SHRIMP U-Pb Dating of Zircon Inheritance in Walash ArcVolcanic Rocks (Paleogene Age), Zagros Suture Zone, NE Iraq: New Insights into Crustal Contributions to Trachytic Andesite Generation

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(Received 3/5/2012 , Accepted 7/6/2012)

ABSTRACT

SHRIMP U-Pb ages were determined on single zircon grains separated from combined samples (i.e. GA8-GA9) belonging to a trachytic andesite, Galalah area,Walash arc volcanic rocks, Northwestern Zagros Suture Zone, NE Iraq. The rock suite in the studied area ranges from calc-alkaline to alkaline (i.e., Ga8-Ga9). The New reconnaissance SHRIMP U-Pb zircon ages of GA8 - GA9 reveal two episodes of Palaeoproterozoic inherited zircon growth:

1- 1953±39 Ma cores.
2- ca. 1777±28 Ma rims. This provides evidence for the ancestry of terrane (i.e. crystalline basement).

which had been pervasively overprinted by Mesoproterozoic thermal events that facilitate the growth of zircon rims.The cathodoluminescence (CL) images show no evidence of the zircon growth during Tertiary magmatism. The rims are wide and darker in CL compared to the cores. The oscillatory zoned cores probably grew from magma of probably dioritic to gabbroic in composition, due to the high zircon Th/U ratio of ~1. The lower Th/U and high-U zircon rims could have grown in a superimposed migmatitic event with the growth of new zircon in localised melting. The core-rim pair of analyses is interpreted as indicating that the zircons are inherited / recycled Paleogene magma due to crustal contamination. The Palaeoproterozoic U-Pb zircon age may be correlated with the Khida terrane (1800-1650 Ma), in the north-westernmost portion of the ‘‘Arabian Craton’’ in Saudi Arabia. Here, a thinned Palaeoproterozoic continental basement fragment in Neo-Tethys might have contaminated the upwelling calc-alkaline magma before erupting.
Keywords: SHRIMP U-P, Zagros, Iraq, Walash, Naopurdan.

حساب عمر الزركون الموروث لصخور قوس والاش Walash البركاني, نطاق درز زاگروس شمال شرق العراق, بتقنية شرمپ SHRIMP) U-Pb): رؤى جديدة حول مساهمات القشرة في تكوين الانديسايت التراكيتي

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الملخص

تم حساب عمر بلورات منفردة من معدن الزركون لمزيج من نموذجين متجاورين(GA8-GA9) والعائدين للانديسايت التراكيتي (Trachytic andesite)، منطقة گالاله، صخور القوس البركاني لـ (والاش Walash)، نطاق درز'ملتحم' زاكروس (Zagros Suture) الشمالي الغربي، شمال شرق العراق وذلك باستخدام تقنية شرمپ SHRIMP) U-Pb). تتسم المعية الصخرية rock suite في منطقة الدراسة من ناحية التراكيب الكيميائية بمديات تتأرجح بين الصخور القلوية الكلسية والقلوية. وقد أظهرت الأعمار الجديدة المستحصلة بواسطة طريقة شرمپ SHRIMP) U-Pb) وجود حدثين two episodes مترابطين من حقب طلائع الحياة القديمه Palaeoproterozoic اثرا على نمو الزركون الموروث:

١– اللباب عمرها ١٩٥٣±٣٩ مليون سنة.
٢– الحافات عمرها ١٧٧٧ ±٢٨ مليون سنة وبذلك اضافت دليلا جديدا عن اصل الصخور (أي صخور القاعدة المتبلورة).

وقد تعرضت تلك الصخور في حقب طلائع الحياة المتوسط Mesoproterozoic الى تغير حراري مما أتاح نمو حافات اضافية لمعدن الزركون. وقد أكدت صور التالق كاثودي cathodoluminescence (CL) عدم توفر اي دليل على نمو الزركون خلال النشاطات الصهيرية للعصر الثلاثي. وعند المقارنة بين اللباب والحافات اتضح من صور التألق الكاثودي CL للأخير اتساع عتمته على نقيض اللباب التي أظهرت التألق الكاثودي CL ذو تنطق متناوب مما يوحي بان الصهير المكون لصخور القاعدة المتبلورة كان دايوريتي dioritic أو گابروي gabbroic في تركيبه. ومن اهم ما يميز الزركون في هذه الصخور هو ارتفاع في النسبة Th/U والتي تقترب من الواحد (~1). أما انخفاض نسبة Th/U مع ارتفاع قيمة U والتي

