J KAU: Earth Sci., vol. 7, pp. 55-73 (1414 A.H. / 1994 A.D.)

The Al Ays Batholith: A Late Proterozoic Granitoid Batholith Associated with the Al Ays Volcanic Arc Complex, Hijaz Terrane, Arabian Shield

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Abstract. The Al Ays batholith is located in the Hijaz microplate of the Arabian Shield. It intrudes the volcanic facies (andesitic and basaltic lavas and pyroclastic material) of the mature arc-derived Al Ays volcano-sedimentary sequence. The batholith is composite, 3-30 km wide by about 50 km long, and ranges from diorite to granite. A 5-point Rb/Sr isochron gave an age of 706 ± 2 Ma and an initial $^{87}Sr/^{86}Sr$ ratio of 0.70319 ± 0.00002.

The granitoid rocks of the batholith are calc-alkaline, metaluminous to subaluminous, with moderate LREE enrichment and a negative Eu anomaly, and show a wide compositional range (SiO_2 54.40-72.30%, CaO 1.16-6.29%, K_2O 1.8-3.94%, Rb 7-85 ppm, Sr 89-397 ppm, Y 7-40 ppm, Zr 40-337 ppm, Rb/Sr ratios 0.06-0.95).

The young age, calc-alkaline association, compositionally expanded nature with a spectrum of rock types from dioritic to granitic, short crustal residence time, and the syn- to late-collisional tectonic environment all suggest a model that the Al Ays volcano-plutonic complex (743 ± 12 to 725 ± 12 Ma) formed as a result of subduction and melting of oceanic lithosphere beneath the pre-existing arc-basement of volcano-plutonic rocks and their sedimentary derivatives.

Introduction

Continental growth of the Arabian Shield was accomplished mainly by addition of arc-related volcanism and plutonism. The evolutionary pattern of the Shield reveals a development from primitive intraoceanic arc terranes (Baish-Bahah, Jeddah and part of Halaban) some 950-800 Ma ago to mature andesite-dominated continental margin terranes (*e.g.*, Halaban, Al Ays) some 800-650 Ma ago (Stoeser and Camp 1985, Stoeser 1986, Brown *et al.* 1989). The subvolcanic plutonic rocks of a diorite suite (quartz diorite, tonalite and trondhjemite of > 800 Ma), probably formed in oceanic island arc environment are well studied and known in the southern Arabian Shield (*e.g.* An Nimas, Wadi Tarib and Wadi Shuqub batholiths; Fleck *et al.* 1980, Greenwood *et al.* 1982, Stoeser 1984, Radain *et al.* 1987). However, the batholiths developed in continental margin environments (*e.g.* the Al Ays batholith) attained less attention.

The Al Ays volcanic complex is dominantly composed of island-arc and fore-arc deposits (Camp 1984) or volcanic and sedimentary facies (Kemp 1981). The fore-arc turbidite deposits unconformably overlie the accretionary prism (Camp 1984) or the Farri marginal basin (Fig. 1, Johnson *et al.* 1987) to the northwest of the Hijaz microplate. The volcanic arc displays chemical and lithological characteristics of modern island arcs (Camp 1984).

The Al Ays batholith (Fig. 2), which intrudes the Al Ays volcanic-arc facies is a composite batholith consisting mainly of diorite (calc-alkalic to calcic) in the west

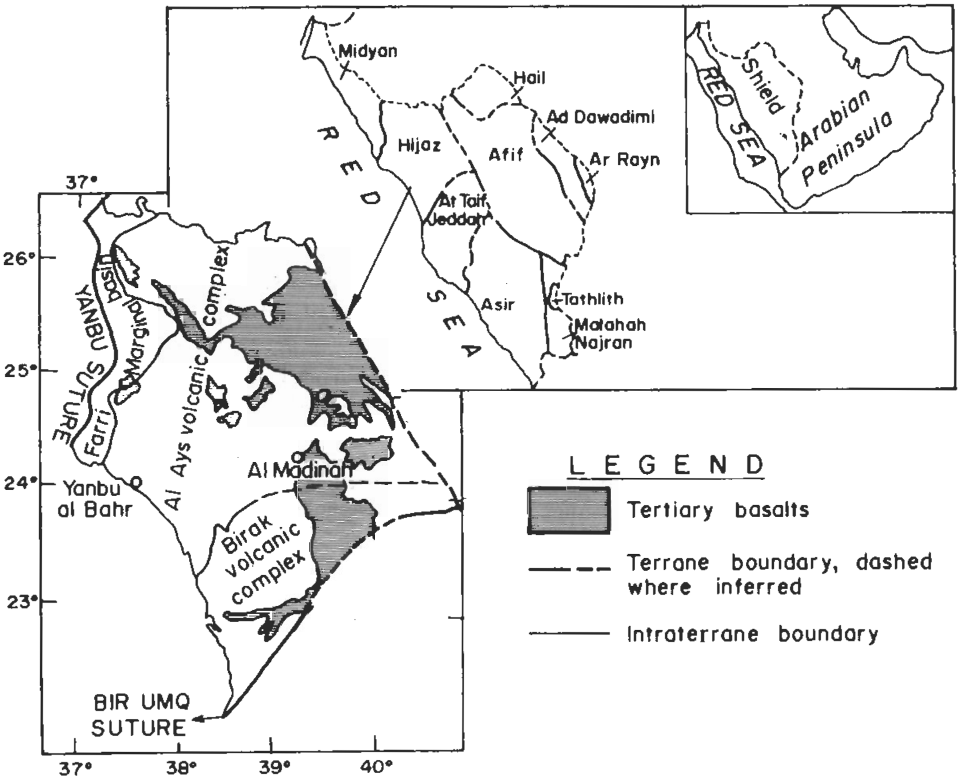

FIG. 1. Terrane map of the Arabian Shield with a breakdown of the Hijaz terrane's stratotectonic units (Johnson *et al.* 1987).

and granodiorite and granite (calc-alkalic to alkalic) in the east. About one-third of the batholith (southern part in the Al Madinah quadrangle: sheet 24D; Pellaton 1981) is referred to as Jibal Al 'Ayn batholith and the remaining part (central-northern in the Khaybar quadrangle: sheet 25D; Delfour and Dhellemmes 1980) is named as Jabal Ar Ra'Ayah batholith. The co-existence of quartz-diorite and granite suites in the batholith argue against the comagmatic/coeval evolution of these suites. The diorite suites are typically found in intraoceanic island-arc environments (Stoeser *et al.* 1982, Chase and Patchett 1988), whereas, granite suites are common at the continental margins, where the crust achieves sufficient thickness and maturity.

