

Picrites from the East Pacific Rise

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ABSTRACT

An entire dredge haul (approximately 1 000 kg) of glassy, fresh picrites was retrieved from the Siqueiros Transform Fault, East Pacific Rise, by an expedition from the Scripps Institution of Oceanography. The picrites were divided into three mineralogical and textural groups: 1) those containing only spinel (2%) and olivine (25%) phenocrysts in a glass matrix; 2) those containing spinel (1%) and olivine (20%) phenocrysts in a glass-microlite matrix; and 3) those containing lesser amounts of spinel (<1%) and olivine (15%) phenocrysts in a glass-plagioclase matrix. Olivine phenocrysts range from Fo₈₉ to Fo₈₆ and comprise up to 25% of some samples. Cr-spinels are ubiquitous but do not make up more than 2% of any rock. Orthopyroxenes, a high pressure phase, are scarce but exist in the chemically most primitive samples, those highest in olivine and spinel. Mineral paragenesis in the picrites appears to be spinel → orthopyroxene → olivine → plagioclase. Glasses trapped in several of the progressively appearing phases allowed microprobe analyses of approximate melt compositions at different stages of magmatic evolution. Whole rock and trace element analyses corroborate the suggestion that these samples are the most primitive yet retrieved from the East Pacific Rise. Ni values range from 190 to 245 ppm and MgO concentrations are all above 9.0 wt.%. Comparison with surrounding basalts indicate that the picrites are very similar in composition to the tholeiitic magma proposed by Batiza *et al.* (1977) as the parent for the proximal volcanics. A magmatic origin below the lithosphere is proposed and the transform fault is considered the most likely conduit for ascent of the melt. Pressure release along the fault may account for some of the partial melting. The resulting melt was rapidly removed from the source area but allowed to begin equilibration (including incipient accumulation) with a pressure gradient in a reservoir beneath the East Pacific Rise.

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RÉSUMÉ

Les picrites de la dorsale Est Pacifique

Une drague entière (environ 1 000 kg) de verre picritique frais avait été recueillie de la faille transformante de Siqueiros pendant une expédition océanographique de la Scripps. Les basaltes picritiques sont divisés en trois catégories selon leur minéralogie et leur texture. 1) ceux contenant uniquement des phénocristaux d'olivine (25%) et de spinel (2%) dans une matrice de verre; 2) ceux avec des phénocristaux de spinel (1%) et d'olivine (20%) dans une matrice de verre et de microlites; et 3) ceux ayant moins de phénocristaux d'olivine (15%) et de spinel (<1%) dans leur matrice de verre et de microlite. Ces phénocristaux d'olivine varient entre Fo₈₉ et Fo₈₆ et forment jusqu'à 25% du volume total dans quelques échantillons. Les spinels chromifères sont présents partout mais ne dépassent pas les 2% dans n'importe quel échantillon. Les orthopyroxènes, une phase de pression élevée, sont rares mais se trouvent dans les phases chimiques les plus primitives, ceux avec plus d'olivine et de spinel. La paragenèse des minéraux dans les picrites est la suivante : spinel → orthopyroxène → olivine → plagioclase. Les phases vitreuses incluses dans plusieurs phases minérales ont permis l'analyse d'un liquide ayant subi différents stades d'évolution magmatique. L'analyse des éléments

majeurs et des traces de la roche totale suggèrent que ces roches sont parmi les plus primitives jusqu'à présent trouvées sur la dorsale du Pacifique Est. Les teneurs en Ni varient entre 190 et 245 ppm et les concentrations de MgO sont toutes au-dessus de 9,0 % en poids. Une comparaison entre les picrites et les basaltes des coulées avoisinantes (analysées par Batiza et autres, 1977) suggèrent que les basaltes picritiques ont une composition très voisine de celle d'un magma tholeiitique proposé comme parent pour les roches éruptives avoisinantes. Une origine magmatique au dessous de la lithosphère est proposée et la faille transformante est considérée comme étant le conduit permettant la montée du magma. Une diminution de pression le long de la faille peut donner naissance à une fusion partielle. Le liquide ainsi formé est rapidement dégagé de sa source mais peut s'équilibrer en formant des cumulats, avec un gradient de pression dans un réservoir en dessous de la dorsale Est Pacifique.

