Comment and Reply on "Use and abuse of crustal accretion calculations"

COMMENT

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In their discussion of crustal growth rates in the Arabian-Nubian Shield, Pallister et al. (1990, Fig. 1) incorrectly alluded to the presence of cobbles of Archean granite in Proterozoic conglomerate northeast of Aswan, Egypt. It has been pointed out by Kroner et al. (1988) that the zircons in the granite cobbles from locality 78 northeast of Aswan (Dixon, 1981) are highly discordant and provide only a poorly defined Early or Middle Proterozoic age for the source terrane. The zircons that Dixon (1981) indicated were Archean in age are present in a quartzite cobble collected from a pebbly mudstone unit in Wadi Murra to the southeast of Aswan near the Egyptian-Sudanese border. Similar orthoquartzite cobbles have been reported in other pebbly mudstone units associated with the ophiolitic melange assemblages of the Eastern Desert nappe pile (Church, 1980; El Bayoumi, 1984; Basta et al., 1986), and Wust et al. (1987) found 2.65 Ma detrital zircons in metasedimentary rocks northwest of Barramiya. The clast component of the pebbly mudstone units is nevertheless largely derived from ophiolitic and arc sources, and the proportion of pre-Pan-African basement material in the Eastern Desert is likely to be relatively low. Older basement material may not therefore form a significant fraction of the Nubian Shield.

Pallister et al. (1990) also contended that the isotopic evidence used to indicate the existence of in situ older basement in the Arabian Shield is equivocal, and that therefore the rate of growth of the Arabian-Nubian Shield could indeed be as high as Reymer and Schubert's (1984) original estimate of 78% (70% using an accretionary-arc thickness of 35 km) of the present-day average crustal growth rate of 1 km^3/yr. However, the "creativity" allowed in estimating relative growth rates during the Late Proterozoic reflects differences of opinion concerning both the surface area occupied by the Pan-African arcs in East Africa, northeast Africa, and Arabia, and the thickness of the accreted crust. Estimates of the surface area range from 0.6×10^6 km^2 for the exposed Arabian Shield alone (Pallister et al., 1990) to $5–6 \times 10^6$ km^2 for the "broader" Arabian-Nubian Shield extended as far to the east as the Indian Ocean and as far north as the Zagros Mountains (Reymer and Schubert, 1984; Dixon and Golombek, 1988). If the southern extension of the Arabian-Nubian Shield into East Africa is taken into account (Vail, 1983), the surface area could be as large as 10×10^6 km^2. Even this is a minimum value, because it is unlikely that the north-trending Pan-African system terminates abruptly at the Zagros Mountains thrust front along a width of more than 3000 km, and because $2–3 \times 10^6$ km^2 or more of arc material of 900–600 Ma age may be present in the Pharusian-Dahomeyian-Mauritanian of West Africa, the Anti-Atlas of Morocco, the Altai-Sayany of Mongolia, and possibly parts of the Sinian of southeast China. If Late Proterozoic terranes currently occupy a surface area of as much as 13×10^6 km^2 and have a thickness of 35–45 km, they would have to contain ~35%–50% older continental detritus and/or postaccretionary mafic intrusive material in order for the Late Proterozoic accretion rate to correspond numerically to the Cenozoic rate. The composition of the lower crust is in this respect perhaps the most important unknown factor in attempts to evaluate the Late Proterozoic crustal growth rates. As in the northeastern Arabian Shield (Cole, 1985), the Eastern Desert melange (Basta et al., 1986) is in places heavily invaded by "within-plate" basaltic intrusive rocks (e.g., some areas of melange in the Wadi Ghadir region are 90% injected by Late Proterozoic "Madaka" basalt), and the crustal volume of intrusive basaltic material may therefore be more significant than might normally be assumed.

If the proportion of older crustal material and younger basalt in Late Proterozoic arc terranes is minimal, the Arabian-Nubian "78% question" of Pallister et al. (1990) concerning Late Proterozoic crustal growth could perhaps be more aptly termed the "178% question," allowing not only the proposition that the Arabian-Nubian Shield is the "graveyard" of much of the Late Proterozoic global arc system, but that the accretion rate during the growth of the Arabian-Nubian Shield was appreciably greater than that of more recent times. This could be taken to support the view that Earth's crust has grown in an *episodic* rather than a *continuous* manner. One could further argue that it is the normal circumstance that arcs undergo tectonic erosion, delamination, and partial or even near total resorption back into the mantle. In this context the anomalous character of the Arabian-Nubian Shield may be more a reflection of some process of successful arc preservation than of an abnormally high rate of arc formation.

