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STRATIGRAPHY OF COPPER OCCURRENCES IN THE ZAMBIAN COPPERBELT

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ABSTRACT

Stratigraphic work still in progress has resulted in a revised correlation of the Lower Roan from Chililabombwe to Luanshya. The Upper Roan/Lower Roan boundary has been redefined at several localities and an attempt has been made to correlate the Lower Roan across the Kafue Anticline. At the regional scale, the stratiform nature of major and minor copper occurrences is highlighted. Not only the prominent orebodies but also anomalous copper values can be correlated over a large area. A sedimentary model emphasizing the close association of ore occurrences with transgressions of the Katanga sea is proposed.

INTRODUCTION

The Zambian Copperbelt is part of a larger mineral province which includes Shaba (Zaire) and also large areas in the Northwestern Province of Zambia. Late Precambrian metasediments which have been correlated with the Katanga rocks and are reputed to be of some economic interest are present to the West in Angola and to the Northeast in the Northern Province of Zambia. Some copper-bearing Late Precambrian metasediments of South-West Africa may be part of the same province (Clifford, 1962; van Eden and Binda, 1972).

The Copperbelt deposits have long been known as classical examples of stratiform orebodies, and are well documented in detailed accounts of the individual mines. The main aims of this paper are:

1. To present a revised stratigraphic correlation, which is the preliminary outcome of stratigraphic studies involving R.C.M. and N.C.C.M. geologists.

2. To discuss some regional aspects of stratigraphic distribution of copper occurrences.

3. To summarize the results of some research carried out in the Copperbelt in the last decade. Some of this information has already been published, but much

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of it remains in company reports which are normally not available to the scientific community.

STRATIGRAPHY

The Roan Group is the lower subdivision of the Late Precambrian Katanga Sequence which covers a large area of Zambia and Zaire. The term Katanga Sequence (Binda and van Eden, 1972) is used here in preference to Katanga System (Mendelsohn, 1961) and to Katangan (Cahen and Lepersonne, 1967). Isotopic ages indicate that the Katanga Sequence was deposited before 620 m.yr. ago, and that the Lower Roan is older than 840 m.yr. and younger than 1,300 m.yr. (Cahen, 1970). In Zambia, the Katanga Sequence is subdivided from top to bottom into Kundelungu, Mwashia, and Roan groups (see insert in fig. 1).

The Roan Group is generally subdivided into a predominantly dolomitic Upper Roan, 500 to 800 m thick, and a predominantly clastic Lower Roan, up to 1,000 m thick (Mendelsohn, 1961). The term Mine Series is used in Zambia for the strata comprising Mwashia, Upper Roan, and Lower Roan (Gray, 1930), whereas in Zaire the term *Série des Mines* (now *Mines Group*) refers to the lithostratigraphic unit between the R.A.T. (*Roches argilo-talqueuses*) and the Dipeta Group (Bartholomé *et al.*, 1973). It is proposed to abandon the term Mine Series (or Group) in Zambia to avoid confusion.

LOWER ROAN

The Lower Roan predominantly comprises clastic metasediments with minor dolomites towards the top. The Luanshya terminology has been used here since it is the most informal and also perhaps the best known. Work aimed at detailed correlation and standardization of stratigraphic terms in the Copperbelt is in progress. This will entail discarding the existing nomenclature which is confused by parochial terms largely related to mining (see figs. 2 and 3).

The present lack of chronostratigraphic horizons in the Roan Group necessitates reliance on lithostratigraphy. The Lower Roan/Upper Roan boundary has caused considerable confusion owing to the arbitrary choice of the point where the section changes from "predominantly clastic" to "predominantly dolomitic." Detailed correlation by Mulgrew (1968 and 1972) from Chililabombwe to Luanshya (Ore Shale Alignment of fig. 1) has indicated that a natural boundary exists as shown in figure 2. In extending this correlation to other parts of the Copperbelt, it must be accepted that the Upper Roan/Lower Roan boundary can be diachronous owing to facies changes.

The Lower Roan can be subdivided from base to top as follows:

RL 7 (Footwall Formation)

At Luanshya, this stratigraphic unit includes all the metasediments between the basal Katanga unconformity and the Ore Shale (RL 6). The Footwall formation,

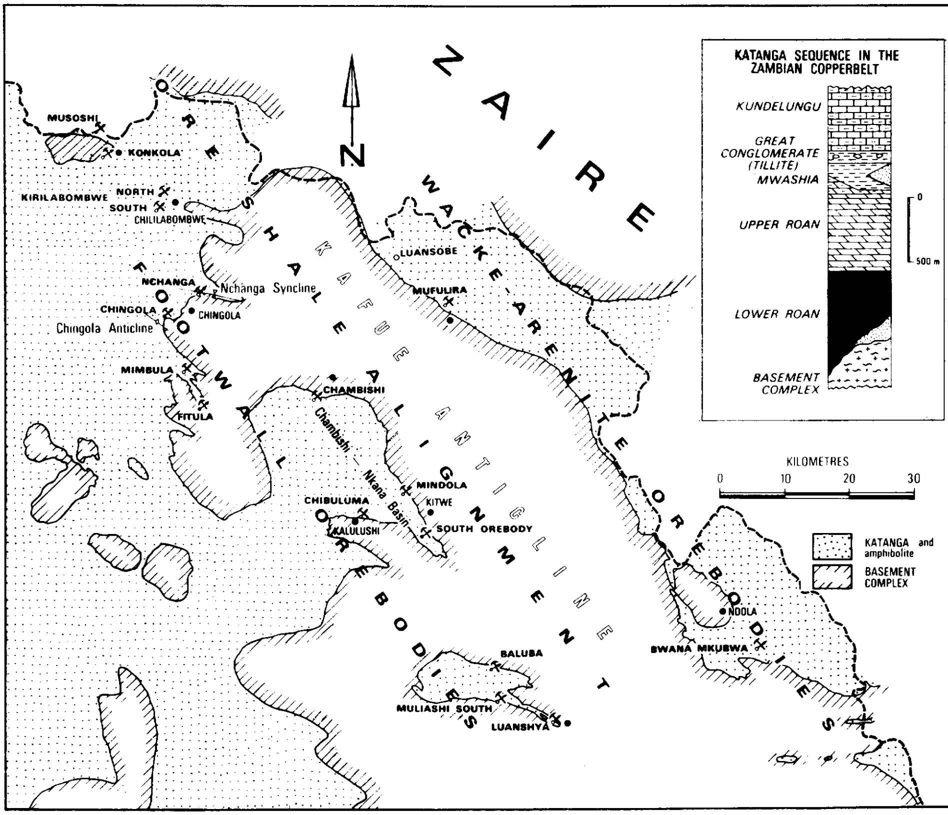

FIG. 1. — *Map of the Zambian Copperbelt and generalized stratigraphy of the Katanga Sequence.*

having been deposited on a rugged topography, varies considerably in thickness from several hundred metres in the valleys to nil over paleogeographic highs.

