

28. BASALTS FROM THE EAST PACIFIC RISE NEAR 9°N DRILLED ON DEEP SEA DRILLING PROJECT LEG 54 COMPARED WITH MARGINAL-BASIN AND OCEAN-ISLAND BASALTS

Y. I. Dmitriev, Institute of Ore Deposits, Petrography, Mineralogy and Geochemistry of the USSR,
Academy of Sciences, Moscow, USSR

ABSTRACT

Aphyric and sparsely plagioclase-clinopyroxene phyric basalts were drilled during Leg 54 on the East Pacific Rise and OCP Ridge near the rise crest. Aphyric basalts have $\text{TiO}_2/\text{Al}_2\text{O}_3 = 0.6\text{--}0.4$ and $\text{SiO}_2/\text{TiO}_2 = 27\text{--}44$, which are typical of basalts of mid-oceanic ridges and fracture zones of marginal seas. Plagioclase-pyroxene phyric basalts have $\text{TiO}_2/\text{Al}_2\text{O}_3 = 0.17\text{--}0.20$ and $\text{SiO}_2/\text{TiO}_2 = 18\text{--}20$; in these respects they are similar to some oceanic-island basalts. Tholeiitic basalts from island arcs form yet a third fundamental basalt type.

INTRODUCTION

During Deep Sea Drilling Project Leg 54, ten holes were drilled on the flanks of the East Pacific Rise near 9°N in the vicinity of OCP Ridge. The holes drilled were Holes 419, 419A, 420, 420A, 421, 422, 423, 428, 429, and 429A (Figure 1). OCP Ridge is a sublatitudinal structural form on the western flank of the East Pacific Rise. The latter, along with other mid-oceanic ridges and fracture zones of marginal seas, belongs to the global oceanic spreading structures system (Gorshkov, 1974; Le Pichon et al., 1973; Karig, 1971; Karig, Ingle, et al., 1975; Katsumata and Sykes, 1969).

Along the mid-oceanic ridges, which have an area equal to that of all the continents of our planet put together (Grachev, 1977), huge volumes of basaltic magmatism occur ($5000\text{--}6000 \times 10^6 \text{ m}^3/\text{y.}$; Baksi and Watkins, 1973). This volcanism produces the oceanic crust. The worldwide occurrence of basalts related to oceanic spreading structures, and manifestations of ore mineralization known to occur there (Dmitriev et al., 1970), are reasons to regard the study of these basalts as one of the primary tasks of contemporary petrology.

The aim of this paper is to reveal—taking the basalts of the OCP Ridge and the adjoining area of the East Pacific Rise as examples—the specific features of tholeiitic basalts of oceanic structures which distinguish them from tholeiitic basalts of oceanic islands and island arcs. Another objective is to find out if there are any differences between tholeiitic basalts of mid-oceanic ridges and tholeiitic basalts of fracture zones of marginal seas.

The composition of tholeiitic basalts of marginal sea-spreading zones was defined on the basis of the study of cores from Sites 54 and 293 (Figure 2) drilled by the *Glomar Challenger* (Legs 6 and 31) in the Philippine Sea, Central Basin fault zone (Fischer, Heezen, et al., 1971) and Yap fracture zone (Karig, Ingle, et al., 1975), as well as rock samples dredged from the Yap fracture

zone during Leg 17 of the USSR R/V *Dmitry Mendeleev* (Bogdanov, 1977; Dmitriev et al., 1977). Chemical analyses were obtained by classical wet-chemical techniques. Mineral compositions were determined by electron microprobe.

PETROGRAPHY AND MINERALOGY OF BASALTS

Tholeiitic basalts of the East Pacific Rise and basalts of Philippine Sea fracture zones consist of three principal petrographic types: aphyric, plagioclase phyric, and plagioclase-pyroxene phyric basalts.

Aphyric Basalts

These basalts occur in all studied holes of the East Pacific Rise, as well as at DSDP Site 54 in the Yap fracture zone of the Philippine Sea. Results of our investigations, along with published data (Gorodnizkii and Sorochtin, 1977; Frolova and Gushin, 1977; Bonatti and Fisher, 1971; Miyashiro, 1975) allow us to regard aphyric basalts as possibly the most voluminous rock type in oceanic spreading structures.

In general, aphyric basalts vary from glassy and very fine grained rocks with variolitic, hyalopilitic, and pilotaxitic textures, to rather coarse grained rocks with intersertal, doleritic, ophitic, and pegmatoid textures.

The common textural feature of all these rocks is the absence or scarcity (<2%) of phenocrysts, which in all cases are represented by olivine.

Aphyric basalts consist of plagioclase, clinopyroxene, ore minerals, a matrix with a variable state of crystallization, and olivine which is not always present but sometimes constitutes up to 5 per cent of the rock (Table 1). Secondary minerals are mainly smectite, calcite, zeolites, and sulfides. The vesicle content is less than 1.8 per cent, and their size is less than 0.9 mm (average size 0.4 mm); they are typically filled with smectite and calcite.

