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Conditions of Depositional Environment of the Sargelu Formation in Rania Area Based on Geochemical Data

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ABSTRACT

The sequence of the Sargleu Formation (Middle Jurassic) in the Hangira section is located at the northwestern Sulaymaniyah Governorate center in Rania City, northeastern Iraq. The studied successions consist of well-bedded limestone and dolomitic limestone, gray in color, interbedded with thin beds of argillaceous limestone rich in organic matter and intertwined at the top of this succession by thin beds of brown chert rich in ammonite fossils. The aforementioned beds are followed by a succession of thin-bedded limestone, brown color alternating with beds of argillaceous limestone and thin beds of chert. The selected section has been studied in terms of geochemical data of some major and trace elements and the ratio between them for ten samples to elucidate the paleoenvironmental conditions, including paleoproductivity, oxidation and reduction conditions, provenance, hydrodynamic conditions, and detrital input. The productivity record of (P/Al, P/Ti, Ba/Al ratios) indicates high paleoproductivity. Redox proxies for trace elements (V/V+Ni), (U/Th), and (Ni/Co) suggest anoxic to oxygen-deficient conditions. The provenance proxies (Al2O3/TiO2 ratio) indicate that the source rocks of the Sargelu Formation are intermediate igneous rocks. The (Zr/Rb ratio) values indicate a deposition in conditions with low water energy. The high ratios of (Si/Al and Ti/Al) indicate a high clastic flow in the sedimentation basin of the Sargelu Formation due to the presence of detrital quartz or organic silica of organisms with a silicate wall, such as Radiolaria. While the high ratio of (K/Al) is attributed to the role of the wind source of clastic flow in the deposits of the formation, or to the nature of the clay minerals present in the deposits of the Sargelu Formation.

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ظروف البيئة الترسيبية لتكوين ساركلو في منطقة رانيا بالاعتماد على البيانات الجيوكيميائية

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الملخص

تتألف تتابعات تكوين ساركلو بعمر (الجوراسي الأوسط) في مقطع هانجيرا الواقع في (مدينة رانية) شمال غربي مركز محافظة السليمانية، شمال شرقي العراق من صخورالحجر الجيري المتطبقة والحجر الجيري الدولوميتي، رمادي اللون، تتخللها طبقات رقيقة من الحجر الجيري الطيني الغني بالمواد العضوية، تتعاقب معها في أعلى هذ التتابع طبقات رقيقة من الصوان البني الغني بمتحجرات الأمونايت. تعلو الطبقات المذكورة آنفاً طبقات رقيقة من الحجر الجيري البني اللون بالتناوب مع طبقات من الحجر الجيري الطيني وطبقات رقيقة من الصوان. اجريت دراسة جيوكيميائية لبعض العناصر الرئيسة والعناصر الأثرية والعلاقة بينها لعشرة عينات كمؤشر لظروف البئية القديمة بما في ذلك الإنتاجية القديمة وظروف الأكسدة والاختزال والمصدرية والظروف الهيدروديناميكية ومدخلات الحطام. يشير سجل الإنتاجية (P/Al, P/Ti, Ba/Al) إلى إنتاجية قديمة عالية. تشير مؤشرات الأكسدة والاختزال للعناصر الأثرية (V/V+Ni)، (U/Th) و(Ni/Co) إلى ظروف نقص الأوكسجين. تشير مؤشرات المصدرية (Al2O3/TiO2) إلى أن الصخور المصدرية للتكوين كانت صخوراً نارية متوسطة. تشير قيم نسبة (Zr/Rb) إلى ترسبها في ظروف ذات طاقة مائية منخفضة. بينما تشير نسب (Si/Al وTi/Al) إلى تدفق حطامي مرتفع في الحوض الترسيبي لتكوين ساركلو، والذي قد يكون ارتفاعه بسبب وجود الكوارتز الفتاتي أو السيليكا العضوية للكائنات الحية ذات الجدار السيليكاتي، مثل الراديولاريا. بينما تُعزى نسبة (K/Al) إلى دور الرياح كمصدر للتدفق الحطامي في رواسب التكوين أو إلى طبيعة المعادن الطينية الموجودة في رواسب التكوين.