يمكن ملاحظتها على حافاتها المتنامية للزركون فانه استدلال على نمو المعدن في ظروف ميگماتيتية migmaticلاحقة ناتجة عن انصهار موضعي لصخور القاعدة. ويتضح من التحاليل العمرية للمزدوجات اللب– الحافة بعدم عائدية عمر الزركون الى صهارة العصر الباليوجيني اي انه موروث inherited أو مسترد recycled نتيجة تلوث الاخير بصخور القشرة القارية. ويمكن مضاهات الزركون حقب طلائع الحياة القديمه المستند على تقنية شرمپ U-Pb SHRIMP مع صخور منطقة خيدأ (1800-1650 مليون سنة) في الجزء الشمال الغربي من الدرع العربي (Arabian Craton) في المملكة العربية السعودية. وفي منطقة الدراسة الحالية يستنتج وجود كتل صغيرة من بقايا صخور القاعدة القارية (continental basement) والعائدة الى حقب طلائع - - - ـاة Palaeoproterozoic (أنموذج خيدا ' Khida-type') محاذية لنيوتيذز Neo-Tethys والتي بدورها قد لوثت الصهير القلوي الكلسي الصاعد قبل أن ينفث حممه في عصر الباليوجين Paleogene.

الكلمات الدالة: شرمپU-Pb ، زاگروس، العراق، والاش، الانديسايت التراكيتي.

INTRODUCTION

The Walash group of Northwestern Zagros Suture Zone (NZSZ), NE Iraq is composed of volcanic and sedimentary unites which are referred to as Walash-Naopurdan Sequences (WNS) (Jassim*, et al.*2006). Several volcanic rock units have been recognised of Eocene - Oligocene age, with a long time span (~19Myr), showing volcanic arc activity along NZSZ. These units display a wide range in composition from early tholeiite dominated, through later calc-alkaline-dominated, to late alkaline domains, with a broad arc tectonic setting (Ali, 2012). Here, trachytic andesite and associated alkaline and sub-alkaline volcanic rocks at Galalah area represent a minor but distinctive component of these rock sequences. Recent studies show that the Walash - Naopurdan Sequences are the major manifestations of relatively long - lived to pulsatory (43.01 ± 0.15 to 24.31 ± 0.60 Ma) arc magmatism (Ali *et al.,* 2012 and Aswad, *et al.,* in submit.) and, are preserved in the main thrust belt of the Penjween - Walash Sub - zone (Jassim, *et al.,* 2006). A thrust fault divides the Penjween - Walash Sub-zone of the NZSZ into the Lower - and Upper Allochthonous Thrust Sheets. The voluminous, Walash - Naopurdan volcanism forms the most intact arc volcanic province and has been referred to as Lower Allochthonous Thrust Sheet (Aswad, 1999, Aziz *et al.,* 2011, Aswad *et al.,* 2011); (Fig. 1). Geochemical and isotopic data (Aswad, *et al.,* in submit. and Ali *et al.,* 2012) provide insights into the origin and evolution of magmatism found at the Neo - Tethyan subducted plate margins. These recently published data indicate that tholeiitic magmas are dominant in the early stages of oceanic island-arc genesis and calc - alkalic magmas are the most common in the mature stage of oceanic arcs and in continental arcs where they may range from basalt/basaltic andesite to alkali basalt / trachytic andesite, including voluminous intermediate (andesitic) rocks (Ali *et al.,* 2012).

A fundamental remaining question then is whether the late arc magmatism of alkali affinity (e.g. trachytic andesite) of Walash group at Galalah area contains additions of (older) continental components to the mantle - derived magmas via partial melting of older basement fragments caused by the addition of heat supplied by mafic magmas (e.g. see Dufek and Bergantz, 2005). We use zircon SHRIMP U-Pb ages from trachytic andesite units of the Walash arc volcanic rocks at Galalah area to identify Palaeoproterozoic crustal source materials involved the petrogenesis of the alkali affinities magmas.

