The method of distinguishing sedimentary environment of sandstone reservoirs by XRF

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Abstract. Although XRF elemental analysis is one of the major methods of depositional environment research in shale, it has not formed a unified standard in sandstone. With XRF portable analysis technology developing recently, the advantages of its portability, economy, high efficiency and the protection of the original sample make it more widely used. This study area has only few wells in the northern part of Xihu Sag with the problem of unclear sedimentary facies and sedimentary environment definition. In this case, the work attempts to determine the ancient depositional environment and typical sedimentary microfacies by using XRF core dense sampling method. According to the test accuracy of the hand-held X fluorescence spectrometer, the environmental discrimination elements of Sr, Mn, Ti, Mg, Ca and Fe were selected. The data of the cementing development layer were excluded by the casting and scanning electron microscopy. This paper normalized the relevant elements by GR curve, and the content of related elements in the fine sediment of one unit is obtained, which eliminates possible misjudgement caused by the content of fine sediment in determination of sedimentary environment in the sandstone reservoir. Then this study uses the standardized elemental and elemental ratio of the study area to determine the ancient depositional environment. Finally, according to the relationship between sedimentary microfacies and elements in the study area, two types of reference plate are selected to determine the sedimentary microfacies, providing the basis for fine grading of sedimentary microfacies.

1. Introduction

The changes of chemical elements in sediments can well reflect the changes of paleoclimate and palaeoenvironment, especially some trace elements, such as Sr, V, Cr and so on, which have less influence in the process of diagenetic transformation[1]. Element analysis plays an irreplaceable role in the study of paleoclimate and paleoclimate. Many elements and their combination standards have been created, but these standards are basically based on shale. There is no uniform method to judge palaeoenvironment and paleoclimate in sandstone. Previous studies on the geochemical properties of elements in sandstone are mainly focused on the use of rare earth elements and some strongly inert trace elements to judge the tectonic setting of the source area and distinguish the properties of the parent rock[2-4]. Some scholars try to judge palaeoenvironment and paleoclimate by the method of mudstone,
sandstone content, which is obviously inappropriate[4]. Affected by the low content of some elements in sandstone, especially some trace elements, and the precision of hand-held X-ray fluorescence spectrometer, when using hand-held X-ray fluorescence spectrometer to measure the content of elements in sandstone, the accuracy of each element in different lithology should be detected first, and the appropriate elements should be selected[5,6]. Secondly, most trace elements are adsorbed on the surface of fine grain sediments, and the content of trace elements in sandstone is affected by many factors, such as paleoclimate, paleotectonic activity, diageneis, fine grain sediment content in sandstone, etc[7-9]. Therefore, it is very important to exclude all kinds of factors for environmental discrimination by using constant and trace elements in sandstone[10-12].

2. Samples and test methods

2.1. Stability cycle testing
Selection of geochemical model stability detection cycle: the detection period is set to 20 s, 40 s, 60 s, 80 s, and 3 times to the same site in the same period. The final test period is selected according to the stability of the results of the three tests. The results show that at 20 s, 40 s cycle, some elements such as Mg, Ti, Y, and Pb have no detection result (ND) in some test cycles, indicating that the test results of the instrument are not stable, and finally combined with the stability of the test. Work efficiency and the guidance of the instrument manufacturer three aspects, select 60 s as the detection cycle of this study (Table 1).

Test each 50cm test point, if there is a deposition interface or other special phenomena, additional test points.

