



# Simple Identification of the Mineralogy and Geochemistry of Sedimentary Environments

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## Abstract

Sedimentary environments are an important part of paleogeography and sedimentology, and there is a long history of using geochemical and mineralogical methods to analyze palaeoenvironmental problems using sedimentary rocks as a research vehicle. By summarizing the important results of previous work on tracing the palaeoenvironment using the composition and distribution characteristics of the macronutrients and trace elements as well as the characteristics of mineral composition, we aim to sort out the mineralogical and geochemical characteristics of the palaeoenvironment. Among them, the identification of paleoclimate, paleoproductivity, paleosalinity, paleodepth and palaeo-oxygen phase are important elements of the sedimentary environment, and it is more important to sort out the mineralogical and geochemical characteristics of them.

## Subject Areas

Geochemistry, Geology, Mineralogy, Sedimentology

## Keywords

Sedimentary Environment, Mineralogy, Geochemistry, Identification, Tracing

## 1. Introduction

Sedimentary petrology has been an important tool for the analysis of paleosedimentary conditions and paleoenvironmental reconstruction since its development in the 19<sup>th</sup> century (Shiaomin Zhu, 2008 [1]; Jingchun Tian, 2016 [2]). The mineral composition, geochemical characteristics and various isotopic indicators of sedimentary rocks can be used to analyze geological problems such as sediment source, environmental evolution and diagenesis in a more clear and syste-

matic way, especially in recent years, new insights have been gained in marine sedimentation, basin evolution, tectonic background and biological extinction by using the comparison of different phase compositions, special mineral analysis and chemical indicator element summary in sedimentary rocks (Xu Yajun *et al.* 2007 [3]; Chen, Quanhong *et al.* 2012 [4]; Neil *et al.*, 2019 [5]; H. Sato *et al.* 2021 [6]; Jocelyn *et al.* 2021 [7]; Coimbra *et al.* 2021 [8]). As an important part of sedimentary rocks, carbonate and silicate rocks, the related petro-mineralogical and geochemical analyses are of great value for paleoenvironmental and paleogeographic analyses, especially the different formation processes of marine and terrestrial carbonate rocks have been profoundly studied for paleoenvironmental inversions (Coimbra *et al.*, 2021 [8]; Noel *et al.*, 2015 [9]; John *et al.*, 2021 [10]). Previous research has produced a large number of results in different fields: in mineralogy, the changes in various mineral assemblages and qualitative and quantitative studies can be used to compare the characteristics of paleogeographic and paleoclimatic changes in different regions; the analysis of the genesis type of quartz in rocks can determine the strength of magmatic hydrothermal activity and the problem of sediment sources; in geochemistry, the content of trace elements and the ratio before each other can be used. In terms of geochemistry, the content of trace elements and the ratio of trace elements to each other can be used as important indicators to judge the palaeoenvironment; the enrichment pattern and anomalies of rare earth elements can be used to effectively understand the thermal source and palaeoenvironmental changes; the content of macronutrients and the content variation pattern between them can also be used to discern the source problem and paleogeographic features (Rusk *et al.*, 2008 [11]; Vos *et al.*, 2014 [12]; Tian Jingchun *et al.*, 2006 [13]; Meyer *et al.*, 2012 [14]; R Coimbra *et al.*, 2021 [8]). In particular, carbonate rocks, which are widely produced around the world, are important vehicles for studying global sedimentary change patterns, biological evolution, global carbon cycle, and other inverse aspects, and are important for guiding the development of oil, gas, groundwater and various mineral resources (Elana *et al.*, 2016 [15]; Coimbra *et al.*, 2021 [8]; Xia Pan *et al.*, 2021 [16]). However, with in-depth analysis, there are many contradictions between these seemingly accurate tracing indicators, which often do not complement each other, and there is a large margin of error in the determination of lower content minerals and trace elements, so comprehensive consideration is needed in the study of palaeoenvironmental problems. This paper summarizes the specific mineralogical and geochemical tracing rules and indicators for sedimentary environments, using the mineralogical and geochemical experiences of previous authors in sedimentary environments, in order to provide a reliable and comprehensive discriminatory basis for the tracing of sedimentary environments.

## 2. Mineralogical Identification

### 2.1. Clay Minerals

In addition to feldspar, quartz, calcite and dolomite, there are various clay sili-

cate minerals in the stratigraphic sedimentary rock samples, and their content, type and morphology can be used to understand the depositional environment and paleoclimate. The use of clay minerals to analyze palaeoenvironment and paleoclimate is currently receiving much attention, and temperature, humidity, lithology and diagenetic environment can affect the formation of clay minerals (Chamley *et al.*, 1989 [17]; Gao Yuan, 2015 [18]; Tan Jie, 2020 [19]). Weathering drenching results in massive kaolinite production, while illite is formed mainly in dry climates and is further transformed by decomposition in warm and humid environments. The paleoclimate of the source area can be inverted by the change of clay mineral species (Deconinck *et al.*, 2000 [20]; Wang, Bing, 2012 [21]). It was found that clay minerals generally occur in sedimentary rocks and are rarely present in magmatic hydrothermal fluids, where illite and kaolinite are more common, and the level of content of both represents the input of clastic source areas and environmental climate changes. When identifying paleoclimate through clay minerals, special attention should also be paid to the genesis of clay minerals. For authigenic and diagenetic clay minerals, their formation is mainly concerned with the characteristics of pore water and the temperature and pressure conditions of diagenesis, which do not correspond to the response of paleoclimate, so the issue of the origin of clay minerals should be confirmed before the analysis (Tan Jie, 2020 [19], Deconinck *et al.*, 2000 [20]).

