A Review of African and South American Ore Provinces Separated by Continental Drift

By Alfred Leube*)

Summary

Several clearly defined ore provinces pre-dating the disruption of Africa and South America during Jurassic and Lower Cretaceous times can be localized. The majority of these ore provinces is situated in the Late Precambrian orogenic belt folded and metamorphosed during the Pan-African—Brazilian Orogenic Cycle between 700 and 450 m. y. ago. The copper and lead-zinc ore provinces of South-west Africa, Zambia and South Brazil and the tin-tungsten mineralization of North-east Brazil and Nigeria are typical examples. The iron-, gold and diamond provinces separated by rifting and following continental drift on the other hand mainly are situated on older cratonic areas of Early or Middle Precambrian age.

Since the confirmation of the theory of continental drift and the recognition of the plate tectonic theory as major concept in world tectonics within the last decade a great number of publications have appeared dealing with metallogenic problems and the formation of ore provinces. A preferred subject for investigations is the metallogenic process caused by the continental collision and, to a less extent, the problems of mineralization of the rift zone itself. The fact, that mineral deposits were generated by drifting processes also outside the collision zones on the shields themselves — as for instance the mineralization in connection with carbonatite complexes and alkaline rocks — has found little attention yet as far as their structural development is concerned.

This is valid also for the relationship of pre-existing ore provinces separated by the drifting apart of the continents. Petrascheck (1968) has opened the discussion of this aspect and contributed substantially to the understanding of metallogenic problems connected with continental drift. In the present paper the term metallogenic-or ore province is used in the sense of Petrascheck (1965) who defines the main characteristics of an ore province as "the entiety of mineral deposits that formed during a tectonic-metallogenetic epoch with a major tectonic unit and which are characterized by related mineral composition and form of deposits ..." In addition Petrascheck points out that "generally mineral provinces should not be considered from the magmatic point of view and the structural control of the mineralization only, but in a wider sense from the general geological environment of the area".

Clifford (1966) similarly stresses the importance of the structural environment when explaining tectono-metallogenic units as the fundamental structural units (like older cratons and younger orogens) characterized by significantly different structural history and by major concentrations of ore bodies. Metallogenic provinces are defined as specific and more localized provinces of mineral concentration within the major units.

*) Dr. Alfred Leube, Institute for Geosciences and Mineral Resources, P. O. Box 51 01 53, D-3000 Hannover.

The present paper tries to coordinate well-defined metallogenic provinces on the Precambrian shields under consideration of the typical mineralization, the structural and depositional environment and age relationship as postulated by PETRASCHECK (1965, 1973).

Following this terminology we have to regard the belts of young Precambrian age formed during the Pan-African and Brazilian Orogenic Cycle respectively and running approximately parallel to the coast of the Atlantic Ocean as one major metallogenic unit. This unit was disrupted roughly conformable to the strike by the rifting. Several provinces typified by different ores can be distinguished, either parallel to the strike or transversal to the rift.

Other ore provinces are situated on the older cratonic areas as for instance on the West African and Guiana Shields forming another tectono-metallogenic unit.

Each attempt to delineate the pre-rifting mineral provinces must envisage numerous difficulties:

1. Fitting Africa and South America together according to a pre-drift reconstruction of HURLEY et al. (1968) or other more recent attempts to occupy their supposed original position, a gap several hundred kilometers wide remains which is covered today by the Atlantic Ocean and young sediments of Lower Cretaceous to Pleistocene age.

2. The data of radiometric age dating especially from South America are still too scare, too widely scattered, and not always sufficiently reliable.

On the other hand the unequal rise of the Brazilian Shield causing the low level of erosion along its margins coroborates the possibility that South American counterparts to well-defined ore provinces in Africa are eroded partially or completely. Vice versa thick mineralized rock sequences seem to be preserved in the extreme south of the Brazilian Shield whereas in South-est Africa they are missing, probably due to erosion.

Referring to the various obstacles opposing an exact correlation of mineralized areas to ore provinces PUTZER (1976) points out that many areas in South America are still too poorly documented regarding their stratigraphy, structure and mineralization as to furnish a basis comparable to the amount of data available fromAfrica. Even important structural units, such as the orogen of the Minas Series or the Middle Precambrian "Transamazonic"tectonic episode have not yet been investigated closely enough with respect to their age, mineralization and extension to allow an acceptable outline of ore provinces.

The immense period of several hundred million years comprized by each unit is due to the long-lasting processes of development of the major structural units during Precambrian times.

A most significant aspect of the synthesis between metallogeny and continental drifting are the practical consequences it implies. Mineral exploration may draw considerable support and new guidelines from the knowlege of these relations. To achieve this it is not sufficient to compare only the marginal areas directly opposite each other on the two separated continents, but to consider in addition the depositional environments and the context of the geological setting of the continents themselves. Thus the model of ore provinces supported by intensive, detailed studies and the exchange of experiences will stimulate exploration under new viewpoints and with appropriate methods and may result in the discovery of hitherto unknown deposits.