GEOLOGICAL SETTING

The Penjween - Walash Sub-zone is exposed in northeast Iraq as part of the Northwestern Zagros Suture Zone (Kurdistan Region) (inset in Fig. 1). It is characterized by two allochthonous thrust sheets (Aswad, 1999; Aziz*, et al.,* 2011), which are referred to as upper and lower allochthonous thrust sheets. In the studied area, the Lower allochthonous is composed of Walash volcano-sedimentary rocks intercalated by Naopurdan sedimentary group forming the Walash-Naopurdan nappe (Fig. 1). The ophiolite-bearing terrane (upper allochthon) encompasses mainly Mawat ophiolitic massif of Albian - Cenomenion (97-105Ma) and Gimo sequence (Aswad and Eliase, 1988). Trachytic andesites at Galalah area represent a minor but distinctive component of the Walash - Naopurdan sequence. The study area (between 44^{o} 50/ 54// - 44^{o} 52/ 7 // E and 36^{o} 36/ 45.6// - 36^{o} 36/ 53// N) is situated within Galalah village, ca. 150 km from Erbil city, (Fig. 1). The area is mountainous, providing good cross sections through units. From bottom to top the Galalah section consists of brecciated, layered and pillowed lavas alternating with mafic and ultramafic volcaniclastic rocks reaching a total thickness of nearly 50 m. This is overlain by 40 m of massive serpentinite and then by marble which appears to be a mélange (a heterogeneous mixture of calcite, chlorite and serpentinite), together with phyllonite. This, in turn, is overlain by a thin layer of radiolarian chert. Above the radiolarian cherts is a crush zone, tectonically overlain by Red Beds (Ali, 2002 and Ali, 2012).

