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Discussion on the sedimentary structure, geochemical characteristics and sedimentary environment of Ping Chau formation at Tung Ping Chau, Hong Kong

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Abstract

Ping Chau Formation has long been regarded as the youngest formation in Hong Kong since its emergence from Tung Ping Chau, an island on the northeast of Mirs Bay of New Territories. On the basis of field survey, the present study re-collates and re-stipulates typical sedimentary structure and sedimentary environment of Ping Chau Formation at Tung Ping Chau. Furthermore, with combination of geochemical laboratory methods for the first time a systematic analysis of the major and trace elements of Ping Chau Formation, and geochemical characteristics of rare earth elements were studied. The results showed that: Ping Chau Formation was formed in a passive continental margin structural environment; the study area belonged to transition facies ranging from brackish water to fresh water, with salinity increase from bottom to top on the profile showing a tendency of gradual salinization, The sedimentary environment of Ping Chau Formation had an anoxic reducing environment; The study concluded that Ping Chau Formation was formed in a reducing environment of brackish water or shore-shallow lake with low salinity.

Key words

Geochemical characteristics, Ping Chau Formation, Sedimentary structure, Sedimentary environment

Introduction

Tung Ping Chau is located at Mirs Bay, on the northeast corner of Hong Kong. To the east of Tung Ping Chau across the sea lies Nan'ao Town (Fig.1a). Outcropped stratum is predominantly dark grey with thinly bedded dolomitic siltstone, intercalated with mudstone (Lai, 1991). Since 1920s, foreign and native researchers began their research and survey of the geology and formation on the island, and determined the basic sequence and outline (Jones, 1995; Owen, 2000; Yao *et al.*, 2004). Three joint investigations held by related institutions from both Chinese mainland and Hong Kong have great by improved and enlarged the understanding of characteristics of Hong Kong's Geology and formation including Ping Chau Formation (Swell *et al.*, 2000; Li and Chen, 1998). However, previous researches, have mainly focused on aspects like fossil specimens and ecological environment of Tung Ping Chau and little attention has been paid on the analysis and research characteristics of Ping Chau Formation sedimentary structure and geochemical features of total rock. As for the geological age of Ping Chau Formation, whether late Mesozoic or early Cenozoic, previous studies determined it based on tectonic setting, relationship of the upper and lower formation, lithology and fossil record. These methods lacked reliable geochronology data and thus left room for further studies on the era of Ping Chau Formation.

Earlier it was believed that the Ping Chau Formation was formed in a lagoon environment, featuring a state between arid to semiarid (Peng, 1978). In 1990s, with the geological study in Hong Kong moving forward, several scholars in succession made further studies on the formation of Ping Chau sedimentary environment. Nonetheless, there were serious divergences among them. Nau (1979) reported that Ping Chau basin belonged to sedimentary type of saline lake and alkaline basin; Li and Chen (1998) stated that Ping Chau Formation was an inland lake facies featuring arenaceous pelitic salt formation. Zhu and Hu (2004) deemed that Ping Chau Formation was formed in a saline lake basin that was in a Na-Ca sulfate depository stage between that of gypsum deposits and halite deposits.

Based on field surveys, the present study collates and stipulates typical sedimentary structure of Ping Chau Formation at Tung Ping Chau, and makes a total rock geochemical analysis of siltstone sample taken from Ping Chau Formation. The study aimed to discuss sedimentary environment of Ping Chau Formation by studying of sedimentary characteristics of formation and total rock geochemical analysis.

Materials and Methods

Territorial geological setting : Tung Ping Chau is an island located on the northeast of Hong Kong, at 114°25' longitude E and 22°32' latitude N. It is about 3 km long and 0.5 km wide, covering an area of about 1.16 km^2.

Ping Chau Formation, a stratum developed from Tung Ping Chau, was formed in the Mesozoic faultbasin of Mirs Bay (Lai and Langford, 1996). It is one of the basins in southeast of China featuring Mesozoic and Cenozoic continental facies–marine-continental facies. Regionally, the sedimentary characteristics of Ping Chau Formation form obvious contrast with those of Sanshui Basin and Dongguan Basin in Guangdong province (Yao *et al*., 2004).

The whole Ping Chau Formation can be divided into three segments, with the lower segment (above 150 m) and upper