## 2.2. Organic Matter

Organic matter is also an important tool for inversion of paleoenvironment and inference of paleoclimate changes, among which the use of biomarkers to indicate sediment sources and reconstruct paleogeography is one of the most widespread tools with important research value in the fields of stratigraphy, sedimentology and oil and gas (Xie Shucheng *et al.*, 2003) [22]. Lipid biomarkers of clear origin as a special class of organic matter are recognized as a good vehicle for studying marine sediments and inversion of paleoclimate, and among them, n-alkanes are widely used in marine, lake, and soil environments due to their wide distribution, simple structure, and high-energy carbon-carbon double bonds (Chen Lilei, 2018) [23]. Different sources of n-alkanes have different distribution characteristics, containing relatively abundant low-carbon number n-aliphatic alcohols generally found in lower aquatic organisms such as algae, while higher plants are relatively enriched in high-carbon number n-aliphatic alcohols (Bianchi, 2012) [24]. It was found that the low carbon number ortho-aliphatic alcohols in lower aquatic organisms such as algae are mainly C17, and the high carbon numbers in higher plants are mainly between C25 and C35, which usually show a predominantly dromedary form and a bimodal form. Therefore, the analysis of sedimentary environments and material sources using organic matter fractions is widely popular in sedimentology and oil and gas fields, and is one of the most widespread means to indicate sediment sources and reconstruct paleogeographic environments.

### 3. Geochemistry

#### 3.1. Recognition of Ancient Productivity

Paleoproductivity is an important indicator for identifying the organic matter content of the depositional environment and the level of nutrients from hydrothermal, volcanic activity, upwelling fluids, and input from terrigenous debris (Brocks *et al.*, 2017 [25]; Di Xiao *et al.*, 2021 [26]). The discrimination of paleoproductivity is generally linked to Ba and Cu. Ba has long been used as an important indicator of marine paleoproductivity due to its long retention time in seawater, its high preservation rate and its relevance to upwelling and surface seawater productivity (Kerstin *et al.*, 2001) [27]; while the typical pattern of Cu in organometallic complex to sediment transport also makes it an important indicator for paleoproductivity reconstruction (Nameroff *et al.*, 2004) [28].

#### 3.2. Paleosalinity Identification

Paleosalinity is an important component of the paleoenvironment, influencing material formation and life activity, and has a significant impact on mineralogical and geochemical aspects of sediments (Rieu *et al.*, 2007) [29]. In carbonates,  $\text{Ca}^{2+}$  and  $\text{Ba}^{2+}$  have low solubility, while  $\text{Sr}^{2+}$  has higher solubility and is precipitated from water much later. And because Sr has a stronger migration ability than Ba in seawater,  $\text{Sr}^{2+}$  replaces  $\text{Ca}^{2+}$  and  $\text{K}^+$  into the sediment when seawater evaporates, while  $\text{Ba}^{2+}$  can also replace  $\text{K}^+$ , but the increase in sulfate concentration makes a part of Ba precipitated as  $\text{BaSO}_4$  situation and seawater is more enriched in Sr (Wang, A., 1996 [30]; Tuchkova *et al.*, 2018 [31]). Therefore, when the Sr/Cu and Sr/Ba ratios are larger, it indicates higher salinity and arid climate; and vice versa, it indicates wet climate (Xiong, S. F. *et al.*, 2011) [32]. When the Sr/Ba value is greater than 1, it indicates a marine-saline medium, and less than 0.6, a freshwater medium (Tian Jingchun *et al.*, 2006) [13]. Rb/Sr is also an important elemental indicator of paleoclimatic conditions, with higher ratios representing a wetter climate and lower ratios responding to arid climatic conditions (Parrish *et al.*, 1980 [33]; Wang Linlin *et al.*, 2018 [34]; Yandoka *et al.*, 2015 [35]).

#### 3.3. Identification of Ancient Water Depth

Paleowater depth, also called the distance offshore, is also a consideration in the depositional environment and has a correlation with the aggregation and dispersion of elements. Some trace elements and REE are indicative of bathymetry, and for sediments, it has been suggested that the REE values of deep-water sediments are greater than those of shallow-water sediments (Pattan *et al.*, 1995 [36]; Xiong Xiaohui *et al.*, 2011 [32]). In general, marine sediments are characterized by Sr-rich and Ba-poor, and the magnitude of  $1000 \times (\text{Sr}/\text{Ca})$  values can be used to visualize the depth of the water environment (Veizer *et al.*, 1974 [37]; Shi Jizhong *et al.*, 2021 [38]). It is found that the variation of  $1000 \times (\text{Sr}/\text{Ca})$  has similar characteristics with Sr/Ba values, and the general variation is less in areas with

local water depth, indicating a closed basin-phase paleogeographic feature; while the general variation of values is larger in areas with shallow water, reflecting an open terrace environment. The variation pattern and size comparison of these values can effectively reflect the periodic fluctuation of paleodepth.