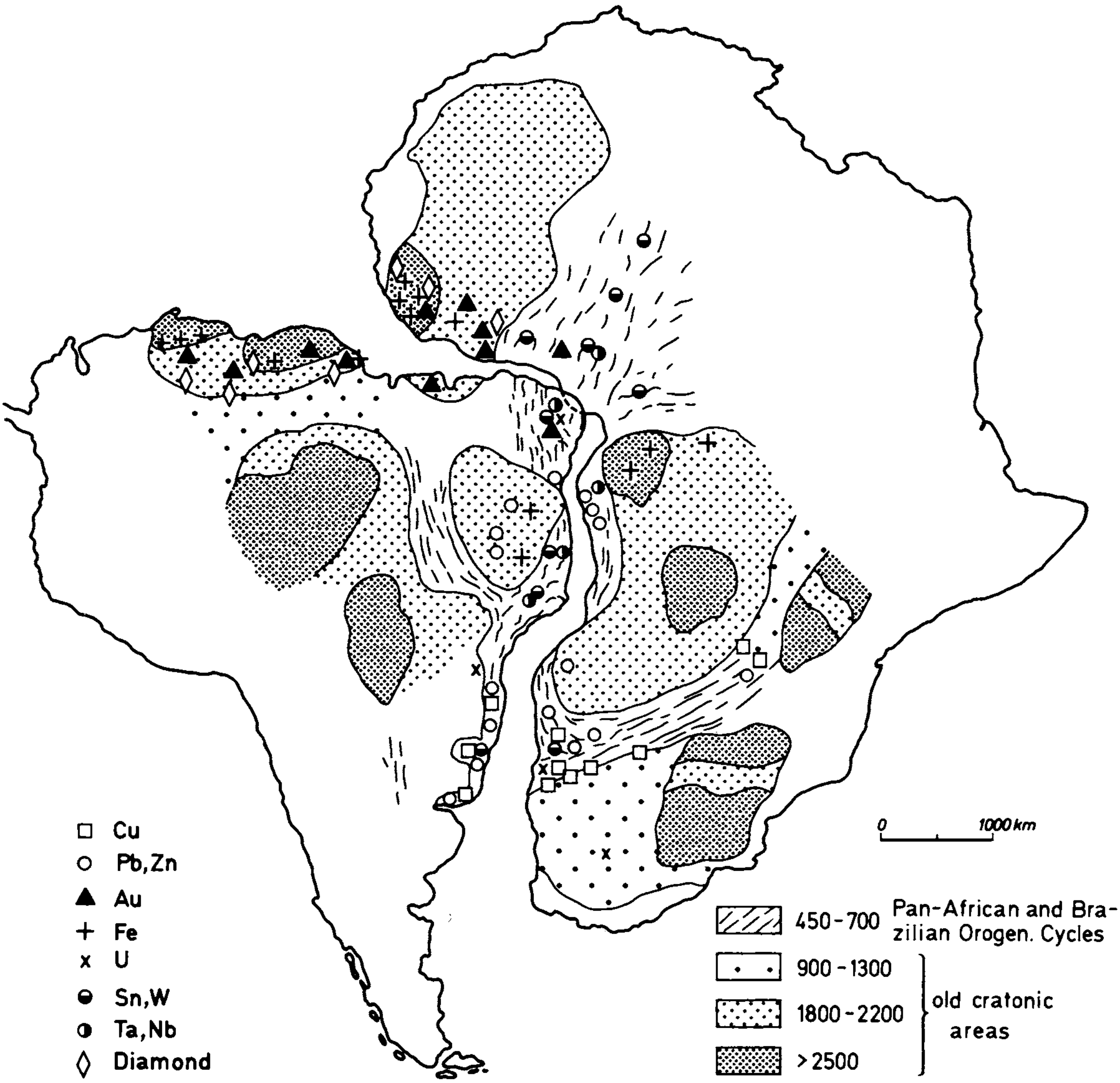

Fig. 1 represents the metallogenic units as far as they are mentioned in this paper. The different ore provinces within these units can be inferred from the symbols used for the various ore deposits.

In this connection the O'okiep Copper Mine (Namaqualand, South Africa) or the lately discovered Pb-Zn-Cu stratabound volcanogenic deposits of the Prieska and Gams Mines in Namaqualand are a challenge.

Table 1: Copper, lead and zinc mineralization in the Damara orogenic belt and its margins

KHOMAS Formation	Mica schist and quartzite amphibolite: basic volcanics mica schist and quartzite tillite	massive sulfides associated with basic volcanics (Cu)	Otjihase Mine Matchless Mine Gorop Mine Hope Mine	OTAVI Formation	Pb-Zn-V in dolomite Berg Aukas Pb-Zn-Cu
HAKOS Formation	schist, carbonates, quartzite, amphibolite, itabirite Blaubeker Formation: tillite, quartzite, conglomerate	disseminated to massive sulfides in quartzite and shale Red-bed type	Oamites Mine Blaubeker Prospect		Tsumeb Mine
NOSIB Formation	phyllite, limestone, quartzite, arkose	Copper-shale type	SW Rehoboth		
KLEIN AUB Formation	quartzite, conglomerate, schist, limestone	Copper-shale type	Klein Aub Mine		
DOORNPOORT Formation	red quartzite, conglomerate, schist, acid & basic volcanics	Copper-shale type	Cuprum-Escadron Mine and others Witvlei area		
OPDAM Formation	basic lavas	Cu in basic lavas			
GRAUWATER Formation	quartzite, schist, basic & acid lava, pyroclasts	massive sulfides in volcanics (Cu)	Kobos Mine		
ELIM-MARIENHOF Formation	acid to intermediate lava, quartzite, carbonatite			KHO-ABENDUS Formation	Pb-Zn in Carbonaceous shale Kamanjab

Damara Group

sedimentary Cu

Orogenesis ± 550 m. y. Orogenesis ± 1000 m. y.

