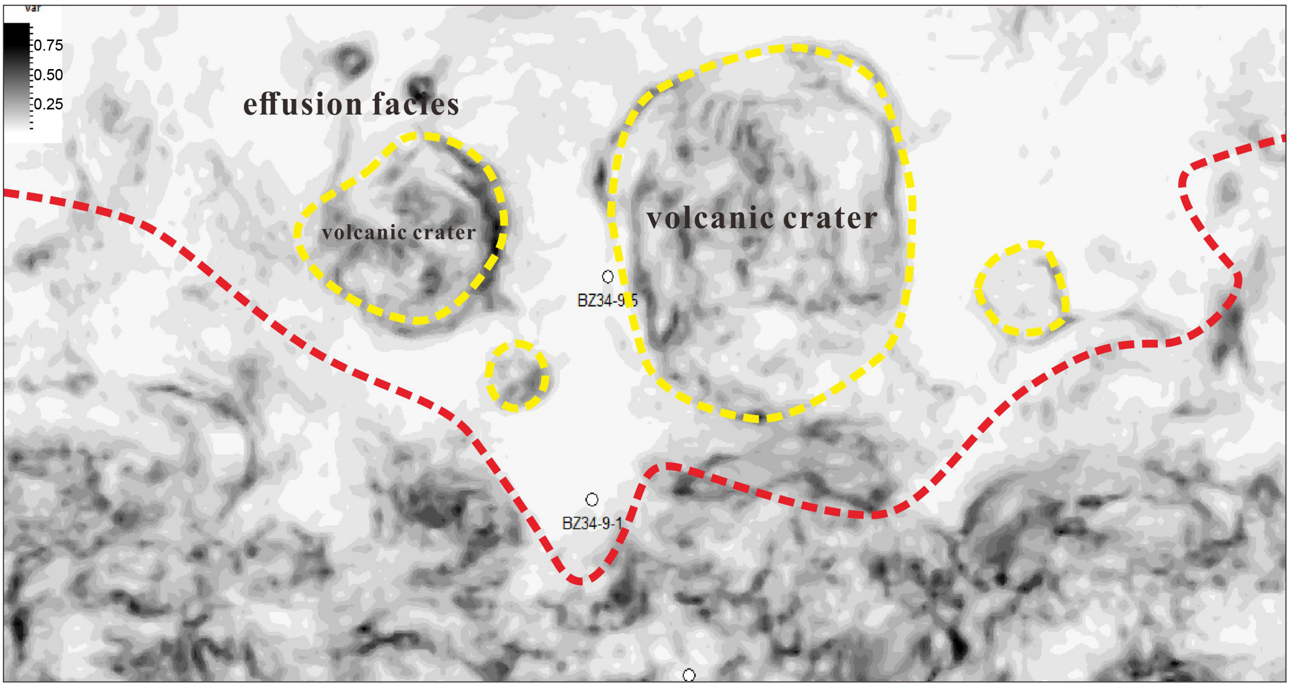

Figure 8. Variance attribute stratum slice.

gradually formed by cold solidification of magma as it flows along the surface. The internal lava of the overflow phase has good continuity and relatively stable distribution. The overflow phase magmatic rock differs greatly from the surrounding rock. On the seismic profile, it mostly exhibits medium to strong amplitude, medium to low frequency, and good continuity seismic reflection characteristics. The parallel to sub parallel reflection structure has a layered shape, and the root mean square amplitude attribute is relatively sensitive to the overflow phase in the study area. It exhibits a sheetlike high amplitude anomaly, with an amplitude value greater than 4500, distributed around the volcanic channel, On the variance slice, it shows a low abnormal value with a slice shape, and the variance value is less than 0.1 (**Figure 7** and **Figure 8**).

