PETROLOGY AND GEOCHEMISTRY OF A CESAR BEDROCK SAMPLE: IMPLICATIONS FOR THE ORIGIN OF THE ALPHA RIDGE

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Abstract

During CESAR expedition, 20 similar bedrock samples were dredged from the walls of a major graben of the Alpha Ridge. These rocks are the only bedrock samples ever recovered from the ridge, providing the only direct evidence for its nature, composition and possible origin.

The sample analyzed is a highly altered fragmental volcanic rock which was rimmed with a crust of manganese oxide. Clasts form about 90% of the rock, are up to 1 cm, and are subround to angular. The rock is heterolithic comprising 92% aphyric, 5% clinopyroxene-phyric, and 3% plagioclase-microphyric clasts. Plagioclase microlites display skeletal form. Clasts commonly contain 50 to 60% vesicles up to 4mm in size and spherical to irregular in shape. Some vesicles may be relict spherulites. The skeletal form of plagioclase microlites, lack of abundant relict crystals, and possible relict spherulites suggests volcanic fragments were glassy to very fine grained. The combined textural evidence (quench textures, high vesicularity, fragmental nature and small clast size) suggests that the volcanic fragments were erupted in shallow water during a phreatomagmatic or Plinian-type eruption.

Rare clinopyroxene phenocrysts comprise the only unaltered portion of the rock. The range of compositions of these phenocrysts is Wo_{51-53}, En_{32-37}, Fs_{12-16}, with significant amounts of Ca, Al, and Ti. These compositions are similar to clinopyroxenes of alkali basalts of Hawaii, Fanning Island and the Hess Rise. Geochemical discriminators also suggest a within plate tectonic environment.

Résumé

Au cours de l'expédition CESAR, 20 échantillons de socle rocheux ont été arrachés des parois d'un grand graben de la dorsale Alpha. Il s'agit des seuls échantillons du socle récupérés de la dorsale et donc de la seule source d'indications directes sur la nature, la composition et l'origine probable de cette dernière.

On a procédé à l'analyse d'un échantillon de roche volcanique détritique fortement altérée et entourée d'une croûte d'oxyide de manganèse. Presque 90% de la roche se compose de fragments dont la dimension peut atteindre 1cm et dont la forme varie de subarrondie à angulaire. Il s'agit d'un échantillon de roche hétérolithique composée à 92% de fragments aphyriques, à 5% de clinopyroxène porphyrique et à 3% de fragments de plagioclase microporphyrique. Les microlites plagioclases présentent des formes squelettiques. Les vacuoles constituant souvent 50 à 60% des fragments, mesurent 4mm de diamètre

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et leur forme varie de sphérique à irrégulière. Dans certains cas, il peut s'agir de sphérulites résiduelles. La forme squelettique des microlites plagioclases, l'absence de cristaux résiduels et la présence présumée de sphérulites résiduelles semblent indiquer que la texture des fragments volcaniques variait de vitreuse à très fine. Toutes les indications recueillies (texture de refroidissement, l'abondance des vacuoles, la nature fragmentaire et la petite taille des fragments) semblent indiquer que les fragments volcaniques proviennent d'une éruption de type phréatomagmatique ou phinien au cours de laquelle ils auraient été projetés dans un milieu marin peu profond.

Seule la partie de la roche composée de rares phénocristaux de clinopyroxène ne présente pas de traces d'altération. Les phénocristaux présentent une gamme de compositions, soit Wo_{51-53}, En_{32-37} et Fs_{12-16}, et renferment des quantités importantes de Ca, Al et Ti. Ces compositions s'apparentent à celles des clinopyroxènes provenant des basaltes alcalins d'Hawai, de l'île Fanning et de la crête Hess. Les données géochimiques semblent également indiquer que le développement du milieu tectonique s'est produit à l'intérieur des plaques.

INTRODUCTION

The geology and tectonics of the Arctic has been the subject of much discussion, most recently summarized by Sweeney (1981), Trettin and Balkwill (1979) and Irving and Sweeney (1982). Plate tectonic models for the evolution of mobile belts of Arctic Canada are highly speculative, partly because the history of the Arctic Ocean is not well understood, and plate tectonic theory postulates that the history of mobile belts is determined by the tectonic events of the adjacent ocean basin (Trettin and Balkwill, 1979). An understanding of the tectonics of the Canadian Arctic therefore requires an understanding of the geology of the Arctic Ocean.

The Arctic Ocean is divided into two major basins, the Amerasian Basin and Eurasian Basin, both of which are floored by oceanic crust overlain by as much as 5km of sediment (Mair and Lyons, 1981). The Lomonosov Ridge forms the boundary between these basins. The Nansen-Gakkel Ridge bisects the Eurasian Basin and the Alpha Ridge bisects the Amerasian Basin (Fig. 5.1). The Nansen Ridge is the northern continuation of the Mid-Atlantic Ridge. The Lomonosov Ridge is believed to be a fragment of continental crust of the Barents shelf that was left behind when spreading began on the Nansen Ridge about 63 Ma.

In the Amerasian Basin, however, neither continental outlines nor magnetic anomalies give a clear picture of plate motion. In addition, the nature of the Alpha Ridge is uncertain. It has been interpreted as a Mesozoic and Cenozoic spreading axis (Vogt and Ostenso, 1970; Hall, 1973), a volcanic arc (Herron et al., 1974), a fossil transform fault (Yorath and Norris, 1975) or a continental fragment (King et al., 1966).

This paper gives a preliminary report on the petrography and geochemistry of one of the first bedrock* samples ever recovered from the Alpha Ridge. This sample provides us with our first direct observation of this elusive feature.

*Bedrock refers to the rocks that comprise the irregular topography of the ridge, as opposed to the overlying, subhorizontal sediments.

ACKNOWLEDGEMENTS

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SAMPLING

The dredge which recovered the bedrock sample was lowered on 15 April 1983 at 0540 hours. At this time the ice station began to drift over the southern graben of the northern ridge at 85°51′7.4″N latitude, 110°1′30.5″W longitude. The dredge was retrieved on the same day at 1640 hours at ice station location 85°51′52.9″N, 110°15′20.3″W.