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Introduction

The Sargelu Formation was initially documented in its type section by Wetzel (Wetzel, 1948 in Bellen et al., 1959), and its name originates in Sargelu village, situated in the Surdash Anticline, in the region of Sulaymaniyah Governorate, Northeastern Iraq. In lithology, thin, black cherty and bituminous limestones, and thin, argillaceous limestones intercalated with thin black cherty ones, dominate in thin forms, most prominently in the upper parts. In terms of its position in a stage, its base of the stratigraphical interval corresponds with the stage of Bajocian, and its top with the stage of Bathonian, according to its fossil associations in the unit. The Sargelu Formation ranks amongst the most economically significant in Iraq, with high contents of organic matter, and thus, such a formation is a key source rock for generating a source of petroleum in its upper Jurassic and lower Cretaceous rocks (Jafar, 2010).

According to Bolton (1958), the Sargelu Formation in the Rania region is composed of black shaly limestone with thin stratification, with cherty black bands, and with accompanying brown dolomitized marls. On the basis of the dominant faunas prevalent, the Sargelu Formation is located in the Bajocian and Bathonian stages. (Hamza,1971 in Al-Hadithi et al., 1976)" describe the Sargelu Formation in the Benafi region, and pointed out that it consists of bluish-gray to black, well-bedded organic limestone and dolomitic in some parts."

Buday (1980) refers that the Sargelu and Muhaiwir Formations were deposited as a result of marine advances during the Middle Jurassic and identified the environment of the Sargelu Formation in its type section as an open marine environment extending to the shallow marine environment, and pointed out that the Sargelu Formation was deposited in a toxic marine environment but some of its beds show good aeration conditions.

(Al-Ahmed, 2001) studied the Sargelu Formation in Northern Iraq and explained that the formation with high organic content is an oil exporter in Iraq, and that the conditions of the sedimentary environment of the formation are deep marine. (Balaky, 2004) while studying the formation in selected sections of Erbil and Dohuk governorates in Northern Iraq, indicated that the abundance of silica in the upper beds of the Sargelu Formation reflects its organic sedimentary origin.

The geochemical study of sediments and knowing the proportions of some elements in them is of great importance in predicting ancient environmental conditions (Tribovillard et al., 2006; Chang et al., 2016). The information obtained from geochemical studies (major and trace elements) in sedimentary successions can also be widely used to obtain important information about clastic flow, oxygenic conditions, and other depositional conditions (Tribovillard et al., 2006).

Many studies have been carried out on the Sargelu Formation, including: (Al-Ahmed, 2006; Sherwani and Balaky, 2006; Al-Fariji, 2008; Jafar, 2010; Al-Taie, 2013; Al-Asi, 2016; Al-Atroshe, 2018; Akram et al., 2021; Al-Dolaimy et al., 2021; Al-Tarim and Al-Shakiri, 2022). This research aims to study the concentrations of some major and trace elements and the proportions between them to deduce some sedimentary conditions during the deposition of the Sargelu Formation.

Location of the Study Area

The Sargelu Formation was studied in the Hanjira village, located within the borders of Sulaymani Governorate, Northeastern Iraq. The Hanjira section is located 95 km Northwest of the Sulaymani center, specifically 1.97 km Northwest of the Rania town, which is located on the Southwestern limb of the Shaweri anticline, at the intersection point (44˚50'55'E) and (36˚16'50'N) (Fig. 1).

Geological Setting

Jurassic successions are exposed in different areas, northern and northeastern Iraq, and are concentrated within the High Folded Zone and the Imbricated Zone as well as the Thrust Zone (Buday, 1980). The Sargelu Formation in the studied section is located within the Imbricated Zone (Fouad, 2015) (Fig. 1).

The Sargelu Formation is one of the formations that make up the Great Arabian Plate (Late Toarcian- Early Tithonian Megasequence-AP7) (Jassim and Buday, 2006).

