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GEOCHEMICAL INVESTIGATION OF THE BAHI FORMATION IN THE WESTERN PART OF SIRT BASIN, LIBYA

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دراسة جيوكيميائية لتكوين الباهي بالمنطقة الشمالية الغربية ، حوض سرت

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تم دراسة 73 عينة صخرية من أربعة آبار نفطية لتكوين الباهي في المنطقة الشمالية الغربية بحوض سرت. شملت الدراسة التحليل الجيوكيميائي لعدد 26 عنصراً من العناصر الرئيسية الشحيحة والنادرة ، لمعرفة الطابع الجيوكيميائي لهذه العناصر بغرض إعطاء لمحة عن مصدر الصخور ولتسليط الضوء على المؤثرات الرجية (التكتونية) على هذه الصخور.

تبرز الدراسة أهمية توزيع العناصر في تكوين الباهي ، إذ أن النسب العالية لوجود أكسيد السيلكا دليل على درجة نضوج الرواسب في حين أن بعض العينات توجد بها نسب بسيطة من هذا الأكسيد ، ويرجع ذلك إلى وجود مواد مصاحبة مثل مواد كربونية إنهيدراتية وطفلية.

إن الإختلاف في نسبة تركيب أكسيدي البوتاسيوم والألمونيوم يعود إلى الإختلاف في توزيع معدني الفلدسبار والطفل سواء كان عمودي أو أفقي. كما أن وجود النسبة العالية لأكسيدي الكالسيوم والماغنسيوم في الجزء العلوي للتكوين ناتجة من وجود المادة اللاحمة والمتكونة من كالسيت ، ودولوميت وإنهيدرايت. ويرجع إنتشار العناصر الشحيحة والنادرة إلى العلاقة المباشرة بتوزيع أكسيدي الألمونيوم والبوتاسيوم عمودياً وأفقياً.

من تطبيق العلاقة بين العناصر الشحيحة والنادرة يتضح أن رواسب الباهي أتت أساساً من صخور رسوبية قديمة.

كذلك أوضحت العلاقة التميزية بين الأكاسيد أن تكوين الباهي قد ترسب على حافة قارية مستقرة مغطاة بصخور رسوبية ناضجة.

ABSTRACT

Seventy three samples from the Bahi Formation from four boreholes in the western part of the Sirt Basin have been analysed for 26 elements to indicate the geochemical signature of the Bahi Formation. Variation in the major elements and the trace elements both laterally and vertically within the formation have been correlated, to give some indication of the provenance and to throw light on the tectonic setting of the sediment.

Geochemical studies of the major and trace elements distribution within the Bahi Formation showing a high SiO_2 *content, indicate a high degree of maturity in most of the samples whereas* K_2O *and* Al_2O_3 *and most of the trace elements are associated with feldspar and/or clay minerals. The relationship between the various trace elements suggests that the Bahi Formation was derived largely from pre-existing sedimentary sources. The discriminant function analysis of the major elements suggests that the Bahi Formation was derived from a craton interior and/or a passive continental margin.*

INTRODUCTION

The Bahi Formation is defined as a heterogeneous clastic rock succession known only from boreholes. The term Bahi has been used widely and rather loosely in the central and western part of the Sirt basin (Barr & Weegar, 1972). This formation occurs at the base of marine Upper Cretaceous formations. Cenomanian marine sediments have been recorded from concession 32. Maastrichtian strata occur above

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the Bahi in concession 11, 16 and in the southern part of concession 32 (Fig. 1). The formation lies unconformably upon either igneous and metamorphic Precambrian rocks, the Cambro–Ordovician Hofra Formation and the Devonian Tadrart Formation. The Bahi Formation consists essentially of two units, the lower one composed of argillaceous sandstone, and the upper being subdivisible into two tongues of coarse to very coarse sandstone with cross bedding and coarse-grained sandstone respectively, separated by a thin bed of argillaceous red siltstone. Glauconite is common in the uppermost part, but seems to be absent in the lower part (Sghair, 1990).

There have been no geochemical studies of the Bahi Formation. In this study, a detailed investigation of major and trace elements has been carried out. On the basis of vertical and lateral lithological variation of the formation a total of seventy-three samples were selected, 13, 27, 20 and 13 from cores in the A2-32, A4-32, D1-32 and F6-32 boreholes respectively. These have been analysed using an X-ray fluorescence spectrometer (Leake *et al.*, 1969; Harvey *et al.*, 1973). Ten major oxides were determined using XRF (SiO_2, TiO_2, Al_2O_3, $Fe_2^*O_3$ (total), MnO, MgO, CaO, Na_2O, K_2O, P_2O_5), and 16 trace elements (Ba, Ce, Co, Cr, Cu, Ga, La, Ni, Pb, Sr, Th, Y, Zn, Zr, U).

The major oxides FeO, H_2O, CO_2 were determined by wet chemical analysis. The FeO was determined by titration of standard dichromate solution with rock solution made by dissolving a measured amount of whole rock powder (0.5 grams) in sulphuric and hydrofluoric acids. The FeO percentage, determined by titration, was used to calculate the amount of Fe_2O_3 present. The amounts of H_2O and CO_2 in the samples were determined using the Penfield method of combustion, adsorption and gravimetry. The amount of total sulphate (SO_3) was determined by using the gravimetric method.

MAJOR ELEMENTS

Several recent studies have investigated the sedimentary geochemistry of elastic rocks in order to indicate their provenance and geotectonic setting by using variable discriminate functions based on major-element data. Bhatia (1983) used the major oxides $Fe_2O_3 + MgO$, Al_2O_3/SiO_2, K_2O/Na_2O, $Al_2O_3/(CaO+Na_2O)$ and TiO_2 as discriminating parameters to indicate the relationship between the geochemical composition of sandstones and the geotectonic settings of their sedimentary basins. He showed that the nature of continental margins and

