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Controls of Mineralization in the Older and Younger Tin Fields of Nigeria

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Abstract

Intense albitization accompanied by mainly Sn and Nb/Ta mineralization, affected late-orogenic pegmatites of the Nigerian basement in certain well-defined areas. The distribution of these pegmatites and of some unusual charnockitic rocks, can be more plausibly related to a proposed ancient lineament system than to regional structural trends.

Mainly Sn and Nb mineralization is also associated with albitization in the anorogenic Jurassic Younger Granite ring complexes, the distribution of which can be related to the same lineament system.

Foci of most intense mineralization in both older and younger tin fields, lie close to the intersection of a prominent east-northeast lineament across central Nigeria with the northward projection of the line of later continental separation.

A continental drift model, involving progressive wedging apart of South America and Africa from the south, can account for the belt of Younger Granite provinces extending north from Nigeria.

Introduction

SCHUILING'S (1967) review of the world's tin fields is among more successful recent attempts to identify mineral belts on a global scale. He concludes that in the upper mantle there may be geochemical culminations of great age, which specific geological events can elevate to near-surface levels, forming ore deposits. Such culminations would presumably be related to the ancient deep-seated lineament systems, which have been identified in many metallogenic provinces as providing the channels for upward movement of ore-bearing solutions.

Nigeria's tin fields are among the important ones of the world and are accordingly well documented. Their distribution, mineralogy, and tectonic setting are reviewed here, in an attempt to trace their development and relate it to possible lines of persistent crustal weakness; and hence to decide whether or not a geochemical culmination may exist beneath Nigeria.

Older Tin Fields

The Basement

The Katangan orogenic cycle was widespread in this part of West Africa (Jacobson, Snelling and Truswell, 1964). Elongate remnants of a late Precambrian geosynclinal succession, now mainly greenschist facies meta-sediments, are tightly folded into a remobilized crystalline basement of much greater age (Grant, 1969). Syn-kinematic and late-kinematic emplacement of diorite, granodiorite, and the distinctive microcline-megacrystic ("Porphyritic") Older Granite, dominated the terminal phases of this cycle.

Acid to basic rocks of charnockitic aspect have been recorded in the crystalline basement (Fig. 1). Syenitic to quartz-monzonitic varieties predominate, their mineralogy and greenish color in fresh outcrop making them superficially similar to some of the Younger Granites (see below), a resemblance strengthened by the presence of fayalite in some facies (Oyawoye, 1965). These rocks pre-date the Older Granites (Hubbard, 1968), but their relationship to them, as well as to the gabbros and non-charnockitic hypersthene-diorites found in several places, is not yet fully clear. There is also a potassic syenite/biotite pyroxenite suite in the southwest near Shaki (Oyawoye, 1967), similar to the infracrustal ring complexes described from Malawi by Bloomfield (1968).

Mineralization

Widespread pegmatite and aplite development marked the closing stages of the Older Granite phase. The pegmatites consist chiefly of quartz, microcline, oligoclase, biotite, muscovite, garnet, and black tourmaline, in various proportions. Superimposed upon this comparatively simple and uniform assemblage was a later localized mineralization of great diversity and some economic importance (Jacobson and Webb, 1946), accompanying a wave of intense albitization. The most important mineralization occurred along a central, east-northeast trending belt (Fig. 1), and was best developed at its eastern end, coinciding quite closely with the southwestern limit of the Jos Plateau, formed principally of Younger Granites (see below).