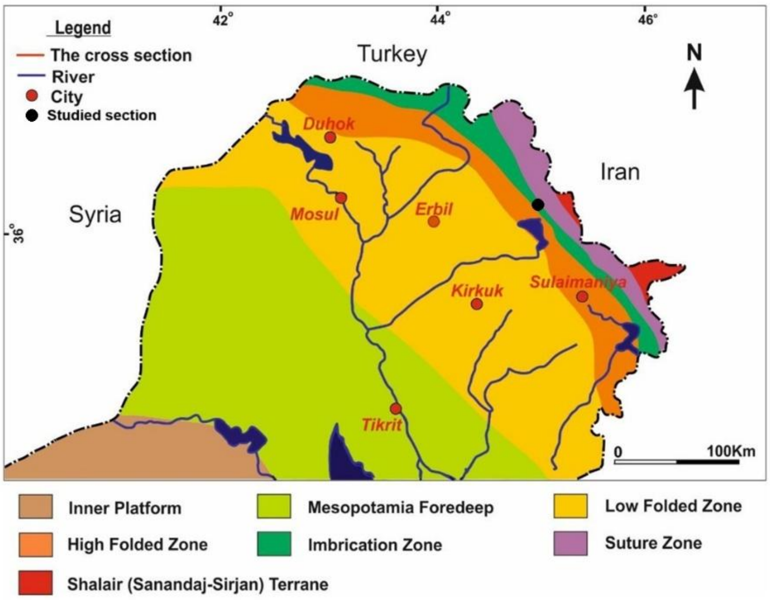

Fig. 1. Tectonic and location map of the study area (after Fouad, 2015).

It includes two sub-sequences, the late Jurassic and the Middle Jurassic. The Saggar, Cotnia, Najma, Naokelekan, and Barsarin formations were deposited in the late Jurassic, while the middle Jurassic sequences included the Sargelu and Muhaiwer formations (Jassim and Buday, 2006; Sharland et al., 2001).

The form of sedimentary basins in the Middle East during the Middle Jurassic (Bajocian and Bathonian) after tectonic movements that led to a significant marine decline during the late Triassic (Sharief, 1982), it began to develop and originate in most areas of Iraq seas within the continent, then deposition of Muhaiwer Formation facies occurred in its shallow parts, while the facies of the Sargelu Formation deposited in its deep parts (Rabu et al., 1990).

In the study area, the Sargelu Formation is bounded at the bottom by the Sehkaniyan Formation and at the top by the Naokelekan Formation. The Sehkaniyan Formation (Upper Liassic) was first described by Wetzel and Morton 1950 in Bellen et al. (1959) in the Sordash anticline near the village of Sehkaniyan, northeastern Iraq.

The Sehkaniyan Formation consists of hard and dark gray dolostone rocks. The formation is located below the Sargelu Formation, and the contact surface between them appears as a conformable surface (Bolton, 1958). The Naokelekan Formation (Late Oxfordian - Early Kimmeridgian) is described in the typical section by Wetzel and Morton (1950 in Bellen et al., 1959), which is located near the village of Naokelekan in northeastern Iraq. The formation consists of thick-bedded light brown limestone interspersed with thin beds of gray-colored carbonate rocks intertwined with thin black shales. The formation is underlain by the Sargelu Formation, and the contact surface between them is sedimentologically conformable (Buday, 1980).

Methods and Materials

The field work involved a number of site trips to the field location in Hanjira village. On-site, ten samples were collected from the Sargelo Formation with regard to rock variation in character. In detail, observations regarding rock bed criteria, including thickness, color, and relation in terms of stratigraphy, were recorded. All indications of presence and life activity, and the presence of bituminous matter, were noted, and proper photograph documentation was conducted. In the laboratory, thin sections of samples collected and prepared in the geologic workshop in the Department of Geology, University of Mosul, and analyzed with a polarized microscope. An analysis and attempt to assess the composition, texture, and the impact of a diagenesis process in rock samples. Besides, X-ray fluorescence (XRF) analysis with the (ADX 2700) device is carried out for ten samples in the University of Baghdad, College of Science. The geochemical analysis is an attempt to assess concentrations of major and trace elements in the Sargelu Formation in order to calculate an elemental proportion as well.

