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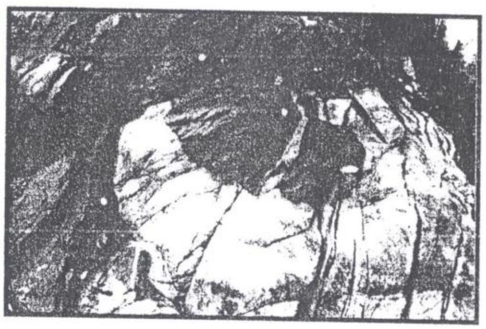
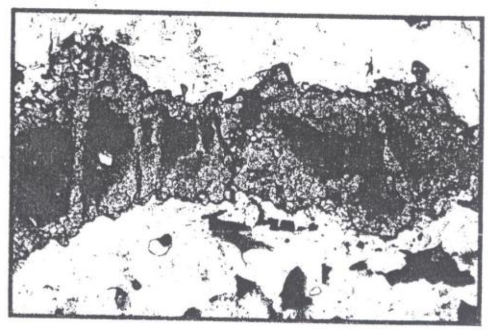
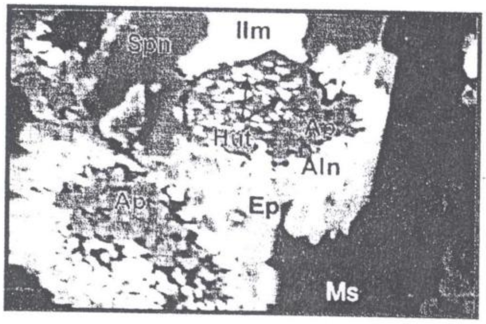
Pan-African Event India and Antarctica







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A type Malani Magmatism : Signatures of the Pan-African Event In the Northwest Indian Shield Assembly of the Late Proterozoic Malani Supercontinent

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Abstract : The plume related Malani magmatism is intra-plate, anorogenic, A-type and is indicative of extensional tectonic environment in the Trans-Aravalli block (TAB, west of the Aravalli- Delhi fold belt) of the NW Indian shield. The Malani supercontinent comprises TAB of the NW Indian shield. Seychelles-Madagascar. Nubian Arabian shield and Yangtze craton of South China. In this paper similarities between these micro continents in terms of bimodal anorogenic magmatism, ring structures, Strutian glaciation and subsequent dessication and discussed. The paleomagnetic data also support the existence of the Malani supercontinent.

Keywords : Malani supercontinent, A-type granite, Rajasthan, Mantle Plume.

INTRODUCTION

The Indian subplate is composed of three geologically different blocks or terranes. The South India Block (SIB), the Bundelkhand Block (BB) and the Trans-Aravalli Block (TAB) which were juxtaposed and sutured during different periods of Earth's history (Radhakrishna, 1989). The Bundelkhand and the South Indian blocks came together during Mid Proterozoic along Central Indian Tectonic Zone (CITZ), the latter has remained active from Early Proterozoic to Recent. The CITZ forms a belt in an ENE-WSW direction and is marked by the Son-Narmada lineament and other associated prominent lineaments. The TAB and BB which are geologically unrelated to each other are separated by NE-SW trending 700km long Proterozoic Aravalli-Delhi mobile belt. (Fig. 1).

Pan African Event

Pan-African Thermo-Tectonic Event : Kennedy (1984) defined the Pan-African as a thermo tectonic event at 500Ma affecting large areas encircling the West African, Congo and Kalahari cratons. It is now in widespread use in other continents and refers to events centered around but not restricted to period from 750-550Ma (Black and Liegeois normal. In South America the term 'Brasilian' is approximately equivalent to the Pan-African (Rogers *et al.*, 1995). The available geochronological data indicate that Pan-African tectono-thermal event at 500-550Ma is more pronounced in the Lesser and Higher Himalaya and South Indian block, south of Palaghat, Cauvery shear zone and in Wanni Complex and High Land Complex of SriLanka. The Himalayan magmatism is of S-type, whereas in Srilanka and Tamilnadu the magmatism has A-type affinity. In the Trans-Aravalli block and South Indian block of the Indian shield event at 650-750 Ma is well documented. This magmatism is of A-type (Kochhar, 2001).

In this paper significance of A-type magmatism of Rajasthan and Haryana is discussed in terms of anorgoenic and 'within plate' setting, and the assembly of Late Proterozoic Malani supercontinent.

Trans-Aravalli Block (Rajasthan and Haryana)

The TAB is unique in the geological evolution of the Indian shield as it marks a major period of anorogenic (A-type), 'Within Plate', high heat producing (HHP) magmatism represented by the Malani igneous suite of rocks (MIS). The Neoproterozoic Malani igneous suite (55,000 km^2; 732 Ma) comprising peralkaline (Siwana), metaluminous to mildly peralkaline (Jalor), and peraluminous (Tusham and Jhunjhunu) granites with cogenetic carapace of acid volcanics (welded tuff, trachyte, explosion breccia and perlite etc.) and characterized by volcano-plutonic ring structures and radial dykes. The suite is bimodal in nature with minor amounts of basalt, gabbro and dolerite dykes. The Siwana ring structure (30 km in EW 25 km in NS direction) is the most spectacular feature of the Thar desert. The representatives of Malani suite also occur at Kirana Hills, and at Nagar Parkar, Sindh, Pakisthan (Qasem Jan et.al, 1997) and is shown in Fig. 1. The Malani magmatism is controlled by NE-SW trending lineaments (zones of extension and high heat flow) of fundamental nature (mantle) and owes its origin to mantle plume (for a review, Kochhar, 2000a). Recently Bonin (2007) has suggested that A-type ring complex granites were produced in planetary environment differing from that prevailing on Earth. Rare felsic material found in the meteoric and lunar record yield dominantly A-type granites.

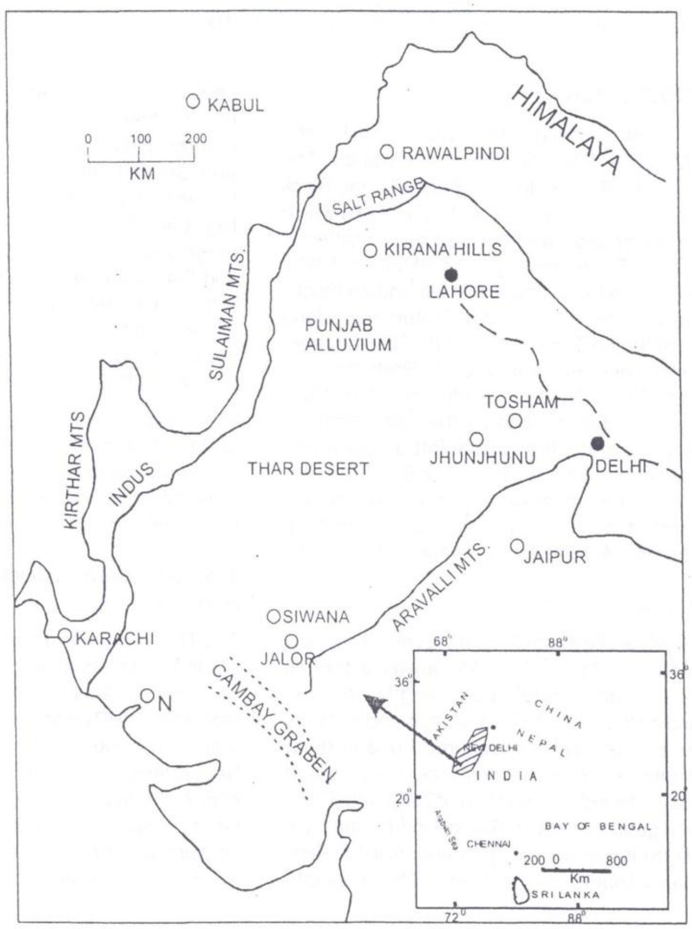

Fig. 1 : Location map of the Malani Igneous Suite S : Siwana, J : Jalor, JH : Jhunjhunu, SD : Sarnu-Dandali, N : Nagarparkar