The predominant lithologic types are coarse-grained clastics with very little argillite, and virtually no carbonates. Correlation of individual units within the Footwall formation is uncertain owing to the local control which Basement hills of varied rock types exercised on sedimentation. The following generalized succession can be recognized at most localities along the Ore Shale Alignment.

Basal Conglomerate (Boulder Conglomerate). — The Basal Conglomerate is extremely variable in thickness, poorly sorted and is generally interpreted as a scree deposit, whereas metasediments above it may have more distant sources, e.g. Nchanga (Binda, 1972*a*).

Footwall Quartzites. — Above the Basal Conglomerate, or directly overlying the Basement Complex, are a few hundred metres of micaceous quartzites and "clean" felspathic quartzites. The latter often exhibit large-scale cross-bedding which is interpreted by Mendelsohn (*in* Mendelsohn, 1961, p. 41) as eolian in origin. At places, however, the eolian origin of these quartzites is in doubt (van Eden and Binda, 1972).

Second Conglomerate. — A lenticular second conglomerate, poorly sorted and containing pebbles and cobbles of various Basement lithologies, occurs at about the same stratigraphic level in most localities from Chililabombwe to Luanshya. Although not correlatable in detail, these occurrences suggest higher energy conditions over a large area in the Copperbelt at about the same time.

The Second Conglomerate is overlain by pink to greyish, medium-grained, felspathic and micaceous metasandstones. Small-scale cross-bedding and thin layers of sandy argillite occur locally and may indicate fluviatile conditions.

Footwall Conglomerate and Sandstone. — Sandstones and conglomeratic lenses directly underlie the Ore Shale. A footwall conglomerate is normally present along the Ore Shale Alignment, but always as discontinuous lenses in sandstone.

Mendelsohn (*in* Mendelsohn, 1961, p. 351) interpreted the Footwall Conglomerate in the eastern part of Luanshya as a series of shoestring conglomerates parallel to an ancient shoreline and stepping down stratigraphically towards the northwest. A marine transgression marks the end of RL 7 sedimentation in the Copperbelt, therefore beach deposits are to be expected towards the top of the RL 7. However, McKenzie (1968) and Binda (1969*a*) showed that, in two small areas in Luanshya, the Footwall Conglomerate was deposited in a high-energy fluviatile environment with current directions towards the south.

Footwall Formation at Mufulira. — At Mufulira, the beds between the base of the "C" horizon (fig. 3) and the Basement Complex have been subdivided by van Eden (1969) and Hodgson (1969) into a lower and upper Footwall separated by a marked truncation plane which is interpreted as a regional disconformity. Wedges of unsorted conglomerate mark the basal unconformity at a few places. A grey quartzite displaying large-scale cross-bedding is the predominant lithotype of the lower Footwall. This quartzite has been interpreted as wind-deposited by Garlick (1967) and Maree (1962), but van Eden (1972) found no clear evidence for eolian origin. Above the grey quartzite, and locally interfingering with it, are cross-bedded reddish grits and quartzites of aqueous origin.

The Mufulira Footwall succession is not easily correlatable with that of the Ore Shale Alignment; an alluvial-fan conglomerate in the lower part of the "C" horizon (van Eden, 1970) may be equivalent to the Footwall Conglomerate. Unimodal current directions from north to south in this conglomerate are consistent with the general transport direction for other areas of the Copperbelt.

RL 6 (Ore Shale)

The Ore Shale is a remarkably persistent horizon that can be traced from Chililabombwe to Luanshya, a distance of approximately 100 km. It is a grey-green, silty argillite, 5 to more than 50 m thick, passing laterally to a black, carbonaceous argillite. Vertical and horizontal variations in lithology have been observed both regionally and locally; a carbonate-rich facies is generally present at the base, and anhydrite concretions are often present near the top.

At Nkana (Kitwe) and Chililabombwe, the Ore Shale is divided into several sub-units. At Luanshya, the RL 6 is sub-divided in two units: a lower argillaceous

