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泰国北部难河构造带二叠纪放射虫、硅质岩和玄武岩

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摘要：在泰国北部难河构造带 Pha Som 变质杂岩中发现保存很好的放射虫硅质岩、玄武岩地层层序. 层状硅质岩含放射虫化石 *Follicucullus porrectus*，地质时代为中二叠世晚期至晚二叠世早期. 其硅质岩 SiO_2 含量均在 92.5% 以上，Al/(Al+Fe+Mn) 平均比值为 0.51，Ce/Ce* 比值为 1.14，为大陆边缘型硅质岩. 玄武岩具有富集大离子亲石元素与高场强元素以及轻稀土富集等洋岛玄武岩的特点. 说明难河构造带中—晚二叠世之交存在洋岛型火山岩和靠近大陆边缘的深海盆地硅质岩，代表了小洋盆的沉积组合. 该构造带闭合时间应在晚二叠世与晚三叠世之间.

关键词：二叠纪；放射虫；硅质岩；洋岛玄武岩；难河构造带.
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Permian Radiolarians, Chert and Basalt from the Nan Suture Zone, Northern Thailand

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Abstract: Well-preserved stratigraphic sequences composed of radiolarian chert and basalt were found in Pha Som metamorphic complex in Nan suture zone, northern Thailand. Bedded chert contains *Follicucullus porrectus*, fossils from late Middle Permian to early Late Permian. These cherts have high SiO_2 (> 92.5%), low Al/(Al+Fe+Mn) ratio (0.51 on average), and high Ce/Ce* ratio (1.14 on average). These geochemical characteristics mentioned above indicate that the cherts deposited on continental margins. The basalt has high abundances of large ion lithophile elements (LILE), high field strength elements (HFSE), and light rare earth lements (LREE), suggesting characteristics of oceanic island basalt (OIB). The OIB characteristics of basalts and deep-sea-basin chert imply that the Nan suture zone was a small oceanic basin, which is similar to modern Southwest Pacific. The Nan Ocean presumably closed during the period from Late Permian to Late Triassic.

Key words: Permian; radiolaria; chert; oceanic island basalt; Nan suture zone.

难河构造带位于泰国北部难省，因沿难河分布而得名. 它向东南经程逸、碧彩纹，延伸到泰—柬边境的庄他武里和沙缴地区，向东北延伸到老挝西北部琅勃拉邦构造带(图 1a)(Hada *et al.*, 1999; Mantajit, 1999)，是东南亚构造框架中一个非常重要的构造单元. 因而较早引起学者们的注意，研究工作较多. 但是，对于难河构造带所代表的古洋盆封闭时代一直存在不同看法，概括起来有 3 种观点：晚三叠世(Hutchison, 1975, 1983, 1989; Mitchell, 1977, 1986, 1992; Asnachinda, 1978; Chantaramee, 1978; Gatinsky *et al.*, 1978; MacDonald and Barr, 1978; Bunopas, 1981; Bunopas and Vel-

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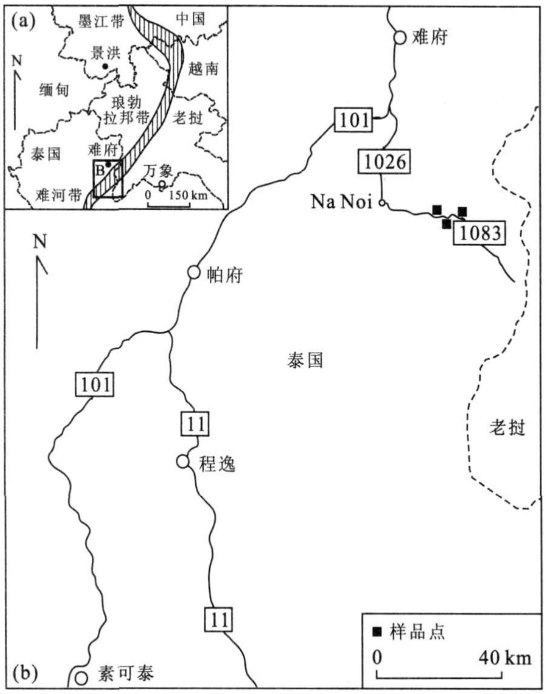