Evidences for Precambrian mantle plume activity in the TAB

Low velocity anomaly

Kennette and Widiwantoro (1999) based on P wave arrival time delineated a low velocity anomaly to the north of Cambay Gulf. This feature is 120 km across and is in marked contrast to high seismic velocities which characterize the lithosphere beneath the peninsular India. This anomaly extends from shallow depth to contact with more extensive low velocity zone below 200 km beneth the Indian lithosphere. The anomaly coincides with the Siwana ring structure, and the low velocity anomaly may represent the conduit of a fossil plume, the Malani plume (Kochhar, 2001).

Gravity and heat flow data

The Marwar terrane of the TAB is characterized by high heat flow and basement high indicating underplating and uplift. The Tusham area is associated with the highest heat flow of $96mWm^{-2}$ in the TAB. The heat flow observed in the around Khetri and Jhunjhunu is $75mWm^{-2}$, with an average value of 60 mWm^{-2} for the Delhi fold belt. High heat flow value of $93mWm^{-2}$ has been reported from Cambay basin.

Chemical and thermal anisotropy

The chemical and thermal anisotropy in the TAB is manifested in the anorogenic magmatism represented by high heat producing A-type, 'Within Plate'. Malani magmatism indicative of extensional tectonic environment, crustal thickness and high heat flow. The bimodal nature of Malani magmatism is exemplified by the occurrence of basalt, gabbro and dolerite dykes of continental alkaline affinity. The trace element pattern is of high abundance of Hf-Zr, Nb, Ga, Zn, Y, REEs (except Eu) of granites and the associated volcanic rocks emphasis the role of halogens in fluxing these elements from the mantle (Kochhar and Dhar, 1993; Kochar, *et al.*, 1995; Kochhar, 2000b; Bhushan, 2000).

Malani Supercontinent

There is a relationship between mantle plume related anorogenic magmatism and assembly of a supercontinent. Plumes initiate continental break up by doming and rifting and rupturing (Morgan, 1972). Preceding Pangea (Late Paleozoic Supercontinent) was the supercontinent of Rodinia generally regarded as persisting to the latest Proterozoic but with wide uncertainities concerning its configuration and times of assembly and dispersal (Rogers *et al.*, 1993). According to Dalziel (1992) breaking up of Rodinia occurred during two phases one at 750 Ma and the younger rifting phase at 550 Ma. The breakup at 750 Ma resulted in the separation of East Gondwana from the present west coast of Laurentia.

Spot paleomagnetic readings at 750 Ma also suggest that neither India nor Australia can be joined in either a traditional East Gondwana or Rodinia fit. The data also does not support the idea of coherent East Gondwana (Meert, 2001) Anekt-Mozambique ocean closed to form Arabian – Nubian shield – the join between East and West Gondwana during 870-640 Ma (Unrug, 1992, Rogers et. al, 1993).

The period ca. 732 Ma mark a major Pan-African tectono-magmatic event of widespread magmatism, of alkali granites and comagmatic acid volcanics (anorogenic, A-type) in the Trans – Aravalli block of the Indian shield, Central iran (Forster, 1987), Nubian – Arabian shield (Kronel *et al.*, 1989) and Madagascar and South China (Yoshida *et al.*, 1999) Kochhar, 2007a, b, Li *et al.*, 1999, 2004); Somalia (Kroner *et al.*, 1990) and Seychelles Hoshino, 1986 Kochhar, 2004).

In view of the widespread ca. 750Ma alkaline magmatism, which is so widespread, and well

Table 1: Similarities between TAB, Nubian Arabian Shield, Seychelles, and South China in terms of bimodal, anorogenic magmatism, protolith, paleopoles and Strutian glaciation and subsequent desiccation

	TAB NW INDIAN SHIELD	SEYCHELLES	NUBIAN ARABIAN SHIELD	S. CHINA YANGTZE BLOCK
Alkali Magmatism granites	Siwana Jalor Tusham ca 745 Ma	Mahe, Ste Anna Praslin ca. 700-755 Ma	Jabal-Al Hasasin Jabal-AS Sawal Dahul Ca. 700-760 Ma	Chengjian ca. 780-745 Ma
Protolith	Archean BGC	Archean BGC	Paleo Proterozoic or older crustal Precursor	-
Paleopole	55-70^0	30^{0}N	-	70^{0}N
Strutian glaciation	Pokhran, Salt Range Boulder Bed	-	Haqf Super Group	Linntua and Nantua deposits
Evaporite/ Carbonate Sequence	Hanseran, Nagaur Bikaner Basin	_	Hormuz Series	Late Sinian Late Precambrian carbonate and phosphates.

developed in TAB, central iran, Arabian – Nubian shield, Madagascar and S.China, Somalia, Seychelles, Kochhar (1996, 2000a,b, 2001, 2007) proposed that all these microcontinents were characterized by a common crustal stress pattern, rifting and thermal regime, Shrutian glaciation and dessication and similar paleolatitudinal positions which could be attributed to the existence of a supercontinent – the Malani Supercontinent, (Table 1) (Fig. 2).

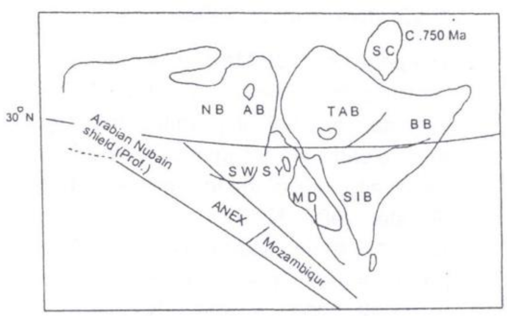

Fig. 2 : Assembly of the Malani supercontinent, TAB : Trans-Aravalli Block, BB : Bundelkhand Block, SIB : South Indian Block, NB-AB : Nubian-Arabian Shield, SM : Somalia, SY : Seychelles, MD : Madagascar, SC : South China

Seychelles

The Mahe (750Ma) and Ste. Anne (764 Ma) granites of Seychelles have been correlated with 732 Ma old hypersolvus (Siwana) and subsolvus (Jalor granites) of MIS. These granites have A-type signatures and owe their origin to the same protolith of Archean crust of (amphibolite) BGC of Rajasthan as indicated by Sm/Nd; Rb/Sr isotopic data. The Seychlles and Malani granites have similar low oxygen isotope ratios ä18% SMOW (+3 TO + 4% (Seychelles granites) and Siwana and Jalor granite) (-0.10 to + 1.8:10, -4.60 to +1.2‰) (Ashwal *et al.*, 2002, Kochhar, 2004).

Similarities between granites of Mis (Jalor and Siwana) and the Seychelles (Mahe, STE. Anne and Praslin) Granites : (Kochhar, 2004)

1. The coeval (730 Ma) (Rb/Sr) hypersolvus (Siwana) and subsolvus (Jalor) granites of MIS (Kochhar and Dhar, 1993) have been correlated with Mahe (750 Ma) and Ste. Anne (764 Ma) granites of Seychelles (Ashwal *et al.*, 2002).