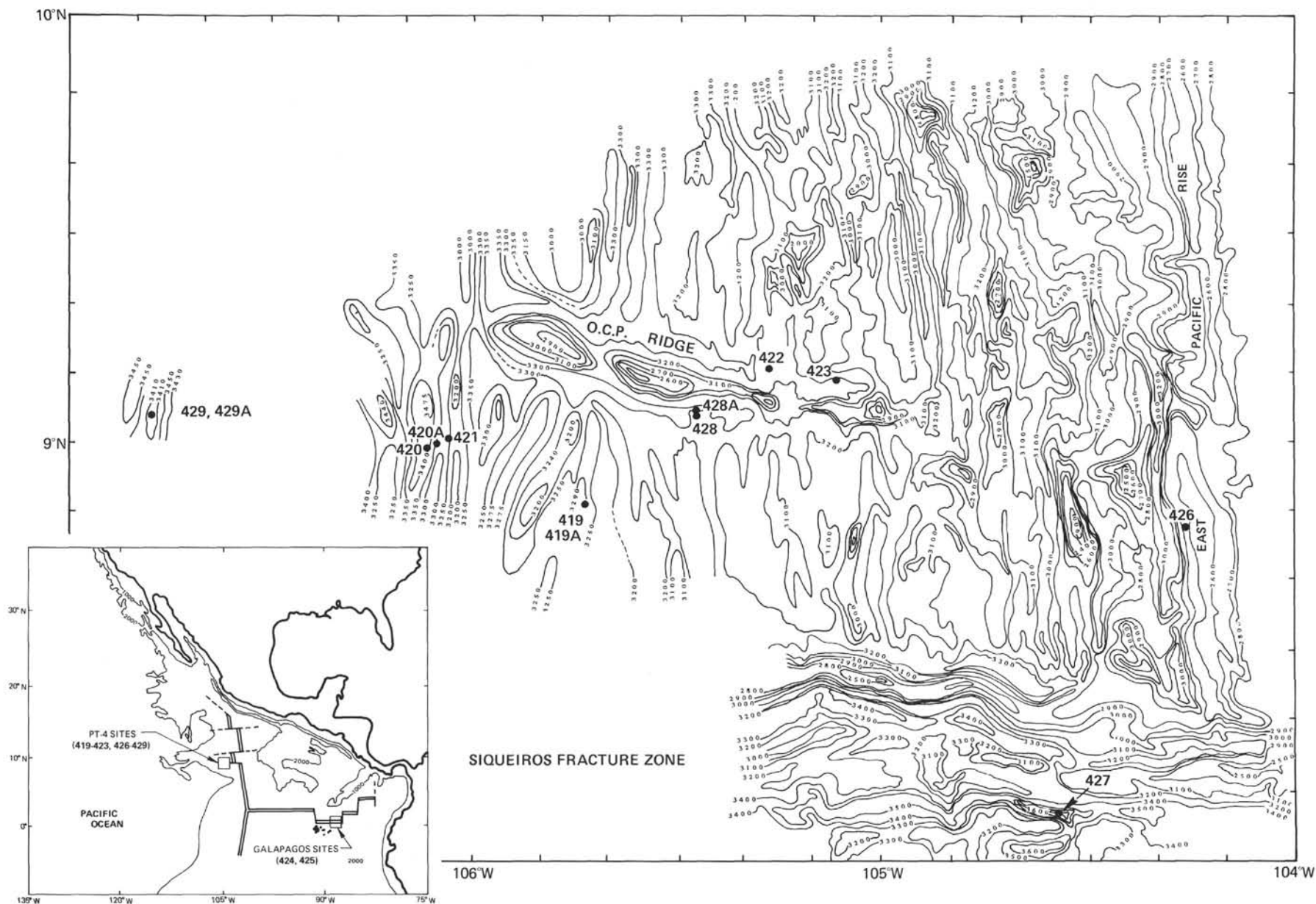


Figure 1. Location of drill holes on the East Pacific Rise, DSDP Leg 54.

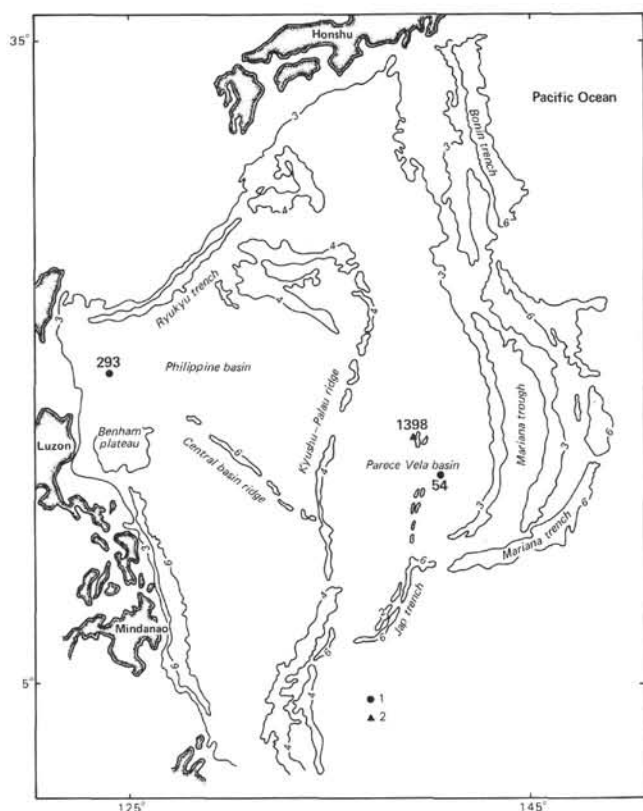


Figure 2. Location of drill holes and dredging stations in the Philippine Sea. 1 = Drill holes; 2 = Dredging station.

Plagioclase occurs as microlites in poorly crystallized varieties of basalt and forms laths with average size 0.1×0.6 mm in coarser grained rocks. The plagioclase composition among both Leg 54 and Philippine Sea basalts varies from bytownite An_{73} to andesine An_{34} (Table 2). The most common are plagioclase with composition An_{69} – An_{64} . The crystals with the highest anorthite content are plagioclase phenocrysts; the lowest An content occurs in the outer rims of zoned crystals. The increase of albite content in plagioclase is accompanied by an increase of Ti and Fe content and decrease of Mg concentration in this mineral. The more albitic plagioclases are associated with more Fe-rich clinopyroxene. For example, plagioclase An_{67} is accompanied by augite $En_{41.5}Wo_{39.0}Fs_{19.5}$, labradorite An_{57} is associated with augite $En_{39.1}Wo_{39.3}Fs_{21.6}$, and andesine An_{38} forms graphic intergrowths with augite $En_{38.4}Wo_{28.5}Fs_{33.1}$.

Clinopyroxene forms sheaf-like clusters in the least crystallized varieties of aphyric basalts; it occurs as aggregates of subparallel prismatic crystals and anhedral grains in interstices between plagioclase crystals. As already mentioned, in some basalts clinopyroxene forms graphic intergrowths with plagioclase. The clinopyroxene of Leg 54 and Philippine Sea aphyric basalts is augite with the following variations of main components: $En_{37.7-27.1}Wo_{48.5-19.9}Fs_{16.8-33.1}$ (Table 3). The most common is augite with a ferrosilite content of 19 to 25 per cent. Pyroxenes with the highest content of Fe form graphic intergrowths with plagioclase and ore minerals ($En_{34}Wo_{36}Fs_{30}$). Zoned and twinned grains of pyroxene are rather common in well-crystallized varieties of aphyric basalts, with the average size of pyroxene grains being 0.5×0.5 mm.

TABLE 1
Modal Compositions of Basalts from the EPR and the Philippine Sea Fracture Zones (wt. %)

Components	East Pacific Rise												Philippine Sea		
	Aphyric Basalts							Plagioclase Phyric Basalts					13	14	15
	1	2	3	4	5	6	7	8	9	10	11	12			
Phenocrysts:															
Plagioclase								2.2	1.2	1.0	1.3	2.6	—	3.7	6.7
Clinopyroxene								2.5	0.6	2.2	1.9	3.0	—	—	—
Olivine								—	—	—	—	—	—	—	—
Minerals of groundmass:															
Plagioclase	36.8	43.7	55.9	14.1	45.6	39.0	40.5		20.2	—	—	—	45.0	26.4	26.9
Clinopyroxene	47.7	30.6	34.2	46.2	45.3	46.2	39.0		46.2	—	—	—	41.9	64.3	42.2
Olivine	—	3.0	—	—	1.1	—	1.0		—	—	—	—	2.1	—	0.7
Ore mineral	5.0	7.3	5.2	—	5.4	6.5	5.8		10.4	—	—	—	4.4	5.6	—
Matrix	10.5	15.4	4.7	39.7	3.2	8.3	13.7	95.3	21.4	96.8	96.8	94.4	6.6	—	23.5

Notes:

East Pacific Rise aphyric basalts:

- 1 = Sample 429-3-1, 107–115 cm.
- 2 = Sample 428A-5-4, 40–55 cm.
- 3 = Sample 428A-5-1, 35–45 cm.
- 4 = Sample 428-5-1, 5–10 cm.
- 5 = Sample 422-9-3, 20–30 cm.
- 6 = Sample 422-7-1, 25–35 cm.
- 7 = Average of 50 calculations.

Plagioclase-pyroxene phyric basalts:

- 8 = Sample 420-14-1, 55–60 cm.

- 9 = Sample 421-3-1, 115–128 cm.

- 10 = Sample 422-10-1, 20–27 cm.

- 11 = Sample 423-6-1, 10–15 cm.

- 12 = Average of 17 calculations.

Fracture zones of the Philippine Sea aphyric basalts:

- 13 = Sample 54-9-1, #8.

Plagioclase phyric basalts:

- 14 = Sample 293-18-1, 134–143 cm.

- 15 = Sample 1398.