Jacobson and Webb were unable to find any consistent pattern in the trend and attitude of the peg-

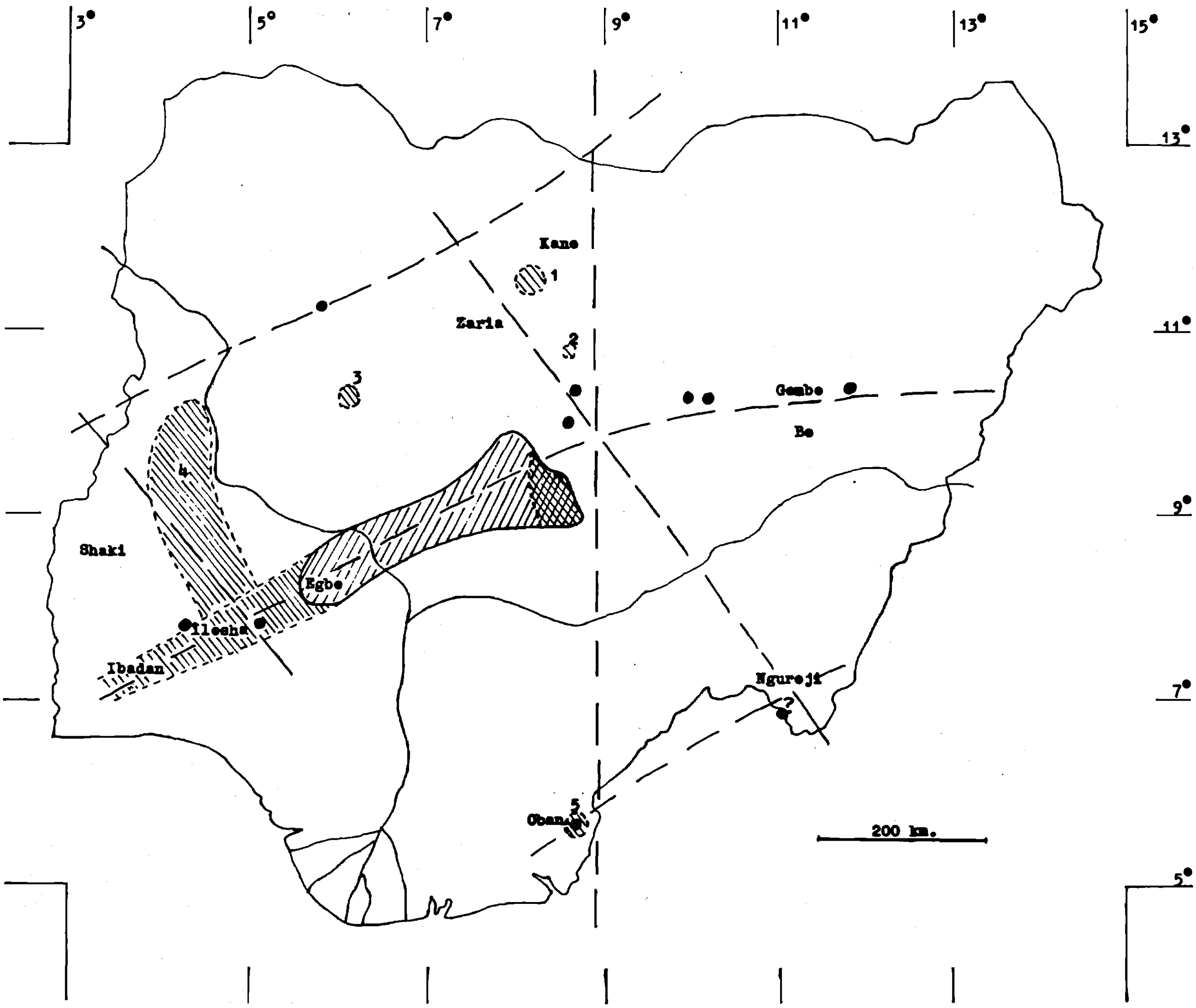

FIG. 1. Outline map of Nigeria, showing postulated ancient lineament system (long dashed lines); recorded occurrences of charnockitic rocks (solid circles; data from Bain, 1926; Raeburn, 1927; Jacobson & Jaques, 1949; Oyawoye, 1964; Hubbard, 1968; Sacchi, 1968); and areas of mineralized pegmatites, for which symbols are as follows: Crossed ruling: richest pegmatites, eastern end of central belt. NE–SW ruling: main central Nigerian pegmatite belt (Jacobson & Webb, 1946). NW–SE ruling: areas of subordinate mineralization. 1. Faiki: Cassiterite, beryl, and tourmaline in quartz-feldspar-muscovite pegmatites (Russ, 1927). 2. Minor pegmatite, with columbite-tantalite, reported from the basement between the Younger Granite complexes of Liruei and Banke (Jacobson and Webb). 3. Beryl occurs in tourmaline-bearing pegmatite; some cassiterite has been recovered from streams draining the region (Russ. 1957). 4. Muscovite- and tourmaline-bearing pegmatites occur along the west bank of the middle Niger valley; some cassiterite and columbite-tantalite occur as stream concentrates as far south as Ilesha (Tattam, 1936, 1937). 5. Muscovite pegmatites contain albite, alkali tourmaline and cassiterite; columbite and beryl occur in nearby alluvials (Raeburn, 1927). Be: Beryl occurrence south of Gombe.

matite dikes, many of which cut at high angles across the general north-south grain of the basement rocks. They did, however, establish that the most richly mineralized pegmatites appear to be those dominated by an initial quartz-microcline-muscovite mineralogy.

Economically the most important minerals are cassiterite and columbite-tantalite, the latter covering the full range in the solid solution series. The principal accessory minerals are beryl, pink and green alkali tourmaline, apatite, and lepidolite.

