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Tectonic Setting and Petrogenetic Evolution of Wadi Erier Rocks, South Eastern Desert, Egypt

Said A. El-Nisr

Geology Department, Faculty of Science, Alexandria University

تطور النشأة الصخرية والوضع التكتونى لصخور وادى عريعر، وسط الصحراء الشرقية، مصر

سعيد عبد الرزاق النسر

كلية العلوم- جامعة الأسكندرية- جمهورية مصر العربية

اعتماداً على الدلائل الجيولوجية والوصفية الصخرية والكيميائية امكن تقسيم صخور وادى عريعر إلى ثلاث طرز وهم: طراز الميتاجابرو- ديوريت، طراز التوناليت- جرانوديوريت وطراز الجرانيت ذو الفلسبار القلوى. يتسم طراز الميتاجابرو- ديوريت بصفات ثوليتية إلى كلس قلوية، ميتالومينى وله نسبة مرتفعة من الزر كونيوم إلى الايتريوم ولكن له تركيزات منخفضة من عناصر الزر كونيوم والنيوبيوم. طراز الميتاجابرو- ديوريت نشأ عن طريق الانصهار الجزئى لطبقة الوشاح العلوى. طراز التوناليت- جرانوديوريت له صفات كلس- قلوية مع وجود نزعة تروندجيمية ويظهر سلاسة فى المتجهات المتغيرة على منحنى هاركر. صخور الجرانوديوريت تكونت عن طريق ٦٠% تبلور جزئى للصهير التوناليتى أغلبهم من معادن الفلسبار والهورنبلند. طراز الجرانيت ذة الفلسبار القلوى يتشابه مع مثيليه من السعودية والسودان حيث نتجوا من اعادة الانصهار الجزئى لتجمعات أقواس الجزر المبكرة النشأة.

Key words: *Erier rocks, Geochemistry, tectonic setting, Petrogenesis.*

ABSTRACT

A combination of geologic, petrographic and chemical criteria is used to classify the Erier basement rocks into three suites namely, the metagabbro-diorite (MGD) suite, the tonalite-granodiorite (TG) suite and the alkali-feldspar granite suite. The MGD suite is tholeiitic to calc-alkaline, metaluminous, with

high Zr/Y ratio but having low concentration of incompatible elements (Zr, Nb and Y). The suite was produced by partial melting of mantle wedge at an active continental margin. The TG suite is calc-alkaline to alkaline with a trondhjemitic affinity. It also exhibits metaluminous to slightly peraluminous composition. The granodiorite variety was formed by 60 % fractional crystallization of a tonalitic magma mostly of plagioclase and hornblende with small amount of biotite at a destructive plate margin. The alkali-feldspar granite suite is weakly peraluminous, late-tectonic A2- subtype granites. It resembles the alkali-feldspar granite associations in Saudi Arabia and the Kadaweb post-kinematic granite of the Red Sea Hills in the Sudan that had been produced by partial refusion of the volcanic-arc protolith.

Introduction

The Egyptian Granitoids occupy a significant part of the Nubian-Shield in northeast Africa. The so-called Older Granitoids had been classified by [1] into two phases. The earlier phase is composed essentially of epidiorite (a term proposed by [2] for one of the Metagabbro-diorite complexes) and metagabbros (mainly altered diorites, quartz-diorites, tonalites and trondhjemites). The second phase is a syntectonic to late-tectonic undifferentiated granodiorites to granites.The term grey granite was designated for granitoid rocks ranging in composition from tonalite, granodiorite to adamellite [3, 4]. According to [5] the gabbro-diorite-tonalite suite belongs to the older episode of igneous intrusion (1000-850 Ma) or to the island-arc stage 950-650 Ma [6] which most probably represents the initial stage of the Pan-African orogeny. The successively more fractionated granitic rocks consist of granodiorite and quartz-monzonite 670-620 Ma [7] which correspond to the batholithic phase 640-590 Ma [6]. This granitic series correlates with the Gattarian or Younger Granite group [8]. The fractionated granitic rocks are followed by abundant post-tectonic (590-565 Ma) LIL-enriched Younger Granites [9, 10]. Geochemical and isotpoic studies have shown that an evolutionary trend can be traced from an early, primitive island arc tholeiites to later calc-alkaline suite of transitional -arc or continental-arc character [11, 12, 13].

The studied granitoid rocks at Wadi Erier (24° 39`N and 35° 02`E) lie 46 kms south of Marsa Alam in the Southeastern Desert of Egypt (Fig. 1). This paper illustrates the petrographical and geochemical characteristics and tectonic setting of the granitoid rocks in wadi Erier in order to clarify their petrogenetic evolution.

Geologic Setting

Granitoids with no simple intrusive form are common within the Eastern Desert of Egypt. Their heterogeneous nature together with no sharp contacts suggest that these rocks have a composite form. The early orogenic gabbro-diorite-tonalite complexes are relatively abundant in the Egyptian part of the

Nubian Shield with an age ranging from 987 Ma to 830 Ma [5, 14]. The basement rocks at Wadi Erier were studied by [15, 16].

A combination of geologic, petrographic and chemical criteria is used to classify the studied basement rocks in Wadi Erier into three suites namely: the metagabbro-diorite (MGD) suite, the tonalite-granodiorite (TG) suite and the alkali-feldspar granite suite. The Erier rocks form rugged terrains with high relief where the alkali-feldspar granite is caping and cutting (as apophyses) the MGD and the TG suites. The TG suite occurs as small intrusion within the MGD suite. The contacts between these two suites and the alkali-feldspar granite suite are sharp although local gradational contacts are recorded. Moreover, xenoliths of different shapes (lens and stretches) and sizes are frequently encountered in the granodiorite variety. Numerous basic and intermediate (porphyrtic variety) dykes and quartz veinlets are cutting the MGD and the TG suites. Faults are noticed in the study area, having NW and NE general trends parallel to the gulfs of Aqaba and Suez, respectively.