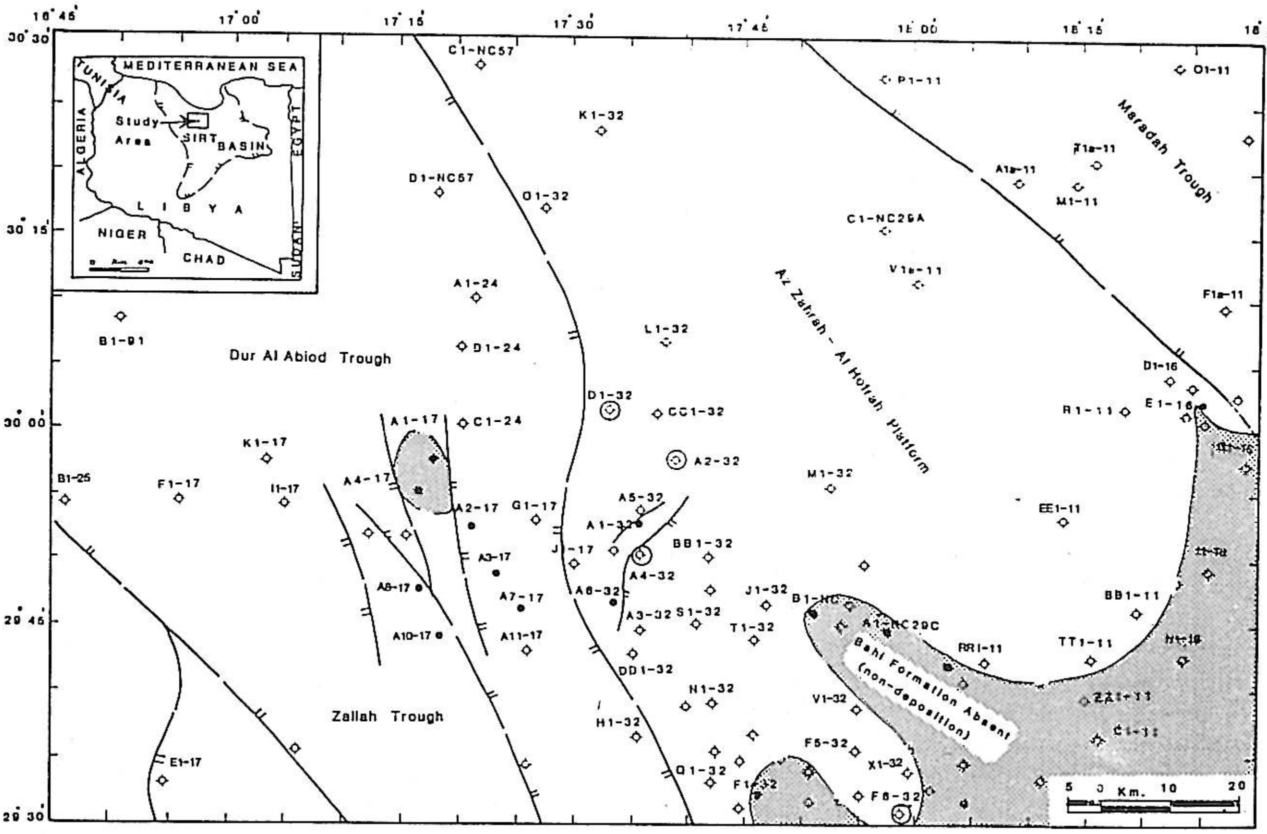

FIG. 1. Location map of the studied area in the western part of the Sirt basin, Libya.

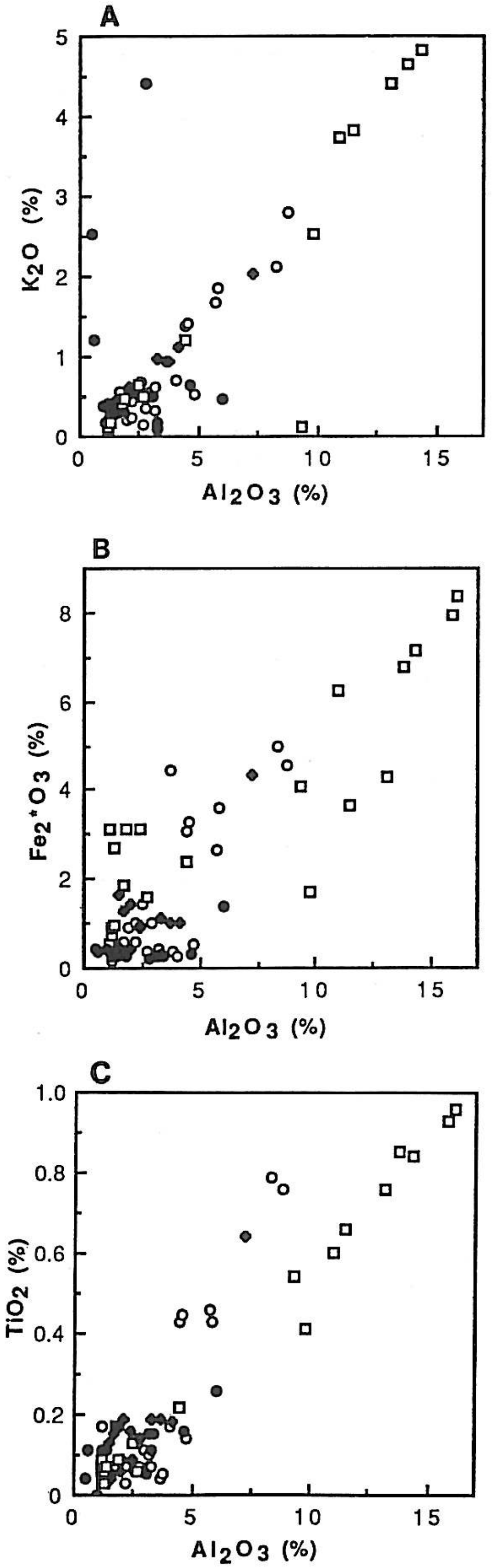

FIG. 2. Plots of Al_2O_3 vs K_2O; Al_2O_3 vs Fe_2^*O (total); Al_2O_3 vs TiO_2; K_2O vs TiO_2 and K_2O vs Fe_2^*O (total).

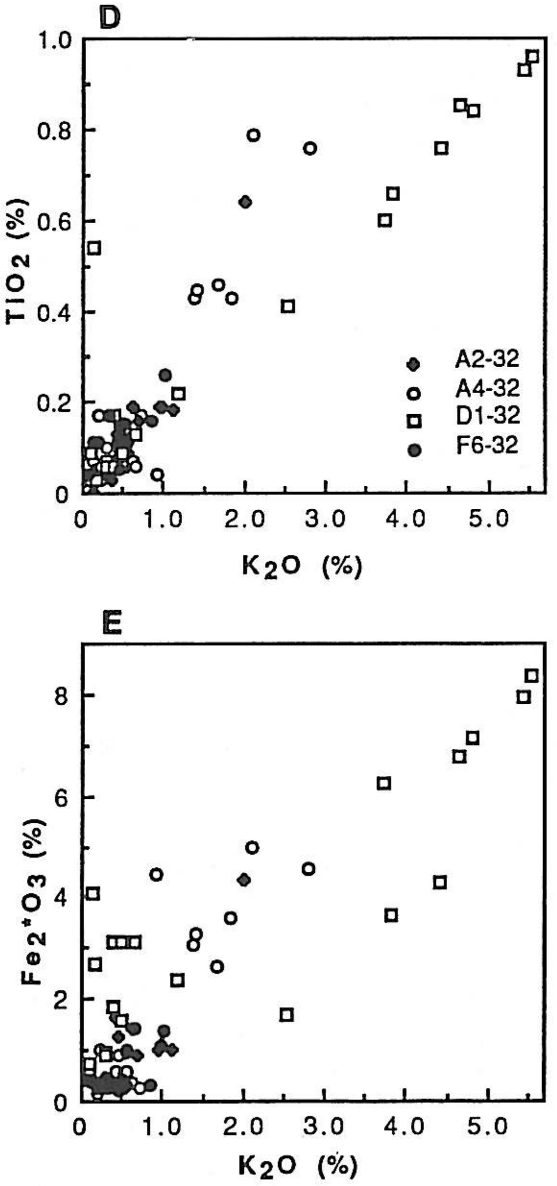

FIG. 2. *Contd.*

ocean basins can be deciphered on the basis of the major element compositions of sandstones.

In this study, the lateral and vertical geochemical variation within the Bahi Formation in the four selected boreholes reflect different mineralogical composition resulting from changes in environmental conditions at the time of deposition and/or different sources for the sediments of this formation.

Major oxides of the Bahi samples from the four boreholes, were plotted against each other on scatter plot diagrams to show the inter-relationships between these elements. The major oxides results show a high content of SiO_2 at the expense of other oxides in most of the studied samples. This suggests a more mature sediment in these samples, whereas in the upper part of the formation at A2-32, D1-32 and F6-32 boreholes, the SiO_2 content is low due to an abundance of evaporites and carbonate as a cement or matrix. In the lower part of the formation the SiO_2 content varies inversely with the clay mineral and feldspar content.