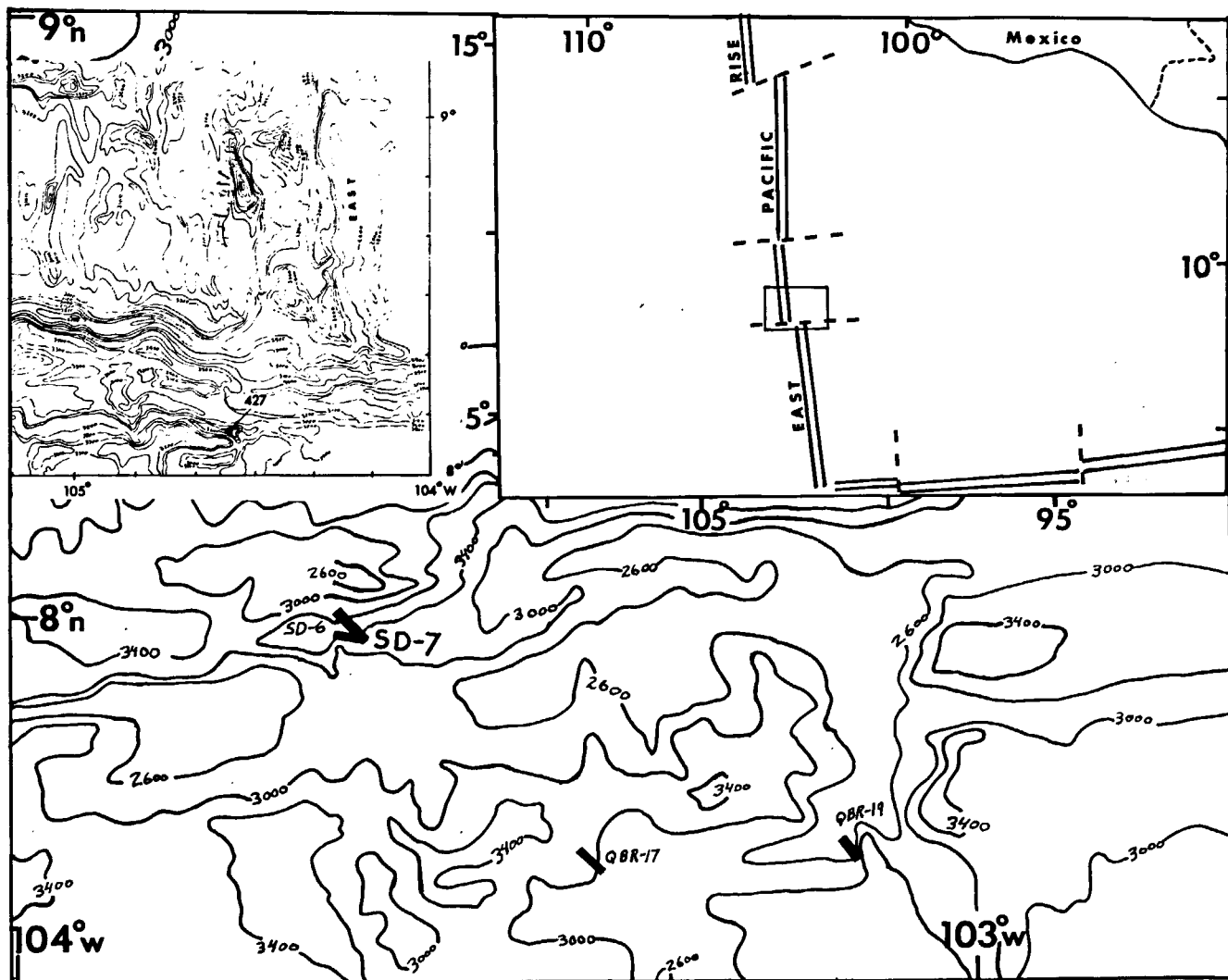
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INTRODUCTION

The Siqueiros Expedition (1974) of the Scripps Institution of Oceanography, comprised a seismic refraction, gravity, and dredging program along the East Pacific Rise and Siqueiros Fracture Zone-Transform Fault. Results of this program have been discussed previously (e. g., Batiza *et al.*, 1977; Orcutt *et al.*, 1975, 1976; Rosendahl, 1976; and Rosendahl *et al.*, 1976) with one major exception, which pertains to a dredge haul of picrites from the Siqueiros Transform Fault. During Leg 54 of the Deep Sea Drilling Project one hole (Site 427) was drilled in the trough created by the

transform system comprising the Siqueiros Fracture Zone. The basic chemical data from these cored basalts are compared with the above mentioned picrites.

Picrites are rare on the sea floor created at mid-ocean ridges and only a few other occurrences are known (e. g., Bougault and Hekinian, 1974; DSDP 45, DSDP 37, DSDP 26). These rocks are not, however, merely curiosities, for it has long been hypothesized that the relatively unfractionated picrites reflect melt compositions from which tholeiitic basalts are derived. In this paper the petrology and chemistry of the Siqueiros picrites is presented and related to magmatic processes at trailing plate edges.



It is hoped that this study as well as previous work by Rosendahl (1976) and Rosendahl *et al.* (1976) will aid marine basalt petrologists/geochemists, paleomagnetic specialists, and marine geophysicists in devising workable models for magma genesis at fast-spreading rise crests.

BACKGROUND

Earlier work in the Siqueiros area has demonstrated that the East Pacific Rise here is underlain by a low-velocity zone that has been postulated as representing a shallow reservoir for tholeiitic liquids generated deeper in the asthenosphere (e. g., Orcutt *et al.*, 1975; Rosendahl *et al.*, 1976). As noted by Rosendahl (1976), the presence of such a reservoir complicates the theoretical extrapolation from tholeiitic chemistry to parental composition because the reservoir would serve as a staging area for a tholeiitic melt prior to its eruption onto the sea floor. Thus, the composition of tholeiitic lavas issued from such a magma chamber cannot be viewed as a simple function of the source parameters (e. g., parental composition, degree and depth of partial melting) upon which are superimposed fractionation and contamination occurring during an uninterrupted ascent to the sea floor. The petrologic and chemical imprints imparted to a liquid during its residence in the reservoir must also be considered (cf. Rosendahl, 1976). In the Siqueiros area it appears that such imprints do modify original basalt chemistries and, among other things, result in more evolved lavas in comparison to Mid-Atlantic Ridge tholeiites. The Siqueiros picrites are informative because they are the product of a melt that apparently was not subjected to a substantial degree of low pressure fractionation during residence in the axial reservoir. Thus, secondary imprints on primary chemistry are few.