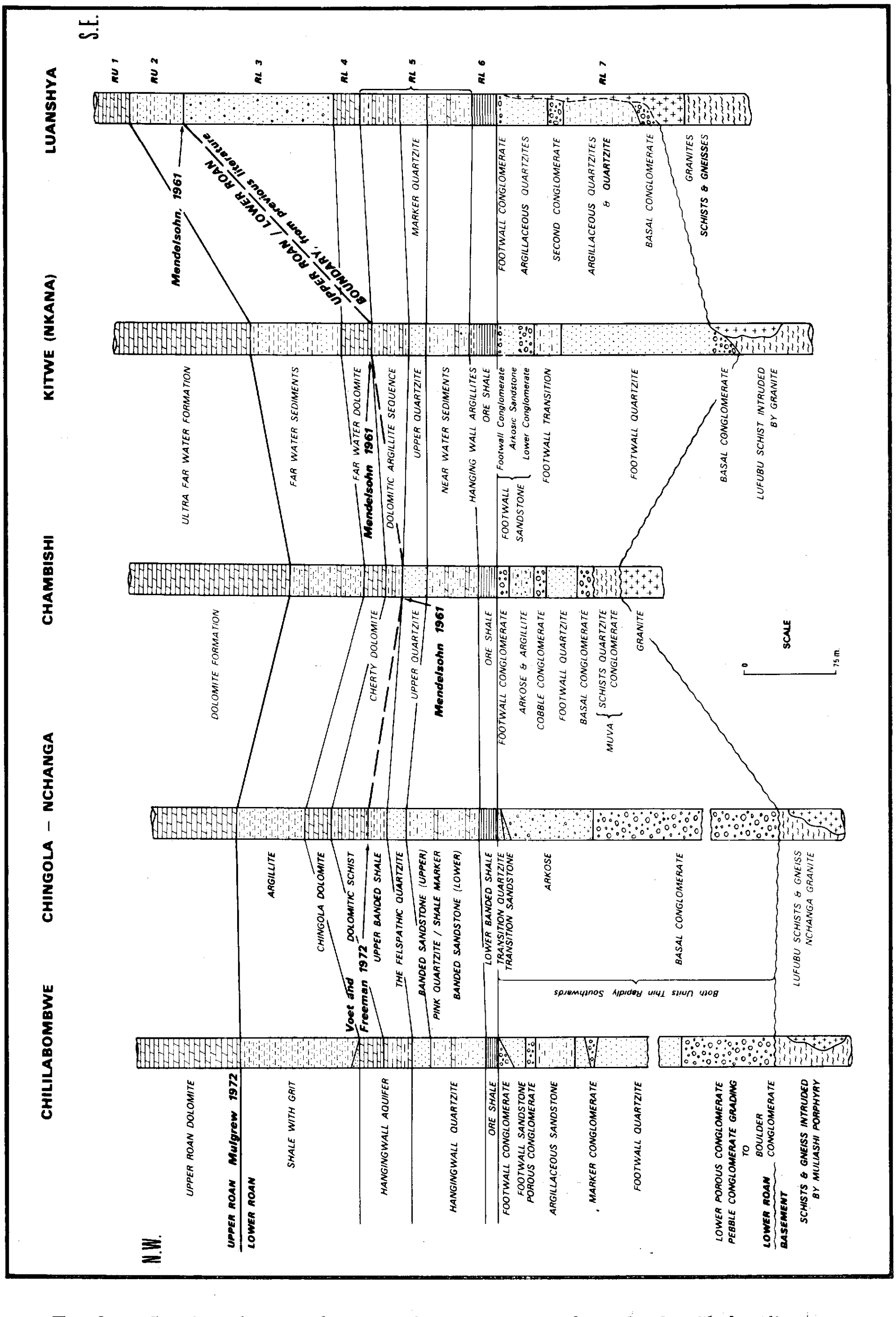

FIG. 2. — *Stratigraphic correlation of the Lower Roan along the Ore Shale Alignment.*

dolomite passing laterally to a calcite-biotite-tremolite schist to the west, and an upper sandy and silty argillite becoming somewhat finer grained and scapolitic, to the west (Mendelsohn, *in* Mendelsohn, 1961, p. 351).

Annels (1972) describes a lateral facies change within the Ore Shale in the Luanshya and Chambishi basins: a silty argillite to the northeast (Luanshya, Mindola, Chambishi), a carbonaceous argillite to the southwest (Nkana South Orebody, eastern edge of Chibuluma, northwestern margin of the Chambishi basin), and a transitional facies separating the two.

The Ore Shale equivalent in the Mufulira syncline is here interpreted to be the section between the base of the "C" and the top of the "B" horizons (fig. 3). "C" and "B" wackes, arenites, dolomites, and argillites can be explained as near-shore, coarser-grained facies of the Ore Shale. On lithologic criteria, the lower boundary of the RL 6 equivalent at Mufulira could be taken at the base of the Mudseam (Inter "B-C"). However, the abrupt change from the cross-bedded (fluviatile?) grits of the footwall to the marine arenites of the "C" horizon (van Eden, 1972) can be equated with the marine transgression at the base of the Ore Shale. Supporting evidence for lithostratigraphic correlation of the "B-C" sequence with the RL 6 is that in both units it is the lowest occurrence, in the Katanga Sequence, of bedded carbonates and stromatolites. Stromatolites have been described from the Inter "B-C" beds at Mufulira (Malan, 1964) and have recently been identified at the same stratigraphic horizon in drillcores from the Ndola area. In the Chambishi-Nkana basin, stromatolites and biohermal carbonates occur at several localities in the Ore Shale (Annels, 1972; Clemmey, pers. comm.).

Southwest of the Luanshya-Chililabombwe alignment, the Ore Shale and the upper part of the Lower Roan pinch out, and dolomitic metasediments of Upper Roan affinity directly overlie Footwall clastics. At the eastern edge of the Chibuluma mining area, a pyritic carbonaceous argillite that correlates with the Ore Shale at nearby Nkana can still be recognized; further to the west, however, the Ore Shale pinches out and dolomite, amphibolite, and albite-chlorite rocks overlie the sandstone and conglomerate.

In the Nchanga-Chingola region, the strata between the base of the Lower Banded Shale (Ore Shale) and the Felspathic Quartzite are about 80 m thick. Further to the southeast, along strike, this part of the succession thins to 8 m of dolomitic quartz-micaschist and the Lower Banded Shale cannot be distinguished. Further west, the Felspathic Quartzite rests directly on rocks which are reliably assigned to the Footwall.

These relationships are consistent with a rapid northeasterly transgression of the Katanga sea at the onset of Ore Shale deposition. The area to the southwest of Kalulushi was too far from the shoreline to receive much clastic material and mainly carbonates were deposited throughout the time of deposition of the upper part of the Lower Roan. Unfortunately, thick but irregular bodies of amphibolite obscure the sedimentary record in this area.

RL 5 (Hangingwall Formation)

The RL 5 includes the units from the top of the Ore Shale (RL 6) to the base of the white dolomite (RL 4). Predominantly arenaceous, the unit is characterized by numerous alternations of arenites and argillites, becoming more dolomitic and schistose towards the top. Several arkosic beds provide useful local markers, but a