Gamsberg granite

In southern Goyas, Brazil, for instance, a copper deposit has been discovered recently which detailed research might prove to be an equivalent to the Namaqualand mineralization of copper around O'okiep.

The data presented so far substantiate such a correlation although the deposits seem to differ in age according to latest determinations.

Copper

A distinct copper province can be distinguished comprizing the Cu deposits of South-west Africa and those of South Brazil and Uruguay.

In South-west Africa sequences of predominantly clastic and pyroclastic rocks with intercalated acid and mafic lava are overlying the Elim-Marienhof group. This sequence was deposited in the Damara orogenic belt which was folded and metamorphosed during the Pan-African Orogenic Cycle for which age determinations give a minimum age of 450 m. y. Rocks belonging to this cycle strike mainly parallel to the coast, except in the Damara Orogen, and stretch to Angola and, beyond the West Congo Geosyncline, to Cameroon, Nigeria and Ghana, mobilizing large parts of the older crust (Hurley & Rand, 1968). Within this sequence showing the considerable thickness of more than 6000 m in the Damara Orogen in South-west Africa, Cu mineralization of conspicuous economic value is found intermittendly. These syngenetic sedimentary Cu-deposits locally are associated with acid and basic lavas. They have been investigated very closely in recent years furnishing a well-documented pattern of mineralization which permits a correlation of this Cu mineralization relative to the structural development (Table 1).

An older cycle of Cu deposits is extending from an area southwest of Windhoek to the Ghanzi area of central Botswana. Copper mineralization is mainly of the shale type. The younger Cu mineralization in the Khomas beds is bound to a narrow zone of amphibolite over a distance of about 400 km. The amphibolite belt is is considered to be an altered basic to intermediate volcanic unit.

In South-west Africa the Damara sequence strikes NE—SW approaching the Atlantic coast between Walfishbay and Luederitz, and mineralization also draws close to the coast (Hope Mine). As mentioned above the South-west African copper mineralization, at least the older cycle, continues towards NE beyond Botswana and possibly can be linked with the copper mineralization of the Zambian copperbelt and the Katanga deposits, although both areas are disconnected by more than thousand kilometers without comparable mineralization. Both areas have to be attributed to the same tectono-metallogenic unit exhibiting ages of formation between 700 and 500 m. y. The deposition of the copperbelt ore has been determined with 550 to 600 m. y.

In both areas syngenetic mineralization in shale which is associated with quartzite and arkose (Lower Roan group) followed by a thick succession predominantly composed of dolomite (Upper Roan group) is the most typical feature.

These features may well be correlated with the mineralization of the lower portion of the Damara group (Table 1). South-west African, Zambian and Katangan together with the copper mineralization of Uruguay and South Brazil treated in the following may therefore be joined to one major ore province.

In South Brazil and Uruguay Precambrian rocks are limited to a narrow strip following the coastline. To the west they are covered by Gondwana rocks and

Uruguay	Rio Grande do Sul		Santa Catarina	Paraná
PIEDRA DE AFILAR SERIES arkose, siltite, quartz, porphyry, rhyolite	CAMAQUA GROUP schist, sandstone, conglomerate, arkose Coxilha formation Guaritas formation intermediate volcanics Sta. Bárbara formation	Cu	BAU conglomerate	
	BOM JARDIM GROUP Crespos formation basic and acid volcanics, sandstone, conglomerates Arroio dos Nobres formation red sandstone, schist, rhyolite Red-bed type Maricá formation arkose, greywacke, schist	Cu	ITAJAI GROUP schist, volcanics, quartzite, greywacke Gaspar formation conglomerate, sandstone Ibirama formation	CASTRO GROUP quartzporphyry Camarinha and Guaratubinha formation
LAVALLEJA SERIES schist, quartzite, itabirite	PORONGOS GROUP quartzite, schist, limestome, dolomite Cerro de Ouro formation Vacacai formation syngenetic Encantadas formation	Cu	BRUSQUE SERIES quartzite, schist, limestone, phyllite, dolomite	ACUNGUI GROUP Agua Clara formation Votuverá formation Pb, Zn, Ba Capirú formation Setuva formation
500 m. y.	650 m. y.			

Table 2: Copper, lead and zinc mineralization in the Ribeira belt (Modified and supplemented after PUTZER 1976)

Paraná basalt. Although the coastal areas of Rio Grande do Sul, Sta. Catarina, Paraná and São Paulo (Ribeiro Orogenic Belt of the Brazilian Orogenic Cycle), which are situated directly opposite to South-west Africa, have been the target of intensive geological research, our knowledge of the genesis and the stratigraphic position is still liable to modifications.

In recent years RIBEIRO (1970), TESSARI & GIFFONI (1970) and LOSS & ROISENBERG (1972) have given detailed account to the structure and stratigraphy of the area concerned. The strata strike mainly ENE—WSW oblique to the coast which they cut at an acute angle south of Itajai, Sta. Catarina. A comparable direction of strike can be observed farther north near Iporanga, Parangá. In both areas the Precambrian basement displays a strike direction roughly similar to that of the Damara Geosyncline in South-west Africa.

