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Research progress of provenance analysis based on heavy mineral data

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Abstract：After having a widely research on thesis about using heavy mineral to analysis source rock, summarized the influence of every parameters in using heavy mineral data to analysis the source direction and source rock's type or in the process of sedimentary ,then given the disadvantages and the advantages of this kind of analysis.The conclusion is that we should take every parameters into consideration especially the long time of the creation of rock when using this method (heavy mineral to analysis origin source). Then there are some opinion about it's future way.

Keyword:- *heavy mineral Material source analysisRock formation Multivariate statistics*
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I. INTRODUCTION

Heavy mineral means the percentage is lower than 1% and density greater than 2.86g/cm3 . Grain size is between 0.25 to 0.05 and chemical property is steady[1-4].Sedimentary provenance analysis can find the position and type of mother rock ,on the other hand it can illustrate the provenance direction and sedimentary system even its control on reservoir quality. Because the heavy mineral is chemical inactive and abrasion resistance so weathering, transportation and diagenism can only make a little difference to it. And it have a higher percentage in the sedimentary rock which is far away from the mother rock zone ,so it can preserve more mother rock's feature ,so it play an important role in provenance analysis .Heavy mineral is a symbol of provenance.As early as 1881 people have started using microscope to analysis heavy mineral and use it for provenance study . But it was limited by the method , most of the research is descriptive.Until 1902 Thomas started using heavy mineral analysis to distinguish the direction and feature of provenance , Then this method become a important one.With more and more research has been doing , Distributive Province was bring up .The relationship between mother rock's type in provenance and heavy mineral combination [5]。This method can work just because different mother rock have different elementary , and you will get different heavy mineral combination after weathering.Fleet's research is a big step of heavy mineral study .New method of counting mineral grain make get any heavy mineral's content is possible .Then this method have a development from analysis feature, appearance to definite complication ,and heavy mineral parameter become widely used[6].The content of special mineral assemblage or the weight of single heavy mineral has a different provenance significance.For Example The summary of staurolite , disthene，sillimanite and andalusite's percentage can reflect what the muture metamorphics have done to sedimentary .Rzi index , Mzi index can reflect the circulation of deep sandstone provenance. ZTR index can represent the maturity of heavy mineral[7-9].Even though it's a long time that people using heavy mineral to do provenance analysis , but with the develop of experiment machine and the analysis method ,analysis single heavy mineral create a new way to do provenance research.You can use EMPA，ICP-MS to get the chemical content of single grain and the time of crystallization ,so you can get more information about provenance.You can use EMPA，ICP-MS to get the chemical content of single grain and the time of crystallization ,so you can get more information about provenance.

Here we use Q type cluster analysis as a example , if you use mathematical analysis to count a lot of heavy mineral data ,so it's easy for you to distinguish the composition between samples ,then you can classify the sphere of influence from different pronvenance and the distribution of heavy mineral zone[10-18].Even though ,because of heavy mineral's abrasive resistant ,good stability and can save more feature of mother rock , sensitive to provenance symbol ,so it was widely used in sedimentary analysis of different era. But in fact ,During the deposition process other parameters may make a difference to combination of heavy mineral and abundance , for example weathering , physical separation , mechanically break , diagenesis and interlayer dissolve (Fig .1)[8, 20].Among this ,later weathering reform and anadiagenesis is especially apparent ,it's sure

that we influence the correction of distinguish of provenance ,But unfortunately when people use heavy mineral doing provenance analysis , most of them never have token the strong influence that this kind of diagenesis has done to heavy mineral into consideration.

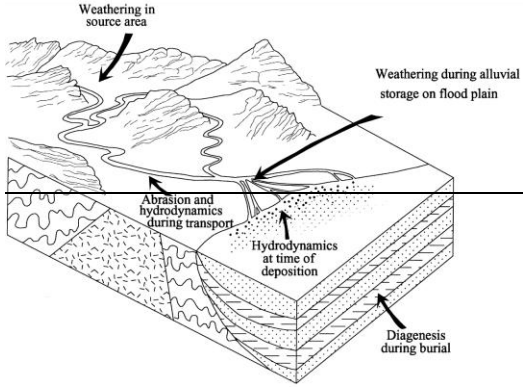

Fig .1. pattern of main controlled factors of heavy minerals[8]

In recent years , The research in xinjang oil Field had make a great breakthrough at HuanMa lake sunken BaikouQuan formation fan-shape delta . But because of there has a long time of lithogenesis, They can take the advantage of heavy mineral data to do the provenance analysis , so can't have a good recognize on fan-shape delta.Now , The conclusion is that have a good recognize of using heavy mineral data to do provenance analysis and pay attention to parameters's influence during the sedimentary process is important to get a correct recognize of fan-shape delta system.

