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Early and Middle Proterozoic Events in Pre-600 Ma
Crust of Northwestern Gondwanaland

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Birimian petrogenesis in the West African craton involved formation of new crust at 2.1-2.2 Ga adjacent to Archean nuclei. The Birimian terranes did not incorporate much older material; they are primarily mantle-derived. In contrast, the Transamazonian Caico gneisses of the Borborema Province in northeast Brazil yield zircon U-Pb ages of 2.15 Ga, but have Nd T(DM) ages of ca. 2.6 Ga, suggesting that older crust was extensively involved in formation of the protolith of the gneisses. Extensive Birimian-age crust has not been identified in Cameroon, but U-Pb and Sm-Nd

geochronology have revealed the presence of mafic dike emplacement and high-grade metamorphic overprints along the northwest edge of the Congo craton at 2.1-2.0 Ga, during the Eburnian tectonothermal event. Thus, 2.0 to 2.2 petrogenesis of varying types is an important aspect of the pre-600 Ma basement. Additional U-Pb zircon dating in the Borborema Province has also revealed the presence of volcanism at ca. 1.8 Ga and 1.1 Ga, showing that a long series of events is represented in crustal rocks which now comprise the Brasiliano mobile belts. Such ages have not yet been found to the east in the African counterparts, but their possible presence must be considered.

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Pan-African Accretion and Continental Terranes of the Arabian Shield, Saudi Arabia and Yemen

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The Proterozoic Arabian Shield of western Saudi Arabia and Yemen formed by terrane accretion during the Pan-African episode. Most terranes are oceanic crustal segments, including island arcs, that range in age from about 900 to 660 Ma. The age of the accretionary events is still poorly known, but they occurred mainly between 750 and 640 Ma. Accretion of the exposed Arabian Shield was completed during the Nabatah orogeny, interpreted as a collisional event between 680 and 640 Ma. This event formed the Nabatah orogenic belt and the Nabatah suture, a left-lateral transcurrent fault zone that contains serpentinite bodies and ophiolite fragments.

Two continental terranes occur within the Arabian Shield. The first, the Khida-Khabid terrane of the eastern Shield of Saudi Arabia, was identified in 1983; new Pb and Nd-Sm isotopic data further elucidate its age and cratonic nature. It is a continental fragment that was detached from an unknown cratonic source and incorporated in a collage of oceanic terranes. Ion probe and conventional U-Pb zircon analyses yield an oldest age of 2600 Ma, with a cluster of ages in the 1800-1600 Ma range. t_{CHUR} model ages range from 2155 to 1294 Ma (ϵ_{Nd} -23.0 to -15.4).

The second continental terrane is identified here, based on new feldspar Pb and whole-rock Nd-Sm isotopic data for samples from the basement of northeastern Yemen. This terrane is represented by the Aden group, a poorly known gneissic complex, that forms much of the basement of northeastern and southern Yemen. The Aden group is overlain by metavolcanic and metasedimentary rocks of possible Nabatah age. t_{CHUR} model ages for both groups of rocks range from 3038 to 400 Ma (ϵ_{Nd} -23.5 to -4.4). The Aden group is dominantly metasedimentary, but contains many muscovite-bearing leucogranite intrusions. Archean to middle Proterozoic t_{CHUR} model ages for these rocks probably reflect the ages of the cratonic source region for the sediments. It is unclear whether the Aden gneisses represent a cratonic fragment within the Arabian accreted terrane or the western margin of a large cratonic plate. If the latter, the Nabatah orogeny may have resulted from the collision of this plate with the accreted oceanic terranes of the western part of the Shield.

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Late Proterozoic Evolution of the Onib-Hamisana Zone, Northeast Sudan: Constraints on Pan-African Accretionary Tectonics

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New structural data from the Red Sea Hills, northeast Sudan, add constraints to accretionary tectonic processes that acted in the Arabian-Nubian shield during the latest Proterozoic. Geometric constraints provided by field data are used in conjunction with Landsat Thematic Mapper imagery to interpret the regional distribution and structural relations of spectrally and lithologically distinctive packages of rocks. These studies indicate that the Onib-Hamisana zone, a prominent structural feature in the northern Red Sea Hills, originated as a post-accretionary fold-and-thrust belt in response to east-west crustal shortening.

