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# Major oxides geochemistry of the Upper Cretaceous extrusive ophiolite unit of Western Anatolia (Turkey)

by *M. Delaloye**, *N. Tuzcu*** and *O. Kaya***

**Abstract**

The Upper Cretaceous extrusive ophiolite unit of Western Anatolia, having unusual stratigraphic and structural setting contrasts with ophiolites but is comparable with modern oceanic crust.

The lavas of the extrusive ophiolite unit are dominantly alkali olivine basalt, basanite and subordinately transitional to olivine tholeiitic basalt, all of which are uniformly undersaturated. The compositional range and chemical variations available from major oxide data are consistent with an extensional back-arc environment where magma either vented to the surface from multiple centres or through multiple conduits. This model contrasts to interarc basins with axial spreading, and can also be inferred on geological grounds.

## Introduction

The western part of Anatolia is divided into five discrete terranes each one consisting of a particular stratigraphic structural rock succession (Kaya 1982 a): (1) Tavsanlı terrane is characterized by tectonic ultramafic rocks, overlying low-grade metabasites, and Upper Cretaceous extrusive ophiolite rocks; (2) Menderès terrane corresponds to the Mederès Massif; (3)Balıkesir and (4) Biga terranes consist primarily of Triassic flysch and extrusive ophiolite rocks, the Biga member is characterized by amphibolite-banded gneisses of the Kazdağ Massif; (5) Teke terrane, consist of imbricated stacked thrust sheets of conformable carbonate and clastic successions, and a structuraly overlying sheet of ultramafic rocks, low-grade metabasites and Upper Cretaceous extrusive ophiolite rocks. The latter three constitute an isolated part of the Tavsanlı terrane (Figs. 1 and 2).

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Earlier works provide a summary of the evolution of the knowledge of ophiolites in Western Anatolia. BRINKMANN (1968, 1976) established the Cretaceous "Middle Anatolian radiolarite-ophiolite zone" and considered that the ultramafic rocks were divided or roofed by "radiolarite-ophiolite" material. KAYA (1972) delineated the uncomformable stratigraphic setting of the Upper Cretaceous submarine volcanic rocks and associated pelagic sediments on a basement consisting primarily of the tectonitic ultramafic rocks and low-grade greenschist to blueschist facies metamorphic rocks. He recognized that the volcanic rocks and the associated pelagic sediments formed a graben fill lapping onto the bounding structural hights of the basement, and, although a spatial relationship existed between the Upper Cretaceous extrusive and pre-Triassic ultramafic rocks, the lack of temporal correspondance would have rejected an application of "ophiolite" as an oceanic crust to West Anatolia. BINGÖL (1976) described the "ophiolitic melange of Upper Cretaceous age" to be made up of blocks of "ultramafic rocks, cherty limestone, radiolarite, spilite, tuff, schist, marble of various dimensions". The "mélange" would have been the product of a northward subduction of the Menderès Massif, and have undergone a widespread glaucophane schist facies metamorphism at its later stage of formation. Uz (1978) considered the "ophiolitic assemblage" to be composed of tectonites and ultramafic cumulates, massive gabbros and gabbroic dykes intruded in the ultramafic rocks, doleritic dykes in flysch series, and basic massive lavas interlayered with flysch strata. The earliest crystallization of ultramafic rocks would have occurred from a "pyrolitic magma" during Upper Cretaceous times, the last products being "basic lavas" accumulated with coeval flysch deposits. The ultramafic rocks later emplaced these spreading centres. KAYA (1981 a) interpreted the ultramafic rocks and, in turn, unconformably overlying low-grade greenschist and blueschist facies metamorphic rocks, and Upper Cretaceous extrusive ophiolite rocks, to constitute an autochthonous assemblage resting on underthrust allochthon of the Menderes crystalline rocks. The underthrusting must have occurred, immediately before Maastrichtian time, following the closure of the basin system in which extrusive ophiolite rocks accumulated.

The term extrusive ophiolite, following KAYA (1978 a), is used here for an assemblage of submarine mafic volcanic rocks with or without the association of pelagic rocks, beeing underlain primarily by ophiolitic ultramafic rocks, regardless of their temporal relationship.

The purpose of this paper is to present the major oxide data of the Upper Cretaceous extrusive ophiolite lavas and to test the hypothesis of a marginal basin origin for the extrusive ophiolite unit. A trace element study of the lavas is in preparation.


*Fig. 1* Major stratigraphic-structural rock assemblages of west Anatolia after KAYA 1981 a.