The sources of both Al_2O_3 and K_2O in the sedimentary rocks are feldspars and sheet silicates such as micas and clays. As a result the abundance of Al_2O_3 can be directly related to the abundance of feldspar, mica and clay minerals. A plot of Al_2O_3 versus K_2O (Fig. 2A), shows a strong positive correlation. This suggests the same source for minerals containing these oxides. TiO_2 content in the sediments is due to terrigenous material consisting of: 1- wheathering residue in the form of chemically unaltered grains like rutile, or in the form of partly decomposed minerals like mica, 2- new products of weathering such as anatase and clay minerals, 3- diagenetic minerals (Wedepohl, 1978, 22-k-1). The plots of TiO_2 versus Al_2O_3 and K_2O (Fig. 2C & D), show a poor positive correlation in some studied samples. This suggests that the TiO_2 content is associated with the clay minerals and/or K-feldspar, whereas the majority of the studied samples show very low content TiO_2, suggesting that the titanium content may be concentrated in oxides or non layer silicates, opaques and rutile minerals which have been detected in the Bahi sediment. In most of the samples from the Bahi Formation in the four boreholes, the plots of Al_2O_3 and K_2O versus $Fe_2^*O_3$(total) (Fig. 2B & E), show a positive correlation suggesting that the $Fe_2^*O_3$ content is conentrated in clay minerals and/or feldspar. However, iron oxide is present in replacement minerals in the weathered feldspar and in cement materials.

Most of the calcium in the sedimentary rocks occurs in the carbonate fraction (Wedepohl, 1978, 20-k-1). The detrital components in the form of Ca-plagioclase and accessory minerals such as apatites contain significant amounts of CaO in their crystal structure. The presence of a positive correlation between CaO and CO_2(Fig. 3A), is related to enrichment of the Bahi sediment by carbonate cement composed of varying proportions of calcite and dolomite, whereas some studied samples show high CaO content with very low CO_2. This is undoubtedly related to the presence of evaporites ($CaSO_4$) in the uppermost part of the formation. Magnesium is present in the sediments mainly as dolomite and phyllosilicates such as chlorite and glauconite. Phyllosilicates are mostly present in shales and to a smaller extent in sandstones, graywackes and arkoses (Wedepohl, 1978, 12-k-1), a plot of MgO versus CO_2 (Fig. 3B), shows a positive correlation in most studied samples, suggesting that the amount of MgO is present mainly in a somewhat dolomitic carbonate cement, whereas small amonts of magnesium may indicate the presence of a phyllosilicate (glauconite).

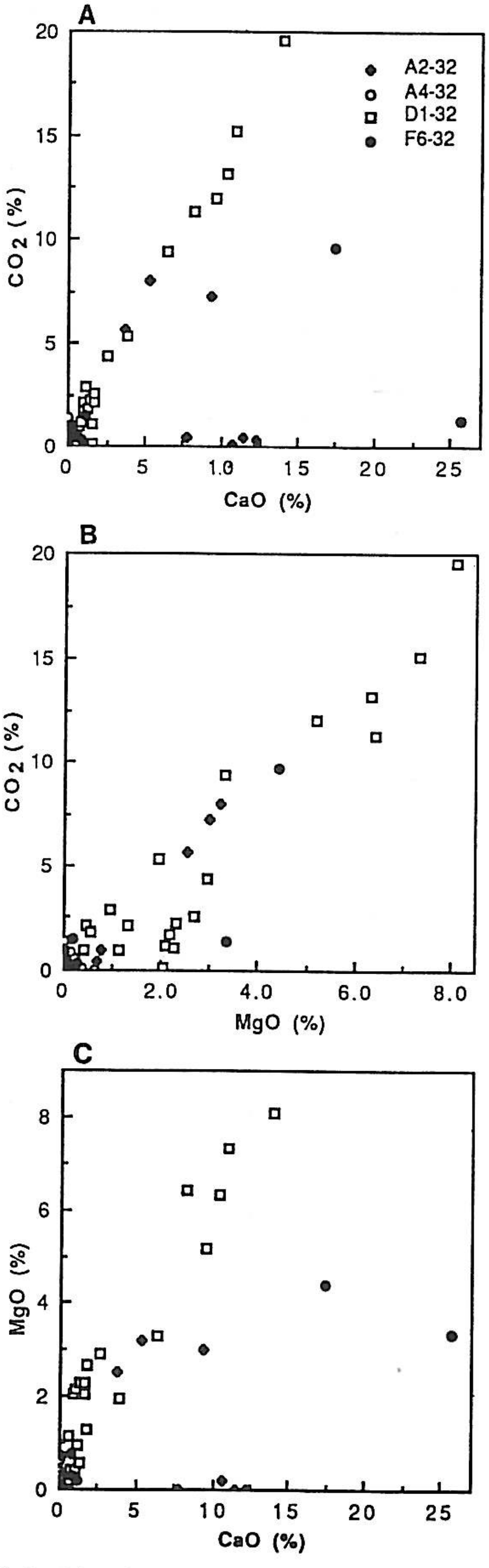

FIG. 3. Plots of CO_2 vs CaO; MgO vs CaO and MgO vs CO_2.

The uppermost part of the formation is rich in glauconite, whilest a plot of CaO with MgO (Fig. 3C), shows two trends which in some samples show a good positive correlation. This suggests that a high content of both oxides is related to an abundance of dolomite whereas in other samples there is a lack of correlation between MgO and CaO. High content of CaO is related to the presence of calcite and anhydrite.

NIGGLI NUMBERS

The use of Niggli numbers can be very useful in distinguishing between K which is derived from detrital feldspar and K from detrital illite, mica or other sheet silicate minerals. The Niggli numbers are based on taking the percentage of the sum of the molecular content of Al_2O_3(al), CaO(c), FeO + Fe_2O_3 + MgO(fm) and $Na_2O + K_2O$(alk).k = $K_2O/Na_2O + K_2O$ (Niggli, 1954, p. 13–15).

A plot of al-alk versus Niggli K has been used to distinguish between K in feldspar and K in sheet silicates such as micas and clay minerals. High al-alk(> 30), indicates clay-rich rocks (shale), whereas low al-alk (< 30) indicates a high feldspar content, supported by negative correlation with Niggli K if the K was largely in potassium feldspar or positive correlation if the K was largely in sheet silicates. The absence of negative or positive correlations suggests that a mixture of the two minerals is present (Van de Kamp & Leake, 1985).

