Study on Geochemical Characteristics and Depositional Environment of Pengcuolin Chert, Southern Tibet

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Abstract

Based on the field investigations and analysis on major elements, trace elements and rare earth elements, the Geochemical Characteristics and Depositional Environment of Pengcuolin Chert are studied.The massive chert is green and brown in colour, has high SiO_2 content and locally enrich Fe and Mn, Al/ (Al+ Fe+ Mn) ratio is lower, in Fe-Mn-Al triangle diagrams, most samples fall into hydrothermal region, trace elements such as Sr, Zr, Cu, Zn and Ba are higher and ΣREE is lower, with Ce negative anomaly and Eu anomaly. Their NASC-normalized REE distribution patterns are slightly left-leaning, which indicate that the chert is hydrothermal origin. In environment discrimination diagram such as $100 \times Fe_2O_3/ SiO_2 – 100 \times Al_2O_3/ SiO_2$, $Fe_2O_3/ (100 - SiO_2) - Al_2O_3 / (100 - SiO_2)$ and $Fe_2O_3/ TiO_2 - Al_2O_3 / (Al_2O_3 + Fe_2O_3)$, most chert samples fall into the areas of mid-ocean ridges or deep-sea. In parameter variation diagrams, samples of PCL-5 and PCL-7 are much closer to the hydrothermal center. It is shown that the Pengcuolin chert, southern Tibet was formed by the hydrothermal systems at convergence and subduction sites of plates.

Keywords: Chert, Geochemistry, Hydrothermal sedimentation, Mid-ocean ridge, Douthern Tibet, Pengcuolin

1. Introduction

Chert, one kind of chemical and biochemical sedimentations, is widely distributed in the orogenic belts, it is the ore-bearing rocks and source beds of many deposits(Cui Chunlong, 2001; Feng Caixia and Liu Jiajun, 2001), chert has the quality of high hardness and strong resistance to weathering, which make it hard to be deformed by the late geological processes and a lot of diagenetic information can be well preserved in it, so chert are commonly used to study the palaeotopography and palaeosedimentary environment(Yang Haisheng *et al.,* 2003). Recently, with the development of testing equipment, approaches studying chert is getting advanced, apart from some traditional methods on the rock occurrence, structure and textural characteristics, mineral contents and geochemical analysis, some advanced techniques such as UV fluorescence, CL and paleomagnetism are applied to study chert, and now more attentions are paid to to the origin, the source and the sedimentary environment of chert (Yang Zhijun *et al.,* 2003).

Systematic field investigations show that chert in southern Tibet develop large scale distribution, is of different ages, various sedimentary formations and deposit in sea and continent sedimentary settings, this offer an ideal place for systematic chert study and so have absorbed many attentions of this field both from home and abroad in recent years (Wang Dongan and Chen Ruijun, 1995; Zhou Yongzhang *et al.,* 2003,2004,2006; Sun Lixin *et al.,* 2004; Zhu Jie *et al.,* 2005; Ren Yunsheng *et al.,*2005; He Junguo *et al.,* 2007).

2. Geological settings and petrologic characteristics

Pengcuolin chert profile, 30 kilometers north away form Lazi county, Xikaze, consist mainly of chert, basalt and ultramafic rocks(Fig.1), Tectonically, it sandwiched between the Himalayan and the Lhasa blocks, abundant tectonic melange and high-pressure m Cambrian as tectonic slices, or emplaced in the Upper Triassic Xiukang Group as well as Upper Jurassic- Lower Cretaceous flyschoid and radiolarian chert.

The chert section contain sequences of chert, basalt and ultramafic rocks, with layered chert developing on the top of the formation, and conformable contacting with the altered basalt in the bottom, showing green and purple color, with the thickness of a few centimeters to tens of meters (Fig.2A). Great deal of brown massive chert are identified , which display grey to brown color, probably due to the local Fe, Me mineralization (Fig 2B).

The chert is mainly composed of authigenic quartz (sometimes more than 90%), chalcedony and opals, and with some calcite, clay minerals, beldongrites and hematites. Fe, Mn mineralization can be clearly observed on the hand specimen (Fig 2C), under microscope, samples are dominated by aphanic-microcrystalline quartz grains (Fig. 2D). chert display different colors, this may due to the constituents contained in the chert, among them, black chert always are rich in organic maternal, red and purple chert often related with hematite, while green chert result from the addition of some ferrichlorite and mixed layer minerals.

3. Sampling and analysis

7 specimens are sampled in Pengcuolin profile, experiments are carried out by the Key Isotope Laboratory, Guangzhou Institute of Geochemistry, Chinese Academy of Sciences. The test process are as follows: first select the samples, and then clean the surface of the rock to remove the weathering layers and impurities, and then are ground into pieces, choose the fresh grains and washed by distilled water for decontamination, and finally are ground to above 200 mesh, dried and preserved. press disk (XRF) is used to measure major elements SiO_2 , other contents are tested by Inductively coupled plasma emission spectrometry (ICP-AES), with the analytical errors<2%. ICP-AES and ICP- MS test solution are prepared by acid solution, the detailed process is: accurately weigh 100mg samples and placed in the sealed Teflon, add l ml concentrated HF and 0.3 ml 1: 1 of HNO3, put on the 150 ℃ heating plate to dry the samples after ultrasonic vibration, and then add equal amounts of HF and HNO_3, sealed and heated for one week(about 100℃), then dissolved in 2 ml 1: 1HNO_3, adding Rh internal standard, and then dilute to 2000 times, finally analysed by ICP-MS of PE Elan 6000. the results are shown as Table 1.