LOCATION AND MACROSCOPIC DESCRIPTIONS

The Siqueiros picrites were found in dredge SD-7, located within the presently active decoupling zone of the Siqueiros Transform Fault. DSDP Site 427 is located west of SD-7, within the trough of the trans-

form (Fig. 1). In all probability the picrite samples were taken from the lower flank of the small ridge that marks the transition between normal spreading fabric, to the North, and the transform fault to the South. The dredge-haul (~ 1 000 kg) consists entirely of fresh picritic basalt, in the form of blocky "pie-shaped" pieces of pillows or curved slabs with glass selvages. Picritic basalts were not recovered in any of the other Siqueiros dredge hauls (see Batiza *et al.*, 1977) including SD-6, which was located very near to SD-7.

The most spectacular picrites are finger- to fist-sized "squeeze-outs" apparently produced as protusions from an advancing front of lava, consisting of concentricallly-jointed black glass embedded with large crystals of pristine olivine. In some of these squeeze-outs olivine crystals make up 20-30% of the sample and individual crystals approach 5 mm in diameter. Because both values are considerably higher than those observed in the rest of the dredge haul, it is concluded that large olivine crystals are preferentially concentrated in the squeeze-outs. The mechanism for this olivine concentration may involve flow differentiation in the toes of advancing pillow lavas, which are enriched in olivine near their bases by simple gravity settling. Similar "squeeze-outs" or "basalt fingers" were observed in the FAMOUS area of the Mid-Atlantic Ridge during submersible dives (Hekinian, pers. comm., 1977).

PETROGRAPHY AND MINERALOGY OF SIQUEIROS PICRITES

The picrites can be divided into three distinct groups on the basis of microscopically determined mineralogy and texture: 1) those containing only spinel and olivine phenocrysts in a glassy matrix (SD-7A); 2) those containing only olivine and spinel phenocrysts in a glass-microlite matrix (SD-7B); and 3) those containing olivine and plagioclase phenocrysts in a 50-50 glass-plagioclase matrix. A few small orthopyroxene crystals (approximately 5 μ m long) are present in the SD-7A samples but are not used as a basis for sample subdivision. The samples fall into groups 1) and 2) of Batiza *et al.* (1977). A condensation of the optical mineralogical data is presented in Table 1.

Table 1
Petrographic data from representative samples of the Siqueiros Picrites.

Sample group	Mineral phases	Abundance	Texture	Remarks
SD-7A	Olivine Spinel Orthopyroxene	25% 2% $\leq 1\%$	Hyalopilitic to Holohyaline	All crystals are euhedral.
SD-7B	Olivine Spinel Plagioclase (5 α) Microlites (<5 α)	20% 1% $\leq 1\%$ 3-6%	Hyalopilitic	All olivines and spinels are euhedral. Plagioclase is very rare, small, and skeletal-reticular. One or two equant plagioclase phenocrysts.
SD-7C	Olivine Spinel Plagioclase Titanomagnetite	15% <1% 15% 1-3%	Intersertal	Flow of reticulate plagioclase crystal groups is evident around larger rounded olivines. Individual plagioclase phenocrysts make up about 5% of the rock and are unzoned, with equant to lath-like morphologies.

◀ Figure 1
Location Map for the Siqueiros Fault Zone, for SD-7 dredge, and DSDP Site 427. The inset for location of Site 427 lies to the West of the larger scale map of the Siqueiros Fault Zone where SD-7 is located.

Olivine

Olivine phenocrysts range in size from 0.05 to 2 mm in diameter. The SD-7A and SD-7B olivines are mainly euhedral, whereas the larger (0.5-2 mm) phenocrysts in the SD-7C group are rounded anhedral to subhedral crystals. Smaller olivine crystals in SD-7C, of the same composition as larger phenocrysts, are sharply euhedral and are apparently in equilibrium with the melt. The rounding of larger phenocrysts is, thus, thought to be mechanical. Compositionally, the olivine ranges from Fo₈₉ in SD-7A to Fo₈₆ in SD-7C (Table 2). Olivine phenocrysts in the primitive tholeiites from dredges SD-6 and SD-8 were found to be Fo₈₆ (Batiza *et al.*, 1977). Microprobe analyses indicate that the olivine crystals are compositionally homogeneous; however, many exhibit a wavy extinction. Glass inclusions are common in the SD-7A and SD-7B crystals, but are nearly absent in the olivines of SD-7C.

Evidence for rapid quenching of actively growing adjacent crystal faces is exhibited by some of the smaller olivines which have a pseudodendritic "swallow-tail" structure.

