A GIS-based grid model for spatial data management and preliminary applications for assessing deep oil-gas resources

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Abstract. With the development and maturity of mid-shallow reservoirs, deep reservoirs have become the main exploration targets recently. Deep oil-gas exploration and evaluation are facing great challenges of multi-source data utilization. The aim of the exploration is to verify the resources, location and scale of deep oil and gas, which could be well managed and calculated by the means of Geographic Information System (GIS). In this paper, a grid management and calculation method of deep oil and gas resources is proposed based on ArcGIS 10.5 software, which was preliminarily applied to evaluate the deep oil and gas resources in Tarim Basin. The hydrocarbon generation intensity is calculated and analyzed according to distinct source rocks, spatial patterns, and temporal sequence. The results show that the hydrocarbon generation intensity in the Lower Cambrian strata of Tarim Basin is considerable in total and concentrated in spatial distribution. The total hydrocarbon generation intensity in argillaceous source rocks is higher than that in carbonate source rocks. Among the four types of hydrocarbons including oil, light oil, gas and methane, the generation intensity of the oil is the highest.

1. Introduction
With the development and maturity of mid-shallow reservoirs, deep reservoirs have become the main exploration targets recently. At present, more than 1000 deep oil and gas fields have been exploited all over the world. However, the unified and standardized definition of deep strata has not formed yet, and the international relative recognition for deep strata is that the buried depth is greater than or equal to 4500m. The potential of deep oil and gas resources is huge, and the proportion of natural gas in deep exploration is relatively high. The marine strata in Tarim, Sichuan and Ordos basins in China show bright prospects for deep oil and gas exploration [1].

The aim of the exploration is to verify the resources, location and scale of deep oil and gas, including residual thicknesses, total organic carbon (TOC) and vitrinite reflectance (Ro%). Oil and gas technology is also developing towards information-orientated and visualization-utilized. The acquisition of deep oil and gas exploration data mostly depends on the progress of geophysical technology. The reform of high-precision 3D seismic technology has promoted the breakthrough of deep oil-gas exploration and strati-graphic profile analysis. Oil and gas resources evaluation provides decision-make support for further oil and gas exploration as well as development through comprehensive analysis of multi-source geological information. The data are mainly from well
logging and drilling engineering [2]. However, the spatial distribution of drilling is irregular and uneven. Deep oil-gas exploration and evaluation are facing great challenges of multi-source data utilization.

The traditional thematic map of oil and gas geology relies on manual interpreting, which possesses high labor intensity and low work efficiency. Therefore, it is hard to realize the comprehensive management and sophisticate analysis of the maps. Su et al. (2012) proposed a global oil and gas geological information sharing system, which organically combined geographic information system and oil-gas resources evaluation [3]. Geographic Information System (GIS) embodies the functions of geospatial data management, three-dimensional spatial analysis, as well as visual expression of images and so on [4].

GIS software has great advantages in the input, management, analysis, processing and visualization of surface and underground geological information. It could realize geographic registration under different coordinate systems, convert and store raster and vector data, output plane and three-dimensional thematic maps, evaluate static and dynamic geological elements, as well as integrate spatial data management and calculation evaluation analysis, which provides an efficient and practicable technology for deep oil and gas exploration.

It is universally acknowledged that the lower Cambrian is the main source rock in Tarim Basin. The value of residual thickness, TOC and maturity (Ro%) of the source rock are easy to be obtained by logging technology. However, there has been a lack of systematic work on the spatial distribution and resource calculation of hydrocarbon source kitchens at present. In this paper, a grid management and calculation method of deep oil and gas resources was proposed based on ArcGIS 10.5 software, which was preliminarily applied to evaluate deep oil and gas resources in Tarim Basin. It shows significance for the calculation and exploration of deep oil and gas resources.

2. Technical Method

2.1. Image processing

The traditional map digitization method commonly uses the method of hand tracking digitization. This paper combines a scanning digitization method [5] with a linear feature extraction method, and proposes an interactive method of linear binarization and feature extraction. The data source of this paper is an atlas of Oil and Gas Resources Evaluation Paper Maps of Tarim Basin. The technical flow chart is shown in Figure 1.