TABLE 2
Compositions of Plagioclase in Basalts from the East Pacific Rise and the
Philippine Sea Fracture Zones

	Crystallochemical Formula	Name/% An
1	(Na _{1.235} Ca _{2.650} Fe _{0.011} Mg _{0.051} K _{0.011})3.958(Si _{9.819} Al _{6.003} Ti _{0.011})15.833O ₃₂ (Na _{1.361} Ca _{2.276} Fe _{0.120} Mg _{0.045} K _{0.009})3.811(Si _{9.648} Al _{6.366} Ti _{0.014})16.028O ₃₂ (Na _{2.105} Ca _{1.532} Fe _{0.126} K _{0.024})3.787(Si _{10.857} Al _{5.012} Ti _{0.023})15.892O ₃₂	Labradorite, An ₆₉ Labradorite, An ₆₄ Labradorite, An ₄₄
2	(Na _{1.476} Ca _{2.406} Fe _{0.109} Mg _{0.070} K _{0.011})4.072(Si _{9.237} Al _{6.789} Ti _{0.007})16.033O ₃₂	Labradorite, An ₆₄
3	(Na _{2.241} Ca _{1.257} Fe _{0.101} K _{0.026})3.625(Si _{10.686} Al _{5.406} Ti _{0.014})16.106O ₃₂	Andesine, An ₃₈
4	(Na _{1.330} Ca _{2.515} Fe _{0.115} Mg _{0.060} K _{0.009})4.029(Si _{9.749} Al _{6.088} Ti _{0.005})15.842O ₃₂ (Na _{1.791} Ca _{2.131} Fe _{0.148} Mg _{0.074} K _{0.015})4.159(Si _{10.195} Al _{5.550} Ti _{0.015})15.760O ₃₂	Labradorite, An ₆₇ Labradorite, An ₅₇
5	(Na _{1.436} Ca _{2.730} Fe _{0.086} Mg _{0.022} K _{0.011})4.285(Si _{9.489} Al _{6.286} Ti _{0.016})15.891O ₃₂	Labradorite, An ₆₆
6	(Na _{1.406} Ca _{2.643} Fe _{0.092} Mg _{0.054} K _{0.004})4.199(Si _{9.978} Al _{7.034})16.012O ₃₂ (Na _{1.903} Ca _{2.218} Fe _{0.149} Mg _{0.043} K _{0.013})4.326(Si _{9.390} Al _{6.567})15.957O ₃₂	Labradorite, An ₆₆ Labradorite, An ₅₆ (core)
	(Na _{2.727} Ca _{1.278} Fe _{0.137} Mg _{0.024} K _{0.028})4.194(Si _{10.091} Al _{6.002})16.093O ₃₂	Andesine, An ₃₄ (fringe)
9	(Na _{1.251} Ca _{2.150} Fe _{0.142} Mg _{0.034} K _{0.013})3.590(Si _{9.675} Al _{6.442} Ti _{0.014})16.131O ₃₂ (Na _{1.429} Ca _{1.973} Fe _{0.146} Mg _{0.018} K _{0.015})3.581(Si _{9.821} Al _{6.307} Ti _{0.019})16.147O ₃₂	Labradorite, An ₆₅ Labradorite, An ₆₀
10	(Na _{1.018} Ca _{2.579} Fe _{0.084} Mg _{0.067} K _{0.009})3.757(Si _{9.410} Al _{6.613})16.023O ₃₂	Bytownite, An ₇₃ (phenocryst)
13	(Na _{1.175} Ca _{2.874} Mg _{0.041} K _{0.011})4.101(Si _{9.518} Al _{6.216} Fe _{0.088})15.822O ₃₂ (Na _{1.360} Ca _{2.651} Mg _{0.074} K _{0.009})4.094(Si _{9.695} Al _{5.987} Fe _{0.146})15.828O ₃₂	Bytownite, An ₇₃ (inclusion in pyroxene) Labradorite, An ₆₈ (inclusion in pyroxene)
	(Na _{1.281} Ca _{2.674} Fe _{0.007} Mg _{0.068})4.12(Si _{9.489} Al _{6.361})15.85O ₃₂	Phenocrysts: Labradorite, An ₆₉
14	(Na _{1.249} Ca _{2.721} Fe _{0.123} Mg _{0.109})4.202(Si _{9.347} Al _{6.485})15.832O ₃₂ (Na _{1.20} Ca _{2.728} Fe _{0.115} Mg _{0.107})4.07(Si _{9.391} Al _{6.472})15.863O ₃₂	Bytownite, An ₇₀ Bytownite, An ₇₃
15	(Na _{0.966} Ca _{3.022} Fe _{0.052} Mg _{0.046})4.086(Si _{9.291} Al _{6.542})15.833O ₃₂ (Na _{1.437} Ca _{2.559} Fe _{0.077} Mg _{0.062})4.135(Si _{9.622} Al _{6.226})15.848O ₃₂	Bytownite, An ₇₆ Labradorite, An ₆₅

Notes:

East Pacific Rise aphyric basalts:

- 1 = Sample 429-3-1, 107–115 cm.
2 = Sample 428A-5-4, 40–55 cm.
3 = Sample 428A-5-1, 35–45 cm.
4 = Sample 428-5-1, 5–10 cm.
5 = Sample 422-9-3, 20–30 cm.
6 = Sample 422-7-1, 25–35 cm.

Plagioclase-pyroxene phyric basalts:

- 9 = Sample 421-3-1, 115–128 cm.
10 = Sample 422-10-1, 20–27 cm.

Fracture zones of the Philippine Sea aphyric basalts:

- 13 = Sample 54-9-1 (#8).

Plagioclase phyric basalts:

- 14 = Sample 293-18-1, 134–143 cm.
15 = Sample 1398/D2-11.

Olivine in aphyric basalts occurs mostly in sporadic, euhedral grains with average size of 0.1×0.2 mm, but sometimes the content of this mineral is as high as 5 per cent. Olivine is usually replaced by secondary minerals. The composition of some fresh grains was determined as chrysolite, Fa_{14-22} (Table 4).

Ore minerals occur as tiny grains and skeletal crystals in the glassy matrix of basalts, as intergrowths with clinopyroxene, and as anhedral filling of interstitial spaces with average size 0.1 mm. The analyzed composition of these grains in Leg 54 basalts shows them to be Fe-Ti oxides, which are usually called titanomagnetites (Table 5).

Comparison of aphyric basalts of the East Pacific Rise with those of the Yap fracture zone of the Philippine Sea shows that the latter contain more plagioclase

with a higher anorthite content, more olivine, and less ore minerals. Clinopyroxene of Philippine Sea aphyric basalts is enriched in calcium in comparison with clinopyroxene of East Pacific Rise aphyric basalts.

Plagioclase Phyric Basalts

On the basis of their modal composition these rocks are similar to aphyric basalts, but they contain up to 11 per cent phenocrysts of plagioclase with lower contents of olivine and a higher proportion of matrix (Table 1).

Plagioclase phenocrysts in Leg 54 and Philippine Sea basalts have compositions ranging from bytownite An_{76} to labradorite An_{69} . Microlaths of plagioclase in the groundmass of the rocks are labradorite An_{65} (Table 2).

Clinopyroxene in the groundmass is represented by augite $\text{En}_{46.9}\text{Wo}_{37.3}\text{Fs}_{15.8}$ (Table 3).