Syngenetic sedimentary Cu occurrences and deposits are located throughout the enormous volcanic and clastic sequences attaining a thickness of several thousand meters and are also found in the underlying Porongos group. Radiometric age dating revealed an age of about 500 m. y. for granites intrusive into the volcano-clastic sequence.(Table 2).

Cu mineralization frequently is connected to andesitic volcanics or, in places, to rhyolites, and also occurs as impregnation in the conglomerates and quartzites. Locally faults and fractures, mylonite- and shearing planes are mineralized. This mineralization seems to have originated predominantly from mobilized sedimentary copper within slightly metamorphosed strata. Cu locally occurs in economic quantities and is being mined at Andrades, Primavera, Camaqua, Cerro dos Martins and Ribeirao da Prata which are among Brazil's only active copper mines today.

Contrary to previous concepts the Cu mineralization must be explained as predominantly syngenetic in origin although epigenetic Cu deposits seem to exist that cannot be derived from mobilized syngenetic ore. Detailed research on these deposits under consideration of modern concepts is to be done.

Assuming the correlation of the Lavalleja, Brusque, Porongos and Açunguí groups with the Khomas/Otavi group is correct, there is evidence that the extraordinarily thick succession of alternating volcanic and clastic mineralized sediments was deposited, after a major orogenesis (650 + m. y.) (CORDANI & BITTENCOURT, 1967) had terminated the marine sedimentation of the above stratigraphic groups, but before the youngest orogenesis with an age of about 500 m. y. (see tables 1 and 2).

The cupriferous, predomiantly sedimentary succession of South-west Africa, on the contrary, is disposed below the marine sequence of the Khomas formation. The possibility should be envisaged that the younger, partly continental and volcanic succession, as encountered in South Brazil, has already been eroded on the African Shield if deposited at all.

Taking into consideration the above mentioned statement that the stratigraphic research on the Precambrian of southern Brazil is still under way, the possibility exists, that new results will prove the successions hitherto considered as Eocambrian not younger, but older than the more intensely metamorphosed Lavelleja, Brusque, Porongos and Açunguí groups. This would enable us to establish an almost perfect relationship to the structural history and mineralization of South-west Africa.

Low-grade metamorphism should in any case not be taken as a proof of the younger age of these so called "Eocambrian" formations.

Lead—Zinc

The various Pb-Zn deposits on both sides of the Atlantic Ocean may be combined to two metallogenic provinces.

The mineralization of South-west Africa and that of Uruguay, Rio Grande do Sul, Sta. Catarina and Paraná correspond in age (500 ± m. y.) and structural disposition. The clastic succession of the Khomas formation passes north of Windhoek into the calcareous Otavi facies. Together with the change of facies the fold axes turn to a NW—SE strike parallel to the coast, continuing far into Angola. Within this range of the change of strike syngenetic sedimentary Pb-Zn deposits occur below the basis of the Damara group (Kamanjab area) as well as in the Damara group itself further east, in the Otavi dolomites of the Otavi Mountains. The deposits below the basis of the Damara group possibly may be regarded as source of metal for the subsequent group of sedimentary deposits in the Otavi dolomite.

The important South-west African Pb-Zn-Cu Mine of Tsumeb in the Otavi Mountain area represents a genetic type which so far has not yet been fully understood. It is at present considered by several leading authors as a mineralized pipe-shaped karst body rather than an epigenetic pipe. The mineralization of the Mississippi-Valley-type, as it is found for instance in the Berg Aukas Pb-Zn-V deposits and numerous smaller occurrences, may be interpreted as being derived from mobilized and redeposited mineralization of the Lower Damaran (Cu) and basement rocks (Pb-Zn).

This lead-zinc mineralization may tentatively be extended towards NE to the significant Zambian lead-zinc district of Broken Hill. The latter shows striking similarities as far as the type of mineralization (Pb-Zn-V) and the country rock of probably the same age (dolomite of the Katanga system) is concerned. Unfortunately a young cover of sediments impedes our knowledge of any further lead-zinc and copper mineralization between South-west Africa and the Broken Hill district south of the Copperbelt.

In the opposite South American region (Uruguay, Rio Grande do Sul, Paraná) the Lavalleja, Porongos, Brusque and especially the Açunguí series is locally mineralized with Pb-Zn and, in few places, with V in marbles, limestones and dolomites. Some of these occurrences are of economic interest. As Pöschl (1968) proved in his studies on the Panelas Mine, Paraná, this mineralization is predominantly of syngenetic origin.

The above mentioned lead-zinc mineralization and the latter of Uruguay and South Brazil must be combined to a major ore province.

In the Congo Republic the Pb-Zn Mine of M'Passa is located in the Pan-African Orogen in the "schisto-calcaire" series of the West-Congo Geosyncline along with several other mines, where new ore reserves could be proved in recent years. Pb-Zn-F occurrences of a similar type, where mineralization is emplaced in slightly disturbed dolomite of probable Damara age unconformably overlying the cratonic basemant, have recently been discovered in central Angola.

This Pb-Zn occurrences of the Congo Republic and Angola on one side and those of Sergipe, Minas Gerais and Bahia on the other can be considered as a distinct metallogenic province. They correspond in age (500—550 m. y.), but in Minas Gerais and Bahia mineralization was emplaced in flat-lying limestones unconformable on the stable São Francisco Craton, whereas in Sergipe and the Congo Republik the mineralized strata were subjected to more intense folding and are situated within the orogenic belt.