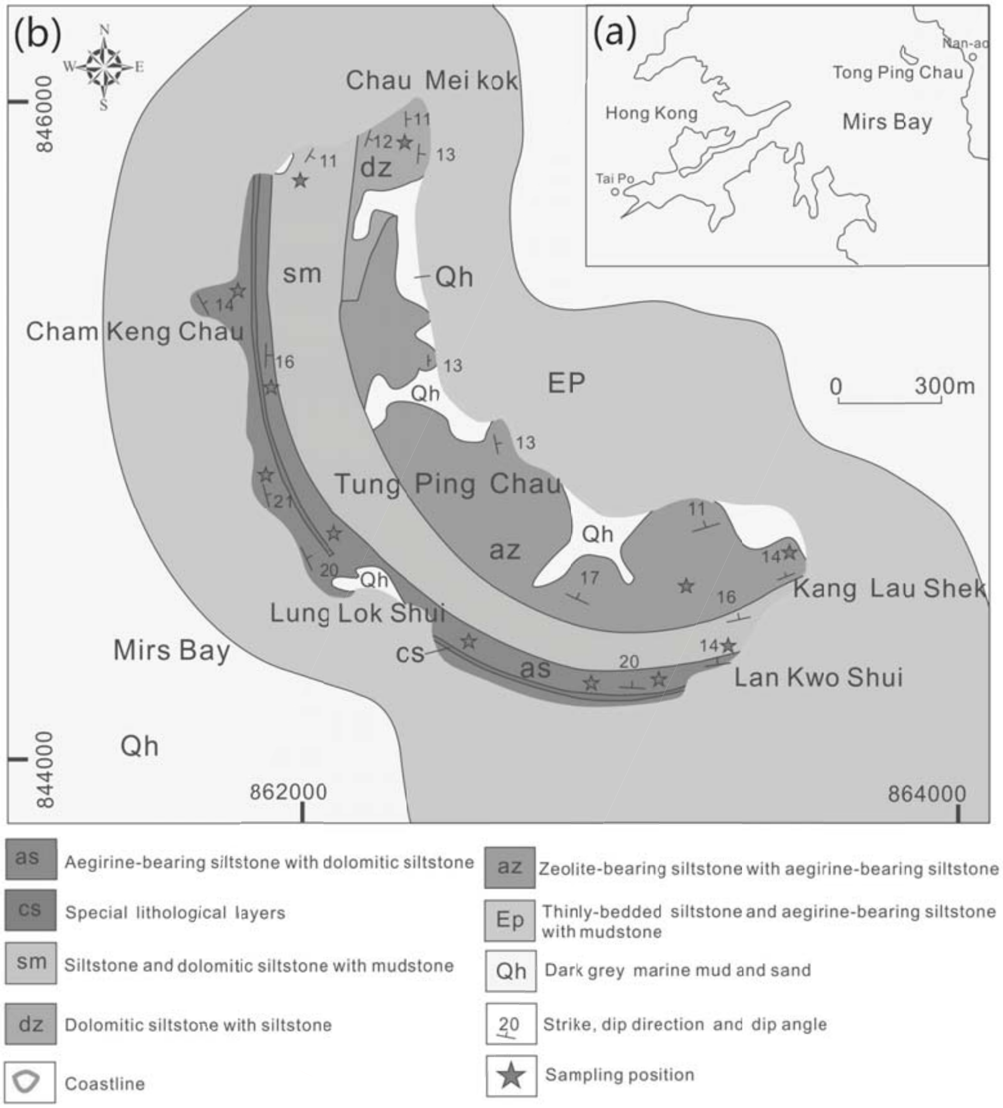


Fig. 1 : Geological map of Tung Ping Chau (revised after Duan and Liu, 2000)

segment (above 100 m) nearly submerged in the sea. Only the middle segment emerges on the Tung Ping Chau. It is about 200 m thick and its lithological characteristics mainly feature siltstone, mudstone, marlstone and dolomitic mudstone. The middle rock stratum can be further divided into three units: the lower unit (about 92 m) is composed of thin-layered aegirine siltstone; the middle unit (about 46 m) comprises of thin-layered siltstone, mudstone and dolomitic siltstone with 1-m thick layer of special hoary rock stratum in blocks; the upper unit (about 62 m) is made up of thin-layered zeolite siltstone with aegirine siltstone (Li *et al*., 1998)(Fig. 1b).

Sample characteristics : In the present study, 12 samples from the middle unit of middle segment of Ping Chau Formation to carry on thin-section examination, clay mineral analysis and total rock geochemical analysis. The sampling sites and rock types are listed below in Table 1.

All the 12 samples were clayey siltstone with the weathering surface tawny and fresh surface grey-greyish black in colour. They had argillaceous silty and laminated structure (Fig. 2 a). The rock was made up of terrigenous arenite and clay. Directionally arranged, terrigenous arenite mainly comprised of feldspar, quartz and debris with all in a sub-angular shape. The major component of silt was less than 0.05 mm along with fine sand of 0.05-0.15 mm. Part of terrigenous arenite presented a laminated beneficiation. Clay comprised of implicit-micro scaly clay minerals in a directional arrangement. Part of clay presented a laminated beneficiation as terrigenous arenite. Metasomatism of dolomite over rock was quite obvious. Dolomite presented hypidiomorphic rhombohedron–xenomorphic granular texture with grain size less than 0.03 mm. Of secondary minerals, most were dolomite, fluorite with few opaque minerals. All these three kinds of components disperse in heaps and work out metasomatism on rock. The grain sizes of dolomite and fluorite were less than 0.3 mm. Opaque minerals were in the shape of needle column. Inside the rock revealed part of aggregation of calcite, epidote, fluorite etc. The aggregation distributes unevenly in different ways such as stripes and nervation in rock. Calcite was usually big, ranging from 0.1-1.8 mm, with xenomorphic granular, long cylindrical or in other shapes (Fig. 2 b).

Methods and procedures of analysis : Before sample analysis, the surface of whole rock samples were cleaned 2 kg of samples

Table1 : Locations and lithology of chemically analyzed samples

Sample number	Longitude	Latitude	Lithology	Sampling site
L-14	22°32' 18"	114°26' 26"	Clayey siltstone	Lung Lok Shui
L-12	22°32' 25"	114°26' 7"	Clayey siltstone	Lung Lok Shui
L-5	22°32' 21"	114°26' 21"	Clayey siltstone	Lung Lok Shui
L-3B	22°32' 33"	114°25' 33"	Clayey siltstone	Lung Lok Shui
L-2C	22°33' 17"	114°25' 24"	Clayey siltstone	Lung Lok Shui
L-2B	22°33' 28"	114°25' 59"	Clayey siltstone	Lung Lok Shui
L-1	22°33' 14"	114°25' 49"	Clayey siltstone	Lung Lok Shui
D-28	22°33' 03"	114°25' 32"	Clayey siltstone	Chau Mei Kok
D-19	22°32' 19"	114°26' 11"	Clayey siltstone	Kang Lau Shek
D-11	22°32' 37"	114°26' 45"	Clayey siltstone	Kang Lau Shek
D-1-6B	22°33' 11"	114°25' 59"	Clayey siltstone	Cham Keng Chau
D-1-1	22°32' 40"	114°26' 25"	Clayey siltstone	Lan Kwo Shui

