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Discuss on the geochemical characteristics and origin of special lithological layers in Ping Chau formation at Tung Ping Chau, Hong Kong

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ABSTRACT

The Ping Chau Formation at Tung Ping Chau, Hong Kong has retained much of its special lithological layers—locally called "Dragon diving into sea", mainly containing rhyolite tuff. Based on careful sampling, this paper tests and analyzes major elements and microelements of these layers. The result shows that "Dragon diving into sea" is supersaturated in silicon, alkali-rich, low-potassium, low-magnesium and low-calcium. Therefore, it is a type of weakly peraluminous rock, which has a similar mineral components to low-potassium (tholeiitic) rocks, rich in light rare earth elements and distributed in a negative europium anomaly V-shaped right sloping curve. The research proves that "Dragon diving into sea" is a pyroclastic base-surge formed by phreatomagmatic eruption.

Key words: Tung Ping Chau, Hong Kong；"Dragon diving into sea"；Geochemistry Characteristics；Origin

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INTRODUCTION

Tung Ping Chau (114°25′E; 22°32′N), sits in Mirs Bayon the Northeastern side of Hong Kong, looking across the DapengPeninsula and Nan'ao town on the Mainland. Nearly 3 km long and 0.5 km wide, Tung Ping Chau covers an area of 1.16 km^2, with its Southern part tipping at an altitude of 46m and its Northern part at an average altitude of 37 m.

Ping Chau Formation at Tung Ping Chau was formed in the Mirs Bay rift basin during the Mesozoic Era (Nau et al., 1986；Lai, 1991；Lai et al., 1996), as one of the numerous continental and sea interface basins formed during the Mesozoic and Cenozoic Erain Southeast China, its sedimentary characteristics are comparable to that of the Guangdong Sanshui Bain and the Dongguan Basin.

The Ping Chau Formation can be divided into three sections: the lower section（＞150m） and upper section（＞100m）are mostly submerged in the sea; the middle section is on the Tung Ping Chau island, and is about 200 meters thick (Lai, 1991), mostly containing siltstone, mudstone, marlstone, and dolomite mudstone. The middle section can be further divided into three units: the lower unit (92 m) are thin layers of aegirinite (acmite) siltstone; the middle unit (46m) are thin layers of siltstone, mudstone and dolomite siltstone with a 1m-layer of grey-white blocks of special lithological layers; the upper unit (62m) are thin layers of zeolite, siltstone aegirinite and siltstone（LI Zuoming et al., 1997）.

Petrologic features

The special lithological layers—"Dragon diving into sea", are situated at the West coast of Tung Ping Chau, Hong King, which is a typical weathering erosion topography of 100 meters long and 0.8 meters think, when viewed from above, the long thick flint rock resembles a dragon "Dragon diving into sea"（Figure 1）. In the past, the rock that is currently famously known as "Dragon diving into sea" was called a "flint layer". Generally speaking, its attitude and thickness are stable, with flat upper and lower surface and is in conformable contact with the surrounding Ping Chau Formation.

Figure 1Special Lithological Layers of Ping Chau Formation "Dragon Diving into Sea"—Rhyolite Tuff

Identification of rock slices shows that "Dragon diving into sea" mainly contains rhyolite tuff and is a typical pyroclastic rock, thus repudiated the assertion that it is a "flint layer" or "siliceous rocks" by predecessors. Its basic structural features are (from bottom up)：

(1) 7cm thick. Grey white- light grey rhyolite structure dacite, with few spots, cryptocrystalline-textured matrix of vesicular and almond structures; porphyritic crystal is quartz and is usually corrosion shaped; plagioclase is about 2-3% and is sericitized; matrix is composed of implicit crystalline felsic minerals and ferrous particles, and is partially in micro-spherulitic texture; there are few and irregular vesicles; almond structures are filled with siliceous matter; secondary alteration includes carbonation and there are chloritization（Figure 2）.