| | |
|---|---|
| PALEOGENE – LATEST CRETACEOUS | GRANITOIDS |
| **NEOAUTOCHTHON (PARALLOCHTHON** in the Teke terrane**)** | |
| BURDIGALIAN | marine clastic rocks : KÖYCEĞİZ CLASTIC sequence (K2) in the Teke terrane |
| EOCENE – (OLIGOCENE) | marine clastic rocks : KÖYCEĞİZ CLASTIC sequence (K2) in the Teke terrane |
| AQUITANIAN – MAASTRICHTIAN - CAMPANIAN | BEYDAĞLARI CARBONATE (B2) sequence |
| PALEOCENE – MAASTRICHTIAN - CAMPANIAN | FLYSCH and sedimentary mélange unit : KÖYCEĞİZ CLASTIC sequence (K2) in the teke terrane ; CARBONATE unit. |
| **ALLOCHTHON** | |
| pre - MAASTRICHTIAN - CAMPANIAN MESOZOIC + PERMIAN | KÖYCEĞİZ CARBONATE (+minor clastics) sequence (K1) |
| pre - MAASTRICHTIAN - CAMPANIAN MESOZOIC | BEYDAĞLARI CARBONATE sequence (B1) |
| LATE MESOZOIC + PALEOZOIC | anchimetamorphic rocks |
| ? PRECAMBRIAN | low-grade greenschist facies METAPELITE (+ marble) unit |
| PRECAMBRIAN | augen-banded GNEISS unit (undiff. schists, migmatites, leptites, pegmatites, agmatites) |
| **AUTOCHTHON** | |
| LATE CRETACEOUS | EXTRUSIVE OPHIOLITE unit |
| ? JURASSIC | anchimetamorphic rocks |
| JURASSIC – ? TRIASSIC | carbonate rocks |
| TRIASSIC | FLYSCH & EXTRUSIVE OPHIOLITE unit |
| PALEOZOIC | flysch - like and carbonate rocks |
| pre - TRIASSIC PRECAMBRIAN | low-grade greenschist, and blueschist facies METABASITE (+ marble) unit |
| pre - TRIASSIC PRECAMBRIAN | medium - grade AMPHIBOLITE - BANDED GNEISS unit |
| PRECAMBRIAN (emplacement age) | tectonitic ULTRAMAFIC unit (+ undiff. metabasites, extrusive ophiolite rocks, layered mafic rocks, mafic dykes) |

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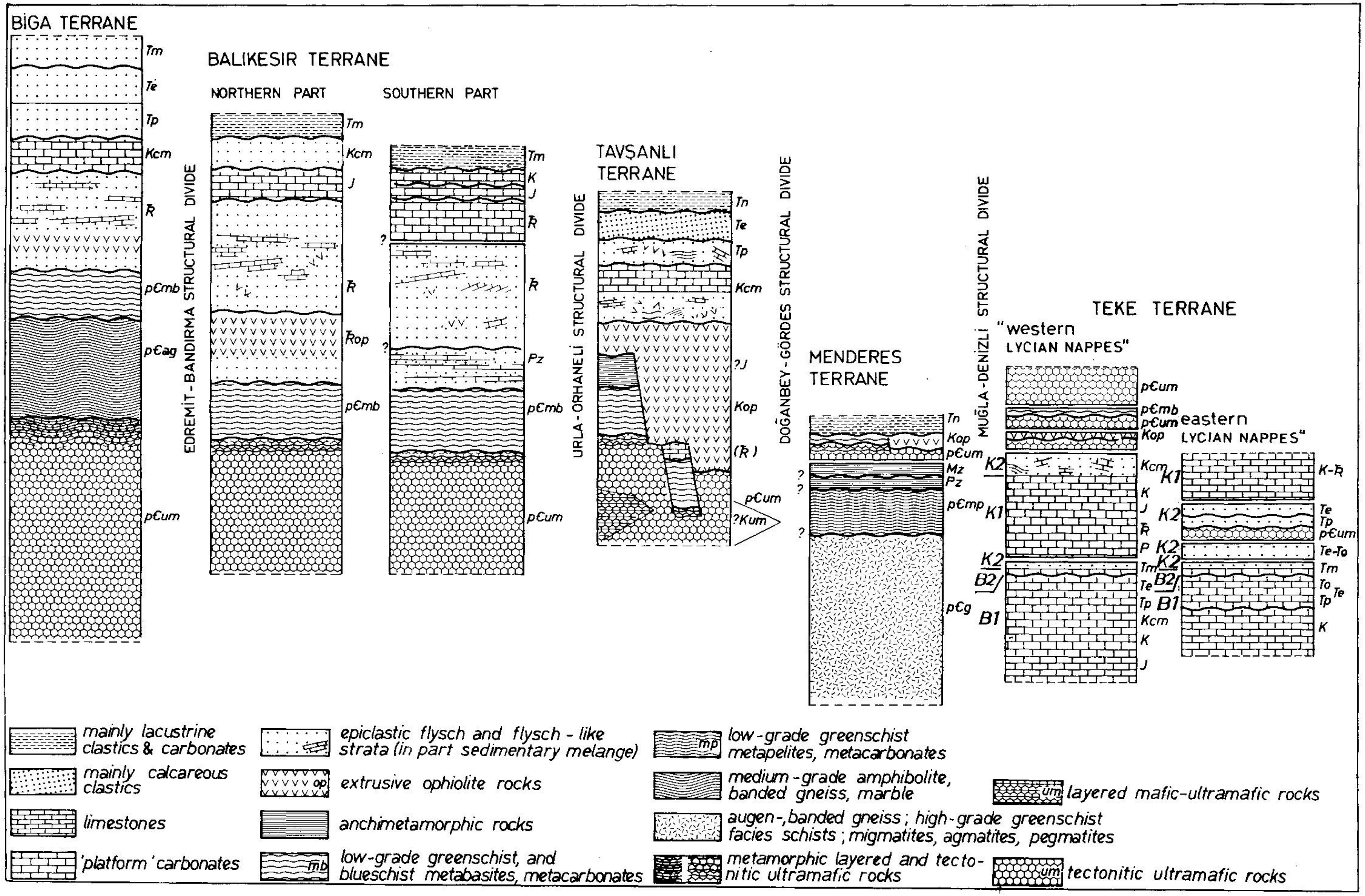


*Fig. 2* Generalized stratigraphic and structural successions of the terranes after KAYA 1981 a.