Petrography

Based on field observations, petrographic and chemical studies, the investigated Erier rocks can be divided into three rock suites.

Metagabbro-diorite (MGD) suite of Wadi Erier consists essentially of plagioclase, amphibole and variable amounts of pyroxene, biotite and quartz. Sericite, epidote, uralite and chlorite are alteration products, whereas, apatite, sphene, zircon and iron-oxides are intercumulus accessory minerals.

Plagioclase feldspar occurs mainly in two distinct types. The first type is coarse-grained euhedral to subhedral prismatic crystals which vary in composition from labradorite to andesine (An54- An34). They are normally zoned and moderately to highly altered to sericite and epidote, especially in the cores. Albite-carlsbad twinning and deformation features (e.g. undulatory extinction, bent crystals) are commonly observed. The second type is randomly oriented small euhedral laths enclosed in the hornblende crystals as post cumulus crystals.

Amphibole occurs as brownish-green hornblende of prismatic crystals exhibiting simple twinning and is partly to completely altered to biotite and/or chlorite. Hornblende crystals contain poikilitic inclusions of plagioclase, apatite, sphene and iron-oxides. Secondary amphiboles are represented by mantled-rim hornblende and uralite around augite core, especially in the more mafic varieties of the MGD suite. Augite is restricted to the most mafic members of the suite. It occurs as small anhedral short prismatic crystals, highly altered to uralite and rimmed by hornblende. Biotite increases in abundance towards the diorite variety forming primary fine brown flakes clustered in a nest-like shape and they are occasionally altered to chlorite. Quartz mainly occurs in some diorite samples as graphic, seive-like texture in the hornblende crystals, or as interstitial grains between the mineral constituents.

Tonalite-granodiorite (TG) suite consists of plagioclase feldspar, biotite, quartz, amphibole, pyroxene and K-feldspar as essential constituents, but in variable proportions. Accessory minerals are represented by sphene, apatite and iron-oxide minerals.

Plagioclase feldspars are represented by subhedral prismatic andesine to oligoclase crystals, moderately altered, zoned and commonly twinned according to the albite-carlsbad law. Biotite, the dominant mafic mineral in the granodiorite variety, is represented by straw yellow to dark brown flakes that tend to cluster in a nest-like shape and is sometimes altered to chlorite. Quartz is relatively abundant in this rock suite and occurs as fine grains and coarse anhedral crystals with numerous fractures that are filled with iron-oxides. Amphibole is represented by green hornblende crystals enclosing quartz granules and is highly altered to biotite. Augite occurs only in the tonalite variety and is highly altered to uralite and mantled by hornblende. Potash-feldspar is restricted to the granodiorite variety and illustrates perthitic texture. Sphene, zircon and iron-oxide minerals are not common in the TG suite.

Alkali-feldspar granite suite consists of plagioclase, K-feldspar, quartz and biotite. Other mineral constituents include sericite, clayey minerals and chlorite as alteration products. Iron-oxide minerals, sphene and zircon are common accessories. Plagioclase occurs as short prismatic subhedral to anhedral crystals of oligoclase with composition (An7). It shows different grades of deformation and alteration effects. Sometimes, plagioclase encloses some quartz and iron-oxide grains.

Alkali-feldspar occurs as large subhedral to anhedral orthoclase crystals, partially altered and highly perthitized (patch and flame types). Sometimes, it encloses quartz and iron-oxide grains. Anhedral microcline crystals are rarely observed. Quartz occurs in two distinct sizes. The coarser one is anhedral and exhibits wavy extinction. The smaller size variety is represented by anhedral grains that fill in between the other mineral constituents. Biotite is represented by brownish-green flakes, partly altered to chlorite (especially along the cleavage planes) with excretion of sphene and iron-oxide granules.

Geochemistry

Analytical Techniques

Twenty three representative samples collected from the Erier granitoid rocks were analysed by a fully automated Philips PW 1404 X-ray fluorescence spectrometer (XRF) to determine their major and trace element contents. International standards with the recommended values of [17] were used for calibration. Major elements were determined from glass discs prepared by the method of [18], while the trace elements were determined from pressed powdered pellets with boric acid as a backing material. All chemical analyses were carried out at the Geology Department, Bergen University, Norway.

Petrochemical Characteristics and Classification

Major and trace element analyses of the studied rock suites of Wadi Erier (Fig. 1) are presented in Table 1 together with their average chemical compositions and some geochemical parameters.
Geochemical classification diagrams (Fig. 2 A, B) after [19, 20], reveal that the investigated Erier basement rocks show wide compositional variations from gabbro to the alkali-feldspar granite. The nomenclature is more or less consistent with the field and the petrographic study.

Major and trace element variations

Most major and trace elements in the investigated suites exhibit a more or less smooth variation trends with increasing SiO_2 (Fig. 3), a feature that can be interpreted by simple fractional crystallization. However, the MGD samples illustrate somewhat scattering and are shifted away from the typical trend, especially with respect to P_2O_5, TiO_2, Rb, Sr and Ba probably due to the cumulus apatite, iron-oxides and plagioclase. Despite the scattering of the MGD samples, the cafemic oxides (CaO, Fe_2O_3*, MgO, TiO_2 and P_2O_5) decrease with increaseing silica (Fig. 3A). This reflects the earlier crystallization of pyroxene and/or olivine and plagioclase. There is also a general increase in the lithophile elements Rb and Ba and a decrease in Sr and the compatible elements Co and V from MGD to TG suites (Fig. 3B). Initially, La and Ce more or less increase with silica in the MGD and then decrease with respect to the TG suite. Such behavior is compatible with the late-stage removal of these elements by minor mineral phases such as sphene and zircon.

