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Cenozoic magmatism of Eastern Sea (South China Sea)

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Abstract. In Eastern Sea (South China Sea), Jurassic - Cretaceous magmatic intrusives are discovered, they were cutting the Pre-Cenozoic sedimentaries. The Cenozoic volcanic basalts are strongly distributed together with Cenozoic sedimentaries. The paper concerns only the volcanic activities with description on their geology, chemistry, geochemistry, isotopic ages and their forming mechanism. In fact, the main topic of the paper is dealt with the forming mechanism of basalt in the dynamics of the opening of Eastern Sea in particular, and of South China Sea in general.

Keywords: Cenozoic; Magmatism; Eastern Sea.

1. Generality on cenozoic geology of Eastern Sea

The geomorphology and general distribution picture of Eastern Sea crust types are presented in Fig. 1. The given data are received from the research of satellite images and of geophysic measurements. The crusts are covered by Cenozoic sedimentaries [2, 3]. Their geomagnetic ages are also represented in Fig. 2 [2, 3]. The geomagnetic anomalies lines N.5 (16.5 Ma) and N.13 (32 Ma) are remarked, they also are recognized as the timing of the opening and closing of Eastern Sea in his geodynamics respectively. The follows are Late Miocene and Pliocene sedimentaries, covered all the territory of the South China Sea. These results are obtained by scientific cooperation between Hanoi University and Paris VI University [8, 9, 12].

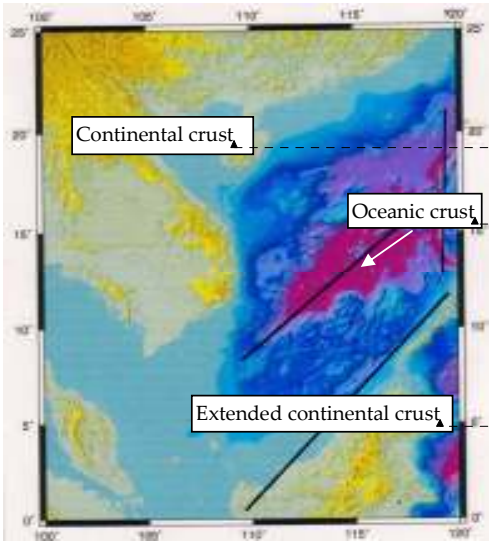

Fig. 1. The geomorphology and structure of crust types of South China Sea.

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2. Petrography and petrochemistry of Eastern Sea basalts

According to the research data of seismic measurements on the Eastern Sea, the volcanic basalts mainly cut out the sedimentaries of Oligocen - Pleistocen. Geomorphological study of the bottom of the sea also makes clear the strong relief character by a lot of underground volcanic mountains.

After the study of volcanic isotopic ages by method K-Ar and by track fission of zircon grains, the ages of basalts varied mainly from 13 Ma to 1924 year. It is clear in Table 1 that the age of basalt on the Re Island is 13 Ma, meanwhile the age of the basalt in Con Co Island is only 3,200 years. In the 1924 year, there was a volcanic activity near Nha Trang City.

From the petrochemical data (Tables 1 and 2) it is clear that basalts of Eastern Sea are belonged to two rock types: alkaline and tholeitic series. The first one is characterized by the Ne-normative mineral, and the second one - by the positive Q- normative and absent of Ne-normative mineral.

Geologically, the basalt bodies mainly cut up the sedimentaries of Oligocene and Midle Miocene ages, they have isotopic ages varied from 13 Ma up to day (1924). It means that they are more young than the closing timing of Eastern Sea (16.5 Ma). But after the drill core samples of Cuu Long and Nam Con Son basins, the intercalation of basalt layers among the sedimentaies also beeing seen (Fig. 3 [15]). Although that, mainly the volcanic activity in Eastern Sea was strongly developed after the closing time of the spreading process of Eastern Sea.