The thickness of the Sargelu Formation in the Hangira section is 40 meters beginning with a succession of 28 meters thick (Fig. 2), which consists of well-bedded limestone and dolomitic limestone, gray in color, interspersed with beds of argillaceous limestone (10-30 cm thick) rich in organic matter, intertwined at the top of this succession by thin beds of brown chert rich in ammonite fossils.

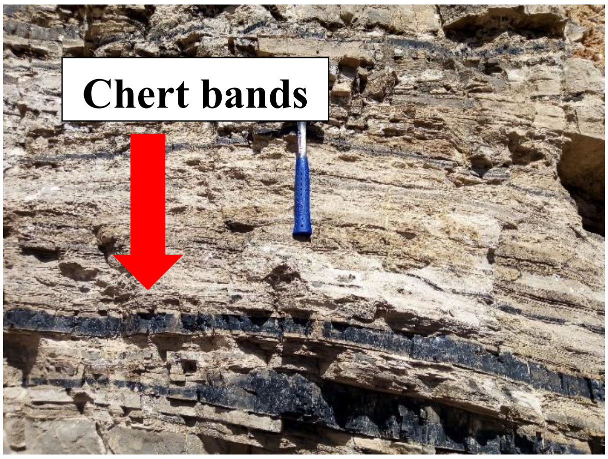

Fig. 2. Field photo showing well-bedded limestone, dolomitic limestone, and chert beds, Hanjera section.

Fig. 3. Field photo showing limestone beds interbedded with chert bands, Hanjera section.

The aforementioned beds followed by another succession of 12 meters thick consisting of well-bedded limestone with a bed thickness of (10-40 cm) of brown color alternating with beds of argillaceous limestone and thin beds of chert with thickness (5-10 cm) (Fig. 3). The above sequences end in brown, thick limestone beds belonging to the Naokelekan Formation (Fig. 4).

According to Al-Shammary et al. (2023b), three dominant microfacies constitute the formation: namely lime mudstone, lime wackestone, and lime packstone. These three microfacies have eight respective subdivisions as in Table 1. Siliceous microfossil occurrences, namely radiolarian tests, which in these microfacies serve as a dominant marker for pelagic depositional environments. All these indications, according to Mohammed Sajed et al. (2024), strongly validate that the depositional environment of the formation is a deep-shelf system with a deep-sea basin.

Table 1: Main and submicrofacies of the Sargelu Formation.

Microfacies	Submicrofacies
Lime mudstone microfacies	Radiolarian lime mudstone
	Bioclastic lime mudstone
Lime wackestone microfacies	Radiolarian lime wackestone
	Bioclastic filaments lime wackestone
	Bioclastic lime wackestone
Lime packstone microfacies	Bositra lime packstone
	Ostracoda lime packstone
	Filaments lime packstone