Incompatible Trace element Patterns

The volcanic-arc characters of the investigated Erier rocks can be noticed on the MORB normalized diagram (Fig. 4) after [21]. In this diagram, the LILE,s (K, Rb, Ba) enrichment and the HFSE (Nb, Zr, Y) depletion together with the negative Nb anomaly characterise magmas erupted at destructive plate margins [22, 23]. A positive Sr anomaly is displayed by the MGD suite (Fig. 4 A, B) which can be attributed to cumulus plagioclase, while the negative Sr anomaly shown by some granodiorite samples and alkali-feldspar granite suite (Fig. 4 D, E) is due to K-feldspar fractionation.

Magma Type

On the AFM diagram (Fig. 5A) the investigated Erier rocks follow the calc-alkaline trend defined by [24]. The alkali-feldspar granite suite falls in a distinctive field stretched along the total-alkali -iron side.The calc-alkaline affinity of both the MGD and the TG suites is also recognized in the K_2O-Na_2O-CaO diagram (Fig. 5B) after [25]. Some tonalite and granodiorite samples have trondhjemitic affinity due to their low K2O contents and K2O/Na2O ratios (Table 1). The alkali-feldspar granite suite is clustered near the K2O-Na2O side (Fig. 5B) with no definite trend. The metaluminous nature of the studied MGD suite (A/NCK < 1) is defined in (Fig. 5C) while the TG suite has metaluminous to slightly peraluminous character (A/NCK 0.9-1). The alkali-feldspar granite suite has weak peraluminous composition (A/NCK 1- 1.1, in Fig. 5C).

Tectonic Setting

The TiO2- Zr diagram of [26] shows the Erier MGD suite plots in the field of arc-lavas (Fig. 6A). The volcanic-arc and within-plate settings of the studied TG and the alkali-feldspar granite suites are shown by using the Rb vs Y+ Nb diagram (Fig. 6B) after [27]. The alkali-feldspar granites show the chemical characteristics (e.g. high Nb, Y, and low MgO, CaO, Rb and Sr as shown in Table 1) of A-type granites of [28, 29] and specifically belong to the A2-subtype granite (orogenically-related A-type according to [30] (Fig. 6C). The transitional tholeiitic to calc-alkaline to alkaline nature of the MGD, TG and the alkai-feldspar granite suites (Fig. 5A, B) together with their high Zr/Y ratio suggest that the investigated rocks were produced in subduction-related environments but at different stages. This is clearly shown on the R1-R2 multicationic diagram (Fig. 6D) after [31]. The MGD and the TG suites fall at the destructive plate margin (Fig. 6D) while the alkali-feldspar granite suite is clearly related to the late-orogenic magmatism.

Discussion

As discussed above, the examined MGD suite shows the geochemical characteristics of the subduction-related magmatism. It exhibits low concentrations of incompatible elements (Nb, Zr and Y), display tholeiitic to calc-alkaline affinity and has metaluminous character with the geochemical signature of primitive to normal continental-arc setting (Fig. 7A). Hence, the geochemical characteristics described above suggest that the MGD suite is mantle-derived origin.

The MGD suite has resulted by emplacement of arc-related gabbroic magma which was previously produced by partial melting of mantle wedge. It is later modified by hydrous fluids enriched in LILE derived from the subducted oceanic crust [30]. Hence, the MGD suite can be considered as an independent magma that was probably emplaced in the cores of contemporary island arcs. Most of the early Pan-African (900-800 Ma) gabbro-tonalite associations [5, 14] exposed at some parts of the Nubian Shield were probably produced by similar processes.

The petrochemical characteristics of the TG suite reveal that it has calc-alkaline character with a trondhjemitic affinity (Fig. 5A, B), metaluminous to slightly peraluminous character (Fig. 5C) and generated in subduction related tectonic setting. Also, the TG suite straddles the normal calc-alkaline continental arc field (Fig. 7A) after [33]. The smooth geochemical variation trends from tonalite to granodiorite varieties (Fig. 3) and the zoned plagioclase crystals together with the decrease of CaO/Y ratio from tonalite to granodiorite varieties, suggest that the fractional crystallization is the major process responsibole for generation of the granodiorite rocks from the tonalitic magma.

The least squares petrographic calculation program GEMIX [34] was applied to constrain the fractional crystallization model for the investigated tonalitic magma as a source for granodioritic magma. Table 2 shows the results of calculations and composition of fractionating minerals used in this model.

The results show a close match (R2 = 0.48) between the calculated and the observed parents major elements values. The most evolved granodioritic magma can be produced by 60 % fractional crystallization of the tonalitic magma. The mineralogical composition of the fractionating phases is 50.12 % hornblende, 37.44 % albite, 6.41 % biotite, 5.29 % anorthite and 0.71 % apatite. The low values of the sum of the squares of residual (R2 = 0.48) indicates a good fit. A parental magma of intermediate composition (tonalitic) as the source for calc-alkaline granites has been advocated by [35, 36].

The petrochemical characteristics of the investigated alkali-feldspar granite suite show that it is weakly peraluminous, late-tectonic and A2- subtype granites related to the culmination of the arc-development.The alkali-feldspar granite magma may be formed by different processes, 1- Partial melting of granulitic lower crust [29, 28], 2- Partial melting of tonalitic source [37, 38], 3- Fractional crystallization of basic magma, 4- Late-magmatic fluid transfer, 5- Crustal fusion model as proposed by [28]. The investigated alkali-feldspar granite suite more or less resembles the alkali-feldspar granite associations of Saudi Arabia [39] and the Kadaweb post-kinematic granite, Red Sea Hills, Sudan [40] as seen in figure (7B). The latter two granite associations have A-type characteristics and were derived by crustal melting of island-arc assemblages. Hence, the investigated late-tectonic alkali-feldspar granite suite had been derived from magma produced by partial refusion of the volcanic-arc protolith.