A plot of al-alk versus Niggli K (Fig. 4A), shows absence of negative or positive correlation suggesting that the K occurs in a mixture of both feldspar and clay minerals. Some of the studied samples, show al-alk > 30. This suggests that most of K may be related to the sheet silicates whereas the majority of the samples have al-alk < 30 suggesting that K is represented in a mixture of both feldspars and clay

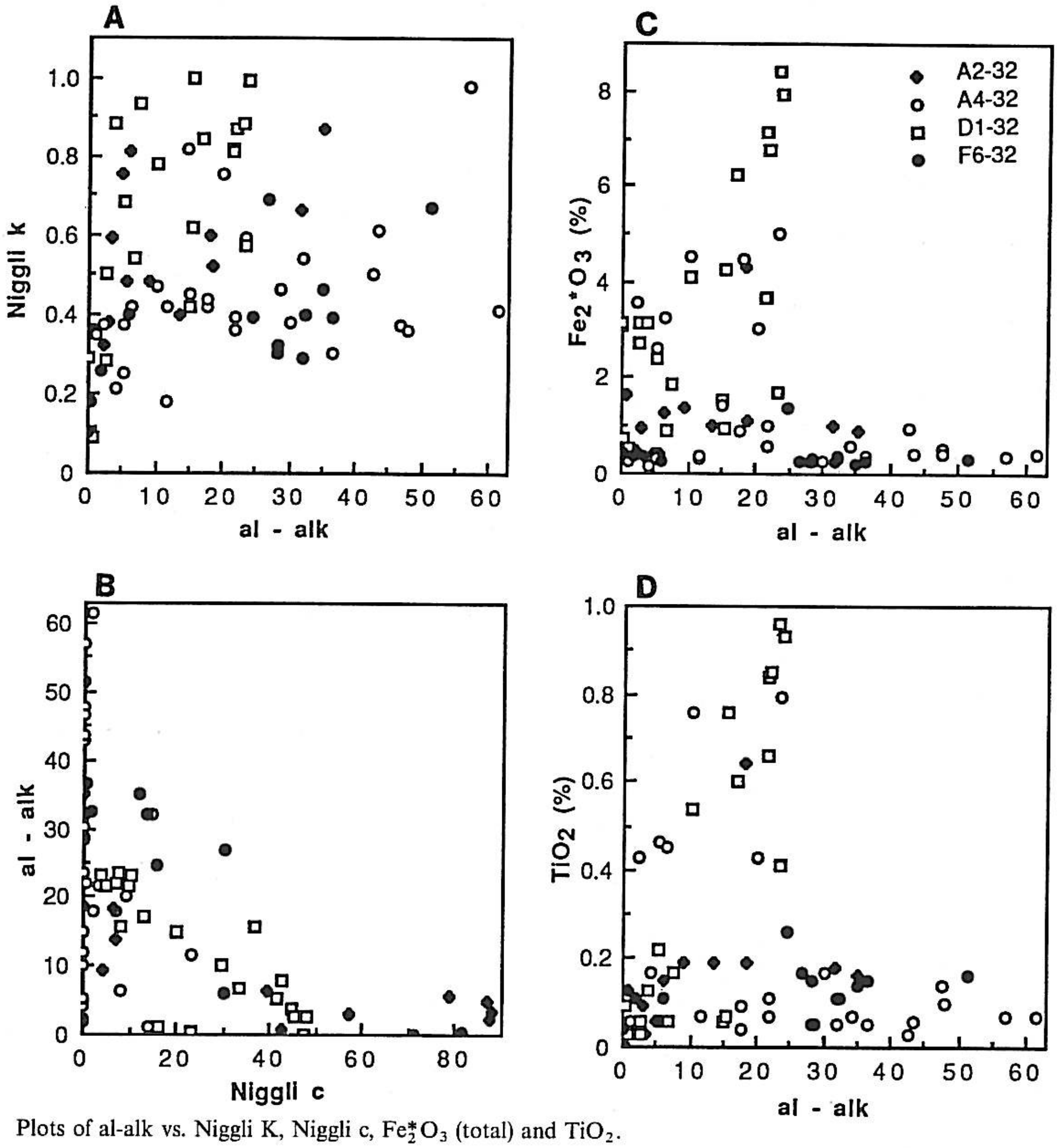

FIG. 4. Plots of al-alk vs. Niggli K, Niggli c, $Fe_2^*O_3$ (total) and TiO_2.

minerals, whereas a plot of Niggli c versus al-alk (Fig. 4B), shows three well defined trends. The dominant trend shows that c is largely related to dolomite (c=50). Another trend shows that c is largely related to calcium carbonate (c=100), whereas some samples show very low content of c (c nearly 0), and this may be related to clay minerals, while the plot of al-alk against $Fe_2^*O_3$ (total) (Fig. 4C), shows two main separate fields. One trend shows a positive correlation suggesting that the $Fe_2^*O_3$ content is largely associated with clay minerals, whereas the other field shows low $Fe_2^*O_3$ content suggesting that Fe may be related to detrital iron oxides and in a plot of al-alk versus TiO_2(Fig. 4D), most of the studied samples show very low content of TiO_2 and an undefined relationship with al-alk. This suggests that the titanium may be present in detrital minerals such as rutile and opaques and to a limited extent in a few samples it is associated with clay minerals giving a poor positive correlation.

TRACE ELEMENTS

Many attempts have been made by various workers to differentiate similar lithological units and to determine the depositional environments of the sediments and their provenance on the basis of trace element distributions. Van de Kamp & Leake (1985) state that the trace elements are useful for provenance determination. They noted that the high values of cobalt, chromium and nickel indicate detritus from mafic and ultramafic sources; barium is a good indicator of a potassium feldspar-rich provenance, and high barium content in arkoses suggests granites and monozonite in the source area. They also showed that most trace elements are concentrated in sheet silicates such as mica and clay minerals; Bhatia and Crook (1983) used the La, Ce, Nd, Th, Zr, Nb, Y, Sc and Co trace elements to distinguish provenance types and tectonic settings; Hickman and Wright (1983) used rare earth elements to determine the provenance of sediments by plotting Y+La+Ce, Ni+Cr and Sr on a triangular diagram; Loring (1981) noted that the concentration of Zn, Cu, Pb, Co, Ni, Cr, V, Se, Hg and Be is low in sands, and increases with reduction in the grain size of sediments; Fenner & Hagner (1967) established a criterion to distinguish between stratigraphical units of similar lithology on the basis of trace element variations. Trace elements have been determined in the analysed samples from the four selected boreholes, in an attempt to understand the characteristics of these elements and their distribution, and to give some indication of the provenance and depositional environment of the Bahi Formation. The following plots of trace elements against each other and versus al-alk may help in this respect.

A plot of K_2O against gallium, lanthanium, rubidium and cerium in the Bahi samples (Figs. 5B, C, E & F), show a positive correlation. This suggests that these trace elements are concentrated in the K-feldspar and/or in the clay minerals, whereas plots of barium, strontium, cobalt, nickel, lead, thorium, uranium, chromium, copper, zinc and yttrium against K_2O do not show any clear correlation. This suggests that they are not concentrated in sheet silicate or K-feldspar. Plots of Al_2O_3 against Ga and Rb in the Bahi samples (Figs. 5A and 5D), show a positive correlation suggesting that gallium and rubidium are mainly concentrated in the clay minerals or in the K-feldspar or in both.

The parameter al-alk provides a measure of the aluminium contained in the clay minerals and micas rather than in the feldspar (Van de Kamp & Leake, 1985). Plots of al-alk against the trace elements lead, chromium, cerium, zinc, yttrium, lanthanium, zirconium and rubidium (Fig. 6), show no positive or negative correlation. This suggests that these trace elements are neither concentrated in the feldspar nor in the clay minerals.

The presence of lanthanium in the sediments is related to an increase in the alkalinity of weathering solutions. It is precipitated and fixed like aluminium, galium and titanium (Wedepohl, 1978, p. 39-57-71-g-l). Cerium content in the sediments could also be due to the increase in alkalinity of weathering solutions. The presence of a positive correlation between lithanium and cerium in the Bahi Formation, suggests that these elements are contributed by the same sedimentary processes, from a source characterized by highly alkaline weathering. Plots of rubidium, yttrium and gallium versus lanthanium (Fig. 7), show a positive correlation. This suggests that these trace elements are largely concentrated in the clay minerals and/or in the feldspar.