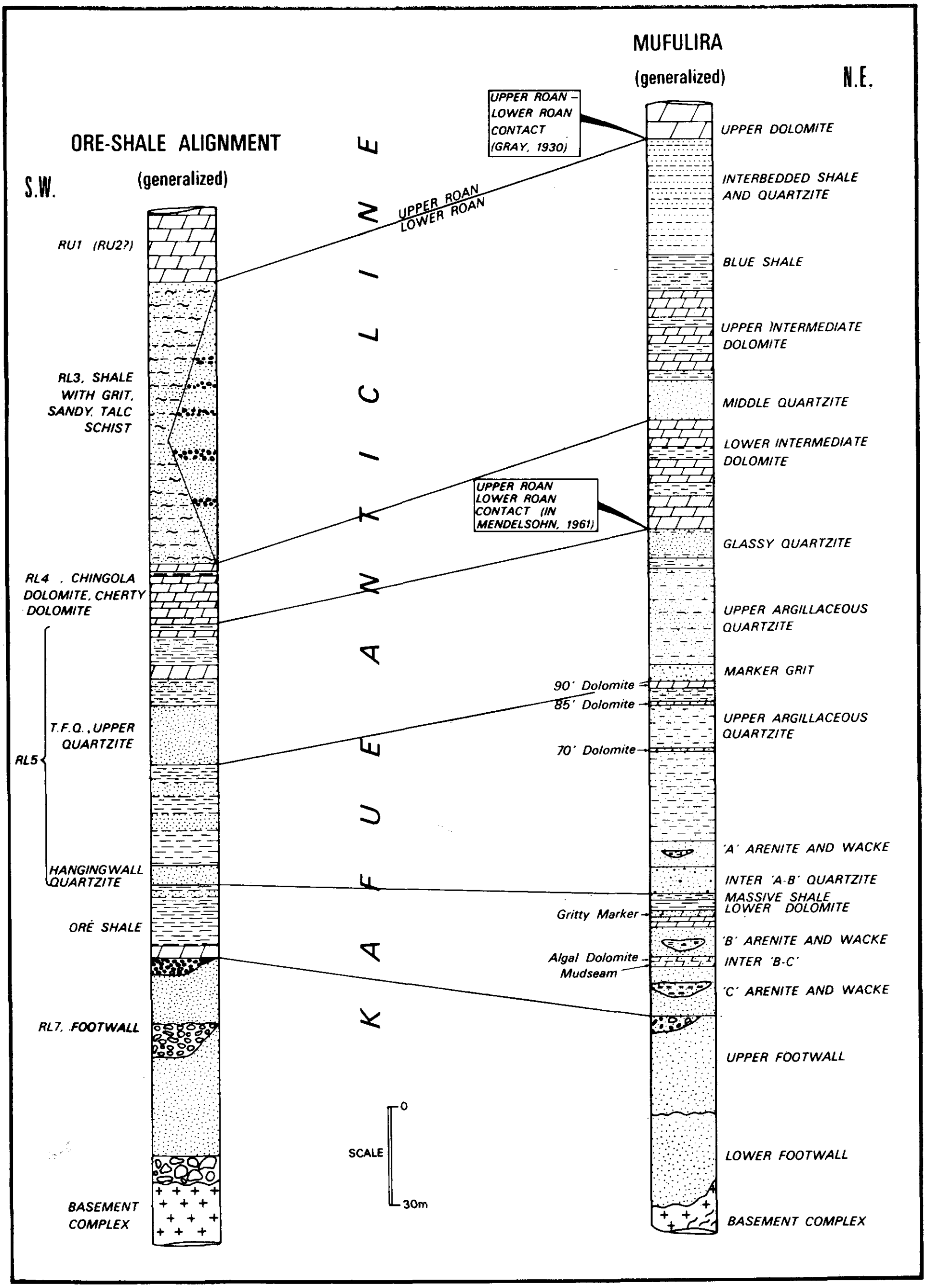

FIG. 3. — *Stratigraphic correlation of the Lower Roan across the Kafue Anticline.*

conspicuous arkose unit (T.F.Q., Upper Quartzite, etc., in fig. 2) can be traced from Chililabombwe to Luanshya. In Luanshya there is a marked lateral change in the RL 5 : mainly arkose alternating with gritty argillite in the east, less sandy and more dolomitic (and anhydritic) towards the west. It should be noted that the Felspathic Quartzite of Chingola (Nchanga) is here correlated with the Luanshya Marker Quartzite, and not with the RL 3 as in Mendelsohn (1961).

A correlation of the RL 5 with the Mufulira succession can be attempted on the basis of tectono-sedimentary events which can be interpolated across the Kafue Anticline. At the top of the Ore Shale there is a gradual coarsening of grain size heralding the hangingwall arenites. These arenites, often cross-bedded and with basal scour features can be interpreted as having been deposited during a regression of the Katanga sea. At Mufulira, evidence of uplift and regressive conditions can be found in the Inter "A-B" quartzite and grit: overlying the Lower Dolomite are some remarkable examples of pre-consolidation slumping in the Massive Shale (Brandt *et al.*, *in* Mendelsohn, 1961, p. 411) followed upwards by a coarse arkose displaying some distinct fluviatile cross-bedding. A convenient upper boundary of the RL 5 equivalent at Mufulira is the top of the Glassy Quartzite (fig. 3).

RL 4 (Chingola Dolomite)

The RL 4 is a 13 to 35 m thick, white to yellowish-brown dolomite with one or two thin beds of argillite towards the top. This unit persists, virtually unchanged in its main characters from Luanshya to Chililabombwe. At each mine it constitutes an important aquifer, if not the principal one, and is known by a variety of local names (fig. 2). The lateral continuity of the Cherty Dolomite with the shale marker near the top, has already been stressed by Hoffman (1967). In Mendelsohn (1961) the Chingola Dolomite, Cherty Dolomite, and Far Water Dolomite were correlated with the Upper Roan of Luanshya, and not with the RL 4 (Lower Roan) as in this paper (fig. 2).

At Mufulira, and along the whole of the Mufulira-Ndola strike, the lithostratigraphic equivalent of the RL 4 is tentatively taken as the Lower Intermediate Dolomite (fig. 3), also the local major aquifer.

RL 3 and Shale with Grit

At Luanshya, the RL 3 consists of more than 100 m of coarse arkose and conglomerate, becoming more argillaceous towards the west. This coarse facies at the top of the Lower Roan in Luanshya has long represented an obstacle to a correct correlation of the Roan Group in the Copperbelt. Mulgrew (1972) observed from the Konkola Dome to Chililabombwe, a lateral facies change from a Luanshya-type arkose to the gritty argillite which is the more common lithotype of the uppermost Lower Roan in the Copperbelt. Mulgrew therefore correlated the RL 3 with: Shale with Grit (Chililabombwe), Argillite (Chingola), Sandy Talc Schist (Chambishi), Far Water Grits and Argillites (Nkana) as shown in figure 2. The coarse arkose is probably a facies deposited near the basin edges during a major uplift, while argillites with lenses of coarse sand represent the basinal facies.

COPPER OCCURRENCES

The relationships between copper occurrences and stratigraphy are discussed at three scales: megascale (regional and large stratigraphic units), mesoscale (single mining property and small stratigraphic units), microscale (from single exposure to microscopic observation).

Copper occurrences include not only orebodies, but also sub-economic mineralization and some geochemical copper anomalies which are at least one order of magnitude above the background. In rocks of the Roan Group, the background copper values are in the order of 10 to 30 ppm as determined by routine A.A.S. methods.