Spinel

Spinel is present in all of the samples examined and are usually included with glass in the larger olivines, but they are most abundant in the SD-7A picrites. Although microprobe analyses were difficult due to the abundant glass inclusions, the average spinel composition appears to be about 43% Al₂O₃, 20% MgO, 25% Cr₂O₃, and 12% FeO* (all expressed as weight percents). Moreover, the compositions of the spinels are relatively constant throughout the entire suite of samples.

Plagioclase

The plagioclase phenocrysts in SD-7B and SD-7C samples are unzoned and range in composition from

An₇₂ to An₇₄ (Table 2). The phenocrysts are predominantly skeletal to subequant laths twinned on the Carlsbad law. A large size range (0.5 to 30 μm in width) exists in the plagioclase crystals, both between and among the sample groups. Microlites in SD-7B are apparently incipient plagioclase laths. Some larger needles of intergrown reticulate arrays of microlites have developed to widths of approximately 5 μm. One such crystal in the SD-7B sample group was analyzed and shown to have a molecular content of An₇₄.

Many of the plagioclase crystals apparently nucleated and grew in a reticulate pattern. The process of crystal development was halted at an early stage in SD-7B basalts and quenching resulted in these geometrical arrays of microlites in a glass matrix. Where portions of the lava proceeded to cool more slowly, typical feldspar laths developed in the same geometrical pattern. Subsequent flowage fragmented the patterns but portions of the array remained intact. These fragments of reticulate crystal groups are similar to the megacrysts of Batiza *et al.* (1977) and Melson and Thompson (1971), but do not have sodic rims or show evidence of resorption. However, the glassy inclusions in the megacrysts do have associated gas bubbles or fluid inclusions as described by Batiza *et al.* (1977).

Orthopyroxene

The orthopyroxenes identified by microprobe analyses, X-ray diffraction, and optical properties (2V ≈ 0) are found only in the SD-7A sample group and occur as a few, small skeletal to euhedral crystals of nearly pigeonite composition ranging from <1 to 5 μm in diameter (Tables 1 and 2). The crystals are untwinned, exhibit parallel extinction, and apparently served as nucleation centers for microlites which typically surround the smaller orthopyroxenes and form "combination grains" floating in a glass matrix. Since the compositions of these microlites is plagioclase, the clusters may represent orthopyroxene analogs to the pyroxene-plagioclase groups described by Batiza *et al.* (1977). The

Table 2

Microprobe major mineral analysis for Siqueiros Picrites.

	Olivine			Plagioclase			Ortho- pyroxene	Cli- no pyroxene
	SD-7A	SD-7B	SD-7C	SD-7B	SD-7C	DSDP Site 427	SD-7A	DSDP Site 427
SiO ₂	40.47	40.21	41.10	50.59	50.93	53.54	53.9	51.34
TiO ₂	00.12	00.19	00.18	—	—	00.07	00.08	00.69
Al ₂ O ₃	0.0	00.14	0.0	30.29	30.63	28.72	1.66	1.67
FeO*	9.41	9.64	10.42	00.58	00.49	00.69	8.69	10.12
MnO	00.55	00.54	00.99	—	—	—	00.20	00.28
MgO	48.67	48.61	47.09	—	—	00.10	31.88	16.74
CaO	00.44	00.54	00.34	14.47	14.71	12.51	3.19	19.09
Na ₂ O	00.23	00.22	00.24	2.83	3.14	4.42	—	00.25
K ₂ O	—	—	—	00.10	00.10	00.10	—	—
NiO	00.29	00.36	00.31	—	—	—	00.22	00.11
TOTAL	100.18	100.28	100.66	99.10	100.01	100.15	99.82	100.29
	Fo ₈₉	Fo ₈₈	Fo ₈₆	An ₇₄	An ₇₂	An ₆₂	Ca ₇ Mg ₇₃ Fe ₂₀	Ca ₄₂ Mg ₃₆ Fe ₂₂

Tabulated data in weight percent.
*All Fe calculated as FeO.

orthopyroxenes have neither the type of zoning described by Bence *et al.* (1975) for clinopyroxenes nor the hour-glass zoning reported by Bryan (1974).

Although orthopyroxenes are volumetrically minor, their presence may indicate elevated pressure during the period of their nucleation and initial growth (Green, Ringwood, 1967). These pressures (>9 kb) are much greater than those thought to exist in shallow magma reservoirs below the East Pacific Rise.

Groundmass

The nondevitrified groundmass in all samples is exceptionally clean. Powdery dusts of opaques are present, but the primary submicroscopic materials are incipient microlites. A few 2-4 μm titanomagnetites (Tables 1 and 2) have grown between some plagioclase laths, but do not comprise more than 3.5% of any sample. The main observable feature in the groundmass is devitrification. All stages of devitrification are present, from pherulites to incipient devitrification centers.

PETROGRAPHY AND MINERALOGY OF DSDP SITE 427 BASALTS

At DSDP Site 427, Leg 54, 28.5 m of basement were penetrated (DSDP, Leg 54 Staff, 1977). The core samples studied by the authors are remarkably uniform in megascopic and microscopic appearance and probably represent a single cooling unit. It is also apparent from shipboard seismic that this basalt was the top of a crystallized ponded flow (DSDP, Leg 54 Staff, 1977). The general microscopic appearance of the studied samples is one of a medium-grained, very sparsely plagioclase phyric basalt.