Hickman and Wright (1983) used this relationship for the Appin Group slates (late Precambrian Dalradian Supergroup of Scoltand) to suggest their provenance. The Ni and Cr end of the diagram represents provenances composed of basic rocks, the Y+La+Ce end represents a provenance composed of granitic rocks whereas the Sr end represents a provenance containing the highest proportion of sedimentary rocks.

A plot of Y+La+Ce versus Sr for the Bahi Formation samples in the four boreholes (Fig. 8), shows a very distinct trend. Virtually all the samples fall in the Sr sector indicating that the Bahi sediment is largely derived from a preexisting sedimentary source.

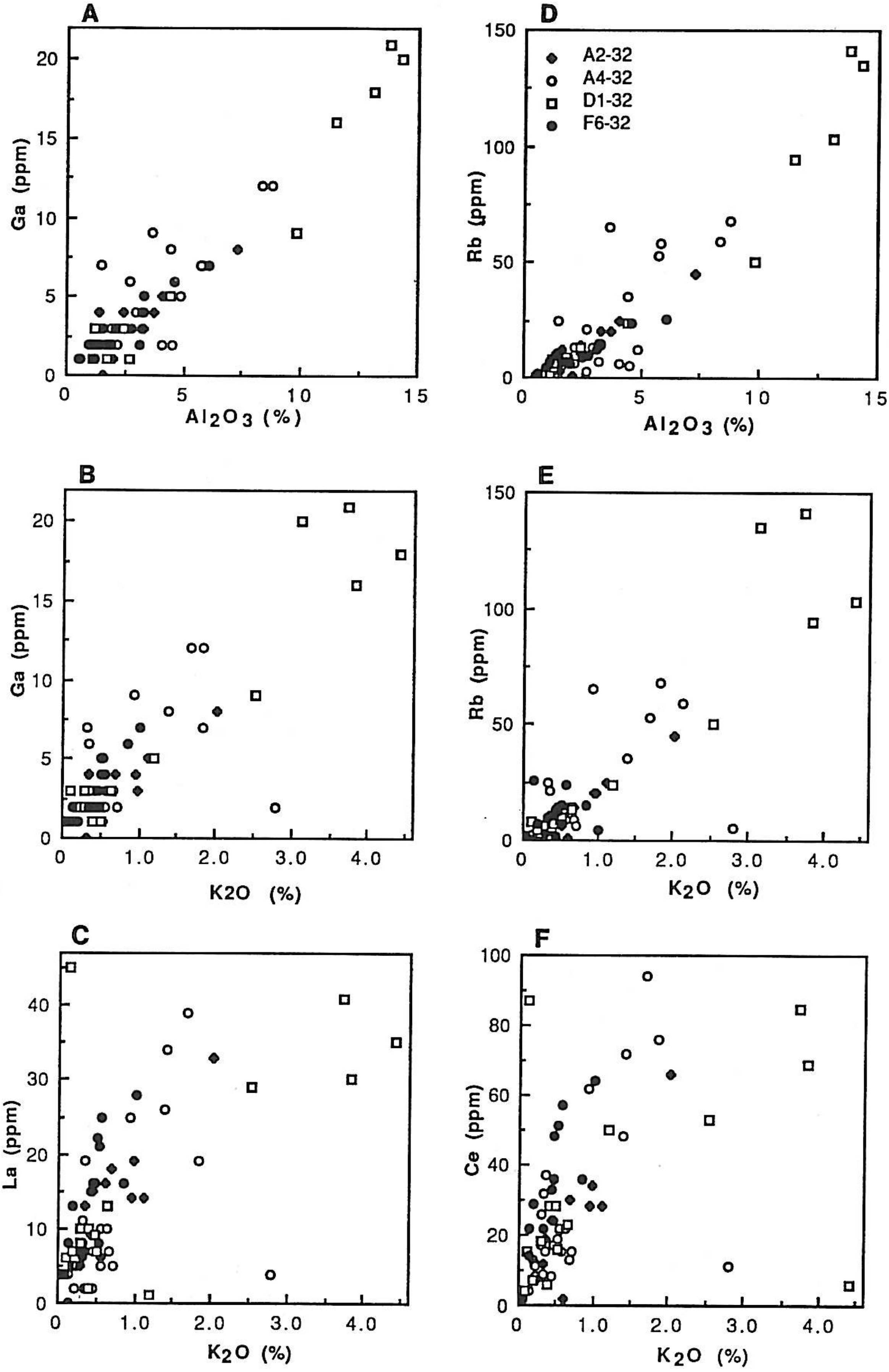

FIG. 5. Plots of Ga and Rb vs Al_2O_3 and K_2O; La and Ce vs K_2O.

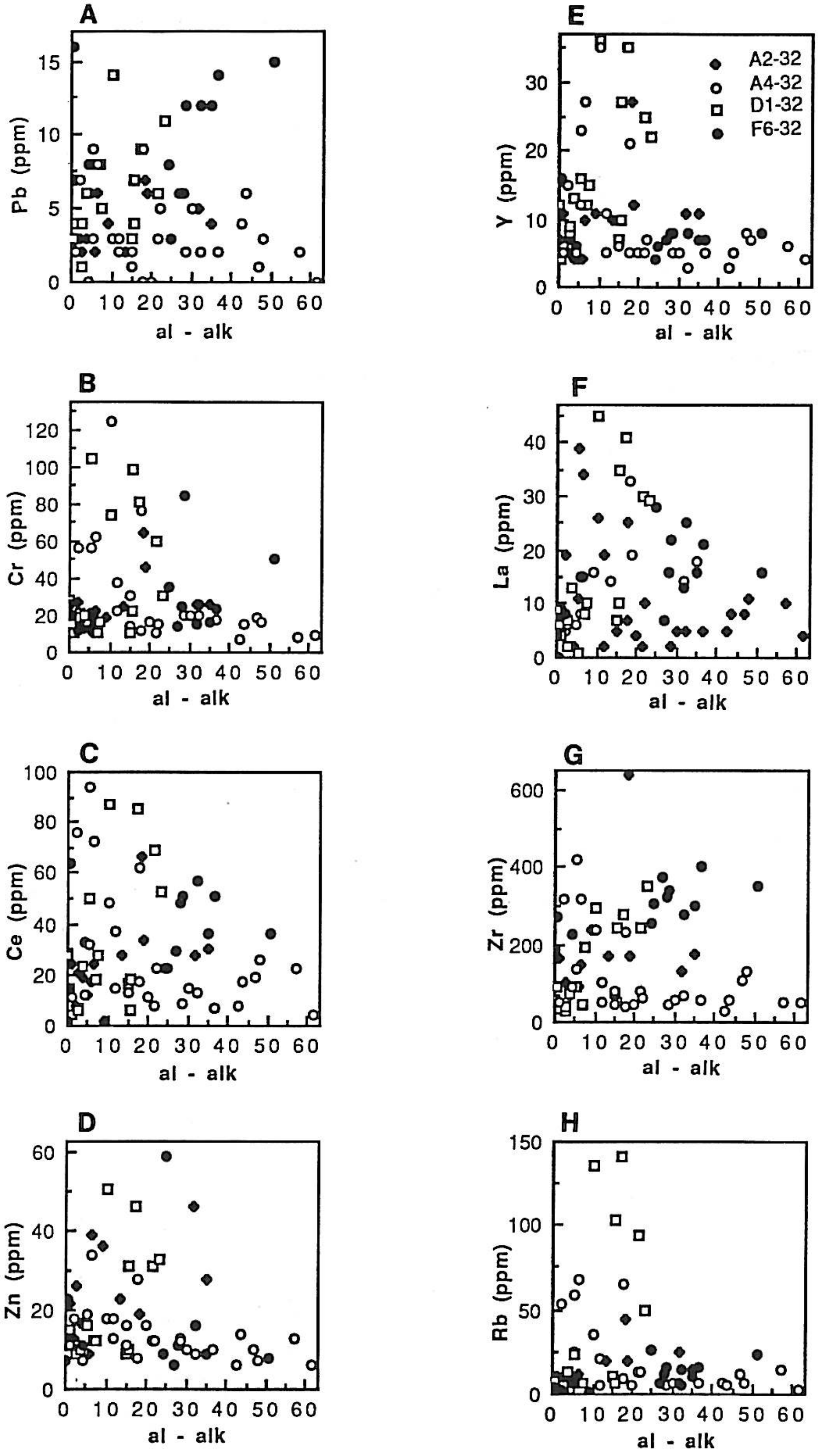

FIG. 6. Plots of al-alk vs pb, Cr, Ce, Zn, Y, La, Zr and Rb.