Table 1. The stable periodic testing of X-ray fluorescence spectrometry

| Total time consuming /s | Al  | Mg  | Ca  | Ti  | Mn  | Fe  | Rb  | Sr  | Y   | Zr  | Pb  | LE  |
|-------------------------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| 19.81                   | 1.53| 1.84| 0.6463| 0.0654| 0.0178| 0.6453| 0.0029| 0.0066| ND  | 0.0137| ND  | 56.02|
| 19.81                   | 1.53| ND  | 0.6362| ND  | 0.0136| 0.6724| 0.0027| 0.006 | ND  | 0.0137| ND  | 58.54|
| 19.81                   | 1.47| 1.91| 0.6512| 0.0683| 0.0205| 0.6607| 0.0029| 0.0067| 0.0008| 0.013| 0.0011| 55.71|
| 39.59                   | 1.56| 1.82| 0.6359| 0.0538| 0.0192| 0.6623| 0.003  | 0.0066| 0.0004| 0.0132| 0.0006| 55.88|
| 39.59                   | 1.62| 2.13| 0.6365| 0.0507| 0.0199| 0.6771| 0.0029| 0.0064| 0.0005| 0.0137| ND  | 55.58|
| 39.59                   | 1.53| 1.39| 0.6361| 0.0507| 0.0224| 0.6825| 0.0031| 0.0065| 0.0005| 0.0132| 0.0009| 56.45|
| 39.57                   | 1.53| 2   | 0.6477| 0.0312| 0.0148| 0.6593| 0.003  | 0.0066| 0.0004| 0.0135| 0.0008| 55.67|
| 39.58                   | 1.56| 2.04| 0.626 | 0.0611| 0.0195| 0.6793| 0.0029| 0.0066| 0.0005| 0.0134| 0.0006| 55.57|
| 39.57                   | 1.56| 1.47| 0.6256| 0.0569| 0.0185| 0.6753| 0.0029| 0.0064| 0.0005| 0.0134| 0.0007| 56.26|
| 79.16                   | 1.6  | 1.46| 0.6211| 0.0532| 0.0171| 0.6667| 0.003  | 0.0067| 0.0006| 0.0137| 0.0001| 56.32|
| 79.18                   | 1.6  | 1.93| 0.6453| 0.0473| 0.0181| 0.6749| 0.0029| 0.0065| 0.0005| 0.0133| 0.0009| 55.61|
| 79.16                   | 1.53| 1.65| 0.635 | 0.0698| 0.0188| 0.6805| 0.0029| 0.0064| 0.0006| 0.0132| 0.0008| 55.95|

2.2. Method precision detection
Summing up the main and trace elements used to distinguish sedimentary environment in previous studies are as follows: Si, Fe, Al, Ca, Ti, Mg, P, Mn, Sr, Rb, Ni, S, Cl, V, Cr. The precision of the above elements was tested by using the national first-class standard material GBW07106. Results as shown in Table 2, the detection error of the element is not positively correlated with the content of the element, and the relative standard deviation (RSD) of the 5 times test is not completely positive correlation with the relative error between the average value and the standard value of the test. It is shown that the precision of the hand-held X-ray fluorescence spectrometer is affected not only by the content of elements, but also by the properties of the elements themselves. The relative standard deviation (RSD) of P element was 12.56% and the relative error was 33.54%. The relative error of Rb is 18.39%. The relative standard deviation (RSD) of other elements is less than 5% and the relative error is less than 10%.
Table 2. Result of precision test

| Elements | The values measured by this method/% | Standard values/% | Average values/% | RSD/% | Relative errors/% |
|----------|-------------------------------------|------------------|------------------|-------|------------------|
| Si       | 40.93 41.03 41.12 41.08 41.12 41.5 | 41.05            | 0.18             | 1.08  |
| Fe       | 2.70  2.71 2.73 2.71 2.76 2.78 2.9960 | 2.7315           | 1.08             | 8.83  |
| Ca       | 0.205 0.203 0.205 0.203 0.206 0.206 0.210 | 0.205            | 0.67             | 2.54  |
| Ti       | 0.1428 0.1471 0.1476 0.1458 0.1488 0.1467 0.1560 | 0.1465           | 1.40             | 6.11  |
| Mg       | 0.037 0.039 0.0375 0.0375 0.0382 0.038 0.0350 | 0.0379           | 1.84             | 8.19  |
| P        | 0.0366 0.0275 0.0393 0.0325 0.03 0.0313 0.0950 | 0.0319           | 12.56            | 66.46 |
| Mn       | 0.0146 0.0164 0.0154 0.0155 0.0154 0.0152 0.0150 | 0.0154           | 3.77             | 2.78  |
| Sr       | 0.0053 0.0054 0.0053 0.0052 0.0053 0.0054 0.0057 | 0.0053           | 1.42             | 6.73  |
| Rb       | 0.0024 0.0023 0.0024 0.0024 0.0024 0.0023 0.0029 | 0.0024           | 2.18             | 18.39 |
| Ni       | 0.0018 0.0017 0.0016 0.0017 0.0016 0.0017 0.0016 | 0.0017           | 4.47             | 5.21  |
| S        | ND      ND      ND      ND      ND      ND      0.085  |
| Cl       | ND      ND      ND      ND      ND      ND      0.004  |
| V        | ND      ND      0.0103  ND      ND      ND      0.003  |
| Cr       | ND      ND      ND      ND      ND      ND      0.002  |