In the Bambuí group of Minas Gerais which corresponds in age to the Porongos /Açunguí groups and lies unconformably above the hardly metamorphous and little disturbed older basement (São Francisco Craton), Pb-Zn-V mineralization of the same stratabound genesis is found near Januária and Itacarambí, Pb-Zn-F mineralization near Montalvania. A large deposit of this type in the Paracatú area recently commenced operation. Similar occurrences are located throughout the Bambuí group which can be traced northward into northern Bahia. In Brazil's most important Pb-Zn producers, the Mines of Vazante (Minas Gerais) and Boquira (Bahia), mobilized syngenetic ore is apparently bound to fault zones.

The metal content of the syngenetic-stratabound mineralization of the Bambuí probably was formed by the erosion of older deposits and deposition of the metal in the Bambuí Sea. Part of the primary syngenetic mineralization of the Bambuí group was subsequently mobilized and precipitated as epigenetic ore (Cassedanne, 1972; Beurlen, 1973).

Tin — Wolfram

On the Brazilian Shield Sn-Wo mineralization is localized in a relatively narrow zone of approximately 200 km in width extending parallel to the coast of the Atlantic Ocean for about 3000 km and striking in NW—SE direction. The Sn-Wo enrichments are distributed intermittently along this zone. As will be pointed out in the following it seems perfectly justified to join them together with Sn-Wo occurrences of Nigeria and those of the Niger Republic into one metallogenic unit of several provinces and subprovinces.

Mineralization is connected to post-orogenic granites of the Brazilian Orogenic Cycle whose age of 700—450 m. y. agrees well with a similar age determination from the West African Orogen. Bullard et al. (1965) and Schuiling (1967) have already stressed the fact that this tin belt ends abruptly at the Atlantic coast allowing conclusions as to the junction of both continents prior to the disruption.

On the Borborema Plateau (Paraíba and Rio Grande do Norte) Sn-Wo mineralization is known to occur mainly in Be-and Li-pegmatites. They show significant tourmalinization and bear a considerable amount of ilmenite. Tantalite in economic concentrations is present in several of these pegmatites associated with the highly tantaliferous Mn-tantalite and Bi-tantalite. The Sn-Wo-Ta pegmatites of the Borborema match perfectly well with those of Nigeria although tantalite occurs more sporadically on the Borborema Plateau. In Nigeria two different phases of formation of Sn-Wo enrichment can be distinguished. The older pegmatite suite carrying cassiterite and wolframite of of the same age as in the opposite region of North-east Brazil, viz. 500 m. y. (Jacobson et al., 1965). The younger suite which is characterized by columbite in addition to cassiterite and wolframite is connected with the so-called Younger Granites with ages of 155 m.y. (mid-Jurassic). Considering the origin of the younger granites it is believed that they were derived from an initial peralkaline melt of local basemant rocks (BOWDEN, 1970).

The Sn-Wo mineralization of these Younger Granites was probably caused by derivation of tin and wolfram from the 500 m. y. basement rocks. The genesis of the Younger Granites and their mineralization is connected with the disruption of the Gondwana Continent beginning during the Jurassic.

As the mineralization of the Younger Granites is related to the commencement or the drifting of both continents it therefore is strictly speaking beyond the scope of this paper which deals with ore provinces existing prior to the disruption. The Younger Granites mark the beginning of the youngest cycle of cratonic magmatism on the African Shield (LEUBE & CISSARZ, 1966).

The Jos Plateau, Nigeria, is the main world producer of columbite which derives from the younger biotite granite and, to a minor extent, from associated riebeckite granites. The old pegmatites had contributed but a small amount to the country's tin and wolfram production and have been exhausted since several years.

The examination of the cassiterite mineralization of Africa and South America reveals evidence of further tin subprovinces. The Sn-Nb-Ta pegmatites of Gabon and the Congo Republic correspond closely with those of São João del Rei and Governador Valadares, Minas Gerais.

The stanniferous pegmatites of São João del Rei hold a position of their own from the geochemical point of view. They are polymetallic pegmatites bearing Sn, Nb, Ta, U, Li, and Zr. Ta and Nb predominate and occur mainly as tantalite and complex uraniferous microlite. Alkali granites nearby seem to display genetic relationship to the pegmatites.

The cassiterite deposits of Central Bahia show a less complex geochemical composition. Cassiterite is found disseminated or as filling of joints and fissures in rhyolites.

A third distinctive tin subprovince comprizes the Sn-Wo pegmatites of the Uis and Brandberg Mines, South-west Africa together with a number of other occurrences, and the Sn mineralization of southern Brazil, all of them with ages in the 500—600 m. y. range.

In Encrusillada, Rio Grande do Sul, Sn-Wo mineralization occurs in the Young Precambrian Porongos group. Greisen with tourmaline, beryl, topaz and monazite are typical accessories. The deposits of the State São Paulo and of Nova Trenta, Sta. Catarina, show a similar paragenesis.

The extensive scheelite area of North-east Brazil (Borborema Plateau), which comprises approximately 30.000 square kilometers, was first considered as hydrothermal mineralization caused by Young Precambrian palingene granites (JOHNSTON & VASCONCELLOS, 1944). EBERT (1970) believes in a mobilization of wolfram mineralization in strata more than 1000 meters below the scheelitiferous marbles. For this preexisting mineralization and mobilization, however, no geochemical proof can be produced. The latest investigations suggest the conclusion that this mineralization is of syngenetic origin and belongs to the reactionskarn type. The scheelite-bearing calc-silicate marble apparently has been formed by exchange of material between the limestone and bordering gneiss.