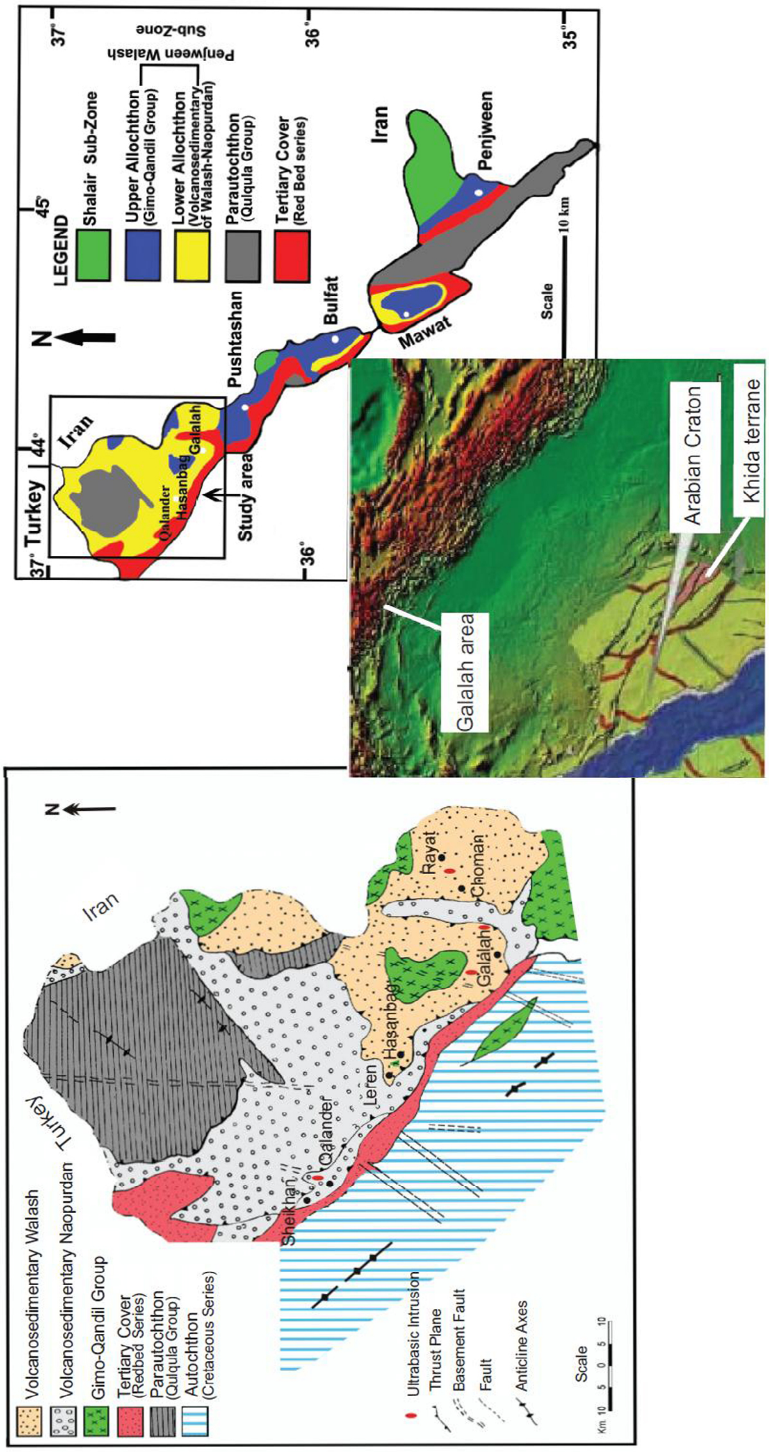

Fig. 1 : Geological Map of Northeastern Iraq shows the location of the Late Hasanbag Arc, Eocene Walash Alkaline (Galalah Choman). Mdified from (Buday, 1975).

ANALYTICAL METHOD AND DATA REDUCTION

Two small samples (GA8 and GA9) of similar lithological character and geological affinity were combined prior to zircon separation. The combined samples were disaggregated using the selFrag™ electrostatic rock crushing equipment at Macquarie University, Australia. Light <3.3 g/cm3 material were removed by flotation in polytungstate heavy liquid. Zircons were separated from remaining >3.3 g/cm3 concentrate by hand-picking under a binocular microscope. Despite that 1 kg of sample was used, only 6 small zircon grains were recovered. The hand-picked zircons were cast into an epoxy resin disc along with the zircon reference material Temora 1. The treated disc was then polished to reveal cross sections of the grains. Cathodoluminescence (CL) images of the zircons were obtained, to select sites for analysis. Zircon dating was carried out using the SHRIMP RG ion microprobe at the Australian National University (ANU). The analytical procedure is described by Williams (1998). Due to the small size of the zircons it was necessary to employ a small (15 μm) analytical spot, and consequently the intensity of the primary O^{2-} ion beam was only ~1.5 nA. Each site was rastered for 120 seconds prior to analysis to remove surface contaminant Pb from around the analytical site. Six scans through the mass stations (nominal masses 196, 204, 204.05=background, 206, 207, 208, 232, 238, 254) were made for each age determination. Reference zircons SL13 with a U content of 238 ppm (Williams, 1998) and Temora 1 with $^{206}Pb/^{238}U$ age of 417 Ma (Black *et al.,* 2003) were used for elemental abundance and calibration of $^{206}Pb/^{238}U$ respectively. The common lead correction was applied using measured ^{204}Pb abundances and model Pb compositions of Cumming and Richards (1975). Data reduction and calibration were carried out by the ANU 'PRAWN' and 'LLEAD' programs, and assessment was carried out using the ISOPLOT program of (Ludwig, 1997). Data are summarised in Table 1. The uncertainties quoted in the Table are 1σ, whereas the errors for weighted mean ages given in the text are quoted at the 2σ level.

Table 1: SHRIMP Iisotopic Results for Single Zircon Grains (GA8-GA9) of Trachytic Andesite from the Galalah Area.

Lab.	U/ppm	Th/ppm	Th/U	$^{204}Pb/^{206}Pb$	$^{208}Pb/^{206}Pb$	$^{207}Pb/^{206}Pb$	$^{206}Pb/^{238}U$	$^{207}Pb/^{235}U$	AGE/ $^{207}Pb/^{206}Pb$
1.1 Core	211.29	225.39	1.06674± 0.02211	0.00011608± 0.00005907	0.30276± 0.00586	0.11975± 0.0018	0.3573± 0.01597	5.89956± 0.28861	1952.54± 27.13
1.2 Rim	801.05	139.44	0.17407 ± 0.0039	0.00010589± 0.00002954	0.04434± 0.00153	0.10969± 0.0009	0.30277± 0.01247	4.57928± 0.19683	1794.33± 15.03
2.1 Core	222.88	246.38	1.10543 ± 0.02283	0.00008335± 0.00005943	0.31925± 0.00543	0.11988± 0.0019	0.34467± 0.01092	5.69726± 0.21158	1954.47± 8.51
2.2 Rim	673.65	140.39	0.2084 ± 0.00591	0.00051401± 0.0000926	0.0383± 0.00353	0.10266± 0.00205	0.32013± 0.01455	4.53146± 0.23502	1672.83± 37.33