4.3. Plane Characterization of Explosion Facies

Due to the presence of a large amount of gas in the magma, during the eruption process, enormous pressure is generated on the surrounding rock, resulting in the explosion of the magma and surrounding rock, resulting in the accumulation of volcanic debris of different particle sizes. The explosion facies sediments near the crater accumulate rapidly, and on seismic profiles, they mostly exhibit parallel sub parallel reflection structures with medium to strong amplitude, relatively high frequency, and medium to poor continuity, or exhibit chaotic reflection characteristics, Under the action of transport media (water, wind), it can be transported to a location far away from the crater, exhibiting relatively good continuity in seismic parallel reflection characteristics. According to analysis, in Bozhong S Oilfield, the root mean square amplitude attribute is relatively sensitive to the response of explosion facies. Because explosion facies are formed by rapid accumulation of volcanic materials, their stratification is poor. Through calibration of Well 6, the plane shows a spotted medium to high amplitude anomaly, with amplitude values greater than 3000 (Figure 9).

4.4. Plane Characterization of Volcanics Facies

Subigneous rock refers to volcanic lava that moves upward along the volcanic channel and intrudes along or through the layer when encountering fractures. It may generate strong reflections on the seismic profile, presenting a parallel to sub parallel reflection structure with good continuity. Subigneous rock in Bozhong S Oilfield is mainly characterized by the occurrence of rock beds, with consistent occurrence and good continuity between the upper and lower surrounding rocks. Subigneous rock is generally developed around the volcanic channel, generally bounded by fractures, and the boundary is relatively regular, According to the calibration of Well E-1, it is generally shown as a flaky high amplitude region on the root mean square stratigraphic section (Figure 10).

4.5. Research Results

Based on the identification of single well facies and profile facies, combined with the interlayer variance attribute and the interlayer root mean square amplitude attribute, a planar distribution map of igneous rock facies was finally obtained (Figure 11). The results show that the overflow and explosion facies in the study area are scattered and dominated by explosion facies. There are also many igneous rocks in the southeast of the study area. According to the distribution location of the volcanic channels, it can be found that the volcanic channels are distributed in two directions, namely, in the NW and NE directions in a beaded