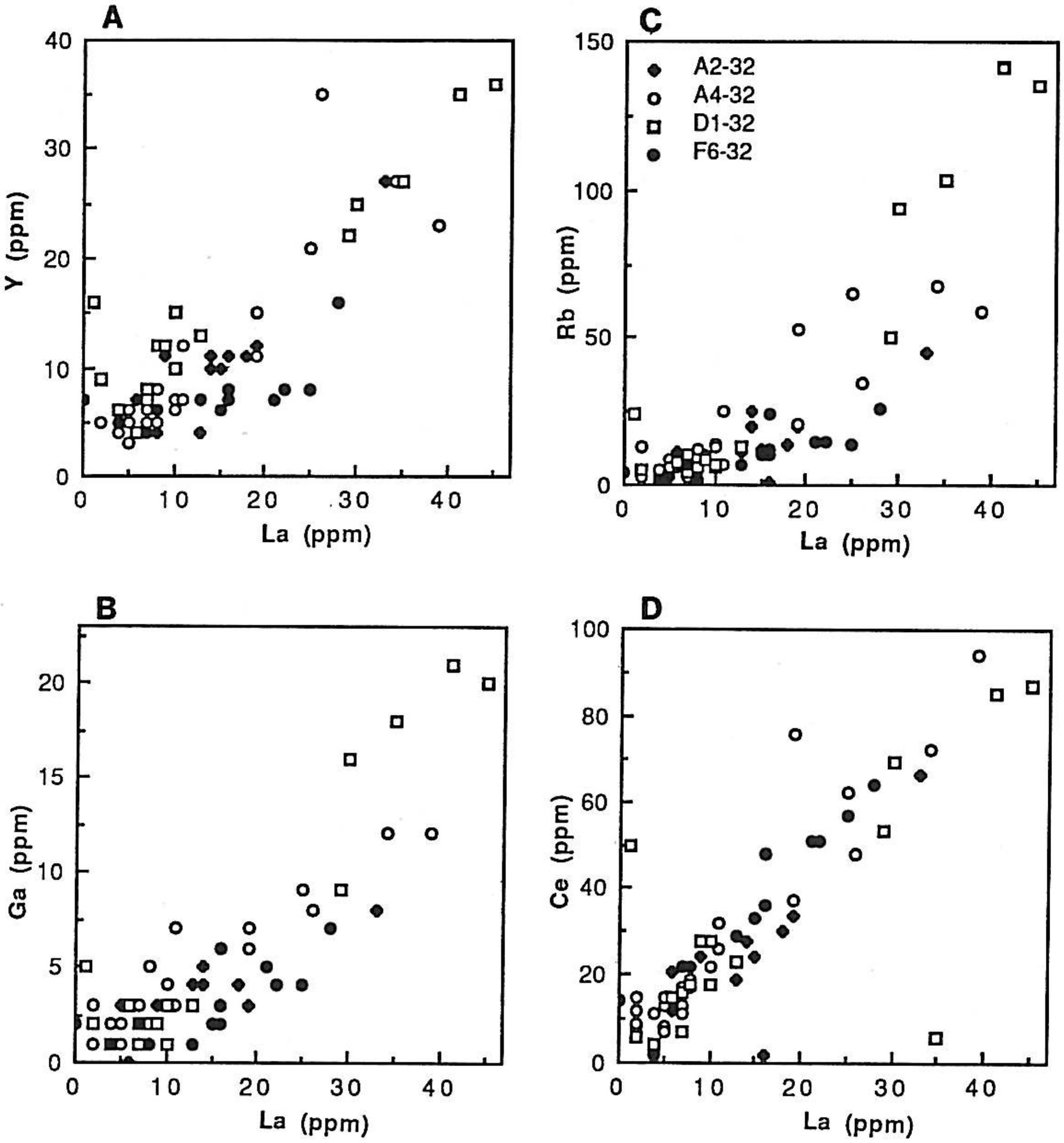

FIG. 7. Plots of La vs Y, Ga, Rb and Ce.

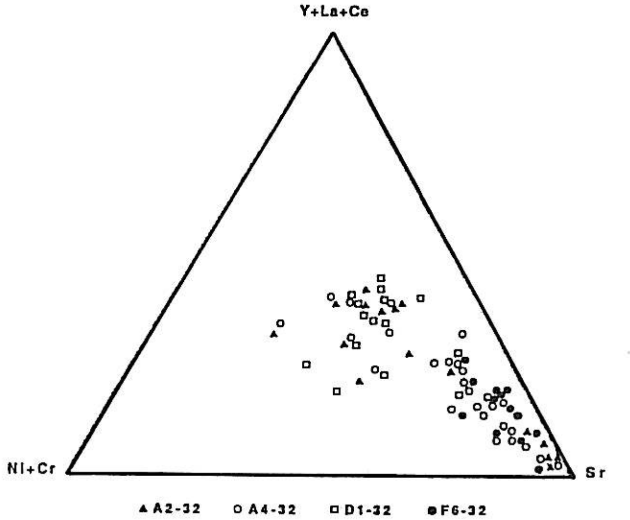

FIG. 8. Plot of Ni+Cr versus Y+La+Ce versus Sr in the four boreholes.

VERTICAL VARIATION OF BAHI GEOCHEMISTRY

The vertical variation in the major element composition, $Al_2O_2Na_2O$, K_2O and $Fe_2^*O_3$ (total) of the Bahi Formation, in the four boreholes, is related to changes in grain size and composition. This may indicate changes in the depositional environment and/or change in sediment provenance. Figs 9A-C, show the vertical distribution of the major elements and the trace elements of the Bahi Formation in boreholes A2-32, A4-32 and F6-32 respectively. In borehole A2-32, the uppermost part of the Bahi Sandstone is characterized by large amounts of clay minerals including chlorite, illite and kaolinite together with glauconite, low silica content, and high portion of the major elements (sample No. 2-1). The upper part of the formation is also characterized by a high CaO content in the form of carbonate and evaporite (samples No. from 2-2 to 2-6) and poor silica content, whereas the lower part of the formation (samples No. from 2-7 to 2-13) (below 1904m) is characterized by smaller grain size, low silica content and also a high proportion of major elements. This reflects a less mature sediment. The high concentration of the trace elements varies inversely with the grain size and thus the maturity of this sediment. However, the concentration of trace elements is high in the samples which show a high proportion of feldspar and clay minerals (Fig. 9A). In borehole A4-32, for a thickness of 7.6m down to 1845m (samples 14-16) and for a thickness of 7m down to 1880m (samples 25-27) there is a reduction in grain size and a compositional change of the Bahi Formation. There is also a decrease in silica content and an increase in other major elements and hence increase in the amount of feldspar and clay minerals. This reflect variation in major elements distribution and indicate relative mineralogical maturity of the Bahi sediments for these intervals (Fig. 9B). There is also a