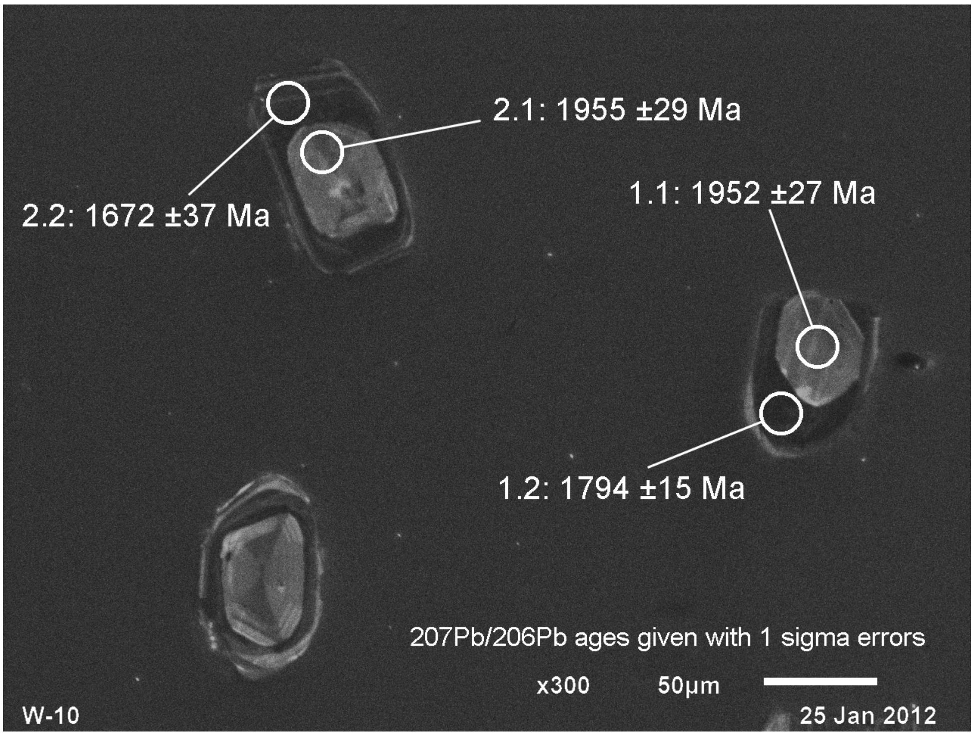

Fig. 2: Cathodoluminescence Image of Dated Zircon (GA8-GA9) Showing Location of 233 SHRIMP RG Ion Microprobe Spots with $^{207}Pb/^{206}Pb$ Ages. Circles Indicate spot Location; Ages Indicated in Ma, Illustrating the Presence of Both Light and Dark CL Core and Rim Domains (i.e. Low and High U, Respectively).

RESULTS AND DISCUSSION

Zircons are very similar in appearance, being small stubby prisms, with structural cores that appear bright and weakly oscillatory-zoned in CL images, and with rims that appear dark in CL images. The sixth grain was the fragment of 162 a longer prism, and as it appears metamict/ variably recrystallised in CL images, it was not analysed. Two core and rim pairs of analyses were undertaken (Fig. 3, Table 1). The two core analyses have lower U, high Th/U ratio and yield concordant U-Pb ages, within error of each other (Fig. 4), with a weighted mean $^{207}Pb/^{206}Pb$ age of 1953±39 Ma (MSWD<0.01). The two rim analyses have higher U, low Th/U ratio and yield more dispersed U-Pb ages, but still within the error of concordia. These yielded a weighted mean $^{207}Pb/^{206}Pb$ age of 1777±28 Ma, with a poor MSWD=9.1. No Phanerozoic zircon growth was detected, but it is evident that the zircons display two episodes of Palaeoproterozoic zircon growth. Several studies have shown that zircon grains are robust against resetting at high temperatures (Gulson and Krogh, 1975; Mezger and Krogstad, 1997; Möller *et al.,* 2002) and thus keep at least a partial record of different thermal events (Kröner *et al.,* 1994). Therefore, the earlier crystals reflect growth of oscillatory-zoned and sector growth zoned zircon from magma, which was probably dioritic to gabbroic in composition due to the high zircon Th/U ratio of ~1. The younger, lower Th/U high-U zircon rims could have grown in a superimposed migmatitic event with the growth of new zircon in localised melting, or could have grown in a subsolidus environment during high grade metamorphism.