TABLE 3
Compositions of Clinopyroxene in Basalts from the East Pacific Rise and the Philippine Sea Fracture Zones

	Crystallochemical Formula	Name/% En, Wo, Fs
1	(Ca _{0.649} Na _{0.022}) _{0.671} (Mg _{0.986} Fe _{0.297} Mn _{0.009} Al _{0.036} Ti _{0.018}) _{1.346} (Si _{1.917} Al _{0.083}) ₂ O ₆	Augite En _{48.9} Wo _{33.3} Fs _{17.8}
	(Ca _{0.719} Na _{0.025}) _{0.744} (Mg _{0.871} Fe _{0.304} Mn _{0.009} Al _{0.049} Ti _{0.023}) _{1.256} (Si _{1.930} Al _{0.070}) ₂ O ₆	Augite En _{43.6} Wo _{37.2} Fs _{19.2}
	(Ca _{0.682} Na _{0.031}) _{0.713} (Mg _{0.881} Fe _{0.368} Mn _{0.017} Al _{0.025} Ti _{0.024}) _{1.315} (Si _{1.901} Al _{0.099}) ₂ O ₆	Augite En _{43.4} Wo _{35.2} Fs _{21.4}
	(Ca _{0.633} Na _{0.025}) _{0.658} (Mg _{0.846} Fe _{0.430} Mn _{0.012} Al _{0.035}) _{1.323} (Si _{1.892} Al _{0.108}) ₂ O ₆	Augite En _{42.7} Wo _{33.2} Fs _{24.1}
	(Ca _{0.387} Na _{0.007}) _{0.394} (Mg _{1.085} Fe _{0.426} Mn _{0.011} Al _{0.045} Ti _{0.014}) _{1.581} (Si _{1.984} Al _{0.016}) ₂ O ₆	Augite En _{54.9} Wo _{19.9} Fs _{25.2}
	(Ca _{0.539} Na _{0.030}) _{0.569} (Mg _{0.962} Fe _{0.358} Mn _{0.011} Al _{0.058} Ti _{0.028}) _{1.417} (Si _{1.943} Al _{0.057}) ₂ O ₆	Augite En _{48.4} Wo _{28.7} Fs _{29.9}
	(Ca _{0.709} Na _{0.043}) _{0.752} (Mg _{0.626} Fe _{0.586} Mn _{0.017} Al _{0.030} Ti _{0.039}) _{1.298} (Si _{1.941} Al _{0.059}) ₂ O ₆	Augite En _{30.5} Wo _{36.7} Fs _{32.8}
2	(Ca _{0.796} Na _{0.027}) _{0.823} (Mg _{0.778} Fe _{0.271} Al _{0.075} Ti _{0.025}) _{1.156} Mn _{0.007} (Si _{1.945} Al _{0.055}) ₂ O ₆	Augite En _{39.3} Wo _{41.6} Fs _{19.1}
3	(Ca _{0.6} Na _{0.042}) _{0.642} (Mg _{0.772} Fe _{0.611} Mn _{0.018} Cr _{0.002} Ti _{0.005}) _{1.408} (Si _{1.906} Al _{0.071} Ti _{0.023}) ₂ O ₆	Augite (core) En _{37.7} Wo _{31.3} Fs ₃₁
	(Ca _{0.550} Na _{0.018}) _{0.568} (Mg _{0.765} Fe _{0.638} Cr _{0.002} Mn _{0.017}) _{1.422} (Si _{1.956} Al _{0.044}) ₂ O ₆	Augite (fringe) En _{38.4} Wo _{28.5} Fs _{33.1}
4	(Ca _{0.763} Na _{0.028}) _{0.791} (Mg _{0.843} Fe _{0.306} Mn _{0.007} Al _{0.036} Ti _{0.046}) _{1.238} (Si _{1.827} Al _{0.173}) ₂ O ₆	Augite En _{41.5} Wo _{39.0} Fs _{19.5}
	(Ca _{0.774} Na _{0.022}) _{0.796} (Mg _{0.792} Fe _{0.333} Mn _{0.006} Al _{0.047} Ti _{0.049}) _{1.227} (Si _{1.817} Al _{0.183}) ₂ O ₆	Augite En _{39.1} Wo _{39.3} Fs _{21.6}
5	(Ca _{0.716} Na _{0.034}) _{0.750} (Mg _{0.836} Fe _{0.253} Mn _{0.010} Al _{0.072} Ti _{0.050}) _{1.221} (Si _{1.920} Al _{0.080}) ₂ O ₆	Augite En _{42.4} Wo _{38.1} Fs _{19.5}
6	(Ca _{0.714} Na _{0.018}) _{0.732} (Mg _{0.936} Fe _{0.298} Mn _{0.007} Al _{0.015} Ti _{0.018}) _{1.274} (Si _{1.953} Al _{0.047}) ₂ O ₆	Augite En _{46.7} Wo _{36.5} Fs _{16.8}
	(Ca _{0.691} Na _{0.035}) _{0.726} (Mg _{0.684} Fe _{0.584} Mn _{0.013} Ti _{0.006}) _{1.287} (Si _{1.931} Al _{0.054} Ti _{0.028}) ₂ O ₆ (intergrowth with ore mineral)	Augite En ₃₄ Wo ₃₆ Fs ₃₀
9	(Ca _{0.626} Na _{0.019}) _{0.645} (Mg _{0.887} Fe _{0.255} Al _{0.118} Ti _{0.030}) _{1.290} (Si _{1.928} Al _{0.072}) ₂ O ₆	Augite En _{45.8} Wo _{33.3} Fs _{20.9}
	(Ca _{0.425}) _{0.425} (Mg _{1.053} Fe _{0.365} Mn _{0.013} Al _{0.068} Ti _{0.016}) _{1.940} Si _{2.005} O ₆	Augite En _{54.3} Wo _{21.9} Fs _{23.8}
10	(Ca _{0.652} Na _{0.023}) _{0.675} (Mg _{1.044} Fe _{0.114} Mn _{0.003} Al _{0.094}) _{1.255} (Si _{1.990} Al _{0.010}) ₂ O ₆	Augite En _{54.1} Wo ₃₅ Fs _{10.9}
	(Ca _{0.663} Na _{0.021}) _{0.684} (Mg _{1.031} Fe _{0.128} Mn _{0.003} Cr _{0.018} Al _{0.086} Ti _{0.013}) _{1.279} (Si _{1.966} Al _{0.034}) ₂ O ₆	Phenocryst, core Augite En _{52.5} Wo _{34.8} Fs _{12.7}
	(Ca _{0.730} Na _{0.024}) _{0.757} (Mg _{0.972} Fe _{0.168} Mn _{0.006} Cr _{0.003} Al _{0.069} Ti _{0.046}) _{1.264} (Si _{1.828} Al _{0.172}) ₂ O ₆	Phenocryst, fringe Augite En _{48.3} Wo _{37.4} Fs _{14.3}
13	(Ca _{0.861} Na _{0.005}) _{0.866} (Mg _{0.670} Fe _{0.363} Mn _{0.007} Al _{0.044} Ti _{0.046}) _{1.130} (Si _{1.872} Al _{0.128}) ₂ O ₆	Phenocryst Augite En _{33.6} Wo _{43.4} Fs ₂₃
	(Ca _{0.817} Na _{0.016}) _{0.833} (Mg _{0.690} Fe _{0.449} Mn _{0.01} Al _{0.009}) _{1.158} (Si _{1.875} Al _{0.12}) _{1.995} O ₆	Augite En _{34.7} Wo _{41.8} Fs _{23.5}
	(Ca _{0.777} Na _{0.026}) _{0.803} (Mg _{0.560} Fe _{0.643}) _{1.205} (Si _{1.869} Al _{0.106} Ti _{0.047}) ₂ O ₆	Fe-augite En _{27.9} Wo _{40.0} Fs _{32.1}
15	Ca _{0.743} (Mg _{0.848} Fe _{0.293} Mn _{0.008} Ti _{0.045} Al _{0.055}) _{1.249} (Si _{1.869} Al _{0.131}) ₂ O ₆	Augite En _{46.9} Wo _{37.3} Fs _{15.8}

Notes:

East Pacific Rise aphyric basalts:

- 1 = Sample 429-3-1, 107–115 cm.
 2 = Sample 428A-5-4, 40–55 cm.
 3 = Sample 428A-5-1, 35–45 cm.
 4 = Sample 428-5-1, 5–10 cm.
 5 = Sample 422-9-3, 20–30 cm.
 6 = Sample 422-7-1, 25–35 cm.