Annotation: “ND” means no results

3. Results and discussions

3.1. Analysis of correlation between element and fine sediment content

GR logging in sandstone can well reflect the fine grain sediment content. The correlation analysis between the selected elements and their corresponding GR logging values is carried out (Fig 1). In the study area, Mg, Mn, Fe, Ti has a good linear positive correlation with GR logging. The correlation between Sr and GR logging is exponential, and the correlation between Ca and GR logging is poor, which indicates that the elements except Ca are mainly enriched in fine grain sediments, so if we use the test results directly to judge the environment or climate, It reflects the content of fine-grained sediments in the core more than the change of environment and climate.

![Fig. 1 Correlation analysis between element content and GR](image)

3.2. Element content calibration, application and effect analysis

In view of the effect of fine grain sediment content on the content of related elements, the trace elements were checked by GR logging before environmental discrimination. According to the correlation formula
between each element and GR log, the element content in unit fine grain sediment was obtained (Fig 1). Then the paleoenvironment and paleoclimate are judged according to the standardized element content. When the paleoenvironment and paleoclimate are judged by element ratio, if both elements are linear positive correlation with GR logging, the effect of fine particles will be eliminated when the molecular denominator is divided, so the results before and after correction of this ratio are the same. If the elements with nonlinear correlation participate in the ratio, all the elements need to use the corrected value for the ratio.

Ancient water depth: according to the results of judging ancient water depth by element method, Mn/Ti is relatively large in the 3600m~3610m depth range, indicating that the water body is relatively deep, but the Sr content before correction is relatively small in this depth. Indicates results contrary to Mn/Ti undefineds criteria. The Sr content after correction was larger than that of Mn/Ti, and the trend was the same as that of Mn/Ti. In the depth range of 3990m~3995m, Mn/Ti is relatively low, indicating that the water body is relatively shallow, but the Sr content is relatively high before correction, which is contrary to the result of Mn/Ti discriminant. The whole Sr content after correction is lower than that of Mn/Ti, and the result is the same as that of Mn/Ti (Fig 2). Paleoclimate judgment: Fe/Mn is small and Ca content is higher in the 3600m~3610m depth range, indicating relative temperature and humidity environment. In the 3990m~3995m depth range, the whole Fe/Mn is larger and the Ca content is lower, indicating the relative arid environment. However, the Mg content before correction is smaller in the 3600m~3610m depth range and larger in the 3990m~3995m depth range, which is contrary to the results of Fe/Mn and Ca. The corrected Mg content indicates that the 3600m~3610m depth range is relatively warm and humid, and the 3990m~3995m depth range is arid environment. Therefore, the corrected Mg content indicator results are consistent with the Ca,Fe/Mn discriminant results (Fig 3). Paleosalinity: when Sr/Ca is used to indicate paleosalinity, the abnormal data are eliminated by correction, and the data distribution is more stable. The abnormal data are mainly caused by the change of fine grain sediment content in the test section, but not by the sharp change of paleosalinity (Fig 4).

