Evaluation of Source Rock Quality in Chang-7 Member of Major Oil Fields in Ordos Basin

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Abstract. Petroleum is an important natural resource for human. The demand for petroleum in the next several decades will continue to be high, which requires the exploitation of more petroleum sources. Chang-7 member of the Ordos basin is proven to be the richest among all members, and this research took a focus on making a comparison between the source rock quality of Chang-7 member in four major oil fields in the basin, to provide a simple view of priority oil fields for exploitation in the future. The research analyzed the source rock quality of four oil fields from the TOC, A%, rock type, R0, sedimentary environment, and kerogen type, and found a superiority of source rock quality of Maling and Zhidan oil field in multiple dimensions, mainly triggered by their sedimentary environment. The research concluded that the oil fields that was once in the central-southern region of the basin contains a slightly better source rock quality among the chosen fields, which is related to a more stable sedimentary environment in the early Triassic.

Keywords: hydrocarbon, petroleum; source rock quality; Chang-7, Ordos Basin.

1. Introduction
The Ordos basin, located in Northwestern China, is a basin that had gone through multiple cycles of tectonic action, and is one of the most complex sedimentary basins that have hydrocarbon generation in the strata underneath. The proved reserve of natural gas, coal gas, and coal is the highest among all sedimentary basins in China.

The physical and chemical characteristics of the hydrocarbon source rock serve an important base knowledge in oil extraction. The experience from the historical records enabled the understanding of the physical and chemical characteristics of hydrocarbon-forming rocks and that of storage rocks. It is crucial to improve our understanding on the hydrocarbon source rock to form a comprehensive view of quality hydrocarbon reserve for industrial use. To provide a simple and clear view of some of the oil fields in the basin, this research will focus on comparing the data collected. Since the data for major oil fields in the Ordos basin had no major comparison between them before, it will be beneficial to do so to reveal the advantages of the source rock at each field to guide the focus of further research.

1.1. Geologic history and general information
The basin of Ordos has a long history of natural gas leakage since about a thousand years ago [1]. There are also other natural resources such as salt, iron, aluminum, and rich geothermal energy. The complex geologic history made hydrocarbon generation possible [2]. Since Neoproterozoic, the basin has gone through the Jinning movement and Caledonian movement during early Paleozoic, making it to be eroded.
The bedrock of the basin was formed from Neoproterozoic, consisting of gneiss, granulite, and granite. The Variscan movement during late Paleozoic forced it to lower its altitude and enabled it to go through the transition from continental environment to between continental and oceanic. The basin was located at an active oceanic-continental margin at this time. It was flooded later during the Carboniferous era. When sea water retreated during the early Permian period, the basin was shifted to an inland river delta [3], in which river and lake sediments accumulates. During the later Triassic period, the basin was a large freshwater lake. But after the Indonesian movement, the basin was uplifted to have numerous valleys and river trenches, further added to its river environment sedimentation. The hydrocarbon source rock in the Ordos basin is mainly dark mudstone [3-6]. Other than dark mudstone, a significant portion of source rock is occupied by oil shale. Because the hydrocarbon source rock in the Ordos basin is low in porosity and permeability, the gathering of hydrocarbon is crucially determined by the thickness and distribution of the source rock [3-5].

The underground area covered by the basin all contains significant amount of oil and natural gas. In specific, a wide natural gas layer, which correspond to the Paleozoic strata, is covered beneath the Jurassic and Triassic liquid hydrocarbon strata. There are multiple existing oil field in the basin, which include the Changqing oil field, the Ansai oil field, the Sulige oil field, and the Jingan oil field. The combined proved oil reserve of these four fields exceeds a hundred million tons, and the combined proved natural gas reserve exceeds 1.6 trillion cubic meters, which proves the importance of these fields and its full potential for the future. From the start of hydrocarbon extraction since almost a hundred years ago, there have been multiple important breakthroughs corresponding to the discovery of these main oil fields in the basin. The proved oil reserve only increased from then, which indicates the possibly of more unknown reserves in the Mesozoic and the Paleozoic strata.