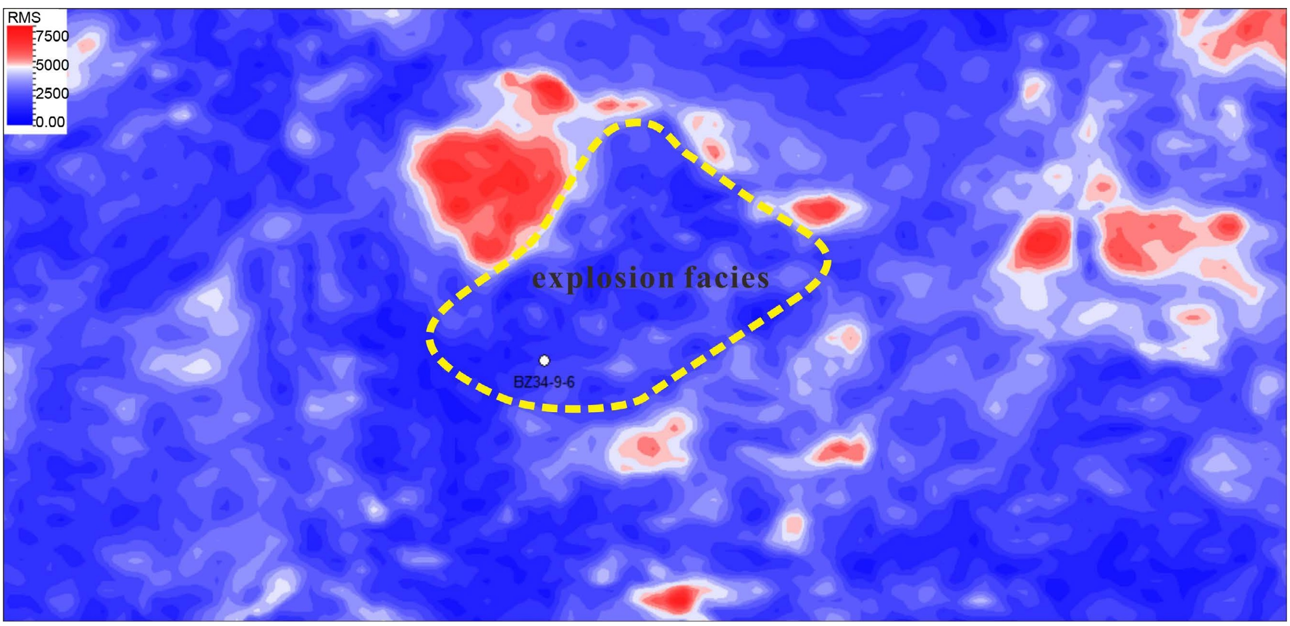

Figure 9. Seismic response characteristics of explosion facies.

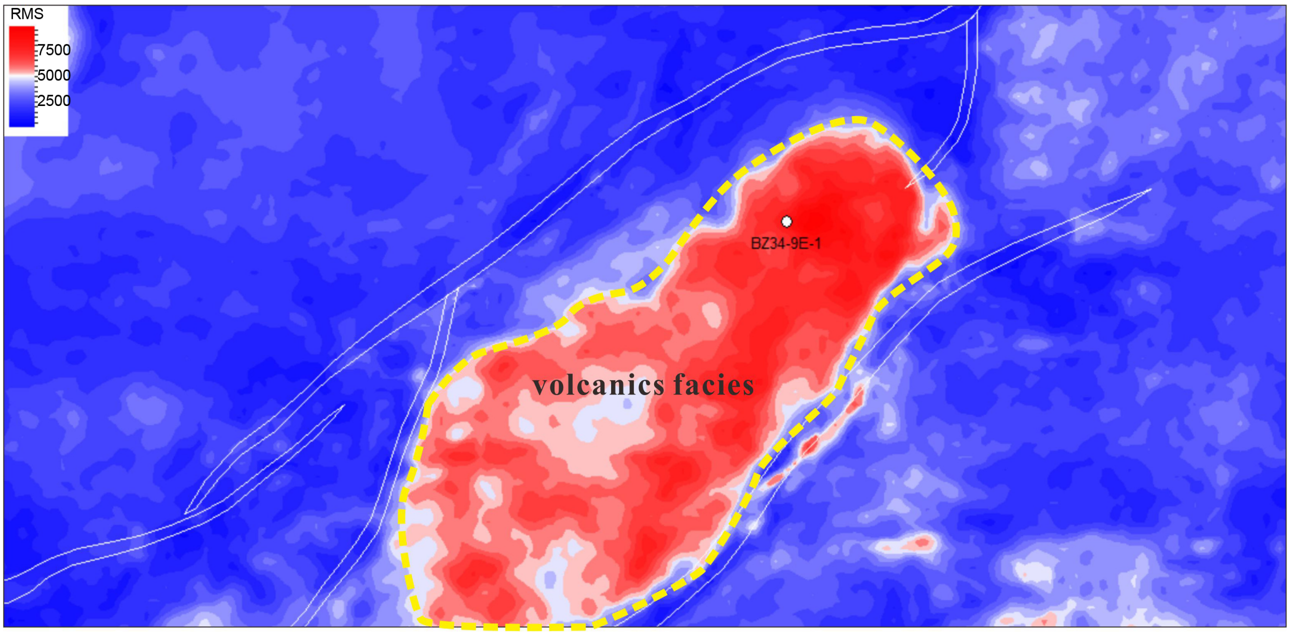

Figure 10. Seismic response characteristics of volcanics facies.