Plagioclase, $\sim \text{An}_{62}$ (Table 2) exists as an intimate intergrowth with clinopyroxene in the matrix and as subhedral, lathy phenocrysts. The phenocrysts comprise less than 2% of the studied samples. Plagioclase of the same composition comprises about 55% of the rock in the form of a matrix intergrowth with clinopyroxene. The plagioclase from DSDP Site 427 are substantially lower in CaO content and higher in Na_2O than the same phase in the Siqueiros picrites. The composition of these plagioclase phenocrysts more closely approximates those reported by Batiza *et al.* (1977) as occurring near the SD-7 dredge at Site SD-6, sample 3.

Clinopyroxene

Comprising about 32% of the DSDP Site 427 basalt, clinopyroxenes occur mainly as a matrix phase. Some phenocrysts of clinopyroxene exist as subhedral glomerocrysts with plagioclase. The clinopyroxenes approximate those of SD-6, # 3 except in the Al_2O_3 and CaO contents. CaO comprises only 16.33 wt.% in the SD-6 samples (Batiza *et al.*, 1977), and exists in levels above 19.0 wt.% in the DSDP Site 427 samples (Table 2).

Al_2O_3 has an inverse relationship with CaO when compared between these sample suites.

Groundmass

The upper 10 cm of the DSDP Site 427 basalt consists of a chilled surface composed of 72 vol.% of glass. The interior of the flow is almost entirely crystallized with only 3 vol.% of glass. Up to 7% of each sample may consist of Ti-magnetites interstitial to the silicate phenocrysts except in the chill zone where opaques are too finegrained to microscopically count.

MINERAL PARAGENESIS AND DEVELOPMENT OF CRYSTAL TEXTURES IN THE SIQUEIROS PICRITES

The crystallization sequence of the major minerals has been established in thin section studies from textural relationships. Spinels were the first to crystallize as indicated by their inclusion in the euhedral and skeletal olivine crystals. The spinels may have afforded crystal nucleation sites for the olivines. Olivine and spinel are enclosed in a plagioclase lath matrix in the SD-7C samples; therefore, the plagioclase crystals must have formed last in this sequence. Orthopyroxenes served as nucleation sites for microlites in SD-7A samples, suggesting that the pyroxenes crystallized prior to the growth of plagioclase.

Quench textures of the orthopyroxenes in SD-7A may not be caused by rapid solidification of the melt during extrusion. Since Green and Ringwood (1967) have reported orthopyroxenes to crystallize from tholeiitic magmas only in the high pressure regime (>9 kb), it is possible that the orthopyroxenes in the SD-7A samples were crystallized prior to extrusion on the ocean floor. The maximum pressure of the water column in the Siqueiros area is no more than 0.7 kb. The dendritic textures and subskeletal-morphologies could have developed when the original magma was removed from the high pressure environment and, thus, the orthopyroxene crystallization suddenly ceased. This textural interpretation requires a rapid accumulation and expulsion of the magma from its shallow, axial reservoir. The CaO content of the orthopyroxenes prevents use of the orthoenstatite geobarometer suggested by Macgregor (1974). However, the olivine-spinel-orthopyroxene assemblage recognized in the SD-7 samples is similar to the spinel peridotite he proposes to be in equilibrium along the oceanic geotherm.

Textural observations support the suggestion that the SD-7A basalts represent mostly vitreous submarine flows, quickly frozen and halted in their process of chemical differentiation. The SD-7B samples contain more microlites in the matrix and few olivines, while SD-7C basalts are dominated by the plagioclase matrix which may have matured, due to extra cooling time, from reticulate arrays similar to those found in the

Table 3
Whole rock chemical analyses major oxides in wt.% (XRF).

	SD-7A	SD-7B	SD-7C	DSDP 427 # 10-4, 127-129
SiO ₂	48.19	47.78	47.74	49.64
TiO ₂	00.83	00.86	01.68	02.35
Al ₂ O ₃	14.12	14.50	14.83	14.01
Fe ₂ O ₃	00.95	00.93	01.07	01.82
FeO	08.37	08.24	09.46	11.70
MnO	00.14	00.14	00.16	00.21
MgO	15.23	13.27	11.29	06.91
CaO	10.19	10.64	12.13	10.29
Na ₂ O	01.41	02.19	02.06	02.98
K ₂ O	00.02	00.06	00.14	00.21
P ₂ O ₅	00.14	00.13	00.15	00.23
LOI (H ₂ O)	00.41	00.26	00.16	00.40
TOTAL	100.0	99.0	100.87	100.75
Trace elements in ppm (neutron activation)				
Co	94.0	68.0	57.0	48.0
Cu	130.0	182.0	164.0	90.0
Cr	930.0	870.0	620.0	131.0
Ni	245.0	195.0	190.0	73.0
Pb	2.0	1.7	1.81	2.2
Sr	140.0	125.0	132.0	130.0
V	120.0	185.0	220.0	428.0

microlites of the SD-7B group. This gradation from rapidly cooling flows to more slowly cooling (perhaps more massive) flows can provide a mechanism for a small amount of sea floor differentiation; however, radical variations in mineralogy cannot be explained by this process.