Tectonic and Geologic Setting

There is a general consensus that the Arabian Shield is made up of at least five oceanic and continental microplates or continental blocks (Asir, Hijaz, Midyan, Afif, Ar Rayn), that are separated by four ophiolite-lined suture zones (Bir Umq, Yanbu, Nabitah, Ar Rayn) (*e.g.*, Stoeser and Camp 1985, Kroner 1985, Pallister *et al.* 1988). The Hijaz microplate contains three superimposed stratotectonic units: the Birak and Al Ays volcanic complexes and the Farri marginal basin (Fig. 1; Johnson *et al.* 1987). The oldest immature intraoceanic Birak volcanic-arc complex consists of low-K_2O basalt, subordinate andesitic to rhyolitic lavas and volcaniclastic-sedimentary rocks (Ramsay 1983), associated with tectonically emplaced and dismembered ophiolite complexes (Bir Umq and Jabal Thurwah); Al-Rehaili and Warden 1980, Nassief *et al.* 1984). The complex is intruded by the Bustan trondhjemite-tonalite batholith (Jackson *et al.* 1984) having a U/Pb zircon age of 807 ± 8 Ma (Camp 1984, citing C.E. Hedge, personal communication). Pallister *et al.* (1988) obtained a U-Pb zircon date of 870 ± 11 Ma for the Thurwah diorite and 838 ± 10 Ma for the Bir Umq diorite.

The Farri marginal basin crops out on the northwestern margin of the Hijaz microplate. Camp (1984) referred to this basin as a strongly deformed accretionary prism overlying a southeast dipping subduction zone. The prism consists of highly metamorphosed and fragmented volcanosedimentary rocks (Al Hinu formation and Farri group of Pellaton (1979)) associated with dismembered ophiolitic assemblage (Camp 1984) or ultramafic bodies (Kemp *et al.* 1980). It is intruded by a batholithic suite of tonalite (Jar tonalite) dated at 796 ± 23 Ma (U-Pb zircon; Kemp *et al.* 1980) and 743 ± 10 Ma (U-Pb zircon; Ledru and Auge 1984). The U-Pb and Sm-Nd dates from the ophiolitic rocks gave ages of 780 to 740 Ma (Claesson *et al.* 1984), 882 ± 12 Ma (Kemp *et al.* 1980) or 776 ± 9 Ma (Ledru and Auge 1984) (Fig. 3).

The Al Ays volcanic complex with an approximate age of 735-705 Ma (Kemp *et al.* 1980), occupies the greater part of the Hijaz microplate (Fig. 3). Kemp (1981) divided the Al Ays group into predominantly sedimentary in the west and mainly volcanic in the east. Camp (1984) interpreted the sedimentary and volcanic facies to fore-arc and volcanic-arc assemblages, respectively. The fore-arc is dominated by a several thousand meter thick succession of arkosic rocks, and unconformably overlies the accretionary wedge, which was developed during southeast convergence of

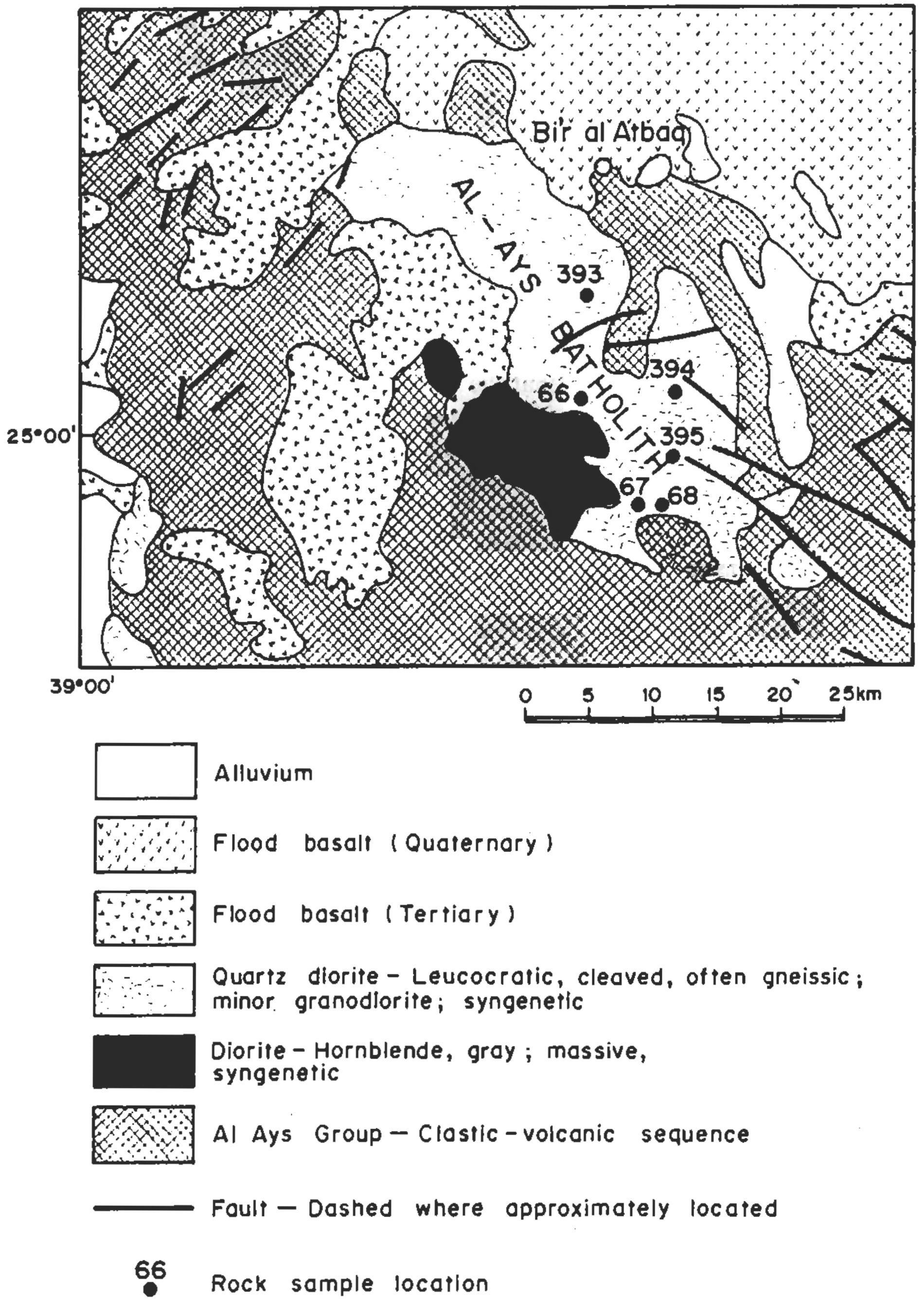

FIG. 2. Geological map of the studied area (after Brown *et al.* 1989) showing geological subdivisions and major faults.