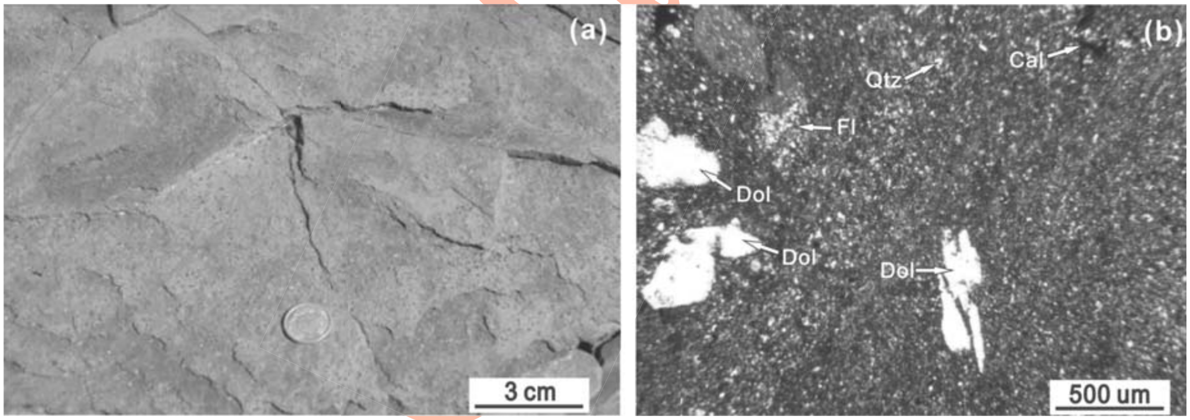


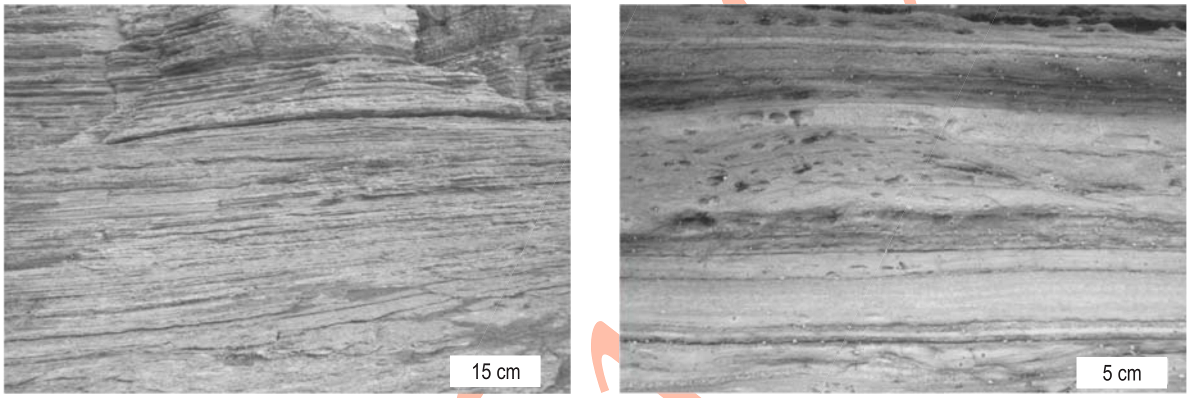
Fig. 2 : (a) Field photo of research samples (b) Microphotograph of siltstones from Ping Chau Formation (cross-polarized light) Qtz. Quartz; Cal Calcite; Dol. Dolomite; Fl. Fluorite

was coarsely crushed with jaw crusher, and then grinded to 200-mesh with vibrating crusher and washed with absolute ethanol. An appropriate amount of sample was used for analysis of major trace element and the rest of the samples sealed in plastic bottles. Total rock geochemical analysis was carried in the laboratory of Hebei Institute of Regional Geological Mineral Survey.

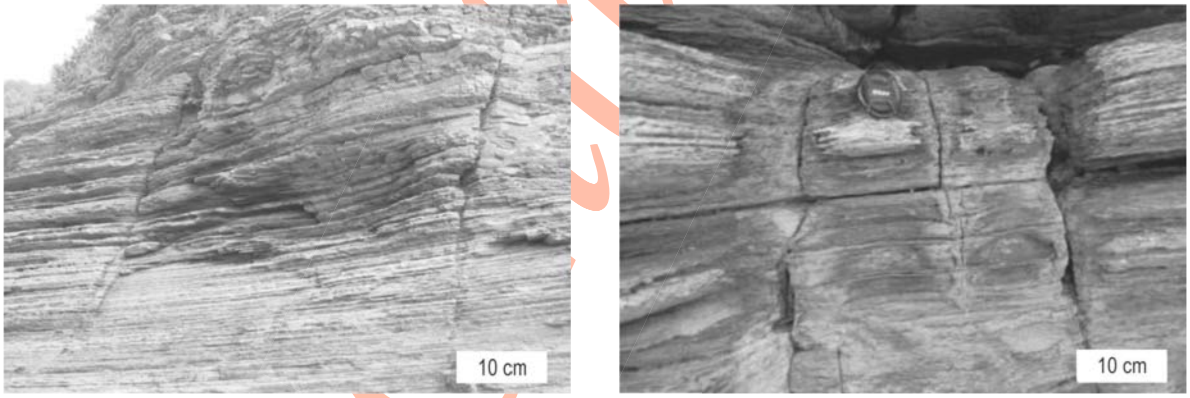
Analysis of major elements was done by scanning wavelength dispersive X ray fluorescence spectrometer (XRF, Thermo Arl Advant XP+) following international (GSP22 and JG22) and national standards (GBW02103). Under 50mA and 50kV, the analysis achieved a precision within 0.5%. The detailed methods and procedures of the analysis were done following the protocols of Liu *et al.* (2005, 2012) and Yang *et al.* (2012), respectively. The trace element and rare earth element analysis uses the high-resolution inductively coupled plasma mass spectrometry (ICP-MS) and followed the international standard GSR-1 and GSR-9. Zhang *et al.* (2011, 2012) and Wang *et al.* (2012).

Characteristics of Ping Chau Formation sedimentary structure : Sedimentary structure is formed during or after the sedimentary process of deposition, under physical, chemical and biological action. It is significant to study sedimentary environment (Chen *et al.*, 2004). On the basis of observations and records of field, characteristics of Ping Chau Formation sedimentary structure were categorized into three types which are as follows:

Bedding structure : The bedding structures developing from Ping Chau Formation included of horizontal bedding, ripple bedding, rhythmic bedding and lenticular bedding. The horizontal bedding developed from the silty mudstone and consisted of horizontal laminas whose thickness was about 2 mm (Fig.3 a). It is regarded that this kind of bedding was formed as matter deposited from suspended solids or solution under stable hydrodynamic force. Thus, horizontal bedding is one of the symbols for low-energy or still-water environment. In ripple bedding, the sand and mud bed alternate with each other and