The scheelites tend to occur in connection with thin beds of marble within a sequence of Young Precambrian sediments and metamorphics 250 m thick. More-over scheelite mineralization was found combined with rich sulfides in the surrounding gneiss and in intercalated layers of amphibolite which partly seem to be altered basic volcanics.

From Dahomea several small scheelite occurrences are known which too are connected to marble (Black, 1959). They appear to be of the same age as those in the Borborema with which they may be correlated.

Gold

The major epigenetic gold deposits are located preferably on older cratonic shields of both continents.

The occurrences of gold quartz veins on the Guiana Shield evidently match those of the West African Precambrian Craton.

On the Guiana Shield the veins are distributed in close vicinity to the granites intrusive into the various volcanic series consisting of green schist and chloritic schist, basic to intermediate meta-volcanics and meta-greywackes. Mineralization is known to have taken place in several phases, the most important of which are connected to granites with ages in the 1800 m. y. range. Gold deposits are concentrated in the northern part of the Guiana Shield in Venezuela, Guiana, French Guiana and Surinam. Several centres of mineralization can be distinguished. The best known is the so-called "Quadrilátero Aurífero de el Callao" to the south of the Serra da Imatacá, about 200 km southest of Ciudad Bolivar, Venezuela. For many decades after its discovery the Quadrilátero belonged to the world's richest gold deposits.

The gold enrichments of the Brazilian territory of Amapá in the far east of the Guiana Shield are mainly placer deposits. The pegmatitic source rocks for the placers fit well into the framework of the gold province.

In the African portion of this gold province primary deposits are arranged along N—NW trending Birrimian axes in Ghana and Upper Volta. The centre of a system of rich gold veins is the Poura gold district (Upper Volta) situated within a series of volcanic green schist in close contact to intrusive granite with an age of about 1800 m. y. The Lay-, Songo- and Zergouré veins (Upper Volta) also form part of the Birrimian gold trend. The gold deposits of the Ivory Coast display similar stratigraphic features.

Within the bearing of the Pan-African Orogenic Cycle younger gold deposits can be traced from Dahomey and Nigeria to the Niger Republic, and southward to the Cameroon Republic. These gold deposits are associated with granitic rocks with ages in the 500—550 m. y. range and match those of Ceará, Rio Grande do Norte and Paraiba with which they combine another gold province. In Brazil they do not reach economic importance, but in Cameroon they are exploited in numerous small mines.

Iron

Itabiritic iron deposits have been formed repeatedly at various times during the Precambrian. In Africa as well as in South America the principal periods of the formation of itabirites seem to be about 3200—2900 m. y., and about 2200, 1800 and 700 m. y. The huge itabirite deposits of Africa are of Old and Middle Precambrian age, whereas during the younger Precambrian itabirites were formed but sporadically and of minor thickness and extension.

The itabirite deposits of Liberia, Sierra Leone and Guinea and those of Venezuela (Serra de Imatacá) form a homologous ore province separated by the continental drift. This province is one of the world's biggest iron ore enrichments. The ore is concentrated in a metamorphosed sedimentary-volcanic series and age determinations indicate an age of approximately 2700 m. y. (HURLEY & RAND, 1973).

In the eastern part of the Guiana Shield itabirites are found intercalated in the intensely folded Old Precambrian. Other iron ore enrichments are known from southern Surinam, Guiana, and Amapá.

The vast itabirite deposits of the Bong Range, Bomi Hills, Bie Hills and the Nimba Range, Liberia, with ages older than 2700 m. y. allow direct correlation to the above mentioned deposits of South America. The ferriferous rock sequences which show enrichments of economic value in places can be traced over great distances in Liberia (200 km) as well as in Venezuela (300 km) directly to the coast of the Atlantic Ocean.

Another iron ore district of comparable magnitude and economic importance, the "Quadrilátero Ferrífero" of Minas Gerais, seems to have its conterpart on the African continent in the iron deposits of Gabon and the northern Republic of Zaire. They are tentatively linked together to an iron ore province as age determinations do not yet allow for a definite classification.

URANIUM

Uranium mineralization in South America and Africa show some remarkable ressemblances. On both continents two different types of uranium deposits show up in equal geotectonic position.

Deposits related to granitic or granitoide intrusives are found parallel to the coastlines in the orogens which were subjected to the youngest metamorphism about 500 m. y. ago.

East-northeast of Swakopmund, South-west Africa, the Rössing uranium deposit lies on the southern margin of a huge oval dome structure composed of metasediments of the Damara group in which alaskite is intrusive. The alaskite is mineralized with uraninite, betafite and uranophane. The alaskite intruded parallel to the bedding and to the schistosity in nearly vertically disposed sediments (BERNING et al., 1976). Rössing is one of the richest deposits and soon will be the biggest syngenetic (by normal differentiation in alaskite) uranium mine in the world.

In Brazil prospecting and detailed investigation has been started recently on uraniferous granitic rocks and pegmatitic granites, 500 m. y. of age, near Curais Novos, Rio Grande do Norte, in the same area which is mineralized with the abovementioned scheelite. No details are available so far, but a certain similarity between the Rössing deposit and these uranite-bearing intrusions is apparent.