During the time the dredge was on the bottom, the ice station drifted about 4km to the north, travelling across the ridge and dragging the dredge up the face of the southern scarp. Seismic reflection profiles across the scarp show that it is composed of acoustic basement (Fig. 5.2). During dredging there were times when the wire was under tension suggesting that pieces of rock were being broken from outcrops.

The two types of rock fragments recovered during this dredging operation were 1) well rounded dropstones, presumably transported by ice from the continent, and 2) about 20 fragments of deeply weathered mafic volcaniclastic rocks. The latter are partly covered with a black layer of manganese oxide. This layer is not continuous around the surface of the samples further suggesting that they were broken from outcrops (Fig. 5.3).

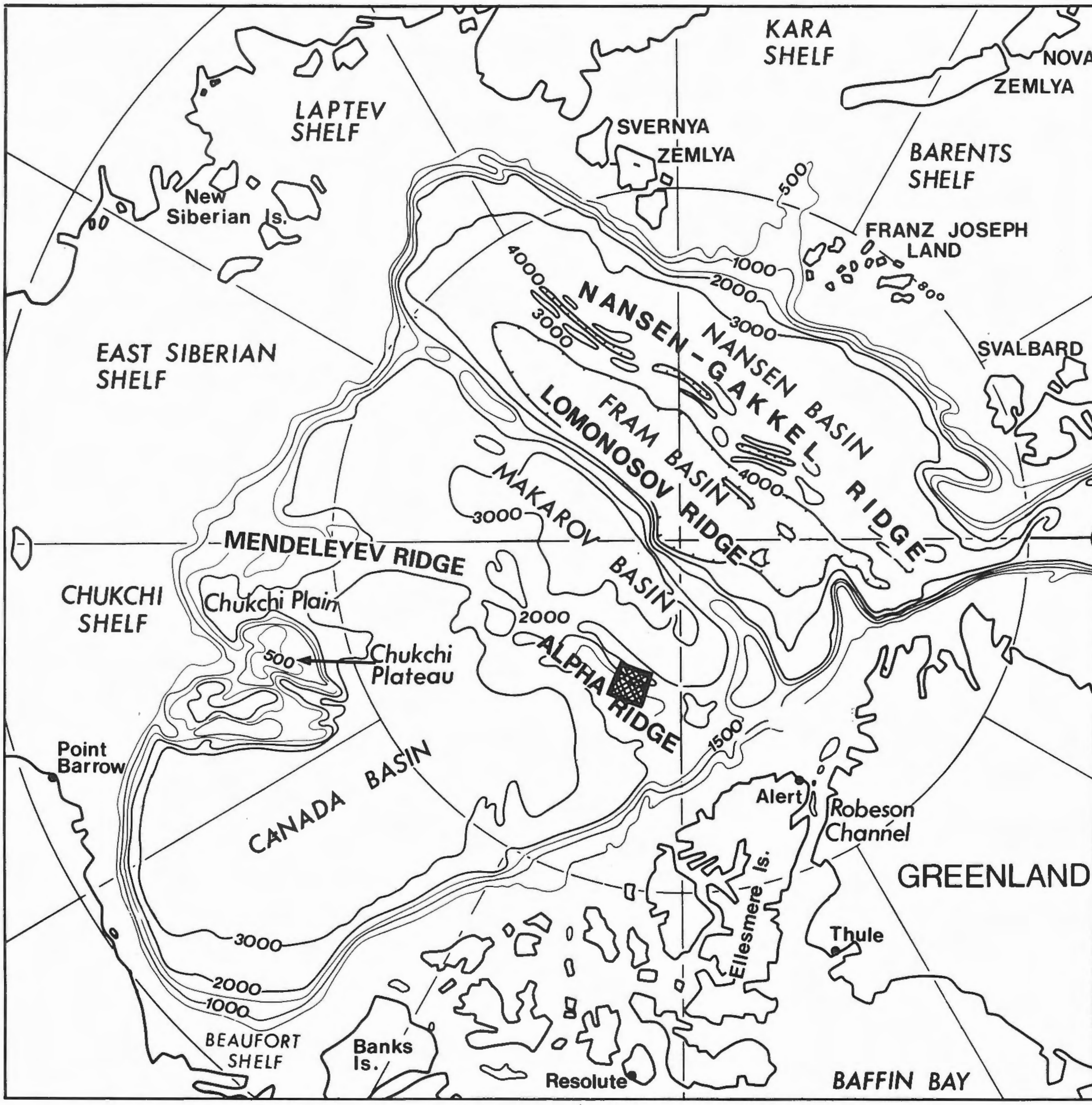


Figure 5.1 Major bathymetric features of the Arctic Ocean, showing the location of the CESAR ice station.

SAMPLE DESCRIPTION

Most of the bedrock samples are archived at the Atlantic Geoscience Centre, Bedford Institute of Oceanography, but pieces of these samples were sent for analysis by the authors and by G.M. LeCheminant at the Geological Survey of Canada in Ottawa. The sample we received is almost completely altered to clays (possibly halloysite and montmorillonite) in a matrix of amorphous material and disordered goethite. It was rimmed by a discontinuous 0.5 to 1cm thick crust of manganese oxides which occur as botryoidal clumps. This outermost crust contains worm tubes which are coated, inside and out, with manganese oxide (LeCheminant, 1983). Although the sample is highly altered, many primary textures and rare primary minerals are preserved and are discussed in this report. For a discussion of secondary minerals see LeCheminant (1983).

The sample is a fragmental volcanic rock (Fig. 5.4). It comprises 85 to 90% clasts which are 0.5 to 1cm in size and angular to subround, although some rounding may be due to alteration. Rare clasts containcurvilinear and vesicle controlled boundaries.