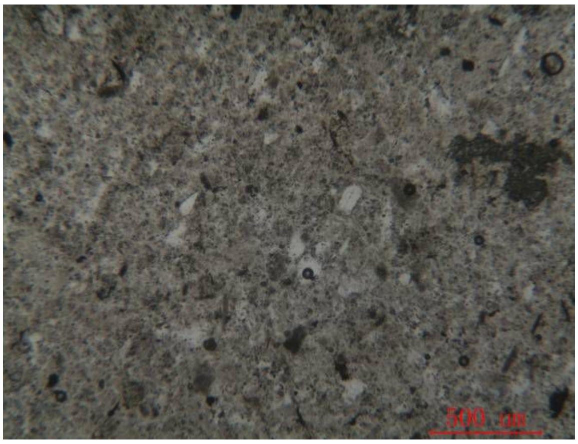


Figure 2Microstructure Picture of Dacite（Cross-polarized Light）

(2) 14cm thick. Light grey medium or thick particles (recrystallization) of rhyolite vitroclastic tuff, tuff-textured bulks, mainly containing vitroclastic matters (about 95%) and about 5% of crystal pyroclasts and a small amount of volcanic dusts; crystal pyroclasts mainly contain quartz and feldspar, normally angular or subangular-shaped and ＜ 0.35mm, scattered or in directional distribution; some may have overgrown boundaries; vitroclastic matters and volcanic dusts and recrystallization are felsitic-felsic minerals structured felsic minerals, with particle diameter ＜ 0.1mm; boundaries of vitroclastic matters are usually vague; there are ambiguous angular-shaped camber surfaces; part of the rock contains scattered carbonates and siliceous matters; there are also irregular fractures filled with limonite and sericite, some of the fractures are zigzag-shaped（Figure 3）.

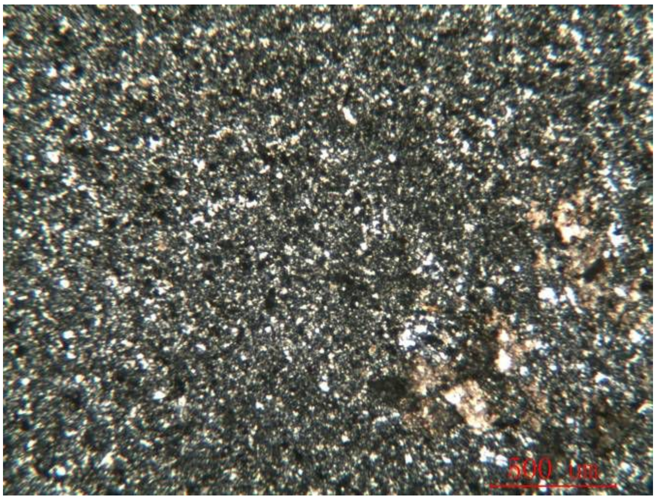


Figure 3 Microstructure Picture of Rhyolite Vitroclastic Tuff （Cross-polarized Light）

(3) 40cm thick. Flesh red thin particles of rhyolite vitroclastic tuff, tuff-textured bulks, mainly containing vitroclastic matters and has a small amount of volcanic dusts; crystal pyroclasts mainly contains quartz and feldspar, normally angular or subangular-shaped, ＜0.05mm, and scattered; vitroclastic matters and volcanic dusts are devitrified as felsitic—felsic minerals, with particle diameter＜0.05mm; boundaries of vitroclastic matters are usually vague; there are ambiguous angular-shaped camber surfaces; slightly laminated-structured; part of the rock contains scattered carbonates and siliceous matters; zigzag-shaped stylolite, filled with limonite and sericite; with vesicular and almond structures and almond structures are filled with crystalloblastic quartz (Figure 4）.

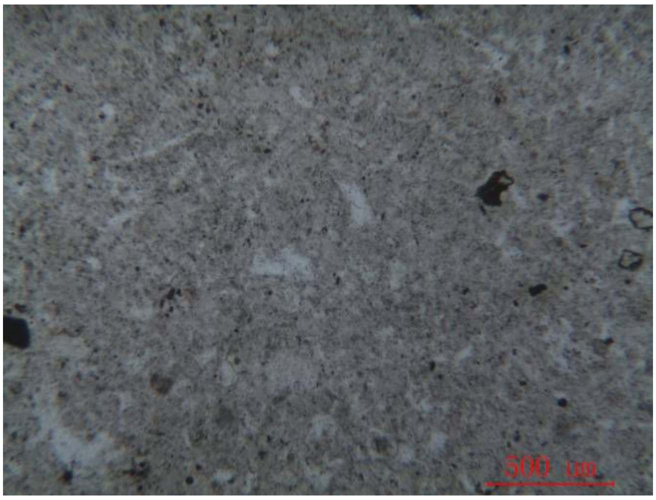


Figure 4Microstructure Picture of Rhyolite Vitroclastic Tuff（Cross-polarized Light）

(4) 1.5cm thick. Grey-black particles of rhyolite vitroclastic stuff, tuff-textured bulks; mainly contains devitrified vitroclastic matters（about 95%） and about 5% of crystal pyroclasts and a small amount of volcanic dusts;clear vitroclastic matters can be seen under single polarizer, chicken bone-shaped, irregular stripes, mainly containing devitrified cryptocrystalline felsic minerals; crystal pyroclasts mainly angular or long angular-shaped contain plagioclase and quartz, with a few in concave angular shape; scattered and＜0.2mm; feldspar and quartz usually have long boundaries; vitroclastic matters and volcanic dusts are recrystallized as felsitic-felsic minerals, with particle diameter ＜0.1mm; boundaries of vitroclastic matters are normally vague; with ambiguous angular-shaped camber surfaces in some parts; part of the rock contains scattered carbonates and siliceous matters; there are also irregular fractures filled with limonite and sericite, some of the fractures are zigzag-shaped（Figure 5）.