2. Role or Archean basement granites complex crust (2.5-2.3 Ga) in the evolution of granites of both the regions. Pb and Nd isotopic compositions of the Siwana granites show that the magma is mantle derived, and for Jalor complex, the combined Sr and Nd data indicate primary mantle derivatives with a variable degree of contamination crust of Archean age (Dhar *et al.*, 1996). According to Ashwal *et al.*, (2002) the Archean crust of BGC Rajasthan, 3.2 Ga of amphibolitic composition with initial Sr and Nd isotopic composition at 750 Ma could be suitable source of Mahe granitic rocks of Seychelles.

3. Tectonic discrimination diagrams: Ga/Al vs. Zr plot of Mahe and Praslin granites indicate A-type affinity, and the data overlap with the fields of Jalor and Tusham granites of MIS. Similarly majority of Seychelles samples plot in the WPG field of Ta vs Yb and Nb vs Y diagrams of Pearce *et al.*, (1984). It is surprising that Ashwal *et al.*, (2002) did not plot these tectonic discriminating diagrams.

4. Oxygen isotopic data : The Seychelles granites are characterized by low^{18}O (+3 to +4) %O as compared to +5 to +11‰ values of most terrestrial igneous rocks. This corresponds well with the low ^{18}O values of +1.0 to 1.8‰ of Siwana granites and -4.0 to 1.21 values of Jalor granites (Kochhar, 2000a).

Torsvic *et al.*, (2001a) obtained a paleomagnetic pole with latitude 74.5°N and longitude 71.2°E at 750 Ma for the MIS, whereas, Klootwijk (1975) has obtained 81°S latitude and 22.4°E longitude for MIS at 729 Ma. Paleomagnetic data place the MIS at 41°N at local paleolatitude when combined with normal polarity site of Klootwijk (1975) and the Seychelles at 30°N (Torsvic *et al.*, 2001). At 750 Ma B.P. Seychelles and MIS were only 600 km apart. Since the 'Within Plate'. Anorogenic nature and extensional tectonic environment of MIS is established, its correlation with Mahe, Praslin and Ste. Anne granites is suggestive of similar setting for the Seychelles granites. Stephens *et al.*, (1997) also favour intraplate, extensional tectonic environment for Seychelles granites which could be related to the plume tectonics. The MIS does not represent Andean type arc on the western margin of Rodinia.

Madagascar

Within central block of Madagascar, Carion granites which have alkaline geochemical signatures and are post tectonic were emplaced during extensional collapse of Pan-African Orogen U/Pb ages of granites of western central Masagascar near Ambistra indicate emplacement age of 804-775 Ma, some of these granites have gabbroic rocks as sleeves (Handke *et al.*, 1999). In this respect they are very much similar to Jalor granites.

The Arabian Shield

The Arabian Nubian shield (ANS) is an accreted terrane composed of crustal domains of island arc, oceanic and continental affinities overlain by post accretionary sediments and volcanics, and invaded by voluminous intrusions. The Saudi Arabia part of the Nubian Arabian shield has been divided into five terranes separated by four suture zones. The three terranes i.e. Asir, Hijaz, Midyan west of the Nabitah suture zone are of ensiamatic character, whereas, eastern two i.e. Afif and Ar-Rayan are of continental to marginal continental character. The three ensiamatic terranes are collectively referred to Arabian-Nubian arc terranes (Stoesser, 1986).

Most of the shield was created in two distinct stages. These are (1) Island arc stage (between 660-900 Ma) in which subduction related processes operated for the generation of magma, and (2) a post accretionary stage (between 550-700 Ma) where magma was generated by fusion of continental protolith (Stoesser, 1986).

According to the Jackson (1986) the post accretionary stage is marked by the presence of granitic intrusions. According to Stern *et al.* (2004) the evolution of the Arabian-Nubian shield occurred between 870 Ma and the end of Precambrian (ca. 542 Ma) and the crustal growth encompassed a time of dramatic climate change (see below).

In southern Yemen, the amalgamation of the two terranes i.e. Abas (west) and Al-Mahfid (east), separated by Al Bayda island arc sequence, is marked by the 760 Ma magmatic activity (Whitehouse *et al.*, 2004). According to Johnson and Kattan (2004) the Asir terrane is more closely linked structurally and tectonically with East African orogen, Madagascar, Ethiopia, Somalia, Yemen and Eritrea than with the northern Shield, and that the southern and northern Arabian shields may be decoupled.

The remanent of the Archean crust as Proterozoic basement has been reported on the basis of lead isotope studies in the Afif terrane. A zircon from trondjhemite along the Al Amar fault has yielded 2067 ± 74 Ma age there by indicating Late Proterozoic crust in the shield. Granodiorite gneiss from Jabal Khida in the easternmost part of the shield has been dated at 1629 ± 20 Ma (Stoesser, 1986).

According to Stoesser *et al.*, (2004) there is no indication of crust formation between 1670-900 Ma as indicated by U/Pb and single zircon data. Between 760-740 Ma ago, the Khida terrane separated from the margin of Paleoproterozoic and Archean continental block-the Arabian craton, presently concealed beneath the Phanerozoic cover in the east but exposed in Yemen.

Magmatism

The Arabian shield contains one of the largest fields of alkali granites in the world. Forty nine major and more than a dozen minor alkali granite plutons occur in the Midyan and Hijaz terranes and in the Nabitah orogenic belt. The alkali granites do not occur SW and easternmost part of the shield. The alkali granites were the last intrusive phase and were emplaced during a span of 180 Ma between 680-510 Ma ago. The alkali granites are spatially associated with metaluminous hypersolvus to subsolvus granites, the latter forming the core of complexes. The alkali granies are also associated with a swarm of alkali rhyolite dykes in the northeastern part of the shield (Stoesser and Elliot 1985). A total of thirty three ring complexes and funnel shaped intrusions have been recognized related to the extensional tectonic regime in the Arabian shield. (Fig. 3) The magmatism (670-570 Ma) is mainly peralkaline to metaluminous with A-type affinity. The granites and the related rock types were emplaced by cauldron subsidence which operated in the final stage of the cratonisation of the Arabian shield (Roobal and White, 1986).

The peraluminous and peralkaline granites with A-type geochemical characteristics are encountered at Jabal-Al Hasasin, Jabal As Sawal Jabal Dahul (Stoesser et. al., 2004). According to Vail and Kuron (1978) high level ring complexes, ring dykes and cone sheets have been reported from the Red Sea Hills and Bayuda desert in NE Sudan. These complexes comprise granites, quartz syenite, nepheline syenite gabbro etc, and have been dated at 700 Ma. The Abas terrane is dominated by 760 Ma granitoids. (Whitehouse et. al., 2004), with Sm-Nd model ages (2.3 Ga) indicating reworking of a Paleoproterozoic or older crustal precursor. These features are very much similar to the Siwana and Jalor granites of MIS (Kochhar, 2006).