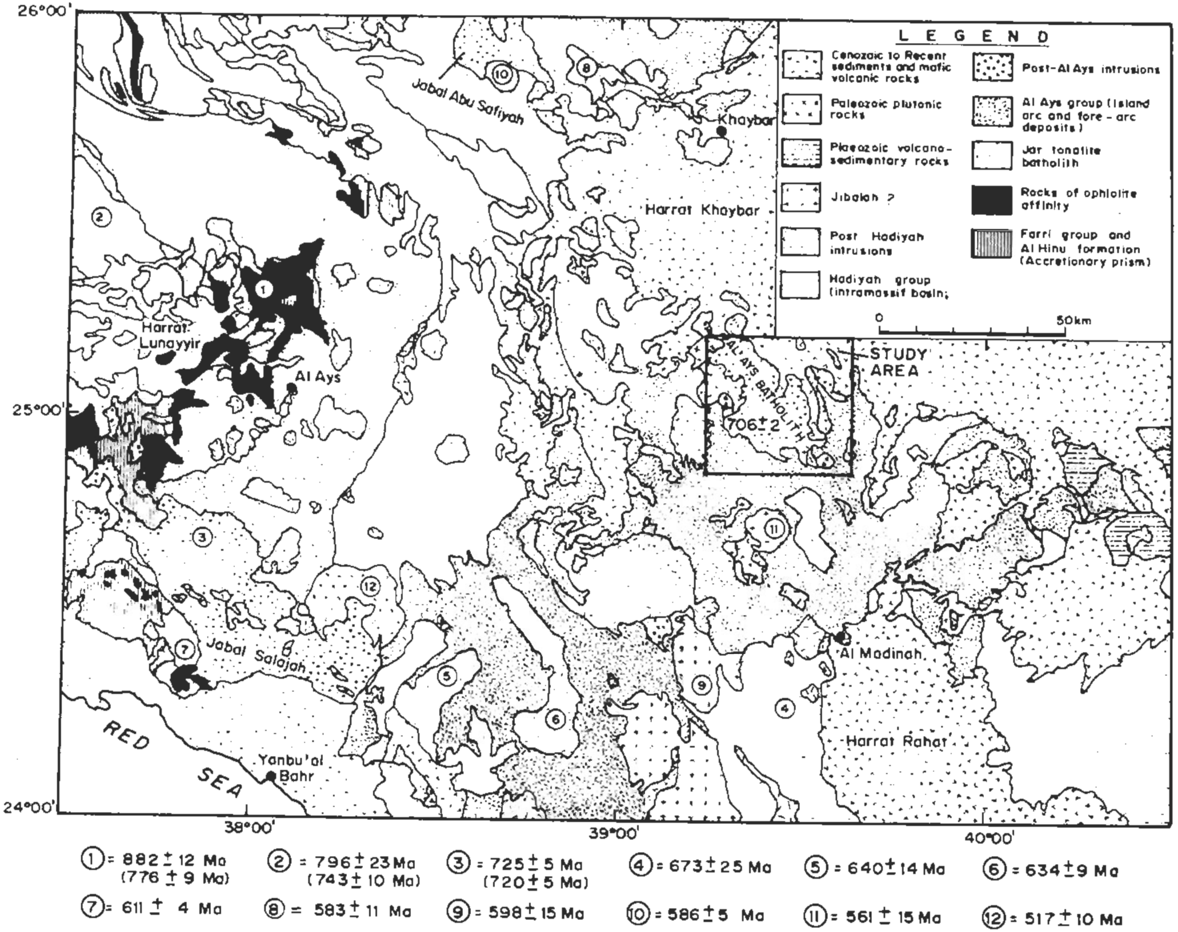

FIG. 3. Simplified geologic map of the Al Ays, Khaybar, Al Madinah and Yanbu al Bahr quadrangles (Kemp *et al.* 1982), showing U/Pb (1, 2, 3, 7; De la Boisse *et al.* 1980) and Rb-Sr (3-4, 8-12; Kemp *et al.* (1980) ages.

oceanic lithosphere at the site of Yanbu suture zone. This arkosic succession can be interpreted as the erosional product of orogenic mountains (predominantly volcanic-arc rocks from the eastern side of the complex) (Brown *et al.* 1989). The sedimentary rocks are intercalated with less abundant calc-alkalic to alkalic volcanic rocks (dacitic and rhyolitic).

The Al Ays volcanic-arc consists mainly of meta-andesite, rhyolite, basalt (high-alumina) and their volcanoclastic and intrusive equivalents. They show the compositional characteristics of a more mature island arc. The earliest post-Al Ays intrusion in the area is the differentiated gabbro-granophyre lopolith of Jabal Abu Safiyah. The tholeiitic chemistry of these plutonic rocks is closely akin to that of the volcanic rocks of the Al Ays complex (Fig. 3; Kemp *et al.* 1980). No reliable age is available for this lopolith. The Rb-Sr age of 705 ± 68 Ma (MSWD = 5.71) dated by Kemp *et al.* (1980) has a large error. However, the later calc-alkaline Jabal Salajah tonalite intruding the metasedimentary rocks of the Al Ays group, in the Yanbu Al Bahr quadrangle to the south (Pellaton 1979) has given a U-Pb zircon age of 725 ± 12 Ma (Kemp *et al.* 1980). The studied 706 ± 2 Ma old the Al Ays batholith of quartz diorite to granite, occurring southwest of the Harrat Khaybar (Fig. 3) is thought as equivalent to this age group (Kemp *et al.* 1980). The batholith intrudes the eastern volcanic facies of the Al Ays group (Farshah formation) which itself rests on volcanic and plutonic rocks probably older than 800 Ma (Ledru and Auge 1984, Pallister *et al.* 1988). The rocks of the batholith extend over a wide compositional range, including diorites, tonalites, granodiorites and granites, but the predominant compositions are granodiorite and granite. The components of the Al Ays batholith are metamorphosed in the greenschist facies which is marked by the presence of chlorite, sericite and epidote. The absence of foliated gneissic texture and migmatites in the batholith shows the lack of intense deformation and metamorphism. However, the Al Ays volcanic facies rocks and the earliest intrusions of the Abu Safiyah complex were affected by large scale folding deformation (Kemp *et al.* 1982).