### 3.4. Identification of the Paleo-Oxygen Phase

The use of redox-sensitive elements, such as V, Ni, U, and Mo, can be used to determine the redox conditions of water bodies (Hu, Xiu-Min *et al.*, 2001). A series of redox condition indicators such as DOP, authigenic U, U/Th, V/Cr, Ni/Co, V/Sc, and V/(V + Ni) have been established by previous authors using a series of trace elements with different redox properties (Jones *et al.*, 1994 [39]; Wignall *et al.*, 1996 [40]; Kimura *et al.*, 2001 [41]; Xiong, Xiaohui *et al.* 2011 [32]). However, at the same time, using these trace elements for indicator identification is, especially for carbonate rocks, also requires attention to the assay method. The use of low concentration of acid dissolution samples can effectively avoid the interference of non-carbonate phase, 10% hydrochloric acid solution may lead to trace non-carbonate phase into the liquid phase, while the use of 5% acetic acid solution can better control the dissolution precipitation of pure carbonate phase (Chen *et al.*, 2005) [42]. It is also necessary to judge whether the surrounding rocks are ready for analysis, for example, Mn/Sr is an effective indicator to discern the degree of alteration of marine carbonates (Veizer *et al.*, 1983) [43], Mn/Sr < 10 means that the carbonate rocks have not experienced strong late alteration, and Mn/Sr < 3 is considered to have preserved original sedimentary information. After a reliable pre-determination, subsequent specific geochemical indicators can better trace the specific characteristics of the depositional environment.

In related studies, V/Cr < 2 is considered as partial oxidizing environment 2 - 4.25 as oxygen-poor environment, >4.25 as anoxic reducing environment (Ernst *et al.*, 1970 [44]; Jones *et al.*, 1994 [39]); Ni and Co are generally enriched in reducing environment, and they show geochemical correlation in content, generally Ni/Co < 5 as oxidizing environment, >7 as reducing environment, and between them as weak reducing environment (Bryn Jones *et al.*, 1994 [39]; Tribouillard *et al.*, 2006 [45]); for V and Sc, V/Sc < 7 as reducing environment, and between them as weak reducing environment. >For V and Sc, V/Sc < 14 is an oxygen-rich environment and >30 is anoxic (Kimura *et al.*, 2001) [41]; U and Th are often used as important indicators to identify redox, and in Th/U < 2 in anoxic environments, reaching 8 in strongly oxic environments (Wignall *et al.*, 1996) [40]; the value of (Cu+Mo)/Zn was proposed and applied early as an indicator of seawater oxidation, with increasing values under reducing conditions and smaller values in oxic environments (Hallberg *et al.*, 1982 [46]; Bryn Jones *et al.*, 1994 [39]). Kimura also pointed out that the value of authigenic U in sedimentary rocks is also an indicator of redox, when U < 5 for oxidizing environment > 8 for anoxic environment (Kimura *et al.*, 2001) [41]. The anomalies of Ce

and Eu in rare earth elements usually reflect the characteristics of the depositional environment, with positive and negative anomalies of Ce representing redox conditions while positive and negative anomalies of Eu reflecting hydrothermal fluid influences (Byrne *et al.*, 1990 [47]; Byrne *et al.*, 1996 [48]; Franchi *et al.*, 2015 [49]). Previous studies have shown that the enrichment of La affects the calculation of Ce and is generally considered a positive anomaly of La and no anomaly of Ce when  $0.95 < (\text{Pr}/\text{Pr}^*) < 1.05$ ,  $\text{Ce} < 0.95$  (Bau M *et al.*, 1996) [50].

#### 4. Summary

In summary, using the mineralogical characteristics of rocks and the geochemical characteristics of elements, geochemical methods can be used to discriminate and tracer different depositional environments:

- 1) Mineralogy can reveal paleogeographic information such as paleoclimate and sediment sources using clay minerals and organic matter components;
- 2) Paleoproductivity can be discriminated by Ba and Cu as indicators; paleosalinity is mainly traced by Sr and Ba for comparison; paleodepth is commonly traced by  $1000 \times (\text{Sr}/\text{Ca})$  value and REE value;
- 3) The indicators of paleo-oxygen phase are more and more complicated, and the reliable and widely used indicators are: V/Cr, Ni/Co, V/Sr, Th/U, (Cu + Mo)/Zn, and Ce and Eu anomalies. Before making the discriminations, it is necessary to pay attention to the determination method of the surrounding rock and the degree of alteration of the surrounding rock.

#### Conflicts of Interest

The authors declare no conflicts of interest.

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