Uranium mineralization is associated also with the Gondwana sediments on both sides of the South Atlantic. In South Africa a few years ago uranium has been discovered in the Lower Beaufort group of the Karroo supergroup west of the town Beaufort-West. Mineralization occurs within a fine-grained pyritic arkose and sandstone alternating with shale. The uranium deposits in the Lower Beaufort group are enriched thinly-bedded lenses in which the uranium minerals occur along the bedding planes and in joint fissures. There appear to be widespread associations of uranium with organic remains and carbonacaeous material. Detrital uraninite is absent (v. BACKSTRÖM, 1974).

Recently the eastern margin of the Paraná Basin of southern Brazil became a major prospecting target for uraniferous sandstones of Permian age. The uranium enrichments are concentrated in the Rio Bonito formation which can be directly correlated with the Lower Beaufort stage of the Karroo supergroup of South Africa. In both cases the uranium ore is found above the coal seams or their stratigraphic equivalent intercalated in sandstone. As the prospecting campaign is under way further information is not yet available.

In the older cratonic areas of both continents Precambrian metamorphosed conglomeratic gold- and uranium placer deposits exist: the Upper Witwatersrand beds in South Africa (2500 m. y.) and the Minas series near Belo Horizonte and in the eastern Serra da Jacobina in central Bahia (1800 m. y. ?). These deposits are — as far as sediments and mineralization are concerned — very similar and have been compared from the genetical point of view by RAMDOHR (1958). They can, however, not be correlated to an ore province as they differ considerably from each other not only in age but also in the structural unit they belong to. The Witwatersrand strata were deposited in a huge, oval-shaped basin on a stable platform of approximately 3000 m. y. of age. The Minas series, on the other hand, was laid down in a definitely mobile geosynclinal belt. This belt extended more than 1000 km and reached cratonic stabilization by subsequent folding.

DIAMOND

In South America at least two periods of emplacement of kimberlitic rocks seem discernible, although only diamond placer deposits have been found so far. The oldest with an age of more than 1600 m. y. Barren kimberlitic pipes of seemingly Cretaceous age have been found in Piauí and recently in Minas Gerais in the vicinity of Cretaceous placers.

The oldest diamonds in placer deposits in South Africa belong to the Witwatersrand beds whose age was determined to be at least 2600 m. y. Consequently the source rocks must be of still older age. The oldest kimberlite pipe encountered from which measurements are available is Premier Mine near Pretoria dated 1800 ± m. y. of age. The last stage of diamondiferous kimberlite emplacement occurred during the Cretaceous.

A distinct diamond province on the West Africa—Guiana metallogenic unit comprizes among others the deposits in Guinea, Sierra Leone, Ghana and in Guiana, Venezuela, Surinam and French Guiana. Primary diamonds worked in their kimberlitic source or their alluvial deposits close to the source occur on the West African Shield in Guinea (Kankan-Begla region) and the Séfadu region of Sierra Leone.

On the other hand numerous producing regions are known, where the alluvial diamonds are believed to be relatively distant from their source rocks as for instance the Sewa placers of Sierra Leone and the Birim and Bonsa placers of Ghana. The Segéla-Tortiya concentration is attributed to the Lower Birrimian sediments on the old stable craton of West Africa. These deposits lead directly to the Guiana placers, the oldest of which occur in the Roraima quartzites aged older than 1600 m. y. The source rocks most likely belong to the 1800 m. y. orogenic cycle.

Other important diamond placers of this age group are situated in the Caroni basin in Venezuela, and in Surinam and French Guiana.

Two different diamondiferous conglomerates are present in Minas Gerais. The older, which are of interest in our context, occur in the Minas Series (Diamantina). They possibly derived from pipes related to those of the Premier Mine near Pretoria, South Africa.

The younger diamondiferous conglomerates (Romaria, west Minas Gerais) are of Upper Cretaceous age and the diamonds are concentrations deriving from nearby pipes of slightly older age (probably Lower Cretaceous).

The Late Precambrian orogenic belts parallel to the Atlantic Ocean on both continents are practically free of primary and secondary diamondiferous rocks ore concentrations except for the submarine coastal and alluvial deposits on the mouth of the Orange River, the diamonds of which have been transported for about 1000 km from the Middle Precambrian cratonic areas.

Although only one clearly developed diamond province separated by continental drift can be recognized, i. c. on the West-African — Guiana unit, diamonds are of special interest as the periods of their emplacement appear to strengthen the hypothesis of a similar contemporaneous metallogenic development of both continents. It is believed that this hypothesis will lead to most interesting practical consequences as far as exploration targets are concerned.

References

ALMEIDA, F. F. DE : Geochemical division of the Precambrian of South America. — Rev. Bras. geocienc., 1, 13—21, São Paulo 1971.

BACKSTRÖM, J. W. v.: Uranium deposits in the Karroo Supergroup near Beaufort West, Cape Province. — In: Formation of uranium ore deposits. Internat. Atom. Energy Agency. Proceeding of a symposium Athens 6—12 May 1974, 419—424, Vienna 1974.

BERNING, J., COOKE, R., HIEMSTRA, S. A. & HOFFMANN, U.: The Rössing uranium deposits, South West Africa. — Econ. Geol., 71, 1, Lancaster Pa. 1976.

BEURLEN, H.: Blei-, Zink-Fluorit-Vererzungen in den Karbonatgesteinen der Bambui-Gruppe, Minas Gerais. — Neue Ergebn. Geol. Erforsch. Lateinamerikas, 117—143, Münster 1973.

