

Terrane Amalgamation and the Late Proterozoic Growth of the Eastern Arabian Shield

Ahmad M. Al-Saleh

*Geology Department, College of Science, King Saud University,
P.O. Box 2455, Riyadh 11451, Saudi Arabia*

ABSTRACT. Some attempts were made in the past to subdivide the Arabian Shield into a number of tectonostratigraphic terranes that were accreted onto the eastern margin of the African Craton towards the end of the Proterozoic. The eastern half of the shield in particular appeared to be a classic example of such a process, as it contained well-defined sutures dotted with genuine ophiolitic assemblages. The most popular terrane scheme for this part of the shield recognizes two blocks (Ar Rayn and Afif Terranes) of continental affinity separated from the western oceanic terranes by the major Nabitah Suture. Closer inspection, however, using recent geochemical and radiometric age data reveals that the Ar Rayn block is merely a rifted fragment of the Afif microcontinent, and should accordingly be considered as a parautochthonous terrane. The Hail structural province in the northern extremity of the Nabitah Belt contains a much more varied assemblage of magmatic rocks than is typical of the Nabitah Suture, as well as having a number of thick, slightly metamorphosed, sedimentary units that are restricted in their outcrop to this region of the shield. All of this, combined with the fact that all the contacts of this province with the rest of the shield are marked by major fault zones, some of which are ophiolite-bearing makes it reasonable to elevate it to full terrane status.

The allochthonous terrane concept gained much popularity with workers investigating the geology of the North American cordillera during the 1970's and 80's; it allowed for the logical explanation of the existence, within the same tectonic

belt, of large fault-bound segments possessing distinctly different stratigraphic, paleontologic and even paleomagnetic characters (Coney *et al.* 1980). Subsequently, these ideas were applied to other Phanerozoic orogens (*e.g.*, Ji and Coney 1986, Stephens and Gee 1989), and comparisons were drawn with presumed recent analogues (Silver and Smith 1983). Precambrian shields despite their stratigraphic/structural complexities and their lack of fossil evidence were soon subjected to the same rationale of growth through the successive addition of disparate lithospheric fragments. In some cases this concept was used with much enthusiasm to decipher the fundamental structure of quite enigmatic and multi-deformational belts following only a cursory examination of some of the most salient aspects of their geology. On the other hand, there is now a tendency for some authors to rule out terrane accretion as a viable mechanism for crustal growth in certain Precambrian orogens (*e.g.* Maboko 1995).

One region where the terrane concept was applied with apparently impressive success was the Arabian-Nubian Shield (Vail 1985), which is now considered as a collage of allochthonous terranes that amalgamated prior to the final collision with the African Craton. The deceptively simple structural layout of the eastern shield left most workers with little doubt as regards the validity of its proposed terrane distribution. However, it is believed here that the current understanding of the terranes of the eastern shield ignores some important local features that must be accommodated in any perceived scheme. The mere existence of regional-scale faulting or the marked difference in age between crustal blocks or even the presence of genuine ophiolitic complexes at their boundaries is not in itself an indisputable sign for the existence of truly allochthonous terranes. It is the aim here to clarify the Late Proterozoic history of the eastern Arabian Shield in the light of recent geochronological and geochemical data.

Existing terrane schemes for the Arabian Shield:

Prior to the introduction of the terrane concept many workers attempted to subdivide the shield into smaller segments on the basis of correspondence of radiometric ages and a general similarity of structural styles and lithostratigraphic units. Geologists working with the BRGM mission had adopted a scheme subdividing the shield into "structural provinces" (Fig. 1) on the basis of investigations summarized by Delfour (1981) and Calvez *et al.* (1983). At this stage there were no implied plate tectonic connotations, and certainly no suggestion that such provinces represented exotic blocks that were assembled only in the latest phases of their development. Instead, the shield was viewed as one coherent crustal unit within which there were considerable variations in sedimentary and volcanic environments as well as differences in deformational patterns.