## Major rock units description

### *The ultramafic unit*

Ultramafic rocks consist primarily of harzburgitic and dunitic tectonites with derived lizardite-chrysotile serpentinite. They contain sporadic fault-bounded masses of layered gabbro, massive gabbro rodingites (KAYA 1972, 1978b), ophispherites (TUZCU, 1982) and microdioritic dykes cutting the ultramafic rocks. The fresh or altered microdioritic dykes do not signify the presence of a sheeted dyke system. KAYA (1978b; 1981a) interprete the ultramafic rock outcrops of West Anatolia, although separated by younger stratigraphic units and structures as a single tectonic unit which has acted as a basement for the overlying metamorphic and non-metamorphic rocks ranging in age from Precambrian to Recent.

### *The Metabasite unit*

Low grade metamorphic rocks are broadly divided into three stratigraphics units (KAYA, in prep.):

1) greenschist facies metavolcanic and metasedimentary rocks (KAYA 1972, 1978), which are partially or completely retrograded to blueschist assemblages (YILMAZ 1979, KAYA 1982b),
2) marble (KAYA 1978b),
3) anchimetamorphic rocks underwent post-tectonical recrystallization blueschist facies.

A Precambrian age for the low-grade greenschist facies metamorphism and a pre-Triassic age for the blueschist facies retromorphose can be suggested on the basis of geological evidences (KAYA 1978, 1981a, in prep.). The metabasite unit grades, in mineralogical and chemical composition, into underlying tectonitic ultramafic rocks through antigorite-schist and tectonitic metaultramafic rocks, suggesting a metamorphosed erosional unconformity (KAYA 1981a, b).

### *The Upper Cretaceous extrusive ophiolite unit*

At least three partly or fully developed extrusive ophiolite units exist in West Anatolia:

1) metamorphic extrusive ophiolite strata as parts of the pre-Triassic metabasite unit (KAYA 1972b),
2) non-metamorphic extrusive ophiolite units of Lower Triassic (KAYA and WIEDMANN, in prep.),

3) Upper Cretaceous elements (KAYA 1972a,b, 1978, 1982).

These sequences are separated by important unconformities and non-ophiolitic stratigraphic units.

The Upper Cretaceous extrusive ophiolite unit is a distinctive complex sequence consisting of submarine mafic volcanic and volcaniclastic rocks, chlorite-rich mudrocks, bedded chert, recrystallized pelagic limestone, intrabasinal and extrabasinal clasts ranging in size from pebble to very large block, and subordinate epiclastic sandstones and illitic mudrocks. Several erosional unconformities occur within the sequence. The extrusive ophiolite rocks rest in depositional contacts on ultramafites (BRINKMANN 1971b, KAYA 1972, 1978b), on low-grade greenschist to blueschist facies metamorphic rocks (KAYA 1972, 1978b) and on nonmetamorphic Triassic rocks (KAYA 1978b). The peculiar extrabasinal clasts which are interbedded in the stratified extrusive material are blueschist and low-grade greenschist facies metabasites, marbles, gabbroic rocks, microdioritic veins, steatized and serpentinized ultramafites. Floating blocks, intrabasinal olistostromes and debris flow deposits delineate widely persistent stratigraphic horizons. The Upper Cretaceous extrusive ophiolite rocks do not characterize the "mafic volcanic complex" of an ophiolite according to the Penrose definition, nor an "ophiolitic melange" as described by GANSSER in 1974 (KAYA, 1981a).

## Geochemistry

The 33 specimens of lavas are collected from surroundings of Kütahya, Manisa and Izmir (Fig. 1). They represent mainly the lowermost lava unit (unit F) of the extrusive ophiolite sequence and do not show significant differences in rock type and chemical composition with regard to locality.

Dry-reduced compositions were determined by recalculating $Fe_2O_3$ and FeO according to a ferric: ferrous ratio of 0.4, substrating excess $CO_2$ above about 0.35% (DESMET 1977) and $H_2O$ (Table I). The dry-reduced oxide compositions are used in all diagrams and for the calculation of CIPW norms. To an arbitrary division on the basis of $SiO_2$ = 53%, the entire specimens of lavas are basalts. The rocks have undergone slight to severe spilitization. The specimens with unusually high $Na_2O$ content have been marked by brackets in Table I, and have been taken into consideration in the interpretations.

Following the nomenclature of GREEN and RINGWOOD (1967) and COOMBS and WILKINSON (1969) the lavas can be classified into alkali olivine basalt, basanite, tephrite, olivine tholeiite and quartz tholeiite (Table I). According to COOMBS (1963, in BEST and BRIMHALL 1974), some olivine basalts possessing low hy/di ratios and having neither ne nor Q can be classified as "transitional basalts" with tholeiitic character. Ol'-Ne'-Q' plot indicates the critically under-