Jacobson and Webb described the central belt only as far west, as Egbe. This zone can be extended through the Ilesha and Ibadan areas (Fig. 1), where albitized muscovite-pegmatites carry tourmaline and beryl. Small amounts of alluvial cassiterite, colummite and tantalite have been recovered in this area (de Swardt, 1953; Jones and Hockey, 1964).

There is no published record of the central belt mineralization extending in the other direction, so that the recent discovery (K. Klinkenberg, pers.

comm.) of beryl-bearing pegmatite a few miles south of Gombe in northeastern Nigeria (Fig. 1), is of particular interest.

Other mineralized areas in the basement are economically less significant. They are described briefly in the caption to Figure 1.

Northeast of this region, south of Nguroji near the Cameroun border, rumors of alluvial cassiterite persist (J. Proudfoot, pers. comm.), although earlier reports were discounted by Jacobson and Jaques (1949).

Tectonic Setting

Also shown on Figure 1 are northeasterly and northwesterly trending axes of broad regional uplift, which were first recognized by J. D. Falconer at the beginning of this century (Balfour Beatty, 1961). The northernmost axis has been modified slightly by recent work (P. McCurry, pers. comm.), and the one passing between Zaria and Kano has been projected southeastward, to intersect an additional line drawn from near Oban on the Calabar dome, through Nguroji, the highest point of the Mambilla Plateau. The north-south line is a northward projection of the Gabon coast, part of the fracture along which Africa and South America presumably separated in the Mesozoic. It is also the only one of these lines to coincide more or less with the structural grain of the Nigerian basement.

The distribution of presently known charnockite occurrences and mineralized pegmatites with respect to these axes, provides some support for the view