Method of using heavy mineral to analysis provenance

2.1 Theoretical base

Heavy minerals are very sensitive to the change of material provenance .If the mother rock is different the composition is different too , after the weathering erosion they have different product which have different heavy mineral assemblages(Table 1) So ,the feature of heavy mineral can be used to restore the mother rock and distinguish the provenance[21] .

Table 1 The relationship between the mineral assemblage of clastic rocks and the types of the parent rocks[19]

Type of parent rock	Mineral assemblage
Recycled sedimentary rock	baritea、glauconite、quartz、quartz cuttings、leucoxene、rutile、round tourmaline、round zircon
Low-grade metamorphic rock	slate and phyllite cuttings、mica、leucoxene、quartz and quartz cuttings、tourmaline
High-grade metamorphic rocks	garnet、hornblende、kyanite、sillimanite、andalusite、staurolite、quartz、mica、acidic plagioclase、epidote、zoisite、magnetite
Acid volcanic rock	apatite、black mica、hornblende、monazite、talc、titanite、quartz、microcline、magnetite、tourmaline
Basic volcanic rock	brookite、pyroxene、anatase、hypersthenic、titanium iron ore and magnetite、chrome iron ore、leucoxene、olivine、rutile、neutral plagioclase、serpentine
Pegmatite	fluorite、blue tourmaline、garnet、monazite、talc、topaz、sodium feldspar、microcline

According to heavy mineral's stability you can classify it to 5 degree(Table 2)[22], the stable heavy mineral weathering resistance is more strong than unstable one .The percentage of heavy mineral will increase with the distance from provenance, the unstable heavy mineral will gradually reduce, stable minerals will gradually increase too, so the type of combination which content stable heavy mineral and unstable heavy mineral will change, This is a way to illustrate the direction of sedimentary.At present, ZTR index ,The percentage of composition which contains zircon ,tourmaline and ruble is a most commonly used to determine provenance

direction method. This method is first proposed by Hubert[7], because these three kinds of heavy minerals in the heavy mineral is the most stable, and is common in almost all crystalline rocks, so the ZTR index as a stability coefficient of heavy minerals, it has become common and effective method.ZTR index is bigger that means the higher maturity of mineral composition and transport distance farther.

Table 2 Stability of common heavy minerals[22]

Stability	Heavy minerals
Super stable	rutile、zircon、tourmaline、anatase
Stable	apatite、Garnet（Iron containing less）、staurolite、Monazite、black mica、ilmenite、magnetite
Moderately stable	epidote、Kyanite、Garnet (iron rich)、sillimanite、Zoisite、Sphene
Instable	Hornblende、actinolite、pyroxene、diopside、Hypersthenic、Andalusite
Extremely unstable	olivine

2.2 Traditional analysis method

When people use traditional method to analysis heavy mineral provenance and the direction oprovenance,theysually use the average of one hole's data during a period then only take distributionof the percentage of heavy mineral or ZTR index into consideration[23-25].In fact ,the sedimentary iscreate at geologist history or current period doesn't matter , most of it was the consequence of manytimes or many sedimentary mixed .If they were created at the same time they have the same or thesimilar heavy mineral combined characteristic . But if they were not created at the same time they have different provenance direction or different type of mother rock . Different time may have differentfeature.So traditional method cannot illustrated the inside relationbetween different heavy minery which come from the same mother rock , and it also ignored the important message of vertical sedimentary from different time , dropped some message from mixed provenance ,especiallysome sedimentary system have distribute to many provenance , so it's hard to distinguish the provenances.

2.3 Multivariate statistical method

In recent years, multivariate statistical methods have been applied widely in the variety of fields [26-31].some scholars have used the data of heavy mineral content as the sample through cluster analysis, the factor analysis of multivariate statistical analysis method etc, who have recovered development scope of different prevenances and its source rock types, better solved the problems of determing depositional period and distinguishing the mixed provenance system. Cluster analysis also called group analysis, it is a multivariate statistical method of classification problem, the essence is according to the degree of similarity or relationship with samples or variables to graually classify [32, 33],through analysis and calculation of related pedigree diagram, which can further reveal in the different level of similarity between individual and group relationship. According to research different purposes and objects, it is divided into the Q type and R type cluster analysis.Q type cluster analysis is to research the mutual relationship among samples and to compare same variables in different samples.The samples were classified by determining the degree of similarity between samples.R cluster analysis is to research the relationship between different variables, that is compare the different variables of the same sample to determine the relationship between different variables and to classify it. Factor analysis is a kind of multivariate statistical analysis method, which can attribute a number of factors which have complex relationship to less integrated factors. Its main idea is "dimensionality reduction", in the premise of less loss of original data information, with a small number of independent factors to replace the original variables as much as possible to reflect the original factor [32, 33].