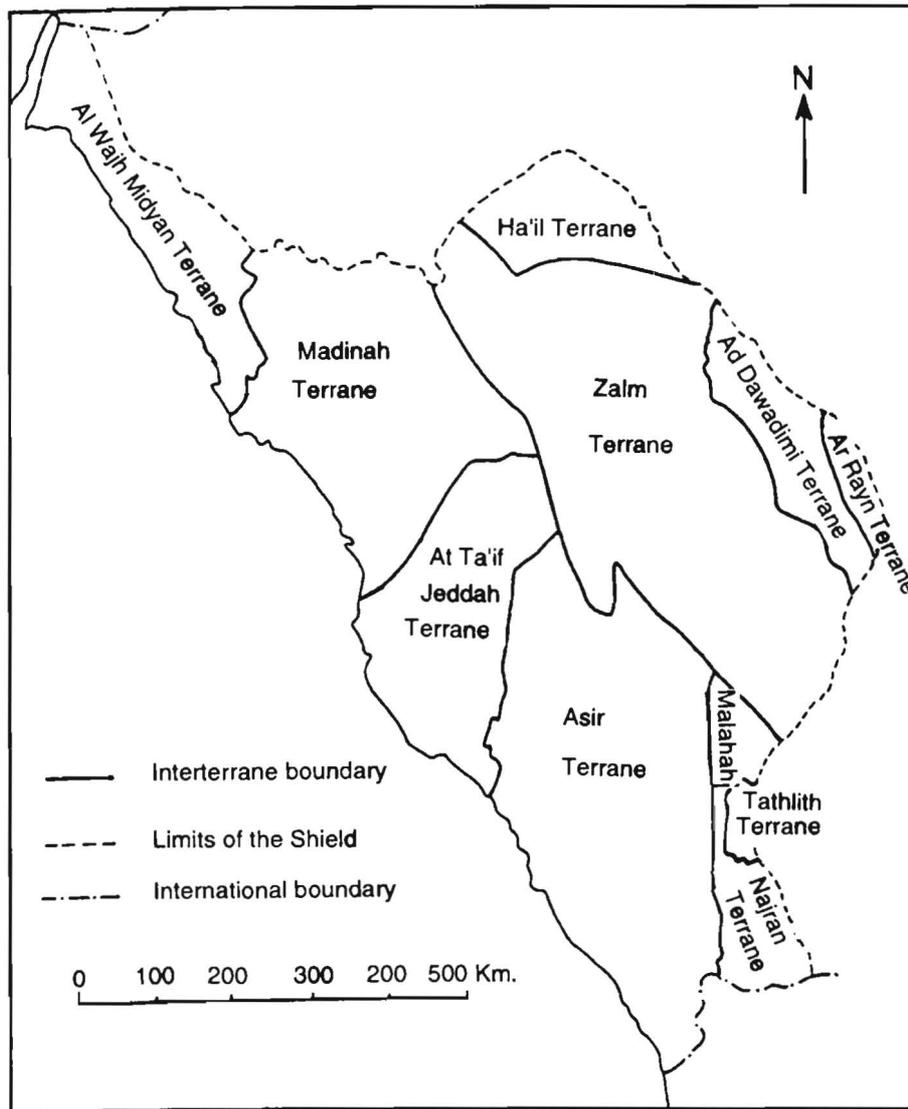


Fig. 1. Structural provinces of the Arabian Shield (after Calvez *et al.* 1983). Shaded areas represent Cenozoic lava fields.