The controlling factors on the presence or absence of inherited zircon include: the temperatures of crustal fusion, the composition of the crust, degree of zircon saturation and residence time in the host magma. Zircon from source rocks is not dissolved in contaminated magma that is saturated with respect to zircon, but rather is incorporated as partially resorbed xenocrysts. Based on the model of (Watson and Harrison, 1983), zircon saturation is a function of bulk-rock chemistry of Zr concentration, and temperature of crystallization T_{Zr}. Zircon saturation thermometry is calculated using the equation of Watson and Harrison (1983), which rearranged for T yields a geothermometer for melt: T_{zr} = 12900/ [2.95 + 0.85M + In (496000/Zr_{melt})]. In this equation T_{zr} is the zircon saturation temperature in Kelvins (however all temperatures in the following text have been converted to ^{o}C), M is the ratio (Na + K +2*Ca)/ (Al*Si), all in cation fraction. Zr_{melt} is the concentration of Zr in the saturated melt (measured in the rock sample) in ppm, and 496000 is the concentration of Zr (ppm) in the zircon. The magma temperature estimates of Galalah-Choman in range of 1100-1150 ^{o}C (Ali, 2012) and T_{Zr} of Ga8 ~1000 .This may reveal that the GA8 (and GA9) magmas were marginally Zr- undersaturated , therefore preserving inherited intact zircon rather then dissolving it in these rocks . Importantly, the Zr-undersaturated magmas (where the magmatic temperature overwhelm exceeds T_{Zr}, the zirconium saturation temperature of Watson and Harrison, 1983) will not have crystallized zircon. This investigation clearly shows that there was no growth of new zircons during the 43.01 ± 0.15 to 24.31 ± 0.60 Ma arc magmatism (i.e. U-Pb ages is not consistent with relative ages Walash volcanites). In the north-westernmost portion of the ''Arabian Craton'' in Saudi Arabia, (Ali, *et al*., 2009) showed that the igneous rocks contain abundant inherited zircons as well as juvenile isotopic characteristics, similar to the cases observed by (Hargrove, *et al.*, 2006). The problem of inherited zircons is not confined to Paleoproterozoic rocks. For example the oceanic basalts and gabbros from the Mid-Atlantic Ridge, known to be only a few million years old and far from any continental crust, contain ancient zircon (Pilot*, et al.,* 1998).

Concerning the trachytic andesite at Galalah, however, conclusions were drawn from the inherited zircon are rather ambiguous because of a combined lack of information on the age, composition and isotopic characteristics of any Arabian Plate basement beneath the studied suite. Here, the character of basement farther northeast of ''Arabian Craton'' (i.e. in the proximity of the plate margin) is uncertain because of Phanerozoic covers as much as 14 km thick. Fortunately, the 1777-1953Ma age stated above is akin to other Paleoproterozoic crustal rocks which are exposed in the Khida terrane (1800-1650 Ma) in the north-westernmost portion of the ''Arabian Craton'' in Saudi Arabia (Whitehouse, *et al.,* 2001; Stoeser, *et al.,* 2004). Stacey and (Stoeser, 1983) recognized that samples from the Khida region had radiogenic $^{207}Pb/^{204}Pb$ and $^{208}Pb/^{204}Pb$ characteristic of evolved continental crust. The latter could be subsequently assimilated by shallow-level magmas, incorporating older zircons in juvenile arc lavas at Galalah area. This subduction signature is confirmed by the Nb/Yb vs. Th/Yb diagram (Fig. 4, Ali, 2012) which shows that almost all the studied rocks fall in the compositional field of arc-related rocks – well above the field of MORB-OIB mantle array , indicating that crustal rocks input may have contaminated the mantle source or perhaps the upwelling magma before erupting. It is well known that the subduction inputs as well as continental crust contamination increase Th.