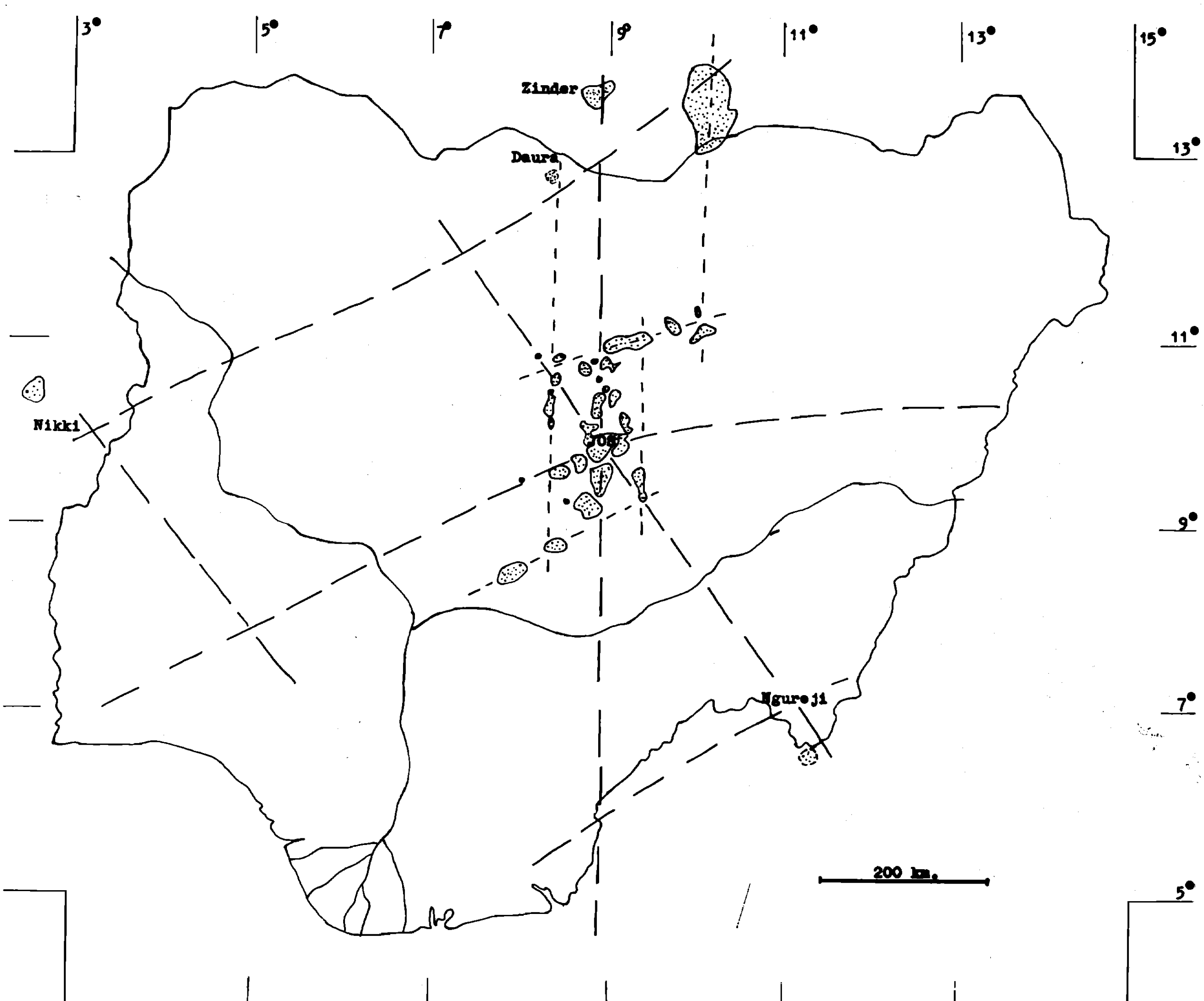

FIG. 2. Outline map of Nigeria, showing distribution of Younger Granite complexes (stippled; data from Geological Map of Nigeria, 1:2 million, 1964; UNESCO Geological Map of Africa, 1:5 million, 1963; Jones, 1934; Jacobson & Jaques, 1949). Lineament system as in Fig. 1, with subsidiary lines (short dashes) through main area of Younger Granite complexes.

that they represent ancient lineaments intermittently active since at least late Precambrian times (Wright, in press). Particularly noteworthy is the alignment of the main mineralized belt with the central axis, and the concentration of richest pegmatites quite near its intersection with the projected line of later continental separation and the subsidiary axis between Zaria and Kano (Fig. 1).