4. Geochemical characteristics and sedimentary environment of chert

4.1 Major elements

Pengcuolin chert contain great amounts of SiO_2, with the average of 75.3%, ranging from 62.05% to 93.64%, and there is an increasing trend from the bottom to the top, while Al_2O_3, averaging 5%, vary greatly from 1.23% to 11.59%, such as sample PCL-5 and PCL-6, being 6.84% and 11.59% respectively. For the content of TiO_2, changing between 0.01% and 0.63%, with the average of 0.23%. Previous studies demonstrate that some major elements such as Fe, Mn and Al play a basic role in identifying the origin of chert (Yang Haisheng *et al.,* 2003; Zhang Fan *et al.,* 2003), contents of Fe and Mn are associated with hydrothermal sedimentation, while Al is related with terrigenous supply. Based on the researches of hydrothermal and biological sedimentation, Adachi (Adachi M *et al.,* 1986) and Yamamoto(Yamamoto K, 1987) pointed out that the ratios of Al/ (Fe+ Mn+ Al) change from 0.01 for hydrothermal origin to 0.60 for biological sedimentation, and the ratios are getting larger with increasing the distance from the hydrothermal system center(Lei Bianjun *et al.,* 2002). In the studied area, Al/(Al+Fe+Mn) value is 0.08-0.59, averaging 0.32 (Table 2), all samples, except PCL-6, plot in the hydrothermal area(Fig 3d). The Al/(Fe+Mn+Al) variations are showed in Fig 4, three minimum values can be observed, indicating that there may be three sedimentations which are near the hydrothermal vent in Pengcuolin profile (Fig. 4).

MnO content in chert stand for the deep ocean hydrothermal sedimentation and TiO_2 is related with terrigenous material, so the ratio MnO/TiO_2 can be used to judge the paleosedimentary environment of chert (Murray RW, 1994). For the chert occurring in the open ocean environment, $MnO/ TiO_2 > 0.5$, while for continental slope and marginal sea deposits, $MnO/TiO_2 < 0.5$, the ratios of Pengcuolin chert are generally higher, being 2.7-76.1, with average of 21.8 (Table 2), indicating that the chert are formed in ocean ridges and deep basins environments. In addition, ratio of Al_2O_3 / (Al_2O_3 + Fe_2O_3) can also be used to identify the sedimentary environment of chert (Sugitani, K *et al.,* 1996), the ratios Al_2O_3 / (Al_2O_3 + Fe_2O_3) for studied area is between 0.18 and 0.17, with the average 0.41 (Table 4), closing to the ratio of ocean ridge.

Murray have mapped the continental margin, ocean basin and ocean ridge projection areas of siliceous rocks based on the sedimentary environment ratios of known chert (Murray R W and Buchholtz M R, 1977), in 100× Fe_2O_3/ SiO_2—100× Al_2O_3/ SiO_2 diagrams (Table 3, Fig.3a), all samples, except PCL-6, fall in ocean ridge areas, while in Fe_2O_3/ (100- SiO_2) —Al_2O_3/ (100- SiO_2) diagrams, all samples plot near the ocean ridge and ocean basin areas (Table 3, Fig 3b), and all samples, except PCL-4, fall in mid ocean and ocean basins in the Fe_2O_3/ TiO_2—Al_2O_3/ (Al_2O_3+ Fe_2O_3) diagram (Table 3, Fig 3c).

4.2 Rare earth elements

Rare earth element can be a good geochemical tracer for study the chert origin, plaeoocean environment as well as the oxidation and reduction conditions (Shimizu H M A, 1977; Ding Lin and Zhong Dalai, 1995), the REE of chert mainly derive from seawater, and some come from the continental and volcanic scraps. It is believed that there is an increasing trend of ∑REE from median ridge (the minimum 1.09×10^{-6}) , ocean basin to continental margin(Murray, R. W et al., 1991). For Pengcuolin chert, all samples except PCL-5 and PCL-7, have low ∑REE, with the average of 77.7ppm (Table 4, 5), general lower than the normal values (>200ppm), which indicate that the chert originate from the thermal water and a little terrigenous contents addition during the diagenetic process. The North American shale normalized pattern shows HREE enrichment, the REE distribution pattern slightly tilted to the left, showing the characteristics of hydrothermal chert (Fig.5), among them, sample PCL-7 display higher ∑REE, possible because of some ∑REE-rich hydatogen sediments mixed during the sedimentation process.