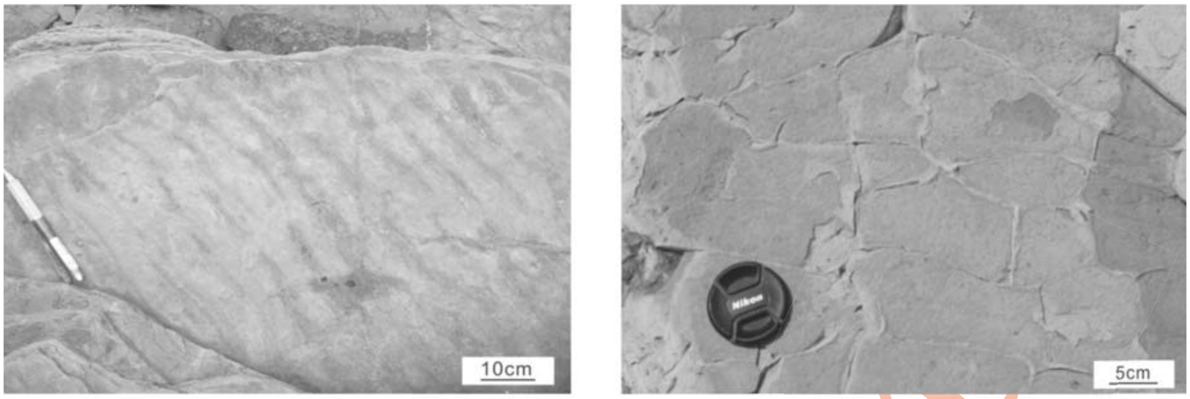


(a) Horizontal bedding (b) Ripple bedding



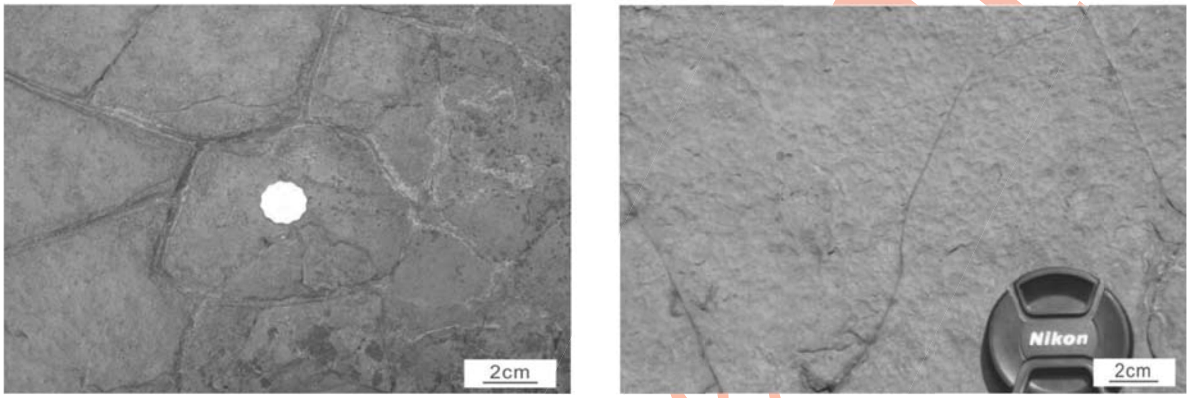
(c) Rhythmic bedding (d) Lenticular bedding

Fig. 3 : Bedding structures developing from Ping Chau Formation



(a) Ripple mark

(b) Latticed mud crack



(c) Polygonal mud crack

(d) Raindrop imprint

Fig. 4 : The bedding surface structure developing from Ping Chau Formation

present an undulate pattern but on the whole the direction of different beds are parallel in extension to the bedding surface (Fig. 3 b). It is usually formed in an environment where strong and weak hydrodynamic forces alternate, or shallow lake environment where sand and mud deposit alternatively.

Rhythmic bedding mainly comprised of siltstone and fine sandstone inter-bedding, silty mudstone and siltstone inter-bedding, and muddy siltstone and stripped siltstone inter-bedding (Fig. 3c). The rock stratum of this bedding was usually thin, about few micrometers and all the stratums were parallel or nearly parallel to each other. The bedding was formed in lakeshore or shallow lake environment. Lenticular bedding usually appeared in dark grey siltstone or silty mudstone of Ping Chau Formation (Fig. 3d). This bedding had fine gravels and appeared as uneven and lenticular in a continuous way. It was formed in a weak hydrodynamic force environment under the condition that supply, sediment and conservation of mud were more favorable to those of sand. Usually, this kind of bedding appeared in sedimentary environment of lakeshore and shallow lake.

Bedding surface structure : The bedding surface structure developing from Ping Chau Formation included of small ripple mark (Fig.4-a), mud crack and raindrop imprint. The mud crack had latticed cracking grains or polygons on the bedding surface and presented a V-shape on the fault surface (Fig. 4b, c). It was assured that it was formed in onshore area where part of the sediment above water shrinks because of water loss.

The raindrop imprint developed from outcrop of silty mudstone (Fig. 4d),which indicated that sediments had once been exposed above water before its concretion and was formed due to impact of raindrop. It can be estimated that at that time there was not much rainfall and the climate was arid or semi-arid type.

Structures resulting from other factors : Apart from the sedimentary structures above, Ping Chau Formation developed sideritic nodule (Fig. 5). The sideritic nodule was formed during complicated biochemical reaction involving iron and organic matter in weak-alkalescence reducing environment (Chen, 2010). The sideritic nodule of Ping Chau Formation was dark

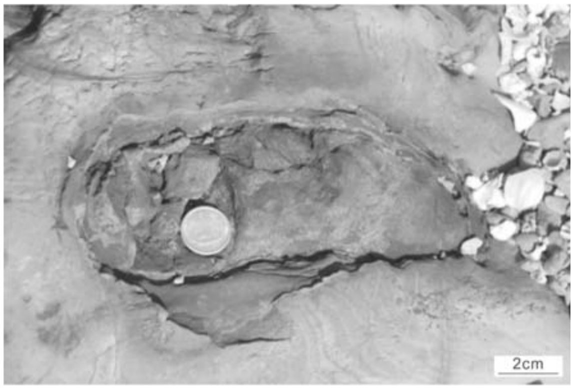


Fig. 5 : Sideritic nodule of Ping Chau Formation

brown and in a long elliptic shape with diameter ranging from 7 to 12 cm. It was hard in texture and consisted of microlite sideritic aggregation with thin outer envelope of concentric Fe oxides. The boundary between sideritic nodule and wall rock was clear and the sideritic nodule was conserved in the stratum in isolation. It was assumed that Ping Chau Formation may have been formed in brackish water reducing sedimentary environment.

Results and Discussion

The major and trace element present of siltstones samples from Ping Chau Formation are as follows : 41%-51.1% SiO_2, 13.3%-16.4% Al_2O_3, 0.42%-0.57% TiO_2, 3.9%-6.68% Fe_2O_3, 2.21%-4.27% MgO, 5.27%-9.32% CaO, 7.73%-9.78% K_2O+Na_2O. The value of Na_2O/K_2O ranged from 0.99 to 2.05, while Al_2O_3/ SiO_2 ranged from 0.30-0.34 (Table 2).

Major element and trace element of siltstones samples from Ping Chau Formation were used to make standardized spider chart (Fig.6), taking average continental upper crust (Rudnick and Gao, 2003) and North America combined shale respectively, as reference material (Gromet *et al*., 1984). As shown in Fig.6, the major element and trace element in sample on the whole were similar to the upper crust and North America shale combination respectively.

From Table 2 and Fig.8, it was observed that the total amount of rare earth elements (∑REE) varied slightly from 80.38×10^{-6} to 270.91×10^{-6}, (averag 176.63×10^{-6}). The value of ∑ LREE/∑HREE is in the middle, ranged from 5.10 to 15.16 and the value of La_N/Yb_N was relatively high, ranging from 5.3 to 19.12, which demonstrated that fractionation of both heavy and light rare earth was at medium degree. The distribution curve of rare earth leaned to right and was smooth on the whole.

Fig.7 shows four standardized rare earth modes of siltstones samples from Ping Chau Formation. On standardized spider chart of chondrite (Fig. 7a), sample showed the same distribution of rare earth element as that of North America shale combination: the curve of light rare earth was sharp, heavy and smooth as compared to heavy rare earth, the light presented a beneficiation and typified an obvious negative anomaly of Eu. Compared with Fig. 7a, on the standardized spider chart of continental lower crust (Fig. 7b), there was a consistent tendency of sharp light rare earth curve and smooth heavy rare earth with a more obvious negative anomaly of Eu and a smaller slope of La-Lu curve. On standardized spider chart of continental upper crust and North America combined shale (Fig.7-c & 7-d), the distribution pattern of rare earth samples were nearly smooth with similar content. Such result signified that Ping Chau Formation typified upper crust or had similar source region with North America shale combination.