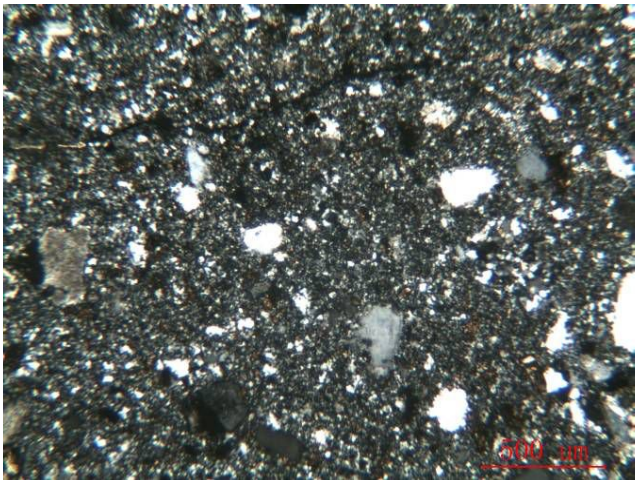


Figure 5 Microstructure Picture of Rhyolite Vitroclastic Tuff（Cross-polarized Light）

(5) 9cm thick. Light yellow- brown medium or thin particles of rhyolite crystal pyroclasts vitroclastic tuff, tuff-textured bulks, layered structure. It contains crystal pyroclasts（15%）, lithic fragments（3-5%）, vitroclastic matters (80-85%) and a small amount of volcanic dusts; crystal pyroclasts mainly contains plagioclase, potassium feldspar, quartz, and muscovite is rarely identified; angular or subangular shaped, or irregular, and 0.2-0.4mm; scattered or in directional distribution; feldspar crystal pyroclasts are usually solidized or serticitized; quartz and some feldspar have long boundaries; lithic fragments mainly contain rhyolite, while granite and andesite are rarely identified; ＜0.7mm, subangular shaped, and scattered; some are recrystallized and have shadows; vitroclastic matters and volcanic dusts are recrystallized as felsitic-felsic minerals, with particle diameter ＜0.1mm;boundaries of vitroclastic matters are normally vague; with ambiguous angular-shaped camber surfaces in some parts; part of the rock contains scattered carbonates and siliceous matters; there are also irregular fractures filled with limonite and sericite, some of the fractures are zigzag-shaped; some parts have almond structures filled with siliceous matters and some centers are filled with chlorite（Figure 6）.

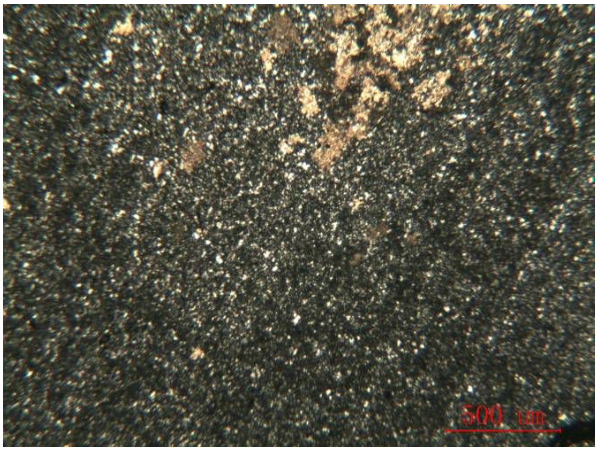


Figure 6 Rhyolite Crystal PyroclastsVitroclastic Tuff（Cross-polarized Light）

Geochemistry characteristics

Table 1 Major Elements of Sample Special Lithological Layers at Ping Chau Formation（%）