According to Shimizu and Masuda (1991), Deep Sea Drilling Plan(DSDP) indicate that Ce/ Ce* values of chert vary from 0.29 to 0.467 (Shimizu H M A, 1977), in the areas near median ridges, due to the hydrothermal activities, negative anomaly is increasing and HREE were strongly depleted compared to LREE (Elderfield, H and Upstill Goddard, R., 1990), such as the sedimentation occurring in the Eastern Pacific, Ce/ Ce* range from 0.1 to 0.36. for Pengcuolin chert, Ce/ Ce* vary from 0.32 to 1.15, with the average of 0.85(Table 5) , and most samples show negative anomaly, especially two samples PCL-7 and PCL-5, the Ce/ Ce* values are much lower, being 0.32 and 0.4, respectively (Fig 6-a), indicating that the profile is closer to the ocean ridge. In addition, a few samples (PCL-4) show weak negative anomaly or even positive anomaly, this possible because there are some Fe, Mn minerals mixed in the samples, which is consistent with the fact that Fe and Mn mineralization can be observed on the hand specimen (Fig 2c). In oxidation ocean environment, Ce^{3+} can be oxidated into lower solubility Ce^{4+}, which can isomorphic displace Mn^{4+} and inter iron and manganese oxides crystalline cells, this migration may result in the Ce negative abnormality in the sea and Ce positive abnormality in the ferromagnesian minerals. It can be concluded that chert only inherit the Ce negative abnormally if hydrothermal sediments are separated with ferromagnesian minerals, and show Ce weak negative abnormality even positive abnormality if the two mixed together.

After studying the cherts occurring in the areas 75km away from the mid-ocean ridges, Murray suggested that the Eu/Eu^* values decrease from 1.35 to 1.02 (Murray, R.W *et al.,* 1990), and Eu positive anomaly is the characteristic of hydrothermal sedimentation. For studied chert, Eu/Eu^* is 0.81-1.05, being positive anomaly, indicating the hydrothermal sedimentary characteristics (Table5, Fig.6-b), in addition, some other REE ratios such as $(La/Ce)_N$ and $(La/Lu)_N$ can also be used to infer the sedimentary mechanism of chert (Wang Zhonggang, 1992), chert occurring in continental margins, ocean basins and ridges have different $(La/Ce)_N$ values, among them, chert near the ocean ridges are strongly depleted Ce, with $(La/Ce)_N$ being 3.5, while chert for ocean basins is 2-3, and chert for continental margins is about 1. For Pengcuolin chert, $(La/Ce)_N$ vary greatly, ranging from 0.8-3.55, with the average of 1.49(Fig 6-e, Table 5). According to Murray RW, parameter $(La/Lu)_N$ or $(La/Yb)_N$ can indicate the separation degree between LREE and HREE, he pointed out that $(La/Lu)_N$ from 0.65 of ocean ridge increase to 1.15 of 85 km away from the ocean ridge, and to the maximum 2.70 in the ocean basin(Murray RW, 1994). For Pengcuolin chert, $(La/Lu)_N$ is 0.53-1.65, averaging 0.95 (Table 5), indicating that the chert deposit in the ocean ridge sedimentary environment.

The REE variation curves show that obvious Ce/ Ce* abnormity in position PCL-5 and PCL-7 can be seen (Fig 5, Fig 6-a)and there are large LREE /HREE separate degree in position PCL-5and PCL-7 (Fig.6-d), moreover, $(La/Ce)_N$ values also show similar features (Fig. 6-e), implying that the sample locations PCL-5 and PCL-7 may close to the hydrothermal center, this results are consistent with the discussions of major elements (Fig.4).

4.3 Trace elements

Many scholars have studied the trace element geochemistries of chert (Murray, R. W *et al*., 1990; Zhou Yongzhang, 1990; Zhao Zhenhua, 1997), Previous studies show that higher amount of Ba, As, Sb, Ag, B and U are characteristic of hydrothermal sedimentation, modern hot sediments generally enrich Cu, Ni, and deplete Co, Ni/Co ratio <3.6 (Crerar, D. A *et al,*1982). Pengcuolin chert have little amount of V, Rb and Sr, less than 10 percent of the Clarke value (Table 4), while Zn, Pb, Zn, Ba, Cu, Cr and Ni vary greatly and positive correlated with major element Fe and Mn. It can be seen From the spider net of trace element that chert has high Mn, Ti contents, reaching 7779 and 3103 ppm, respectively (Fig 7, Table 4), among them , high amount Ti is because of the input of terrigenous sediments, and higher Mn due to the coprecipitation of Mn and chert, this phenomenon can also be seen on the Fe, Mn mineralization of hand specimen (Fig 2C). The spider net (Fig 2C) demonstrate that Pengcuolin chert enrich Sr, Zr, Cu, Zn and Ba, Ni/Co is 1.08-3.16, averaging 1.84, less than 3.6 (Table 4), indicating that the chert is of hydrothermal origin.

4.4 Discussion

Geochemical characteristics of chert show that the studied chert is of typical hydrothermal features, among them, for major element, chert have lower Al/ (Al+ Fe+ Mn) values, averaging 0.32, and most samples plot in the hydrothermal area in Al/ (Al+ Fe+ Mn) diagram, trace elements such as Sr, Zr, Cu, Zn and Ba contents are higher, Ni/Co< 3.6, while ∑REE contents are lower, with Ce/Ce* abnormity and Eu/Eu^* positive abnormality, exhibiting the hydrothermal characteristics.

According to previous studies, the stable property of chert can be used to identify the sedimentary environment(Cui Chunlong, 2001; Lei Bianjun *et al.,*2002; Yang Haisheng *et al.,* 2003), the analysis results show that Pengcuolin chert are formed in big oceanic ridges and ocean basin surroundings.