CHEMICAL ANALYSES

Both whole rock chemical analyses (Table 3) and electron microprobe analyses of mineral phases and glasses (Tables 2 and 4) were performed on the samples. The whole rock analyses were obtained by XRF with use of USGS standards. Triplicate analyses were performed and in no case did the averages of these analyses deviate by more than 8% from the mean. The reported electron microprobe analyses are an average of five analyses with less than 5% variation about the mean.

Table 4
Microprobe analyses of SD-7 glass.

	SG*	OG**	MG***
SiO ₂	46.55	49.96	50.93
TiO ₂	00.76	00.87	01.01
Al ₂ O ₃	17.96	19.44	17.27
FeO	06.93	07.43	07.67
MnO	00.24	00.15	00.20
MgO	12.40	06.70	11.03
Cr ₂ O ₃	00.49	00.28	00.25
CaO	14.14	14.96	11.36
Na ₂ O	00.10	00.27	00.36
NiO	00.13	00.04	00.06
TOTAL	99.7	100.1	100.22

All data in weight percent.

*SG, glass included in spinels.

**OG, glass included in olivines.

***MG, matrix glass.

Trace element analyses were obtained by neutron activation from the Nuclear Engineering Laboratory at Virginia Polytechnic Institution and State University.

Siqueiros Picrites

The whole rock data and microprobe analyses of interstitial glasses give credence to the statement by Batiza *et al.* (1977) that the SD-7 samples are the most primitive rocks yet obtained from this part of the East Pacific. Also, the criteria described by Kay *et al.* (1970) and Frey *et al.* (1974) for primitive oceanic tholeiites are easily satisfied by the chemistry of the SD-7 samples. For example, in all samples the MgO weight percent exceeds 9.0 and the Ni content varies between 190 and 245 ppm.

Comparison of SD-7 whole rock chemistries with those from other dredged samples of tholeiite in the Siqueiros area (particularly SD-6) shows a relative enrichment in MgO, Ni, and Cr and depletion in FeO*, V, Na₂O, P₂O₅, and K₂O, more or less along the extrapolations of the fractionation trends observed in dredge SD-6 (Fig. 2). These trends also follow those reported by Kay *et al.* (1970), Melson *et al.* (1968), Shibota and Fox (1975), and Wright (1974) for oceanic tholeiites. Significantly, most of the fractionation trends seen in dredge SD-6 can be produced or at least approximated by simple subtraction of MgO, in the form of olivine, from SD-7 picrites. In fact, the SD-7A sample group appears to have an average composition that is quite similar to the hypothetical melt from which Batiza *et al.* (1977) subtracted 5 wt.% of Fo₉₀ to explain the relatively unfractionated SD-6 and SD-8 tholeiites. Two oxides, Al₂O₃ and CaO, do not lie along the SD-6 fractionation trends, but rather show gradual enrichment with decreasing MgO content (Fig. 2). This represents a reversal in the SD-6 trends and is probably caused by the transition from an olivine-controlled crystallization sequence in the SD-7 samples to plagioclase control in the SD-6 samples. Figure 2 clearly suggests that the SD-7 picrite groups (SD-7A, SD-7B, SD-7C) represent three different stages of fractionation, with SD-7A being the least evolved.

DSDP Site 427, Leg 54

Both whole rock chemistry and individual mineral phase chemistry are constant throughout the core from DSDP Site 427. A typical whole rock analysis is presented in Table 3 and representative analyses of plagioclase and clinopyroxene are shown in Table 2. The constant nature of the chemistry at 427 further supports the thesis that only one flow unit was sampled by drilling.

The whole rock chemistry at Site 427 suggests that this lava flow was genetically related to the majority of Siqueiros samples described by Batiza *et al.* (1977). In Figure 2 it can be seen that values for DSDP Site 427 rocks plot along the extrapolated fractionation trends of the SD-6 basalts. The only significant variation seen in Site 427 trace elements from SD-6 trends is

in Cr content. The lower concentrations of this trace metal at Site 427 may be attributed to the absence of olivine, spinels or other phases which incorporate Cr as a major ion.

Thus, it can be postulated that the SD-7 picrites may be chemically similar to a parental magma that, when further differentiated, gave rise to the basalts ponded at DSDP Site 427.

Analysis of Glassy Phases in the Siqueiros Picrites

Within the SD-7A group three stages of glass development were noticed: 1) glass trapped in spinels (SG), which are believed to be the first minerals to crystallize (cf. Batiza *et al.*, 1977; Yoder, 1976); 2) glass trapped in olivines (OG); and, 3) matrix glass (MG). Because these glass stages offered a unique opportunity to monitor the early evolution of a chemically primitive tholeiitic liquid, each was analyzed with the microprobe (Table 4). The spinel glass is poorest in silica while the olivine glass and matrix glass are progressively more silica-rich. This sequence appears to be directly related to progressive SiO_2 enrichment in the fractionating magma. Al_2O_3 , FeO^* , and MgO concentrations vary according to the host mineral and its ability to buffer the included glass by preferentially incorporating or excluding certain elements from its structure. Thus, Al_2O_3 is depleted in the trapped Al-rich spinel glass and subsequently becomes enriched in the olivine-trapped glass. The crystallization of plagioclase may again deplete the melt in Al, which is reflected in the composition of the matrix glass. Similarly, MgO is depleted in the melt from which olivine is crystallizing, and FeO is lower in the glass included in the high-Fe spinel phase. CaO is relatively constant in the first two glasses, Sg and Og, but is depleted in the melt giving rise to matrix glass. This lowering of CaO content in the melt may reflect the appearance of the plagioclase phase, which crystallized after the olivine. The Ni, Cr, and Ti trends reflect the general differentiation indices suggested by Wright (1974). Both Ni and Cr decrease with time while Ti apparently becomes enriched in the melt.