Interestingly Forster (1987) compared the Infra-Cambrian and Cambrian rhyoliths and the associated granites of Central Iran with the Malani rhyolites and the Pan-African granites of Arabian shield. The similarly has been attributed to the Gondwana connection based on paleomagnetic data. Central Iran held a position south of equator during Infra Cambrian and later drifted from the southern margin of the Gondwanaland to its present position as a microplate. According to Kroner et. al., (1990), the period between 850-750 Ma represents the most significant crust formation event in all parts

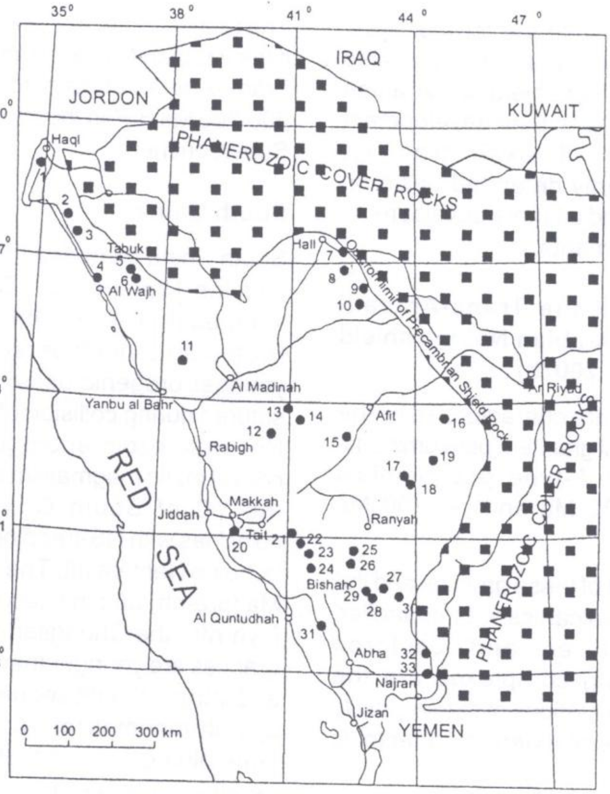

Fig. 3 : Map showing the location of Ring complex (RC), Single ring structure (SR), Beejar plutons (BJP) and Calderas (C) in the Arabian shield

Sr. No.	Location	Type	Geochemical Affinity
1	Sawda Complex	RC	AA
2	Dabbagh Complex	RC	AA
3	Sulay Siyah Complex	RC	P
4	Liban pluton	BJP	P
5	Habd Complex	BJP	P
6	Warid Complex	RC	AA
7	Jabal Salma Complex	C	AA
8	Jabal AL-Makhrugah	SR	P
9	Jabal Raha	C	AA
10	Jabal Silrilah	SR	AA
11	Martabah Comples	RC	P
12	Jabal Ramram	C	P
13	Jabal Hadash Shara	RC	P
14	Jabal Hadbad Dayahm	RC	AA
15	Jabal as Safwah	RC	AA
16	Jabal Arawan	RC	AA
17	Jabal Kursh	RC	AA

Sr. No.	Location	Type	Geochemical Affinity
18	Jabal Dahul Complex	RC	AA
19	Uyaijah ring dyke	RC	AA
20	Unnamed Complex	RC	P
21	Jabal Al-Qunnah	RC	P
22	Unnamed ring dyke	SR	AA
23	Khutamah ring dyke	SR	P
24	Aquq ring dyke	SR	P
25	Jabal Munirah	RC	P
26	Jabal Al Najiah	RC	P
27	Jabal Bani-Bisqan	RC	AA
28	Jabal Al-Hasser	RC	AA
29	Jabal Refdah	RC	P
30	Unnamed Complex	RC	P
31	Lakathah Complex	RC	P
32	Wadi Idimah Complex	RC	AA
33	Jabal Ashirah Complex	RC	AA

AA : Alkaline affinity, syenite, alkali granite with riebeckite, aegirine etc. A-type. P Peraluminous / metaluminous affinity of ANS including Somalia in the form of felsic intraplate magmatism. Rogers (1990) has also suggested that both Indian shield and Arabian Nubian shields are similar in their development including production of alkali granites, subsidence of thick partly deformed basin on recently formed crust and ultimate development of platformal cover sediments.

Similarities between the Trans-Aravalli Block (TAB) and the Arabian Nubian shield (ANS) (Kochhar, 2006, 2007b)

1. Both the terranes are characterized by the occurrence of alkali granites (peraluminous-peralkaline with A-type geochemical signatures) at 732 Ma and ca. 700 Ma respectively.
2. The emplacement of these granites and the associated acid volcanics was controlled by ring structures and cauldron subsidence. Ring complexes are the continental manifestations of plume activity and are indicative of extensional tectonic environment.
3. Both the terranes preserve the remnants of Archean crust ie. BGC of amphibolitic facies (3.2 Ga in the TAB (Kochhar, 2004) and trondjhemite of 2.6 Ga in the Afif terrane of ANS. This order crustal protolith has acted as precursor to the younger alkali granites.
4. In both the terranes the alkali granites mark the cratonisation of the shield.
5. Both the terranes are characterized by similar peralkaline and peraluminous granite hosted mineralisation of U, Th, Nb, Ta REEs, Sn, W, Li and F etc. In this respect they are akin to the younger granites of Nigeria. (Kochhar, 1998, 2000a and b, Vallinayagam, 1999 and Somani 2006).
6. Both the terranes are characterized by the occurrence of evaporites-carbonate sequence and show evidence of Strutian glaciation.

The aforesaid similarities can only be explained if the Arabian Nubian shield was attached to the Trans-Aravalli block of the Indian shield around 600-700 Ma B.P. in the configuration of the Malani Supercontinent.

South China

South China comprises the YC to the northeast and the Precambrian Cathysia block to the southeast. The YC has as Late Archaean-Proterozoic nucleus surrounded mostly by younger orogenic belts. Both the blocks were sutured during collision of Grenville age (Fig. 4). Neoproterozoic anorogenic magmatism and coeval mafic magmatism are widespread around the YC of South China. The magmatism coincides with NS-trending Kangdian rift and NE-trending Nanhua rift. The first one at ca. 830-795 Ma (pre-rift) and the second one at 780-745 Ma (syn-rift), the Chengjian magmatism. The later granites are younger than 1.0 Ga Siban orogeny and intrude the rift sequence. Both the pre- and syn-rift magmatism have been attrbibuted to superplume because of its intraplate setting, peralkaline to alkaline affinity and association with coeval swarms of mafic dykes. Emplacement of the dyke swarm initiated the break-up of Rodinia. The superplume may represent two normal plumes to account for these two episodes of magmatism. According to Wang and Li (2001), at places the ca. 780-750 Ma granites are unconformably overlain by Upper Sinian sequence (750 Ma), which is interpreted to have formed a rift cover. Li *et al.* (2004) have correlated the syn-rift (780-745 Ma) magmatism with the Malani magmatism besides those of Laurentia, South Africa and Australia.