图1 研究区大地构造位置（a）及地理位置图（b）（Hada *et al.*，1999；Mantajit，1999）

Fig. 1 Tectonic location (a) and geographical map (b) of study area

la，1983；Panjasawatwong，1991；Hada *et al.*，1999），晚二叠世—早三叠世（Stauffer，1974；Thanasuthipitak，1978；Ridd，1980；Metcalfe，1986；Hayashi，1988；Cooper *et al.*，1989）和中二叠世（Helmcke，1982，1985，1986；Helmcke and Kraikhong，1982；Helmcke and Lindenberg，1983；Burton，1984；Sengör，1984；Hahn，1985；Barr and MacDonald，1991）.最近，笔者在泰国北部难河构造带开展地质调查过程中，沿新开公路（1083线，图1b）发现保存较好的玄武岩—紫红色放射虫硅质岩层序.经室内研究，这些层状硅质岩中放射虫化石丰富，虽保存较差，但部分个体仍然可以鉴定，具有地质时代意义.本文通过放射虫动物群地质时代研究、玄武岩和层状硅质岩岩石地球化学分析，结合区域地质考察和前人资料，探讨难河构造带古洋盆的性质和演化.

1 地质背景

在研究区，难河构造带位于Lampang和Sirikit Dam地体之间，沿难河呈NS向条带状展布.Pha Som变质杂岩是难河构造带的主要组成部分，由一些构造地层断片组成，主要岩性包括火山岩、片岩、变质砂岩、蛇纹岩及层状硅质岩.根据区域地质调查，1∶25万地质图将Pha Som变质杂岩地质时代确定为石炭系—二叠系（Hess and Koch，1975）.区域上，Pha Som变质杂岩与上二叠统—下三叠统Pak Pat火山岩呈断层接触.Pha Som变质杂岩和Pak Pat火山岩被上三叠统和侏罗系红层角度不整合覆盖.本文研究样品就采自Pha Som变质杂岩的基性火山岩及紫红色层状硅质岩（图2）.

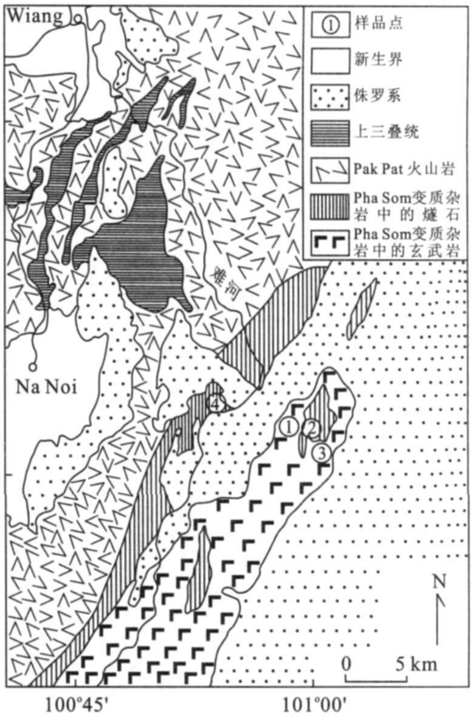

图2 研究区地质简图及采样位置（Hess and Koch，1975）

Fig. 2 Geological sketch map of study area and sampling sites

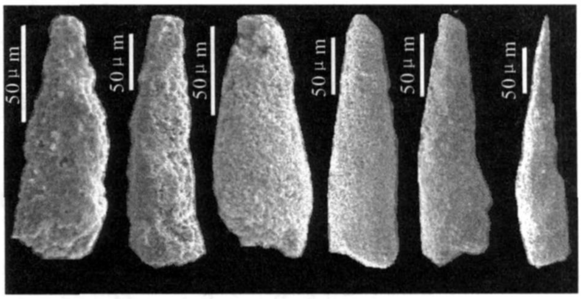

图3 难河构造带放射虫化石（*Follicucullus porrectus*）

Fig. 3 *Follicucullus porrectus* fossils determined in Nan suture zone

表 1 泰国北部难河构造带硅质岩和玄武岩的主量元素(%)和微量元素(μg/g)分析结果[a]