Conclusion

A combination of geologic, petrographic and chemical criteria is used to classify the studied Erier rocks into three suites namely, the metagabbro-diorite (MGD) suite, the tonalite-granodiorite (TG) suite and the alkali-feldspar granite suite. The MGD suite is tholeiitic to calc-alkaline, metaluminous (A/NCK < 1) and exhibits low concentrations of incompatible elements (Zr, Nb and Y) together with high Zr/Y ratio. These chemical features characterize the volcanic-arc lavas produced at destructive plate margin. Hence, the MGD suite resulted by the emplacement of a primary melt produced by partial melting of mantle wedge at an active-continental margin.

The tonalite-granodiorite suite has calc-alkaline character with trondhjemitic affinity, metaluminous to slightly peraluminous (A/NCK 0.9-1), and follows the normal calc-alkaline lavas produced at destructive plate margin. The investigated granodiorite variety is comagmatic with the tonalitic one, since they lie on the same trend on Harker variation diagram. Hence, the granodiorite has been formed by 60 % fractional crystallization of tonalitic magma mostly of plagioclase and hornblende at destructive plate margins.

The alkali-feldspar granite suite consists of leucocratic, K-rich granites (4 % K_2O, on average), weakly peraluminous (A/NCK > 1), late-tectonic magmatism of A2-subtype granites related to arc-magmatism. The investigated alkali-feldspar granite suite more or less resembles the alkali-feldspar granite associations in the Saudi Arabia and the Kadaweb granite in the Sudan that were produced by partial refusion of the volcanic-arc protolith.

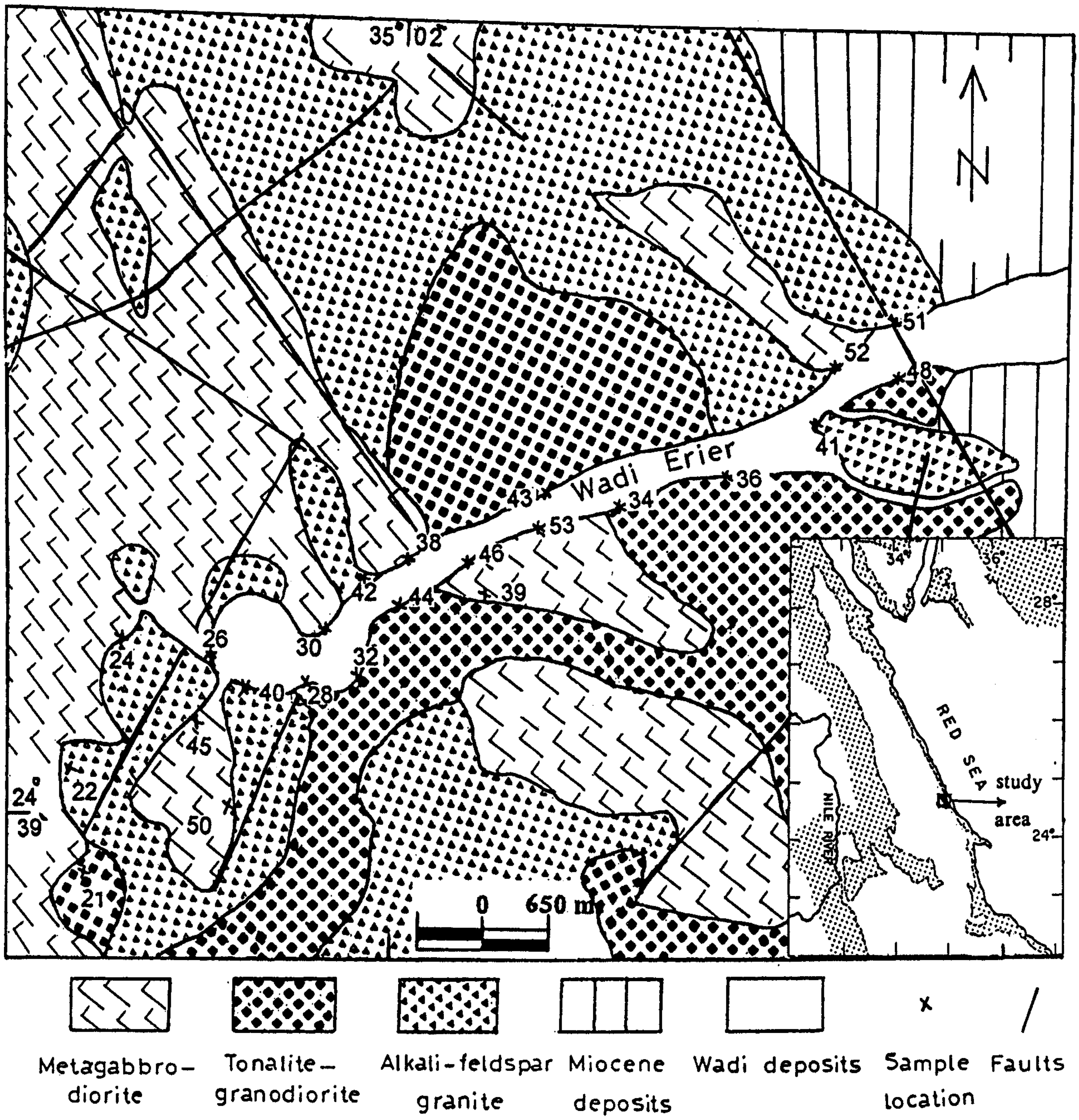


Fig. 1: Modified geologic map of wadi Erier granitoid rocks in Hamata sheet, scale 1: 500 000 after Conoco (1987) [41].