![Figure 1. Technical flow chart of this study](image-url)
2.1.1 Input data
Printed maps are scanned into digital raster image by scanner, which are subsequently input into ArcGIS software. Ten points including Hotan, Korla, Shaya, Bachu, Minfeng, Keriya, Zep, Wuqia and Yuli are taken as control points, and the projection coordinate system is defined to transform spatial coordinates of the scanned maps. All maps will be registered into a uniform coordinate system using control points.

2.1.2 Image vectorization
After spatial correction, the maps are binarized with adjusted threshold to extract linear features. The feature information of contour and boundary are extracted by automatic tracking vectorization method. The vectorization of linear objects in ArcGIS software follows the general topological rules. In particular, the lines in the same line layer cannot overlap, and the different line layers cannot intersect. As shown in figure (a) of Figure 1, the linear features are sophisticate. Therefore, manual intervention was a necessary step for refining the elements, including broken line connection, node disconnection and noise elimination.

2.1.3 Image rasterization
Consequently, the vector maps are rasterized into $1 \times 1 \text{ km}^2$ and the maps are clipped by the extracted boundary to facilitate the subsequent data management, calculation and analysis. The results of current Ro% (b), TOC (c) and Residual Thickness (d) Grid maps of Lower Cambrian argillaceous source rocks in Tarim Basin are shown in Figure 1.

![Figure 1](image)

**Figure 1.** (a) and (b) Current Ro% isoline Vector and Grid map of Lower Cambrian bottom boundary in Tarim Basin; (c) and (d) Current TOC and Residual Thickness Grid maps of Lower Cambrian argillaceous source rocks in Tarim Basin. Here, Ro%, TOC and residual thickness are variables for calculating hydrocarbon generation.

![Figure 2](image)

**Figure 2.** (a) and (b) Current Ro% isoline Vector and Grid map of Lower Cambrian bottom boundary in Tarim Basin; (c) and (d) Current TOC and Residual Thickness Grid maps of Lower Cambrian argillaceous source rocks in Tarim Basin. Here, Ro%, TOC and residual thickness are variables for calculating hydrocarbon generation.
2.2. Grid calculation
Lying between Tianshan Mountains and Kunlun Mountains, Tarim Basin is the largest inland basin in China. It is a large-scale composite and stable basin with multiple sets of source rocks restricted by numerous deep faults. Multi blocks and multi-layer systems in Tarim Basin are abundant in petroleum and natural gas resources. The average drilling depth of Tarim Oilfield has exceeded 6000m around 2010, and the maximum drilling depth has reached over 8000m in 2011 (Well Keshen 7, drilling depth 8023m) [6]. The computation of hydrocarbon-produced capacity is fundamental to the exploration of Tarim Basin. Cambrian strata is widely distributed in the north of the basin, and a good source rock of Tarim Basin with high abundance of organic matter and great amount of resources [7].

In this study, the hydrocarbon generation intensity of source rocks is calculated using the following equation:

\[ m = S \times h \times m \times TOC \times f(Ro) \]  

Here, \( m \) is the mass of generated hydrocarbon, \( S \) is the area of the pixel, \( h \) and \( TOC \) are the residual thickness and percentage of total organic carbon of source rocks, respectively. All of the above data are derived from the gridded deep oil-gas resources maps in Tarim Basin. \( \rho \) is the density of the rocks, which is set as 2740 g/m\(^3\) for carbonate source rocks and 2610 g/m\(^3\) for argillaceous source rocks, respectively in this study. \( f(Ro) \) is hydrocarbon generation function, which was derived from a laboratory simulation with a thermal history reconstructed using basin modeling software and its unit is mg/g \( \times TOC \) [8]. In this study, it is calculated on the basis of Type II kinetic parameters of hydrocarbon generation proposed by Tang [9].

The area of Tarim paper map used in this paper is 5195.62 million km\(^2\). The amount of hydrocarbon generation per pixel was calculated on the basis of the gridded deep oil-gas resources maps in Tarim Basin. We adopted a method of Polynomial Segment Fitting to fit hydrocarbon generation curve in this paper. The hydrocarbon generation intensities of methane, gas, oil and light hydrocarbon were calculated and analyzed according to distinct source rocks, spatial patterns and temporal sequence.