Table 1 Major element (%) and trace element (μg/g) contents in cherts and basalts from the Nan suture zone, northern Thailand

	样品	N1-1	N1-2	N1-3	TL-6	GM-10	T130	T131-1	T131-3	T132-2	T13-4	T13-5
	岩性	玄武岩	玄武岩	玄武岩	玄武岩	玄武岩	硅质岩	硅质岩	硅质岩	硅质岩	硅质岩	硅质岩
	产地	Nan	Nan	Nan	德钦[b]	耿马[c]	Nan	Nan	Nan	Nan	Nan	Nan
主量元素	SiO_2	49.03	45.37	46.31	46.83	46.27	96.27	97.13	95.13	92.83	96.4	95.16
	TiO_2	3.12	3.57	3.65	3.01	3.15	0.07	0.06	0.08	0.15	0.07	0.1
	Al_2O_3	14.93	14.84	15.08	14.9	13.71	1.01	0.89	1.53	2.31	1.01	1.51
	Fe_2O_3	2.56	2.42	2.87	2.57	3.19	0.6	0.44	0.87	1.47	0.63	0.86
	FeO	9.08	8.77	7.58	9.03	10.2	0.1	0.05	0.05	0.03	0.03	0.05
	MnO	0.12	0.14	0.16	0.2	0.24	0.12	0.08	0.15	0.22	0.12	0.13
	MgO	4.71	4.41	4.14	6.63	5.81	0.46	0.21	0.42	0.69	0.41	0.41
	CaO	7.96	7.74	8.03	8.43	9.44	0.16	0.09	0.15	0.17	0.11	0.14
	Na_2O	2.92	3.3	3.6	3.01	2.94	0.14	0.06	0.17	0.2	0.09	0.01
	K_2O	0.72	1.13	0.93	0.89	0.87	0.3	0.36	0.58	0.79	0.36	0.61
	P_2O_5	0.46	0.48	0.52	0.43	0.59	0.02	0.01	0.02	0.03	0.02	0.03
	H_2O^+	4.07	4.33	4.19	3.3	3.26	0.49	0.36	0.64	0.85	0.53	0.74
	CO_2	0.15	3.32	2.72	0.03	0.07	0.14	0.14	0.07	0.14	0.1	0.1
	总量	99.83	99.82	99.78	99.26	99.74	99.88	99.88	99.86	99.88	99.88	99.85
微量元素	Be	1.34	1.49	1.61			0.19	0.15	0.31	0.48	0.21	0.34
	Sc	13.6	13.8	13.3	31	22.0	7.69	10.2	11.9	11.2	10.4	8.99
	V	186	230	308	308	441	7.79	7.74	10.0	13.2	6.56	11.7
	Cr	112	32.4	41.8	140	81	9.43	6.29	3.76	5.41	3.14	5.73
	Co	35.6	38.7	39.5	29	57.0	5.39	2.28	6.34	8.46	4.04	5.73
	Ni	78.9	83.0	84.6	87	82.2	19.0	8.76	17.7	36.2	9.41	14.9
	Cu	66.2	64.1	64.2	133	125	10.5		24.4	20.7	5.16	46.6