In general, the chemical changes in magmatic compositions, from initial oxide crystallization to final quenching on the ocean floor, can be followed with these data. SG represents a relatively unfractionated melt somewhat similar in composition to the SD-7A group, while the MG composition more closely approximates the fine-grained tholeiites described by Engel and Engel (1964). Rather than to compare hypothesized fractionation sequences between different samples, it is possible to monitor the same trends within one rock and thus see actual changes in one melt.

IMPLICATIONS TOWARD MAGMATIC EVOLUTION

Of prime interest is the fact that the samples from the SD-7 site are among the most chemically primitive tholeiites yet retrieved from the East Pacific Rise. Their

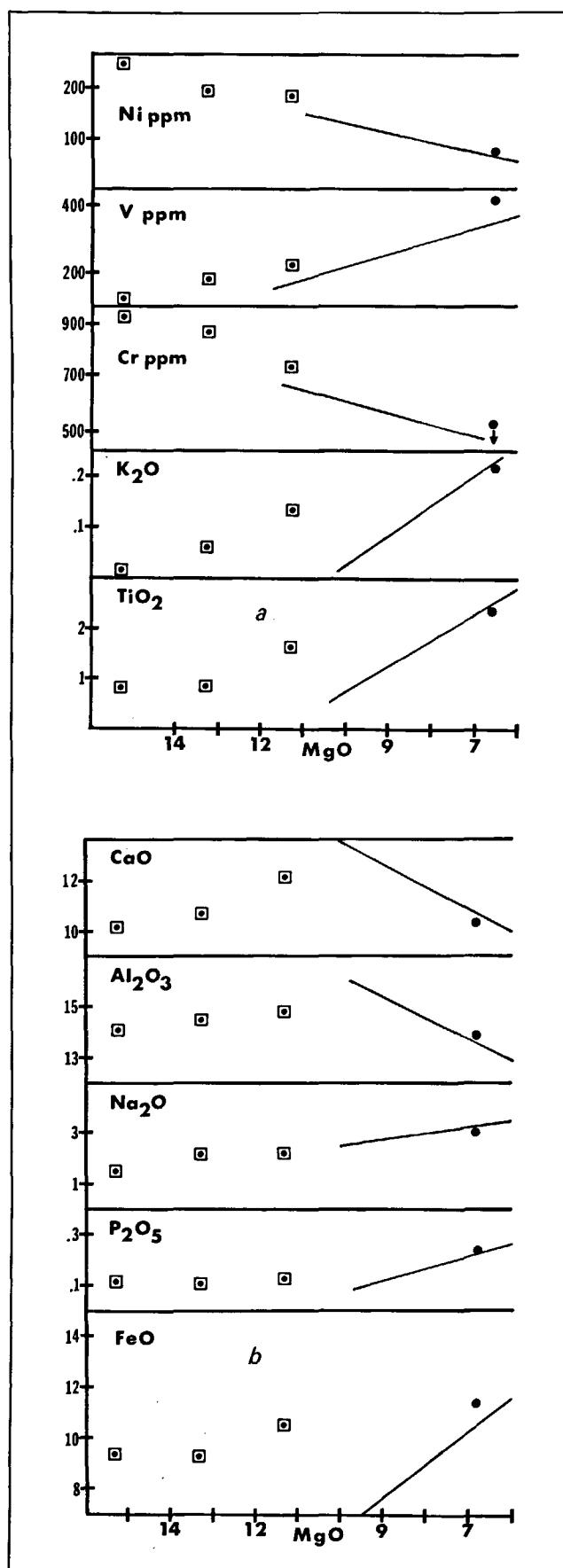


Figure 2
MgO variation diagrams relating Siqueiros picrites, SD-7A, SD-7B, and SD-7C (squares enclosing solid dots); approximate SD-6 (linear) fractionation trends (Batiza *et al.*, 1977); and representative analyses from DSDP 427 (large solid dot). Note: the Cr value for 427 plots below the diagram base and is so indicated by an arrow.

mineralogy, textures, and chemistry are important data in themselves without further interpretation. It is, however, felt that these rocks provide some insight into the modes of magmatic differentiation (crystal fractionation, phenocryst flotation, and gravity settling) along a rapidly accreting plate margin.

The young age of these samples is indicated by their geographical proximity to the East Pacific Rise, a fast spreading center; the freshness of their olivine phenocrysts; and, the lack of primary or secondary palagonite as described by Hekinian and Hoffert (1975).