So, it is concluded that since Mesozoic, when Tethys from open to close, with the oceanic crust spreading, material overflow from the depth, and magmas eruptions of seafloor take place, during this process, Ultramafic, mafic rocks and a variety of volcanic lava are formed, at the same time, due to the strong friction, pressure reduction and deformation of plates are caused by the plate convergence and subduction, oceanic hydrothermal system is produced around the ridges and hot point of seafloor, forming a geochemical areas favorable for silica enrichment, preservation, contraction and saturation, and then silica precipitate constantly from Jurassic to Cretaceous, thus forming the sick chert formation.

5. Conclusions

(1) For Pengcuolion chert, SiO_2 contents vary greatly, ranging from 62.05% to 93.64%, with the average of 75.3%, and tends to increase from the bottom to the top.

(2) Al/ (Al+Fe+Mn) values for chert are lower, averaging 0.32, most samples fall into the hydrothermal district in Fe-Mn-Al triangle diagrams; trace elements Sr, Zr, Cu, Zn and Ba are higher, Ni/Co is 1.08-3.16, less than 3.6; ∑REE are lower, averaging 77.7ppm, Ce/Ce* (averaging 0.85) show negative abnormality, Eu/Eu^*(0.81-1.05) is positive anomaly, $(La/Ce)_N$ and $(La/Lu)_N$ is1.49 and 0.95, respectively. Major, trace elements and REE all show hydrothermal characteristics, indicating that the chert is of hydrothermal origin.

(3) MnO/TiO_2 is 21.8, Al_2O_3/ (Al_2O_3+Fe_2O_3) is 0.41, in diagram 100×Fe_2O_3/SiO_2 —100×Al_2O_3/SiO_2, Fe_2O_3/ (100-SiO_2)—Al_2O_3/ (100-SiO_2) and Fe_2O_3/TiO_2—Al_2O_3/ (Al_2O_3+Fe_2O_3), all samples fall into or near the ocean ridge and deep sea areas, implying that the chert are formed in the ocean ridge or deep sea basin environment.

(4) Major elements and REE variations Ce/Ce*, LREE /HREE and $(La/Ce)_N$ show that sample location PCL-5 and PCL-7 may close to the hydrothermal center.

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etamorphic rocks are identified, with the related volcano- magmatic arc zones in the north, ophiolite and melange developing in the south. the ophiolite melange mainly include ophiolithe, upper Triassic-lower Cretaceous sedimentary melange and J-K ophiolite melange, which are pushed on the Precambrian gneiss and schist, and quartz schist of

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Table 1. Major contents of Pengcuolin cherts (w/ %)

sample	SiO_2	Al_2O_3	CaO	Fe_2O_3	K_2O	MgO	MnO	Na_2O	P_2O_5	TiO_2
PCL-1	93.64	1.23	0.88	3.02	0.32	0.09	0.20	0.31	0.03	0.07
PCL-2	80.83	6.14	1.08	5.40	0.13	0.57	0.94	3.17	0.08	0.29
PCL-3	88.64	4.19	0.58	3.17	0.05	0.10	0.51	1.84	0.04	0.15
PCL-4	87.53	3.46	1.65	5.10	0.01	0.81	0.61	0.11	0.01	0.01
PCL-5	51.22	6.84	0.97	31.56	1.43	0.63	1.69	2.44	0.19	0.63
PCL-6	63.16	11.59	6.06	4.62	0.05	3.21	1.27	6.55	0.11	0.37
PCL-7	62.05	1.55	7.30	5.60	0.60	0.90	7.76	0.28	9.84	0.10
average	75.3	5.00	2.65	8.36	0.37	0.90	1.85	2.10	1.47	0.23

Table 2. Major element ratios of Pengcuolin cherts

sample	Al/(Al+Fe+Mn)	Fe/Ti	(Fe+Mn)/Ti	Fe_2O_3/TiO_2	MnO/TiO_2	$Al_2O_3/(Al_2O_3+Fe_2O_3)$
PCL-1	0.22	52.8	56.8	44.2	2.88	0.29
PCL-2	0.42	22.2	26.53	18.5	3.23	0.53
PCL-3	0.46	24.7	29.1	20.8	3.33	0.57
PCL-4	0.31	595	673	510	61	0.4
PCL-5	0.13	58.2	61.6	50.4	2.71	0.18
PCL-6	0.59	14.7	19.1	12.5	3.45	0.71
PCL-7	0.08	65.3	165.5	55	76.1	0.22
average	0.32	119	147.4	101.63	21.81	0.41

Table 3. Major ratios for environment discrimination of cherts

sample	BCL-1	BCL-2	BCL-3	BCL-4	BCL-5	BCL-6	BCL-7	average
100×Fe2O3/SiO2	3.23	6.7	3.6	5.8	61.6	7.3	9	13.89
100×AL2O3/SiO2	1.3	7.6	4.7	3.95	13.4	18.4	2.5	7.41
Fe2O3/(100-SiO2)	0.47	0.28	0.28	0.41	0.65	0.13	0.15	0.34
Al2O3/(100-SiO2)	0.19	0.32	0.37	0.28	0.14	0.31	0.04	0.24