	Zn	135	144	131	109	147	30.6	9.64	26.3	43.8	20.9	25.4
	Ga	22.1	23.8	25.1			3.41	2.38	4.31	5.68	2.82	4.19
	Rb	18.8	39.9	34.5	18	13.5	16.0	18.1	27.6	37.9	16.1	30.2
	Sr	148	425	425	336	365	17.7	15.2	19.4	20.9	12.9	17.3
	Y	29.6	33.0	35.7	26.91	24.85	3.15	3.01	6.54	9.85	3.58	5.90
	Zr	244	253	274	174	161	16.1	10.6	19.4	32.8	15.6	23.2
	Nb	23.4	20.9	21.8	23	22.6	2.34	2.15	2.69	3.32	2.59	3.03
	Cs	0.69	0.97	0.77			0.33	0.32	0.47	0.67	0.31	0.49
	Ba	117	143	140	188	540	40.2	40.4	46.1	90.5	51.3	59.8
	La	28.7	28.1	32.7	20.04	25.82	1.79	2.72	3.99	7.74	3.49	3.15
	Ce	52.7	53.0	60.7	52.45	63.52	5.36	8.17	11.5	18.2	6.45	9.46
	Pr	7.08	7.29	8.35	6.48	7.44	0.53	0.66	1.10	1.87	0.82	0.86
	Nd	33.4	35.0	38.9	29.01	33.34	2.84	3.20	5.25	8.08	3.78	4.19
	Sm	7.89	8.40	9.22	6.76	6.51	0.60	0.66	1.16	1.64	0.72	1.00
	Eu	2.48	2.59	2.95	1.95	2.39	0.13	0.13	0.27	0.36	0.14	0.23
	Gd	7.10	7.67	8.22	6.39	6.09	0.55	0.59	1.15	1.64	0.69	0.89
	Tb	1.16	1.31	1.42	0.95	0.91	0.093	0.10	0.18	0.27	0.11	0.14
	Dy	6.24	7.06	7.39	6.03	0.53	1.01	1.57	0.65	0.81		
	Ho	1.21	1.41	1.46	1.30	0.87	0.11	0.10	0.21	0.35	0.14	0.18
	Er	3.00	3.61	3.52	3.01	2.40	0.30	0.29	0.55	0.89	0.38	0.52
	Tm	0.37	0.43	0.46	0.42	0.38	0.045	0.038	0.078	0.14	0.054	0.082
	Yb	2.18	2.57	2.91	2.65	2.34	0.33	0.27	0.59	0.95	0.42	0.57
	Lu	0.31	0.37	0.40	0.31	0.28	0.051	0.040	0.087	0.14	0.068	0.091
	Hf	6.51	6.83	7.40	7	4.4	0.34	0.29	0.47	0.84	0.39	0.54
	Ta	1.64	1.57	1.59	5	1.9	0.078	0.075	0.11	0.17	0.088	0.12
	Pb	2.45	1.89	2.06		30.6	2.73	1.41	3.53	3.55	4.69	3.40
	Th	2.64	2.31	2.50	6	17.6	0.60	0.73	1.07	1.61	0.81	0.93
	U	0.64	3.06	1.73		0.4	0.44	0.27	0.46	0.39	0.23	0.64