The rock is heterolithic and the three clast types observed are 1) 93% brown to orange-yellow, apparently aphyric clasts; 2) 5% yellow-brown clasts containing up to 30% euhedral to subhedral pyroxene phenocrysts which are 1 to 2mm in size (Fig. 5.5); and 3) 2% dark brown clasts

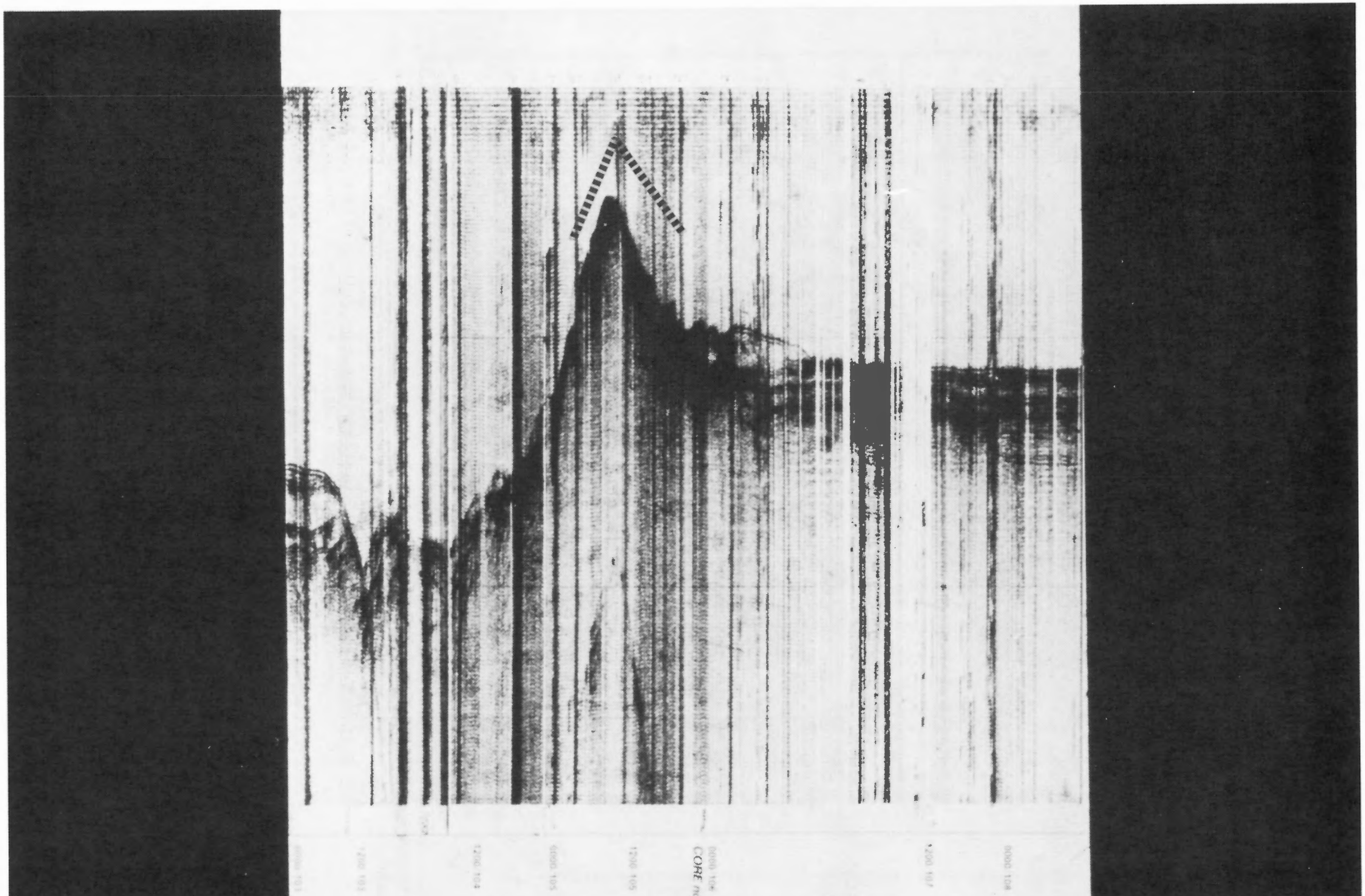


Figure 5.2 Seismic reflection profile showing the location of the dredge which recovered bedrock samples.

containing 3 to 5% pseudomorphs of plagioclase microlites up to 0.2mm in length (Fig. 5.6), which occasionally display skeletal form. Some of these clasts contain rare possible pseudomorphs of olivine. The matrix is now mostly secondary clay minerals.

Most clasts are moderately to highly vesicular or scoriaceous, containing up to 50 or 60% vesicles, but the third clast type tends to be moderately or sparsely vesicular. Vesicles generally are either 0.5 to 1mm in diameter and apparently spherical, or 2 to 4mm in size and irregular in shape. Most fragments contain both types of vesicles (Fig. 5.7). Vesicles are rarely elongate perpendicular to grain boundaries. All vesicles are filled with white to yellow secondary clay minerals which commonly are spherulitic. These may be pseudomorphs of clay minerals and goethite after spherulites but these would be difficult to distinguish from filled vesicles.

The presence of skeletal plagioclase microlites and absence of abundant relict crystals and spherulites(?) suggests the volcanic rock fragments were glassy, hypocrystalline, or cryptocrystalline.

Clinopyroxene phenocrysts

Rare clinopyroxene phenocrysts comprise the only unaltered portion of the rock. Pyroxene compositions from a glomerophyric grain were determined by microprobe at Dalhousie University. Spots of several different grains were analyzed, without regard for the position of the spot with respect to the rim or core of the grains. These spot analyses are shown on Table 5.1, along with a clinopyroxene microprobe analysis done by the Geological Survey of Canada on a different sample from the CESAR bedrock collection. The GSC analysis is significantly higher in Na_2O than the Dalhousie analyses. We do not know the reason for this discrepancy, but it may be a function of the standards used at the different microprobe facilities, chemical zonation of the grains (the GSC analysis apparently represents only one spot), or reflect slightly different chemistry of the different samples. The range of compositions is Wo_{51-53}, En_{32-37}, Fs_{12-16}. These compositions plot above the salite field on the pyroxene quadrilateral (Fig. 5.8) and also contain significant amounts of Ca, Al, and Ti.