REPLY

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One of the main purposes of our paper was to correct misconceptions about the presence and extent of pre–Late Proterozoic basement in the Arabian segment of the Arabian-Nubian Shield. We are therefore especially grateful to Church for pointing out a misleading statement regarding radiometric ages from conglomerate and mudstone in the Nubian segment of the shield. Our reference (Pallister et al., 1990, p. 36) to "*Archean cobbles* in Proterozoic conglomerate northeast of Aswan, Egypt (Dixon, 1981)" was inaccurate, and we should have denoted the cobbles simply as "pre–Late Proterozoic," in light of the discordant character of the zircon data. For the Arabian-Nubian Shield, the most fundamental chronostratigraphic boundary is defined by the earliest occurrence of ensimatic arc rocks (ca. 920 Ma) that signifies the onset of Wilson-cycle processes of new crust formation in Arabia. Our Figure 1 was drawn to illustrate the geographic distribution of localities where Pb-isotopic data require some input from pre–920 Ma sources; the Archean-Proterozoic time boundary at 2500 Ma is largely immaterial in this region. We agree with Church that "the proportion of pre–Pan-African basement material in the Eastern Desert is likely to be relatively low" and, indeed, we stated that the presence of ancient (pre–920 Ma) zircon in Arabian ensimatic settings and in the Eastern Desert localities "could be explained by sedimentary or tectonic transport of continental material into the dominantly oceanic accretionary terranes."

We also agree with Church on other points that are implicit in our paper: that the world-wide extent of arc crust contemporaneous with the Arabian-Nubian Shield (ca. 920 to 620 Ma) is not well known, but might be considerably greater than even the Reymer and Schubert (1984) Nile-to-Zagros hypothesis that raised our "78% question"; that one of the most important unknowns is the origin and composition of the lower crust below accreted arc terranes; and that *episodic* rather than *continuous* accretion should be the model in any quantitative estimate for rates of crustal growth. However, we reiterate that the geologic uncertainties are large, especially those involved in determining the lateral extent of arc terranes and their initial accretionary thicknesses. Thus, the several crustal accretion calculations (and the resulting speculations) that have been attempted for the Pan-African province should be evaluated chiefly for the reasonableness of their starting conditions and assumptions. We were reluctant to engage in such an attempt, but ran the calculations for the Arabian segment of the shield merely to show that, for a relatively well studied area, the numbers do not require anomalous crustal growth rates to account for the accretionary volume.

COMBINED REFERENCES CITED

Basta, E.Z., Church, W.R., Hafez, A.M.A., and Basta, F.F., 1986, Proterozoic ophiolitic melange and associated rocks of Gebel Ghadir area, Eastern Desert, Egypt: International Basement Tectonics Association Publication 5, p. 115–123.

Church, W.R., 1980, Late Proterozoic ophiolites: Orogenic mafic and ultramafic association: Colloques Internationaux du Centre National de la Recherche Scientifique, no. 272, p. 105–118.

Cole, J.C., 1985, Reconnaissance geology of the Uqlat as Suqur quadrangle, sheet 25/42 A, Kingdom of Saudi Arabia: Saudi Arabian Deputy Ministry for Mineral Resources Technical Record USGS-TR-05-5, 42 p.

Dixon, T.H., 1981, Age and chemical characteristics of some pre-Pan African rocks in the Egyptian Shield: Precambrian Research, v. 14, p. 119–133.

Dixon, T.H., and Golombek, M.P., 1988, Late Precambrian crustal accretion rates in northeast Africa and Arabia: Geology, v. 16, p. 991–994.

El Bayoumi, R.M., 1984, Ophiolites and melange complex of Wadi Ghadir area, Eastern Desert of Egypt: Pan African crustal evolution in the Arabian Nubian Shield, International Geological Correlation Program 164: King Abdulaziz University Faculty of Earth Sciences, Bulletin 6, p. 329–342.

Kroner, A., Reischmann, T., Wust, H.J., and Rashwan, A.A., 1988, Is there any pre–Pan-African (>950 Ma) basement in the Eastern Desert of Egypt?, *in* El-Gaby, S., and Greiling, R.O., eds., The Pan-African belt of Northeast Africa and adjacent areas; tectonic evolution and economic aspects of a Late Proterozoic orogen: Wiesbaden, West Germany, Friedrich Vieweg und Sohn, p. 95–120.

Pallister, J.S., Cole, J.C., Stoeser, D.B., and Quick, J.E., 1990, Use and abuse of crustal accretion calculations: Geology, v. 18, p. 35–39.

Reymer, A., and Schubert, G., 1984, Phanerozoic addition rates to the continental crust and crustal growth: Tectonics, v. 3, p. 63–77.

Vail, J.R., 1983, Pan African crustal accretion in NE Africa: Journal of African Geology, v. 1, p. 285–294.

Wust, H.J., Todt, W., and Kroner, A., 1987, Conventional and single grain zircon ages from metasediments and granite clasts from the Eastern Desert of Egypt: Evidence for active continental margin evolution in Pan-African times: Terra Cognita, v. 7, p. 333–334.