a. 分析单位：武汉综合岩矿测试中心；b. 德钦数据引自沈上越等，1994；c. 耿马数据引自沈上越等，2002.

2 放射虫动物群特征和地质时代

室内硅质岩切片和氢氟酸处理分析表明，这些紫红色硅质岩多数含有放射虫化石，部分样品放射虫含量达70％以上，绝大多数放射虫化石因重结晶无法鉴定，但少数个体外形轮廓仍较清楚，它们是*Follicucullus porrectus* Rudenko（图3）．该放射虫结构简单，特征鲜明，容易鉴定，地质分布较短，是中二叠世最晚期至晚二叠世最早期的放射虫带化石（Ishiga，1990；Feng，1992；冯庆来和刘本培，1993；王玉净，1994；吴浩若和咸向阳，1994）．

3 硅质岩地球化学特征及沉积构造背景

本文研究的硅质岩样品共8件，其中6件（T130、T131-1、T131-2、T131-3、T132-2和T133）采自样品点②，另外2件（T13-4和T13-5）采自样品点④（图2）．室内切片观察表明，样品T131-2和T133有较多石英脉，不适合地球化学研究；其余6件样品无石英脉或石英脉稀少，切除风化表面后，用于地球化学分析，分析结果见表1．

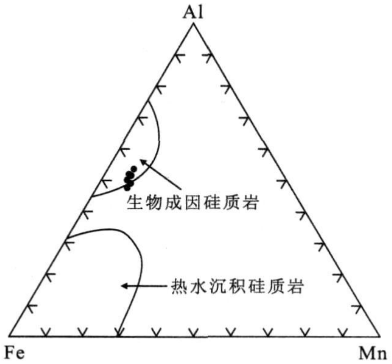

图4 难河构造带硅质岩Al-Fe-Mn图解（Adachi *et al*.，1986）

Fig.4 Al-Fe-Mn discrimination diagram for chert in the Nan suture zone

从表1可以看出，6件硅质岩样品的SiO_2含量均在92.5％以上，陆源泥质沉积物含量极少，属于纯硅质岩（SiO_2含量为91.0％～99.8％）的范畴（Murray *et al*.，1992a）；元素Al、Ti、Mn和Fe被认为是判别硅质岩沉积古地理背景和物质来源的重要元素，Mn和Fe在洋脊附近的富金属沉积物中富集，可作为洋盆中心热液注入的标志，而Al和Ti则与陆源Si关系密切，可作为陆源物质加入的标志（Baltuck，1982；Adachi *et al*.，1986；Yamamoto，1987；Murray，1994；王东安和陈瑞君，1995）．Al/（Al＋Fe＋Mn）比值不随时间变化，是判断物质来源及衡量沉积物中热液沉积物含量的重要指数（Bostrom and Peterson，1969）．Adachi *et al*.（1986）和Yamamoto（1987）指出该比值在0.01（纯热液成因）到0.60（纯生物成因）之间变化．由表1中主要元素分析结果得出，研究区硅质岩的比值为0.49～0.54，均属生物成因．利用Adachi *et al*.（1986）和Yamamoto（1987）拟定的Al-Fe-Mn三角图解进行判别，研究区样品的投点均落在生物成因硅质岩区（图4），说明这些硅质岩属于生物成因，没有热液活动的参与．$Al_2O_3/(Al_2O_3+Fe_2O_3^T)$比值为0.61～0.67，与大陆边缘硅质岩（平均值0.60）相一致．Murray（1994）根据Al、Ti、Fe和Si氧化物比值的相互关系，提出了区分洋脊硅质岩和大陆边缘硅质岩的判别图（图5）．从图5a中可以发现难河构造带硅质岩均落入大陆边缘区内．在图5b中，这些硅质岩落入大陆边缘与远洋盆地重叠区域．由此可见，难河构造带硅质岩可能沉积于离陆地较近的大洋盆地边缘地区．

在测试的6件样品中，有3件样品的$(La/Yb)_N$

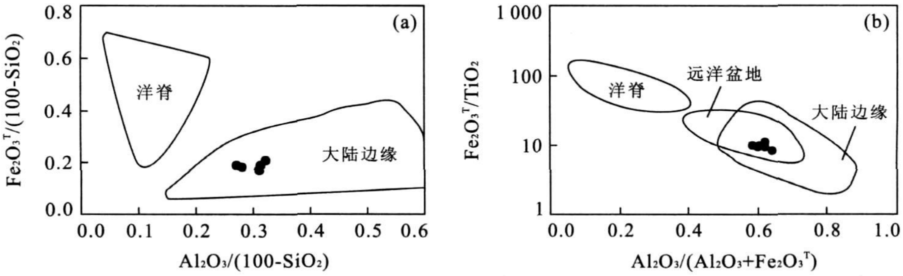

图5 难河构造带硅质岩形成环境判别图（据Murray，1994）

Fig.5 Tectonic setting discrimination diagram for cherts in the Nan suture zone

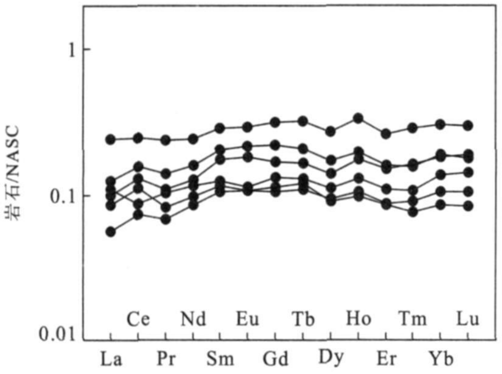

图 6　难河构造带硅质岩北美页岩(NASC)标准化的 *REE* 分布形式(北美页岩 *REE* 值引自 Gromet, 1984)