The most widely accepted terrane model for the Arabian Shield is that developed by Stoesser and Camp (1985). They argued for the existence of five

terrane separated by four ophiolite-bearing suture zones (Fig. 2) along which the terranes collided in the period from 715 to 630 Ma. Each terrane was regarded as having developed independently from the others, thus possessing its own lithostratigraphic units and magmatic arc(s) in the true sense of a tectonostratigraphic terrane. In this model the shield is split into two major sectors by the Nabitah Fault (which the authors refer to as the Nabitah Mobile Belt); the eastern sector is made up principally of the Afif Terrane separated by the Al-Amar Suture from the much smaller Ar Rayn Terrane. These two blocks constitute the eastern shield which according to Stoeser and Camp has a distinct continental affinity as compared with less-evolved oceanic western terranes. The Ar Rayn Terrane coincides with the Ar Rayn structural province of the BRGM, and the Al-Amar Suture is the equivalent of the Ad Dawadimi province. The Afif Terrane extends over the Ad Dafinah and Afif provinces, while the Hail province to the north was regarded as the northern extension of the Nabitah Mobile Belt.

Another comprehensive attempt to divide the shield into a number of displaced fragments was that of Johnson and Vranas (1984) who identified 10 allochthonous terranes (Fig. 3) which broadly resemble the structural provinces of the BRGM. The Zalm Terrane in this classification corresponds roughly with the Afif Terrane of Stoeser and Camp, the Al-Amar Suture is represented by the Ad Dawadimi Terrane while the Ar Rayn Terrane remains unchanged. The Hail Terrane occupies the northeastern corner of the shield as did the Hail province of the BRGM, albeit with a slightly different shape and smaller area.

The fact that all proposed models are in close agreement with regard to the distribution of structural entities in the eastern shield creates the impression that genuine tectonostratigraphic terranes do exist in that part of the shield and that the relationships between them are simple and well-understood. However, closer inspection of the body of evidence supporting these arguments may indicate otherwise.

Discussion

The majority of reliable age estimates from the Arabian-Nubian Shield are confined to the extended Pan-African time period (1200-450 Ma). Nevertheless, recent radiometric data supported by other indirect evidence point to the presence of an early Proterozoic or even Archean basement particularly in the eastern Arabian Shield. Data from lead isotopes (Stacey *et al.* 1980, Stacey and Stoeser 1983) indicate the existence of an ancient continental core within the two eastern terranes of the Arabian Shield, whereas the isotopic signatures of the terranes west of the Nabitah Suture were found to be almost entirely oceanic. Nd isotopic data for the

Arabian Shield are sparse but available analyses emulate the pattern of Pb isotopes (Harris *et al.* 1990).