Paleomagmatism and Strutian glaciation

The APWP palaeomagnetic poles at ca. 800 Ma place South China at 55-70°N at par with high paleolatitudes of India during Malani rhyolite period (Ca. 750Ma) (Li at al.,2004, Torsvic *et al.*, 2001). The migration of India to higher paleolatitudes could be the cause of Precambrain glaciation as exemplified by the Pokhran boulder in Rajasthan which is of glaciogenic origin

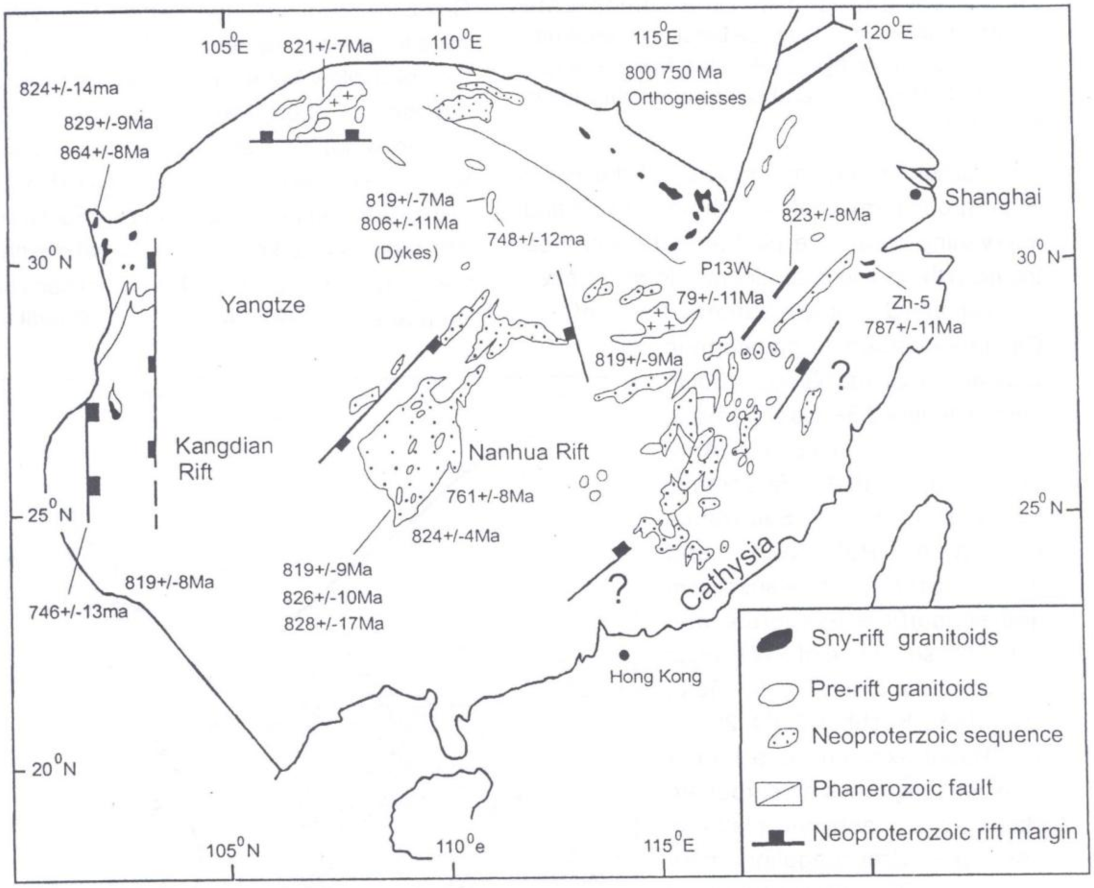

Fig. 4 : Neoproterozoic tectonic framework of South China New ages are highlighted bold

(Chauhan *et al.*, 2001, Pareek, 1984 and Sinha-Roy *et al.*, 1998). Incidentally, the Pokhran diamicitite correlates with other Precambrain diamictites in the lesser Himalaya such as Blaini boulder bed, Manjir and Bhimdasa in Jammu and Kashmir, Tankaki in Hazara, and Buxa Group (Shergaon pebbled bed) in Arunachal Pradesh (Valdiya, 1995, Virdi, 1995, Tiwari, 2003). Interestingly, Bose *et al.* (1997) have reported acid pyroclastics such as welded tuff, ash flow tuff, lapilli tuff, volcanic clasts from the Late Proterozoic formations of Lesser Himalaya, viz. Shimla Group, Blaini Formation, Infrakrol Formation and the Krol Group. The source of these pyroclastics could be attributed to the nearby Tusham acid volcanics of Malani age. It is possible that the precursor to the Lesser Himalyan terrane was contiguous part of the TAB during Late proterozoic. The boulders of Malani granites also occur in the Salt Range. In the YC, Liantua and Nautua (748 Ma) deposits are of glaciogenic origin. Around 700Ma Bp India started drifting towards the tropical latitudes and around 600 Ma, India was near the equator. According to Pooranchandra Rao *et al.*, (1997) there has been large polar movement between the Malani rhyolite and other lower Cambrian period poles indicating rapid migration of the Indian subcontinent from the northern to southern hemisphere latitudes. During this period, the northern margins of India were subjected to desiccation. The carbonate, mainly dolomite and phosphate deposits of Late Sinian-Late Precambrian age in Yangtze block, corresponds with Hanseran evaporates in the Marwar basin of TAB, SW Punjab, and Bilara phosphorites in Rajasthan.

The carbonate evaporate facies of the Hauq Supergroup form a belt of evaporate basin and intervening carbonate platform which can be traced in these micro-continents:Hormuz Series of Arabian Gulf and southern Iran, Infra – Cambrian carbonate plateform in Central Iran, Ghabar Group of South Yemen, India Ad Series of Somalia, Wadi Fatima Series and Abla Formation, South Arabia Saramuj Formation of Jordan, Salt Range Formation, Pakisthan, and evaporites of Nagaur-Bikaner basin and subsurface evaporate and anhydrite sequence of SW Punjab and Haryana, India (Fig. 5) (Gorin *et al.*, 1982, Kochhar, 2004, 2006). The Huaqf axis formed a barrier between evaporites an carbonate platform and or anhydrite platform. The Oman-Ural megalineament controlled the distribution of evaporite-carbonate sequence.

Recently, Singh *et.al.,* (2006) have described Neoproterozoic evaporite sequence from Lesser Himalaya comprising gypsum and anhydrite, gypsum + carbonate, and halite from the Kashmir sub-basin (Ramban, Assar belt), and Chamba subbasin (Bathri) respectively, and halite from the Guma-Drang area of Mandi, Himachal Pradesh. According to Illyin 1990, the continental margins of Vendian-Early Precambrian super-continental comprising South China, Kazakhstan, Mongolia and proto-Tethys were the sites of equatorial sedimentation in the form of shallow water carbonate and phosphorite deposits. A short-lived positive excursion in carbon isotope values noticed at phosphorite level in the Birmania (Upper Carbonate) Formation in the TAB and in the basal part of Tal Group in Krol basin is also known from Dahal member of the Yuhucun Formation of Meishucunian zone-II (Kumar *et al.*, 1997). According to Pandit *et al.*,