Figure 1. Distribution of oil fields and stratigraphy of the region [7]
1.2. Research target
The oil fields chosen for the research include Jingan oil field, Ansai oil field, Maling oil field, and Zhidan oil field. These are the ones that researchers have formed deepest understanding of. Because hydrocarbon source rock present at multiple strata aligned vertically. A comparison of the quality and chemical composition of the source rock among these fields will be conducted. Jingan oil field (or Jingbian oil field), developed back in 1996, is a continental facies metamorphic oil field mainly formed in the upper-Triassic strata. Jingan oil field is located on the middle of the Yishan slope [2-5]. According to Jingan oil field development log, Jingan oil field is a typical “triple low” oil field: it has ultra-low permeability, low pressure, and low oil production. The reserve rock has rich water content, which forms an obstacle in oil extraction. The major composition of sandstone in the reserve is feldspar. Ansai oil field, on the other hand, was one of the first fields developed during 1984-1995, and is in continental-marine transitional deposition facies. The oil field is located at the middle of the basin, slightly to the southeastern side. The lower reserve rock is mainly dense and less porous Triassic sandstone, similar to that of Jingan oil field. In the upper-Triassic strata, the main composition shifted from sandstone to dark mudstone [8-12].

Maling oil field (south to Qingyang oil field in the figure), although developed since about 1971, have very similar characteristics as the Ansai oil field. The field is located at the south part of the basin. The main source rock is composed of mudstone and oil shale, both in the upper-Triassic strata. Since the source rock has low permeability and low porosity, the gathering of hydrocarbon is near or at the hydrocarbon source rock.

For this research, a series of data from chang-7 strata is used for the four oil fields to be analyzed. The chang-7 strata represent a specific piece of strata in the upper-Triassic strata. Because of the massive gathering of dead organic material (mainly Algae and single-celled organisms) during the Triassic era, the chang-7 strata is extremely rich in Type-I kerogen, which indicates a very rich hydrocarbon reserve. Therefore, research on the strata will provide the most utilizable information for the oil industry.

1.3. Hydrocarbon source rock
Petroleum geology is where the formation, transportation, and storage of petroleum and natural gas are analyzed. The hydrocarbon generation of source rocks is an essential part of oil and gas generation, so the study of source rocks is of great significance. In general, there are three types of hydrocarbon source
rock, including oil source rock, natural gas source rock, and oil-gas source rock. Paul Hunter defined hydrocarbon source rock as those that generated and extracted fine-grained oil and natural gas deposition that can serve for industrial uses. Specifically, hydrocarbon source rock is required to possess enough concentration of kerogen (or organic material) and reach the minimum temperature for those materials to be converted into petroleum or natural gas (which requires the source rock to be buried at sufficient depth). To measure the quality of the source rock, multiple variables should be used to serve as indicators. The general measurement of source rock quality encompasses four variables, which are total organic content (TOC), hydrocarbon content (HC), Chloroform asphalt content, and hydrocarbon potential. Other than this important indicator, the maturity of the source rock, the thickness, temperature, and other variables also participate in the determination [2-3].

Chemically evaluating the source rock, data of kerogen is the best indicator of the usefulness of hydrocarbon reserve. Kerogen, by the definition of Paul Hunter, refers to the organic content in sedimentary rocks that cannot dissolve in base, non-oxidizing acid, and non-polar organic solvents. Kerogen is a kind of high polymer with no consistent chemical formula. Asphalt, also called Bitumen, is the dissolving counterpart of kerogen. Kerogen is the main organic content in sedimentary rocks, and almost all hydrocarbon oil formation is from kerogen [19]. Therefore, to understand the source rock quality from a chemical aspect, kerogen must be evaluated. There are three main types of kerogen. Type I kerogen contains a large percentage of ester with straight chain carbons. It is low in aromatic carbon and other functional groups. Type I kerogen is ideal for hydrocarbon formation because it is low in oxygen and high in hydrogen. Type II kerogen contains a higher percentage of aromatic carbon and functional groups with oxygen, which has less potential of forming hydrocarbon than Type I kerogen. Type III kerogen contains high oxygen content, aromatic carbon, and other functional groups. It is low in alkane. Type III kerogen is the worst type to form hydrocarbon, although a considerable amount of hydrocarbon can still be formed from it. The main method to study kerogen is through pyrolysis, which refers to the decomposition of organic content under high temperature in the environment of no oxygen. In this method, the decomposition temperature, R0 change during pyrolysis, and distribution of carbon isotopes are all important aspects for study. The decomposition temperature represents the length of the carbon chain in the kerogen, since later data collection shown a dominance of type I and II kerogen in the source rock. R0 change during pyrolysis can further reveal the maturity of the source rock. The distribution of carbon isotopes can generally reflect the type of kerogen presenting in the source rock; it functions more towards a support to the former analysis.