Table 5.1 CESAR clinopyroxene chemistry. Samples 1A-1H were analyzed at Dalhousie University. Data for sample GSC is from LeCheminant (1983).

CESAR pyroxene chemistry

Sample CESAR 10

Number	1A	1B	1C	1D	1E	1F	1G	1H	GSC
SiO_2	49.19	49.49	48.18	49.48	45.27	45.77	44.61	48.47	44.19
TiO_2	1.78	1.96	2.16	1.64	2.96	2.81	2.15	2.19	3.16
Al_2O_3	4.68	5.08	6.01	5.54	8.63	8.93	6.05	5.70	8.64
Cr_2O_3	—	0.16	—	0.21	0.09	—	0.07	—	0.26
FeO*	5.96	6.17	5.95	6.24	5.84	7.79	7.14	6.84	7.99
MnO	—	—	—	0.07	—	0.06	—	—	0.08
MgO	14.12	14.20	13.29	14.26	12.21	11.92	13.59	13.68	12.04
CaO	23.22	23.42	23.19	23.69	23.41	23.55	22.55	23.22	23.47
Na_2O	—	0.12	—	0.16	—	0.43	0.31	—	1.07
K_2O	—	—	—	—	—	—	—	—	0.01
V_2O_5	—	0.16	—	0.07	0.08	0.16	0.14	—	—
Total	98.94	100.77	99.79	101.36	99.47	101.41	97.63	100.11	100.91
Si	1.842	1.828	1.799	1.818	1.706	1.700	1.728	1.803	1.644
AlIV	0.158	0.172	0.201	0.182	0.294	0.300	0.272	0.197	0.336
AlVI	0.049	0.049	0.063	0.058	0.089	0.091	0.005	0.053	0.048
Fe**	0.187	0.191	0.217	0.192	0.216	0.242	0.231	0.213	0.252
Mg	0.788	0.782	0.740	0.780	0.682	0.660	0.784	0.758	0.676
Ca	0.932	0.927	0.928	0.933	0.945	0.937	0.977	0.925	0.947
Na	—	0.009	—	0.011	—	0.031	0.023	—	0.078
Ti	0.050	0.054	0.061	0.045	0.084	0.078	0.063	0.061	0.090
Mn	—	—	—	0.002	—	0.002	—	—	0.003
En	37.33	37.15	35.24	36.97	33.25	32.00	35.36	35.97	32.15
Fs	11.61	11.90	13.61	11.93	13.73	15.41	13.69	13.26	15.73
Wo	51.06	50.95	51.15	51.09	53.02	52.58	50.95	50.78	52.12