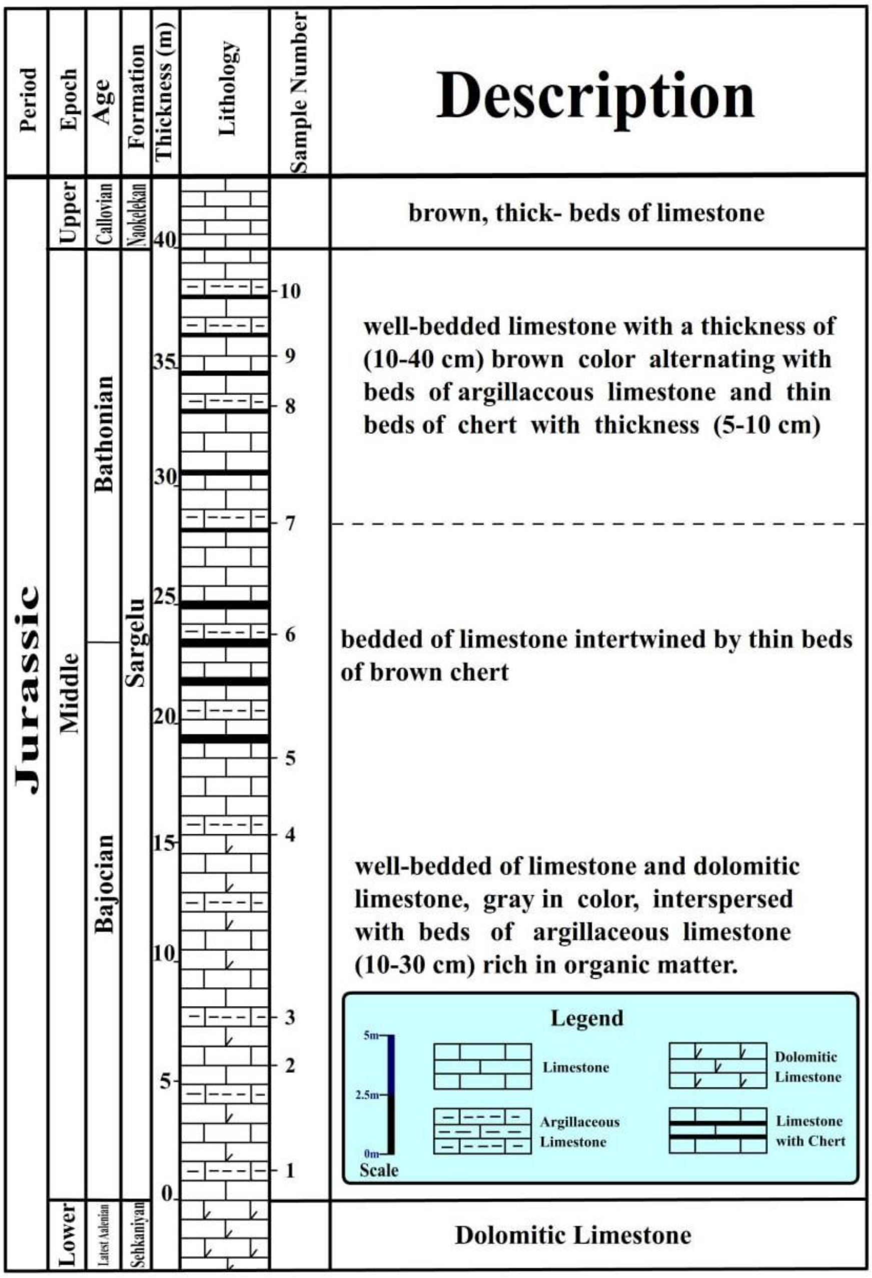

Fig. 4. Columnar lithology of Sargelu Formation in Hanjira section.

Results and Discussion

Paleoproductivity

The concentrations of some major and trace elements, as well as the ratios between them, are determined for ten samples distributed across the Sargelu Formation to extrapolate certain conditions of its depositional environment that accompanied the deposition of the Sargelu Formation. Table 2 shows these ratios.

Phosphorus (P)

Phosphorus is a life-supporting element for all living forms on the planet, acting as an important nutrient for living beings in view of its role in a variety of processes in living forms (Shen et al., 2015; Tribovillard et al., 2006). In addition, it forms an integral part of soft skeletal structures responsible for assimilation of phosphorus in tissue development (Shen et al., 2015; Tribovillard et al., 2006). Phosphorus in sediments has a strong relation with productivity at the surface, and it is buried with organic matter during the decomposition of living forms. In reduced environments, phosphorus can become mobilized in organic matter, and even in areas with high productivity in living forms, its depletion can occur (Schenau et al., 2005). High concentrations of phosphorus in sediments in upwelling allow for increased cycling of nutrients, and in consequence, high organic productivity with organic compounds, including calcareous deposits (Böning et al., 2004; Schenau et al., 2005).

Phosphorus deposition is preferentially mineralized over organic carbon and subsequently mobilized in pore water during its migration in the water column. In a secondary stage, endogenous phosphate can form too. To exclude, at least in part, the role of terrestrial detrital contribution, productivity in terms of phosphorus is conventionally considered in terms of (P/Ti) or (P/Al) and not in terms of absolute concentrations of phosphorus (Algeo et al., 2011).