BLACK, R.: Note sur les indices de Scheelite et de Tantalite decouverts par la Mission Rouchon (1954—1956) dans la secteur de Dadjo, Rep. Dahomey. — Rap. BRGM, Dakar 1959.

BOWDEN, P.: Origin of the younger granites of Northern Nigeria. — Contrib. Mineral Petrol., 25, 153—162, Berlin 1970.

BOWDEN, P. & TURNER, D. C.: Peralkaline and associated ringcomplexes in the Nigeria—Niger province, West Africa. — The Alkaline Rocks, 330—351, London 1974.

BULLARD, E., EVRETT, J., SMITH, A. & GILBERT, E.: The fit of the sediments around the Atlantic. — In: Symp. on Cont. Drift, 41—51, London 1965.

CASSEDANNE, J.: Estudo syntetico das jazidas de chumbo e de zinco do Brasil. — In: 5. Simpó. de Geol. do Nordeste, 41—51, Recife 1972.

CLIFFORD, T. N.: Tectono-metallogenic units and metallogenic provinces of Africa. — Earth Planet. Sci. Letters, 1, 421—434, Amsterdam 1966.

CORDANI, U. G., AMARAL, G. & KAWASHITA, K.: The Precambrian evolution of South America. — Geol. Rdsch., 62, 309—317, Stuttgart 1973.

CORDANI, U. G. & BITTENCOURT, J.: Determinacões de idade K-Ar em rochas do Grupo Açungui. — An. XXI Congr. Bras. Geol., 218—233, Curitiba 1967.

EBERT, H.: The Precambrian geology of the "Borborema belt" (states of Paraiba and Rio Grande do Norte; Northeastern Brazil) and the origin of its mineral provinces. — Geol. Rdsch., **59**, 3, 1292—1326, Stuttgart 1970.

HURLEY, P. M.: The confirmation of continental drift. — Scient. Amer., **218**, 4, 52—64, New York 1968.

HURLEY, P. M. & RAND, J.: Review of age data in West Africa and South America relative to a test of Continental Drift. — In: The history of the earth's crust., 153—160, Princeton 1968.

HURLEY, P. M. & RAND, J.: Outline of Precambrian chronology in lands bordering the South Atlantic, exclusive of Brazil. — In: The Ocean Basins and Margins, I, 391—410, New York 1973.

JACOBSON, R. R. E., SNELLING, N. J. & TRUSWELL, J. F.: Age determinations in the geology of Nigeria, with special references to the older and younger granites. — Overseas Geol. Min. Resources, **9**, 168—182, London 1963.

JOHNSTON, & VASCONCELLOS, F. M. DE: Scheelite in Northeastern Brazil. — Econ. Geol., **40**, 34—50, Lancaster Pa. 1945.

LEUBE, A. & CISSARZ, A.: Formation of mineral deposits in relation to the structural development of the Kaapvaal Craton. — Mineral. Deposita, **1**, 201—225, Berlin 1966.

LOMBARD, J.: Carte Minérale de l'Afrique. — 1 :10 Mio., UNESCO, Paris 1968.

LOSS, E. L. & ROISENBERG, A.: Contribução a caracterização geotectônica da seqüência sedimentar Eo-Paleozo ia do Rio Grande do Sul. — Pesquisas, Inst. Geosci. Univ. Rio Grande do Sul, 7—12, Porto Alegre 1972.

PETRASCHECK, W. E.: Typical features of metallogenic provinces. — Econ. Geol., **60**, 1620—1634, Lancaster Pa. 1965.

PETRASCHECK, W. E.: Kontinentalverschiebung und Erzprovinzen. — Mineral. Deposita, **3**, 56—65, Berlin 1968.

PETRASCHECK, W. E.: Some aspects of the relations between continental drift and metallogenic provinces. — In: Implications of continental drift to the Earth Sci., 567—572, London 1973.

PÖSCHL, A.: Die Pb-Erzlagerstätten des Rio Ribeira de Iguape Bezirks (Südbrasilien), — N. Jb. Mineral., 1/2, 33—41, Stuttgart 1968.

PUTZER, H.: Metallogenetische Provinzen in Südamerika. — Stuttgart (Bornträger) 1976 (in print).

RAMDOHR, P.: Die Uran- und Goldlagerstätten des Witwatersrand, Blind River Districts, Dominion Reef, Serra da Jacobina. — Abh. dt. Akad. Wiss., Kl. Chem., Geol., Biol., **3**, 1—35, Berlin 1958.

RIBEIRO, M.: Geologia da folha de Bom Jardim, Rio Grande do Sul, Brasil. — Bol. Div. de Geol., **247**, 1—142, Rio de Janeiro 1970.

SCHUILING, R. D.: Tin Belts on the Continents around the Atlantic Ocean. — Econ. Geol., **62**, 540—550, Lancaster Pa. 1967.

SUSZCZYNSKI, E. F.: Mapa Metalogenetico do Brasil, 1 :5 Mio. — Ministério das Minas e Energia, Dep. Nac. da Prod. Mineral, Rio de Janeiro 1973.

TESSARI, R. J. & GRIFFONI, L. E.: Geologia da Região Piratini — Pinheiro Machado — Bagé, Rio Grande do Sul. — Ministério das Minas e Energia, Dep. Nac. da Prod. Mineral, **246**, 1—123, Rio de Janeiro 1970.