Younger Tin Fields

The Granites

The high level anorogenic volcanic-plutonic Younger Granite ring complexes (Fig. 2), of Middle Jurassic age (Jacobson, Snelling and Truswell, 1964), are classic examples of their kind (Jacobson, MacLeod and Black, 1958). Granites overwhelmingly predominate in the province, but in some complexes their emplacement was preceded by basic and intermediate intrusions, ranging from olivine gabbro to quartz monzonite and syenite. The latter are transitional towards the distinctively greenish fayalite-bearing amphibole granites and granite porphyries, which resemble some of the basement charnockites already mentioned, and are the least acid members of the granitic suite. They are also free of the late deuteric albitization found in the other two main granite types. These are the peralkaline riebeckite granites (more properly arfvedsonite granits, Borley, 1963), and the biotite granites. The latter are the commonest and carry most of the mineralization.

Mineralization

Economic mineralization in the Younger Granites is much more significant than in the basement. It is principally developed in the central region surrounding Jos (MacKay, Greenwood, and Rockingham, 1949), although some other centers are important (Russ, 1927). Cassiterite and columbite are dominant, the latter being here confined to compositions near the niobium end of the solid solution series (Jacobson et al., 1958). Both minerals are found mainly in albitized-biotite granite, but their paragenesis is rather different.

Cassiterite occurs in small quantities as an accessory in some granites (Williams and others, 1956), but is concentrated chiefly in roof-zone greisens, which generally carry topaz and dark green lithia mica (Jacobson et al., 1958). Wolfram is the second most important economic mineral in the greisens, but tends to occur in veins cutting the contact rocks rather than in the granites themselves.

Columbite heads an impressive list of primary accessories in the granites, some of which also have economic potential, for example pyrochlore (MacKay and Beer, 1952) and zircon, the latter having high Hf/Zr ratios in some varieties (Jacobson et al., 1958).

Northwest of Jos is what appears to be the only occurrence of beryl in the Younger Granites (Jacobson et al., 1958), and small amounts of genthelvite are recorded from pegmatite in albite-biotite granite near Jos itself (von Knorring and Dyson, 1959). The virtual absence of beryllium minerals from the Younger Granites contrasts strongly with the comparative abundance of beryl in the older tin fields. It is also important to record that tourmaline, one of the commonest minerals in basement pegmatites, has never been recorded from the Younger Granite province (Jacobson et al., 1958).

Tectonic Setting

The proposed lineament system of Figure 1 is reproduced in Figure 2, with some generalized lines added in the main Younger Granite field. The following features are noteworthy: 1. The central north-south belt of maximum Younger Granite development straddles the north-south lineament. 2. Individual masses in the north-south and east-northeast trending chains of complexes tend to be elongated in these two directions. 3. The principal mineralization is centered round Jos, coinciding with a major lineament intersection, which is also the region of maximum negative gravity anomaly (Ajakaiye, 1970). It is also where the only beryllium minerals known in the Younger Granite province are found.

Origin of the Mineralization

Older Tin Fields

Albitization and mineralization in basement pegmatites was the product of virtually the last fluids of any significance to crystallize at the close of the Katangan metamorphic cycle. The question is: Were those fluids true late residual liquors, which migrated to structurally controlled lower P/T regions, dissolving and concentrating valuable metals from the rocks through which they passed, and ultimately depositing them in the pegmatites? Or did the fluid originate at deeper levels, released by pressure relief partial melting and channelled upwards along the lineament system, as isostatic uplift of the orogen commenced in the final stages of the cycle?

In the first case, the distribution of mineralized pegmatites should show some correspondence to the dominant north-south structural trends in the basement. In the second case, a pattern such as that shown in Figure 1 would be expected, the distribution of earlier charnockites suggesting also that the lineament system was active at a comparatively early stage in the Katangan cycle.

The evidence is inconclusive, however, and for more convincing arguments favoring a deep source of mineralizing fluids, we must consider the Younger Granites.