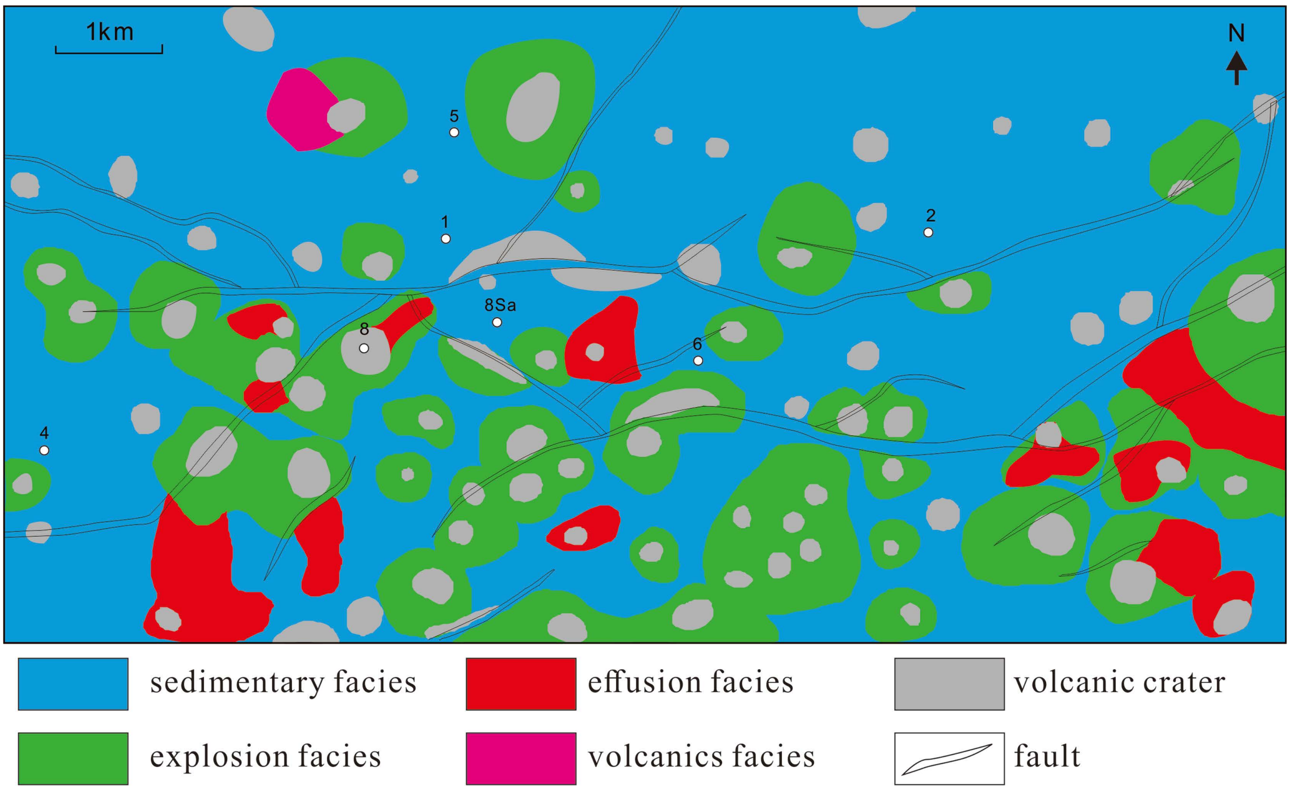

Figure 11. Plane distribution of igneous Lithofacies belt in the eastern third member.

pattern, indicating the path of magma migration in the underground, mainly along the NW and NE directions. At relatively weak overlying strata, magma overflows the surface in a central or center fissure manner. As the magma migrates, its energy gradually decreases and is released at major faults, Volcanic