MEGASCALE

At the megascale, the stratigraphic control of copper occurrences is remarkable. The following points serve to highlight this control:

1. *Ore occurrences are restricted to Lower Roan rocks*: nearly all of the Zambian copper is mined from approximately the middle portion of the Lower Roan, from about the Cobble Conglomerate (in the RL 7) to the base of the Chingola Dolomite (RL 4). In a sedimentary column 1 000 to 1 500 m thick, orebodies, and also most of the anomalous values, are confined to a well defined 150-200 m thick stratigraphic interval. The only notable exceptions are the various copper occurrences in rocks of the pre-Katanga Basement Complex (Pienaar, *in* Mendelsohn, 1961, p. 30). Some of these lesser occurrences have been interpreted by Mendelsohn (*in* Mendelsohn, 1961, p. 140) as the product of downward percolation from overlying mineralized Lower Roan rocks. Voet and Freeman (1972) have recorded primary copper sulphides in Basement rocks at Chingola and interpreted them as the remnants of the copper lodes which provided a source for some Lower Roan orebodies.

2. *There is a distinct regional-stratigraphic pattern in the distribution of the orebodies.* The Zambian Copperbelt can be sub-divided into three sub-parallel belts striking northwest-southeast (fig. 1).

To the extreme southwest is a belt in which economic copper mineralization is restricted to arenites older than the Ore Shale. Examples of those orebodies are Chibuluma and Chibuluma West, Mimbula and Fitula, and a few relatively small deposits which are being explored south of Kalulushi. In these areas the Ore Shale is absent or represented by argillite which can be pyritic and carbonaceous as in Chibuluma, or phyllitic and quartzitic as at Mimbula and Fitula. This mineralization is, however, not restricted to the belt indicated in figure 1, but encroaches onto other areas (e.g. Footwall orebodies at Chambishi and Nkana).

The central belt is the Ore Shale Alignment and constitutes a most spectacular example of stratiform orebodies stretching over a strike-distance of more than one hundred kilometres from Musoshi, in Shaba, to Luanshya. Along this belt the Katanga metasediments are preserved from erosion in separate structural basins (fig. 1). The orebodies are confined to the 5 to 50 m thick Ore Shale, except at Nchanga where orebodies occur locally in most of the Lower Roan succession up to the Chingola Dolomite (RL 4). More than one half of the Zambian copper is mined from this alignment. The Ore Shale is not of ore grade along the whole of the strike, but its copper content is always at least two orders of magnitude above the background.

Minor Footwall and Basement mineralizations are present at several localities along the alignment.

To the northeast of the Kafue Anticline, from Luansobe to Bwana Mkubwa, lies a belt of orebodies in arenites and wackes (e.g. Mufulira) that are here correlated with the Ore Shale. The Lower Roan succession is continuous along the belt, but gaps between known orebodies are wider than on the Ore Shale Alignment.

3. *Orebodies are controlled by paleotopography.* A characteristic of the Copperbelt orebodies is their localization adjacent to paleohills of the early-Katanga topography; this criterion has become a most useful guide to exploration. The copper-bearing horizons are generally lean above paleohills, attain maximum values on the slopes, and become lean again above paleovalleys. This paleotopographic control is more noticeable in the arenaceous orebodies (Garlick, 1967; Whyte and Green, 1971) than in the argillite orebodies, although certainly effective in the latter also (Mendelsohn, *in* Mendelsohn, 1961, p. 124).

At places, during deposition of the RL 6 and its equivalents, Basement paleohills were the depositional sites of stromatolitic carbonates. These algal mounds, although not totally depleted in copper, are not generally of ore grade. Arenites and argillites adjacent to the mounds are the sites of rich ore (Garlick, 1964).

4. *Major and minor copper occurrences are stratiform and correlate throughout the Copperbelt.* In figure 4 are shown copper graphs of seven drillholes from mining and exploration areas in the Copperbelt. Stratigraphic columns and graphs have been drawn on drilled thickness—not true thickness.

Copper values have been truncated at the 500 ppm mark, but orebodies are indicated to distinguish them from lesser geochemical anomalies. The seven drillcores in figure 4 may not be entirely representative of the respective areas: they represent some of the preliminary results of a larger geochemical investigation.

The anomalous copper values can be subdivided stratigraphically in four horizons.

Peak (1): Footwall anomalies occurring in arenites and conglomerates, and not related to Ore Shale mineralization. The two small anomalies at Chambishi and Mwambashi (fig. 4) may correlate with the Chibuluma, Mimbula, Fitula orebodies, the Nkana Footwall orebody, and the deposits south of Kalulushi. However, owing to the somewhat erratic nature of Footwall orebodies, closely-spaced stratigraphic and geochemical work is needed to assess the continuity of these anomalous copper values.

Peak (2): This peak occurs in the Ore Shale, and in the ore wackes and arenites northeast of the Kafue Anticline, and may transgress into the immediately underlying Footwall rocks.

The peak is still noticeable even where the copper concentration is not of ore grade or thickness, e.g. Luansobe. Peak (2 A), the "A" Orebody of Mufulira, is here correlated with the lower part of the RL 5, and thus possibly with the Intermediate Orebody at Nchanga.

Peak (3): The peak at, or above, the Glassy Quartzite (Upper Q., Marker Q., T.F.Q.), although never emphasized in previous literature, is probably the best evidence of stratigraphic control of copper distribution. This mineralization attains