In a study of stratum sediment provenance, the Q cluster analysis method should be alternative firstly and to divide the vertical characteristics of the same or similar sample group as the depositional stage apart, which represents the sediment supply a certain period or a certain type of native rock. In the basis of determining the depositional stage, mainly through two methods analyse the provenance and native rock types. One method is to use Q cluster analysis method and spreate sediments of the characteristics of the same or similar samples from the same depositional system in sedimentary basin, each kind of this group represents the sediment the supply of

a depositional system. Then according to the ZTR index, the source direction is determined. However, in the same depositional system, as a complete geological system, the various factors must have the intrinsic relation, detrital material of terrigenous origin eroded, transported and deposited process may go through the different native rocks, but the same native rocks weathered down the rocks as a whole is operates in the whole geological system. Therefore, based on the Q cluster analysis to dtermine the depositional system, the different heavy mineral variables will be used for factor analysis by the analysis of main control factors in the whole geological system, so as to determine the overall existence and then identify the charastic of heavry mineral to reflect the types of rock from native rock area [11]. Another method is that using R-type cluster analysis process data of a period of heavy mineral, the close and distant relationship between different types of heavy minerals show, and then obtained from different native rocks of the heavy mineral assemblages,that is the type of native rock. The same type of heavy minerals assemblages as the same source system is divided into different provenance area in study area. On this basis, various types of the heavy mineral assemblages represent the sedimentary period of sediments as a independent system to calculate the ZTR index, sketch ZTR isogram. ZTR index gradually increased in the direction of the clastic rock composition is high, the distance to transport and the directions of suppling sediment[12].

While the second method of R-type cluster analysis can get heavy mineral assemblages and further get the type of native rock, but R-types cluster analysis can get more the types of the heavy mineral assemblages, the type of nativerock analysis is not clear, especially the main provenance and the secondary provenance is hard to distinguish. However, the method of factor analysis by reducing the dimension get the heavy mineral assemblages that is a simple type, this method can not only good to judge the type of native rock, especially through the variance contribution differentiating between primary and secondary provenance,but also it is most ideal to judge native rock type and primary or secondary provenance.

II. FACTORS AFFECTING THE ANALYSIS OF HEAVY MINERALS

Although the heavy mineral stability is strong, it is be changed in every hour and moment. Heavy mineral alteration can occur native rock weathering and transportation, silting (syndiagenesis), epidiagenetic process and the uplift and exhumation in the stage, but with silt settlement and long epigenetic into rock interaction effect was most obevious [34].

3.1 Affecting factors of syngensis and diagenesis

In some areas of Vegetation development, due to bacterial degradation of organic matter creating in a large number of acidic groundwater and accompanying releated penetration and chemical corrosion effect, resulting in the rapid disappearance of heavy placer minerals in surface sediments such as kyanite, hornblende, epidote and garnet.with the further increase of the depth, the dissolution is reduced, the heavy minerals will reappears[35-36]. By putting garnet in a warm dicarboxylic acid conditions, Hansley think that organic matter produced by organic acid under the condition of a certain temperature will lead to garnet fast dissolving [37] and the stability of tourmaline may also will lose stability because of the organic matter decomposition of H_2S [8] . Similarly, in the Triassic sandstone, Morton (1986) abundant content of apatite in the coastal sand, but in marginal sea environment was significantly reduced and in the rivers and the top of the Delta, apatite can be completely missing due to the effect of acidic groundwater [38].Hester (1974) have found that garnet and epidote stone appeared in the southeastern United States weathered Cretaceous sandstone and obviously lacked in the same stratum weathering [39].In a word, in the organic rich stratum and adjacent to the stratum, the dissolution can quickly change the stability of the heavy mineral ,even changed original combination characteristics of heavy minerals, thus affecting the provenance of judging . Many research results also show that heavy minerals will gradually disappeared along with the burial diagenesis and depth increased and the entire profile shows a different sequence of heavy minerals in the same source region. [40-44]. Diagenesis is not only destructive to heavy minerals, but also constructive action. Liu et al. (2015) found secondary epidote in the upper Triassic of the Ordos Basin [45]. Similar, the alignment of Junggar basin Triassic System in Baikouquan group heavy mineral analysis also found that existes same secondary epiodte and the secondary epidote tojudge on provenance had a great impact. These results of the study suggest that it is difficult to accurately distinguish the sediment provenance that are likely to have suffered in the late weathering or settlement in the transformation of the strata only through the heavy minerals garnet, apatite, kyanite, indicative of the presence or absence. Therefore, in order to heavier mineral assemblage judge source area, the primary factor is avoid to late weathering or settlement reconstruction effect of the statistical results.