*Total Fe analyses as FeO

**$Fe^{2+}+Fe^{3+}$

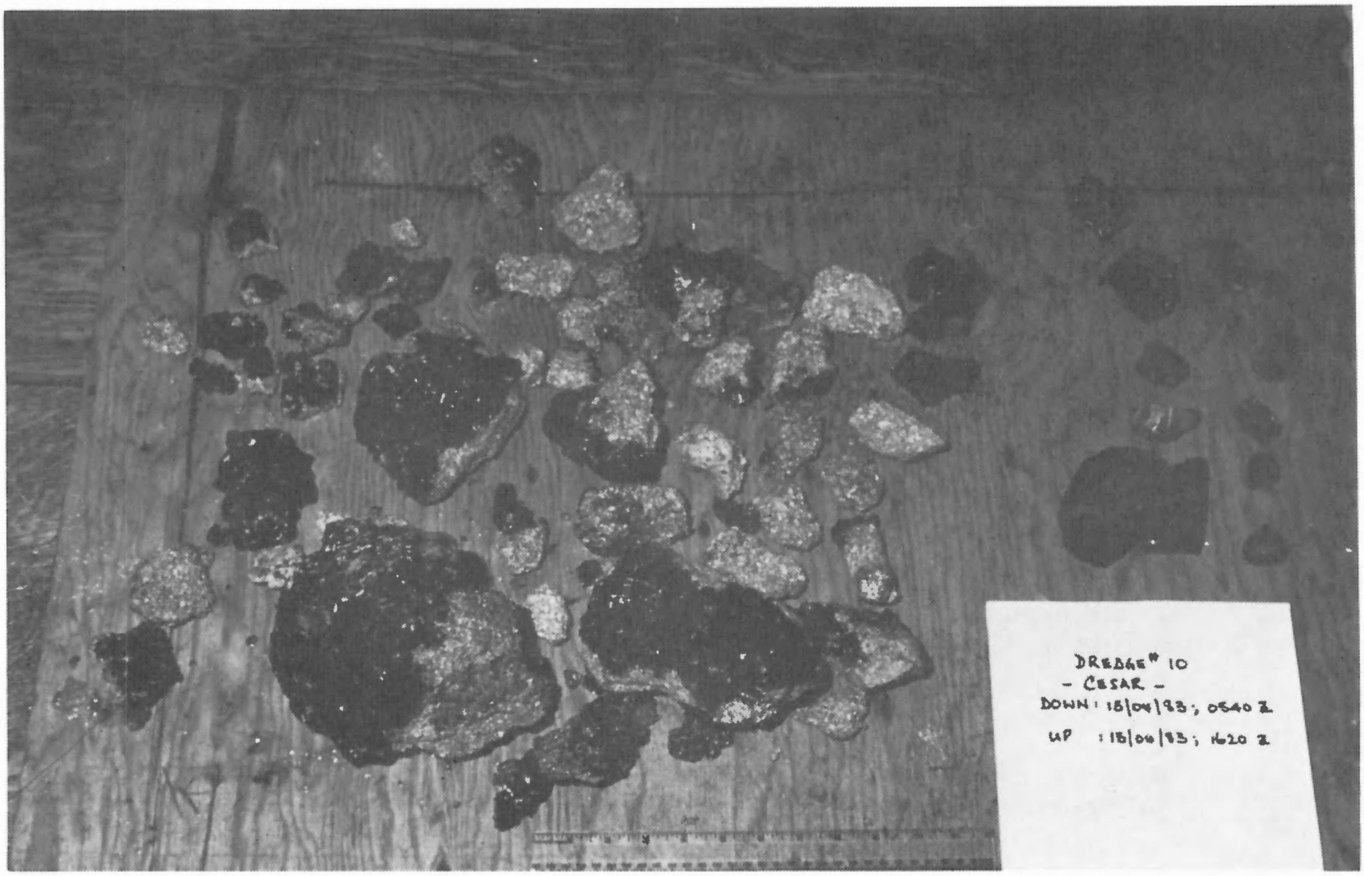


Figure 5.3 Rocks recovered by dredge. Those on the right are ice rafted dropstones, which are surrounded on all sides by manganese oxides. The rocks on the left are highly altered basaltic volcaniclastic rocks. The dark material is manganese oxides highly riddled with worm tubes. It only covers one side of the rocks suggesting that these rock fragments were broken from outcrops.

INTERPRETATION OF TECTONIC ENVIRONMENT

It is not possible to determine the origin of the Alpha Ridge based on only one sample. Such interpretation requires a suite of strategically positioned samples. Even so, textural and geochemical information gained from this sample may place important constraints on the origin of the ridge.

Textural analyses indicate that the volcanic rock fragments were rapidly cooled. The fragments apparently were glassy or very fine grained and rare plagioclase microlites have a skeletal form which is typical of rapidly quenched submarine basalts (Bryan, 1972).

Most rock fragments are highly vesicular suggesting a shallow water extrusive depth, at least less than 400m depth (Moore and Schilling, 1973; Jackson et al., 1976). However, highly vesicular basalts may be erupted at depth greater than 200m if the magma has a high volatile content (Dudas, 1983; Moore et al., 1982).

The fragmental nature of the rock, small clast size and high vesicularity of the clasts suggests phreatomagmatic or Plinian eruption (Self, 1982a,1982b). The fragments may have been transported after initial deposition but little reworking is suggested because 1) although the rock is heterolithic, a single clast type predominates; 2) many grains are angular or subangular; and 3) any amount of reworking would be expected to result in destruction of the delicate, scoriaceous clasts.

Because the rock is highly altered, the original composition can only be interpreted on the basis of primary and relict mineralogy. The salitic composition of the CESAR clinopyroxenes and their high TiO_2 and A_2O_3, but low SiO_2 content is typical of alkali basalts (Deer et al., 1966; Nisbet and Pearce, 1977; Leterrier et al., 1982), and the CESAR clinopyroxenes are chemically similar to alkali basalts of Hawaii, Fanning Island, and the Hess Ridge (Fig. 5.8). This chemical similarity of clinopyroxenes suggests that the clasts of the CESAR sample were alkali basalt. The occurrence of pseudomorphs of plagioclase microlites and possibly olivine is consistent with this interpretation.

Geochemical characteristics of volcanic rocks may be related to their tectonic setting. For such highly altered samples whole-rock geochemistry is of questionable significance, although these analyses are in progress. However, because there is a relationship between clinopyroxene composition and the composition of the host magma, unaltered clinopyroxene mineral grains can give an indication of the