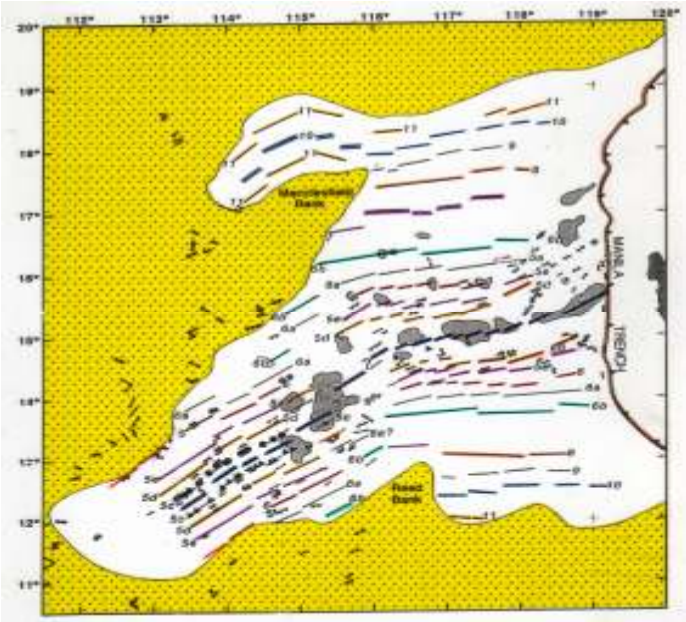

Fig. 2. Schema distribution of geomagnetic anomaly lines [2, 3].

Table 1. The chemistry compositions,isotopic ages of basalt formations of the Eastern Sea [13]

Sites	XL II	XL I	1-Cendre	1-Cendre	Kawit-Is	Re- Is 1	Re-Is-2	QN	Con Co Is	Khe Sanh	DBP
Rock type	BA	AB	AB	OT	OT	OT	OT	AB	OT	OT	OT
SiO_2	43.26	45.01	49.5	50.4	49.44	49.87	52.9	44.77	52.67	48	55.26
TiO_2	2.76	2.03	2.34	1.9	2.67	2.2	1.57	2.85	1.78	2.68	2.04
Al_2O_3	12.28	13.84	13.51	13.91	13.87	15.32	15.01	14.17	16.5	14.61	16
FeO*	12.15	12.78	11.67	11.52	11.42	10.93	0.43	11.51	10.22	10.83	9.66
MnO	0.2	0.15	0.16	0.15	0.16	0.14	0.14	0.22	0.12	0.15	8.16
MgO	12.96	9.22	7.86	8.18	8.5	7.1	7.45	11.21	4.17	8.62	5.36
CaO	10.99	9.86	9	9.13	9.13	8.18	8.93	10.12	5.67	9.15	6.15
Na_2O	2.87	2.76	3.27	3.13	3.13	3.11	3.28	3.22	4.92	3.09	3
K_2O	1.32	2.48	2.27	7.83	1.83	2.1	0.92	0.94	3.22	1.54	2.04
P_2O_5	0.94	0.56	0.42	0.38	0.38	0.57	0.29	1	0.72	0.54	0.32
K_2O/Na_2O	0.46	0.81	0.61	0.58	0.53	0.704	0.28	0.201	0.65	0.458	0.68
Zr/Y	10.9	10	7.1			7.8	5.3	11	11	9.2	9.1
Zr/Nb	236.6	251.8	262.3			164	100	263.2	4.06	200	5.98
Rb/Sr	0.17	0.08	0.06			0.03	0.05	0.07	0.08	0.01	0.22
Ba/Zr	3.64	3.29	2.3			3.25	2.24	3.9	3.35	2.93	1.75
n	2	3	6	8	8	4	3	2	1	1	1
Age(Ma)	0.4-1.1	0.4-1.1	1.27 - 0	7	7	0.4-1.2	12	7.1	0.35	1	1

* Sites : XL: Xuan Loc; QN: Quang Ngai; DBP : Dien Bien Phu.
Types: BA: bazanite; AB: Alkaline Basalt; OT: Tholeite basalt.