Plagioclase-pyroxene phyric basalts:

- 9 = Sample 421-3-1, 115–128 cm.
 10 = Sample 422-10-1, 20–27 cm.

*Fracture zones of the Philippine Sea**Aphyric basalt:*

- 13 = Sample 54-9-1 (#8).

Plagioclase phyric basalt:

- 15 = Sample 1398/D2-11.

TABLE 4
Compositions of Olivine in Aphyric Basalts of the East Pacific Rise (2.5) and the Philippine Sea Fracture Zones

	Crystallochemical Formula	Name	% Fa
2	(Mg _{1.608} Fe _{0.351} Mn _{0.008} Ca _{0.014}) _{1.981} (Si _{1.005} Al _{0.006}) _{1.011} O ₄	Chrysolite	18
5	(Mg _{1.695} Fe _{0.284} Mn _{0.005} Ca _{0.011}) _{1.995} Si _{1.003} O ₄	Chrysolite	14
13	(Mg _{1.743} Fe _{0.270} Mn _{0.005} Ca _{0.010} Ni _{0.001}) _{2.029} Si _{0.985} O ₄	Chrysolite	14
	(Mg _{1.578} Fe _{0.437} Mn _{0.008} Ca _{0.014}) _{2.037} Si _{0.980} O ₄	Chrysolite	22

Note: 2 = Sample 428A-5-4, 40–55 cm; 5 = Sample 422-9-3, 20–30 cm; 13 = Sample 54-9-1 (#8).

The ore minerals are titanomagnetite with a TiO₂ content of 19.6 to 22.9 per cent (Table 5).

Plagioclase pyritic basalts were recovered only from the Yap fracture zone and Central Basin fault of the Philippine Sea.

Plagioclase-Pyroxene Pyritic Basalts

The rocks of this type are fairly widespread in the studied transect of the East Pacific Rise. In Hole 423, plagioclase-pyroxene pyritic basalts exclusively were recovered. In Holes 420 and 421 they are accompanied by subordinate amounts of aphyric basalts, and in Hole 422 plagioclase-pyroxene pyritic basalts underlie aphyric basalts. Plagioclase-pyroxene pyritic basalts do not occur among the rocks sampled from fracture zones of the Philippine Sea.

The appearance of plagioclase-pyroxene pyritic basalts differs sharply from that of aphyric and plagioclase pyritic basalts, the most obvious differences being textural. Plagioclase-pyroxene pyritic basalts are mainly very poorly crystallized rocks with a glassy or cryptocrystalline groundmass which contains 10 to 11 per cent of pyroxene and plagioclase microphenocrysts (Table 1). The textures of the matrices are vitrophyric, variolitic, hyalopilitic, pilotaxitic and, in the best crystallized varieties, micro-intersertal. The groundmass of the rocks contains microlites of plagioclase, sheaf-like aggregates of clinopyroxene, incipient crystals, and tiny grains of ore minerals. Some samples (Hole 420) contain up to 1.1 per cent of olivine.

Clinopyroxene dominates among phenocrysts and is represented by zoned augite with core compositions of En_{54.1}Wo₃₅Fs_{10.9}, and En_{52.5}Wo_{34.8}Fs_{12.7} on the rims.

The sizes of phenocrysts are up to 0.6 × 0.5 mm. They occur as glomerophyric clusters (sometimes with plagioclase), contain inclusions of plagioclase laths, and form graphic intergrowths with plagioclase. There are simple twins of clinopyroxene. Pyroxenes in the groundmass have more ferruginous compositions (En_{54.3–45.8}Wo_{21.9–33.3}Fs_{20.9–23.8}) than phenocrysts.

Plagioclase phenocrysts are of a size up to 0.2 × 1.2 mm and composition An₇₃. Plagioclase of the groundmass of the rock is represented by An_{65–60} (Table 2).

Ore minerals of plagioclase-pyroxene pyritic basalts have significantly higher TiO₂ contents (Table 5) than ore minerals of aphyric and plagioclase pyritic basalts.

An important feature of some plagioclase-pyroxene pyritic basalts (mainly from Site 423) is that they are visibly banded. The bands have widths up to 12 mm and they are of a brown color of varying intensity. Under the microscope, it is obvious that the lighter bands contain essentially more microcrystals of plagioclase and clinopyroxene (usually with subparallel orientation), whereas the darker bands consist mainly of glass. Plagioclase-pyroxene pyritic basalts contain up to 2.1 per cent of vesicles. The average size of vesicles is 0.2 mm, maximum 0.5 mm. The cavities of vesicles are empty, or filled with smectite.

The textural variation of basalts in cores of the holes studied gives several clues about the way diverse cooling units (flow, pillows) formed on the sea floor.

There are three textural sequences of aphyric basalts. The first sequence is represented by aphanitic and very fine grained basalts with glassy margins, minor vesicles, and zones of secondary alterations along fissures. Judging from the grain size, the thickness of these basalt bodies cannot be more than several decimeters. It thus seems that basalts of this type constitute blocks of pillow lavas or thin lava flows (Hole 429).

In the second sequence, glassy and aphanitic rocks change downhole to fine-grained basalts, with first small then large numbers of vesicles. Farther downhole the number of vesicles decreases and the rocks become coarse-grained. At the bottom of the cooling unit the sequence reverses. This asymmetric pattern of basalts with a roof-zone of vesicular rocks is typical of lava flows

TABLE 5
Compositions of Ore Minerals in Basalts of the East Pacific Rise (2–9) and the Philippine Sea Fracture Zones (13–15) (wt. %)

Sample (Interval in cm)/Type of Basalt	SiO ₂	TiO ₂	Al ₂ O ₃	Fe ₂ O ₃	MnO	MgO	CaO	Total
2 Aphyric basalts: 428A-5-4, 40–55 cm	0.74	19.4	3.0	75.4	0.56	0.85	0.21	100.16
3 428A-5-1, 35–45 cm	0.31	18.2	1.3	76.2	0.65	0.65	0.10	97.41
5 422-9-3, 20–30 cm	0.80	21.0	1.9	75.0	0.70	1.70	0.17	101.27
6 422-7-1, 25–35 cm	0.98	22.5	2.4	75.0	0.60	1.00	0.25	102.73
9 Plagioclase-pyroxene pyritic basalt: 421-3-1, 115–128 cm	5.00	27.0	3.0	64.4	0.79	0.29	0.88	101.36
13 Aphyric basalt: 54-9-1 (#8)	0.96	22.7	1.6	76.6	0.77	0.72	0.27	103.62
15 Plagioclase pyritic basalt: 1398/D2-11	1.6	22.9	2.4	70.4	0.51	1.1	0.24	99.15
	1.2	19.6	2.3	75.2	0.49	0.56	0.25	99.90

and sheets, which are evidently exposed in Holes 428 and 428A.

In the third type of sequence, one can see fairly well crystallized massive rocks intercalated with finer grained basalts with vesicles. The symmetric decrease of the degree of crystallization up and down the center of the body is characteristic of stratiform intrusive bodies (sills). It is possible that basaltic sills were drilled in Hole 422, but judging by the small number of vesicles in these rocks, they could also constitute thick basalt flows, extruded at depths of several kilometers where the pressure of the water column prevented volatile fractionation from the melt. Solidification took place under conditions similar to hypabyssal environments of crystallization of sills associated with trap basalts of continental platforms.