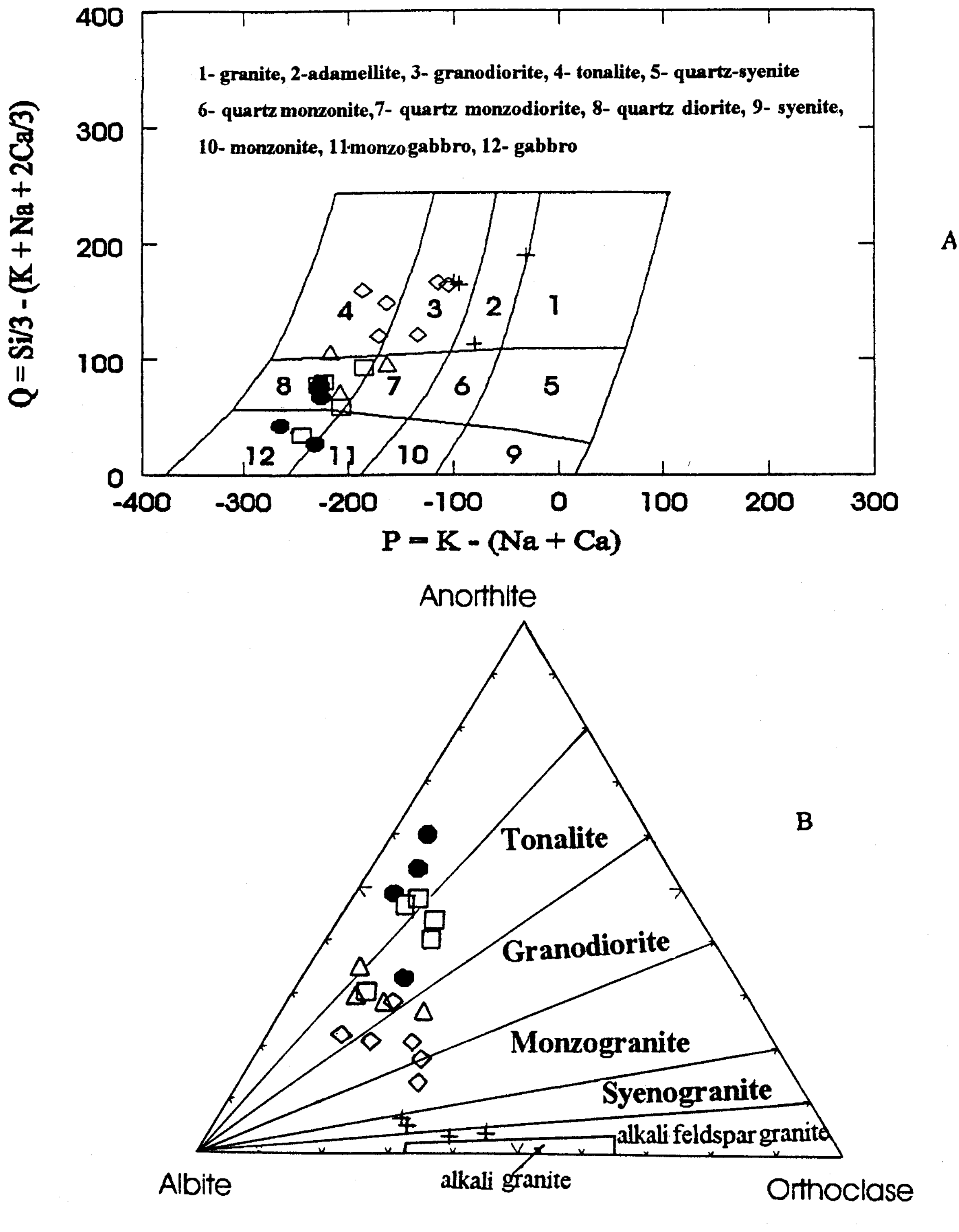


Fig. 2: Chemical classification diagrams for Erier granitoid rocks.
A: after Debon and Le-Fort (1983).
B: after Streckeisen (1976).
Filled circle: gabbro, open square: diorite, open triangle: tonalite, open rhomb: granodiorite, cross: alkali-feldspar granite