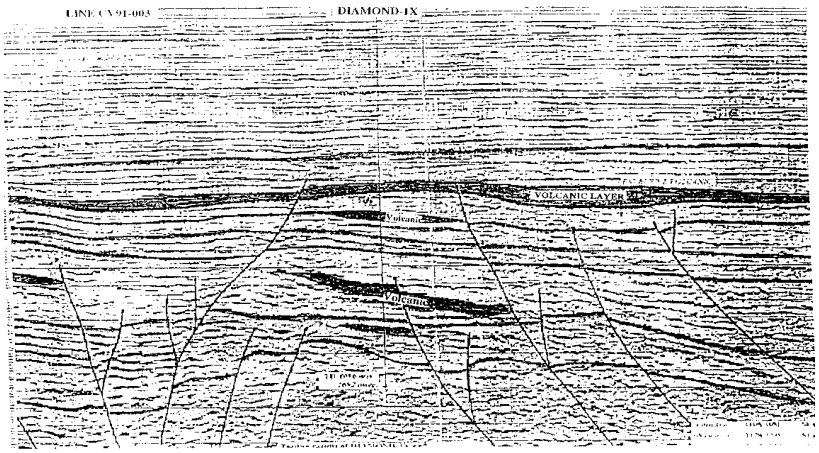

Fig. 3. Seismic section of Cuu Long basin reflected the "stratified layers" of volcanic bodies (black) in the Midle Miocene sedimentaries [15].

Table 2. Normative composition of some basalts of Eastern Sea

	1	2	3	4	5	6	7
SiO_2	51.11	50.00	46.95	52.91	49.71	48.9	46.73
TiO_2	1.73	2.43	2.36	1.40	2.10	3.74	3.40
Al_2O_3	16.01	13.98	15.87	15.10	16.22	16.23	16.70
Fe_2O_3		-	-	-		-	-
FeO	9.92	10.78	11.09	8.21	10.80	10.15	10.11
MnO	0.12	0.13	0.15	0.14	0.11	0.14	0.19
MgO	4.05	5.60	7.00	6.97	6.03	3.06	6.12
CaO	5.50	8.42	7.05	9.00	10.86	9.18	9.52
Na_2O	4.77	3.38	2.64	3.12	3.08	3.57	3.28
K_2O	3.12	2.01	2.66	0.72	0.51	2.11	2.19
P_2O_5	0.70	0.75	0.61	0.24	0.30	1.11	0.62
Total	97.03	97.48	96.38	97.81	99.73	98.21	98.9
Q				0.97			-
C				-			-
Or	18.44	11.88	15.72	4.26	3.02	12.48	12.95
Ab	31.82	28.6	21.89	26.40	26.06	30.21	18.07
An	13.06	17.04	23.60	25.07	28.94	22.03	24.38
Lc	-	-	-	-	-	-	-
Ne	4.63	-	0.24	-	-	-	5.25
Di	8.10	16.49	6.11	14.76	19.12	14.18	15.70
Wo	-	--	-	-	-	-	-
Hy	-	-	-	23.14	8.45	1.89	-
Ol	16.07	13.14	22.93	-	7.87	6.34	13.18
Mt	-	-	-	-	1.74	1.64	1.62
Il	3.29	4.62	4.48	2.66	3.99	7.10	6.46
Ap	1.62	1.74	1.41	0.56	0.65	2.42	1.35
Cc							

Table 3. The chemical compositions of stratified layers of basalts among the sedimentaries of Cuu Long Basin [15]