3.3. Analysis of paleoenvironmental evolution
The main target layers in the study area are H3 and H4. This paper summarizes the variation of elements in the two layers at different depths and analyzes the paleoenvironmental variation during the deposition of the two layers. The Sr, Mn/Ti, Mg content of the H3 member is higher than that of the H4 member, and the Fe/Mn, Sr/Ca is lower than that of the H4 section, indicating that the lake water increases due to the climate changing to the temperature and humidity and the rainfall increasing after the H4 deposition period enters the H3 deposition period. As the water becomes deeper, the salinity of the lake decreases and the lake transgressions occur (Fig 5).

The distribution of elements in the top and bottom of H4 is relatively stable, indicating that the paleoenvironment in the top and bottom of H4 is relatively stable. In the bottom of H4, the content of Mg increases first, then decreases briefly, and then increases gradually. The Fe/Mn ratio decreases first. A brief increase, and finally a gradual decrease. The results show that paleoclimate in the study area experienced the process of drought, temperature and humidity, and the change of climate was accompanied by the process of water body changing from shallow to deep to shallow to deep. The upper segment of the front half in H4 is similar to the last half in H4, and has experienced a process from short-term drought, temperature-humidity, short-term temperature and humidity to drought, and from shallow to deep to shallow. Salinity from high-low-high, paleoenvironmental integrity experienced two cycles.
Fig. 2 Comparison of palaeobathymetry discriminant results before and after the correction

Fig. 3 Comparison of paleoclimate discriminant results before and after the correction
3.4. Analysis of sedimentary facies in coring section of study area

Based on the regional background data, according to the core characteristics description and logging response characteristics, the braided river delta front subfacies are developed in the study area. The
microfacies are mainly differentiated waterways, estuarine dams and underwater distributary interbay. The typical characteristics of microfacies of underwater distributary channel are the development of bottom scour, normal grain sequence, common parallel bedding and block bedding, and the typical characteristics of estuarine dam microfacies are the development of reverse grain sequence or compound grain sequence, common parallel bedding and block bedding. The typical characteristics of the microfacies in the interdistributary bay are that the gray-black silty mudstone is the main one and the wave-like bedding is common. Apart from these typical sedimentary microfacies, it is difficult to define the microfacies only from the core for the large set of sandstone with no grain sequence change, including stratification or no bedding.

When the trace element plate was used to distinguish the marine sedimentary facies from the continental sedimentary facies, the boundary of the different sedimentary facies was clear because of the great difference between the marine facies and the continental sedimentary environment. The scope of work area in this study is relatively small, and the differences among various sandy sedimentary microfacies are not significant, so many elements and the ratio of elements to elements are less adaptable when the plate is selected. Finally, through repeated screening and comparison, two types of plates, AL/Ti-Si/AL and Rb/Sr - Fe/Mn, were obtained. The plates can distinguish the three main sedimentary microfacies in the study area, but there are overlaps among the different microfacies. Other means of validating each other are needed to distinguish between types (Fig 6). Therefore, if the microfacies type can not be determined in the core, the core observation results and the element plate can be combined to achieve accurate phase determination.

![Fig. 6 Sedimentary microfacies identification chart in the north of Xihu formation](image)

4. Conclusion

(1). Most of the trace elements and some of the main family elements in the strata are mainly attached to the surface of the fine grain sediments, so the content of the fine grain sediments in the sandstone should be considered first when the paleoclimate and paleoenvironment are distinguished by the elements in the sandstone. In this paper, GR logging is used to calibrate the content of fine grain sediment. Firstly, the correlation between GR logging and element content is obtained, and the element content is standardized by using correlation formula to eliminate the effect of fine grain sediment content on element content in sandstone. The paleoclimate and paleoenvironment were judged by the element values before and after standardization, and the results after correction were found to be more accurate.

(2). The measurement of dense elements in core by hand-held X-ray fluorescence spectrometer and the establishment of plate can provide the basis for accurate identification of sedimentary facies and solve the problem that the sedimentary microfacies of some thick sandstone in the study area can not be determined. The advantages of this method, such as portability, economy, efficiency and protection of the original, will inevitably lead to the application of element analysis technology to more fields.
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