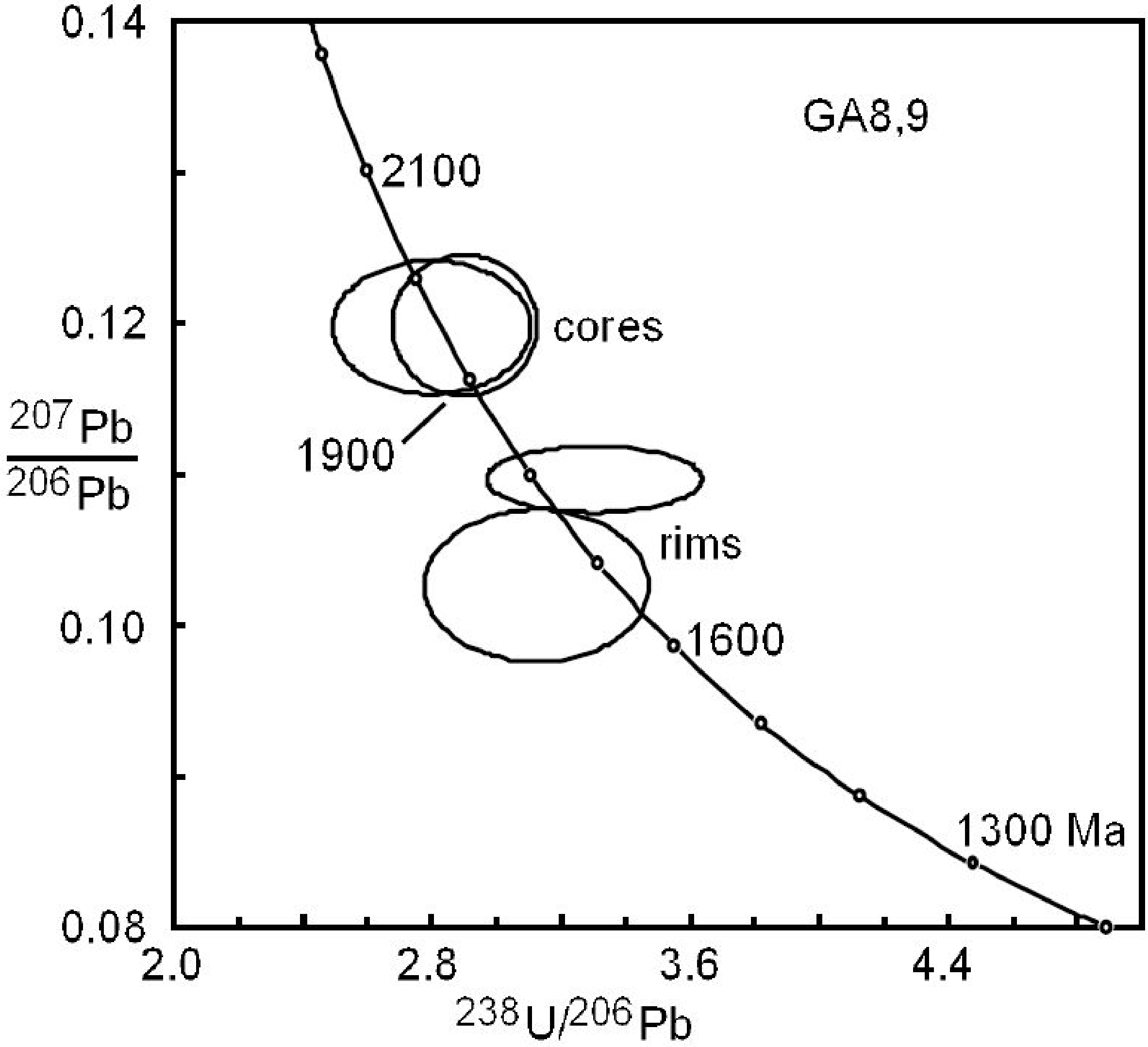

Fig. 3: Concordia Diagrams Showing SHRIMP Analyses 238 of Single Zircons for GA8-GA9 Samples from the Galalah. Concordia Diagram Showing SHRIMP Analyses of Spots Shown in the Images of (Fig. 2) The Ellipses Around the Data Point's Analytical Errors are Depicted at the 2σ Level in ^{238}U /^{206}Pb and $^{207}Pb/^{206}Pb$.