Younger Tin Fields

The Younger Granite magmas probably originated in the upper mantle, as salic melts, generated by pressure relief partial melting, and concentration of low-melting constituents beneath a broad crustal dome (still recognizable as the Jos Plateau), and modified by interaction with basement rocks (Bailey and Schairer, 1966; Wright, 1969). The fact that the main Younger Granite area is a region of marked negative gravity anomaly (Ajakaiye, 1970), supports this thesis. It virtually excludes the presence of a large subjacent basic magma body, from which the salic rocks could have differentiated, or which could have induced syntectic crustal melting (cf. Turner, 1969).

If the ultimate origin of the granites was the upper mantle, are the ore mineral constituents similarly derived, or were they extracted and concentrated from the crustal rocks through which the salic magmas rose?

Hypotheses involving the second alternative are faced with the following difficulties: 1. The volume of Younger Granite mineralization is much greater than that in the basement, even in the area of maximum pegmatite concentration. 2. Low melting constituents move upwards during regional metamorphism (e.g. Eade, Fahrig & Maxwell, 1966), so that basement mineralization is likely to decrease with depth below present erosion levels; and Younger Granite roof zones cannot have been much above the present land surface, because volcanics are preserved at several centers. Rising columns of Younger Granite magma could not therefore have remobilized large amounts of lower melting constituents from *deeper* crustal levels, because those constituents were no longer there. Only minimal amounts could have been extracted from the *upper* crust, which was cold and rigid and which they penetrated by fracturing and not by melting (Jacobson et al., 1958). 3. Boron, beryllium and tantalum are virtually unrepresented in the Younger Granites, but tourmaline, beryl and tantalite are common in basement pegmatites. Fluorine, tungsten and hafnium are quite well represented in the Younger Granites, but only sparsely in the pegmatites. If tin and niobium were incorporated into the Younger Granites from the basement, why did the boron, beryllium and tantalum not enter them also? And whence came the fluorine, tungsten and hafnium of the Younger Granites?

These arguments do not negate earlier inferences that the Younger Granite magmas resulted from interaction between basement and salic melts rising from depth. Indeed, one obvious possibility is that the dry and high-temperature amphibole-fayalite granites represent such melts modified by the charnockitic basement rocks which they so much resemble. It is merely contended that basement/melt interaction must have been completed at some depth below the surface (Wright, 1969), and that the ore mineral constituents were not basement-derived, but originated at deeper levels as part of the primary melts.

Origin of the Doming and Regional Considerations

Jurassic doming of the Younger Granite Plateau was a precursor of the tectonic events leading to development of the Benue trough (Wright, 1969a). Africa and South America were being wedged progressively apart from the south throughout most of Cretaceous time, but stresses initiating the break probably became active in the Jurassic (Siedner and Miller, 1968). A tensional north-south split in the south of the composite South American/African continental plate, would cause a compressional bulge