Paleosalinity analysis is the most common and effective method of element analysis having geochemical characteristics, especially trace element as a common measuring indicator. However, with various factors disturbing the beneficiation and conservation of trace elements in rocks, to reveal precise paleosalinity of sedimentary environment needs to take various studies into consideration (Wang *et al*., 1994). In the present study equivalent boron content, value of B/Ga and value of Sr/Ba in paleosalinity analysis was used.

Previous study material indicate that clay sediment in water is capable of adsorbing boron, and there is a linear relationship between mass fraction of boron and salinity in water, in other words, higher the salinity, bigger the mass fraction (Deng and Qian, 2002). On the basis of K_2O content in sample and revised boron content (Yi *et al*., 2009), an equivalent boron content via graphic method, according to Walker's theoretical conversion curve (Walker, 1963, 1968), can be obtained.

From Table 2 and Fig.9, it was seen that the equivalent boron content of all the samples fell into 60×10^{-6} to 230×10^{-6} range. According to standard of equivalent boron content worked out by Walker (1963), the sedimentary environment of Ping Chau Formation belonged to brackish water environment or low salinity environment. Furthermore, the equivalent boron content increased from bottom to top on the profile, which indicated that salinity in water tend to increase.

Strontium and barium are have chemical characteristics among alkaline earth metals. Strontium has stronger transfer ability than barium. In fresh water lake where aqueous medium presents strong acidity and low mineralization degree with few sulfate ions, both strontium and barium are found in lake as carbonates. When salinity of water and mineralization degree increase, barium deposits as barium sulfate and strontium deposits in strontium sulfate, respectively, only when lake or sea concentrates to a certain degree after evaporation. On the basis of these findings, the ratio of strontium to barium is taken as another symbol of paleosalinity (Shi *et al*., 2003; Tao *et al*., 2009).

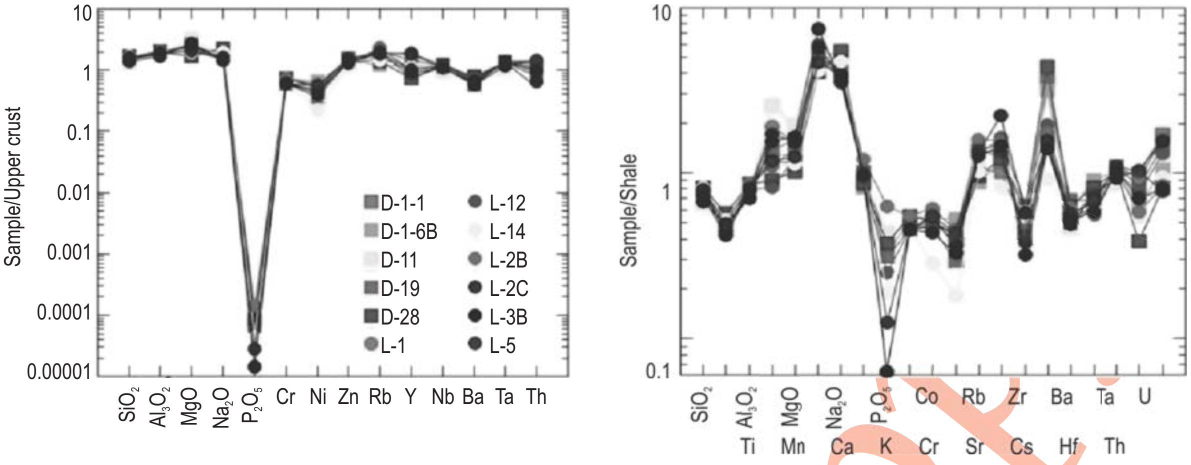


Fig. 6 : Standardized spider chart: major element and trace element in Ping Chau Formation sample compared with the upper crust and North America shale combination

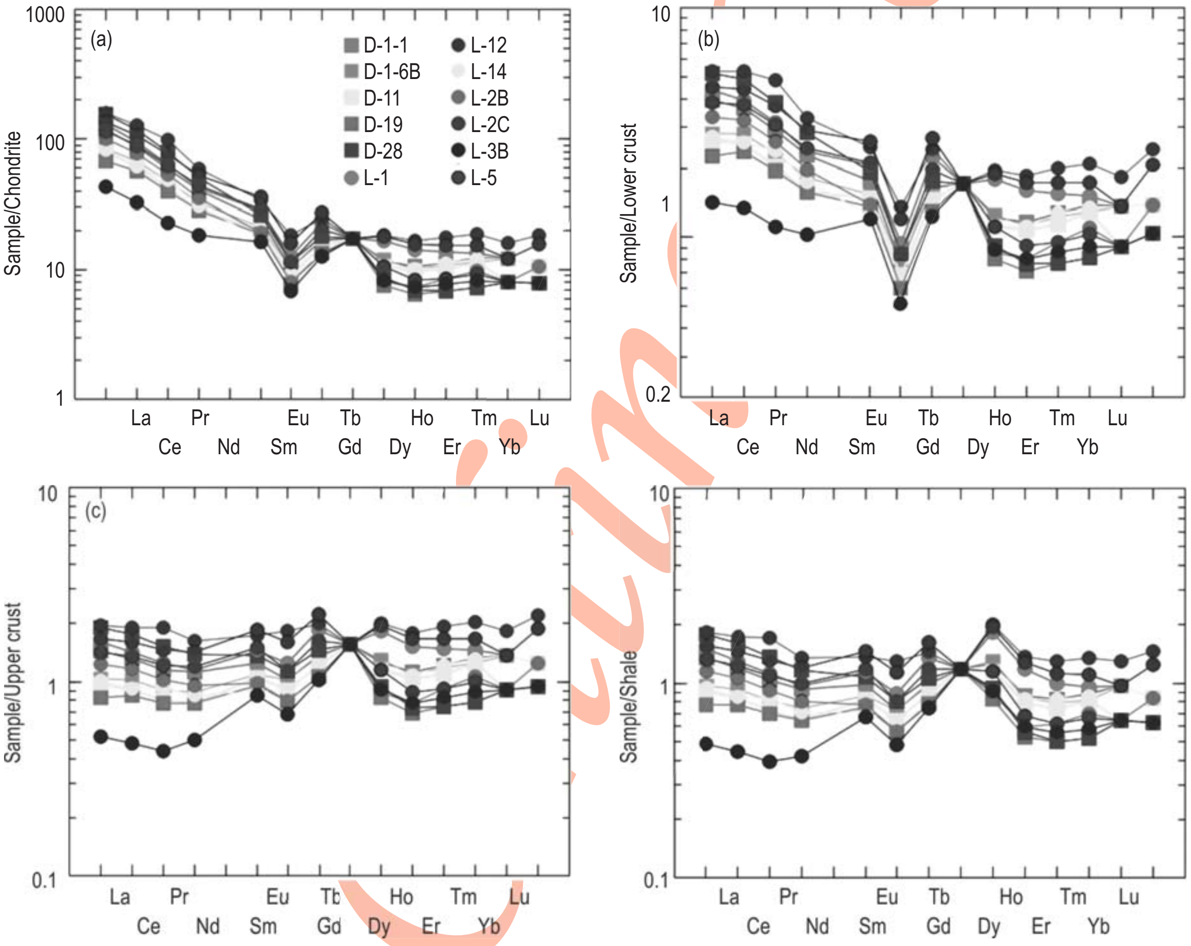


Fig. 7 : Rare earth element in Ping Chau Formation sample compared with chondrite, the lower crust, the upper crust and North America shale combination