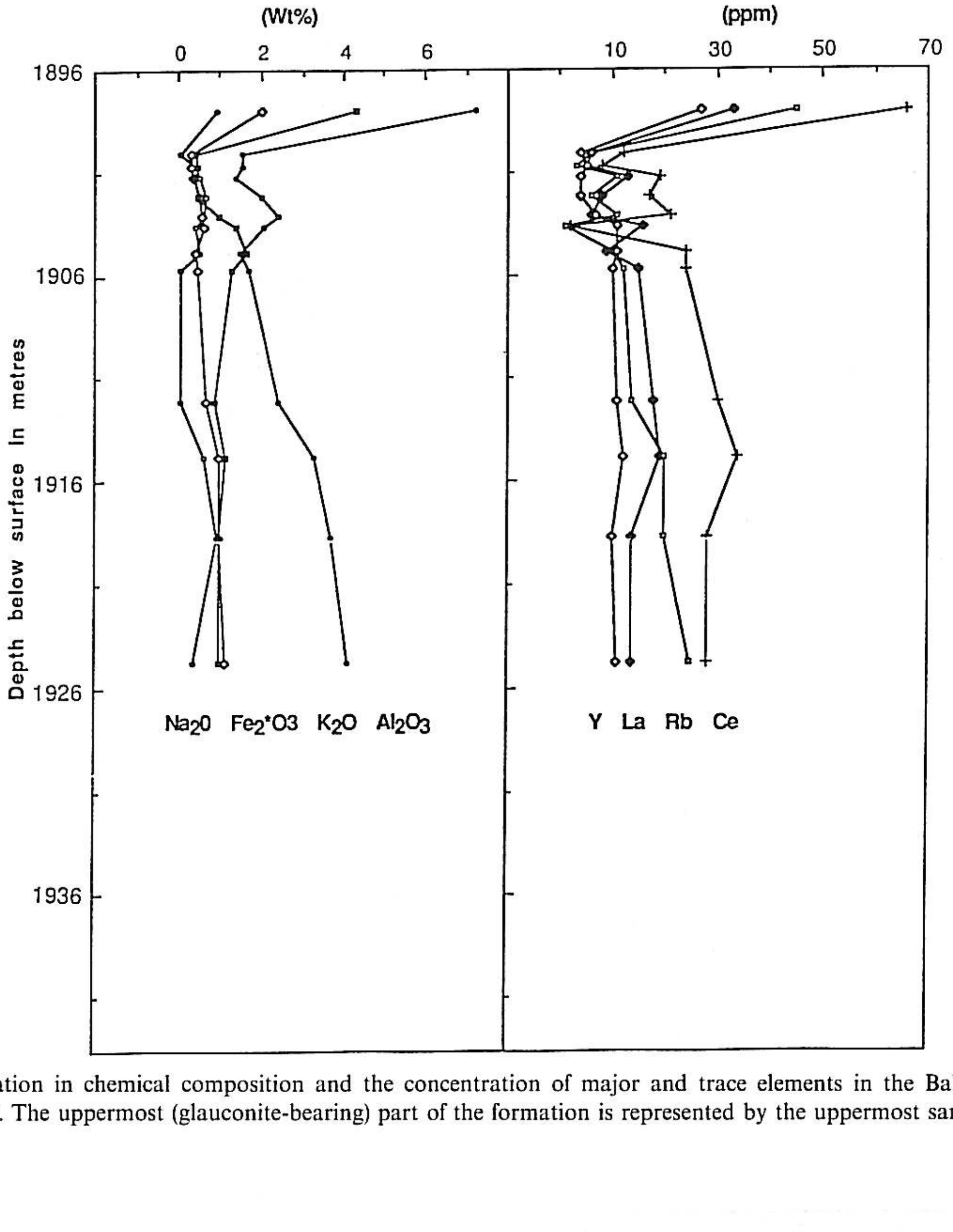

FIG. 9A. Variation in chemical composition and the concentration of major and trace elements in the Bahi Formation (A2-32 borehole). The uppermost (glauconite-bearing) part of the formation is represented by the uppermost sample.

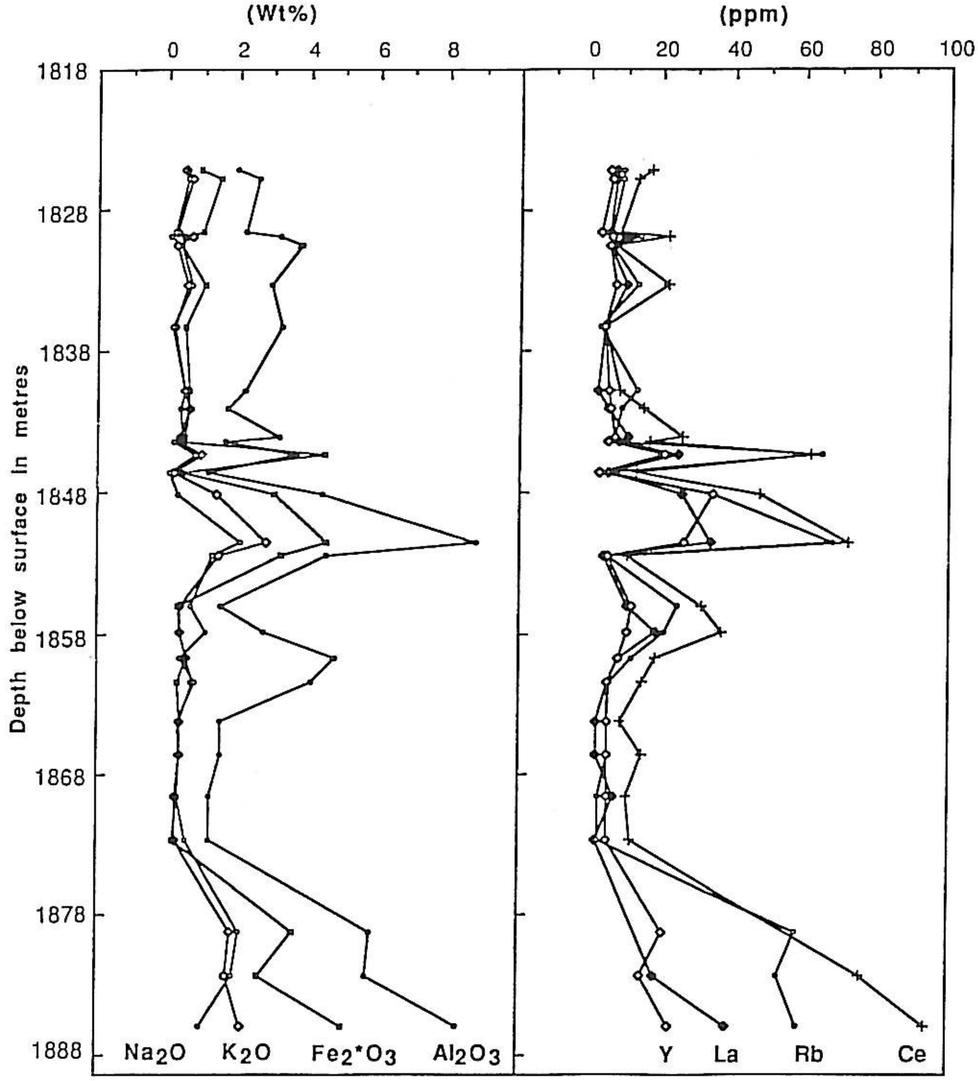

FIG. 9B. Variation in Chemical composition and the concentration of major and trace elements in the Bahi Formation (A4-32 borehole). The uppermost (glauconite-bearing) part of the formation is not represented.

change in the trace elements distribution particularly with respect to lanthanium, cerium, rubidium and yttrium, which show increasing concentration with reduction in grain size. In borehold F6-32, variation in major and trace elements is related to the low silica content and high CaO and MgO content particularly in the upper part of the section whereas the lower part is characterized by high silica content reflecting increase in quartz. This indicates a more mature sediment (Fig. 9C).