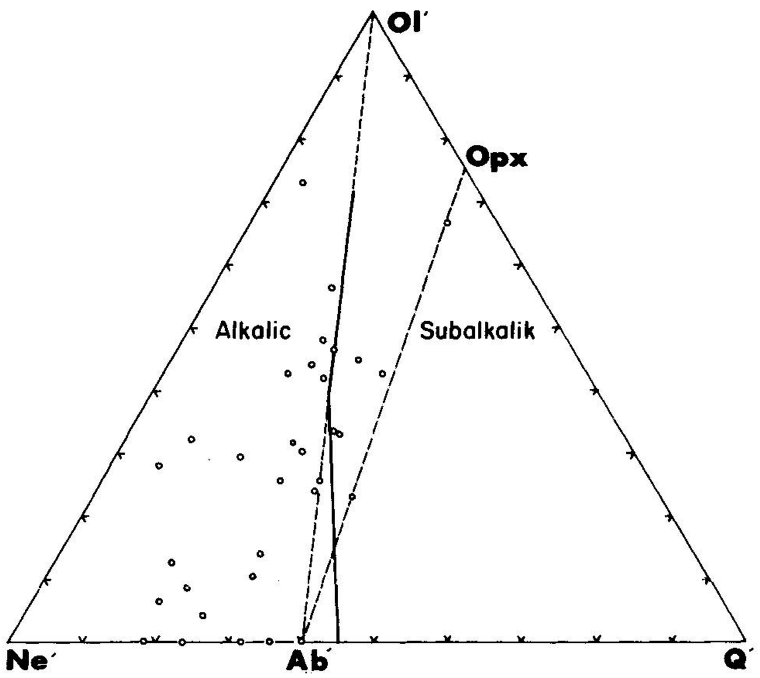


*Fig. 3* Ol'-Ne'-Q' projection of the extrusive ophiolite basalts. The heavy solid line is IRWINE and BARAGAR (1971) line for separating alkalic and subalkalic fields. Traces separating the critically undersatured, undersaturated and oversaturated fields are from YODER and TILLEY (1962).

saturated to undersaturated nature of the extrusive ophiolite lavas (Fig. 3). On the total alkali vs. silica plot (Fig. 4) the alkalic group covers the alkali olivine basalts, basanites and tephrites, and apparently dominates over the subalkalic group representing the olivine tholeiites and quartz tholeiite. Undersaturated alkalic and subalkalic basalts are comparable to those of the extensional back-arc areas (e.g. South Auckland, RAFFERTY and HEMING 1979; Penguin Island of Bransfield Strait, WEAVER and others 1979; East Otago in New Zealand, COOMBS and WILKINSON 1969; British Columbia, NICOLLS and others 1982), oceanic Islands (e.g. Azore Islands, WHITE and others 1979; Mauritius, BAXTER 1976) and extensional continental areas (e.g. Western Colorado plateau; BEST and BRIMHALL 1974). In general the extrusive ophiolite basalts show a continuous spectrum of composition.

On the $K_2O$ vs. $SiO_2$ diagram, representing the normal island arc associations (e.g. Sunda arc: WHITFORD and others 1979), the analyzed basalts fall in the tholeiitic, high-K tholeiitic or calc-alkalic, and high-K calc-alkalic fields (Fig. 5). The restricted compositional range ($SiO_2$ = 43.21%-52.50%) the low abundance of calc-alkalic lavas lying between the extremes of high-K calc-alkalic and tholeiitic lavas, and the lack of rhyolitic and high-K alkaline associations argue against a normal island arc setting. The high $K_2O$ content of the basalts may not preclude the possibility of back-arc basin setting (maximum value