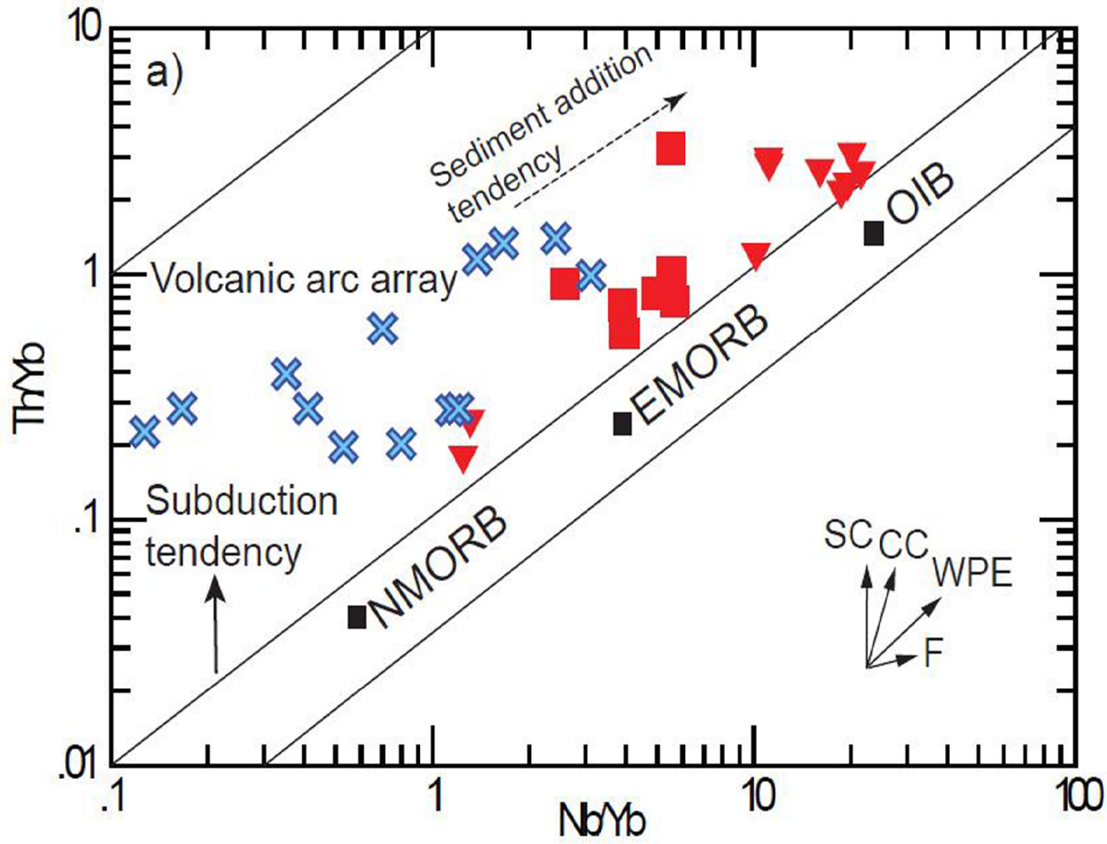

Fig. 4: Th/Yb versus Nb/Yb Diagram Indicates an Island arc Character for all Samples, Although Walash Samples Actually Belong to a Back-Arc Basin (Data from Ali *et al.,* 2012). Symbols: Filled Red Square = Walash Calc-Alkaline Samples; Filled Light Red Triangle = Walash Alkaline Samples; Blue Cross = Naopurdan Arc Samples. The Trends for WPE = Within-Plate Enrichment; SC = Subduction Zone Flux; CC = Crustal Contamination; F = Fractional Crystallization.

CONCLUSIONS

1- The U-Pb zircon age data presented here give the first direct information on Palaeo - to Mesoproterozoic 'Khida - type ' basement crustal materials contributing to trachytic andesite generation during Paleogene subduction-related magmatic activity.

2- The analyses plot on or near concordia, with cores giving a $^{207}Pb/^{206}Pb$ age of 1953±39 Ma (MSWD<0.01), which is significantly older than the rims of the zircons with an age of ca. 1789 Ma. Mild Zr-undersaturation, and estimations for negligible dissolution rates of inherited zircons, confirms the Palaeproterozoic crustal assimilation of Paleogene calc-alkaline magma.

3- Broadly similar results of concordant U–Pb ages lying in the range of 1800-1650 Ma have been documented for zircons from the Paleoproterozoic crustal rocks the Khida terrane (Arabian Craton). Variations in Nb/Yb vs. Th/Yb support the assertion that an existence of Palaeproterozoic crust beneath the Zagros suture zone.
4- The U-Pb SHRIMP zircon dating in this study shows that present rocks are complex and heterogeneous on all scales and therefore the analyses of a large number of inherited and detrital zircons at Galalah and other areas to elucidate petrogensis and provenance studies have become an important area of research.

ACKNOWLEDGEMENTS

Sample preparation and zircon dating was funded by Geoquest. A. Nutman is thanked for undertaking the analyses.

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