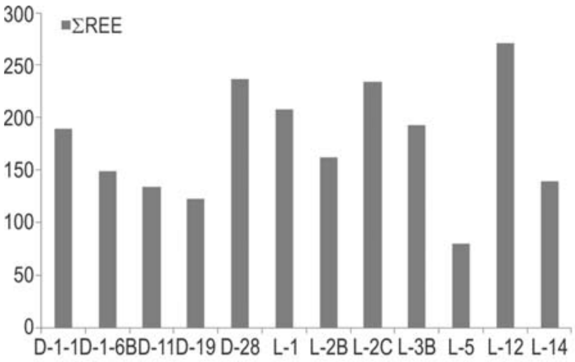


Fig. 8 : Histogram of total amount of rare earth element in siltstones samples from Ping Chau Formation

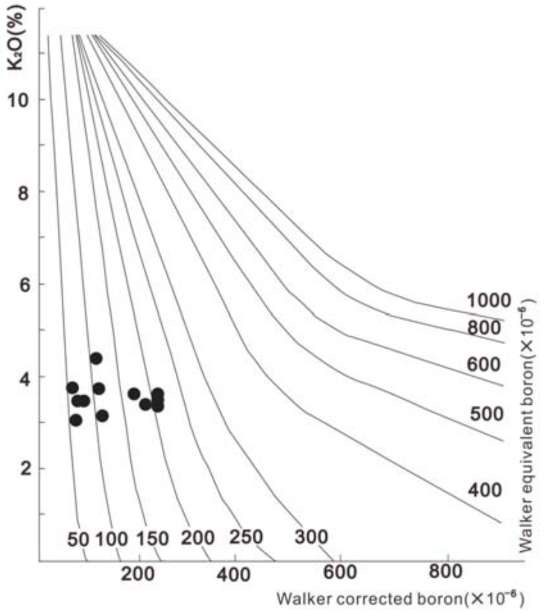


Fig. 9 : Conversion curve of Walker equivalent boron from Ping Chau Formation siltstone samples

Usually it is held that in marine facies environment the value of Sr/Ba > 1, while in continental facies environment the value of Sr/Ba < 1. In the latter facies, it can further be specified that the value from 0.6 to 1 indicates transition facies while that below 0.6 is fresh water. Except for the sample L-2C whose ratio was 1.41, all the other samples fell between 0.4 and 1, averaging to 0.7. The result showed that area is an intense transition facies environment with brackish water sedimentary type of that facies.

In sedimentary process, the redox of water may cause depletion or beneficiation of some trace elements. Abundant studies showed that trace elements like V, U and Ni produce intense beneficiations in strong adsorption rocks like shale and mudstone; elements like V and U tend to produce beneficiation more easily in the reducing environment, while Co and Ni prefer oxidation environment. Till now, V/(V+Ni) and Ni/Co have been widely applied in the study of redox conditions and many scholars have obtained some empirical value (Dill *et al*., 1988; Hatch and Leventhal, 1992; Jones and Manning, 1994). For example, V/(V+Ni) above 0.54 represents anaerobic environment, V/(V+Ni) between 0.45-0.60 represents oxygen-poor sedimentary environment, V/(V+Ni) below 0.46 represents oxygen-rich sedimentary environment. Ni/Co above 1.8 reveals reducing conditions, respectively.

According to the relationships between trace elements content and redox conditions judgment above, it can be concluded that the study area was oxygen-poor environment as V/(V+Ni) was between 0.73 and 0.85, averaging to 0.78. In the meantime, the area was also oxygen-poor reducing environment as Ni/Co was between 1.83 and 2.36, averaging to 1.97.

Distribution of rare earth elements (REE) in sedimentary rock can also reveal the redox conditions of ancient water. The main REE indicator applied to judge the redox environment was Ce anomaly. The study showed that the degree of Ce anomaly could alertly reflect the redox conditions of sedimentary environment (Lu and Jiang, 1999). The degree of Ce anomaly can be represented by δCe (Eq. 1) and Ce_{anom} (Eq. 2).

$$\delta Ce = Ce/Ce^{*} = Ce_N/(La_N{*}Pr_N)^{1/2} \qquad \text{(Eq. 1)}$$

$$Ce_{anom} = \lg[3Ce/(2La_N+Nd_N)] \qquad \text{(Eq. 2)}$$

δCe < 1 signifies negative anomaly, or Ce depletion, which represents a oxidation environment; δCe > 1 shows positive anomaly, which represents a reducing environment. $Ce_{anom} < -0.1$ indicates negative anomaly, which represents an oxidation environment; $Ce_{anom} > -0.1$ indicates Ce beneficiation, which represents a reducing environment. From data analysis it was found that δCe of sample was between 1.01 and 1.09 with $Ce_{anom} > -0.1$ so it can be concluded that area had reducing environment.

Moreover, Ce/La ratio can reflect change of paleoxygenation facies in water. Ce/La > 2 represents a reducing environment; Ce/La < or approaching 1.5 represents an oxygen-rich environment. As Ce/La ratios of samples average out to 2.02, the research area became reducing environment. Such result is consistent with that obtained by indicators V/(V+Ni) and Ni/Co and sedimentary structure. Therefore, on the whole the redox alert elements indicate that Ping Chau Formation was formed in an oxygen-poor water environment.

The content and ratio of different trace elements in sedimentary rocks are widely applied in fields such as judging sedimentary environment. Among these indicators, content allocation, variation and combination of ratio, and distribution of paleosalinity all reflect the paleoclimate characteristics to some extent (Ni *et al*., 2010).