Sample	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	Cr_2O_3	TiO_2	MnO	P_2O_5	SrO	BaO	LOI	Total
1	84.7	8.84	0.55	0.06	0.04	4.73	0.85	<0.01	0.02	0.01	<0.01	<0.01	0.05	0.88	100.5
2	73.7	15	1.16	0.47	0.1	8.59	0.47	<0.01	0.09	0.01	<0.01	0.01	0.04	1.46	101
3	72.9	15.2	1	0.42	0.13	8.83	0.29	<0.01	0.12	0.01	<0.01	0.01	0.02	1.55	100.5
4	76.8	13.25	0.65	0.38	0.1	7.71	0.25	<0.01	0.07	0.03	<0.01	0.01	0.02	0.94	100
5	71.4	15.2	1.53	0.68	0.27	7.87	1.58	<0.01	0.09	0.12	0.08	0.01	0.01	2.1	101
6	71.1	12.8	2.16	2.15	0.48	7.49	0.26	<0.01	0.07	0.09	<0.01	0.01	<0.01	3.41	100
7	68.9	9.1	2.21	4.41	1.19	4.87	0.95	<0.01	0.08	0.25	<0.01	0.01	0.05	7.26	99.3

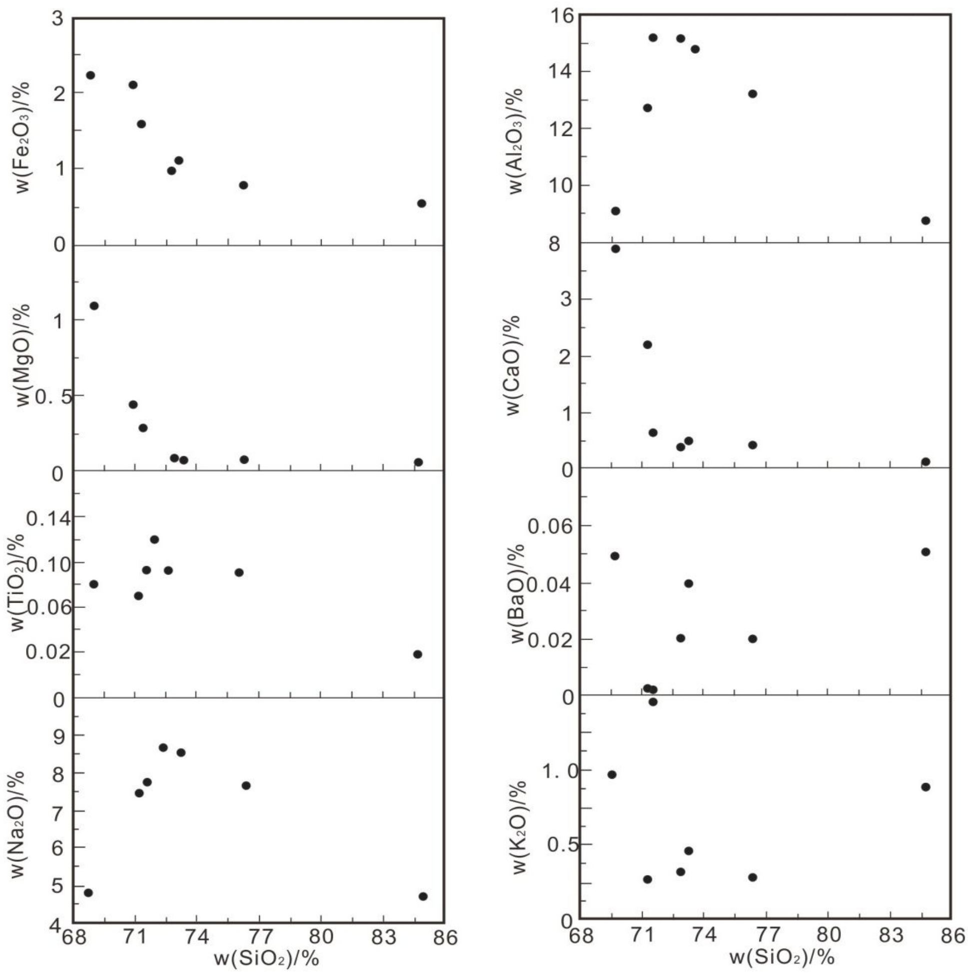


Figure 7Harker Diagram for Major Oxides of Sample Special Lithological Layers at Ping Chau Formation

Table 2 Microelements of Sample Special Lithological Layers at Ping Chau Formation

Sample	Ag	Ba	Ce	Co	Cr	Cs	Cu	Dy	Eu	Ga	Gd	Hf	Ho	Lu	Mo	Nb
1	<1	371	32.3	0.7	<10	1.08	<5	2.59	0.3	11.9	2.07	1.3	0.49	0.1	2	3
2	<1	313	22	0.5	<10	12.25	<5	1.99	0.31	18.4	2.21	4.2	0.37	0.11	3	11.4
3	<1	202	42.4	0.7	<10	17.8	<5	2.57	0.52	20.8	3.39	5.7	0.43	0.13	2	15.3
4	<1	149.5	12.6	0.6	<10	6.51	<5	0.98	0.16	17.9	1.23	2	0.17	0.04	<2	6.7
5	<1	109.5	84.8	3	<10	4.8	7	2.39	0.49	22.5	3.98	5.4	0.39	0.11	2	14.8
6	<1	27.1	44.7	2.1	<10	2.06	<5	4.42	0.51	16.8	4.25	3.5	0.83	0.3	5	8.5
7	<1	407	33.4	1.1	<10	1.46	<5	3.39	0.5	13	3.8	3.8	0.56	0.24	<2	11.2