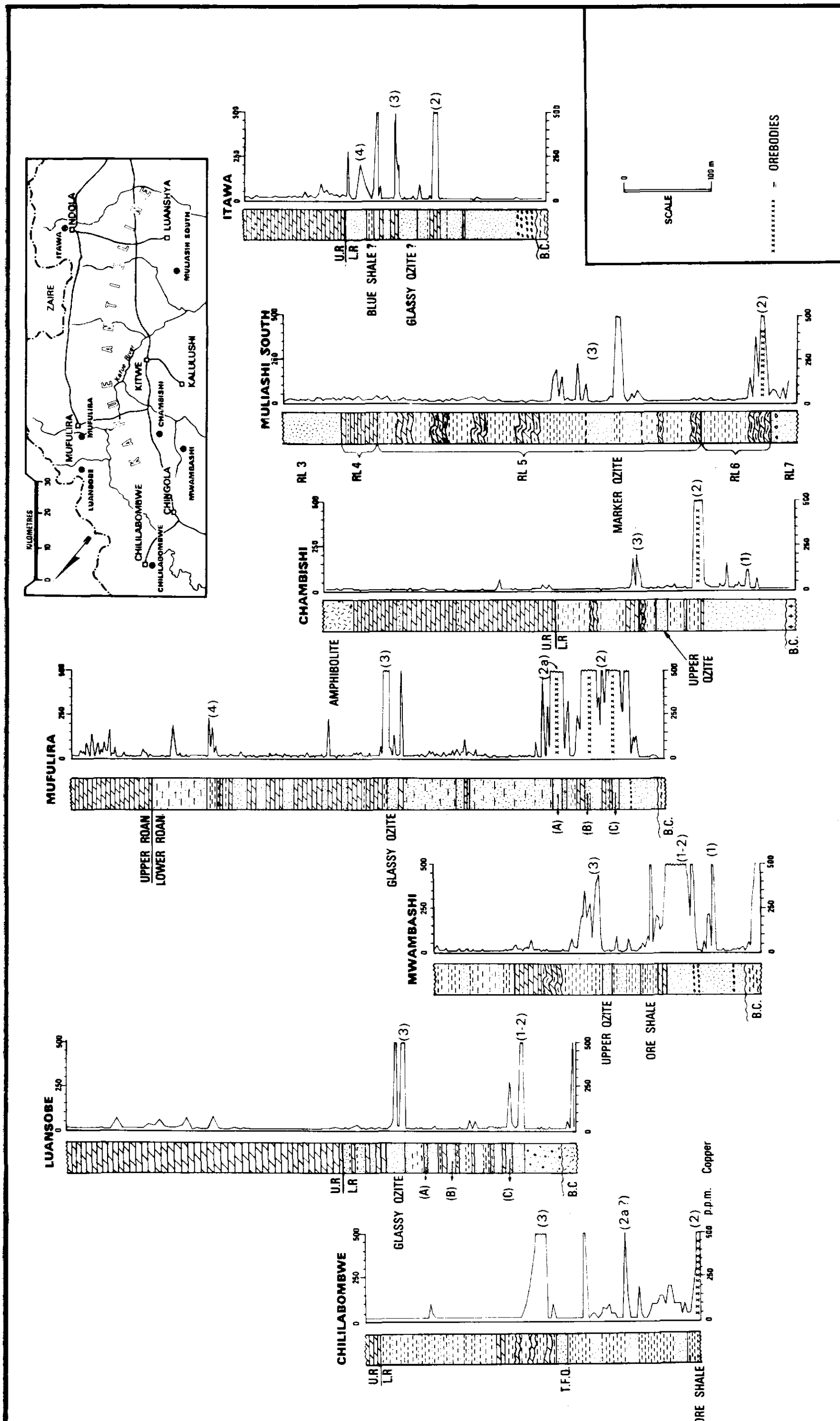

Fig. 4. — Stratigraphic distribution of major and minor copper occurrences in seven drillholes from the Zambian Copperbelt.

ore grade in the Nchanga-Chingola region where it constitutes the Nchanga Upper Orebody. Elsewhere the mineralization consists of a few visible grains of chalcopyrite and has values between a few hundred and a few thousand ppm copper. At Chambishi and Chililabombwe the mineralization is often found in the Cherty Dolomite (fig. 4). In a few exploratory drillholes east of Chililabombwe, where the Ore Shale is not of ore grade, the only distinct mineralization (up to 1 % total copper) is also in the dolomite. Along the whole of the Luansobe-Ndola alignment, the anomaly is confined to the top of the Glassy Quartzite and overlying argillite, and it is so persistent that it is used by the Mufulira geologists as a stratigraphic criterion for the identification of the Glassy Quartzite and Lower Intermediate Dolomite.

Peak (4): At places, anomalous copper values have been detected in the uppermost subdivision of the Lower Roan, the RL 3 and its equivalents. Unfortunately not enough information is available on these anomalies and on their exact stratigraphic position.

At Mufulira and in the Ndola area, anomalously high copper values are known to occur in the Blue Shale and in the argillaceous and dolomitic quartzites associated with it. In a small area at Mwambashi, copper mineralization has been encountered in a carbonaceous argillite which could be the equivalent of the Blue Shale. At Lufubu North, northwest of Luanshya, there is a small pocket of mineralization with values up to 1.5 percent total copper in interbedded arkose and argillite a few metres above the RL 3/RL 4 contact.

MESOSCALE

Local factors, not all of which are necessarily stratigraphically significant, are also responsible for finer variations in the distribution of copper at individual mines.

The Ore Shale Orebodies

Chililabombwe (Bancroft) and Musoshi. — At the northern tip of the Zambian Copperbelt only the Ore Shale mineralization is economic and has been exploited at three shafts: Kirila Bombwe North and South orebodies, and Konkola. At Musoshi Mine in Zaire, 3 km along strike from the Konkola Orebody, the Ore Shale is broadly similar to that of the Chililabombwe region but individual in detail.

At all four localities the Ore Shale is dominantly a silty argillite around 10 m thick but there are fine differences between each property in lithology and mineralization. Lithological subdivision into units of a metre or so has been extended over the North and South orebodies which are separated by a barren gap, probably a bioherm, but at Konkola Orebody only the basal unit (unit A) is recognizable.

This unit is the basal carbonate schist which is usually recognizable throughout the Ore Shale Alignment. At Musoshi, the carbonate schist is missing and the Footwall Conglomerate is overlain by a massive siltstone (orebody unit B of Chililabombwe). This massive siltstone is unmineralized at Musoshi and well mineralized at South Orebody. At North Orebody, there is a gradual transgression of mineralization from near the top of unit B into the underlying unit A, and even into the Footwall, with increasing depth. At North Orebody, changes in mineralization at the top of the Ore Shale are gradual, whereas at the bottom they are erratic and significant over short distances; east of the mine, the mineralization becomes gradually subeconomic as a result of the downward transgression of economic values relative to a stratigraphic marker (Anderson, 1968). Thus while the Ore Shale thickness remains unchanged, the orebody thins by 3 m over a horizontal distance of 650 m.

Nchanga. — The Lower Banded Shale (Ore Shale) constitutes an important orebody about 20 m thick. In the Nchanga-Chingola area, the Lower Banded Shale (L.B.S.) is dominantly a black, carbonaceous laminated argillite similar to the South Orebody facies at Nkana. Details of stratigraphic variations in mineralization are largely obscured by supergene effects, but some general observations can be made. South of the Nchanga-Chingola region in the area of the Chingola open pit, gradual impoverishment in copper is accompanied by thinning of the L.B.S. North of the Nchanga Syncline, the L.B.S. is grey and silty rather than black and carbonaceous and it is generally sub-economic. An important exception in this area is at River Lode open pit where a cupriferous lamprophyre dyke intrudes the Ore Shale. The coincidence of the intrusion with the local mineralization of the L.B.S. may be fortuitous, but the ore is apparently not stratigraphically controlled, and the relationship merits further investigation.

Chambishi. — At Chambishi, the Ore Shale is a silty argillite, rich in carbonate towards the base, sandy at the top. To the west and to the south it passes laterally to a pyritic-carbonaceous argillite. Garlick (*in* Mendelsohn, 1961, p. 281) described sedimentary thinning and changes to sandy facies against two Basement paleohills. A 500 m wide barren gap atop a Basement paleohill separates Chambishi Main Orebody from Chambishi West.