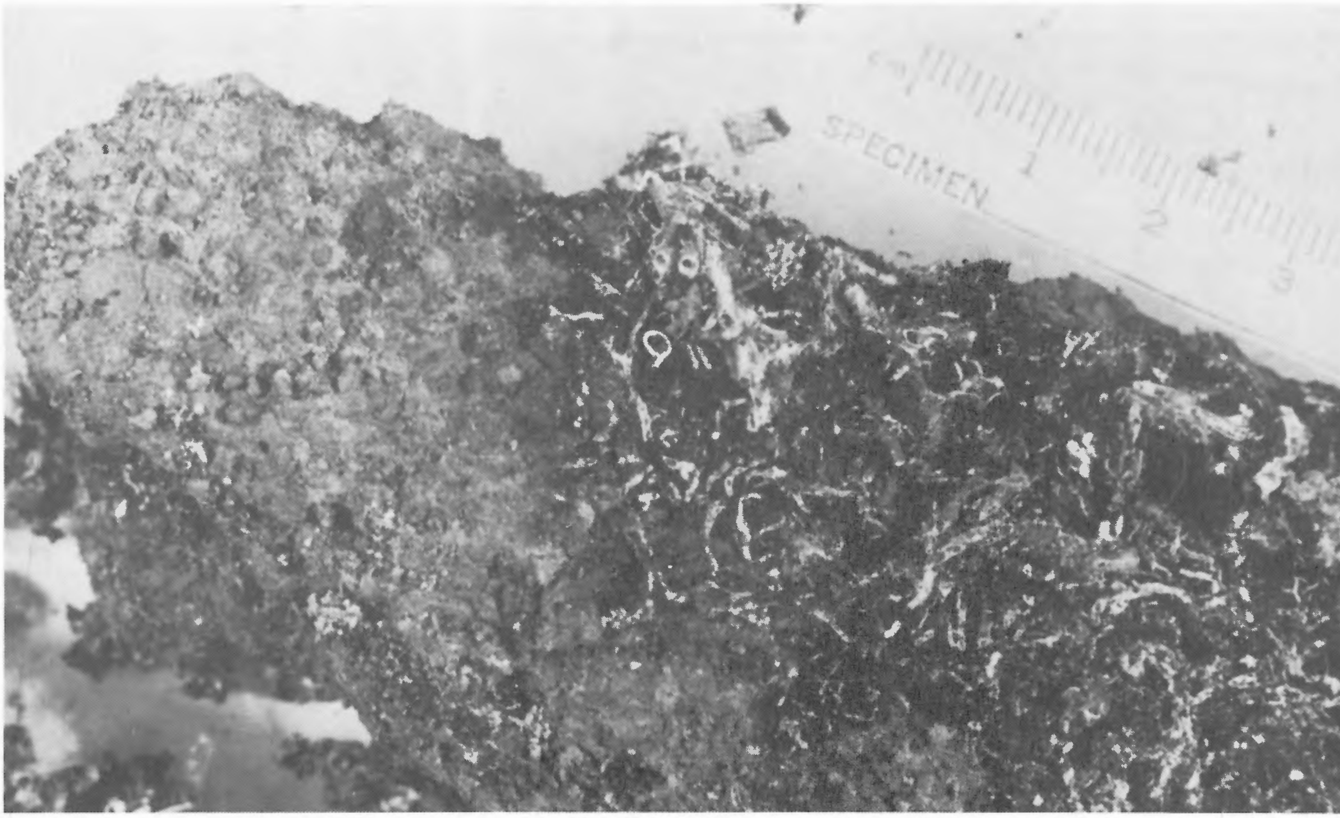


Figure 5.4 Close-up of volcanic rock sample showing the fragmental nature of the rock and the black manganese oxides with worm tubes.

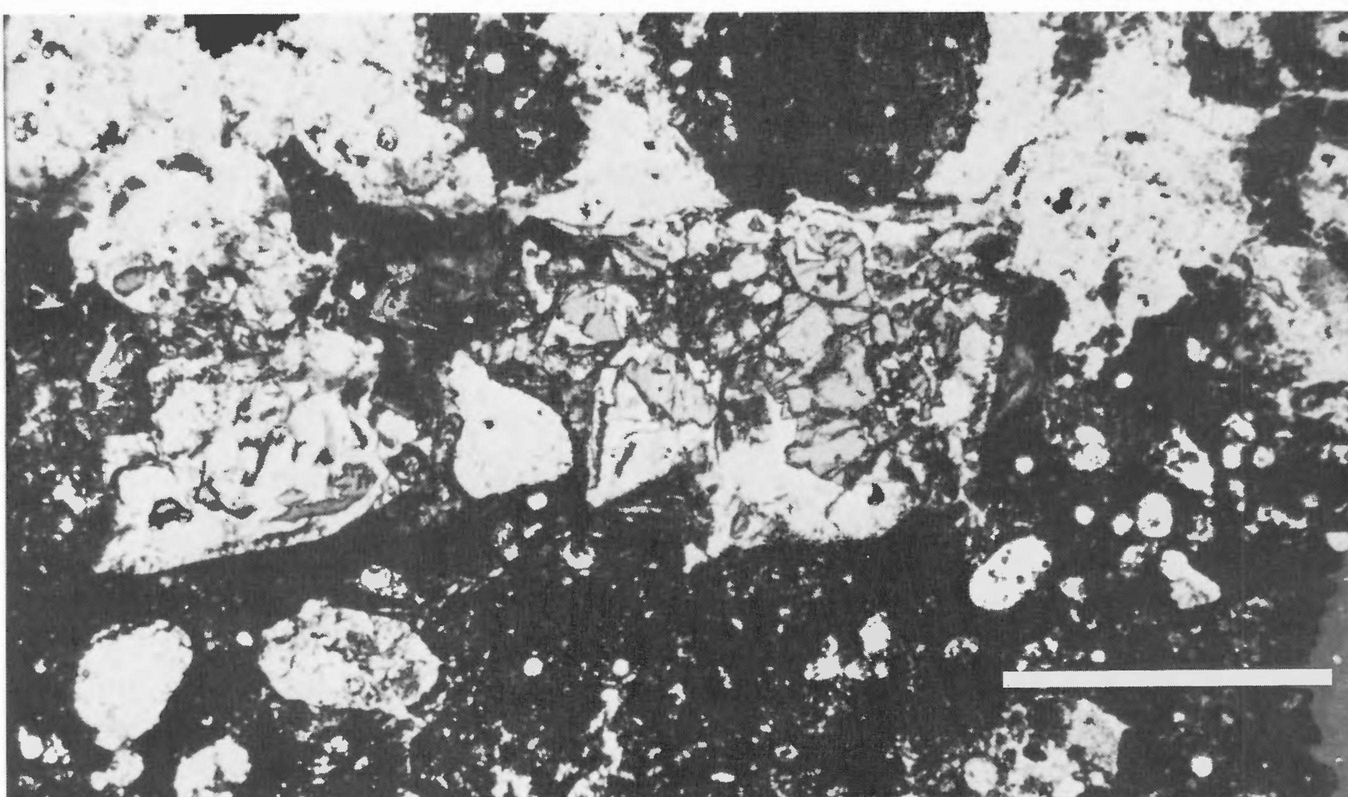


Figure 5.5 Highly altered volcanic clast which contains fresh clinopyroxene phenocrysts. Bar scale is 1mm, plane polarized light.