Table 4. REE and trace element contents of Pengcuolin cherts

T C	Ti	V	Cr	Mn	Co	Ni	Cu	Zn	Ga	Rb	Sr	Y	Zr	Nb	Ba	Hf	Ta	Pb	Th	U
PCL-1	206.5	12.64	21.47	3652	8.33	12.9	56.1	14	1.89	10.3	13.3	5.22	10.4	0.64	41.84	0.3	0.05	7.516	0.81	0.25
PCL-2	1439.1	45.1	54.64	4104	54.4	58.7	50.4	64.4	7.08	5.02	31.7	17.4	77.6	5.55	207.2	2.3	0.46	33.4	5.54	0.89
PCL-3	695.4	16.31	10.86	3717	6.46	12	6.45	17.3	4.85	1.52	8.94	13.2	53.3	3.57	16.73	1.74	0.35	8.73	5.41	0.86
PCL-4	1451.9	20.24	26.19	5477	13.2	30.2	28.2	28.4	4.95	6.13	25.4	15.9	42.5	4.35	56.35	1.3	0.3		4.65	0.97
PCL-5	3103.2	454.9	80.81	4573	27.3	86.3	38.3	95.9	12.3	51.3	79.1	51	162	10	243.9	4.04	0.79	57.49	9.06	2.78
PCL-6	2119	70.37	56.58	1639	28.5	52.8	113	43.5	7.21	1.94	22	14.9	104	4.87	15.56	3.46	0.58	5.39	8.03	1.06
PCL-7	585.6	82.41	13.46	7779	15.6	29.8	33.7	76.4	4.49	21.1	260	117	23.7	1.6	318	0.71	0.16	49.61	1.4	8.86
average	1371.5	100.3	37.72	4420	22	40.4	46.5	48.6	6.12	13.9	62.9	33.5	67.6	4.37	128.5	1.98	0.38	27.02	4.99	2.24
REE	La	Ce	Pr	Nd	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu						
PCL-1	6.02	12.14	1.46	5.68	1.12	0.24	1.11	0.19	0.96	0.22	0.58	0.08	0.47	0.07						
PCL-2	20.42	45.78	5.11	19.84	3.92	0.83	4.11	0.64	3.65	0.77	2.12	0.3	1.96	0.31						
PCL-3	12.35	24.15	3.23	12.31	2.49	0.47	2.54	0.43	2.49	0.55	1.52	0.23	1.49	0.21						
PCL-4	14.96	37.97	4.31	17.94	3.79	0.88	3.46	0.53	2.96	0.6	1.52	0.22	1.26	0.2						
PCL-5	60.23	53.73	17.51	68.42	13.9	2.81	12.7	2.11	11.8	2.37	6.7	0.95	6.37	0.99						
PCL-6	15.87	37.55	4.6	18.54	3.52	0.71	3.29	0.55	3.18	0.67	2	0.31	2.18	0.39						
PCL-7	109.5	62.53	20.97	86.43	16.3	3.98	19.7	3.12	17.7	3.5	8.71	1.13	6.17	0.86						
average	34.19	39.12	8.17	32.74	6.43	1.42	6.7	1.08	6.1	1.24	3.31	0.46	2.84	0.43						

Table 5. REE ratios of Pengcuolin cherts

sample	∑REE	LREE /HREE	Ce/Ce*	Eu/Eu*	$(La/Yb)_N$	$(La/Ce)_N$	$(La/Lu)_N$
BCL-1	30.33	7.26	1	0.91	1.09	1	1.11
BCL-2	109.75	6.92	1.1	0.89	0.9	0.9	0.85
BCL-3	64.45	5.82	0.94	0.81	0.72	1.04	0.76
BCL-4	90.6	7.43	1.15	1.05	1.02	0.8	0.97
BCL-5	260.57	4.92	0.4	0.92	0.81	2.27	0.79
BCL-6	93.37	6.42	1.07	0.91	0.63	0.86	0.53
BCL-7	360.52	4.92	0.32	0.95	1.53	3.55	1.65
average	144.23	6.24	0.85	0.92	0.96	1.49	0.95

(Note: Ce* is theoretical Ce value interpolated by La and Pr abundances, namely, (La+Pr)/2, Eu* is theoretical Eu value interpolated by Sm and Gd abundances, namely, (Sm+Gd)/2, the subscript "N" stand for REE chondrite-normalized value)

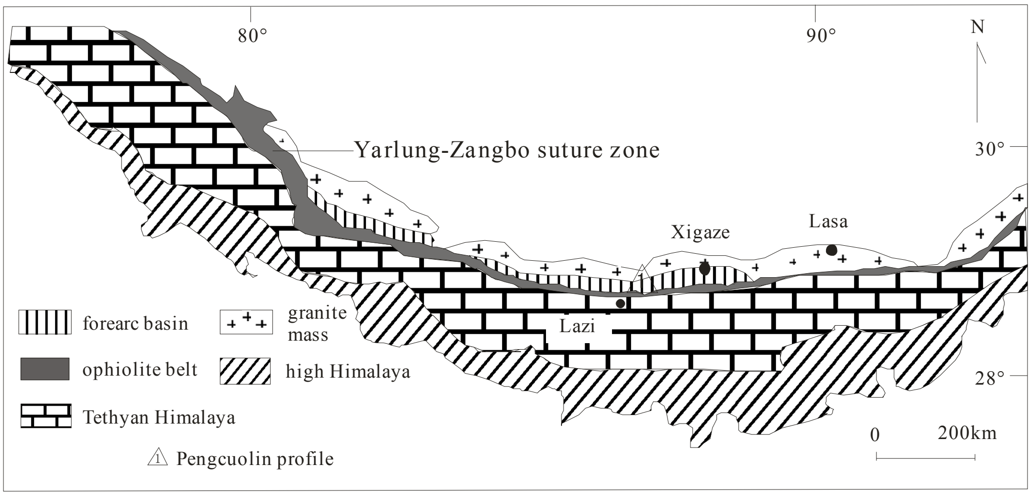

Figure 1. Profile location of Pengcuolin Chert (redrawn after WAN Xiaoqiao *et al.,* 2003)