Petrography

The northwest-southeast trending Al Ays batholith shows a continuous spectrum from granite to granodiorite, tonalite, quartz diorite and eventually diorite. The diorite, quartz diorite and granodiorite form a NE-SW trending magmatic belt in the middle of the batholith. The trend of the belt is similar to belts of intermediate plutonic rocks of the Hijaz microplate (Stoeser 1986). The diorite is essentially a dark greenish gray with medium to fine-grained texture. It consists mainly of plagioclase and clinopyroxene with minor sphene, apatite and opaque minerals (iron oxides and hydroxide, sulfides). Plagioclase is more-or-less altered to sericite and epidote-zoisite. Relict clinopyroxene is altered to hornblende which is itself altered to chlorite-actinolite. The quartz diorite and granodiorite are generally pale gray. They consist of plagioclase (sericitized and saussuritized), potassium feldspar, clinopyroxene (altered to amphibole and chlorite), quartz and accessory minerals: apatite, sphene, epidote and carbonate. The granite and granodiorite rocks which occur on either side of the magmatic belt are pale gray, fine- to medium-grained, occasionally coarse-grained, with hypidiomorphic-granular texture. They are composed of K-feldspars (30-40%: orthoclase, microcline), plagioclase (25-40%: oligoclase, andesine), quartz (20-25%), and ferromagnesian minerals (2-10%: *e.g.* chloritized amphibole and biotite). Accessory minerals are sphene, zircon, apatite, epidote and opaque. Perthitic feldspar forms large subhedral laths. Plagioclase is variably sericitized and saussuritized. The overall mineralogy of these rock types is metamorphic.

Analytical Methods

Four granitoid samples were analyzed for major oxides, trace elements and REE. Analyses were performed by inductively coupled plasma-source mass-spectrometry at the Royal Holloway and Bedford New College, University of London. Accuracy is estimated as better than 2% for major elements and 5 to 10% for trace elements. In addition, 3 major elements analyses presented by Delfour and Dhellemmes (1980) are also used in the variation diagrams (Table 1).

The Rb and Sr contents and Rb/Sr ratios were determined by XRF spectrometry on pressed powder pellets (Pankhurst and O'Nions 1973). Sr was separated by applying standard ion exchange techniques. Sr isotope ratios were measured on the thermal ionization mass spectrometer (VG Isomass 54E) at the Faculty of Earth Sciences, King Abdulaziz University (KAU), Jeddah. During this investigation, the $^{87}Sr/^{86}Sr$ ratio of standard NBS 987 was measured as 0.710260 ± 0.00004 (n = 24) normalized to a $^{87}Sr/^{86}Sr = 0.1194$. The isochron/errochron was calculated by the regression analysis method of York (1969), and all isotope errors are quoted as 2-sigma of the mean. The age calculation was made by using the computer program of McSaveney (Faure 1977), which was modified at the KAU to suit the HP 9845B desktop computer. The ^{87}Rb decay constant used is $1.42 \times 10^{-11} \times a^{-1}$ (Steiger and Jager 1977). The goodness of fit of the regression line is quoted as the MSWD (Mean Square of Weighted Deviates) of McIntyre *et al.* (1966), calculated here as the ratio of 'chi-squared to degree of freedom' (chi-squared/(N-2). The cut-off point between isochron (MSWD < 2.5) and errochron (MSWD > 2.5) was determined following the methods of Brooks *et al.* (1972).

Geochemistry

The granitoids show a calc-alkaline trend on an AFM diagram (Fig. 4 (B)), and are classified mainly as granite on the normative An-Ab-Or plot (Fig. 4(A)). On the A/NK versus A/CNK diagram (Fig. 5), the rocks are subaluminous to metaluminous. In terms of tectonic discrimination of granitoids (Maniar and Piccoli 1989), the rocks plot within or close to the fields of thick and mature continental crustal rocks (post-orogenic, continental arc), with one sample falling in the field of oceanic plagiogranite (OP). The diagram clearly exhibits continental-biased nature of the granitoid rocks.

The major-element discrimination diagram (Fig. 6), of Sylvester (1989) to discriminate collision-related granites (> 68 wt % SiO_2) such as alkaline, strongly

TABLE 1. Geochemical analyses of granitoid rocks from the Al Ays batholith, Hijaz terrane, northwestern Arabian Shield.

	Granitoid rocks				Granites*		
	NH-66	NH-67	NH-68	NH-393	RD-2910	RD-2919	RD-2936
Major elements (weight percent)							
SiO_2	72.30	67.49	66.28	54.40	72.21	69.75	70.00
TiO_2	0.21	0.40	0.47	1.30	0.38	0.46	0.30
Al_2O_3	15.81	15.01	15.12	15.76	12.65	15.22	13.67
Fe_2O_3	1.31^{+}	2.34^{+}	2.66^{+}	10.79^{+}	0.69	0.87	0.97
FeO	–	–	–	–	2.59	1.90	2.91
MnO	0.04	0.05	0.05	0.15	0.08	0.05	0.12
MgO	0.50	0.77	0.91	3.71	0.47	1.39	0.98
CaO	2.54	1.74	1.16	6.29	2.57	1.93	2.74
Na_2O	6.17	4.78	5.62	3.51	3.92	5.05	4.00
K_2O	1.80	3.92	3.75	1.89	3.38	3.55	3.94
P_2O_5	0.07	0.10	0.11	0.20	0.14	0.13	0.11
L.O.I.	–	–	–	–	0.82	0.44	0.68
Total	100.75	96.60	96.13	98.00	99.92	100.74	100.42
Trace elements (parts per million)							
Ba	452	475	452	315	–	–	–
Co	8	8	11	28	–	–	–
Cr	6	9	11	34	–	–	–
Cu	7	11	15	45	–	–	–
Li	28	12	12	15	–	–	–
Nb	2	5	6	4	–	–	–
Ni	20	14	14	22	–	–	–
Sc	3	4	5	30	–	–	–
V	19	30	32	225	–	–	–
Y	7	26	28	40	–	–	–
Zn	43	44	49	88	–	–	–
Zr	40	270	337	148	–	–	–
La	10.29	29.00	24.00	17.00	–	–	–
Ce	22.73	58.00	49.00	30.00	–	–	–
Nd	11.00	26.00	25.00	16.00	–	–	–
Sm	2.06	4.80	4.90	5.00	–	–	–
Eu	0.47	0.70	0.70	1.00	–	–	–
Dy	1.27	3.20	3.40	6.00	–	–	–
Yb	0.62	2.20	2.40	3.70	–	–	–

* = Data from Delfour and Dhellemes (1980).
$^{+}$ = All Fe calculated as Fe_2O_3.
– = Not analysed.

peraluminuous, and normal and highly fractionated calc-alkaline types, exhibits normal calc-alkaline nature of the Al Ays arc-batholith. The absence of data points in the fields of alkaline (A-type and highly fractionated felsic I-type), strongly peraluminous, and highly fractionated calc-alkaline granitoids suggest syn-collisional or subduction related tectonic environment for the batholith.