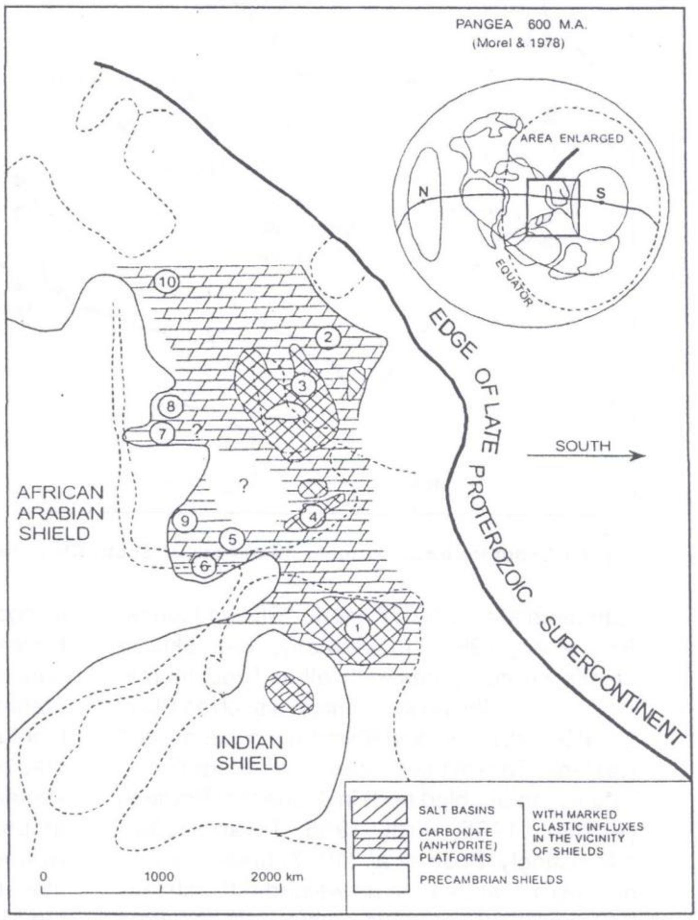

Fig. 5 : Paleogeography of the Late Precambrian-Early Cambrian sediments 1. Salt Range, Pakistan. 2. Zagros Crush Zone, Central Iran, 3. Harmuz Series, arabia, 4. Haqf group, Oman, 5. Ghabar group, S. Yeman, 6. Inda Ad Series, Somatra, 7. Wadi Fatima Sena, S. Arabia, 8. Wadi Fatima Series, Nougra, S. Arabia, 9. Alba Formation, N. Yeman, 10. Saramuj Formation, Jordan, SW Punjab, Haryana, Rajasthan NW India.

(2001), extremely low C_{13} values in the Bilaria carbonate indicate glacial-related cold climatic conditions, while positive shift in the carbon isotope values in the upper formations implies a warmer climatic condition. The Bilara carbonate group carbon isotope profile have close correspondence with global carbon isotopic evolution curve in Haqf, Oman, Siberia platform, Mongolia and Morocco and elsewhere. Li *et al.* (2004) have proposed a 90^0 spin of Rodinia that brought the entire supercontinent into equatorial latitudes. The spin was the result of initiation of a subequatorial superplume by ca. 750 Ma. The spin corresponds with reversal of geomagnetic field during the deposition of each group of Vindhyan Supergroup, i.e. Kaimur, Rewa and Bhander. During the Kaimur period (1400-750 Ma) there have been at least three reversals of geomagnetic field (Pooran-chandra *et al.*, 2003). The combined 800-700 Ma apparent polar wander path implies pole to equator rapid velocities of 20 cm/yr for India and South China, which is unlike the other continents such as Australia and Congo. (Kochhar 2001) suggested that since the Indian subplate is a mosaic of three major tectonostratigraphic blocks with different magmatic and metamorphic histories, the position of India in the assembly of a Late Proterozoic supercontinent should not be viewed as a single entity. For example, the southern tip of the SIB (south of Palaghat Cauvery shear zone), Sri Lanka and Madagascar along with the Eastern Antarctica formed a supercontinent (Idnurm and Radhakrishna, 1999). In other supercontinent assembly Meghalaya lies SW of Yilgam craton of Australia, Bungar hills and Wind Mill Islands in an Antarctican continuation of Frazer mobile belt. Due to similarities of bimodal, anorogenic magmatism in South China, India and Australia, Li *et al.,* (2003) have suggested that the superplume was responsible for the break-up of supercontinent during Neoproterozoic. The Malani plume was responsible for the separation of TAB from East Gondwana. The Malani plume may be the present day position of subequatorial plume at 750 Ma. B.P. proposed by Li *et al.* (2004) (Fig. 6). In view of the occurrence of widespread bimodal, anorogenic plume-related magmatism, Strutian glaciation and similar palaeolatitude position, the YC of South China fits well in the reconstruction of the Malani supercontinent. The position of South China between Australia and Laurentia is debatable because of an alternate equatorial Rodinia supercontinent, excluding high-latitude cratons in India and South China (Li *et al.*, 2003). Whether the Precambrian glaciation in India and South China was due to the flight of these terranes to high latitudes during the Malani rhyolite period or the glaciation was of low latitude due to increased CO_2 drawdown and global albedo affected by waning of plume volcanism is debatable. The evidences presented here

Fig. 6 : Paleogeogrpahic reconstrution of Rodinia 'in tact' at 750 Ma

supported the idea of polar Strutian glaciaton in the TAB and Lesser Himalayan terrane. (Kochhar, 2007a).

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REFERENCES

ASHWAL, L.D. DEMAIFFE, and TORSVIC, J. (2002): Petrogenesis of Neoproterozoic granitoids and related rocks from the Seychelles, the case for an Andean-type arc origin, Jour. Petrol., v.43, no. 1, pp.45-84.

BANERJEE, D.M., and MAZUMDAR, A. (1999): On the Late Neoproterozoic- Early Cambrian trasition events in part of east Gondwanaland. Gond. Res., v.2, pp.199-211.

BHUSHAN, N., (2000): Neoproterozoic magmatism of the Malani igneous suite, W. Rajasthan, India, Geol. Surv. Ind. Spl. Pub. No. 55, pp.319-332.

BLACK, R. and LIEGOIS, J.P., (1993): Cratons, mobile belts, alkaline rocks and continental lithospheric mantle: The Pan African testimony. J. Geol. Soc. London. v.150, pp.89-98.

BONIN, B., (2007) : A-type granites and related rocks: evolution of a concept, problems and prospects. Lithos, v.97, no.1,2, pp.1-29.

BOSE, U., NAGAL, S.C., SHARMA, N.L., PRASHRA, K.C., SHARMA, V.K. and BASSI, U.K., (1997): Pyroclastice in the Late Proterozoic formation of the Simla Himalaya, Jr. Geol. Soc. Ind. v.49, pp.539-545.

CHAUHAN, D.S., MATHUR, K.M. and NARAYAN RAM (2001): Geological nature of the Pokaran Boulder Bed: Paleoenvironmental, paleoclimatic and stratigraphic implication Jr. Geol. Soc. Ind. v.58, pp.425-433.

Dalziel, L.W.D. (1992): On the organization of American plate in the Neoproterozoic and the breakout of Laurentia GSA Today, v.2, pp.237-241.

DHAR, S., FREI, R., KRAMER, J.N.D., NAGLER, T.F., and KOCHHAR, N. (1996): Sr., Pb and Nd isotope studies and their bearing on the petrogenesis of Jalor and Siwana complexes, Rajasthan, India. Jr. Geol. Soc. Ind., v.48, pp.151-160.

FORSTER, H. (1987): Ignimbrite cauldrons, alkali granites and mineral deposits in fault block mountains. Geol. Rundsch., v.76/2, pp.373-388.

GORIN, G.E., RACZ, L.G; and WALTER, M.R. (1982): Late Precambrian-Cambrian sediments of Hugf Group. Sultanate of Oman. AAPG Bull. v.68, pp.2609-2627.

HANDKE, M., TUCKER, R.D., and HAMILLION, M.A. (1997): Early Neoperoterozic (800-790) intrusive igneous rocks in central Madagascar, Geochemistry and pertogensis. Geol. Soc. Abstr. Program, v.29, p.468.

HOSHIMO, M. (1986): Amphiboles and coexisiting ferromagnesian silicates in granitic rocks in Mahe, Seychelles. Lithos, v.9, pp.11-21.