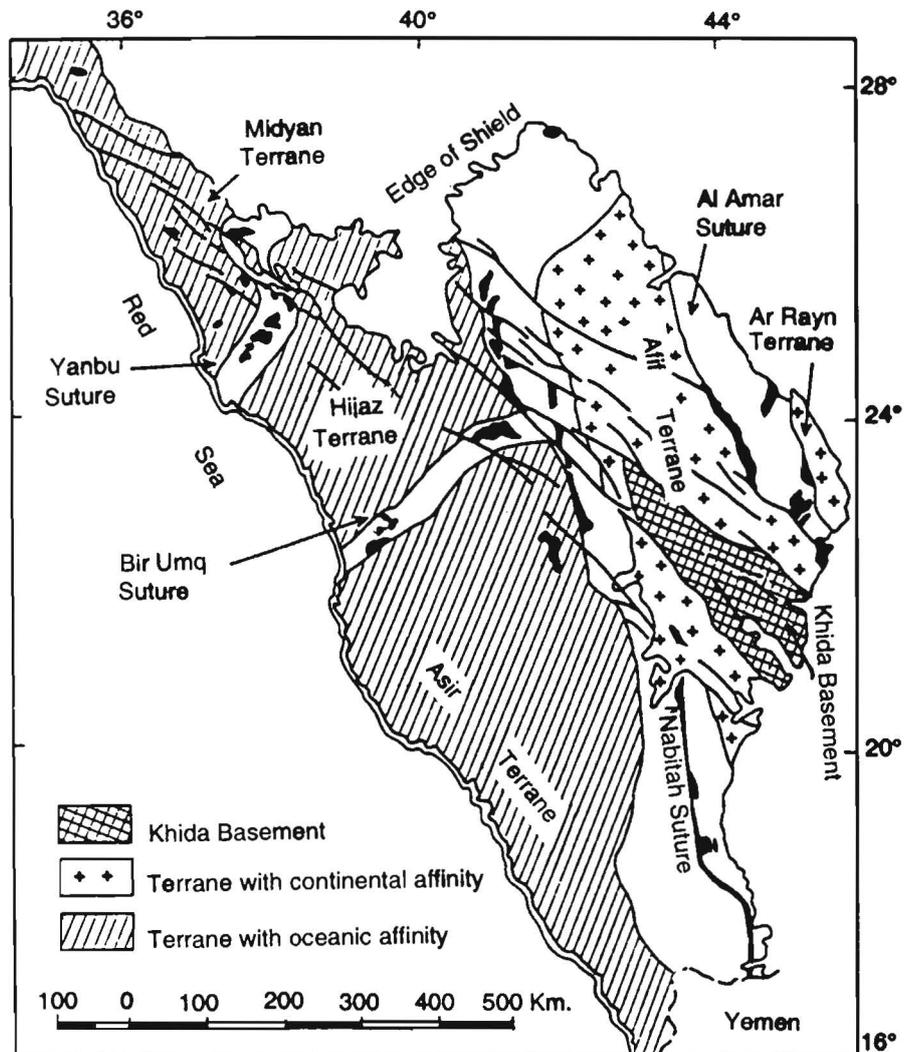


Fig. 2. Tectonic map of the Arabian Shield showing the distribution of terranes and suture according to Stoeser and Camp (1985).