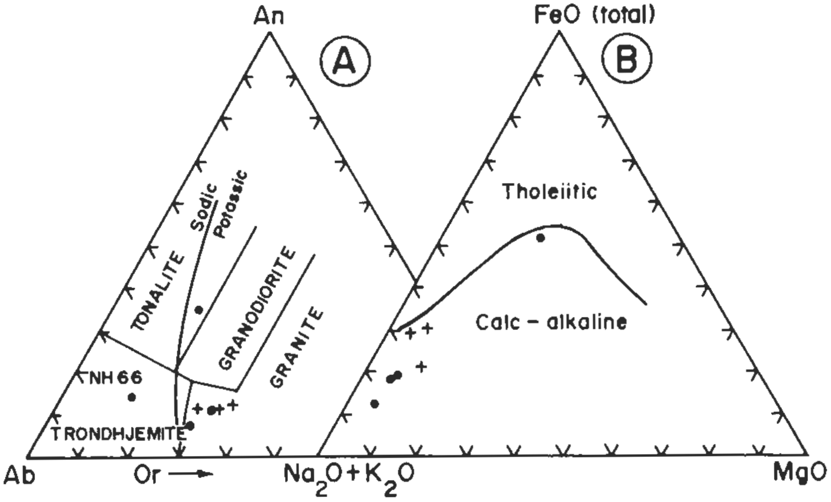

FIG. 4. An-Ab-Or(A) and AFM(B) plots for granitoid rocks of the Al Ays batholith. ● = New chemical data from this study; + = Old chemical data after Delfour and Dhellemes (1980).

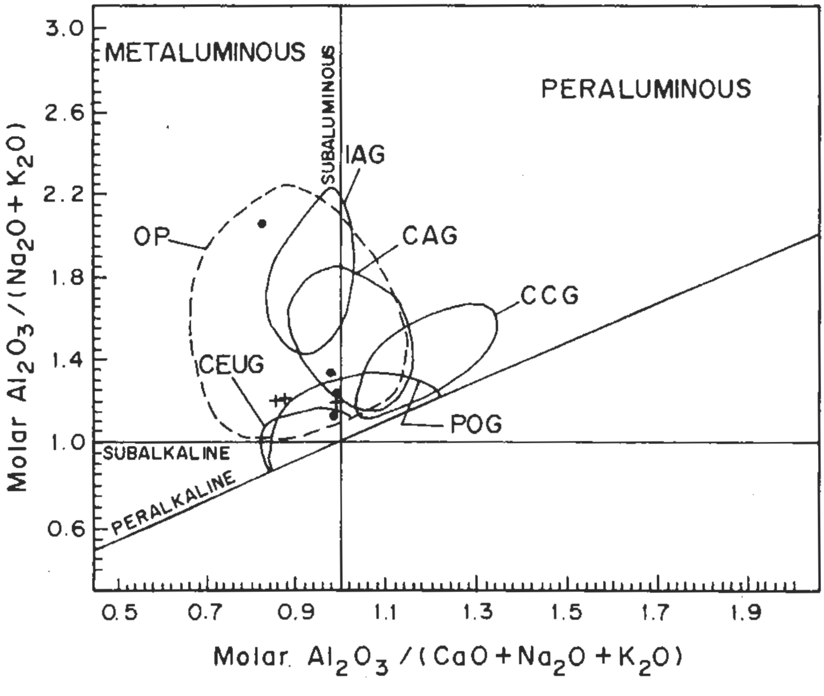

FIG. 5. A/NK verses A/CNK plot for granitoid rocks of the Al Ays batholith. OP = Oceanic plagiogranite; IAG = Island arc granitoids; CAG = Continental arc granitoids; CCG = Continental collision granitoids; POG = Post orogenic granitoids; CEUG = Continental epeirogenic granitoids. Symbols as in Fig. 4.

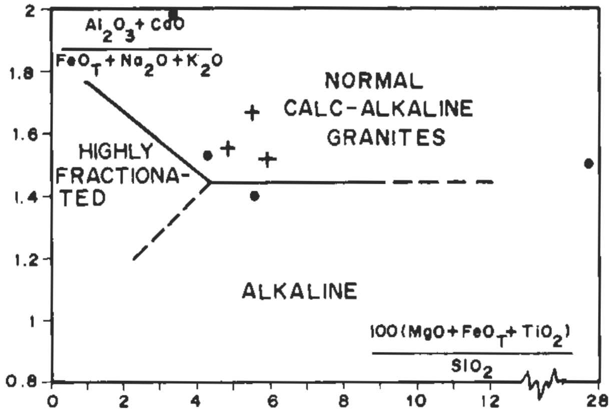

FIG. 6. Major element discrimination diagram (after Sylvester 1989) showing normal calc-alkaline affinities for granitoid rocks of the Al Ays batholith. Symbols as in Fig. 4.

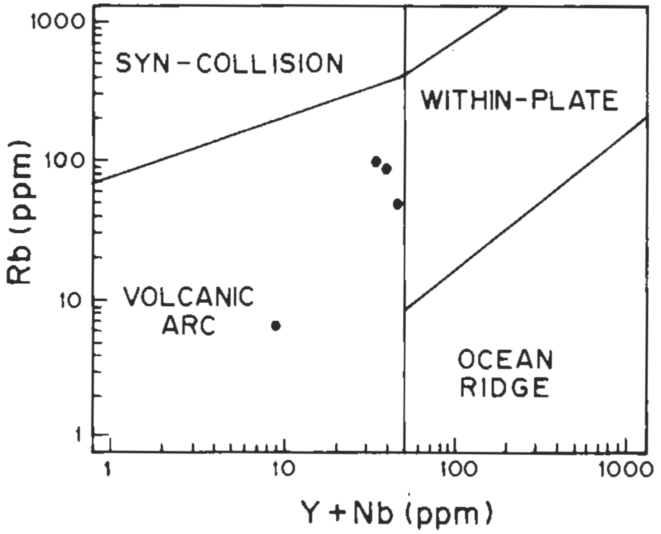

FIG. 7. Rb-Y + Nb discrimination diagram (Pearce *at al.* 1984) for granitoid rocks of the Al Ays batholith. Symbols as in Fig. 4.

On the Rb versus Y + Nb tectonic discrimination diagrams (Fig. 7; Pearce *et al.* 1984), the granitoids of the Al Ays batholith fall in the field of volcanic arc granites, plotting close to the boundary of within plate (anorogenic) granites.