IDNURM, M., and RADHAKRISHNA, T. (1999): Australian and Indian Proterozoic APWPs and time of amalgamation of India and Australia. In T. Radhakrishna and JDA Piper (Eds.). the Indian Subcontinent and Gondwana : A Paleomagnetic and rock magnetic perspective. Geol Soc. Ind. Mem., v.44, pp.33-44.

ILYIN, A.V., (1990): Proterozoic supercontinent, its latest Precambrian rifting, breakup, dispersal into smaller continents and subsidence of their margins: Evidence from Asia Geology, v.18, pp.1231-1235.

JACKSON, N.J. (1986): Petrogenesis and evolution of Arabian felsic plutonic rocks, Jr. African Earth Sci., v.4, pp.47-50.

JOHNSON, P.R., and KATTAN, F.H. (2004): Geochronological and structural reappraisal of Asian Terrane assembly, Southern Arabian Shield. 32 IGC, Florence. Abstr. Part 2, p.1190.

KENNEDY, W.Q. (1964) : The structural differentiation of Africa in the Pan-African (~ 600Ma) tectonic episode Univ. Leeds Res. Inst. Afr. Annual Report. V. 8, pp. 48-49.

KENNETT, B.L.M. and WIDIYWANTRO, S. (1999) : A low velocity wavespeed anomaly beneath northwestern India: A seismic signature of the Deccan plume? Earth Planet Sci. Lett., v. 165, No. 1, pp. 145-156.

KILNER, B., MACNIOCAILL; and BRASIER, M. (2005)

: Low latitude glaciation in the Neoproterozoic of Oman. Geology v. 33, pp. 413-416.

KLOOTWIJK, C.T. (1975) : A note on paleomagmetism of the Late Precambrian Malani rhyolites near Jodhpur, India. J. Geophys. v. 41, pp189-200.

KOCHHAR, N. (1996) : 750 Ma supercontinent: evidence from the Indian shield. Special Symposium F. 9. The breakup and accretion of the Asia continent. 30th IGC, Beijing, China, v. 1/3, p. 255.

KOCHHAR, N. (1998) : Rare metal potential of the A-type Malani Granties, NW peninsular India, Ind. Mineral, v. 52, pp. 271-276.

KOCHHAR, N. (2000 A) : Mantle plumes, anorogenic magmatism and super-continent. Proc. workshop on Plume tectoncis. NGRI, Hyderabad, pp. 20-24.

KOCHHAR, N. (2000 B) : Attributes and significance of the A-type Malani magmatism, northwestern peninsular India. In M.Deb (Ed.) Crustal Evolution and Metallogeny in the northwestern Indian shield, Chapter 9, pp. 183-217, Narosa Publishing House, New Delhi.

KOCHHAR, N. (2001) : Anorogenic magmatism, mantle plume and assembly of the Late Proterozoic sueprcontinent, NW Indian shield. GRG/CIGE Misc. Publ. No. 12, pp. 22-27.

KOCHHAR, N. (2004) Geological evolution of the Trans-Aravalli Block (TAB) of the NW Indian shield: constraints from the Malani igneous suite (MIS) and its Seychelles connection during Later Proterozoic. Geol. Surv. Ind. Spl. Pub. No. 84, pp. 247-264.

KOCHHAR, N. (2006) : The Malani supercontinent : Middle East connection during Late Proterozoic. 6th International Conference on the Geology of Middle East. Al Ain, UAE, Abstract, p. 230.

KOCHHAR, N. (2007 A) : Was Yangtze cration. S. China attached to the Trans-Aravalli Block of the NW Indian shield during Late Proterozoic ? Current Sci., v. 92, pp. 295-297.

KOCHHAR, N. (2007 B) : The Malani super-continent Proc. IX convention of Mineralogical Society of India and National Seminar on PGE Gold and Diamonds in India, pp. 144-151, NGRI, Hyderabad.

KOCHHAR, N. (2008) : A –type Malani magmatism, NW Peninsular India. IN A.K. Singhvi, A. Bhattacharya and S. Guha (Eds.) Glimpses of Geosciences Research in India. The Indian Report to IUGS 2004-2008, INSA, New Delhi. pp 176-181

KOCHHAR, N., and DHAR, S. (1993) : The association of hypersolvus-subsolvus granites: A study of Malani igneous suite. India. Jr. Geol. Soc. Ind. v. 42, pp. 449-467.

KOCHHAR, N., DHAR, S., and SHARMA, R. (1995) : Geochemistry and tectonic significance of acid and basic dykes associated with Jalor magmatism, west Rajasthan. Geol. Soc. Ind. Mem. 33, pp. 375-389.

KRONER, A., EYAL., M., and EYAL, Y. (1990) : Eartly Pan-African evolution of the basement around Elat, Isreal, and the Sinai peninsul revealed by single zircon evaportion dating, and implications for crustal accretion rate. Geology, v. 18, pp. 545-548.

KRONER, A., REISCHMANN, T., TOJT, Y., ZIMMER, M., STERN, R.J., HUSSEIN, U., MANSOUR, M., EYAL, M., EYAL., Y., and SASSI, P. (1989) : Timing mechanism and geochemical pattern of arc accretion in the Arabian-Nubian shield and its extension into Isreal and Somalia. Extended Abstr. 28th IGC, Washington, DC, USA, v. 2, p. 2/231.

KUMAR, G., SHANKER, R., MAITHY, P.K., MATHUR, V.K., BHATTACHARYA, S.K., and JANI, R.A. (1997) : Terminal Proterozoic-Cambrian sequences in India: a review with special reference to Precambrian-Cambrian boundary. Paleobot., v. 46, pp.19-33.

LI, Z.X., EVANS, D.A.D., and ZHANG, S. (2004) : A 90° spin on Rodinia: possible casual links between the Neoproterozoic supercontinent. super plume, true polar wander and low latitude glaciation. Earth Planet Sci. Lett., v. 220, pp. 409-421.

LI, Z.X., LI, X.H., KINNY P.D., WANG, J. ZHANG, S., ZHU, H. (2003): Geochronology of Neo-proterozoic syn-rift magmatism in the Yangtze craton, sourth China and correlation with other continents: evidence for a mantle super-plume that broke up Rodinia. Precamb. Res., v.122, pp.85-109.

LI, Z.X., LI, X.H., KINNY, P.D., and WANG, J. (1999): The breakup of Rodinia, Did it start with a mantle plume beneath south China. Earth Planet. Sci. Lett., v.173, pp.171-181.

MEERT, J.G. (2001): Growing Gondwana and rethinking Rodinia: paleomagnetic perspective. Gond. Res., v.4, pp.278-288.

MORGAN, W.J. (1972): Deep mantle convention plumes and plate tectonics. AAPG Bull. v.56, pp.203-213.

PALIWAL, B.S., and RATHORE, P.S. (2000): Neoproterozoic volcanics and sedimentaries of Jodhpur, A reappraisal In K.C. Gyani and P.Kataria (Eds.) Tectonomagmatism, geochemistry and metamorphism of Precambrian terrain University Press, Udaipur, pp.75-96.

PANDIT, M.K., SIAL, A.N., JAMRANI, S.S., and FEROEIRA, V.P. (2001): Carbon isotopic profile across the Bilara group rocks of trans-Aravalli Marwar supergroup in Western India : Implications for Neoproterozoic – Cambrian Transition Gond. Res., v. 4, pp. 387-391.

PAREEK, H.S. (1984): Pre-Quaternary geology and mineral resources of north-western Rajasthan, Mem. Geol. Surv. Ind., v.115, pp.1-99.