(×10^{-6})

Table 2 Microelements of Sample Special Lithological Layers at Ping Chau Formation（×10^{-6}）

Sample	Nd	Ni	Pb	Pr	Rb	Sm	Sn	Sr	Ta	Tb	Th	Tl	Tm	U	V	W	Y	Yb	Zn	Zr
1	9.1	<5	20	2.77	24.2	2.16	2	15	0.5	0.46	2.44	<0.5	0.16	2.07	<5	1	12.3	0.75	19	59
2	9.2	<5	37	2.77	20.1	2.2	2	69.1	3.1	0.39	2.24	<0.5	0.11	4.5	5	1	9	0.68	41	219
3	18.5	<5	26	5.63	17	3.84	3	90.9	3.9	0.57	3	<0.5	0.13	6.37	6	1	12.1	0.76	76	315
4	5.1	<5	27	1.5	12.5	1.25	2	49	1.6	0.2	1.7	<0.5	0.05	2.02	7	1	4.3	0.32	41	90
5	25.9	7	64	8.54	55.1	4.55	5	56	4.8	0.57	5.76	<0.5	0.11	6.86	18	1	10.6	0.69	55	302
6	18.6	8	54	5.38	8.7	4.01	2	88	2	0.79	4.54	<0.5	0.32	4.06	5	1	22.2	1.9	52	212
7	13.7	<5	49	3.83	30.6	3.98	2	111	1.5	0.7	5.4	<0.5	0.22	3.7	7	1	13.4	1.42	31	246

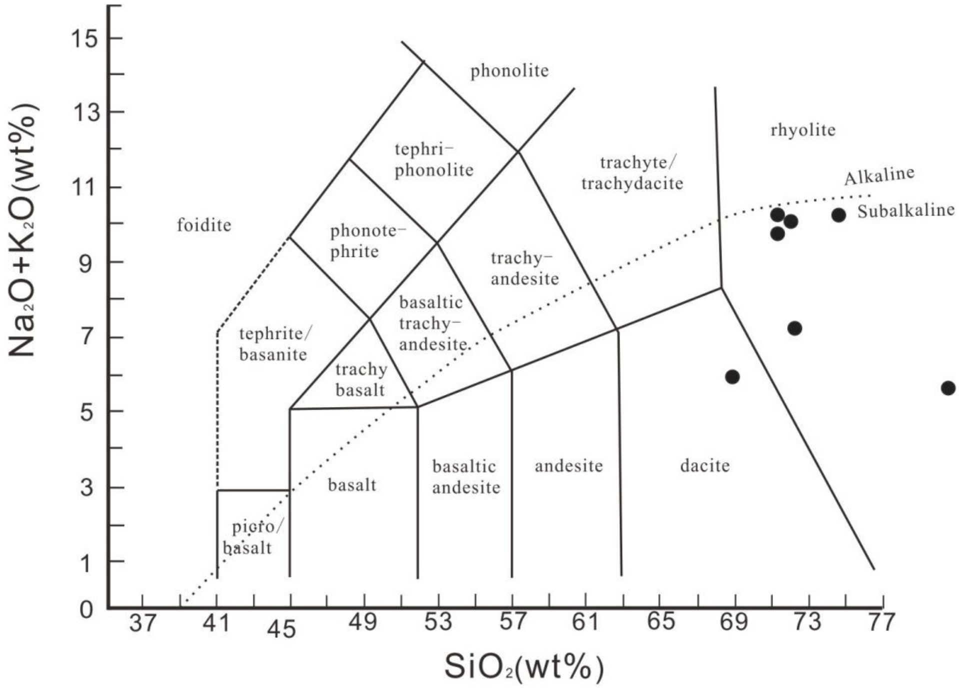


Figure 8 TAS Analysis Diagram for Sample Special Lithological Layers at Ping Chau Formation（Classification Based on Middlemost,1994；Boundaries Based on Irvine & Baragar,1971）