On the R_1-R_2 multicationic diagram (Fig. 8: De la Roche *et al.* 1980), the granitoids plot mostly in the late-orogenic field, with one sample falling in the field of destructive plate margin magmatism (pre-plate collision) designated by Batchelor and Bowden (1985). The late orogenic nature of the magmatism indicates that the rocks of the Hijaz terranes had achieved sufficient thickness and maturity before generation of the Al Ays batholith.

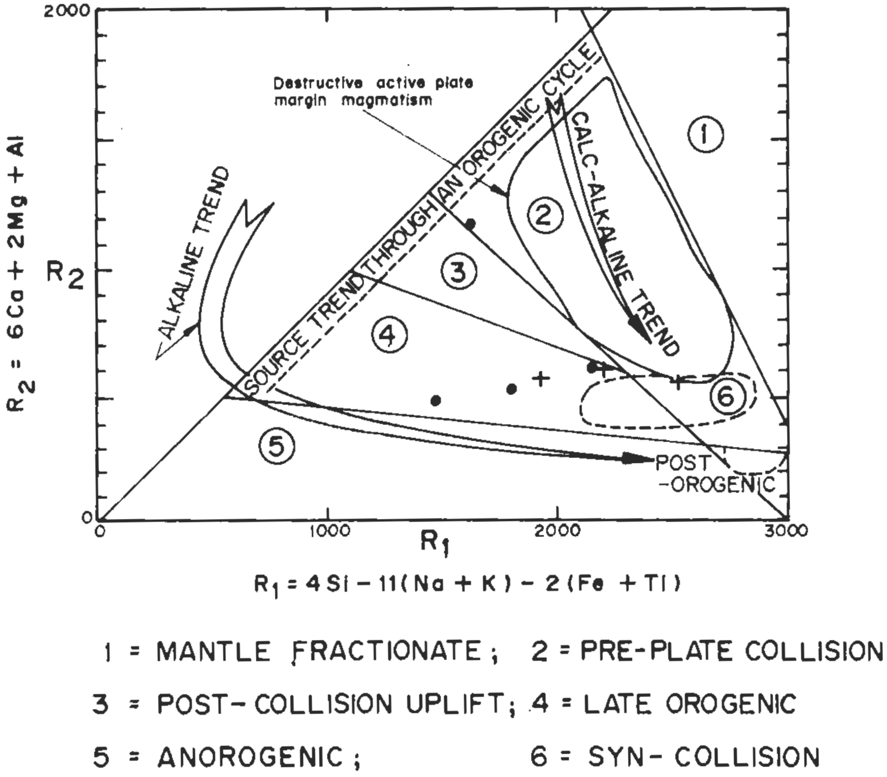

FIG. 8. R_1-R_2 chemical, mineralogical and tectonic environments diagram for granitoid rocks of the Al Ays batholith. Symbols as in Fig. 4.

On the Na_2O/Al_2O_3 versus K_2O/Al_2O_3 diagram (Fig. 9), devised by Garrels and Mackenzie (1971) to discriminate between igneous and sedimentary protoliths, the granitoid rocks of the Al Ays batholith fall within the fields of igneous as well as sedimentary. The most distinctive feature revealed by this diagram is the more sodic composition of some of the Al Ays granitoid rocks which are plotted in the region of volcanogenic sediments (the Kitchi schist of Upper Michigan and the average pelagic sediment of the Pacific ocean). These sediments are thought to be the product of fragmented and altered basaltic or slightly more silicic lavas developed in an oceanic trench environment. The REE contents (REE = 48.44-123 ppm; Fig. 10) are low, and three samples out of four have small negative Eu anomalies (Eu/Sm = 0.15-0.23), whereas the remaining one sample (NH-66) contains little or no Eu anomaly. All samples indicate enrichment in light rare-earth elements (LREE) relative to heavy rare-earth elements (HREE). The LREE/HREE ratios range between 4.43-10.91.

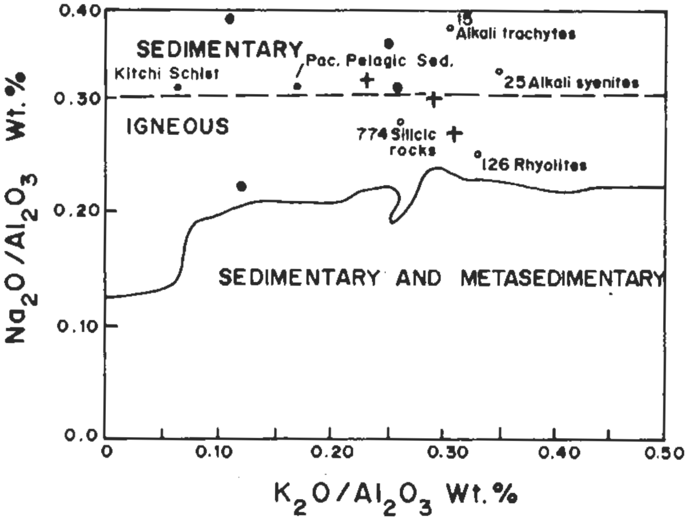

FIG. 9. Na_2O/Al_2O_3-K_2O/Al_2O_3 variation diagram for granitoid rocks of the Al Ays batholith. Fields of igneous, sedimentary and metasedimentary rocks are after Garrels and Mackenzie (1971). o = Average compositions of different rock types. Other symbols as in Fig. 4.

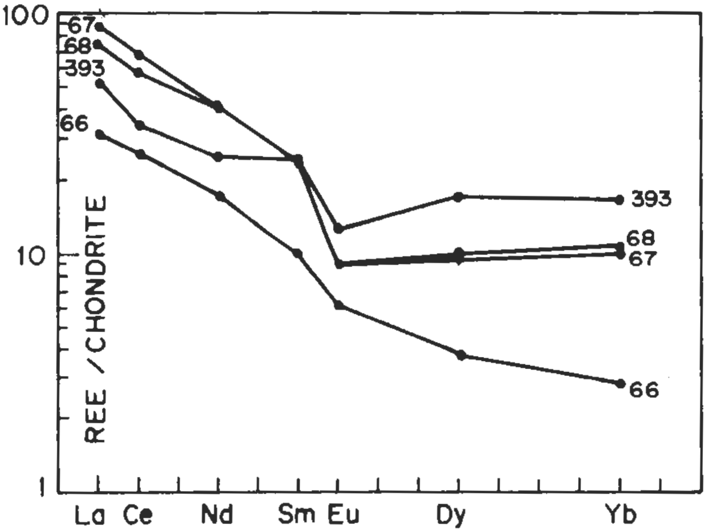

FIG. 10. Chondrite-normalized rare earth elements (REE) pattern of the Al Ays batholith.