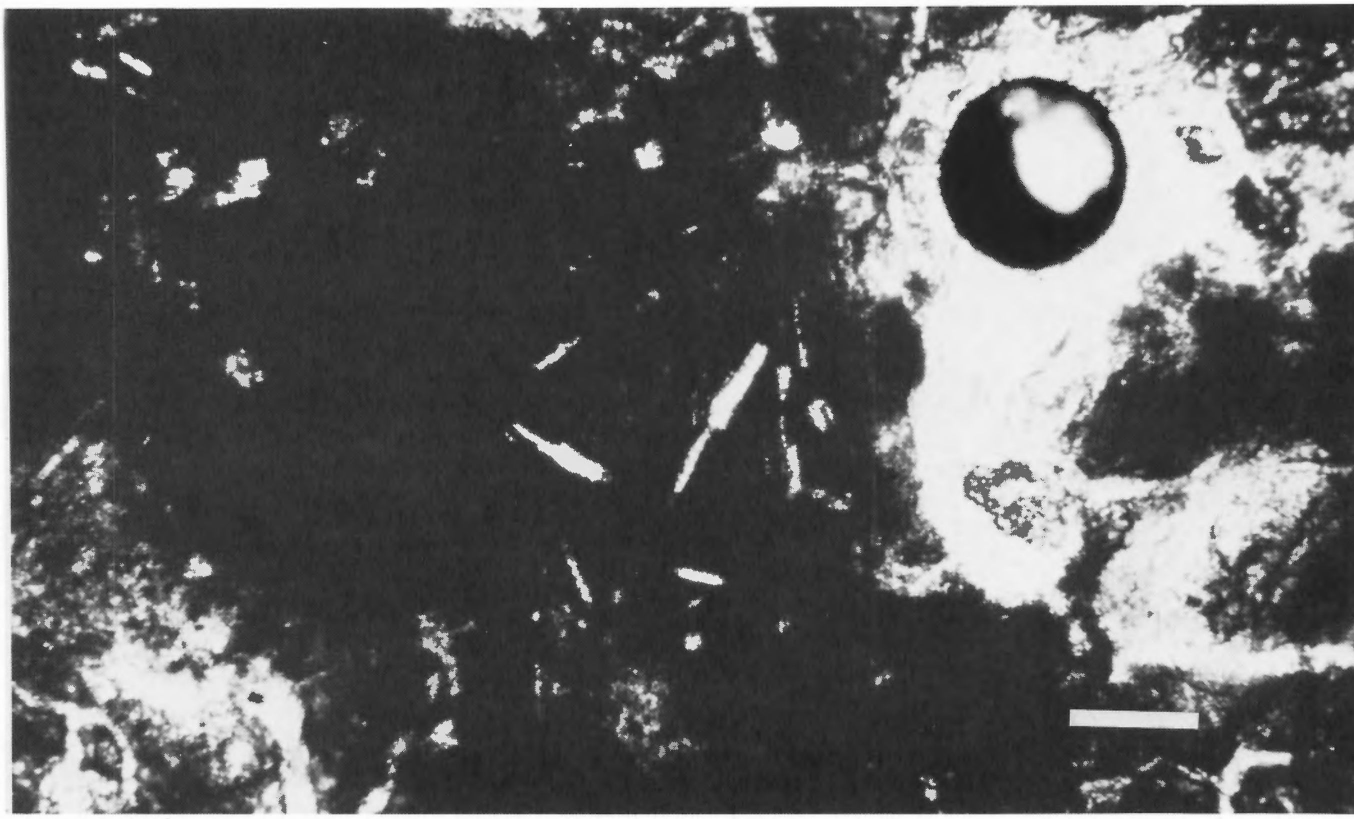


Figure 5.6 Plagioclase microlites in one of the volcanic rock fragments. Bar scale is 0.1mm, crossed nicols.

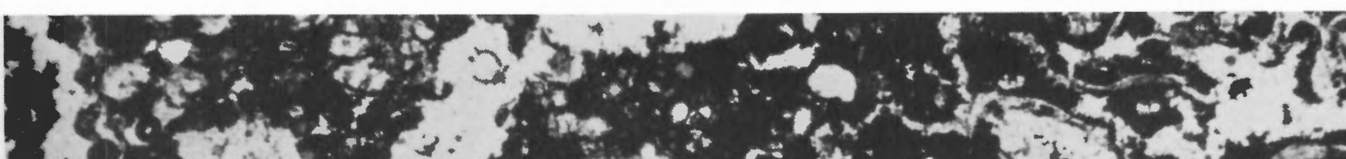


Figure 5.7 Highly vesicular and angular volcanic rock fragment. Bar scale is 1mm, plane polarized light.

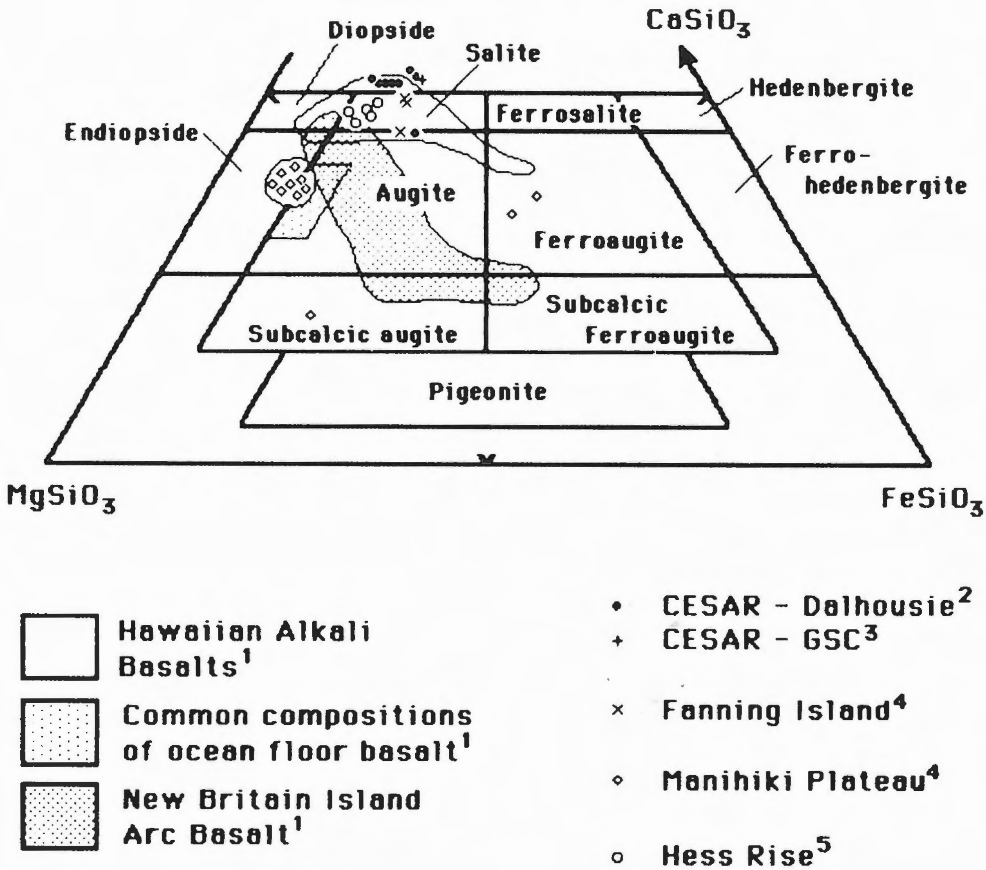


Figure 5.8 Pyroxene quadrilateral showing the composition of the CESAR clinopyroxenes in comparison with the compositions of clinopyroxenes from other areas. Data are from 1) Basaltic Volcanism Study Project, (1981), 2) this study, 3) LeCheminant, (1983), 4) Jackson et al., (1976), and Clague, (1976), and 5) Vallier et al., (1981).