Fig. 6　NASC-normalized *REE* distribution patterns for cherts in the Nan suture zone

比值为 0.5～0.7，2 个样品比值接近 0.8，1 件样品的比值接近 1，平均值为 0.72，表明稀土元素分异较弱．大量研究表明，稀土元素的 Ce/Ce^* 比值，是判别硅质岩沉积环境的有效标志，洋中脊附近硅质岩的 Ce/Ce^* 比值为 0.30±0.13，大洋盆地的比值为 0.60±0.13，大陆边缘的比值为 1.09±0.25(Murray *et al*.，1990，1991，1992b；Murray，1994)．应用北美页岩(NASC)对本文研究样品进行标准化，稀土元素模式曲线如图 6 所示，本文研究样品中有 1 件 Ce/Ce^* 比值为 0.83，有微弱的负异常，1 件无明显的异常，其余的 4 件均有较明显的 Ce 正异常，Ce/Ce^* 比值变化于 1.15～1.35 之间，6 件样品的平均值为 1.14，属于大陆边缘型硅质岩的范畴．

4　玄武岩地球化学特征及成因背景

该区火山岩已发生弱的蚀变，H_2O^+ 的含量均有不同程度地增高(表 1)．首先对岩石化学成分进行校正(莫宣学等，1998)，然后投入 Zr/TiO_2-Nb/Y 图(图 7a)及 TAS 图(图 7b)．图 7a 显示，本区的火山岩中有两个样品投点落入碱性玄武岩区，另外一个样品投点位于碱性玄武岩与亚碱性玄武岩的分界线上；图 7b 亦显示类似的结果，3 个样品均落入 B 区，为玄武岩，其中两个样品在 Irvine 线之上，一个位于 Irvine 线下方，分别属于碱性及亚碱性玄武岩系列．总的来说，该区火山岩主要为碱性玄武岩系列．火山岩的化学成分与我国"三江"地区洋岛玄武岩类似，以富 Ti、P 和 K(TiO_2 2.14%～4.70%、P_2O_5 0.24%～1.30%、K_2O 0.1%～1.87%)为特征(侯增谦等，1996)，与中国德钦、耿马洋岛火山岩相同(沈上越等，1994，2002)．将火山岩的化学成分投入 TiO_2-MnO×10-P_2O_5×10 及 FeO^T/MgO-TiO_2 图解，分别落入洋岛玄武岩区及洋岛碱性玄武岩区(图 8)．

本区的火山岩与洋脊玄武岩(MORB)相比，显示大离子亲石元素(LILE)强烈富集(图 9a)．其中 Rb 富集程度最高，相当于 MORB 的 8～30 倍，Ba 富集程度相对较低，为 MORB 的 4～10 倍．Nb、Ta、Zr、Hf、P 和 Ti 等高场强元素也显示出强烈富集的特征，其丰度大体相当于 MORB 的 2～10 倍．总的特征与现代洋岛玄武岩相似(莫宣学等，1998)，呈

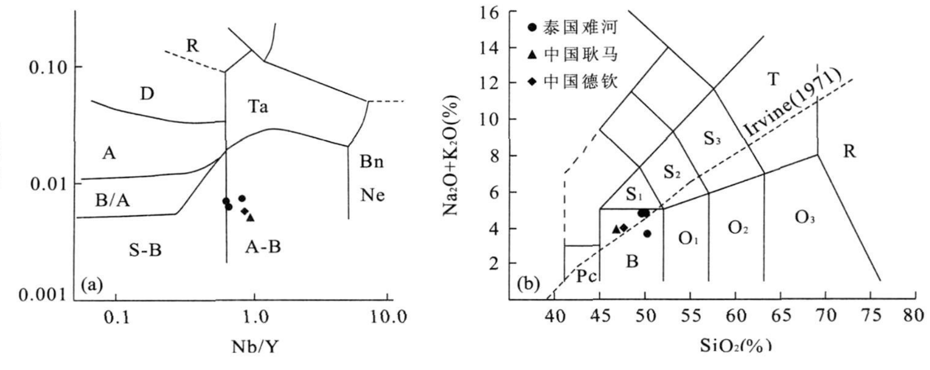

图 7　难河构造带火山岩 Zr/TiO_2-Nb/Y 图解(a)(据 Winchester *et al*.，1977)和难河构造带火山岩 TAS 图解(b)(据 Le Bas *et al*.，1986)