Rb-Sr Geochronology

Analytical data for Rb-Sr isotopes are listed in Table 2. Five whole-rock samples ranging from diorite to granite yield a Rb-Sr isochron age of 706 ± 2 Ma (MSWD = 2.0), and an initial Sr ratio of 0.70319 ± 0.00002 (Fig. 11). The age of 706 ± 2 Ma is in good accord with other Rb-Sr ages reported for the arc-related volcanic-sedimentary and plutonic rocks of the Al Ays Group. The host Al Ays Group silicic tuffs from Bir Faqarah (Al Madinah quadrangle) and north Khaybar (Khaybar quadrangle) yielded Rb-Sr ages of 743 ± 12 (MSWD = 3.71, initial Sr ratio 0.7027) and 725 ± 16 Ma (MSWD = 2.55, initial Sr ratio 0.7046, respectively (Kemp *et al.* 1980). The Jabal Salajah tonalite batholith which intrudes the Al Ays Group in the west of the Yanbu al Bahr quadrangle produced a U-Pb zircon age of 725 ± 12 Ma (De la Boisse *et al.* 1980). The calc-alkaline granite and granodiorite (agc) and alkali leucogranite (aga), which intrude the Al Ghamrah formation of the Al Ays Group in the Khaybar quadrangle have yielded a Rb-Sr age of 705 ± 30 Ma (Vialett 1979).

TABLE 2. Rb-Sr abundance and isotopic data.

Sample number	Rb (ppm)	Sr (ppm)	$^{87}Rb/^{86}Sr$	$^{87}Sr/^{86}Sr$ ± 2 Sigma
Granitoid rocks (Al Ays arc-batholith)				
NH-66	7	397	0.0509	0.703700 ± 0.000400
NH-67	82	198	0.2292	0.712660 ± 0.000112
NH-68	85	89	0.4210	0.727218 ± 0.000452
NH-393	24	157	0.1140	0.706500 ± 0.000132
NH-394	11	170	0.2352	0.704125 ± 0.000160
NH-395	60	147	1.1817	0.713301 ± 0.000244

Discussion and Conclusion

Two distinct evolutionary models have been suggested for the Al Ays-Al Madinah region of northwestern Saudi Arabia. Kemp *et al.* (1982) proposed that the area evolved through process of repeated intracratonic rifting with associated volcanism and sedimentation, emplacement of ophiolite like ultramafic rocks and compression accompanied by folding, metamorphism and syntectonic plutonism. Camp (1984) argued against this interpretation and suggested that the lithologic and structural features are remarkably similar to those of known areas of convergent plate boundary settings. He recognized an accretionary prism of highly tectonized and metamorphosed volcanosedimentary rocks with oceanic crustal material (ophiolite) overlying a southeast dipping subduction zone (Yanbu) and the ensimatic Al Ays group island arc and fore-arc turbidite deposits, unconformably overlying the accretionary prism to the south east of the trench axis. Johnson *et al.* (1987) named the accretionary prism of Camp (1984) the Farri marginal basin. The ophiolitic rocks (780-740 Ma: Claesson *et al.* 1984) of the prism are roughly coeval with a nearby suite of preaccretionary tonalite (796 ± 23 and 743 ± 10 Ma: Kemp *et al.* 1980), supporting a back-arc environment for the ophiolite. The trace-element geochemistry of the ophiolite rocks shows a juvenile oceanic lithosphere, which generates during back-arc spreading (Pallister *et al.* 1988). The co-existence of felsic (rhyolite) and mafic (low-K

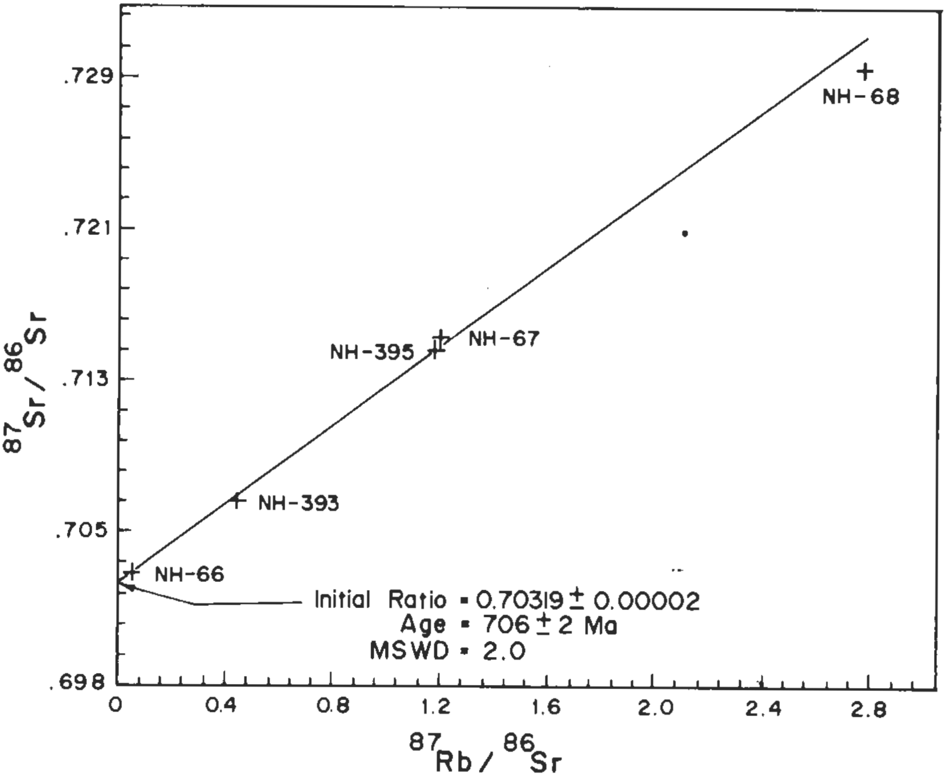

FIG. 11. Rb/Sr isochron for granitoid rocks of the Al Ays batholith.

tholeiitic basalt) volcanisms in the area are attributed to the break-up of an earlier continental crust followed by the sea-floor spreading (Johnson *et al.* 1987). The chracteristic feature of the Al Ays volcanic rocks such as abundance of rhyolite and welded tuffs, low- to high-K contents and alkalic geochemistry suggest the formation of the volcanic rocks in rifts above continental crust or older arc complexes (Calvez *et al.* 1983). Brown *et al.* (1989) correlated the Al Ays group rocks with the Ablah group which developed as a consequence of the rifting of older volcanic complexes (Bidah-Hali and Abha-Bisha) in the southwestern Arabian Shield.