Table 2 : Analyzed geochemical data and major parameters (Major elements: wt%; Trace elements: ×10^{-6})

Sample No.	D-1-1	D-1-6B	D-11	D-19	D-28	L-1	L-2B	L-2C	L-3B	L-5	L-12	L-14
SiO_2	48.4	45.6	41	50	51.1	47.8	48.9	42.6	49.8	45.5	48.7	51.1
Al_2O_3	16.3	15.3	14	15.65	16.1	15.05	16.35	13.3	15.15	14.8	14.95	16.4
Fe_2O_3	4.42	5.79	6.32	3.9	4.93	4.53	5.07	6.68	4.74	4.25	4.88	3.75
CaO	5.29	7.02	9.32	5.91	5.27	6.96	6.39	9.58	6.02	7.41	7.75	5.37
MgO	2.5	2.87	4.27	3.49	2.21	3.35	3.08	3.59	2.75	3.37	2.67	2.48
Na_2O	6.04	6.06	4.47	4.95	6.52	4.39	4.38	4.21	4.64	4.56	4.29	5.61
K_2O	3.74	3.01	3.47	3.69	3.18	3.73	4.43	3.52	3.65	3.6	3.54	3.6
Cr_2O_3	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	<0.01	0.01	0.01	0.01
TiO_2	0.51	0.53	0.44	0.45	0.57	0.44	0.49	0.49	0.44	0.42	0.52	0.52
MnO	0.13	0.14	0.28	0.15	0.1	0.21	0.12	0.17	0.13	0.19	0.09	0.12
P_2O_5	0.06	0.05	0.07	0.05	0.06	<0.01	0.1	<0.01	0.02	<0.01	0.04	0.03
SrO	0.02	0.03	0.04	0.03	0.03	0.04	0.04	0.05	0.03	0.04	0.04	0.02
BaO	0.05	0.04	0.03	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.05
LOI	11.35	12.7	16.3	12	9.21	12.55	11.4	15	11.15	15.1	11.05	10.95
Total	98.8	99.2	100	100.5	99.3	99.1	101	99.2	98.6	99.3	98.6	100
Ba	443	387	305	323	414	348	407	318	368	343	345	378
Ce	84.2	65	58.3	54.1	111.5	90.6	74.2	102	86.3	31	120.5	59.1
Co	11.6	12.3	10.7	10.9	11.7	11.8	12	12.5	12.7	10	11.2	6.5
Cr	60	60	50	50	60	50	60	50	50	50	50	50
Cs	54.6	48	21.6	22.9	66	25.3	26.7	23.5	22.7	20.9	29.3	13.85
Cu	23	21	19	21	21	20	23	20	21	22	21	22
Dy	4.41	4.45	3.98	2.9	3.34	6.36	3.09	6.8	3.99	3.17	7	3.98
Er	2.77	2.65	2.52	1.65	1.71	3.39	2.05	3.8	2.1	1.86	4.43	2.83
Eu	0.92	0.91	0.84	0.71	0.97	1.1	0.66	1.41	1.03	0.62	1.61	0.8
Ga	20.6	20.6	19	21.4	21.2	20.9	22.1	18.8	22	20.1	20.3	22
Gd	5.19	5.13	4.6	4.06	5.53	7.01	4.05	8.39	6.17	3.86	7.52	3.91
Hf	3.4	4.5	3.1	3.1	4.1	3.1	2.8	3.7	3.3	2.9	3.7	3.2
Ho	0.9	0.87	0.83	0.55	0.59	1.22	0.62	1.33	0.71	0.62	1.42	0.86
La	43.3	31	29	24.9	56.6	48.1	36.8	49.6	42.5	15.7	58.3	30.1
Nd	28.6	22.8	20.2	20	35.7	30.1	24.9	37.3	31.1	13	42.1	22.1
Ni	24	29	21	20	23	22	25	23	24	18	24	12
Pb	41	50	40	44	45	51	58	54	64	44	36	22
Pr	8.15	6.46	5.72	5.47	10.75	8.79	7.27	10.35	8.63	3.11	13.5	6.65
Rb	167	139.5	190.5	221	153.5	225	257	211	218	204	207	162.5
Sm	5.63	4.85	4.69	4.31	6.12	6.48	4.4	8.26	6.74	3.84	7.81	4.02
Sc	5	5	4	4	5	5	5	6	5	5	4	4
Sr	203	239	300	249	242	298	317	447	267	295	332	162.5
Ta	1.3	1.3	1.1	1.4	1.3	1.4	1.3	1.2	1.4	1.3	1.3	1.4
Tb	0.78	0.77	0.68	0.54	0.69	1.09	0.54	1.21	0.81	0.56	1.46	0.71
Th	14.5	9.12	11.25	12.05	5.66	13.55	8.47	15.1	14.85	10.25	11.05	7.93
Tl	<0.5	0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	0.5	0.5	<0.5	<0.5
Tm	0.44	0.41	0.41	0.26	0.26	0.48	0.35	0.55	0.33	0.29	0.67	0.43
U	5.36	3.31	3.93	4.49	2.53	4.93	2.59	4.86	2.42	2.49	4.07	2.94
V	85	85	80	62	95	73	86	105	75	77	66	66
W	3	3	3	3	5	3	3	4	3	3	4	5
Y	26	24.6	23.5	15.8	16.4	32.1	22.3	39.6	21.9	20	41	24.6
Yb	2.69	2.55	2.47	1.61	1.83	2.63	2.3	3.3	2.12	1.86	3.94	2.6
Zn	112	96	90	98	98	106	91	93	110	101	97	85
Zr	94	135	81	86	122	82	80	120	80	67	134	122
B	30	20	30	30	50	50	60	70	80	90	90	90
Revised boron content	68.18	56.48	73.49	69.11	133.65	113.94	115.12	169.03	186.3	212.5	216.1	212.5
Equivalent boron content	60	70	80	75	150	105	100	190	205	230	215	210
ΣREE	189.28	149.27	134.26	122.24	237.18	208	161.99	234.17	192.74	80.38	270.91	139.05
LREE	171.15	131.26	118.52	109.47	222.5	185.09	148.37	208.7	176.13	67.21	244.2	122.65

Cont..

HREE	18.13	18.01	15.74	12.77	14.68	22.91	13.62	25.47	16.61	13.17	26.71	16.4
LREE/HREE	9.44	7.29	7.53	8.57	15.16	8.08	10.89	8.19	10.6	5.1	9.14	7.48
La_N/Yb_N	9.75	6.98	9.8	8.41	19.12	10.83	12.43	11.17	14.36	5.3	9.85	6.78
δEu	0.51	0.55	0.53	0.51	0.53	0.5	0.51	0.51	0.48	0.48	0.64	0.62
δCe	1.05	1.08	1.06	1.09	1.06	1.03	1.06	1.05	1.06	1.04	1.01	1
La/Yb	14.43	10.33	14.5	12.45	28.3	16.03	18.4	16.53	21.25	7.85	14.575	10.03
Ce_{anom}	1.6	1.51	1.47	1.45	1.7	1.62	1.56	1.67	1.61	1.26	1.73	1.47
Ce/La	1.94	2.09	2.01	2.17	1.97	1.88	2.01	2.05	2.03	1.97	2.075	1.96
Sr/Ba	0.46	0.62	0.98	0.77	0.58	0.86	0.78	1.41	0.73	0.86	0.96	0.43
Sr/Cu	8.83	11.38	15.79	11.86	11.52	14.90	13.78	22.35	12.71	13.41	15.81	7.39
U/Th	2.35	2.89	2.75	3.25	2.28	2.18	2.59	2.52	2.56	3.08	2.49	2.61
V/Cr	0.35	0.25	0.27	0.21	0.38	0.39	0.3	0.32	0.31	0.21	0.33	0.29
Ni/Co	6.71	11.58	10.33	15.78	6.04	5.52	8.64	7.77	8.26	14.83	7.43	9.11
B/Ga	1.46	1	1.58	1.4	2.36	2.39	2.71	3.72	3.63	4.47	4.43	4.09