Fig.7　Zr/TiO_2-Nb/Y (a) and TAS (b) diagrams for the basalt in the Nan suture zone

S-B. 亚碱性玄武岩；A-B. 碱性玄武岩；B/A. 玄武岩—玄武质安山岩；A. 安山岩；D. 英安岩；R. 流纹岩；Ta. 粗安岩；Bn. 碧玄岩；Ne. 霞石岩；Pc. 苦橄玄武岩；B. 玄武岩；O_1. 玄武安山岩；O_2. 安山岩；O_3. 英安岩；S_1. 夏威夷岩(Na 质)、钾质粗面玄武岩(K 质)；S_2. 橄榄粗面岩(Na 质)、钾玄岩(K 质)；S_3. 长粗面岩(Na 质)、安粗岩(K 质)；T. 粗面岩(Na 质)、粗面英安岩

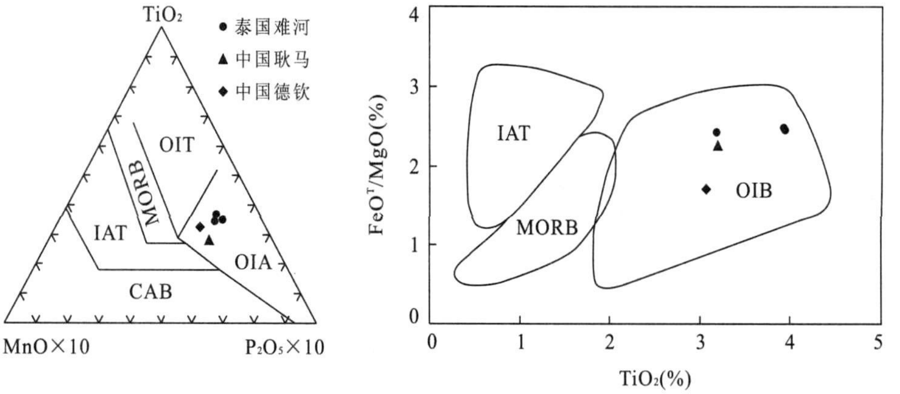

图 8 难河构造带玄武岩 TiO_2-MnO×10-P_2O_5×10 与 FeO^T/MgO-TiO_2 构造背景判别图解

Fig. 8 TiO_2-MnO×10-P_2O_5×10 与 FeO^T/MgO-TiO_2 diagrams for discrimination of tectonic settings of basalts in the Nan suture zone

OIT. 洋岛拉斑玄武岩；OIA. 洋岛碱性玄武岩；MORB. 洋中脊玄武岩；IAT. 岛弧玄武岩；CAB. 钙碱性玄武岩；OIB. 洋岛玄武岩

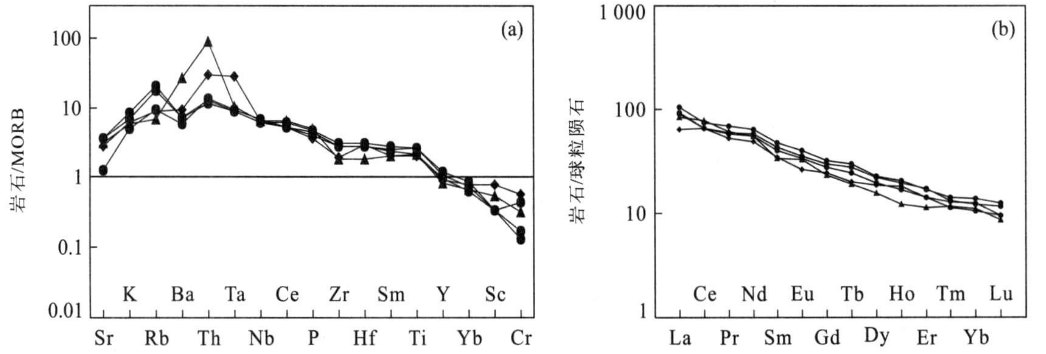

图 9 难河构造带洋中脊玄武岩(MORB)标准化的微量元素丰度型式(a)图(MORB 数据引自 Pearce，1982)和难河构造带球粒陨石标准化的稀土元素配分模式图(b)(球粒陨石 *REE* 值引自 Boynton，1984)