	1	2	3	4	5	6	7	8	9	10
SiO_2	45.18	50.38	47.26	47.67	49.34	47.47	49.00	47.39	50.16	48.56
TiO_2	1.45	0.95	1.68	1.67	1.88	1.26	1.32	1.19	1.32	1.33
Al_2O_3	17.67	17.70	15.38	17.42	16.59	16.92	15.90	17.16	15.68	16.44
Fe_2O_3	2.28	3.04	4.08	3.53	9.76	3.14	2.18	10.94	5.18	8.47
FeO	6.27	4.30	8.08	6.36	-	8.15	6.27	-	4.92	-
MnO	0.14	0.11	-	0.14	0.30	0.16	0.10	0.17	0.12	0.11
MgO	6.85	5.63	6.77	6.67	6.45	9.00	5.87	8.87	7.38	5.84
CaO	6.03	7.81	4.78	3.67	2.69	2.11	5.86	2.09	9.61	5.90
Na_2O	4.75	3.09	3.02	5.29	0.61	2.45	5.22	2.45	3.34	5.22
K_2O	1.38	1.42	2.10	0.66	7.84	4.06	0.79	4.41	0.10	0.82
P_2O_5	0.32	0.39	0.11	0.29	0.27	0.16	0.21	0.16	0.16	0.24
S	0.10	0.10	-	0.10	-	0.10	0.10	-	0.10	0.10
LOI	6.90	4.68	6.23	6.12	3.77	4.67	6.57	4.67	1.47	6.57
Total	99.32	99.60	99.49	99.49	99.50	99.41	99.39	99.50	99.54	99.50

From Table 3, the total amount of (Na_2O + K_2O) is more than 5-6%, what confirms that the alkality of rocks is high and it is belonging to the alkaline basalt type.

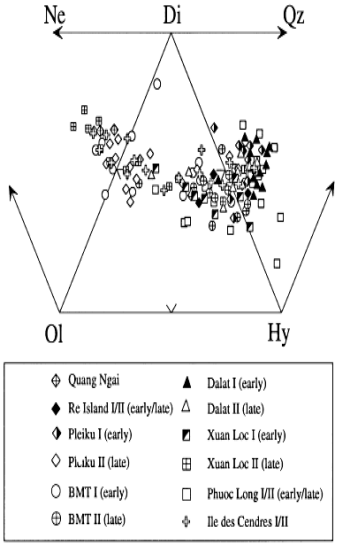

Fig. 4. CIPW normative variation for Eastern Sea basalts in comparision with on-land volcanic activity. Remark that the basalts is from Island as Re Island, Ile des Cendres [13].

3. Discussion about the forming mechanism

For discussion about the forming mechanism of basalt volcanic activity of Eastern Sea, it is necessary to remark the two following data:

1) By calculation of formation pressure of basalts (O' Hara diagram; by barometer), the alkaline basalts were formed at the depth of more than 90 km (pressure more than 30 kbars); meanwhile, the tholeitic basalts were formed at the depth of about 18-30 km (pressure of about 6-10 kbars) (refer to Table 1).

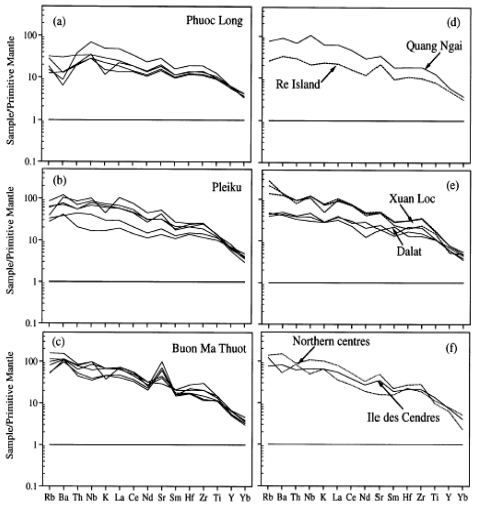

Fig. 5. Spider diagram for comparing basalts from the Island and on-land.

Table 4. Isotopic compositions of basalts of South China Sea [10].

Samples	Sr 87/86	Nd 143/144	ε Nd	Pb 206/204	Pb 207/204	Pb 208/204
D8-2	0.703594	0.512929	5.68	18.704	15.609	38.325
D8-4	0.703561	0.512916	5.42	18.600	15.632	38.848
D9-3	0.704433	0.512922	5.54	18.667	15.535	38.677
D9-2	0.703976	0.512813	3.41	18.954	15.588	38.991
D10	0.704007	0.512805	3..26	18.875	15.593	38.931
O23-40	0.703814	0.512952	6.13	18.601	15.557	38.629
O23-37	0.703991	0.512898	5.07	18.543	15.606	38.598
23-37-7	0.703936	0.512894	4.99	18.481	15.567	38.618
23-35-6	0.704355	0.512913	5.36	18.411	15.575	38.554
75-31	0.703689	0.513035	7.72	18.521	15.520	38.402
M32283	0.704222	0.513184	10.65	17.864	15.447	37.605
Pal-5	0.704453	0.513129	9.58	17.886	15.449	37.648