Pan-African accretionary processes have some similarities to Phanerozoic ophiolite and island arc accretion in the western North American Cordillera, where penetrative fabrics commonly record periodic intraplate shortening events rather than collisional processes between exotic crustal fragments. Such an analogy implies a mechanism for crustal thickening by structural as well as igneous processes during evolution of an accretionary belt in a long-lived convergent margin setting, consistent with the observation that Pan-African magmatism was more evolved with time. This view emphasizes that an interplay of deformation and magmatism resulted in protracted crustal accretion in contrast to models of static volcanic arc evolution and subsequent short-lived collision.

V32A-9 1545h INVITED

On the Distribution of the Continental Masses of Gondwanaland: A Case Study From the Arabian-Nubian Shield

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We generated a digital mosaic from 23 Landsat thematic mapper (TM) scenes covering 0.3 x 10⁶ km² of Pan-African (550-950 Ma) outcrops along the Red Sea Hills in Egypt, Sudan, and Ethiopia (Nubian Shield), and Saudi Arabia (Arabian Shield). The outcrops were contiguous before the opening of the Red Sea 25 Ma ago. The mosaic utilizes TM band ratios sensitive to the rock content of

Pb-bearing, spectrally opaque, hydroxyl- and/or carbonate-bearing minerals, allowing lithologic and structural correlations on a regional scale. The following crosscutting features align upon rotating the Arabian Shield 5.43° +/- 0.02° around a pole (lat. 36.0°N long. 13.5°E; apical angle of error cone = 1.6°): 1) Granitic complexes of similar age and composition north (25 km) of Al Wajh city (Arabia) and in the Wadi Ghadir area (Eastern Desert, Egypt), 2) NW-trending sinistral Najd-related Alhamd and Abu Masarib shear zones (Midyan region, Arabia) align with the Hafafit and Sibai (central Eastern Desert, Egypt), shear zones respectively, 3) A minor sinistral Najd-related shear zone crosscuts the eastern (Midyan region, Arabia) and western (south Eastern Desert, Egypt) Red Sea shores at 24° and 22° 30' latitude, respectively, 4) N-S trending Hamisana shear zone (Sudan) extends in Arabia as the Hanabiq shear zone, 5) NE-trending Yanbu and Bir Umq sutures (Arabia) align with the Gerf Nappe (south Eastern Desert, Egypt) and Nakasib suture (Sudan), respectively, and 6) N-S trending Baraka mobile belt (southern Sudan) and Affaf belt (Arabia). Results favor coast to coast reconstructions (e.g., McKenzie et al. 1970; Girdler and Underwood, 1985; Bohannon, 1986), and are inconsistent with models advocating wide separations between the restored Red Sea shores (e.g., Le Pichon and Francheteau, 1978; Cochran, 1983). Implications for utilizing Landsat imagery for correlating the widely separated continental masses that once formed the Gondwanaland are clear.

V32A-10 1600h

Contrast Between an Old and a Young Gondwana Shield

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The Indian (IND) and Nubian-Arabian (NAS) shields both have outcrop areas of ca. 10⁶ km², similar depths to MOHO, and consist of five to ten separate terrains sutured to form the shields. Stabilization ages (shown by locking of isotopic systems, emplacement of post-orogenic granites, and covering by platform sediments), however, are Archean to early Proterozoic for IND and late Proterozoic/early Paleozoic for nearly all terrains in NAS. Some of the IND terrains were probably uplifted prior to Proterozoic suturing, as shown by deformation of low-grade sedimentary cover lying on higher-grade basement.

IND consists primarily of tonalite/trondhjemite gneiss (mostly meta-igneous) and granulite-facies rocks (meta-igneous and metasedimentary). NAS consists mostly of calcalkaline magmatic (arc) rocks and arc-related metasedimentary suites, generally in lower metamorphic grades than rocks in IND, and contains significant amounts of post-orogenic (alkali-feldspar) granites. Many of the lithologic differences between IND and NAS are probably related to the greater depth of erosion in IND. Limited evidence from sedimentary suites formed immediately after shield stabilization, however, indicates that the younger NAS was originally formed with more K and other LIL elements than the rocks of IND. Some of the sialic component in IND crust may have resulted from compositional modification of the shield after stabilization and suturing.