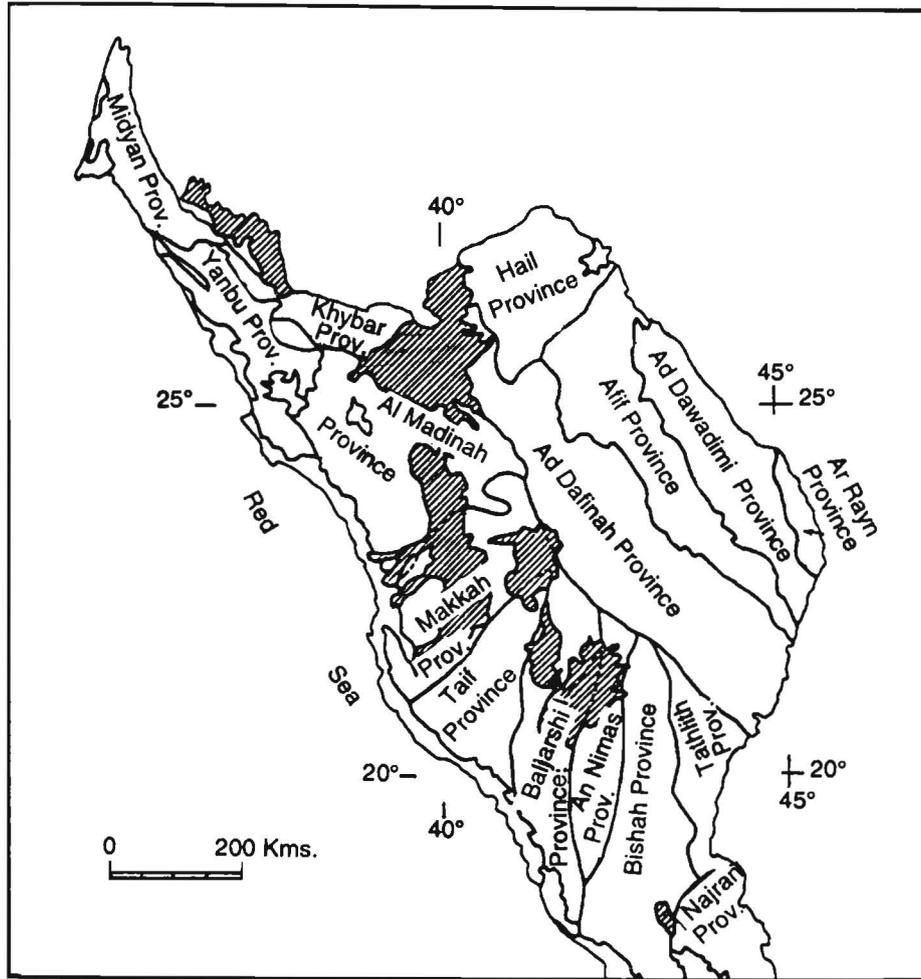


Fig. 3. Allochthonous terranes of the Arabian Shield according to Johnson and Vranas (1984).

Stacey and Hedge (1984) reported a U/Pb zircon upper intercept age of 1630 Ma from the granodiorite of Jabal Khida in the southeastern corner of the Afif Terrane, thus presenting the first undeniable confirmation for the existence of a pre-Pan African basement in that part of the shield; the authors interpreted this age as being that of an underlying basement from which a granodiorite melt was extracted, and considered the lower intercept age (658 Ma) to be the time of emplacement. Another early Proterozoic (1773 ± 32 Ma) date from the Kabid gneiss

further east was reported by Stacey and Agar (1985). Consequently, this southeastern corner of the Afif Terrane was named the "Khida basement" (Fig. 2) by Stoeser and Stacey (1988). More detailed ion probe and conventional U/Pb as well as Sm/Nd dating further north by Agar *et al.* (1992) delineated the extent of this older basement. The only evidence for the presence of an older crust beneath the Ar Rayn Terrane is a U/Pb date of 2067 ± 74 Ma obtained by Calvez *et al.* (1985) from inherited zircons separated from the plagiogranites of the Bir Assaliyah ophiolitic rocks at the eastern border of the Al-Amar Suture.

The incorporation of ready-made crustal fragments into an evolving orogenic belt is generally considered as the best explanation for the extremely high crustal growth rates reported from some Phanerozoic orogens. Although crustal growth estimates from Precambrian shields are less well constrained, most authors agree that the Arabian Shield had undergone rapid growth in the period between 920 and 620 Ma (see Harris *et al.* 1990 for a review). There remains considerable doubt on whether the "older" basement of the southern Afif extends beneath the whole of the eastern shield where the lead isotopes are transitional in nature between those from the continental and oceanic realms. Stoeser and Stacey (1988) regarded this transition as being the outcome of mixing ensimatic arc leads with more evolved leads from subducted sedimentary material. An obvious source for these evolved leads would be the Khida Basement itself due mainly to its geographic proximity and the lack of evidence to suggest the existence of another ancient continental mass in the vicinity of the Ar Rayn and northern Afif terranes during the late Proterozoic. The Khida Basement was interpreted as a rifted fragment of either the Mozambique Belt (Stoeser and Camp, 1985), or an Archean continental mass concealed beneath the Phanerozoic cover rocks east of the shield (Stoeser and Stacey 1988). It can be envisaged that following the rifting event, the eastern and northern margins of this block underwent continuous volcanomagmatic accretion and growth of continental crust associated with a westerly-dipping subduction zone(s); this combined with sedimentary recycling of material derived from the Khida Basement itself produced the transitional leads of the newly-formed crust.

There is a general consensus regarding the position of the Ar Rayn Block in all the proposed terrane schemes; this thin strip on the eastern periphery of the shield was always recognized as an independent structural entity and hence accorded full terrane status. This is due mainly to the fact that it is separated from the Afif Terrane by the well-defined Al-Amar Suture which is bound on both sides by two major ophiolite-bearing faults that enclose a thick succession of metamorphosed flyschoid greywackes known as the Abt Schist. The evidence for the previous existence and later consumption of a segment of oceanic crust in this region is so compelling that even critics of suture distribution in the Arabian Shield agree that "a reasonable case