*Table 1 a*

| | ALKALI OLIVINE BASALT | | | | | | | | | | | | BASANITE | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | K 21 | H 977 | H 976 | K 24 | K 23 | H 970 | K 20 | H 973 | H 974 | MA 65 | (MA 58) | (MA 61 i) | MA 65 i | MA 67 | MA 85 | MA 64 | MA 84 | MA 61 | (MA 66) |
| $SiO_2$ | 43.21 | 43.37 | 44.21 | 44.71 | 45.86 | 45.96 | 46.19 | 46.51 | 47.18 | 49.07 | 50.07 | 52.13 | 44.52 | 45.10 | 46.56 | 46.91 | 48.77 | 49.51 | 49.73 |
| $Al_2O_3$ | 11.41 | 9.42 | 10.07 | 10.51 | 9.80 | 14.81 | 11.68 | 10.38 | 12.28 | 15.98 | 19.82 | 15.62 | 16.58 | 17.04 | 17.58 | 16.10 | 16.16 | 16.31 | 15.36 |
| $TiO_2$ | 3.30 | 2.81 | 2.81 | 2.85 | 2.80 | 0.31 | 2.92 | 2.53 | 3.19 | 1.08 | 1.55 | 0.82 | 1.01 | 1.04 | 0.53 | 0.98 | 0.76 | 1.12 | 0.76 |
| FeO | 8.65 | 8.45 | 7.75 | 7.76 | 7.80 | 2.52 | 7.25 | 7.73 | 7.59 | 4.53 | 4.45 | 3.67 | 4.35 | 4.92 | 4.49 | 4.87 | 4.19 | 4.33 | 3.59 |
| $Fe_2O_3$ | 5.34 | 5.64 | 5.27 | 5.18 | 5.26 | 7.70 | 4.88 | 5.21 | 5.22 | 3.08 | 2.99 | 2.45 | 2.79 | 3.41 | 3.07 | 3.32 | 2.89 | 2.98 | 2.47 |
| CaO | 10.43 | 13.63 | 13.51 | 11.46 | 11.72 | 14.00 | 11.27 | 11.61 | 9.93 | 11.81 | 8.91 | 9.90 | 14.00 | 13.88 | 14.02 | 14.01 | 13.92 | 14.02 | 13.15 |
| MgO | 13.70 | 14.94 | 12.12 | 13.03 | 13.21 | 8.56 | 10.03 | 11.97 | 9.27 | 8.26 | 2.88 | 7.53 | 6.20 | 9.02 | 7.92 | 8.63 | 7.06 | 6.57 | 7.31 |
| $Na_2O$ | 2.07 | 1.18 | 2.42 | 2.34 | 2.69 | 2.23 | 3.20 | 2.50 | 3.33 | 5.59 | 5.76 | 6.31 | 3.50 | 3.54 | 3.43 | 3.01 | 5.06 | 3.81 | 5.51 |
| $K_2O$ | 0.62 | 0.16 | 0.17 | 0.47 | 0.42 | 0.77 | 0.85 | 0.76 | 1.41 | 0.99 | 2.34 | 0.56 | 0.76 | 0.66 | 1.48 | 0.83 | 0.17 | 0.35 | 0.95 |
| MnO | 0.20 | 0.17 | 0.18 | 0.18 | 0.17 | 0.25 | 0.18 | 0.16 | 0.16 | 0.12 | 0.15 | 0.15 | 0.11 | 0.16 | 0.16 | 0.12 | 0.16 | 0.11 | 0.15 |
| $P_2O_5$ | 0.50 | 0.35 | 0.40 | 0.44 | 0.38 | 0.86 | 0.49 | 0.37 | 0.49 | 0.27 | 0.20 | 0.17 | 0.21 | 0.20 | 0.15 | 0.23 | 0.17 | 0.24 | 0.18 |
| $CO_2$ | 0.35 | 0.35 | 0.35 | 0.32 | 0.35 | 0.35 | 0.35 | 0.35 | 0.32 | 0.35 | 0.35 | 0.35 | 0.35 | 0.35 | 0.35 | 0.35 | 0.35 | 0.35 | 0.35 |
| | **CIPW** | **NORM** | | | | | | | | | | | | | | | | | |
| Q | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| Or | 3.66 | 0.95 | 1.00 | 2.78 | 2.48 | 4.55 | 5.02 | 4.49 | 8.33 | 5.85 | 13.83 | 3.31 | 4.49 | 3.90 | 8.75 | 4.91 | 1.00 | 2.07 | 5.61 |
| Ab | 15.54 | 9.51 | 12.63 | 17.31 | 18.00 | 18.37 | 20.29 | 19.23 | 23.40 | 21.76 | 23.24 | 31.04 | 8.88 | 5.99 | 3.80 | 11.24 | 16.62 | 21.75 | 14.56 |
| An | 20.01 | 19.94 | 16.11 | 16.29 | 13.43 | 28.13 | 15.00 | 14.86 | 14.40 | 24.57 | 21.32 | 12.64 | 27.29 | 28.66 | 28.20 | 27.97 | 20.88 | 26.37 | 14.37 |
| Ne | 1.07 | 0.26 | 4.25 | 1.35 | 2.58 | 0.27 | 3.68 | 1.04 | 2.59 | 4.67 | 13.82 | 12.11 | 11.23 | 12.98 | 13.66 | 7.71 | 14.19 | 5.68 | 17.37 |
| Di | 22.56 | 35.95 | 38.27 | 29.44 | 33.44 | 27.80 | 29.91 | 32.00 | 25.13 | 25.61 | 17.45 | 28.04 | 32.56 | 30.90 | 32.18 | 31.82 | 37.49 | 33.11 | 39.41 |
| Hy | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| Ol | 21.24 | 19.03 | 12.56 | 17.17 | 16.19 | 5.91 | 11.12 | 14.72 | 11.29 | 9.02 | 1.56 | 6.49 | 2.96 | 8.99 | 6.82 | 7.99 | 2.93 | 3.19 | 2.22 |
| Mt | 7.74 | 8.18 | 7.64 | 7.51 | 7.63 | 6.62 | 7.08 | 7.55 | 7.57 | 4.47 | 4.34 | 3.55 | 4.05 | 4.94 | 4.45 | 4.81 | 4.19 | 4.32 | 3.58 |
| Il | 6.27 | 5.34 | 5.34 | 5.41 | 5.32 | 1.73 | 5.55 | 4.81 | 6.06 | 2.05 | 2.94 | 1.56 | 1.92 | 1.98 | 1.01 | 1.86 | 1.44 | 2.13 | 1.44 |
| Ap | 1.16 | 0.81 | 0.93 | 1.02 | 0.88 | 1.99 | 1.14 | 0.86 | 1.14 | 0.63 | 0.46 | 0.39 | 0.49 | 0.46 | 0.35 | 0.53 | 0.39 | 0.56 | 0.42 |