Judging by their very poor state of crystallization, both glassy varieties with trachytic banded texture and asymmetrically crystallized basaltic bodies with vesicular roof-zones (both mainly plagioclase-pyroxene phyric basalts) occur in the form of thin flows. The higher (10–15%) content of vesicles in plagioclase-pyroxene phyric basalts, in comparison with aphyric and plagioclase-phyric basalts, and especially the presence in these rocks of tubular vesicles (Holes 420, 421, and 423) which indicates jet degassing of lava, are evidence of plagioclase-pyroxene phyric basalt extrusion at shallow depths or with a higher volatile content in the melt.

These comparisons show that aphyric and plagioclase-pyroxene phyric basalts occur on the East Pacific Rise, whereas aphyric and plagioclase phyric basalts occur in the spreading zones of marginal seas.

GEOCHEMISTRY OF BASALTS

Geochemical data are of primary importance for determining the characteristics of poorly crystallized basalts of different types which cannot be distinguished petrographically or in hand samples. To elucidate the specific features of the basalts from the different oceanic spreading centers under consideration here, available chemical analyses of basalts from the East Pacific Rise and the Philippine Sea fracture zones are listed together with average analyses of basalts from analogous structures as well as other types of oceanic tholeiitic basalt in Table 6.

The direct comparison of chemical analyses is not, as a rule, very illustrative. In practice, different systems of recalculation, various coefficients, and a number of variation diagrams are conventionally employed. The alkali-silica diagram of Macdonald and Katsura (1964) is here used to show that all rocks analyzed are distributed in the field of tholeiitic basalts (Figure 3). It has also been shown that tholeiitic basalts of mid-oceanic ridges have typical values of $K/Rb = 700\text{--}170$ (Carmichael et al., 1974), $Ba/Sr < 0.20$ (Engel et al., 1965), and $K_2O/(Na_2O + K_2O) < 0.10$ (Peterman et al., 1971). Table 7 shows these ratios calculated for average analyses of tholeiitic basalts in the different structural settings (e.g., East Pacific Rise and Philippine Sea fracture zone). The plagioclase phyric basalts of the Philippine Sea fracture zones are the nearest analogue of average

tholeiitic basalts of mid-oceanic ridges in terms of K/Rb . However, aphyric basalts of the East Pacific Rise have a generally lower value of this ratio (Table 7). The value Ba/Sr for East Pacific Rise rocks is higher than the average ratio calculated for mid-oceanic ridges, and in aphyric basalts it reaches values typical of alkali basalts. Using the ratio $K_2O/(Na_2O + K_2O)$, aphyric basalts of the East Pacific Rise are the nearest analog of the rocks of mid-oceanic ridges and fracture zones, but plagioclase phyric basalts of the Philippine Sea deviate considerably from average values and exceed values typical of island-arc basalts (Table 7, Figure 4). Use of these ratios therefore gives contrary indications of the structural settings of these groups of basalts. Because Na_2O , K_2O , MgO , CaO , K , Rb , and Ba are highly mobile during alteration (Hart, 1970), use of these elements or oxides by themselves or as ratios can be misleading, and is possibly the explanation for these conflicting indications of setting. If we use less mobile elements and their ratios (TiO_2/Al_2O_3 on Figure 5 and SiO_2/TiO_2 on Figure 6), however, mid-oceanic ridge tholeiites and basalts of other oceanic spreading structures can be clearly distinguished from tholeiitic basalts of oceanic islands and island arcs. These diagrams show that aphyric and plagioclase phyric basalts of the East Pacific Rise and Philippine Sea fracture zones, as well as average basalts of other mid-oceanic ridges and rift zones, constitute a rather compact group, one which is clearly separated from points on the figures representing tholeiitic basalts of oceanic islands and island arcs.

Furthermore, on Figures 5 (Al_2O_3 versus TiO_2) and 6 (SiO_2 versus TiO_2) one can see the separate fields for plagioclase-pyroxene phyric basalts which, as mentioned above, differ petrographically from other rocks of the East Pacific Rise and the Philippine Sea. Plagioclase-pyroxene phyric basalts also differ from other basalts of the regions studied by their high contents of V_2O_5 and TiO_2 and their lower contents of MgO . On Figures 5 and 6, these rocks plot in the field of tholeiitic basalts of oceanic islands and therefore probably share a similar evolution.

Even though the chemistry of aphyric and plagioclase phyric basalts is very similar, there are nevertheless certain chemical features specific to each rock type. For example, plagioclase phyric basalts of the Philippine Sea fracture zones are notable for their higher content of Al_2O_3 , higher SiO_2/TiO_2 ratios, lower contents of TiO_2 and V_2O_5 , and lower TiO_2/Al_2O_3 ratios as compared with aphyric basalts of the East Pacific Rise.

CONCLUSIONS

This petrological and geochemical comparison of tholeiitic basalts of the East Pacific Rise near 9°N and Philippine Sea fracture zones indicates that aphyric and plagioclase phyric basalts with ratios of $TiO_2/Al_2O_3 = 0.06\text{--}0.14$ and $SiO_2/TiO_2 = 27\text{--}44$ are exclusively associated with oceanic spreading structures (mid-oceanic ridges and fracture zones). Some basalts with higher values of TiO_2/Al_2O_3 and lower SiO_2/Al_2O_3 also occur on the East Pacific Rise and in these respects resemble tholeiitic basalts of some oceanic islands. Tholeiitic

TABLE 6
Compositions of Tholeiitic Basalts from Different Structural Ocean Zones (wt. %)

Major Elements	East Pacific Rise												Philippine Sea			Average Compositions of Basalts from Different Structural Ocean Zones									
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23		
SiO ₂	49.97	51.53	49.41	49.96	48.94	49.59	49.90	50.00	50.73	48.50	50.00	49.81	46.73	44.78	48.97	50.25	49.78	48.59	50.00	47.50	49.8	49.4	51.1		
TiO ₂	1.88	1.70	1.74	1.66	1.60	1.67	1.71	2.27	2.75	2.20	2.54	2.44	1.13	1.02	1.41	1.56	1.29	1.31	1.30	1.58	1.5	2.5	0.83		
Al ₂ O ₃	13.39	15.36	15.27	14.45	15.70	14.39	14.76	13.50	13.90	13.20	13.80	13.60	17.21	16.67	16.06	16.09	16.92	14.58	15.33	13.46	16.0	13.9	16.1		
Fe ₂ O ₃	2.59	2.03	2.95	5.65	1.89	2.52	2.94	3.54	4.63	2.45	5.50	4.03	5.42	1.69	5.30	2.72	1.94	4.67	1.38	5.31	10.0	12.4	11.8		
FeO	8.14	6.60	6.69	5.31	6.91	7.06	6.78	8.43	5.94	10.84	6.86	8.02	4.01	9.60	5.72	7.20	7.32	6.33	9.30	6.55	—	—	—		
MnO	0.22	0.18	0.15	0.16	0.20	0.22	0.19	0.27	0.17	0.37	0.26	0.27	0.15	0.31	0.17	0.19	0.16	0.17	0.13	0.24	—	—	—		
MgO	7.91	6.51	8.08	5.63	8.79	7.98	7.48	6.51	6.11	7.42	6.15	6.55	7.68	11.12	6.10	7.02	8.18	7.02	8.0	6.87	7.5	8.4	5.1		
CaO	11.90	11.92	11.49	11.58	11.87	12.80	11.93	10.67	11.15	10.67	10.16	10.66	12.12	9.74	11.15	11.81	11.34	12.17	11.6	11.28	11.2	10.3	10.8		
Na ₂ O	2.70	2.57	2.77	2.66	2.73	2.63	2.68	2.63	2.78	2.53	2.79	2.68	2.70	1.42	2.50	2.81	2.77	2.55	2.53	2.61	2.75	2.13	1.96		
K ₂ O	0.10	0.12	0.12	0.48	0.19	0.15	0.19	0.37	0.47	0.34	0.31	0.37	0.24	0.19	0.34	0.20	0.16	0.15	0.04	0.13	0.14	0.38	0.40		
H ₂ O ⁻	0.39	0.17	0.37	0.50	0.21	0.15	0.30	—	0.44	0.50	—	0.24	0.61	—	0.95	—	—	—	0.29	—	—	—	—		
H ₂ O ⁺	0.55	0.52	0.80	0.84	0.53	0.57	0.63	1.20	0.74	0.58	1.42	0.98	1.47	2.92	0.68	—	—	2.10	—	3.00	—	—	—		
P ₂ O ₅	0.14	0.12	0.14	0.14	0.16	0.13	0.14	0.16	0.20	0.19	0.20	0.19	0.10	0.10	0.21	—	—	—	0.58	—	—	—	—		
CO ₂	0.27	0.26	0.20	0.24	—	—	0.16	—	—	—	—	—	0.53	0.14	0.24	0.15	0.14	—	0.13	0.65	—	—	—		
S	0.09	0.10	0.08	0.15	0.08	0.06	0.09	0.04	0.03	0.12	0.06	0.06	0.04	0.11	0.02	—	—	—	0.04	—	—	—	—		
Cr ₂ O ₃	0.03	0.13	0.06	0.08	0.06	0.04	0.07	0.03	0.04	0.03	0.02	0.03	0.08	0.08	0.04	—	—	—	—	—	—	—	—		
V ₂ O ₅	0.11	0.06	0.06	0.06	0.05	0.07	0.07	0.09	0.08	0.09	0.07	0.08	0.04	0.05	0.03	—	—	—	—	—	0.03	0.025	0.005		
BaO	0.015	0.011	0.012	0.011	0.011	0.006	0.011	0.021	0.011	0.023	0.023	0.02	0.011	0.002	0.01	—	—	—	—	—	—	—	—		
SrO	0.014	0.016	0.015	0.015	0.021	0.017	0.016	0.014	0.016	0.018	0.014	0.016	0.020	0.009	0.04	—	—	—	—	—	0.001	0.01	0.005		
Total	100.41	99.91	100.41	99.58	99.94	100.05	100.05	99.75	100.19	100.07	100.18	100.05	100.29	99.95	99.94	100.0	100.0	99.64	100.65	99.18	98.9	99.48	98.12		