can be made for situating the Al-Amar ophiolitic rocks in proximity to a suture" (Church, 1988). These ophiolites possess certain chemical and isotopic peculiarities that distinguish them from normal MORBs; for example they display a strong depletion of high field strength elements and an enrichment in large ion lithophile elements compared with normal MORB (Al-Shanti and Gass, 1983; Al-Saleh, 1994), a diagnostic feature of back-arc basin basalts especially those formed in ensialic settings. Moreover, they also exhibit an apparent depletion of ^{206}Pb , a feature that led Pallister *et al.* (1988) to suggest contamination by continental lead during the early stages of rifting of a continental margin. This ensialic marginal basin is thought to have been well-established by 695 Ma as deduced from the U/Pb dating of the Urd gabbro from the western section of the suture by Stacey *et al.* (1984), and closure was timed at 680 Ma on the basis of $^{40}\text{Ar}/^{39}\text{Ar}$ dates from the metamorphic sole of that complex. It should be noted here that the difference between the magmatic age of the Urd gabbro and the emplacement age of the ophiolite, which is in the order of 15 Ma, is the average age of a back-arc basin of this type according to Saunders and Tarney (1991). All this indicates that the Ar Rayn Block was part of the Afif microplate separated from it by an ephemeral marginal basin and that it was never far removed from its place of origin.

A main feature in the terrane map produced by Johnson and Vranas (1984) which is absent in the scheme of Stoesser and Camp (1985) is the Hail Terrane. This segment was regarded by the latter authors as being the northernmost exposed part of the Nabitah Suture. However, there exists a marked overall dissimilarity in internal structure, rock types and geochronology between these two entities. For example, much of the Nabitah Suture consists of syn-tectonic gneissose granites and migmatites injected into basic and intermediate meta-volcanics in the form of gneiss domes and antiforms which were later invaded by unfoliated alkali-feldspar granites (Schmidt *et al.* 1979); in contrast, the Hail Terrane contains a much more varied assemblage spanning the whole spectrum of sub-alkaline magmas from mafic/ultramafic plutonic complexes to diorite, granodiorite and monzogranitic plutons which are often associated with abundant cogenetic extrusives (Williams *et al.* 1986, Quick and Doebrich 1987); these older units are intruded by Late Proterozoic-Early Cambrian alkali and peralkali granites of batholithic dimensions (Ekren *et al.* 1987). In contrast with the Nabitah Suture where plutonism occurred in two main pulses during the relatively short time span between 690 and 640 Ma (Stoesser and Stacey 1988) the Hail Terrane possesses a much longer history of almost continuous volcanomagmatic activity from 740 to 565 Ma (Williams *et al.* 1986). A prominent feature of this terrane is the presence of slightly metamorphosed thick sedimentary and pyroclastic successions such as the Zarghat Formation to the west and the Hadn Formation in the central region; no such units exist within the Nabitah Suture. More importantly, the contacts between this terrane and the rest of

the shield are marked by major fault systems; the strike-slip Halaban-Zarghat Fault separates it from the Nabitah Suture, and a southeast-dipping major thrust fault extends over the entire length of the contact with the Afif Terrane. Along the latter fault zone the Afif crust was thrust over the southern rim of the Hail Terrane, and it has a special significance since it contains slivers of ultramafic and gabbroic rocks as well as listwanite (carbonatized serpentinite) (Quick and Doebrich 1987), an assemblage typical of ophiolite sheets in the Arabian Shield (Pallister *et al.* 1988).

Conclusions

In spite of the overall difference in the isotopic signature between the Ar Rayn and Afif terranes especially in terms of their initial lead isotope ratios (Stoeser and Stacey 1988 and references therein) there is an almost complete transition between the lead data from the northern Afif Terrane, the Al-Amar Suture and the Ar Rayn Terrane. Lead isotopes from these three regions form a distinct group transitional in nature between the continental leads of the southern Afif Terrane and the oceanic leads of the primitive arc terranes of the western shield. It can be envisaged that following the rifting event that separated the Khida Basement from its precursor (*e.g.* the Mozambique Belt) continued crustal growth along its eastern and northern margins led to the formation of the northern segment of the Afif Terrane.