2. Methodology

Zhou Zongying et al. conducted a research in which the hydrocarbon potential in major basins in the east coast of Africa are compared. In which, multiple aspects of hydrocarbon reservoir rock and source rock is compiled into tables and profoundly analyzed. Variables such as TOC, kerogen type, and rock permeability, are used to conduct evaluation [13]. This research will adapt a similar analysis structure to what Zhou Zongying et al. did.

In this research, multiple variables are used to compare the physical and chemical state of hydrocarbon reserve between the strata beneath the four chosen oil fields, to formulate a more comprehensive understanding of them. Variables used in this research for comparison to evaluate source rock quality include rock type, total organic content (TOC), chloroform asphalt content (A%), R0, and quality of kerogen. Total organic content refers to the total amount of organic content in rock (concentration in units). The purpose of this data is to use the concentration of carbon in rock to determine the location and abundance of organic content in the source rock. Chloroform asphalt content reveals about the richness of organic content in the source rock with TOC together. R0, vitrinite reflectance, is a variable to measure the chemical maturity of the source rock. Kerogen, the main content that forms usable hydrocarbon when undergo chemical processes, is an important aspect that reveals the quality of the source rock. These variables are crucial data for evaluating the hydrocarbon source rock, therefore, separate analysis of them is conducted among different parts in the section 3.
In this section, four major aspects of source rock are analyzed, including the rock type, the abundance of organic matter, the type of the organic matter, and the maturity of organic matter. Variables to measure the abundance of organic matter in source rock include TOC and A%. Aspect for measuring the type of organic matter is the type of kerogen. R0 is used to measure the maturity of organic matter in the source rock.

3. Data Analysis

3.1. Measurement standard and data collection

To measure the source-rock quality in Chang-7 region, the standard to evaluate different aspects of the source rock need to be specified first. Specific physical characteristics and quantitative criteria are used to define the quality of the source rock, ranked from non-source rock to rich, from left to right.

**Table 1.** Source rock quality measurement standards [12]

| Quality       | Non-source rock | Poor             | Medium to rich | Rich                |
|---------------|-----------------|------------------|----------------|---------------------|
| Rock Phase    | River           | Shallow lake to  | Shallow to half-deep lake | Half-deep lake to deep lake |
| Type          | Red mudstone    | lakeside         | deep lake      | dark grey mudstone  |
| TOC (%)       | 0.4             | 0.6-1.0          | >1.0           |
| A (%)         | 0.1             | 0.5-1.0          | >1.0           |
| HC (%)        | 0.1             | 0.2-0.5          | >0.5           |
| S1+S2 (mg/g)  | 0.5             | 2.0-6.0          | >6.0           |
| HC/C (%)      | 1               | 3-8              | 8-20           |

From numerous of other research on Chang-7 strata in Ordos basin, the data of variables mentioned in methodology section are listed. If a specific characteristic of the set of number for an oil field is given in the research, it is attached under the interval of the data set, like “Mode 2%-6%”.

**Table 2.** Source rock data of the chosen oil fields [1-3,6,8,10,12,14-20,22]

| Chang-7 Region | TOC            | A%              | Type                                           | R0            |
|----------------|----------------|-----------------|------------------------------------------------|----------------|
| Total          | 2%-14%         | 0.01-14.82      | Oil shale / dark mudstone                      | 0.7%-1.15%    |
|                | (Mode 2%-6%)   | (Mode 0.75)     |                                                |                |
| Jingan         | 0.96%-4.27%    | 0.024-2.84      | Dark mudstone and oil shale                    | 0.7%-1.2%     |
| Ansai          | 2.47%          | 0.261           | Black shale (with carbon) and siltstone        | 0.73%-1.06%   |
| Maling         | 6%-14%         | 0.779           | Black shale and mudstone                       | `0.68%-1.08%  |
| (Highest over 30%) |            |                 |                                                |                |
| Zhidan         | 3.34%-7.84%    | 0.563-1.196     | Dark mudstone                                 | 0.64%-1.14%   |
| (Medium 5.77%) |               | (Medium 0.884)  |                                                | (Medium 0.88%)|
| (Medium)       |                |                 |                                                |                |

3.2. Source rock type

**Table 3.** Evaluation of Rock Type

| Subject          | Data                                      | Quality                                              |
|------------------|-------------------------------------------|------------------------------------------------------|
| Standard         | From poor to rich: red mudstone - Greyish green mudstone – Grey mudstone – dark grey mudstone |                                                                 |


To find out the general cause and effect relationship between the geographic location and source rock richness in southern part and northern part of the basin, a graph of sedimentary environment can be used as a reference.