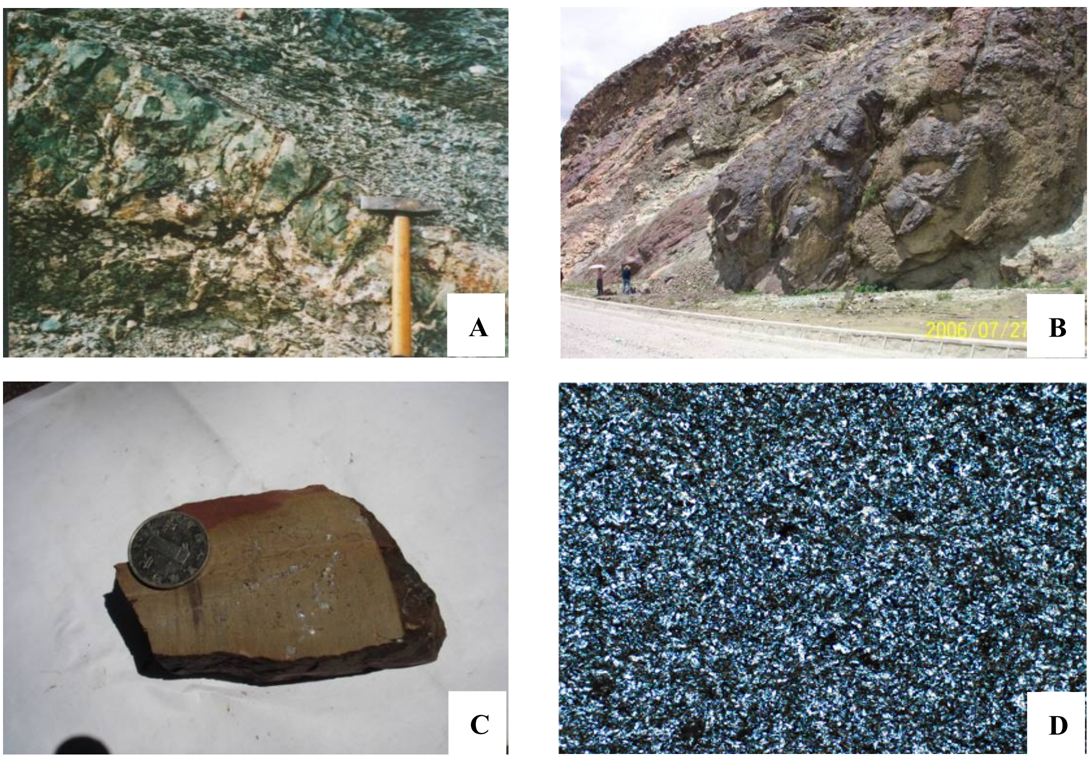

Figure 2. Field photos and microscope images of Pengcuolin chert

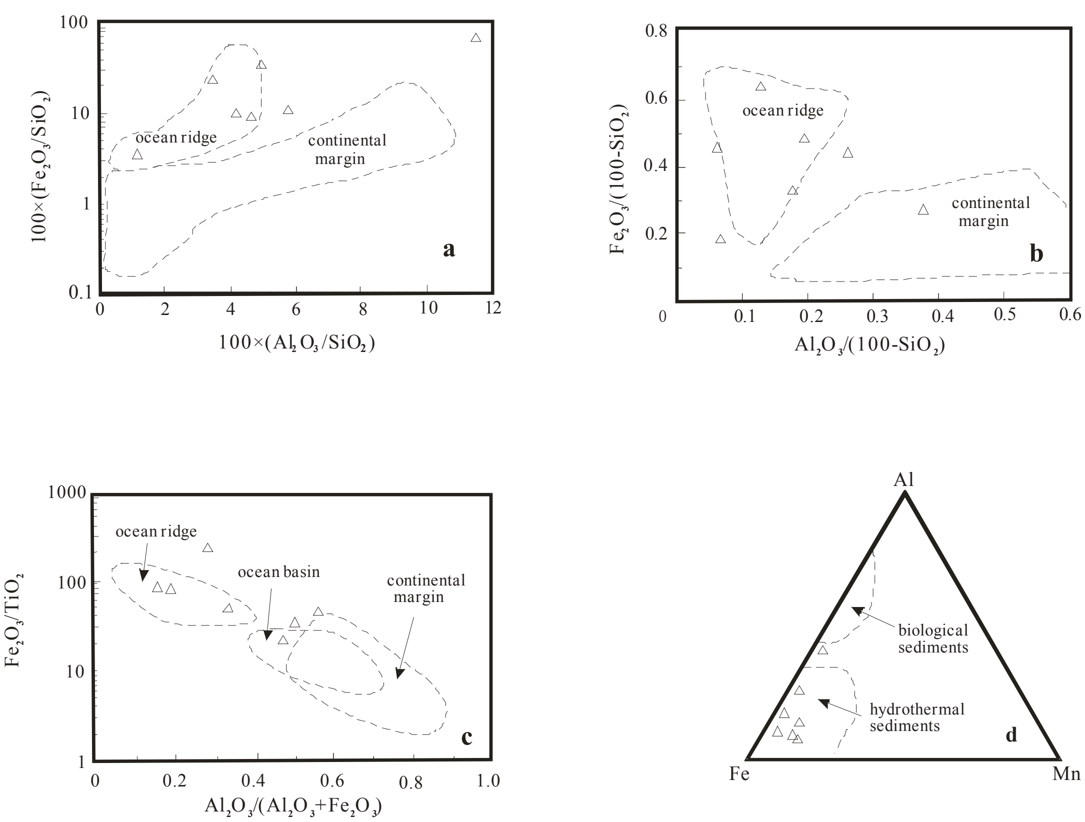

Figure 3. Major element diagrams of Pengcuolin cherts

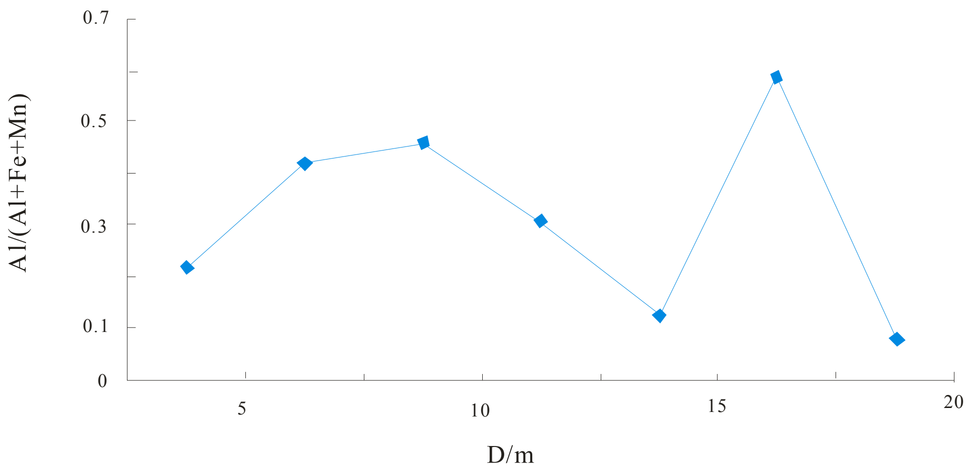