Notes:

Aphyric basalts:

- 1 = Sample 429-3-1, 107–115 cm.
- 2 = Sample 428A-5-4, 40–55 cm.
- 3 = Sample 428A-5-1, 35–45 cm.
- 4 = Sample 428A-5-1, 5–10 cm.
- 5 = Sample 422-9-3, 20–30 cm.
- 6 = Sample 422-7-1, 25–35 cm.
- 7 = Average of six analyses.

Plagioclase-pyroxene phyric basalts:

- 8 = Sample 420-14-1, 55–60 cm.
- 9 = Sample 421-3-1, 115–128 cm.
- 10 = Sample 422-10-1, 20–27 cm.
- 11 = Sample 423-6-1, 10–15 cm.
- 12 = Average of four analyses.

Aphyric basalt:

- 13 = Sample 54-9-1 (#8).

Plagioclase phyric basalts:

- 14 = Sample 293-18-1, 134–143 cm.
- 15 = Sample 1398.
- 16 = Average of six analyses of EPR basalts (Engel et al., 1965).
- 17 = Average of seven analyses of Mid-Atlantic Ridge basalts (Engel et al., 1965).
- 18 = Average of 12 analyses of Mid-Indian Ridge basalts (Fischer, Bunce, et al., 1974; Simpson, Schlich, et al., 1974).
- 19 = Average of four analyses of Red Sea basalts (Whitmarsh, Weser, et al., 1974).
- 20 = Average of seven analyses of Gulf of Aden basalts (Fischer, Bunce, et al., 1974).
- 21 = Basalt of Mid-ocean ridge (Condie, 1976).
- 22 = Basalt of Oceanic islands (Condie, 1976).
- 23 = Basalt of island arcs (Condie, 1976).

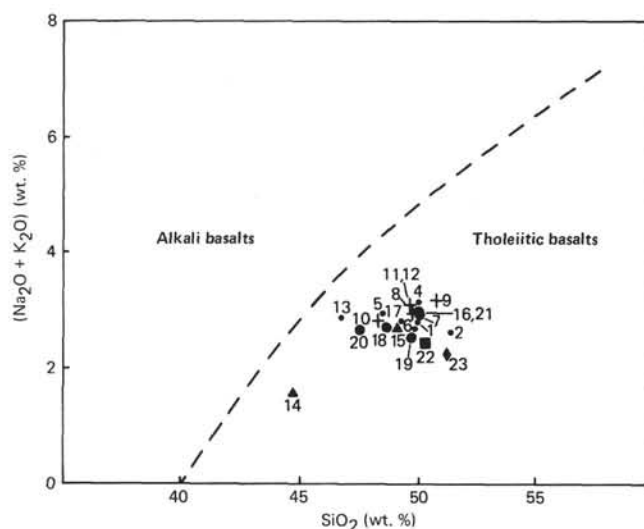


Figure 3. Variation diagram for SiO_2 versus $(\text{Na}_2\text{O} + \text{K}_2\text{O})$. Data points plotted are identified numerically according to the sample identification listing of Table 7. Legend: 1 = Aphyric basalts; 2 = Plagioclase - aphyric basalts; 3 = Plagioclase - pyroxene aphyric basalts; 4 = Average basalt of mid-ocean ridges and rift zones; 5 = Average basalt of oceanic islands; and 6 = Average basalt of island arcs. Curved dashed line is boundary between alkalic (above) and tholeiitic basalts (below) of Macdonald and Katsura (1964).

basalts of island arcs, however, typically have lower values of $\text{TiO}_2/\text{Al}_2\text{O}_3$ (lower even than most ocean-ridge aphyric and plagioclase aphyric basalts) but higher $\text{SiO}_2/\text{TiO}_2$, exceeding that in ocean-ridge basalts.

ACKNOWLEDGMENTS

Chemical analyses presented in this paper were carried out by Y. V. Dolinina, E. M. Naktinas, and M. Zilgalve. Determinations of separate components were done by S. I. Vronskaya, S. A. Gorbacheva, V. M. Zharova, L. F. Kartasheva, T. N. Kolobaeva, A. N. Merzljakova, E. I. Tichomirova, and E. P. Orlova. The chemical composition of rock-forming minerals was studied using an electron microprobe by G. N. Muravizkaja.

REFERENCES

Baksi, A. K., and Watkins, N. D., 1973. Volcanic production rates: comparison of oceanic ridges, islands and the Columbia Plateau basalts. *Science*, v. 180, p. 4085.