Table 2: Some elemental ratios of depositional Conditions of the Sargelu Formation.

Sample No.	P/Al	P/Ti	Ba bio	V/(V+Ni)	U/Th	Ni/Co	Al_2O_3/TiO_2	Zr/Rb	Si/Al	Ti/Al	K/Al
M1	0.06	0.68	77.29	0.46	1.12	12.33	13.39	2.21	2.92	0.08	0.27
M2	0.14	2.47	32.40	0.65	2.93	24.40	20.16	3.66	2.61	0.06	0.24
M3	0.05	0.61	31.94	0.63	3.86	40.34	12.91	1.98	11.77	0.09	0.30
M4	0.14	1.70	38.10	0.47	8.15	86.94	13.38	1.69	7.25	0.08	0.33
M5	0.09	1.53	34.93	0.48	1.38	13.02	18.40	1.94	2.50	0.06	0.45
M6	0.02	0.31	80.56	0.62	4.19	12.16	15.75	1.98	2.59	0.07	0.49
M7	0.05	0.55	40.84	0.46	8.76	111.44	13.52	1.64	6.77	0.08	0.60
M8	0.04	0.56	37.83	0.69	4.67	25.32	15.90	1.07	3.03	0.07	0.38
M9	0.04	0.42	92.05	0.67	5.36	93.19	10.52	2.62	2.66	0.11	0.42
M10	0.06	0.57	74.38	0.74	8.92	35.01	11.63	1.63	3.14	0.10	0.40
Ave.	0.07	0.94	54.03	0.59	4.93	45.41	14.56	2.04	4.52	0.08	0.39
Max	0.14	2.47	92.05	0.74	8.92	111.44	20.16	3.66	11.77	0.11	0.60
Min	0.02	0.31	31.94	0.46	1.12	12.16	10.52	1.07	2.50	0.06	0.24

P/Al Ratio

The results of this work confirm that the mean (P/Al) value is approximately 0.07, with a range between 0.02 and 0.14, as in Table 2. These observations confirm that in this work, the mean (P/Al) value is larger in comparison with its documented mean in shales, and it is 0.008 according to Wedepohl (1971). That confirms high productivity in Sargelu Formation samples. These observations agree with (Hetzel et al., 2009; Liu et al., 2019), who regarded (P/Al) values are high in a range between (0.01 and 0.03). Thus, observations evidently confirm that the Sargelu Formation accumulated under high productivity in terms of its biological productivity.

P/Ti Ratio

The (P/Ti) values in the Sargelu Formation range between (0.31 and 2.47) with an average of (0.94) as in Table 2. All these values point to high productivity in samples under consideration in consonance with productivity values postulated by Algeo et al. (2011). Specifically, a (P/Ti) value less than (0.34) signifies low productivity, and a value exceeding (0.79) signifies high productivity. Ratios between (0.34 and 0.79) represent indicative intermediate productivity. In general, phosphorus enrichments in black horizons are most frequently accompanied by augmented primary productivity supported through augmented availability of nutrients.

Organic Barium (Ba) (Ba/Al Ratio)

Barium in marine environments is present in a variety of forms, including the form of the mineral barite, in living beings' skeletal structures, and in organic matter. In such forms, its presence is a result of marine organism metabolic processes, in which barium is taken in and incorporated, or adsorbed onto, a silica or a carbonate skeleton, or transported with organic matter, possibly derived from detrital sources. There is a strong organic carbon-barium association (Dymond et al., 1992; Tribovillard et al., 2006). Organic barium (Ba_{bio}) is a well-established proxy for initial organic productivity (Dymond et al., 1992; Francois et al., 1995), and reflects specifically incorporated barium through living activity, and can therefore discriminate between incorporated barium derived through processes not living in origin, such as through hydrothermal activity, and through incorporation with detrital matter associations (Martinez-Ruiz et al., 2014; Eagle et al., 2003; Ding et al., 2018). Quantitation of organic barium (Ba_{bio}) is most commonly calculated through the use of the following equation:

$$Ba_{bio}=Ba_{total}-(Al_{total}*Ba/Al_{alum}.) = Ba_{total}-(Al_{total}*0.0075)$$

Where the value of the (Ba/Al_{alum}) ratio in detrital aluminum silicates is (0.0075) in the rocks of the Earth's crust (Dymond et al., 1992), and when the values are positive, the productivity is high, and when they are negative or very little, they indicate low productivity. The percentage of organic barium (Ba_{bio}) in the Sargelu Formation has positive values ranging between (31.94-92.05) with an average of (54.03). Note Table (2). These positive values indicate high old productivity.