Mineralization in the Chambishi Ore Shale is stratiform and analogous to other deposits along the same belt, but peculiar to Chambishi are barren breccia zones, approximately 10 m wide, that cut across both stratification and folds. The argillite within these zones is intensely albitised and veined. Jolly (1971) concluded that copper, sulphur, and iron minerals in the breccia were replaced by soda and carbonate minerals.

Nkana (Kitwe). — The regional Ore Shale facies change, from silty argillite in the north to black argillite in the south (Annels, 1972), cuts obliquely through the northeastern limb of the Nkana syncline. In the north, at Mindola, the Ore Shale is subdivided in several lithotypes, but copper concentrations do not appear to favour any particular subunit (Jordaan, *in* Mendelsohn, 1961, p. 297). It is noteworthy that higher-grade mineralization occurs near the top of the Ore Shale at Mindola, and near its base at South Orebody. A biohermal barren gap interrupts the continuity of the orebody in silty argillite, with rich ore occurring in the argillite adjacent to the bioherm.

Luanshya. — The vertical and lateral distribution of copper minerals has been described in detail by Mendelsohn (*in* Mendelsohn, 1961, p. 351), and by Lee-Potter (*ibid.*, p. 343) and Vink (1972) for the Baluba area. In summary, two orebodies, both in Ore Shale (RL 6) are mined at Luanshya: an upper orebody in silty argillite in the eastern part and a lower orebody in tremolite-biotite-carbonate schist in the west (Muliashi South). In the tightly folded central part of the mine workings, where the two orebodies overlap, they are separated by a pyrite-rich zone. A barren gap has been described by Mendelsohn (*op. cit.*) in the same general area: the Ore Shale passes laterally to a talcose dolomite that has tentatively been interpreted as a bioherm, although no algal structures have been identified within it (Garlick, 1964). Towards the west, at the fringe of the lower orebody, the upper boundary of economic mineralization transgresses downwards until only the basal part of RL 6 is of ore grade and is overlain by pyritic argillite.

Possibly the step-down of mineralization towards the west should be considered within the context of the regional transition towards the Footwall Orebodies belt. However, Footwall mineralization at Muliashi South and in the adjacent Roan Extension occurs only where the basal RL 6 attains ore grade, and may be the result of later redistribution from the overlying carbonate schist (Binda, 1969*b*).

Wacke and Arenite Deposits East of the Kafue Anticline

The wackes and arenites which are here correlated with the RL 6 and basal RL 5 are the host rocks of several orebodies along the Luansobe-Ndola strike. Of these only Mufulira is discussed briefly.

The stratiform nature of the Mufulira copper deposit, with three superimposed and discrete orebodies in metasandstones, has been emphasized in several published accounts. Each of the three ore horizons represents the beginning of a transgressive cycle (Maree, 1962). The lowermost of these orebodies ("C") extends for a strike length of approximately 5 km, with a 400 m wide barren (pyritic) gap over a Basement paleohill. The hangingwall of this orebody shows remarkable stratigraphic control: with the exception of a small area in which "C" and overlying "B" orebodies coalesce, the upper boundary of the "C" orebody is marked by a 30 cm thick dolomitic siltstone (Mudseam). The lower boundary and the lateral extent of the ore do not appear to be controlled either by stratigraphy or by lithology. The economic mineralization transgresses lateral facies changes from carbonaceous wackes to well sorted arenites and extends, locally, into the underlying Footwall arenites and conglomerate. At places, the whole of the section from the Footwall arenites to the top of the "A" horizon (see fig. 3) is of ore grade, perhaps the result of diagenetic redistribution of copper minerals (van Eden, 1972).

At the orebody fringes, copper minerals give way abruptly to pyrite to the west and to barren arenites to the east without apparent change in lithology. However, copper concentrations of ore grade are known to occur in metasandstones of the "C" horizon a few kilometres to the northwest of Mufulira. The same general characteristics are to be found in the "B" and "A" orebodies: excellent stratigraphic control on the economic hangingwall, erratic positioning of the footwall, apparent lack of lithologic control over the lateral extent of the ore.

Footwall Orebodies

At all of the mines where the Ore Shale or the correlative ore wackes and arenites are exploited, there are erratic patches of copper ore in the clastic metasediments of the Footwall. Occurrences immediately below the Ore Shale are generally attributable to later remobilization of copper minerals. A zone of oxidation at the base of the Ore Shale occurring locally at most deposits even at great depths, is evidence of late remobilization. However, especially in the Footwall Orebodies belt (fig. 1) there are orebodies that are sufficiently separate from the Ore

Shale, or its assumed position, to be considered unrelated to overlying copper concentrations and possibly deposited during an earlier marine transgression. The stratigraphic distribution of these "separate" Footwall ore occurrences requires more regional study, but the following common characteristics can be mentioned.

(*a*) They show stronger paleotopographic control than Ore Shale deposits, being invariably located near Basement highs.

(*b*) They occur in virtually all lithotypes, from the Basal Conglomerate to the sandstones of the upper Footwall, but not in the large-scale cross-bedded quartzite that Garlick (1967) considers as eolian in origin. At Mimbula, six zones of copper mineralization are recognized by Smit (*in* Mendelsohn, 1961, p. 280) between the base of the Katanga Sequence and the base of the Ore Shale; of these zones, only one, 2 to 10 m thick, has any lateral persistence.

(*c*) They are stratiform but lenticular in shape and relatively small by Copperbelt standards.

(*d*) They are often higher grade than the Ore Shale deposits, e.g. Chibuluma West (Whyte and Green, 1971), and Fitula.

Hangingwall Orebodies

The occurrence of high copper values at correlatable stratigraphic horizons above the Ore Shale and its equivalents has already been noted and illustrated in figure 4.

The Felspathic Quartzite and a few metres of the overlying dolomitic argillite constitute Nchanga's Upper Orebody. It is remarkable that such a continuous arenaceous unit attains ore grade in only two relatively small areas, one on the southern limb of the Nchanga Syncline, the other to the south in the Chingola Syncline.

The Nchanga Intermediate Orebody is a smaller lenticular occurrence, mainly in the Pink Quartzite (fig. 2) and may be correlative with the Mufulira "A" Orebody.

While some of the Hangingwall ore in the Nchanga-Chingola region is regarded as redeposited from supergene solutions, the Upper Orebody shows sulphide mineral zoning at depth which is thought to be primary, and the main copper mineral is chalcopyrite.