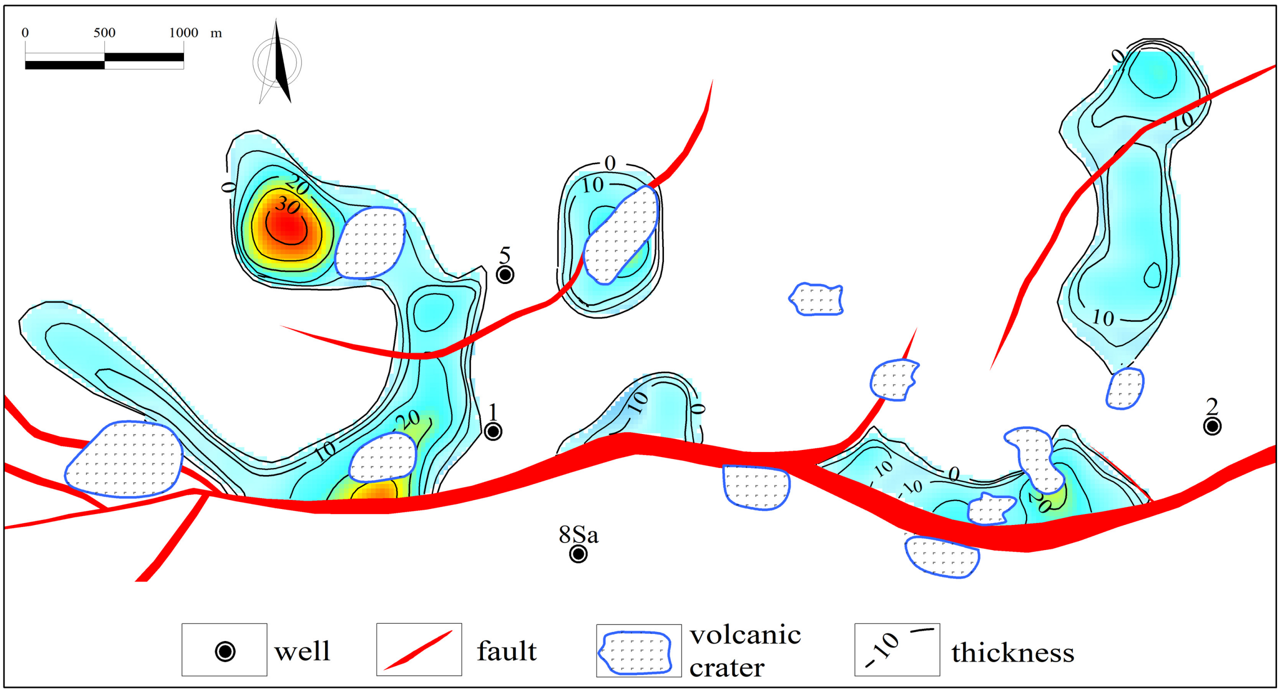

Figure 12. Distribution thickness of igneous rock in the third member of the east.

activity gradually weakened in the north of the study area, with less volcanic material distributed。

Finally, the thickness maps of igneous rocks of the East Third Member I and II oil formations were drawn (**Figure 12**). From the early to late stages of the Dongying Formation, volcanic activity increased and the distribution scale of igneous rocks gradually increased. From the East Third Member II oil formation to the I oil formation, the development scale of igneous rocks gradually increased, with the development area increasing from 0.28 km^2 to 0.56 km^2. This technology realizes the quantitative description of igneous rocks, guides the optimization research of development well locations, and realizes the efficient development of oil fields.

5. Conclusion

1) Through seismic facies analysis, the seismic facies identification characteristics of three volcanic development modes in the study area, namely, central composite layered volcanic mechanism, central hydrothermal volcanic mechanism, and central fissure composite layered volcanic mechanism, were obtained, and the development mechanism was analyzed, and corresponding development pattern diagrams were summarized.

2) The plane distribution characteristics of igneous rocks in Bozhong S oilfield are finely characterized through technical means such as stratigraphic slicing, seismic attribute extraction, and attribute optimization analysis. The seismic reflection characteristics of volcanic crater, effusion facies, explosion facies, and volcanics facies are summarized. The variance stratigraphic slice is more accu-

rate in depicting the plane of volcanic crater, and the root mean square amplitude stratigraphic slice is more accurate in depicting the plane of effusion facies, explosion facies, and volcanics facies.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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