3. Results and Discussion
As a result, the mass of four types of hydrocarbons generated by two lower Cambrian source rocks in Late Ordovician and present in Tarim Basin was calculated (Table 1). The results of oil, gas, light hydrocarbon, and methane generation intensity of argillaceous source rocks of Lower Cambrian in Tarim Basin are shown in Figure 3 (present) and Figure 4 (Late Ordovician). The hydrocarbon generation intensity in the Lower Cambrian of Tarim Basin is considerable in total and concentrated in spatial distribution. The total hydrocarbon generation intensity is the sum of the oil and gas hydrocarbon generation intensity. The total hydrocarbon generation intensity of argillaceous source rocks (164.39 billion tons in Late Ordovician and 296.61 billion tons at present) is higher than that of carbonate source rocks (161.32 billion tons in Late Ordovician and 233.51 billion tons at present). The former is concentrated in the middle while the latter is concentrated in the northeast of Tarim Basin. Among the four types of hydrocarbons, the generation intensity of oil is the highest, which reaches 151.50 billion tons in late Ordovician and 218.52 billion tons at present.

The time series variation of hydrocarbon generation reflects evolution and development of source rocks. At the end of Ordovician, most areas of Tarim Basin have not reached the threshold of hydrocarbon generation [10]. Therefore, from the end of Ordovician to the present, the total hydrocarbon generation in Tarim Basin has increased remarkably. Total hydrocarbon generation intensity of argillaceous source rocks in the present age is approximately 132.22 billion tons, which is higher than that in late Ordovician.
Figure 3. Oil (a), gas (b), light hydrocarbon (c) and methane (d) generation intensity of argillaceous source rocks in Late Ordovician of Lower Cambrian in Tarim Basin.

Figure 4. Oil (a), gas (b), light hydrocarbon (c) and methane (d) generation intensity of argillaceous source rocks at present of Lower Cambrian in Tarim Basin.
Table 1. Statistics of hydrocarbon generation intensity of Lower Cambrian strata

| Type                                | Late Ordovician | Present          |
|-------------------------------------|-----------------|-----------------|
|                                     | Max(ton/km²)    | Sum(ton)        |
|                                     | Max(ton/km²)    | Sum(ton)        |
| Argillaceous source rocks - Oil     | 2.6319E+06      | 1.5150E+11      |
| Argillaceous source rocks -         | 2.6630E+06      | 2.1852E+11      |
| Gaseous hydrocarbon                 | 5.5641E+05      | 1.2894E+10      |
| Argillaceous source rocks - Light   | 2.6672E+05      | 8.1194E+09      |
| hydrocarbon                         | 2.5772E+05      | 2.0683E+10      |
| Argillaceous source rocks - Methane | 4.4020E+05      | 4.4050E+09      |
| Argillaceous source rocks - Total   | —               | 1.6439E+11      |
| hydrocarbon generation intensity    | 3.5522E+07      | 3.8469E+10      |
| Carbonate source rocks - Oil        | 4.1291E+06      | 1.3692E+11      |
| Carbonate source rocks - Gaseous    | 1.5384E+06      | 2.4390E+10      |
| hydrocarbon                         | 2.4509E+06      | 8.0232E+10      |
| Carbonate source rocks - Light      | 3.9894E+05      | 1.1422E+10      |
| hydrocarbon                         | 3.9894E+05      | 1.4731E+10      |
| Carbonate source rocks - Methane    | 3.6325E+06      | 1.1724E+10      |
| Carbonate source rocks - Total      | —               | 1.6132E+11      |
| hydrocarbon generation intensity    | 8.9379E+07      | 5.7895E+10      |

4. Conclusions
This paper proposed a grid model for spatial data management and deep oil-gas resources assessment based on GIS, and the results showed it is effective with low residual errors and high precision. It provided an innovative and integrated method for management, evaluation and visualization of deep oil and gas resources in the studied basin. The method was preliminarily applied in Tarim Basin to calculate the hydrocarbon generation intensity according to distinct source rocks, spatial patterns, and temporal sequence.

The hydrocarbon generation intensity of the Lower Cambrian strata of Tarim Basin is considerable in total and concentrated in spatial distribution. The total hydrocarbon generation intensity of argillaceous source rocks is higher than that of carbonate source rocks. Among the four types of hydrocarbons, the generation intensity of oil is the highest. From the end of Ordovician to the present, the total hydrocarbon generation in Tarim Basin has increased remarkably.

The future research should be applied to the comparative analysis of hydrocarbon production in different geological periods, which could reveal the evolution pattern and distributing disciplinarian of deep oil and gas resources. The applicability of the grid model and calculation method in other deep reservoirs need to be verified in the future.

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