Fig. 9 MORB-normalized trace element (a) and chondrite-normalized *REE* distribution (b) patterns for basalts in Nan suture zone

K-Ti 上隆的富集型，Ba、Th、Ta 较中国德钦、耿马洋岛玄武岩略低(沈上越等，1994，2002)．岩石稀土丰度值中等，$\sum REE = 153.82\times10^{-6}\sim178.6\times10^{-6}$．$(La/Yb)_N$ 亦较高，为 7.36～8.3，无 δEu 负异常(0.97～1.02)．稀土配分模式为轻稀土强烈富集型(图 9b)，属于较典型的碱性玄武岩模式，与中国德钦、耿马洋岛玄武岩相一致，可以与大洋岛屿碱性玄武岩的 *REE* 配分模式相对比．

5 讨论与结论

从放射虫动物群、放射虫硅质岩和玄武岩地球化学特征来看，Pha Som 变质杂岩中的紫红色层状放射虫硅质岩和玄武岩形成于近大陆边缘的洋盆环境．硅质岩 SiO_2 含量较高，均在 92.5% 以上，$Al_2O_3/(Al_2O_3+Fe_2O_3^T)$ 比值为 0.61～0.67，多数样品具有较高的 Ce 正异常，Ce/Ce^* 平均值为1.14，为大陆边缘型硅质岩．基性火山岩具高 Ti、P 的特点，K、Rb 和 Ba 等大离子亲石元素与 Nb、Ta 等高场强元素含量高，轻稀土元素强烈富集，属于典型的洋岛碱性玄武岩．大陆边缘型硅质岩与洋岛玄武岩的共生组合表明在中－晚二叠世之交，该构造带为具有洋岛的小洋盆构造背景，靠近大陆边缘，代表了古特提斯演化晚期的构造古地理格局．

由此可以看出，晚二叠世早期，难河地区古特提斯洋盆仍然存在，其封闭时代应在晚二叠世中期之后．从区域地层来看，上三叠统与 Pha Som 变质杂岩及 Pak Pat 火山岩呈角度不整合接触，前者为造山后的磨拉石沉积，难河地区古特提斯洋盆应该封闭于晚三叠世之前．Macdonald and Barr(1984)和 Barr and Macdonald(1987)认为 Pak Pat 火山岩形成于岛弧环境；Panjasawatwong(1991)则认为 Pak Pat 火山岩成分比较复杂，既包含岛弧背景的火山岩，也有洋岛环境的岩石；而Singharajwarapan *et* *al*.(2000)强调 Pak Pat 火山岩形成于大洋岛弧环境. Barr *et al*. (2000) 根据锆石同位素研究, 将 Lampang 地体内部 Doi Luang 火山岩带的年龄确定为中三叠世早期, 并把 Doi Luang 火山岩带解释为难河古特提斯洋盆向西俯冲形成的陆缘岛弧带. Doi Luang 火山岩带和 Pak Pat 火山岩带形成的大地构造背景尚需深入研究, 这也是探索难河古特提斯演化的关键.

关于难河构造带与滇西南地区构造带的对比, 存在较大分歧: 有的学者将哀牢山构造带与琅勃拉邦构造带、难河构造带对比(Wu *et al*., 1995; 钟大赉, 1998; Singharajwarapan *et al*., 2000); 但也有学者认为难河构造带向北延伸到思茅地块内部, 可能已被红层覆盖(王义昭等, 2000); 还有学者将难河一程逸构造带与澜沧江构造带相连, 思茅地块和泰国东北部的呵叻地体对比(Barr *et al*., 2000). 从 Pha Som 混杂岩的时代和地层特征来看, 难河构造带与朗勃拉邦构造带、墨江构造带对比更合理.

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