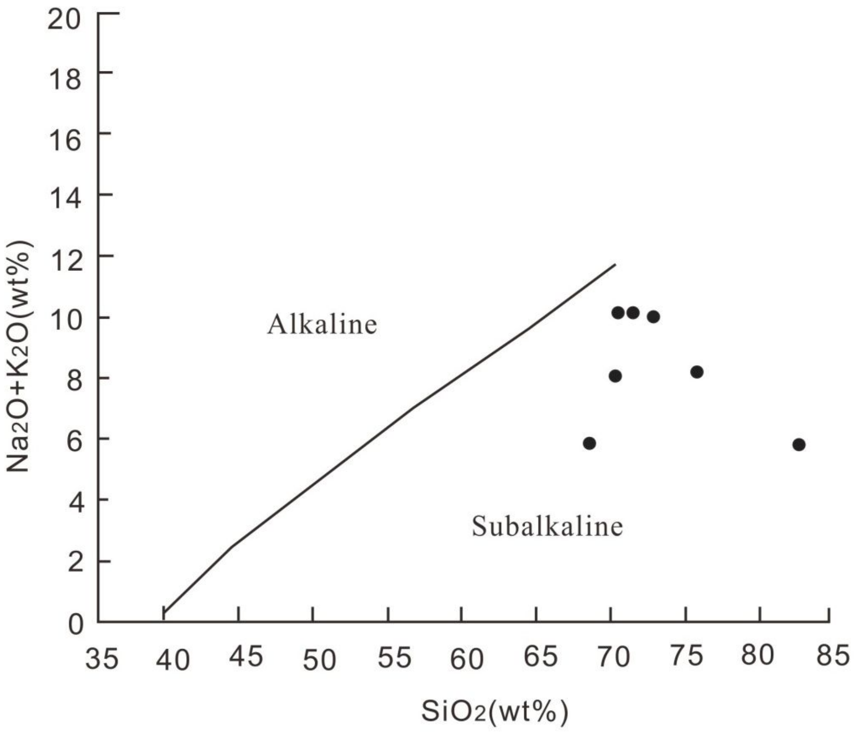
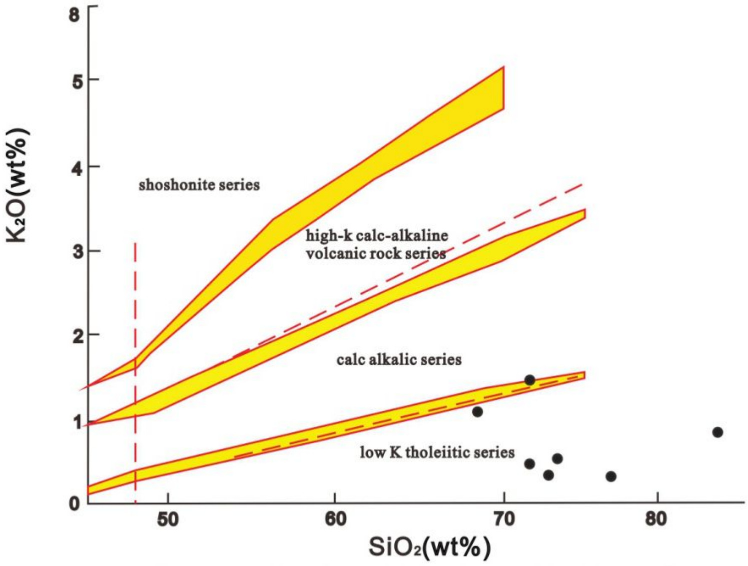


Figure 9 Si0₂-Alk Diagram for Sample Special Lithological Layersat Ping ChauFormation (Based on Irvine, 1971)



Note：Yellow areas according to the Peccerillo & Taylor; The red dotted line according to Middlemost, 1985

Figure 10 K_20-SiO_2 Diagram for Sample Special Lithological Layersat Ping ChauFormation

From Table 1 (Major Elements of Sample Special Lithological Layers at Ping Chau Formation) and Table 2 (Microelements of Sample Special Lithological Layers at Ping Chau Formation), it is clear thatin special lithological layers, rhyolite tuff(SiO_2) is 68.9％-84.7％, it is supersaturated in silicon, Al_2O_3 is 8.84％-15.2％, it is alkali-rich(w（Na_2O＋K_2O）＝5.58％-9.45％）, low-potassium（w（K_2O/ Na_2O）＝0.03％-0.19％）, low-magnesium （w（MgO）＝0.04％-1.19％）, and low-calcium（w（CaO）＝0.06％-4.41％）. Hanker diagram shows a negative correlation between SiO_2content and the content of Al_2O_3, Fe_2O_3, TiO_2, MgO, CaO and Bao（Figure 7）; it also proves a positive correlation between K_2O content and SiO_2 content, well demonstrating that they are homogenous.