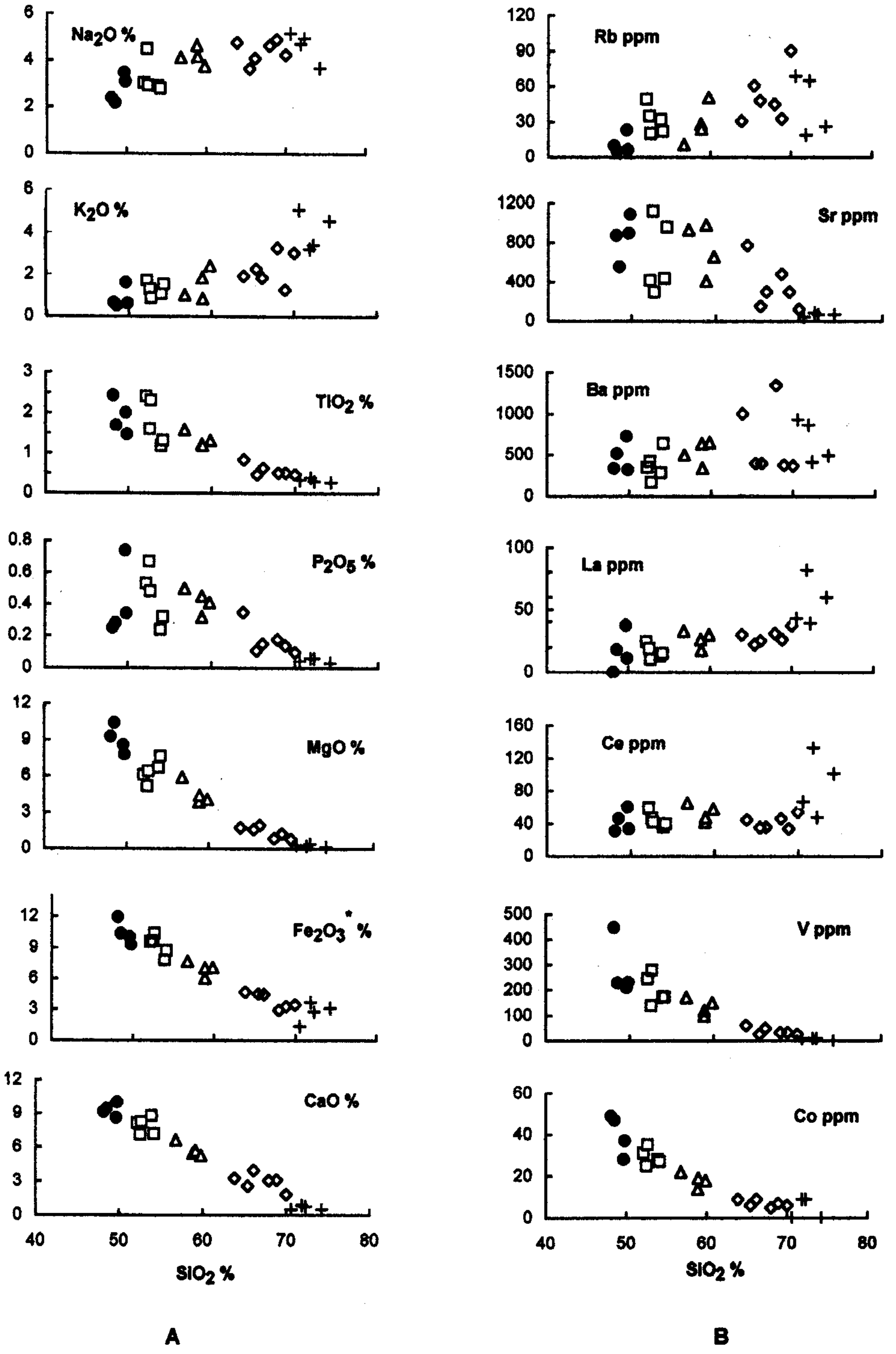


Fig. 3: Harker variation diagrams for Erier granitoid rocks
A: major oxides (%).
B: trace elements (ppm).
Filled circle: gabbro, open square: diorite, open triangle: tonalite, open rhomb: granodiorite, cross: alkali-feldspar granite

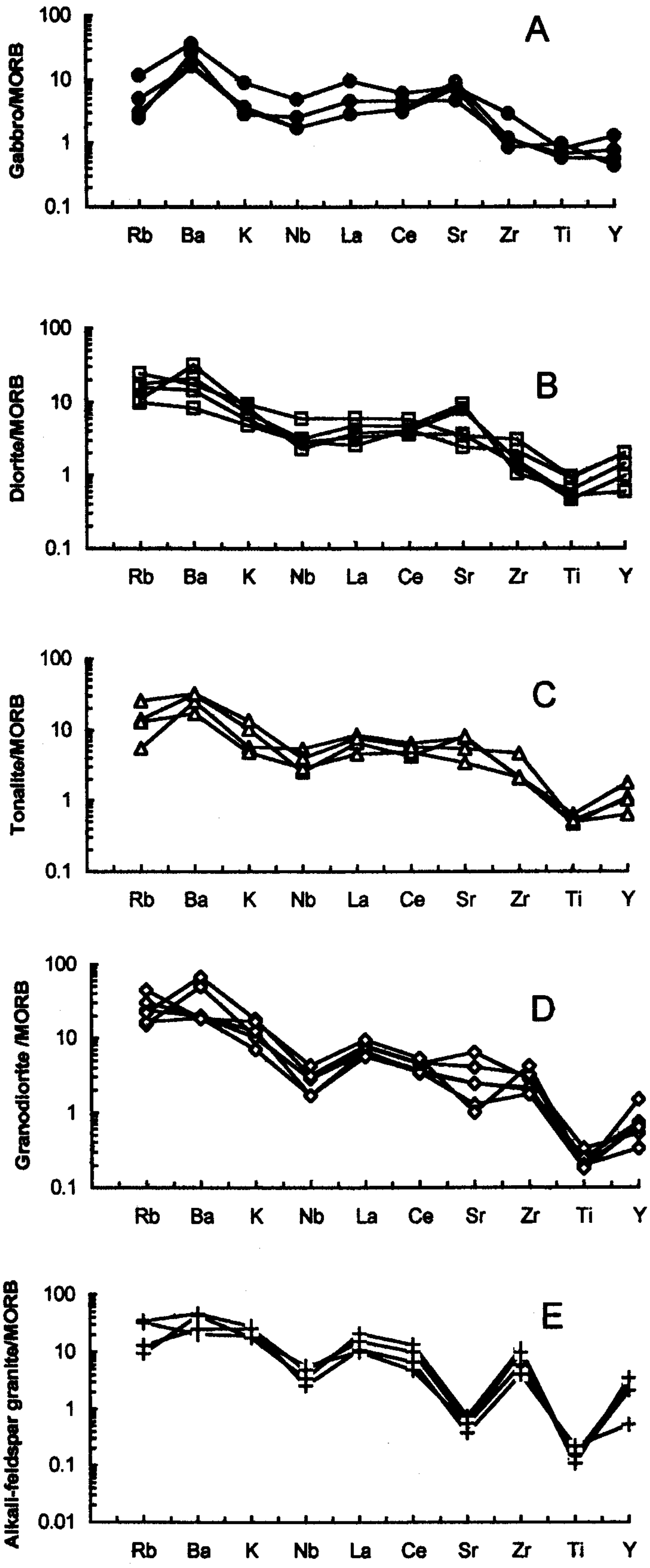


Fig. 4: MORB normalized incompatible trace element patterns for Erier granitoid rocks. MORB values after Pearce (1982).