The Al Ays batholith with a compositionally-expanded (diorite to granite) to compositionally-restricted (granodiorite to granite) range indicates Andinotype (I-type) to Hercynotype (S-type) tectonic environments (Pitcher 1982, Chappel and White 1974). Ikeda (1978) reported that during emplacement, the granitoid rocks were contaminated with country rocks, acquiring the wide compositional spectrum. He found quartz diorite and tonalite where the surrounding rocks were basic igneous types and granite and granodiorite where country rocks were acid igneous or sedimentary. The Al Ays arc-batholith with a wide compositional range probably passed through the older arc complexes made up of metavolcanic and metasedimentary rocks. The batholith with a calc-alkaline nature, subaluminous to peraluminous character and a wide compositional range of SiO_2 (54.40-72.30 wt %), TiO_2 (0.21-1.30 wt %), K_2O (1.8-3.94 wt %), Rb (7-85 ppm), Sr (89-397 ppm), Y (7-40 ppm), Zr (40-337) and a Rb/Sr ratios (0.06 to 0.95; Fig. 12) (Table 1), suggest volcanic-arc and continental margin (or mature island arc) tectonic environments (Maniar and Piccoli 1989). However, the probability of a continental margin tectonic setting is indicated in various plots (Fig. 5, 8, 10, 12). The enrichment of LREE relative to HREE is the characteristic feature of syn to post-orogenic plutonic rocks (Drury 1978). Trondhjemites and dacites (granodiorite) with negative Eu anomalies from young island arcs and plagiogranites from ophiolite complexes are characterized by low REE contents (REE = 34-131 ppm) and LREE/HREE ratios ($(La/Lu)_{cn}$ = 0.34-1.7), whereas rocks from continental or continental margin setting have large REE content (range REE 60-499 ppm) and LREE/HREE ratios (range $(La/Lu)_{cn}$ = 8.9-66) (Arth 1979, Barker *et al.* 1979). Sample 66 with high Al_2O_3 (15.81 wt %), high Na_2O (6.17 wt %), low REE contents (REE 48 ppm), steep REE curve and no Eu anomaly may have continental trondhjemitic characteristics. The initial $^{87}Sr/^{86}Sr$ ratio of 0.70319 ± 0.00002 reflects a short crustal residence time, consistent with derivation from fractionation or remelting of mostly mantle-derived rocks. Thus, the 706 ± 2 Ma Al Ays batholith is interpreted as derived from partial melting of early (> 800 Ma) and late (743-725 Ma) arc-basements of volcanic-plutonic rocks and their sedimentary derivatives in a convergent plate boundary setting.

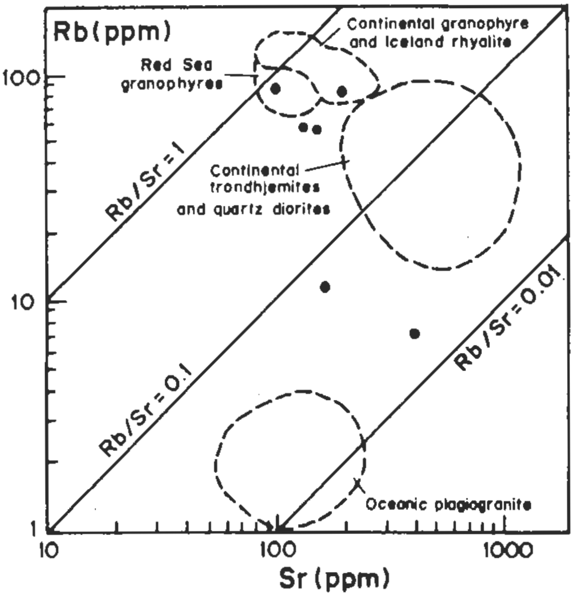

FIG. 12. Rb/Sr variation diagram showing volcanic-arc to continental margin tectonic environments for the Al Ays batholith. Symbols as in Fig. 4.

Acknowledgement

We thank Dr. A.M. Al-Shanti of the Faculty of Earth Sciences, King Abdulaziz University and the two anonymous reviewers for constructive and helpful comments on an earlier version of the manuscript.

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باثوليت العيس : باثوليت جرانيتي قبل كمبري متأخر مصاحب لمعقد صخور العيس البركانية ، منطقة الحجاز - المملكة العربية السعودية

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المستخلص . يقع باثوليت العيس في صفيحة الحجاز في الدرع العربي ، ويقطع السحن البركانية (صخور الانديزايت والبازلت والصخور الفتاتية) للتتابع البركاني - الرسوبي لقوس العيس المتقدم . وهذا الباثوليت متعدد التركيب عرضه ٣-٣٠ كم وطوله حوالي ٥٠ كم ويتراوح تركيبه الصخري من ديورايت إلى جرانيت .

منحني خط تقدير الأعمار (ايزو كرون) Isochron ربيديوم/استرانشيوم أعطى عمرًا يصل إلى ٧٠٦ ± ٢ مليون سنة ونسبة الاسترانشيوم ٨٧/الاسترانشيوم ٨٦ المبدئية تصل إلى ٧٠٣١٩, ٠ ± ٠٠٠٠٢, ٠ والصخور الجرانيتية للباثوليت ذات تركيب كلسقلوي ، ألمونية إلى تحت ألمونية ، مع وجود إغناء للعناصر الأرضية النادرة الخفيفة LREE وشاذة سلبية للأيوربيوم ، كما تظهر مدى واسع في تركيب ثاني أكسيد السيليكون ٤٠, ٥٤-٣٠, ٧٢٪ و أول أكسيد الكلسيوم ١٦, ١-٢٩, ٦٪ و أكسيد البوتاسيوم ٨, ١-٩٤, ٣٪ وكذلك بعض العناصر الشحيحة مثل الربيديوم ٧-٨٥ جزء/بالمليون والاسترانشيوم ٨٩-٣٩٧ جزء/بالمليون والسيزيوم ٧-٤٠ جزء/بالمليون والزركونيوم ٤٠-٣٣٧ جزء/بالمليون ونسبة الربيديوم/استرانشيوم Rb/Sr ٠٦, ٠-٩٥, ٠ .

العمر الحديث للصخور الكلسقلوية ذات التركيب المتسع المدى من ديورايت إلى جرانيت وذات زمن بقاء قشري قصير ، وبيئة التصادم التشوهي المرافق أو المتأخر كل ذلك يقترح أن معقد العيس البركاني - الجوفي (ذا العمر ٧٢٥± ١٢ إلى ٧٤٣± ١,٢ مليون سنة) تكوّن نتيجة انضواء وانصهار الغلاف المحيطي أسفل القوس القاعدي المتواجد والمكون من الصخور البركانية - الجوفية ومشتقاتهم الرسوبية .