3.2 Other influencing factors

In addition to considering the impact of diagenesis, Heavy mineral analysis is influenced by many factors. From the sedimentary environment and hydrodynamic force, the development of gravity flow in the area, the differentiation heavy minerals is not obvious, so it is difficult to determine the provences through the ZTR index

or coefficient of stability.

From heavy mineral characteristics, Stability: heavy mineral stability is not static and the difference is great under different environment, especially by the diagenesis effect is more significant. Comparative experiments demonstrate that the zircon, rutile of stability degree is strongest in different pH conditions (PH is about 3.6-10.6), compared with tourmaline mechanical stability stronger [46]. By observing under microscope, stable garnet will be dissolved and created corrosion pits in the diagenesis [34, 47], however less stable epidote in some environments is extremely stable, appear epidote overgrowths and authigenic epidote [47]. Density and shape: some heavy minerals are enriched in the region near the source and the hydrodynamic force conditions, such as titanium iron ore, although strong stability, because of its heavy, in the far source area low-energy hydrodynamic conditions but fewer. Biotite flaky minerals, being easily changed by hydrodynamic force, suffers from wash and wear and not easy to be deposited in the strong hydrodynamic environment, because of its small weight, it can be enriched under the weak hydrodynamic conditions. It shows that the enrichment of heavy minerals is related to both its own specific gravity and hydrodynamic force.

From the analysis method, lithology and heavy mineral content: Statistics of heavy minerals ,to make lithology to statistics, sandstone and conglomerate may have different characteristics of heavy minerals, if with statistics and calculate the average value is bound to ignore the differences in different lithology of heavy minerals,which may result in the wrong. In secondary heavy minerals: when selecting heavy minerals, it is important to determine whether or not they are in secondary or not, because they can't indicate the provenance, which may result in the failure of its judgment. Such as epidote is usually attributed to deterioration or corrosion causes of variation and is easy to be influenced by the meteoric water leaching, but in the older strata, there are also the existecence of secondary epidote [47]. However, to pyrite, traditionally considered the authigenic minerals, which are also developes in magmatic and metamorphic rocks. Therefore, the judgment of secondary heavy minerals should not only rely on the traditional experience, but also it should fully combine diagenesis with other factors. Clustering analysis and improvement: multivariate statistical method can better recognise for heavy minerals relatives, identifying the provenance of primary and secondary, but there are also many problems, for example, whether the data standardization, the selection of clustering method. Of course, this multivariate statistical method is not only used in the analysis of the provenance, but also it is very common in the particle size analysis, debris analysis and soon [49, 50]. The author believes that the clustering analysis of heavy mineral and debris integrated can accurate identification of heavy minerals and native rock, as well as the clustering analysis of heavy mineral and grade data integrated can be better identification of sedimentary environment and hydrodynamic characteristics. In the analysis of heavy minerals, high content of heavy minerals have stronger indication, but some low content of heavy minerals may have some important geological significance, ignored the understanding of it because it is low content, the same native rocks may exist different heavy mineral assemblage and a heavy mineral or the same heavy mineral combination may correspond to different native rock, especially not typical of heavy minerals in the presence of cases,it is hard to accurately judge native rock properties. Therefore, it is important to consider the factors affecting the distribution and content of heavy minerals to juedge of provenance through the analysis of heavy minerals.

III. CONCLUSION AND PROSPECT

The heavy minerals is the extremely sensitive indicator in source changes,which has been widely applied in the provenance analysis. But this method still has many issues to be resolved in the provenance analysis,specially in the detailed research on the effect of heavy mineral diagenesis.Currently, the research of diagenesis on heavy minerals is isolated and lack of system.

The method and technique of provenance analysis are effectively recognized by the majority of scholars, which also play a leading roles for some time to come. Although there are still some issues to ponder, some residual problems will be researched with the deeper and detailed research methods ,the improvement of measuring precision techniques and the occurrence of new measuring methods.

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