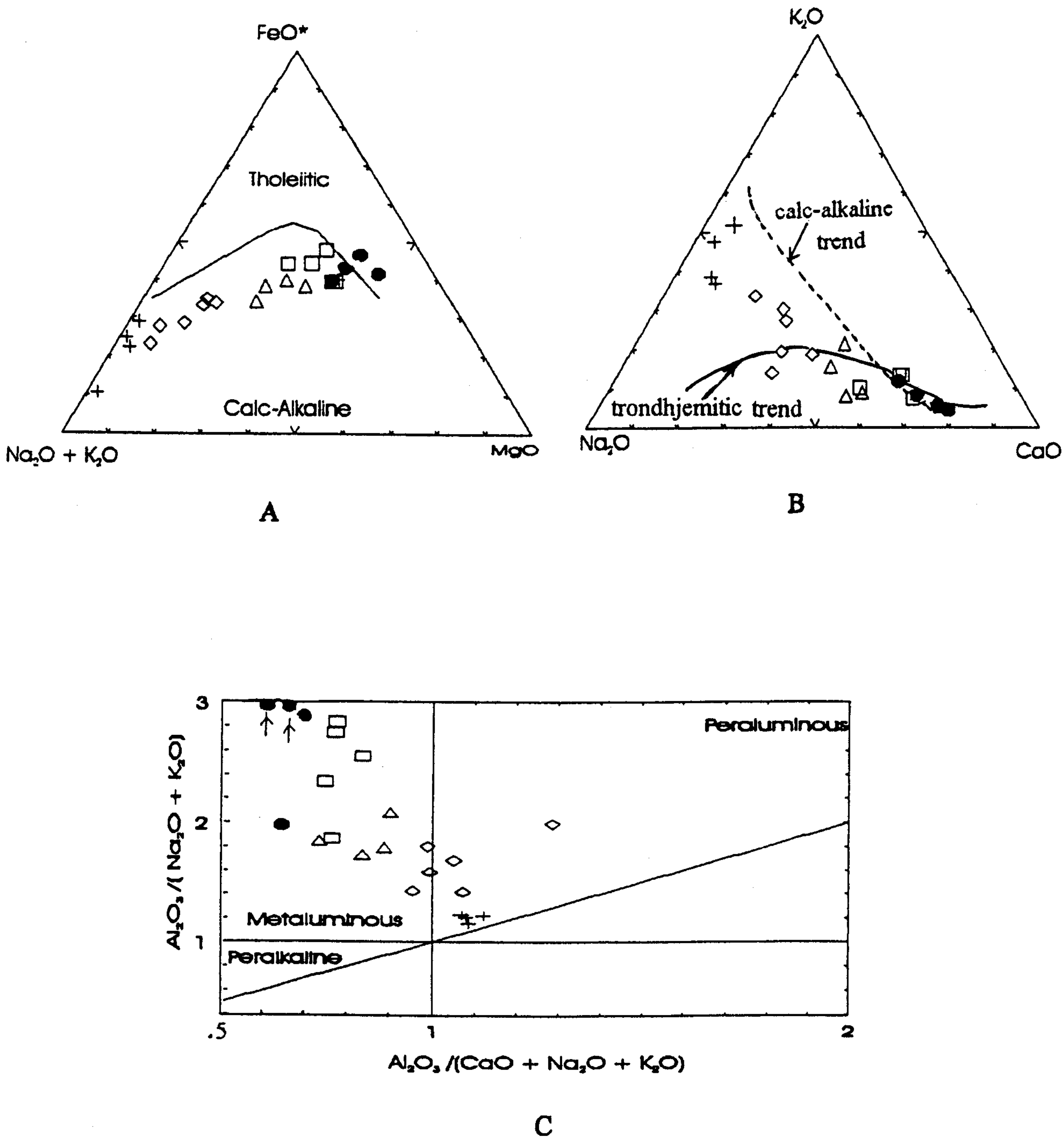


Fig. 5: Plots of the magma type for the Erier granitoid rocks.
A: AFM diagram after Irvine and Baragar (1971).
B: K2O-Na2O-CaO diagram (calc-alkaline and trondhjemitic trends after Barker & Arth 1976).
C: Shand , s index diagram [42].
Filled circle: gabbro, open square: diorite, open triangle: tonalite, open rhomb: granodiorite, cross: alkali-feldspar granite