A/CNK of all tuff samples slightly changes between 0.9 and 1.59, showing that it is a weakly peraluminous rock. In Figure 8 (TAS Analysis Diagram for Sample Special Lithological Layers at Ping Chau Formation), all samples except sample 7 belong to sub-alkaline rhyolite series. In Figure 9 ($Si0_2$-Alk diagram), all samples belong to sub-alkaline series, which is consistent with the identification result of rock slices.

From Figure 10 (K_2O-Si_2O), all chemical parameter points of samples belong to low-potassium（tholeiitic） series, indicating that it is a low-potassium（tholeiitic）rock.

Table 3 Quantity of Rare Earth Elements for Sample Special Lithological Layers at Ping Chau Formation（$\times10^{-6}$）

Sample	Ce	Dy	Er	Eu	Gd	Ho	La	Lu	Nd	Pr	Sm	Tb	Tm	Yb
1	32.3	2.59	1.28	0.3	2.07	0.49	10.7	0.1	9.1	2.77	2.16	0.46	0.16	0.75
2	22	1.99	0.93	0.31	2.21	0.37	13.2	0.11	9.2	2.77	2.2	0.39	0.11	0.68
3	42.4	2.57	1.2	0.52	3.39	0.43	28.8	0.13	19	5.63	3.84	0.57	0.13	0.76
4	12.6	0.98	0.43	0.16	1.23	0.17	6.9	0.04	5.1	1.5	1.25	0.2	0.05	0.32
5	84.8	2.39	1.07	0.49	3.98	0.39	41.8	0.11	26	8.54	4.55	0.57	0.11	0.69
6	44.7	4.42	2.32	0.51	4.25	0.83	21.4	0.3	19	5.38	4.01	0.79	0.32	1.9
7	33.4	3.39	1.6	0.5	3.8	0.56	18.1	0.24	14	3.83	3.98	0.7	0.22	1.42

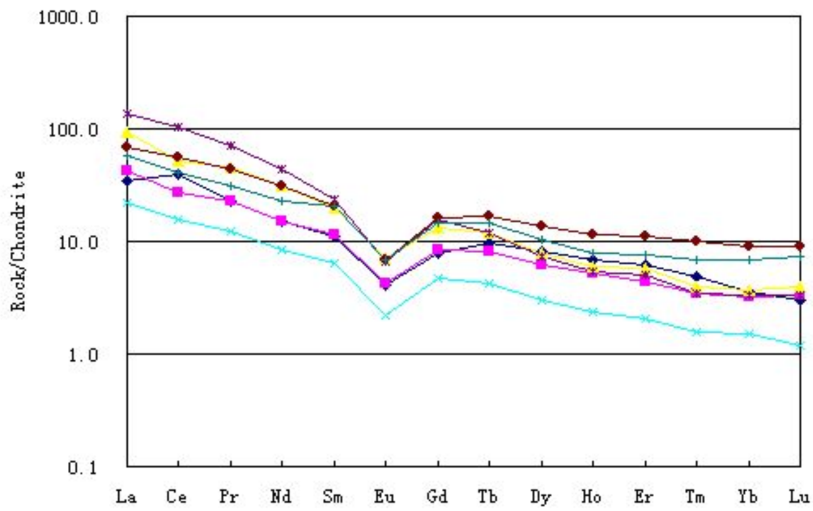


Figure 11 Standardized Diagram for Rare Earth Elements-composed Chondrite of Special Lithological Layers at Ping Chau Formation （Standardized Data from Boynton,1984）

Table 4 Quality and Ratio of Light and Heavy Rare Earth Elements forSample Special Lithological Layers at Ping Chau Formation （×10^{-6}）

∑REE	177.72	165.83	305.49	87.94	438.31	324.37	257.36
LREE	127.52	123.35	249.13	67.23	382.96	226.96	181.16
HREE	50.20	42.48	56.36	20.71	55.35	97.41	76.20
LREE/HREE	2.54	2.90	4.42	3.25	6.92	2.33	2.38

From Table 4, the total amount of rare earth element ∑REE is : 87.94×10^{-6}-438.31×10^{-6}. LREE/HREE=2.32-6.92, indicating that it is rich in light rare earth elements; rare earth elements are distributed in a negative europium anomaly V-shaped right sloping curve; with obvious fractionation feature of light and heavy rare earth elements, （La/Yb）$_N$ is between 5.12-27.54; distribution curves are parallel, indicating that rock samples come from the same magma region.