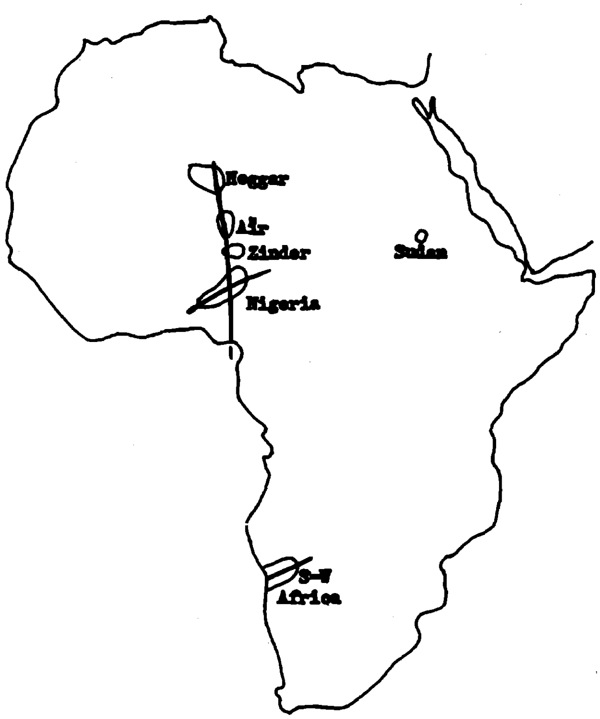

FIG. 3. Outline map of Africa, showing position of the granite provinces, tin fields and major lineaments mentioned in text. Note in particular the Nigerian Arc (de Kun, 1965) along the projected line of continental separation between Africa and South America.

further north along the same line (as can be demonstrated with a sheet of paper).

The present location of the Nigerian Younger Granite province can be attributed chiefly to the intersection of the east-northeast lineament with this axis of compressional upwarp. The northward continuation of the axis corresponds to the elongate metallogenic province which de Kun (1965) called the Nigerian Arc, and on which are situated the Younger Granite provinces of Zinder and Aïr (Fig. 3). The late-kinematic Lower Palaeozoic Hoggar granites also lie on the arc, supplementing the evidence from Figure 1, that the line of continental separation was an active lineament long before separation actually took place.

Southward along the same line (Fig. 3) lie the South-West African tin fields, which resemble those of the Nigerian basement in mineralization, structural setting, and age (de Kun, 1965; Clifford, 1967). The Jurassic ring complexes of South-West Africa (Siedner, 1965) form a broad east-northeast trending belt parallel to the structural grain of the Damaran basement, suggesting controls of mineralization and igneous activity not unlike those deduced for Nigeria's tin fields.

Concluding Remarks

1. There is good evidence that an ancient lineament system controlled the development of Nigeria's tin fields. Nigeria is still not well known geologically, however, and there is abundant scope for improving the pattern presented here and relating other aspects of the country's geological history to it, as was done in a preliminary way for the Cenozoic volcanics (Wright, in press). Since the lineaments were first identified as geomorphic axes, they may still be active, and it is suggestive that the two warm spring centers known in Nigeria, both lie close to the main east-northeast axis (Rogers, Imevbore, and Adegoke, 1969).

2. The existence of a lineament system and the connection between Younger Granite emplacement and crustal doming, combine with the geochemical contrasts between older and younger tin fields, to indicate a deep source for the ore fluids. Similar conclusions have been reached in many other areas (Wisser, 1960).

3. The question of whether or not a geochemical culmination (Schuiling, 1967) exists beneath Nigeria remains unresolved. Petrological and geochemical settings are similar to those in other tin fields, but is this because the geological processes that created the settings also concentrated ore constituents from the mantle or lower crust? Or did those processes merely tap pre-existing concentrations (culminations) via deep-seated lineaments? A definitive answer is still some way off, but one final question may suggest lines of further study: If there is no geochemical culmination beneath Nigeria, then why are the very similar granites of, for example, the rest of the Nigerian Arc, South-West Africa, and the Sudan (Almond, 1967), not so strongly mineralized as those in Nigeria?

Note Added in Proof

Noble's (1970) comprehensive survey of metal provinces in the western U.S.A. led him to conclude that the relationship between igneous intrusion and ore emplacement might be more tenuous than is commonly supposed. Implicit in his findings is the suggestion that high grade metamorphism and/or magma formation may trigger ore mobilization from mantle sources. This possibility is highly relevant in the Nigerian context. Thus, although Younger Granite mineralization is largely confined to the biotite granite members, not all of these are in fact ore-bearing. In the older tin fields, the maximum concentration of mineralized pegmatites (Fig. 1) is actually well removed from any of the typical "Older Granites," with which such pegmatites are supposed to be closely associated (Jacobson & Webb, 1946). In fact, in this area of concentration the nearest granite is a small and quite atypical muscovite bearing variety (Jacobson & Webb, 1946).

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