From differentiation principal of Sr and Ba, it can be conclude that their deposition is relevant to evaporation and thus the value of Sr/Ba reflects the level of evaporation in sedimentary environment. The average value of Sr/Ba of samples was 0.7, which indicated typical transition facies sediment. The change of B content signified that water was between brackish water and fresh water, with salinity increasing from bottom to top. Thus indicates that the area's climate was semi-arid with a tendency to be more arid. Usually Sr/Cu value between 1.3 and 5.0 represents a humid climate while that above 5.0 represents an arid climate (Chen *et al*., 2012). The values of Sr/Cu of samples were all between 7.39 and 15.19, with an average of 13.40, which was far more than 5.0. Therefore, the study area had an arid climate.

From the change of content in total rock, it can be seen that samples of rocks from Ping Chau Formation, high proportion of Mn content, the lower ratio of Fe/Mn, and higher ratio of Mg/Ca, Al_2O_3/TiO_2, K_2O/TiO_2, K_2O/Na_2O, and Al_2O_3 /Na_2O, all indicate that sedimentary period the climate was hot and arid.

In terms of general characteristics of rock, the main component of rocks in Ping Chau Formation is calcium-rich clayey siltstone. The rhythmic alternations of laminated and stripped stratums reflects change of water level of seasonal lake. Lack of signs of residual gypsum or halite deposits indicate that sedimentary water was not saline. Furthermore, clay content in Ping Chau Formation was more than 30%, which indicates that hydrodynamic force in sedimentary water was relatively weak. It can be concluded that paleoclimate in study area was warm arid climate on the basis of sedimentary structures like mud crack, raindrop imprint and nodule that developed from Ping Chau Formation. The sequence of sedimentary rocks during sedimentary period of Ping Chau Formation indicated that it was shore-shallow lake sediment mainly under arid climate, sometimes affected by humid climate.

In recent years, several researchers (Fang *et al*., 2000; Li *et al*., 2003; Wang *et al*., 2005; Zeng *et al*., 2006) have reached at the agreement to judge the structural environment by sandstone based on the studies of sandstone and mudstone in the structural environment and have achieved a satisfying result that different structural environments are under different geodynamics conditions, which determine the pattern of sedimentary basins and thus geodynamics conditions can determine the source region type of sediments and sedimentary process.

In a study carried out in Australia, while solving the problem of whether geological characteristics of sandstone are highly sensitive to the structural environment during the formation period of sedimentary basins, Bhatia *et al.* (1986)found that there was a corresponding relationship between trace elements content and source region type and structural environment, and they gave REE characteristics of sedimentary rocks in different structural environments and judging graphs (Fig. 10) of trace elements La-Th-Sc (Bhatia 1983; Bhatia *et al*., 1986; Bauluz *et al*., 2000; Zhang, 2004; Zhu *et al*., 2010). Fig.10 shows that most samples were in area of passive continental margin and the allocation pattern of REE in siltstone from Ping Chau Formation

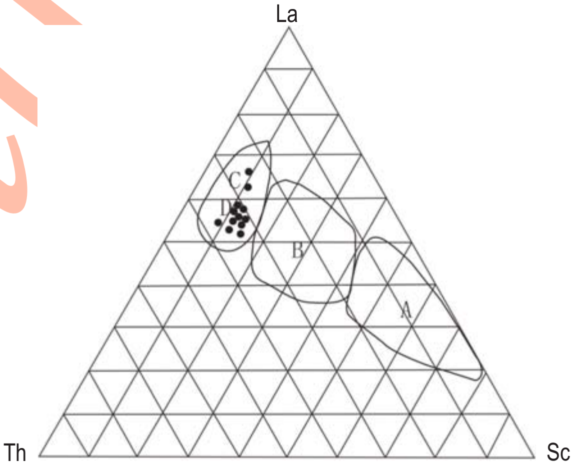


Fig. 10 : Judging graphs of trace elements La-Th-Sc in siltstones from Ping Chau Formation (Bhatia *et al.*, 1986); A: Oceanic island arc (OIA); B: Continental island arc (CIA); C: active continental margin (ACM) and D: passive continental margin (PCM)

Table 3 : REE characteristics of greywacke from sedimentary basin of different structural environments (Bhatia 1983; Bhatia *et al*., 1986)

The source region type of the structural environment	La /10^{-6}	Ce/10^{-6}	REE /10^{-6}	La/Yb	$(La/Yb)_N$	LREE/ HREE	δEu
Oceanic island arcUncut magmatic arc	8±1.7	19±3.7	58±10	4.2±1.3	2.8±0.9	3.8±0.9	1.04±0.11
Continental island arc Cut magmatic arc	27±4.5	59±8.2	146±20	11.0±3.6	7.5±2.5	7.7±1.7	0.79±0.13
Active continental margin Uplift basement	37	78	186	12.5	8.5	9.1	0.60
Passive continental marginStructural highland inside craton	39	85	210	15.9	10.8	8.5	0.56
Average in the study area	38.83	78.15	176.63	15.39	10.4	8.96	0.53

Table 4 : Characteristic ratios of trace elements of arenites in different structural environments (Tribovillard *et al*., 2006)

Structural environment	w(Rb)/w(Sr)	w(Zr)/w(Hf)	w(Zr)/w(Th)
Oceanic island arc	0-0.1	45.7	34.6-61.4
Continental island arc	0.32-0.98	36.3	19.1-23.9
Active continental margin	0.65-1.13	26.3	8.8-10.4
Passive continental margin	0.79-1.59	29.5	13.3-24.9
Average in the study area	0.8	29.2	11.15

was similar to REE component pattern of modern sediments in passive continental margin (Zhao, 1997). Both samples and modern sediments possessed light rare earth beneficiation with a smooth allocation pattern of heavy rare earth featuring a negative Eu anomaly.

In sedimentary rocks of terrigenous arenite, it is advantageous to judge sedimentary structural environment with trace elements like Rb, Sr, Zr, Hf and Th. From the characteristic ratio of different trace elements in siltstone samples from Ping Chau Formation, the values of w(Rb)/w(Sr), w(Zr)/w(Hf) and w(Zr)/w(Th) were similar to that of structural environment of passive continental margin. Therefore, from the results of characteristic ratios of trace elements, it was found that the structural environment of source region of samples typifies that of passive continental margin.

In conclusion, the results showed that Ping Chau Formation at Tung Ping Chau, Hong Kong was formed in a reducing environment of brackish water or shore-shallow lake with low salinity in a passive continental margin structural environment.

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