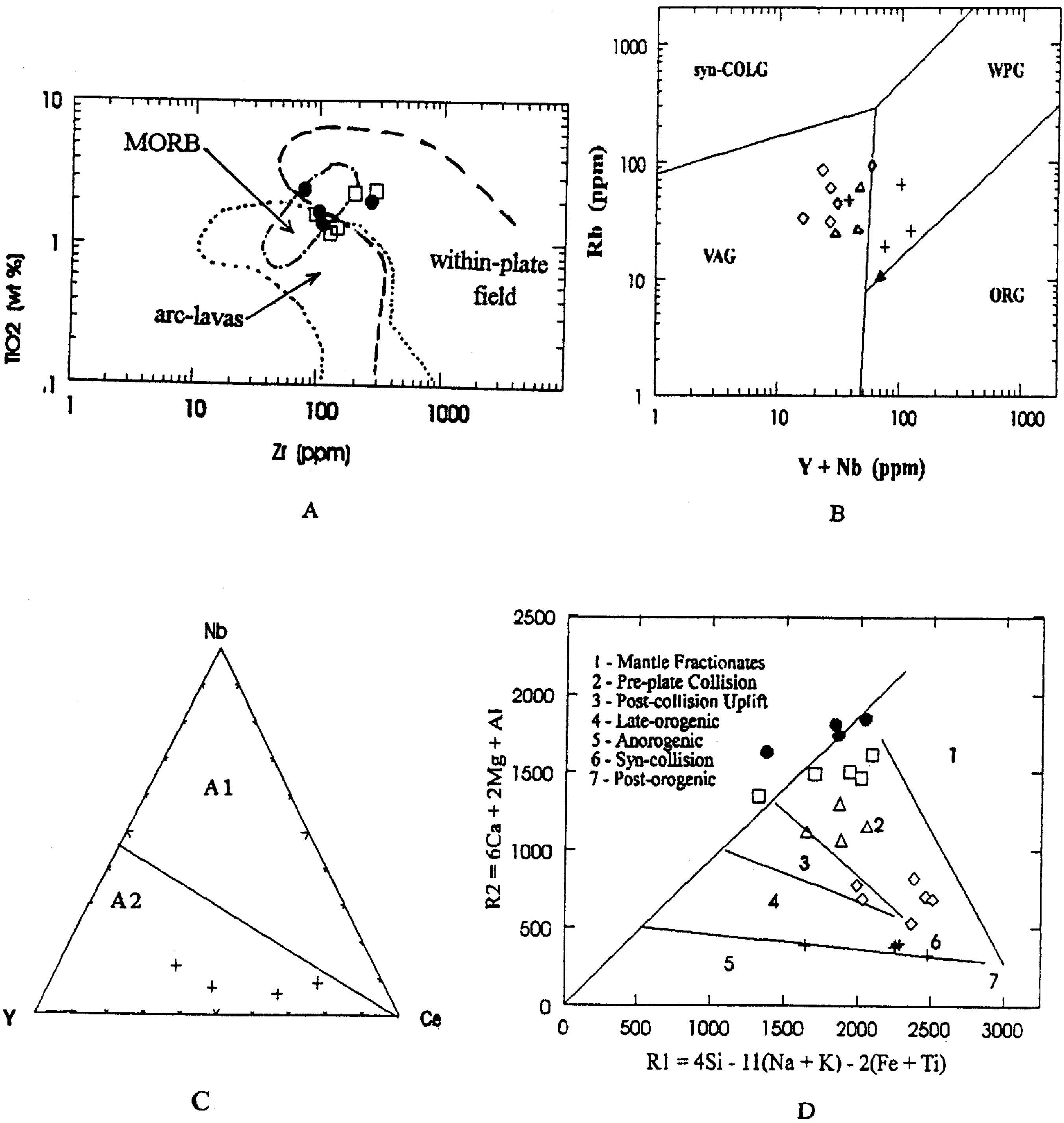
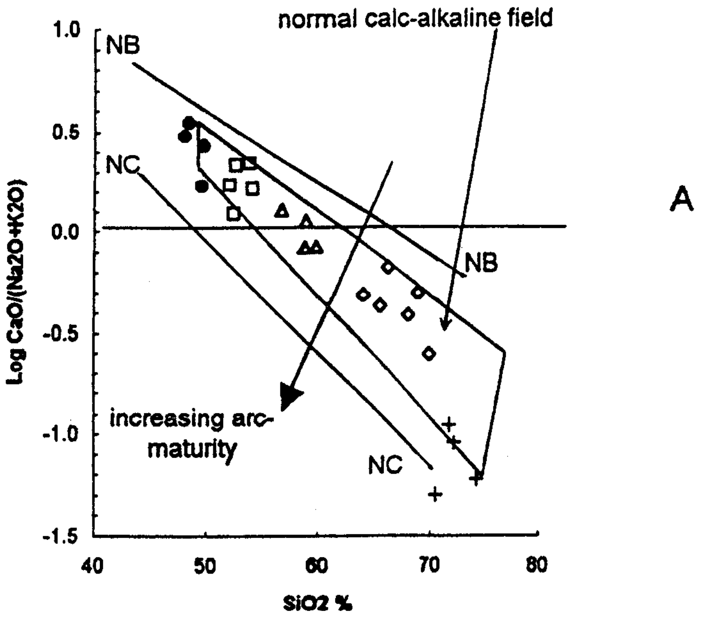


Fig. 6: Tectonic discrimination diagrams for Erier granitoid rocks.
A: TiO2-Zr diagram, after Pearce (1980).
B: Rb-(Y+Nb) diagram, after Pearce et al. [27].
C: Nb-Y-Ce ternary diagram, after Eby [30].
D: R1-R2 multicationic diagram, after Batchelor and Bowden [31].
Filled circle: gabbro, open square: diorite, open triangle: tonalite, open rhomb: granodiorite, cross: alkali-feldspar granite



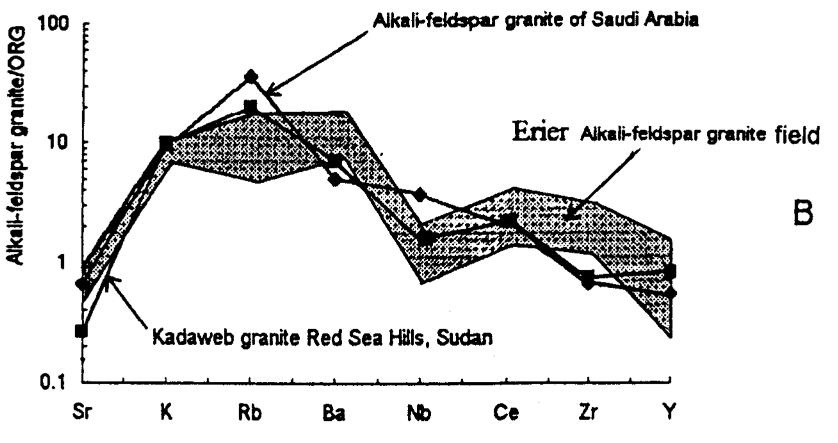


Fig. 7:
A: SiO2- log CaO/ (Na2O+K2O) diagram, after Brown [33].
NB: Primitive-arcs of Solomon Islands [42].
NC: Mature continental-arc of new Guinea [43].
B: ORG-normalized diagram for the Erier alkali-feldspar granite suite.
ORG values after Pearce et al., [27].
B: ORG-normalized diagram for the Erier alkali-feldspar
granite suite. ORG values after Pearce et al. [27]
Filled circle: gabbro, open square: diorite, open triangle: tonalite, open rhomb: granodiorite, cross: alkali-feldspar granite

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