POORANCHANDRA RAO, G.V.S., MALLIKHARJUNA, J., and CHAKO, S.T., and SUBRAHMANYAM, K. (1997): Paleomagnetism of Baghain sandstone Formation, Kaimur Group. Jr. Ind. Geophys. Union, v. 1, no.1, pp. 41-48.

POORANCHANDRA RAO, G.V.S., SINGH, S.B. and PRASANNA LAKSHMI, K.J. (2003): Paleomagnetic dating of Sankra dyke Swarms in the Malani igneous suite, western Rajasthan, India. Current Sci. v.85, pp.1486-1492.

POWELL, C.MC A., LI, Z.X., MCELIHINEY, M.W., MEERT, J.G. and PARK, J.K. (1993): Paleomagnetic constraints on timing of the Neoproterozoic breakup of Rodinia and the Cambrian formation of Gondwana geology, v.2, pp.889-892.

PEARCE, J.A. HARRIS, N.B.W. and TINDLE, A.G. (1984): Trace element dissemination diagram for the tectonic interpretation of granite rocks. Jour. Petrol. v.25, pp.956-963.

QASIM JAN, M., LACHARI, A., and ASIF KHAN, M. (1997): Petrography of the Nagar Parkar igneous complex, Tharparkar, SE Sindh Geol. Bull. Univ. Peshwar, v.30, pp.227-249.

RADAHKRISHNA, B.P. (1989): Suspect tectono-stratigraphic terrane elements in the Indian subcontinent. Jr. Geol. Soc. Ind., v.34, pp.1-24.

RAMSAY, C.R. (1986): Specialized felsic plutonic rocks of the Arabian shield and their precursors. Jr. African Earth Sci. v.4, pp.153-168.

ROGERS, J.J.W. (1990): Comparison of India and Nubian shield. In S.M.Naqvi (Ed.) Precambrian continental crust and its economic resources. Development in Precamb. Geol., 6, Elsevier, New York.

ROGERS, J.J.W., UNRUG, R., SULTAN, M.: The assembly of Gondwana, Final Report, Continental Dynamics Program, pp.1-60.

ROGERS, J.J.W. UNRUG, R., and MOHAMMED, S. (1993): Tectonic assembly of Gondwana, J. Geodyn. v.19 pp.1-34.

ROOBAL, M.J. and WHITE, D.L. (1986): Cauldron subsidence and calderon above Arabian felsic plutons : a preliminary survey. Jr. African Earth Sci. v.4, pp.123-134.

SINGH B.P., SINGH S.P. and SACHAN, H. (2006): Post depositional transformation during burial and exhumation in the Neoproterozoic evaporite sequence NW Himalaya. India. Jr. Geol. Soc. Ind. v.68, pp.1058-1068.

SINHA-ROY, S., MALHOTRA, G., and MOHANTY, M. (1998): Geology of Rajasthan, Geol. Soc. Ind. Publ. Bangalore. 278p.

SOMANI, R.L. (2006): Evolution of the tin-tungston and copper-bearing hydrothermal solutions associated with Tusham igneous compelx, Bhiwani, Haryana: a fluid inclusion study. Jr. Geol. Soc. Ind., v.67, pp.379-386.

STEPHENS, W.E., JEMIELITA, R.A. and DAVIES, D. (1997): Evidence for ca. 750 Ma intraplate extensional tectonics from granite magmatism from the Seychelles: new geochronological data and implications for Rodinia reconstruction and fragmentation. Terra Nova, 9, p.166.

STERN, R., AVIGAD, D. BEYTH, M., GEBRESILASSIE, S., KUSTER, D., MEHARE, K., and MILLER, N. (2004): The Neoproterozoic Snowball earth hypothesis and the Arabian – Nubian shield, 32nd IGC, Florence, Italy, Scientific sessions: Abstract (part2), p.1191.

STOESSER, D., WHITEHOUSE, M., and STACEY, J. (2004): Neoproterozoic evolution of the Khida terrane: Saudi Arabia : A detached microplate of the Arabian Shield, 32nd IGC, Florence, Italy, Scientific sessions: Abstract (part2), p.1190.

STOESSER, D.B. (1986): Distribution and tectonic setting of plutonic rocks of the Arabian shield. Jr. African Earth Sci. v.4, pp.21-46.

STOESSER, D.B. and ELLIOTT, J.E. (1985): Reconnaissance geology of the Al-Qasr Quadringle, sheet 27/41C Kingdom of Saudi Arabia, Open file Report – USGS-OF-05/2, Scale 1:100,000

TEWARI, V.C. (2003): Sedimentology, paleobiology and stable isotope chemostratigraphy of the terminal Neoproterozoic Buxa dolomite, Arunachal Pradesh, NE Lesser Himalaya, Him. Geol. v.24, pp.1-18.

THOMSON, P.R., AND KATTAN, F.N. (2004): Geochemistry and structural reappraisal of the Asir terrane assembly, S. Arabia Shield, 32nd IGC, Florence, Italy, Scientific sessions : Abstract (part2), p.1190.

TORSVIC, T.H., CARTER, I.M., ASHWAL, L.D. and BHUSHAN, S.K. PANDIT, M.K. AND L.D. JAMTVEIT, B. (2001): Rodinia refined or obscured : paleomagnetism of the Malani igneous suite, N.W. India Precamb. Res., v.108, pp.319-333.

UNRUG, R. (1992) : The supercontinent cycle and Gondwanaland assembly, componenet cratons and the teming of suturing events. J. Geodyn. v.16, pp.215-240.

VAIL, J.R. and KURON, J.L. (1978): High level igneous emplacement in the Red Sea Hills, Sudan Geol. Runds. v.67, pp.521-530.

VALDIYA, K.S. (1995): Proterozoic sedimentation and Pan-African geodynamic development in the Himalaya. Precamb. Res. v.76, pp.35-55.

VALLINAYAGAM, G. (1999): Nb, Zr, REE-rich granite rock from Piplun area of Siwana ring complex, w. Rajasthan, India. In Geological evolution of north western India, B.S. Paliwal (Ed.) Scientific publishers, Jodhpur, pp.94-102.

VIRDI, N.S. (1995): Proterozoic sedimentary cycles and geotectonic evolution of the southern margin of Proto-Tethys: evidence from the western Himalya, J. Petrol. Geol., v.4, pp.1-27.

VIRDI, N.S. (1999): Co-existing Late Proterozoic glacigene sediments and evaporites in theLesser Himalaya and eastern Indian shield –expression of contemporaneity of low latitude glaciation and tropical dessication. In B.S. Paliwal (Ed.) The Indian Precambrian, Scientific Publishers, Jodhpur, pp.502-511.

WHITEHOUSE, M., FLOWERDEW, M., WINDLEY, B., AL-KHIRBASH, S., and BA-BTTAT, M. (2004): The Al Bayda arc, Yemen: A 200 Ma record of Neopertoerozoic accretion at the eastern margin of the Arabina-Nubian shield. 32nd IGC, Florence, Italy, Scientific sessions: Abstract (part2), p.1190.

WANG, J., and LI, Z.X. (2001): Sequence stratigraphy and evolution of the Neoproterozoic marginal basins, along south eastern Yangtze cration. Gond. Res. v.4, p.17-26.

YOSHIDA, M., RAJESH, H.M., and SANTOSH, M. (1999): Juxtaposition of India and Madagascar : a perspective, Gond. Res. v.2, pp.449-467.