Figure 4. Partial variations of Al/ (Al +Mn + Fe) in chert profile

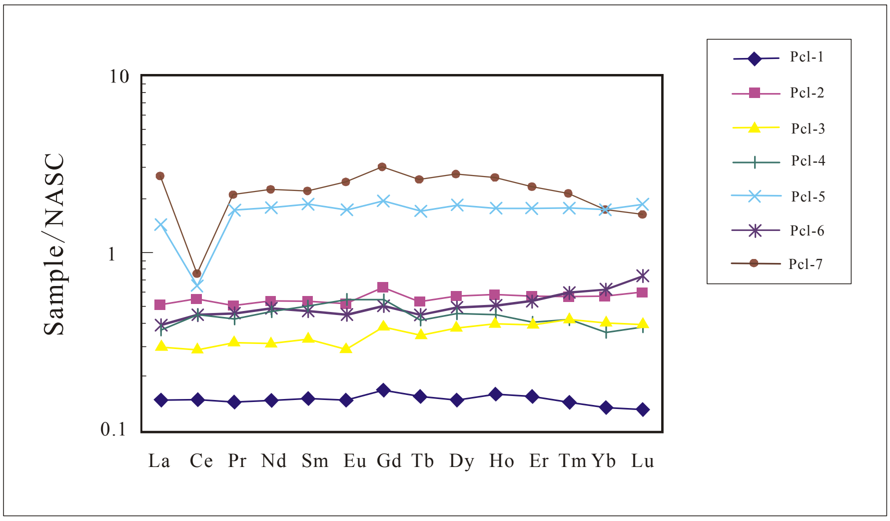

Figure 5. NASC-normalized REE distribution pattern of Pengcuolin cherts (Note: NASC-normalized REE stand for REE chondrite-normalized of North American Shale Composite)