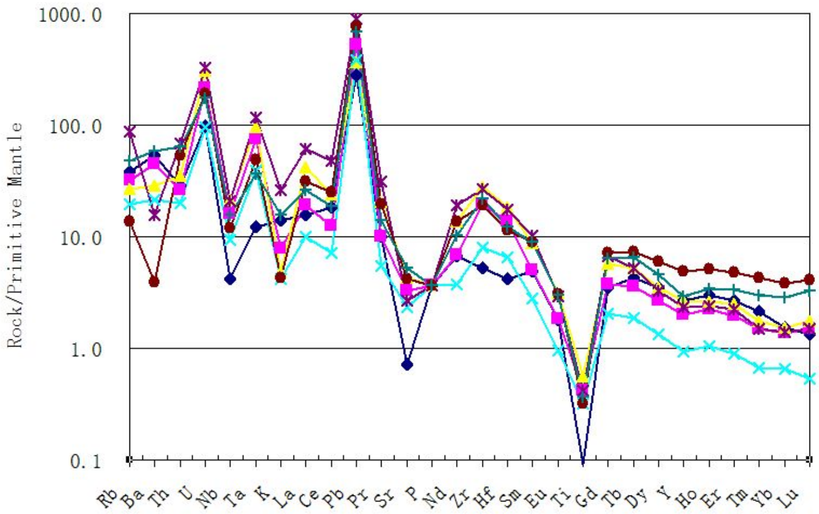


Figure 12Standardized Spider Diagram for Microelements in Primitive Mantle of Sample special lithological layers at Ping Chau Formation （Based on Standardized Data of Sun &Mc Donough,1989）

All samples demonstrates a similar pattern in Figure 12,indicating that it is relatively rich in large ion lithophile elements（LILE）such as Rb , low-Ba,relatively rich in high field-strength element（HFSE）such as Th, U, Pb, Zr, and Hf, very poor in Sr, P, and relatively poor in Ti, Ce, Ta, and Nb. These features prove that magma may come from the crust.

Discussion on the Origin Mechanism
Previously, there are several possible origin theories of special lithological layers at Ping Chau Formation—"Dragon diving into sea": ①Siliceous matte layer produced by weathering；②Sediments of volcanic ashes；③Chemical sediments due to acid rains from the Cretaceous to Paleocene period；④Hydrothermal sediments due to hot spring activities. Existing researches have already find there is no gradual conformable contact between these special lithological layers and the lower layers, thus repudiating the weathering theory. Similarly, studies on geomagnetic polarities and iridium concentration fails to support the third origin theory. Chen Longsheng proposes the fourth origin theory（Chan Long Sang, 2002）.

Based on petrological analysis and geological study of "Dragon diving into sea", this paper proposes that "Dragon diving into sea" is a pyroclastic base-surge formed by phreatomagmatic eruption. A pyroclastic base-surge is the product of phreatomagmatic eruption, which is an important volcanic activity caused by rapidly-expanding, low-density surge of vapor-solid density flows（Xu Debing, et al., 2005）. Eruptive materials that forms "Dragon diving into sea" mainly contains bedrock fragments and magma fragments, usually in angular shape and with different particle sizes, the majority is volcanic dusts. Some of the magma fragments have irregular vesicles, and some have almond structures mainly containing siliceous matter. These fragments are sources of parallel or cross stratification rocks.

"Dragon diving into sea" is in relatively complex stacking sequence, with obvious cyclicity and formed mainly by phreatomagmatic eruption with some volcanic ashes produced in the later phase of eruption. The phreatomagmatic eruption can be divided into two or more sub-cycles, and each with clear features. It is divided into three sections: (1) in the thin lower section, fragments are fairly thick, with shell-shaped fractures. Fragments are angular or subangular-shaped, poorly-sorted, with flat and extending bottom surface. There are obvious erosion channels in some parts; (2) in the thick middle section, fragments are thin millimeter–centimeter sized particles, its extension is relatively stable, and mainly contains volcanic ashes and tuff. The boundary between the middle and the upper sections is clear; (3) in the upper thin section, fragments are thick subangular particles, poorly-sorted; it develops vertically, and has flat upper surface which is in conformable contact with the above siltstone layer; lithic fragments mainly contain rhyolite.

CONCLUSION

After identification of rock slices, special lithological layers at Ping Chau Formation—"Dragon diving into sea" are rhyolite tuff, supersaturated in silicon, alkali-rich, low-potassium, low-magnesium, low-calcium, and are peraluminous rocks with low-potassium（tholeiitic）components. It is rich in light rare earth elements, and rare earth elements are distributed in a negative europium anomaly V-shaped right sloping curve. Based on petrological analysis and geological study of "Dragon diving into sea", this paper arrives at a preliminary conclusion that "Dragon diving into sea" is a pyroclastic base-surge formed by phreatomagmatic eruption.

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