DISCRIMINANT FUNCTION ANALYSIS AND TECTONIC SETTINGS

In the past, several attempts have been made to use discriminant function analysis for sandstone geochemistry to classify individual sandstone samples into predefined groups on the basis of multiple variables in order to identify the tectonic setting of the provenance. Bhatia (1983) used discriminant function analysis to classify sandstone suites using eleven major element oxides as variables and chose five sandstone suites in eastern Australia to represent his predefined groups. Discriminant scores for the analysed Bahi samples from the four boreholes have been calculated using the unstandardised function coefficient (Bhatia, 1983), the results are plotted with respect to function I versus function II (Fig. 10).

All the studied samples in the Bahi Formation, from the four boreholes, fall into the passive margin field except for two samples from the F6-32 borehole which fall into oceanic island arc and one from the A4-32 and two from the D1-32 boreholes which fall into the active continental margin field. Passive margins are characterized by mineralogically mature sediments deposited in plate interiors, at stable

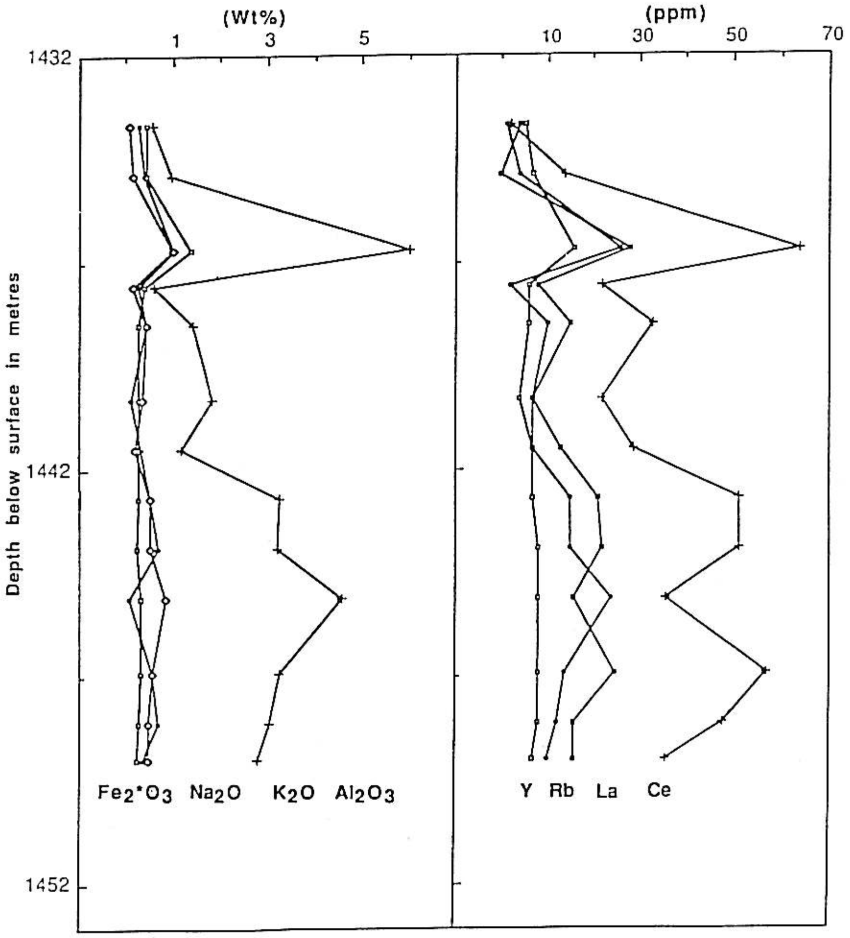

FIG. 9C. Variation in chemical composition and the concentration of major and trace elements in the Bahi Formation (F6-32 borehole). The uppermost (glauconite-bearing) part of the formation is not represented.

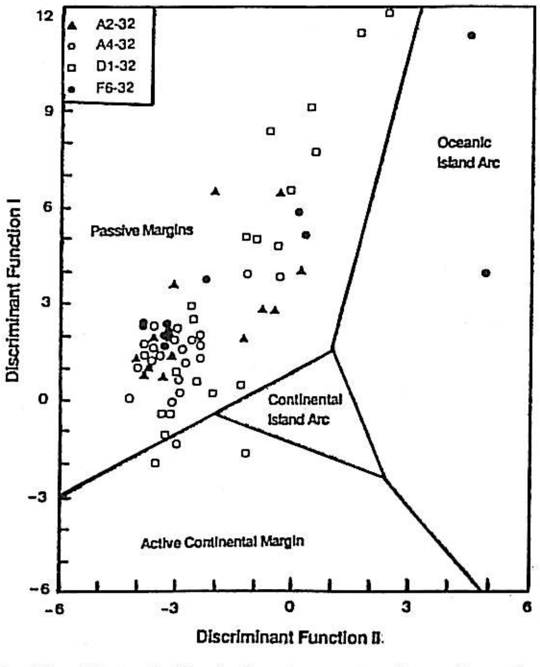

FIG. 10. Plot of discriminant scores along Function I versus Function II in the Bahi Formation in the four boreholes, using Bhatia's (1983) fields of various tectonic setting.

continental margins or in intracratonic basins. Derived sediments are characterized by recycled quartz-rich sediments originating in older adjacent continental terranes (Bhatia, 1983).

CONCLUSIONS

The significance of the major and trace element distribution within the Bahi Formation leads to the following conclusions:

The high amount of SiO_2 in most of the Bahi samples is considered to indicate a high degree of maturity. The low content of SiO_2, encountered in some samples, is probably due to enrichment of the sediment with carbonate, anhydrite and clay minerals. The variation of K_2O and Al_2O_3 is probably due to variation of feldspar and clay mineral content both laterally and vertically. The high content of CaO and MgO in some of the studied samples, particularly in the upper part of the formation, is related to enrichment with cement composed of varying proportions of calcite, dolomite and anhydrite.

Most of the trace elements (La, Rb, Ce, Zn, Ga and Y) show a positive correlation with Al_2O_3 and K_2O

but a lack of correlation with al-alk. This may be related to the presence of these trace elements in both K-feldspar and clay minerals. The relationships between Y + La + Ce, Ni + Cr and Sr, show that the Bahi sediment is derived primarily from a pre-existing sedimentary source.

Lateral and vertical distribution of the Bahi Formation show considerable variation in major and trace elements. This is related to specific lithofacies probably resulting from variation in the environmental conditions at the time of deposition of the unit. It is clear from the various geochemical plots that there is variation from boreholes involving clear correlation, particularly in boreholes D1-32 and A2-32, but which are not evident in boreoles A4-32 and F6-32. This implies slightly different depositional controls and local diagenetic variations.

The discriminant function analysis technique shows that the Bahi Formation is derived from a passive continental margin with a mature sandstone cover.

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