### Table 4 Sediment Information [3,11,19,20,21]

| Subject | Sedimentary environment       | Organic sediment Type                        |
|---------|--------------------------------|----------------------------------------------|
| Total   | Lake-river delta              | N/A                                          |
| Jingan  | Shallow lake – river delta    | N/A                                          |
| Ansai   | Shallow lake – river delta    | Phytoplankton, other mirgoorganism           |
| Maling  | Deep lake – shallow lake      | Algae, phytoplankton                         |
| Zhidan  | Deep lake- shallow lake       | Algae, phytoplankton                         |

The chang-7 strata of Maling and Zhidan oil field are in deep and shallow lake sedimentary environment, which means the source of organic sediment are better in terms of quality as compared to Jingan and Ansai oil field, which are in shallow lake and river delta environment. Lake sedimentary environment generally have less turbulent current than river delta environment, which enables the accumulation of finer sediments at the lake bottom. This can account for one of the reasons that the source rock quality at Maling and Zhidan are better than Jingan and Ansai (for Chang-7 strata).

The available hydrocarbon from oil shale is significantly higher than that from mudstone. The average TOC of Chang-7 member is 10.63% while the mudstone is only 2.21% [14], which means, the field with more shale contains better abundance of hydrocarbon. The data of TOC content is closely related to the depositional environment, rock type, and kerogen type. The relationship between them will be discussed later.

#### 3.3. The type of organic matter

To further understand the quality of source rock, it is crucial to develop a full understanding of the kerogen content in the source rock and the physical and chemical characteristics associated with it. The type of Kerogen in Chang-7 strata is very consistent among all regions of Ordos basin. The main type consists of type I and II with a dominant chemical composition of amorphous lipoids, although there are traces of hystrichosphaera and spore content.

### Table 5. Type of Kerogen in the source rock from different fields [1,14]

| Subject | Type                     |
|---------|--------------------------|
| Total   | Mainly type I and II     |
| Jingan  | Type I (and II)          |
| Ansai   | Type I (and II)          |
| Maling  | Type I                   |
| Zhidan  | Type I                   |

The type of kerogen in the source rock, as shown by table 5, is mainly Type I and II, which means the basic potential of generating hydrocarbon in all rocks within the field is at a good standard. However, there is a distinction between the different type of source rocks. For example, the kerogen in mudstone, for chang-7 strata, is mainly type II kerogen [14]; and for the kerogen in oil shale rock, it is mainly type I and II kerogen. To combine this information with the depositional environment, since deep lake
The sedimentary environment (Maling and Zhidan) is far from the turbulent current of river or river delta front, the water is more stable, which enables the stable accumulation of planktons, clay particles, and volcanic eruption compounds, forming an extremely rich oil shale rock with main kerogen type of type I. The transition area between river delta and lake environment contains stronger and more turbulent water current that interfere with the deposition of fine-grained particles. In this environment, the material that are able to accumulate in the bottom becomes continental clastic and terrestrial plant fragments, forming mudstone and silty-mudstone with dominant kerogen of Type II. In this case, the Chang-7 member of Maling and Zhidan contains mainly Type I kerogen, which matches the depositional environment mentioned earlier (deep lake environment). The Chang-7 member of Ansai and Jingan oil field contains mainly of Type I mixed with type II kerogen, which makes sense given the depositional environment. Therefore, this is another evidence of the superiority of Chang-7 member in the south. Given the ancient geographics of the region, this makes sense; the central part of the basin, back in the early Triassic, is mainly deep lake sedimentary environment; the edge section of the basin all have shaped alluvial fans delta plains, which encompasses a bad sedimentary environment for fine grained sediments.

3.4. The abundance of organic matter

In the next several tables, every variable is compared to the standard and are ranked based on their interval. Although there will no significance to compare the source rock type data because of the fact that all of them can be categorized as “rich” source rock, it is still listed for the completeness of data collection.