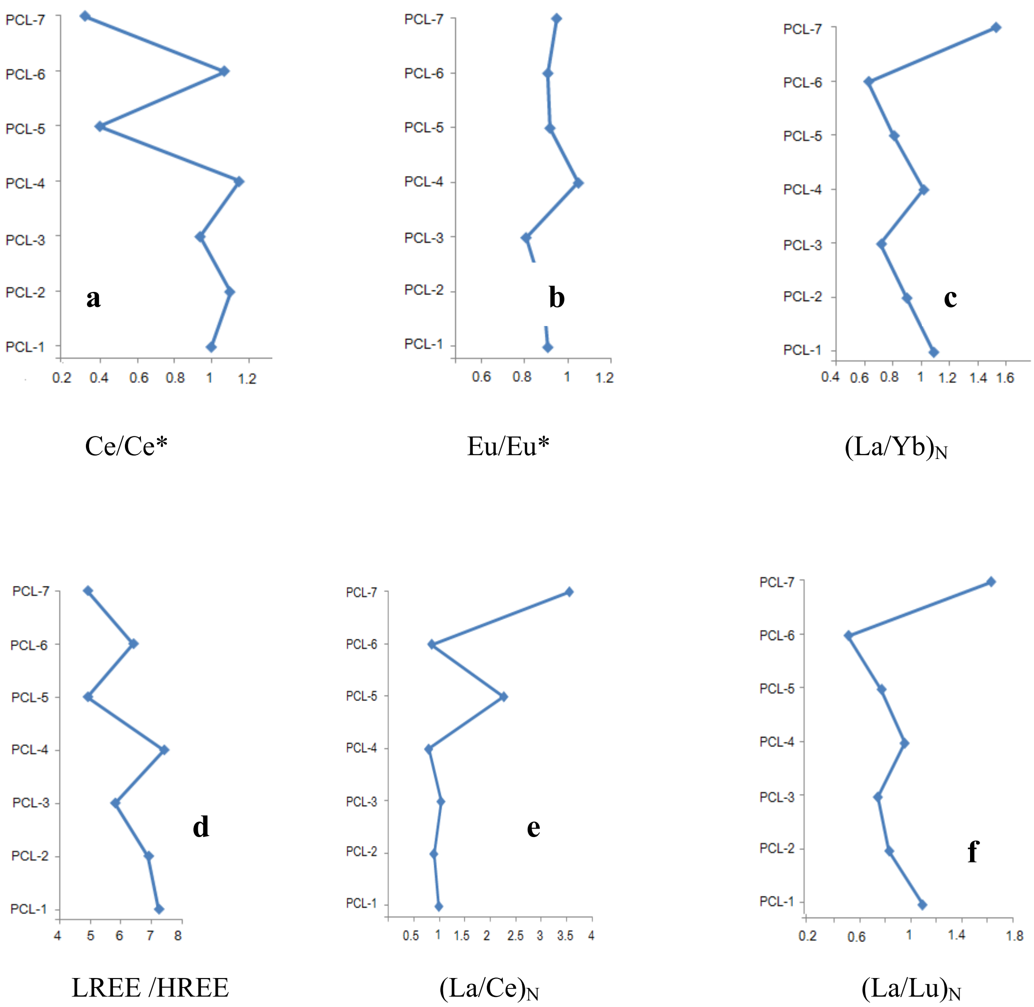

Figure 6. REE parameter variations of cherts

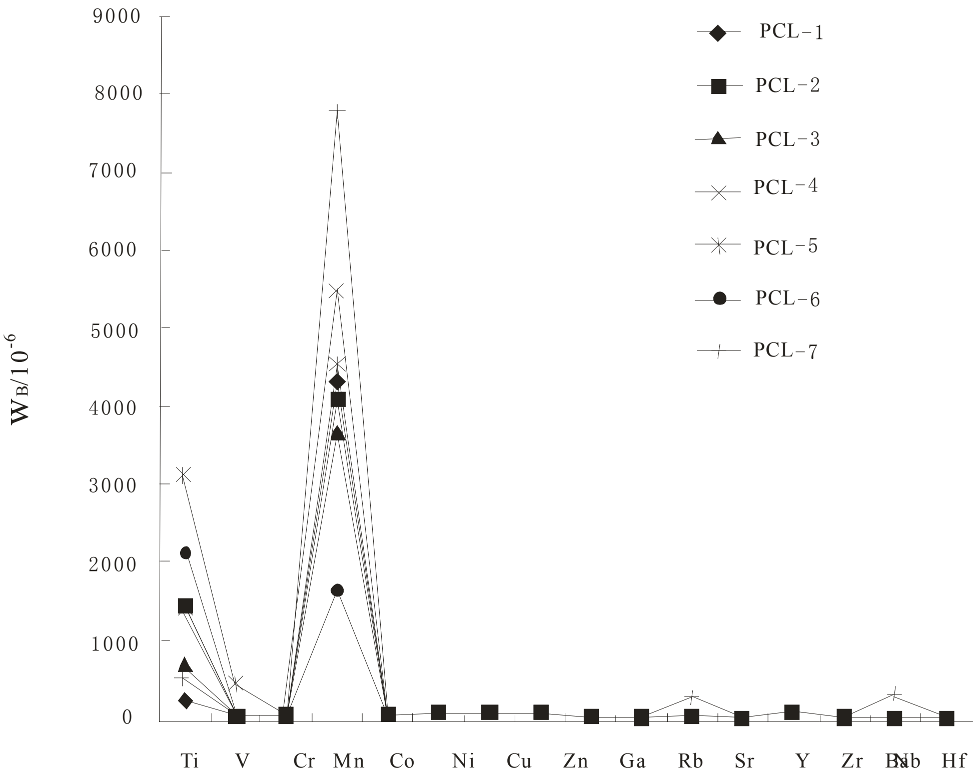

Figure 7. Spider distribution patterns of trace elements