2) The isotopic study (Table 4) all of the isotopic ratios (Sr-87/86; Nd 143/144; Pb 206/204; Pb 207/204; Pb 208/204) confirms that the alkaline basalt belonged to the partial

melting of type PREMA (PREvalent MAntle composition), it means that they are not belonged to the Depleted (DM) or Enriched Mantle (EM) (Fig. 6).

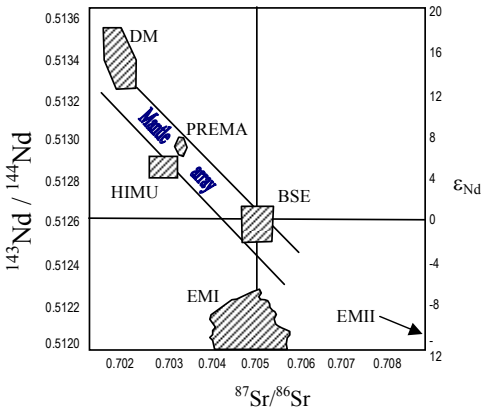

Fig. 6. Corellation diagram of isotopic ratios Nd 143/144 and Sr 86/87.

There are two problems to be disscused:

1. Why the volcanic activity has strongly developed only after the time of closing spreading process ?

2. Why there are two basalt types - alkaline and tholeitic - of different formation depths (from 90 km to 20 km) during a single geodynamic process ?

Historically, there were a lot of hypotheses explaining geodynamics of the formation of South China Sea [2, 3, 11, 12, 14, 17-22].

A new hypothesis is proposed by the authors as follows:

The main cause of the formation of thermal dome for rising up mantle together with partial melting is the appearance of big mantle plume near the margin of Asian continent at that time.

At first, the mantle plume during its rising up gives rise the subduction to the Borneo site (Palawan subduction), then, the subduction was extending the continental crust at the margin of Asia continent. In the depth of the Mantle, the partial melting has started but the magma liquidus was else lay with the batch melting in the depth (after the form of spider diagram). In sequences, alkaline basalt magma was formed.

During the rising up of the mantle plume, magma liquidus reservoirs from the depth were moving to the surface but not extrusing on the Earth surface. At the small depth near the surface, magma liquidus reservoir became tholeitic magma feature with positive Sr anomaly (Fig. 5). But the partial melting mechanism else remained the batch melting character (after the form of spider diagram).

When the opening process of Eastern Sea was stoped, but the magma still remains in the depth of about 20 km but not extruses on the surface.

Additionally, under influence of the collision between the two continents India and Eurasia, a big strike slip of north-south direction (extended from Red River fault) was appeared, which moved the opening axis of Eastern Sea to the south. In consequenses, the oceanic crust was outcroped in the form of a triangle. So, the continental crust even has became thinked but covers all the surface of the south part of Eastern Sea. In these conditions, the magma liquidus reservoirs were lain in the depth. Only after closing of the rifting process, the new fault - normal or thrust kinds (from Oligocen) were opening the canals for strong volcanic activity. So, the volcanic rock types of South China Sea are very different from the magma activity kind of the all marginal seas.

Fig. 7. Some images of volcanic activity on Con Co Island (Quang Tri Province). Photographer: Phan Truong Thi.

11-1. Basalt flow; 11-2. Basalt layer with a lot of big bubbles; 11-3. Neogene sedimentary; 11-4. Image of a volcanic apparatus filled by sea water; 11-5. From the volcanic apparatus there is a basalt flow; 11-6. Neogene sedimentary (light brown color) was lain under a basalt flow (grey color); 11-7. A volcanic bomb among the sedimentary; 11-8. Sedimentary with horizontal layers; 11-9. The fault cutted sedimentaries; 11-10. The fault cutted sedimentaries.

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