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U-Pb Zircon Ages of Gneisses From the Pan-African Dahomeyide Orogen, West Africa

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The Pan-African Dahomeyide represents the western limit of an extensive zone of micro-continental aggregation in western Africa and defines the southeastern margin of the West African Craton (WAC). The metamorphic internal zone of the orogen is underlain by gneisses characterized by shallow-dipping foliations and bounded by ductile shear zones which indicate craton-verging thrust shear displacements. One of these boundaries is interpreted as a crustal-scale shear zone; its lower part consists of protomylonite derived from Early Proterozoic (~2.1 Ga) crust. Immediately above, in the upper plate, lies eclogitic granulite facies garnet mafic gneiss which apparently recrystallized at P~1.0-1.5 GPa and 800-900°C. U-Pb analyses of zircons from this mafic gneiss yielded an age of 610 ± 2 Ma. Migmatite which structurally overlies the mafic gneiss contains zircons with older cores that underwent Pb-loss and/or metamorphic growth at ca. 560 Ma. Analyses of zircons in porphyritic biotite gneiss, intrusive into the migmatite, lie on a chord with an upper intercept of 650 Ma and lower intercept of 415 Ma. These zircon ages, together with available Rb-Sr and K-Ar analyses of samples from the same units, provide important constraints on possible magmatic and tectono-thermal events in the Dahomeyides. In the light of the U-Pb zircon data, the 510-580 Ma obtained from Rb-Sr whole-rock analyses, clearly represent cooling ages. The 590-610 Ma from K-Ar analyses of hornblendes, on the other hand, may represent the age of the peak metamorphic event. We interpret the older, upper intercept, 650 Ma U-Pb zircon age as the crystallization age of the gneiss protolith formed during extensive crustal melting, prior to crustal imbrication and onset of significant uplift and cooling.

V32A-13 1645h

Tectonothermal History of Terrane Accretion During Cadomian Sinistral Transpression in NW France

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The North Armorican Massif (NW France) represents the type locality for the Cadomian orogen. Tectonothermal and magmatic events ascribed to this orogen span a period between c. 700 Ma and c. 525 Ma, during which a late Proterozoic (Brioverian) succession of supracrustal rocks was heterogeneously deformed and metamorphosed. Evolution of the belt has been interpreted in terms of the amalgamation of arc complexes and syn-orogenic supracrustal rocks within a sinistrally transpressive plate boundary at the NW margin of Gondwana-Land.

The North Armorican Shear Zone separates Cadomian elements of the North Armorican Composite Terrane (NACT) from the Variscan Central Armorican Terrane. Within the NACT, ductile sinistral strike-slip shear zones are interpreted to separate (from N to S) the Tregor-La Hague (TLHT), St. Brieuc (SBT), St. Malo (SMT) and Mancellian (MT) Terranes. Additionally, ductile sinistral strike-slip shear zones imbricate internally each of these terranes. Within the TLHT, deformed quartz diorites within an early arc suite record U-Pb zircon ages which suggest crystallization at c. 700 Ma. Hornblende ⁴⁰Ar/³⁹Ar isotope correlation ages of c. 600 Ma are interpreted to date post-peak metamorphic cooling following deformation and metamorphism of the arc system. By contrast, within the SBT, U-Pb zircon ages suggest crystallization of calc-alkaline complexes at c. 660 Ma and in the interval c. 600-585 Ma. However, ⁴⁰Ar/³⁹Ar plateau and isotope correlation ages of 570-565 Ma for hornblende from both metamorphic and magmatic rocks and for metamorphic muscovite suggest that post-peak metamorphic cooling was significantly younger in the SBT than in the TLHT to the N. Both of these terranes contrast with the SMT and MT, where U-Pb zircon and monazite and Rb-Sr whole-rock ages of c. 540 Ma have been reported from anatectic granites of the SMT and similar monazite ages have been reported from granites of the MT. Muscovites from a granite complex record ⁴⁰Ar/³⁹Ar plateau and isotope correlation ages of 527-521 Ma, and are interpreted to reflect post-magmatic cooling. These data suggest that the earliest arc complex is exposed within the TLHT, and that post-

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Cover Caption. Successive stages in the construction of universal multi-fractals. Turbulent temperature fields with resolution increasing from top to bottom; represented as a surface, plot incipient singularities are particularly evident in the low resolution image in the design. The photograph courtesy of Shawn Lovejoy, McGill University, Department of Physics, Montreal, Canada.