### Table 6. Evaluation of the abundance of organic matter

| Subject | TOC% | A%       | Quality           |
|---------|------|----------|-------------------|
| Total   | 2%-14% (Mode 2%-6%) | 0.01-14.82 (Mode0.75) | Rich/Medium to Rich |
| Jingan  | 0.96%-4.27% | 0.024-2.84 | Medium to rich    |
| Ansai   | 2.47% | 0.261%   | Rich/Poor         |
| Maling  | 6%-14% (Highest over 30%) | 0.779 | Rich/Medium to Rich |
| Zhidan  | 3.34%-7.84% (Medium) | 0.563-1.196 (Medium) | Rich/Medium to Rich |

From the table above, the total extent of TOC ranges from 2% to 14%, which does not represent the distribution of TOC data in different regions. The mode of data ranges from 2% to 6%, which means that a majority of data points are position at the lower end of this range. In the four fields chosen, only Jingan oil field have its lower end below the marker of 1% (rich), therefore, it is marked as medium to rich, although technically all fields should be marked as “rich”. Among them, Zhidan oil field and Maling oil field have the highest average TOC, and some data samples collected at Maling oil field exceeds 30%, which is the reason it is categorized in the highest ranking. As for Ansai and Jingan, the average TOC is just above 2%, which cannot match the magnitude of that of Maling and Zhidan. The data of A% have a large range of distribution, but the average of data is basically within 1%. In this case, based on the standard, all data of A% should not be categorized into “rich” ranking. However, the average of Maling and Zhidan is significantly higher than that of Jingan and Ansai oil field. The data of Ansai is categorized into “poor category”. Since Maling and Zhidan is located at the more southern part of the basin, it’s possible to argue that the south rock richness at the south part of the basin is better than the north part, which matches the conclusion from prior evidence.
3.5. The maturity of organic matter

| Subject | Data       | Quality          |
|---------|------------|------------------|
| Standard | N/A        |                  |
| Total   | ~0.7%-1.15%| Mature – Over mature |
| Jingan  | 0.7-1.2%   | Mature – Over mature |
| Ansai   | 0.73%-1.06%| Mature           |
| Maling  | 0.68%-1.08%| Mature           |
| Zhidan  | 0.64%-1.14% (Medium 0.88%) | Mature           |

From the table, Ansai, Maling, and Zhidan oil fields have the most consistence in the maturity of the source rock. The R0 value is basically within the range of 0.5%-1.0%, which matches the standard of mature source rock. All three oil fields have their lower end above the 0.5% mark and their higher end a little above 1% mark. They are not marked as mature to overmature because their average is well within the mature range. Jingan is between mature and over mature, which is less stable than the rest three of the fields. Its higher end is 1.2%, which is significantly above 1%. Also, given its lower end as high as 0.7%, the range is placed at mature to overmature. This evidence can only partially support the hypothesis, given Jingan being less consistent than other three oil fields instead of Jingan and Ansai being less consistent than the other two.

4. Conclusion

Based on the results of the research, Maling and Zhidan oil fields contains superior source rock quality in their richness and maturity due to a stable sedimentary environment for fine-grained organic material to deposit. Therefore, the Chang-7 members in the central-southern region contains better source rock quality than the oil fields located at the edge part of the basin, since they were primarily in deep lake sedimentary environment, whilst others were in more shallow water bodies that have stronger turbulent current that blocked fine-grained sediments from accumulating in the bottom. This caused the kerogen type of central members to be primarily Type-I with higher TOC, A%, and R0, which should continue to be priority of petroleum extraction in the next. The oil fields located at edge, on the other hand, have main sediment material of terrestrial plant fragments that result in source rock with Type-II kerogen with lower TOC, A%, and R0 than what previously mentioned.

Further research can focus on detailed chemical analysis on the organic content in the source rock, since there is a limited capacity for data in this research, for example, to research on the ratio between carbon and oxygen in the chemical analysis. Also, to determine the validity of the results of this research, it is suggested that further research should drill in the Chang-7 strata in two locations: one between Maling and Zhidan oil field; another one between Maling and Ansai oil field. The first exploratory drill serves as a confirmation of the source rock quality in the south part of the basin, and the second drill means to determine the boundary between “good” source rock and lower quality source rock.

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