MICROSCALE

The accumulation of copper minerals on bedding planes and their even dissemination in the more massive lithotypes have had such large coverage in previous literature as to require only brief mention in this paper.

In the Ore Shale, a distinction must be made between lower carbonate schist and upper argillite. In the carbonate schist it is often difficult to distinguish the original bedding, and the copper minerals usually occur as augen-like blebs, veinlets, and concentrations that rather reflect the metamorphic than the sedimentary history of the rock. In the bedded argillite there are some remarkable concentrations of sulphide grains along bedding planes, whereas in the more massive argillite the ore is evenly disseminated, and the grain size is directly related to that of the rock. Clearly diagenetic in origin are the concretionary spherical bodies a few centimetres in diameter occurring at several localities towards the top of the Ore Shale. Calcium sulphate occupies the centre of the spherules and a thin lining of chalcopyrite or pyrite surrounds it, in contact with the host rock.

The ore-bearing arenaceous rocks display some spectacular concentrations of copper sulphides on bedding surfaces. At Mufulira and Chibuluma, Garlick (1967) described accumulations of copper sulphides along bottomset and foresets of cross-bedding, in hollows of ripple-marks, in erosional potholes, and in a variety of other sedimentary structures. The concentration of sulphide grains along the dark laminae of foresets, which are also richer in detrital heavy minerals, in preference to the light laminae, in cross-bedded arenites of the "C" horizon at Mufulira, is suggestive of detrital deposition of the ore minerals (Garlick and Fleischer, 1972). As an alternative explanation van Eden (1972) suggested that the constituents of the dark laminae had a greater chemical affinity for copper circulating in intrastratal solutions during diagenesis.

Attempts to identify the mechanisms of deposition of the ore grains through microscopic examination have so far proved unsuccessful. Original sedimentary textures are obscured by diagenetic and metamorphic reorganization, and the sulphides normally occupy interstitial positions among detrital and metamorphic grains.

DISCUSSION AND CONCLUSIONS

Work which is still in progress has resulted in a revised stratigraphic correlation of the Lower Roan. The RL 3 of Luanshya is correlated with the beds overlying the Cherty Dolomite in the Chambishi-Nkana basin and with the Shale with Grit of Chililabombwe, and not with the Felspathic Quartzite as formerly (fig. 2). The position of the Lower Roan/Upper Roan boundary has been redefined at several localities on lithologic criteria, regardless to the fact that it can be diachronous away from a type section. At Mufulira, for example, the contact steps down stratigraphically towards the southeast owing to the disappearance of the clastic units overlying the Lower Intermediate Dolomite.

Stratigraphic work on the beds underlying the Ore Shale is still in its early stages, and correlation of these clastic lenses may prove difficult owing to their impersistence and local provenance of the materials. The units between the top of the Footwall and the Upper Roan dolomites can be satisfactorily correlated along strike on both flanks of the Kafue Anticline. Correlation across the three belts of figure 1 is possible at a large scale, but uncertain in detail owing to facies changes and to the presence of thick bodies of amphibolite in the southwestern part of the Copperbelt. Correlation of these Late Precambrian metasediments is necessarily lithostratigraphic since time indicators are lacking. Stromatolites and microfossils which have been recorded in Katanga rocks (Malan, 1964; Paltridge, 1968; Binda, 1972*b*, 1973) are still inadequate for detailed biostratigraphy.

Garlick (*in* Mendelsohn, 1961, p. 89; 1969) suggested that the marine transgression during which the Ore Shale was deposited, was checked at the site of the Kafue Anticline before crossing it, and that the Mufulira ore horizons are therefore younger than the Ore Shale. It is, however, more likely that the post-RL 6 uplift correlates and is synchronous with that at the end of the Massive Shale deposition at Mufulira. In this case the Mufulira "C" and "B" arenaceous horizons must be considered as the near-shore facies of the Ore Shale. Thus an important corollary of this correlation is that the stratigraphically more persistent copper occurrences may be time-dependent.

The association of orebodies with transgressions of the Katanga sea has been stressed by several authors (Mendelsohn, *in* Mendelsohn, 1961, p. 125; Maree, 1962; Garlick, 1969). It has been shown in this paper that, not only the orebodies, but also some minor copper occurrences are strongly controlled by stratigraphy (fig. 4). If all copper occurrences, major and minor, are considered within the stratigraphic and sedimentologic framework of the Lower Roan, the following succession of events can be envisaged:

(1) Transgression covering at least the southwesternmost part of the Copperbelt. Copper occurrences associated with this transgression are those of the Footwall, e.g. Chibuluma. The northern extent of this transgression has not yet been investigated: the predominance of continental sediments at Mufulira suggests a limit may have existed to the southwest of this area. The regression closing this cycle may extend to the Footwall Conglomerate.

(2) A transgression which advanced swiftly towards the northeast over the whole of the Copperbelt, depositing the Ore Shale as well as "C" and "B" wackes and arenites of Mufulira. Minor oscillations of the shore line in the paralic zone produced two cycles in the Mufulira area, while in the centre of the basin the Ore Shale sedimentation was continuous. Uplift and regression, with deposition of the Hangingwall Quartzites and Inter-"AB" grits and quartzite closed this cycle.

(3) Transgression and minor oscillations of the shore lines expressed by the alternations of arkose and argillite in the lower half of the RL 5 formation. Ore occurrences associated with these episodes are the "A" Orebody at Mufulira and the Intermediate Orebody at Nchanga. Minor copper peaks in the Hangingwall beds at Chililabombwe (fig. 4) may be related to these cycles.

(4) Transgression beginning with the Glassy Quartzite (T.F.Q., Upper Quartzite), with marine conditions continuing until the top of the Chingola Dolomite (Cherty Dolomite). To this cycle can be attributed the minor but widespread ore occurrences (3) of figure 4, and the Nchanga Upper Orebody.

(5) Local but violent uplift expressed by the coarse clastics of the RL 3 at Luanshya and Konkola, while marine conditions probably prevailed throughout most of the Copperbelt. Local copper occurrences in the Blue Shale, and in the RL 3 at Lufubu North (Luanshya) may be attributed to cycles towards the close of Lower Roan deposition.

Although the primary source of the metal and the mode of its emplacement remain a matter of speculation, the sedimentary model proposed above is an attempt at a regional interpretation of stratigraphic, sedimentologic, and geochemical information up to date. It takes account of the stratiform nature of the ore occurrences, their regional-stratigraphic continuity, and their cyclical recurrence in the Lower Roan.

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