*Table 1b*

| | TEPHRITE | | | | | | OLIVINE THOLEIITE | | | | | | | QUARTZ THOLEIITE |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | K 29 | (MA 59) | MA 92 | MA 81 | MA 82 | (MA 62 e) | H 979 | H 972 | K 22 | K 25 | K 27 | (K 26) | H 969 | MA 91 |
| $SiO_2$ | 52.02 | 47.53 | 49.80 | 49.97 | 50.24 | 50.30 | 46.50 | 47.38 | 48.12 | 50.14 | 50.80 | 52.50 | 52.54 | 51.43 |
| $Al_2O_3$ | 15.64 | 20.24 | 18.87 | 18.29 | 15.10 | 15.95 | 13.05 | 13.10 | 14.38 | 15.93 | 14.85 | 17.13 | 15.16 | 17.12 |
| $TiO_2$ | 0.99 | 1.61 | 1.57 | 1.70 | 0.71 | 0.73 | 3.01 | 2.12 | 1.50 | 0.85 | 1.29 | 1.42 | 1.36 | 1.89 |
| FeO | 3.56 | 4.42 | 4.34 | 4.23 | 3.33 | 3.31 | 7.19 | 8.23 | 8.19 | 5.07 | 5.89 | 5.98 | 7.22 | 4.34 |
| $Fe_2O_3$ | 2.39 | 3.09 | 2.90 | 2.88 | 2.46 | 2.23 | 4.92 | 5.53 | 5.68 | 3.53 | 3.56 | 2.31 | 4.90 | 2.90 |
| CaO | 10.49 | 14.03 | 14.00 | 13.25 | 14.05 | 13.33 | 8.84 | 10.80 | 10.66 | 7.76 | 9.78 | 4.39 | 7.08 | 14.00 |
| MgO | 7.02 | 2.90 | 2.74 | 2.81 | 5.89 | 6.08 | 10.95 | 10.24 | 7.45 | 11.60 | 10.27 | 10.56 | 6.30 | 2.87 |
| $Na_2O$ | 4.84 | 2.76 | 4.32 | 4.81 | 4.35 | 5.37 | 2.15 | 2.13 | 2.88 | 2.81 | 3.70 | 5.48 | 4.59 | 3.50 |
| $K_2O$ | 1.46 | 2.43 | 0.18 | 0.55 | 2.06 | 1.44 | 2.34 | 0.22 | 0.81 | 1.44 | 0.07 | 0.09 | 0.41 | 0.16 |
| MnO | 0.11 | 0.11 | 0.22 | 0.16 | 0.17 | 0.15 | 0.15 | 0.17 | 0.19 | 0.14 | 0.17 | 0.16 | 0.81 | 0.14 |
| $P_2O_5$ | 0.26 | 0.28 | 0.27 | 0.27 | 0.17 | 0.17 | 0.45 | 0.24 | 0.11 | 0.05 | 0.08 | 0.26 | 0.10 | 0.49 |
| $CO_2$ | 0.35 | 0.35 | 0.35 | 0.35 | 0.35 | 0.35 | 0.35 | 0.35 | 0.35 | 0.05 | 0.07 | 0.35 | 0.18 | 0.35 |
| Q | - | - | - | - | - | - | - | - | - | - | - | - | - | 3.87 |
| Or | 8.63 | 14.36 | 1.06 | 3.25 | 12.17 | 8.51 | 13.83 | 1.30 | 4.79 | 8.51 | 0.41 | 0.53 | 2.42 | 0.95 |
| Ab | 27.98 | 10.10 | 29.45 | 29.04 | 11.61 | 13.79 | 18.19 | 18.02 | 24.37 | 23.78 | 31.31 | 49.37 | 38.84 | 29.62 |
| An | 16.64 | 35.66 | 31.57 | 26.69 | 15.59 | 15.16 | 19.05 | 25.45 | 23.92 | 26.60 | 23.71 | 20.08 | 19.55 | 30.53 |
| Ne | 7.03 | 7.18 | 3.85 | 6.32 | 13.65 | 17.15 | - | - | - | - | - | - | - | - |
| Di | 26.70 | 21.43 | 21.09 | 20.51 | 37.71 | 38.88 | 17.30 | 21.22 | 22.80 | 9.17 | 19.33 | - | 12.06 | 20.52 |
| Hy | - | - | - | - | - | - | 1.32 | 17.91 | 4.29 | 11.03 | 6.42 | 6.91 | 16.44 | - |
| Ol | 5.69 | - | - | - | - | - | 15.80 | 3.46 | 8.30 | 13.36 | 11.45 | 18.91 | 0.52 | - |
| Mt | 3.47 | 4.48 | 4.20 | 4.18 | 3.57 | 3.23 | 7.13 | 8.02 | 8.24 | 5.12 | 5.16 | 3.35 | 7.10 | 4.20 |
| Il | 1.88 | 3.06 | 2.98 | 3.23 | 1.35 | 1.39 | 5.72 | 4.03 | 2.85 | 1.61 | 2.45 | 2.70 | 2.58 | 3.59 |
| Ap | 0.60 | 0.65 | 0.63 | 0.63 | 0.39 | 0.39 | 1.04 | 0.56 | 0.25 | 0.12 | 0.19 | 0.60 | 0.23 | 1.14 |

of 2.02%, RAFFERTY and HEMING 1979) and oceanic island setting (maximum value of 2.56%, Azores Islands, WHITE and others 1979).

On the AFM plot the calc-alkaline and tholeiitic rocks are not distinguishable and there is no trend of Fe-enrichment (Fig. 6). As indicated by the plot of $SiO_2$ vs. FeO*/MgO (Fig. 7) and the plot of $TiO_2$ vs. FeO*/MgO (Fig. 9) the absence of Fe-enrichment with fractionation excludes the possibility of mid-ocean ridge and Hawaiien-type oceanic island settings. The plots are also different from the discontinuous trends with slight Fe-enrichment typical of some oceanic island rocks (BAXTER 1976, LEMAÎTRE 1962).

On the FeO*-MgO-$Al_2O_3$ diagram of PEARCE and others (1977) most of lavas fall in the fields of ocean ridge floor and oceanic islands (Fig. 8). Some chemical

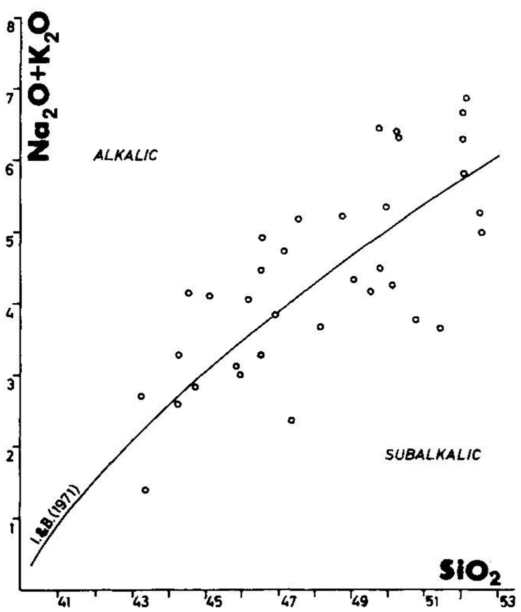


*Fig. 4* Total alkalic vs. silica diagram for the extrusive ophiolite basalts. Owing to slight to severe spilization, the lava specimens lying near the IRVINE and BARAGAR (1971) line can originally be subalkalic.