Oxidation and reduction conditions

V/(V+Ni) Ratio

Vanadium is a minor, oxidation state-sensitive element, and its abundance increases under anoxia (Jones and Manning, 1994; Hatch and Leventhal, 1992; Tribovillard et al., 2006). Meunier (1994) reported that vanadium can occur in substitution for aluminum in clays in an octahedral position during diagenesis processes (Tribovillard et al., 2006). Hatch and Leventhal (1992) even constructed a (V/(V+Ni)) value that with a value > 0.84 is indicative of toxic environments, 0.54 < (V/(V+Ni)) < 0.84 indicative of depletion in oxygen, 0.46 < (V/(V+Ni)) < 0.54 indicative of semi-oxygen (dysoxical) environments, and (V/(V+Ni)) at and below 0.46 indicative of high concentrations of oxygen environments.

In the current study, the ratio (V/(V+Ni)) ranges between (0.46-0.74) at a rate of (0.59) (Table 2); and therefore, most of the rocks of the Sargelu Formation were deposited under anoxic to semi-oxygen (dysoxic) environmental conditions.

U/Th Ratio

The chemical behavior of uranium is similar to thorium, and U/Th is utilized in terms of checking for oxidation-reduction state. Any value of U/Th > 1.25 signifies an environment with a lack of oxygen, and values between 0.75 and 1.25 denote a dysoxic-suboxic environment (Jones and Manning, 1994; Zhang et al., 2019). Conversely, a value < 0.75 signifies an environment with an abundance of oxygen (Jones and Manning, 1994; Zhang et al., 2019). In Sargelu Formation samples, U/Th values range between 1.12 and 8.95 with an average of 4.93 (Table 2). All such values are about 0.38 in excess of the general U/Th in a shale (Wedepohl, 1971). High U/Th values in the current study mean that the Sargelo Formation had been deposited in an oxygen-lacking environment.

Ni/Co Ratio

The nickel/cobalt (Ni/Co) ratio can also be used as an indication of the conditions of deposition in terms of the abundance of oxygen. If the ratio is greater than (7.0), then the depositional conditions are of scarce or no oxygen (anoxic), and if they are between (5.0-7.0) the conditions are moderate in terms of the abundance of oxygen (dysoxic), but if the ratio is less than (5.0), the conditions are abundant in oxygen (Dypvik, 1984; Jones and Manning, 1994).

This percentage in the Sargelu Formation samples is at a rate of (45.41) with a range between (12.16-111.44) (Table 2), and these values indicate deposition in oxygen-scarce conditions.

Provenance

Al_2O_3/TiO_2 Ratio

The (Al_2O_3/TiO_2) ratio is commonly used for source rock determination (Hayashi et al., 1997; Zeng et al., 2019). In general, a value exceeding 21 signifies felsic acid igneous rocks, a value between 8-21 signifies intermediate igneous rocks, and a value less than 8 signifies basic igneous rocks. For Sargelu Formation samples, (Al_2O_3/TiO_2) value ranges between (10.52) and (20.16) with an average of (14.56) (Table 2). This signifies that Sargelu Formation source rocks have predominantly an intermediate igneous character.