A great deal of chemical and geologic information indicates a co-magmatic parental source for the SD-7 samples. The general similarity of the chemical characteristics is obvious from the data presented in Table 2. The three sample groups at SD-7 might be considered as representing different stages of crystallization from chemically and genetically related melts. There is a relative increase in the Fe, Na, K, Mn, Sr, Cu, Hf, Ti, and Si contents in the SD-7B and SD-7C samples from the SD-7A values. There is also a simultaneous decrease in the Mg, Co, Cr, Ni, and Rb contents in the SD-7B and SD-7C below their concentrations in the SD-7A basalts. These trends have been cited by Kay *et al.* (1970), Frey *et al.* (1974), and Wright (1974) as differentiation indices for genetically related magmas.

Further evidence to support one original source for these rocks is the consistency of the spinel compositions. These oxides are found in all of the samples in varying amounts and all of the spinels have the same approximate composition (Al_2O_3 , 43 wt.%; MgO , 20 wt.%; Cr_2O_3 , 25 wt.%; FeO^* , 12 wt.%) regardless of the major sample group of the host rock.

In an explanation of the origins for the SD-7 sample groups the primitive nature of the samples and two mineralogic differences, occurrence of orthopyroxene and the relative abundance of olivine, might be considered. A proposed scheme for the development of such a system follows.

The primitive chemistry of all the picrite samples and the obvious elevated pressures at which the orthopyroxene-bearing samples crystallized (Green, Ringwood, 1967) infer that the precursor magma for these samples was rapidly removed from a mantle source, where incipient orthopyroxene crystallization and olivine accumulation had begun, and erupted before significant additional fractionation or chemical differentiation could occur.

Rosendahl *et al.* (1976) have proposed a single magma chamber as underlying the East Pacific Rise north of the Siqueiros region. Their seismic data also indicated possible feldspar flotation near the top of the chamber and possible denser layers towards the base. The actual dimensions of the chamber were not derived.

The higher quantities of olivine and spinel, and the presence of orthopyroxene in the SD-7A samples may be an indication of mineral segregation by gravity settling of denser phases. Thus, the relative abundance of denser minerals in SD-7A samples may represent an incipient cumulate layer forming near the base of some

deep magma reservoir below the transform. The samples of SD-7B and SD-7C are progressively lower in olivine than SD-7A and orthopyroxenes are absent. These mineralogical differences could represent either flotation of the feldspar phase or magmatic differentiation at lower pressures (near the top of the reservoir) than were applied to the magmatic precursor of the SD-7A basalts. If this interpretation is valid then variations within the parental magma were partially governed by differential mineral settling and/or floating or by crystal fractionation in various pressure regions of one deep magma reservoir. Longer periods of residence in the reservoir would allow advanced chemical fractionation, and formation of cumulate bodies and related ore deposits which would be accreted laterally as oceanic layer 3. A diagrammatic model for this interpretation is presented in Figure 3.

Thus, some tholeiitic magmas may be due to partial melting of mantle material intersecting a transform fault zone. Melting may have been induced by pressure release at this juncture. Sequential pressure release could result in orthomagmatic banding at the base of the reservoir. The resulting melt may be rapidly removed from the source area but allowed to equilibrate with the pressure gradient in a deep-seated staging area. Crystallization during residence in the reservoir, during transit, and on the sea floor would account for the chemical variations.

It is recognized that the volumetric proportions of olivine have been increased (over the original proportions) due to accumulation; however, the total effect of that process is indefinable since the olivines are chemically identical.

CONCLUSIONS

The following relationships are apparent:

- 1) The basalts comprising all of the SD-7 samples bear striking resemblance to the primitive tholeiites described in the literature.
- 2) The glass compositions included in early crystallized phases can give significant insight into the nature of the original melt and its subsequent derivatives.

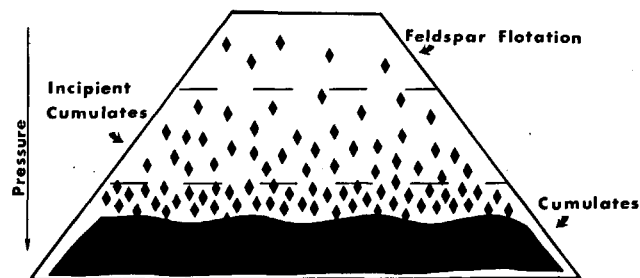


Figure 3

Diagrammatic cross section of a stratified magma chamber possibly underlying an active spreading center, intersected by an active transform fault. Black diamonds represent the related abundances of olivine, Cr-spinels, and other dense phases that respond to gravity by accumulation at the reservoir base. Approximate geometry of the chamber is modified from Rosendahl (1976).

3) The SD-7 basalts represent the most primitive samples yet obtained in the Siqueiros fracture zone and may be genetically related to the more fractionated samples from adjacent dredge sites. Accumulation of olivine may have altered the original magmatic bulk chemistry.

4) An explanation for the variation in mineral assemblages seen in the SD-7 samples is crystal separation due to density differences in a layered magma chamber. Thus, residence time in one magma chamber might influence the chemical composition of resultant lava flows through physical as well as chemical processes.

5) The mantle below the East Pacific Rise, Sequeiros Fracture Zone, gives rise to forsterite-spinel-orthopyroxene magmas during partial melting. These magmas then may fractionate and mature, or they may (more rarely) be rapidly expelled and erupted in the primitive state along fracture zones.

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