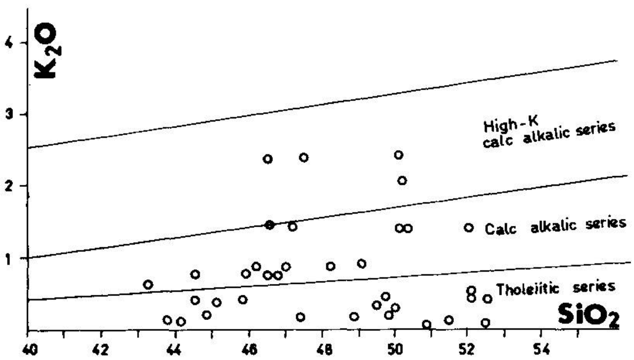


*Fig. 5* $K_2O$ versus $SiO_2$ plot of the extrusive ophiolite basalts on the classification scheme for normal island arc basalts, adopted from WHITFORD and others (1979).

characters of the lavas are not compatible with an ocean ridge setting, but do not preclude the possibility of an ocean island setting. The plot and the dominantly undersaturated lava composition may suggest an extensional tectonic situation; i.e. a system of normal faults which would have served as magma conduits, and would have been accompanied by upper mantle upwelling. An extensional back-arc environment (but not axially) spreading apart interarc basin can be suggested to correspond to the environmental pecularities reflected by ocean ridge and oceanic island basalts.

$TiO_2$-FeO*/MgO plot (Fig. 9) delineates a $TiO_2$-bimodality which is common for many ophiolitic basalt units (COISH and CHURCH 1979). The low-$TiO_2$

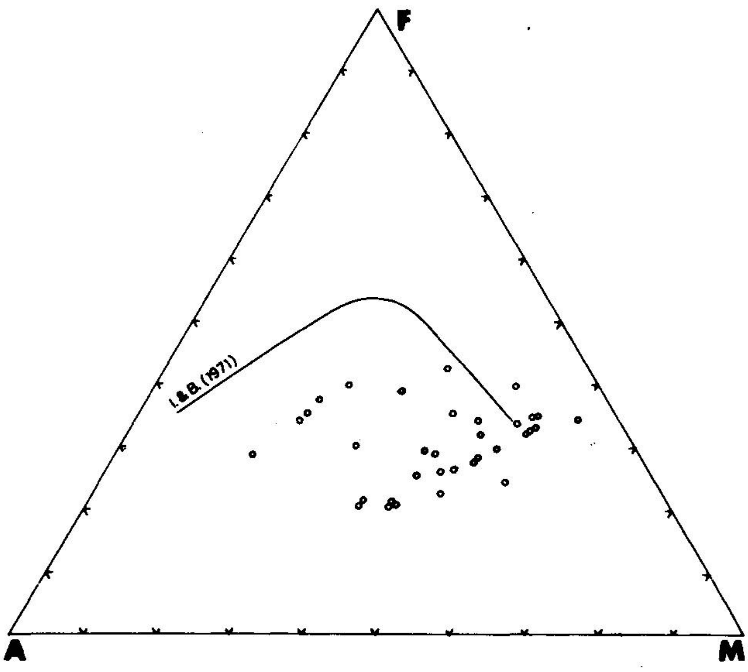


*Fig. 6* AFM diagram for the extrusive ophiolite basalts. F = FeO + 0.9 $Fe_2O_3$.

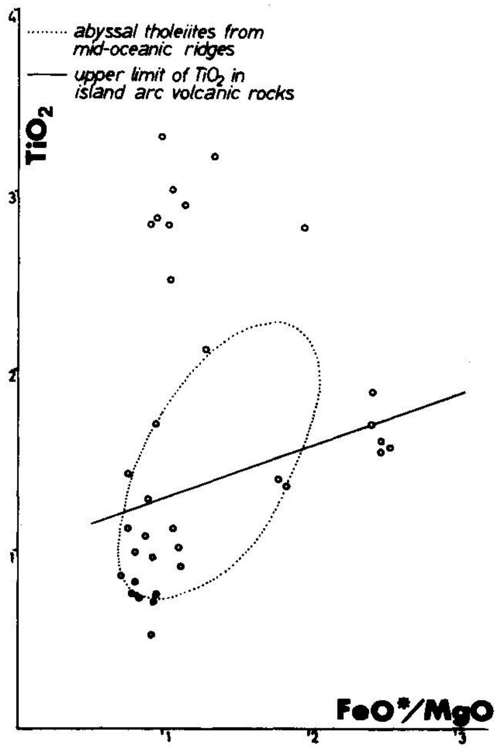


*Fig. 7* $SiO_2$ versus $FeO^x/MgO$ of the extrusive ophiolite lavas on the MIYASHIRO (1974) diagram.