Hydrodynamic Conditions

Hydrodynamic conditions represent an integrated system that includes the influence of water depth, wave base, and current speed. The quantitative preservation of organic matter increases with a decrease in water energy (Liu et al., 2006). The hydrodynamics of the basin can be inferred through the ratio (Zr/Rb), which can reflect the changes occurring in hydrodynamic conditions. Zircon enrichment usually occurs in coarse sediments, but is depleted in fine sediments. As for the element Rubidium, it is generally deposited in low-energy environments and is associated with fine-grained minerals such as clay minerals. Therefore, if the ratio (Zr/Rb) is high, it usually indicates an environment with high hydroenergy, while if this ratio is low, it indicates an environment with low energy (Liu et al., 2006), as the ratio of values that are Less than (2) and at a rate of (0.9) to low water capacity with the presence of thinning and black color of the sediments (Liu et al., 2006).

The ratio (Zr/Rb) in the models of the Sargelu Formation ranges between (1.07-3.66) with an average of (2.04) (Table 2), and these values may indicate that the Sargelu Formation was deposited in conditions with low water energy, which is associated with the deposition of thinned black chert.

Detrital input

Si/Al Ratio

Silicon (Si) and aluminum (Al) are generally immobile elements during diagenetic processes and are often used as evidence of clastic flow (Sageman and Lyons, 2005; Tribovillard et al., 2006). Silicon is mainly found in the siliciclastic (quartz) part and the organic part (Kidder and Erwin, 2001). As for aluminum, its presence is limited to the fine part of aluminum silicate and is rich in kaolinite and smectite, and is formed as a result of severe chemical weathering under the influence of humid and warm climate conditions (Yeasmin et al., 2017).

The Si/Al ratio has been used in many studies as a means of determining clastic flow, as it represents the ratio of quartz to clay (Murphy et al., 2000; Rimmer, 2004), and changes in the Si/Al ratio are preferably interpreted to reflect changes in silicon flow (Si) which is independent of alluvial processing (Werne et al., 2002). This ratio in the samples of the Sargelu Formation ranges between (2.5-11.77) at a rate of (4.52) (Table 2), and these values are higher than its value in the shale rate (3.11) (Wedepohl, 1971), which indicates a high clastic flow in the sedimentation basin of the Sargelu Formation, whose high values may be due to the presence of detrital quartz or organic silica of organisms with a silicate wall such as Radiolaria.

Ti/Al and K/Al Ratios

The assessment of detrital preparation is determined via (Ti/Al and K/Al) ratios (Tribovillard et al., 2006; Rakociński et al., 2018). The origin of titanium comes through wind flow (aeolian inputs), and (Ti/Al, therefore, is an expression of wind activity (aeolian activity (Challands et al., 2009) and weathering of adjacent volcanic rocks (Boström, 1970). In Sargelu Formation samples, the (Ti/Al) ratio ranges between (0.06-0.11) with an average of (0.8), and the (K/Al) ratio ranges between (0.24-0.60) with an average of (0.39) (Table 2). For comparison, (Ti/Al and K/Al in the composition of shale) are (0.05 and 0.34, respectively (Wedepohl, 1971). Higher values, in contrast to (in shale), could be an expression of wind clastic flows' impact in Sargelu Formation deposits, or the specific character of clays in Sargelu Formation sediment.

Conclusion

The findings of the current study can be synthesized below:

1. The studied section of the Sargelu Formation in Hanjira, northeastern Iraq, consists predominantly of dolomite and limestone, with organic matter-enriched argillaceous limestone and thin chert intercalation.
2. Geochemical analyses of rock units in the formation have been performed in an attempt to evaluate paleoproductivity, oxidation and reduction, provenance, hydrodynamic, and detrital input. Ratios of P/Al, P/Ti, and Ba/Al in general imply high productivity values.
3. Redox proxies for trace metalloelement (e.g., V/(V + Ni), U/Th, and Ni/Co) record anoxia to semi-oxygenated (dysoxia).
4. The Al_2O_3/TiO_2 proportion suggests that the source rocks for the Sargelu Formation are intermediate igneous rocks in general.
5. The Zr/Rb ratio proves that the Sargelu Formation had been accumulated in an environment with low-energy water.
6. Ratios of Si/Al, Ti/Al, and K/Al indicate high clastic contribution in the Sargelu Formation sedimentary basin, with a dominant source of clastic material being driven by wind.

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