- Bogdanov, N. A., 1977. Ofioliti kontinentov i dna okeanov. *Geotectonica*, v. 1, p. 126-128.
- Bonatti, E., and Fisher, D. E., 1971. Oceanic basalts: chemistry versus distance from oceanic ridges. *Earth Planet. Sci. Lett.*, v. 11, p. 4.
- Carmichael, I. S. E., Turner, F. J., and Verhoogen, J., 1974. *Igneous Petrography*: New York (McGraw-Hill).
- Condie, K. C., 1976. *Plate Tectonics and Crustal Evolution*: New York (Pergamon International Library of Science, Technology, Engineering and Social Studies).
- Dmitriev, Y. I., Barsukov, V. L., and Udinzhev, G. B., 1970. Riftovye zoni okeana i problemi ruboobrazovania. *Geochemie*, v. 8, p. 935-943.
- Dmitriev, Y. I., Bokatikov, O. A., and Arakeljan, M. M., 1977. Vozrast basaltov glubokovodnykh zhelobov sapadnoi chasti Tichogo okeana. Tezisi dokladov k XX ubileinoi sessii komissii po opredeleniu absolutnogo vozrasta geologicheskikh formazii, Irkutsk, p. 60-61.
- Engel, A. E. J., Engel, C. G., Havens, R. G., 1976. Chemical characteristics of oceanic basalts and the upper mantle. *Bull. Geol. Am.*, v. 76, p. 719.
- Fischer, A. E., Heezen, B. C., et al., 1971. *Initial Reports of the Deep Sea Drilling Project*, v. 6: Washington (U.S. Govt. Printing Office).
- Fischer, R. L., Bunce, E. T., et al., 1974. *Initial Reports of the Deep Sea Drilling Project*, v. 24: Washington (U.S. Government Printing Office).
- Frolova, T. I., and Gushin, A. B., 1977. Basalti okeanov i ostrovnich dug, sravnitelnye karakteristiki i uslovia generazii. Tezisi 1-go sjezda sovetskikh okeanologov, vip. 3, Geologia morei i okeanov, Nauka, Moscow, p. 70-71.
- Gorodniskii, A. M., and Sorochin, O. G., 1977. Magmatizm okeanicheskikh plit i proischozhdenie podvodnykh gor i ostrovov. Vulkanizm i geodinamika, Nauka, Moscow, p. 29.
- Gorshkov, G. S., 1974. Problemi sovremennoi vulkanologii, v. kn. "Evoluzia vulkanizma v istorii zemli." Tr. 1-go Vsesoyuznogo paleovulkanologicheskogo simpoziuma, Moscow, p. 10-11.
- Grachev, A. F., 1977. Riftovye zoni Zemli. Nauka, M.
- Hart, R. A., 1970. Chemical exchange between sea water and deep ocean basalts. *Earth Planet. Sci. Lett.*, v. 9, p. 269-279.
- Karig, D. E., 1971. Structural history of the Mariana Island Arc system. *Geol. Soc. Am. Bull.*, v. 82, p. 2.
- Karig, D. E., Ingle, J. C., Jr., et al., 1975. *Initial Reports of the Deep Sea Drilling Project*, v. 31: Washington (U.S. Government Printing Office).
- Katsumata, M. and Sykes, L. R., 1969. Seismicity and tectonics of the Western Pacific: Izu-Mariana-Caroline and Ryukyu-Taiwan regions. *J. Geophys. Res.*, v. 74, p. 5923-5948.
- LePichon, X., Francheteau, J., and Bonnin, J., 1973. *Plate Tectonics*: New York (Elsevier).

TABLE 7
Geochemical Characteristics of Tholeiitic Basalts from Different Structural Ocean Zones^a

Ratio	East Pacific Rise												Fracture Zones of the Philippine Sea			Average Analyses of Tholeiitic Basalts							
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
K/Rb	—	~615	~580	436	<955	<760	~544	—	787	—	—	—	—	623	1052	—	—	—	—	—	1160	630	660
Ba/Sr	1.07	0.69	0.80	0.73	0.52	0.35	0.69	1.5	0.69	1.28	1.64	1.25	0.55	0.22	0.25	—	—	—	—	—	0.08	0.29	0.22
$\text{K}_2\text{O}/(\text{Na}_2\text{O} + \text{K}_2\text{O})$	0.04	0.05	0.04	0.15	0.07	0.05	0.06	0.12	0.14	0.12	0.10	0.12	0.08	0.12	0.12	0.07	0.05	0.06	0.02	0.05	0.05	0.15	0.17
$\text{TiO}_2/\text{Al}_2\text{O}_3$	0.14	0.11	0.11	0.11	0.10	0.12	0.11	0.17	0.20	0.17	0.18	0.18	0.06	0.06	0.09	0.10	0.08	0.09	0.08	0.12	0.09	0.18	0.05
$\text{SiO}_2/\text{TiO}_2$	26.6	30.3	28.4	30.1	30.1	29.7	29.2	22.0	18.4	22.0	19.7	20.4	41.4	43.9	34.7	32.2	38.6	37.1	38.5	30.1	33.2	19.8	61.6

^aFor legend, see Notes to Table 6.

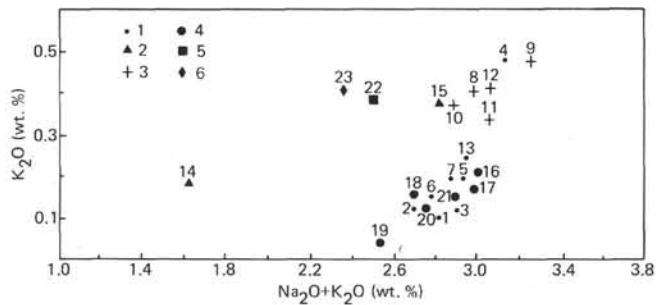


Figure 4. Variation diagram for K_2O versus $(Na_2O + K_2O)$. Everything else as in Figure 3.

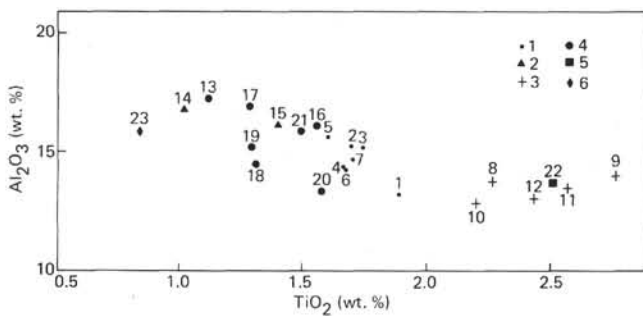


Figure 5. Variation diagram for TiO_2 versus Al_2O_3 . Everything else as in Figure 3.

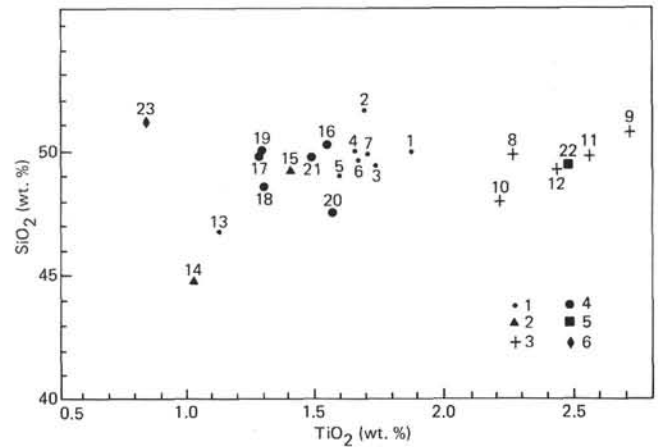


Figure 6. Variation diagram for SiO_2 versus TiO_2 . Everything else as in Figure 3.

- Macdonald, G. A., and Katsura, T., 1964. Chemical composition of Hawaiian lavas. *J. Petrol.*, v. 5, p. 82-133.
- Miyashiro, A., 1975. Classification, characteristics and origin of ophiolites. *J. Geol.*, v. 83 (2), p. 249-281.
- Peterman, K. E., Zell E., and Hedge, C. E., 1971. Related strontium isotopes and chemical variations in oceanic basalts. *Geol. Soc. Am. Bull.*, v. 82 (2), p. 493-500.
- Simpson, E. S. W., Schlich, R., et al., 1974. *Initial Reports of the Deep Sea Drilling Project*, v. 25: Washington (U.S. Government Printing Office).
- Whitmarsh, R. B., Weser, O. E., et al., 1974. *Initial Reports of the Deep Sea Drilling Project*, v. 23: Washington (U.S. Government Printing Office).