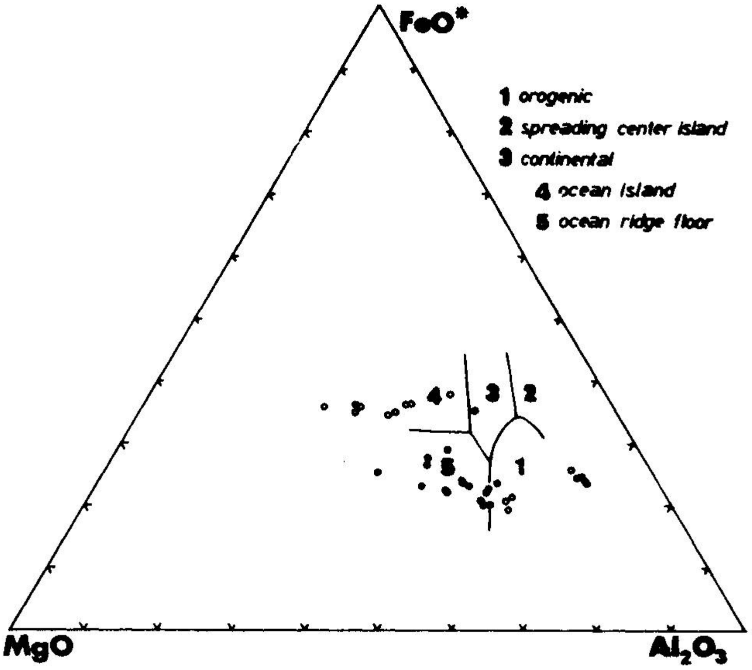


*Fig. 8* $FeO^x$-MgO-$Al_2O_3$ plot of the extrusive ophiolite basalts on the diagram of PEARCE and others (1977). The boundaries based mainly on Cenozoic volcanic rocks.

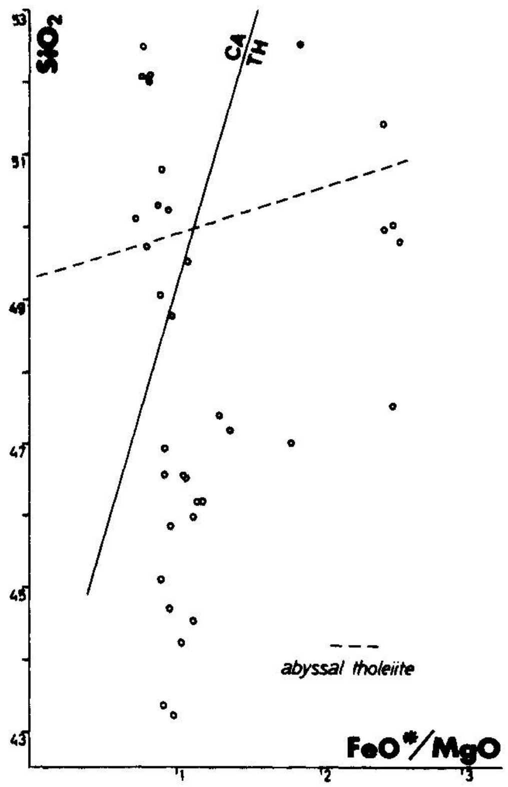


*Fig. 9* Variation of $TiO_2$ content against FeO*/MgO ratio in the extrusive ophiolite rocks. Field of mid-oceanic tholeiites and upper limit of $TiO_2$ in island arc volcanics from MIYASHIRO (1977).

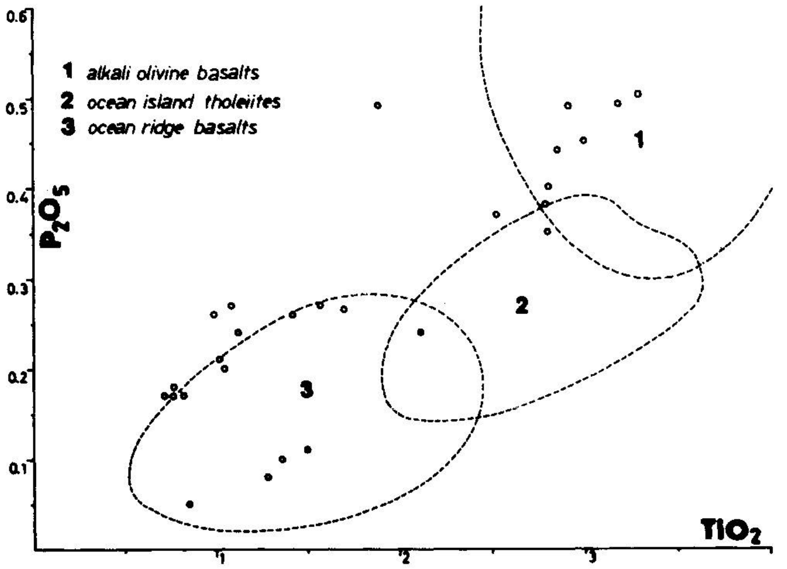


*Fig. 10* $TiO_2$ versus $P_2O_5$ plot of the extrusive basalts on the diagram of RIDLEY and others (1974).

cluster is falling in the field of ocean-ridge floor (MIYASHIRO 1977) and may suggest a formational mechanism of basaltic volcanism similar to spreading centres; i.e. back-arc areas. SUN and NESBITT (1978) relates low-$TiO_2$ lavas to marginal basins with axial spreading. High-$TiO_2$ content is apparently not uncommon in alkaline and subalkaline basalts of back-arc origin (e.g. maximum values of 3.25%: RAFFERTY and HEMING 1979; 2.99%: NICHOLLS and others 1982).

Because the low- and high-$TiO_2$ distribution is not related to an apparent fractionation process, a back-arc area where magma vented to the surface through multiple sources seems to be the most probable tectonic environment. Although $TiO_2$ contents up to 4.58% (East Molokai in Hawaii, BEESON 1976) are common in oceanic islands, $TiO_2$ vs. $P_2O_5$ plot after RIDLEY and others (1974) does not support such a tectonic setting (Fig. 10).

Finally it seems most likely that the Upper Cretaceous extrusive ophiolite basalts could have originated in an extensional back-arc environment where magma either vented to the surface from multiple centres or through multiple conduits, instead of in an axial ridge typifying the interarc basins.

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