It has been demonstrated that the Ar Rayn Block represent a rifted fragment from the Afif Terrane that was separated from it by a short-lived marginal basin and thus can not be thought of as a truly exotic crustal fragment. However, the presence of a well-developed suture zone between the two blocks and the fact that most of the exposed rocks in Ar Rayn belong to the post-rifting period makes it reasonable to represent this part of the shield as a parautochthonous terrane. Applying the same rationale, the Ad Dawadimi Terrane could be reinstated as in the scheme of Johnson and Vranas.

A stronger case can be presented for the Hail structural province where tectonic contacts and gross dissimilarities in geologic history between it and adjoining structural units warrants its designation as a genuine allochthonous terrane. Timing of the collisional event is not as well-constrained as it is in the Al-Amar zone, yet it is noticed that there is a general cessation of dioritic and tonalitic magmatism at around 650 Ma (Cole and Hedge, 1985). This earlier assemblage is supplanted by highly-evolved suites of alkali-feldspar granite, syenogranite and alkali granite (Quick and Doebrich, 1987) that persisted until about 565 Ma (Stuckless *et al.* 1984). It can be inferred that such a change marks the transition from a subduction-related igneous regime to one where anatexis processes are dominant; in

other words, the approximate time limit of 650 Ma can be taken as the point when the Hail Terrane docked with the northern Afif micro-continent; however, if the Ar Rayn and Ad Dawadimi terranes extend northwards to the eastern margin of the Hail Terrane as suggested by Johnson and Stewart (1995) then an earlier date (before 695 Ma) for this docking event must be considered. Nevertheless, the time range for such collision partially overlaps that of tectonic activity along the Nabitah lineament, and may explain why this distinct crustal fragment was unjustifiably incorporated into that suture.

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التحام الأقاليم التكتونية وعلاقته بنمو الدرع العربي خلال الزمن البروتيروزوي المتأخر

أحمد بن محمد عبد الله الصالح

قسم الجيولوجيا - كلية العلوم - جامعة الملك سعود - ص. ب. (٢٤٥٥) - الرياض ١١٤٥١
المملكة العربية السعودية

تمت بعض المحاولات في الماضي لتقسيم الدرع العربي إلى عدد من الأقاليم التكتونية والتي التحمت بالحافة الشرقية للراسخ الأفريقي قرب نهاية الزمن البروتيروزوي . يبدو الجزء الشرقي من الدرع العربي بشكل خاص كمثال تقليدي لمثل هذه العملية ، حيث يحتوي على خطوط التحام جيدة التكوين وحاوية على تجمعات أوفيولايت حقيقية . أكثر التقسيمات قبولاً لهذا الجزء من الدرع تصنفه إلى كتلتين (أقليم عفيف وأقليم الرين) ذات أصل قاري ، ويفصلهما عن الأقاليم الغربية المحيطة بالأصل خط التحام النبيتية الرئيسي . إن البحث الدقيق باستخدام المعلومات الجيوكيميائية وأعمار الصخور يبين أن كتلة الرين هي مجرد كتلة منفصلة من صفيحة عفيف ويجب بذلك اعتبارها أقليماً غير منقول . منطقة حائل البنائية في الطرف الشمالي من حزام النبيتية تحتوي على تجمع من الصخور النارية أكثر تنوعاً مما يوجد في خط التحام النبيتية ، كما أنها تحتوي على عدد من الوحدات الرسوبية السمكية قليلة التحول والتي تنحصر مكاشفها في هذه المنطقة من الدرع . بناء على ذلك ، وبالإضافة إلى كون جميع حدود هذه المنطقة مع بقية اجزاء الدرع عبارة عن نطاقات فوالق رئيسية بعضها يحتوي على الأفيولايت يجعل من المقبول رفع رتبة هذه المنطقة إلى اقليم تكتوني .