original rock type and extrusive environment (Leterrier et al., 1982; Nisbet and Pearce, 1977). Discrimination diagrams from Leterrier et al. (1982) distinguish between ocean island and intracontinental alkali basalts and related rocks (basanites, etc.), and orogenic and nonorogenic tholeiitic and calc-alkali basalts with about 87% confidence based on the cationic values of Ca, Na and Ti for the structural formulae of the clinopyroxenes. The CESAR samples clearly plot in the alkali basalt field (Fig. 5.9). CESAR clinopyroxene compositions also plot in the within plate alkali basalt field (WPA) on the TiO_2, MnO, Na_2O discriminator from Nisbet and Pearce (1977; Fig. 5.10). These diagrams do not discriminate between continental and oceanic within plate alkali basalts.

The similarity of the CESAR clinopyroxenes to those of ocean islands, along with results of the discrimination diagrams suggests a within plate tectonic environment of extrusion for the CESAR bedrock sample. Alkali basalts are most common in intraplate areas but are found elsewhere (Best, 1982).

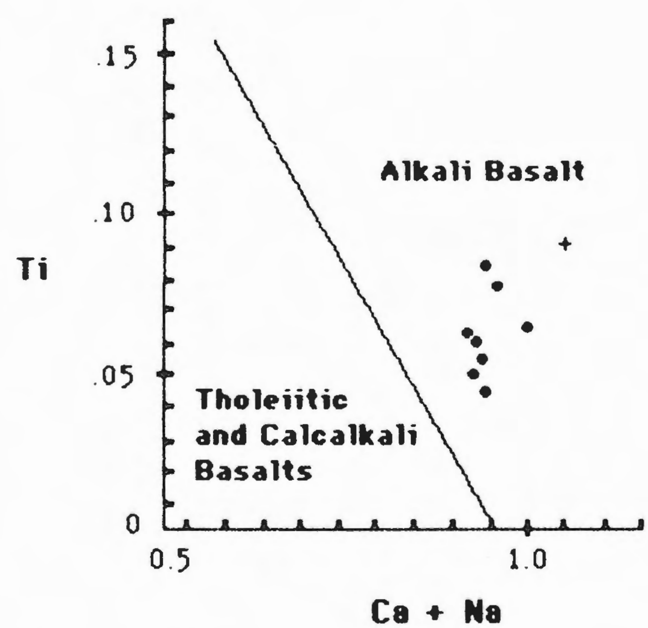
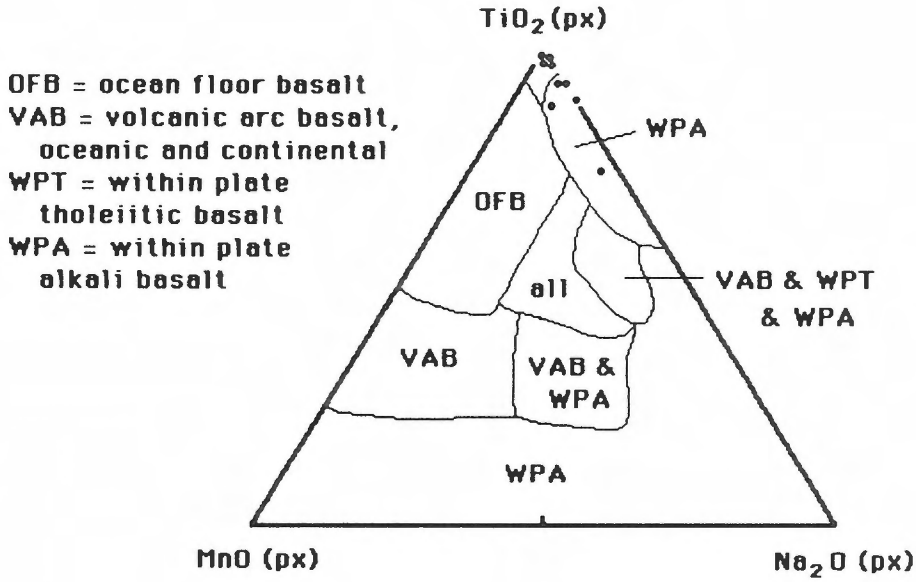


Figure 5.9 CESAR clinopyroxene compositions plotted on discrimination diagram from Leterrier et al. (1982). These compositions clearly plot in the alkali basalt field.

CONCLUSIONS

The CESAR bedrock sample is composed of highly altered fragments of hypocrystalline or cryptocrystalline,

Figure 5.10 Triangular diagram from discriminating between basalts of different tectonic settings based upon the relative amounts of TiO_2, MnO and NaO in pyroxenes, from Nisbet and Pearce (1977). The CESAR compositions clearly plot in the within plate alkali basalt field.



sparsely to highly vesicular, and sparsely clinopyroxene and olivine(?)-phyric alkaline basalt. The fragments probably were erupted subaqueously, but in shallow water. Geochemical discriminators suggest a within plate tectonic environment, although alkali basalts are found elsewhere.

Further geochemical studies of this rock are underway and include major, trace, and rare earth element analyses. However, if the Alpha Ridge was at a shallow depth, as we suggest, then it may have been the source rock for much of the sediment recovered in the CESAR sediment cores. These cores then probably will provide the best available suite of rock and mineral samples for determining the volcanic evolution and paleogeography of the Alpha Ridge.

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