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SEDIMENTARY GEOLOGY OF A LATE PRECAMBRIAN COPPER DEPOSIT AT KITWE, ZAMBIA

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ABSTRACT

A preliminary depositional model is proposed for an orebody in a calcareous mud/carbonate/evaporite sequence of the Zambian *Lower Roan Formation.* A complex of tidal flat, marine and lagoonal lithofacies are described. Copper grades decrease seawards and laterally around sea floor topographic and lithologic features. Ore shoots have a predictable lineation possibly caused by tidal currents. Features indicative of the contemporaneous nature of mineralization and sedimentation are common.

INTRODUCTION

Rokana Division N.C.C.M. Ltd. mine a copper/cobalt deposit at Kitwe on the Zambian Copper belt (fig. 1). Ore is extracted from the deposit by underground and opencast methods for an annual tonnage of 5.7×10^6 tons grading ± 1.8 % Cu.

The ore deposit is stratiform, being confined to the lower two thirds of a 20-30 m thick stratigraphical unit, the *Ore Formation.* The paper is concerned with the sedimentary geology of this unit.

The mine lies on the eastern limb of the Nkana Syncline, a structurally complex south-east extension of the main Chambishi Nkana Basin (fig. 1). Many of the stratigraphical terms in this paper have been developed in the producing mine and do not conform to recommended stratigraphic nomenclature nor are they lithologically precise, e.g. *Porous Sandstone* is mainly a dolomite.

STRATIGRAPHY

The stratigraphy is best described by reference to figure 2. Within the mining area rocks of the *Katanga System* rest on a buried landsurface of *Basement Complex.* Of the four groups within the *Katanga* only the Lower Roan is dealt with in this paper.

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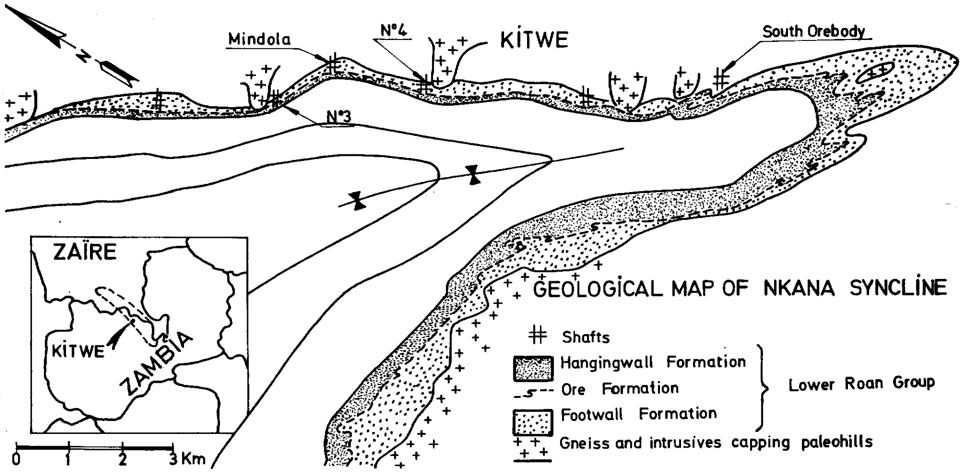

FIG. 1. — *Geological Map of Nkana Syncline showing Lower Roan Group.*

LOWER ROAN GROUP

At Rokana the *Lower Roan* is subdivided into three formations, i.e. *Footwall Formation, Ore Formation, Hangingwall Formation.*

The *Footwall Formation* rests with a marked unconformity on the *Basement Complex.* These generally coarse clastic sediments are interpreted as a fluvial basin infill. It is thickest in the paleovalleys (200-250 m) and often tongues out against paleohills. The sequence contains intraformational conglomerates and at least one unconformity. The first major break in the pattern of deposition is marked by the onset of carbonate rich sedimentation.

The *Ore Formation* commences at this break in sedimentation pattern, the physical expression of which, the *Geological Footwall,* is a marked non-sequence. The underlying coarse clastics are coated by a thin calcareous mud, often displaying oscillation ripples and enclosing pods of evaporites (Ferrodolomite and Anhydrite). Overlapping this plane are the orebody sediments. These are generally a rhythmic sequence of dolomites, calcareous muds, silts and evaporites. Two groups of lithological subdivisions are recognized.

The upper *Hanging wall Formation* is a mixed sequence of calcareous silts, shales, dolomites, anhydrites and coarse clastics. The first clastic band, the *Hangingwall Quartzite,* overlies the *Ore Formation.* The interpretation is of shallow marine and tidal flat evaporites deposition with regular regression due to fluvial sediment input from a northerly source.

LITHOLOGICAL SUBDIVISIONS OF THE ORE FORMATION

The Ore Formation displays marked lateral and vertical facies variation. Two main groups of subdivisions are recognized (fig. 1, *4*).

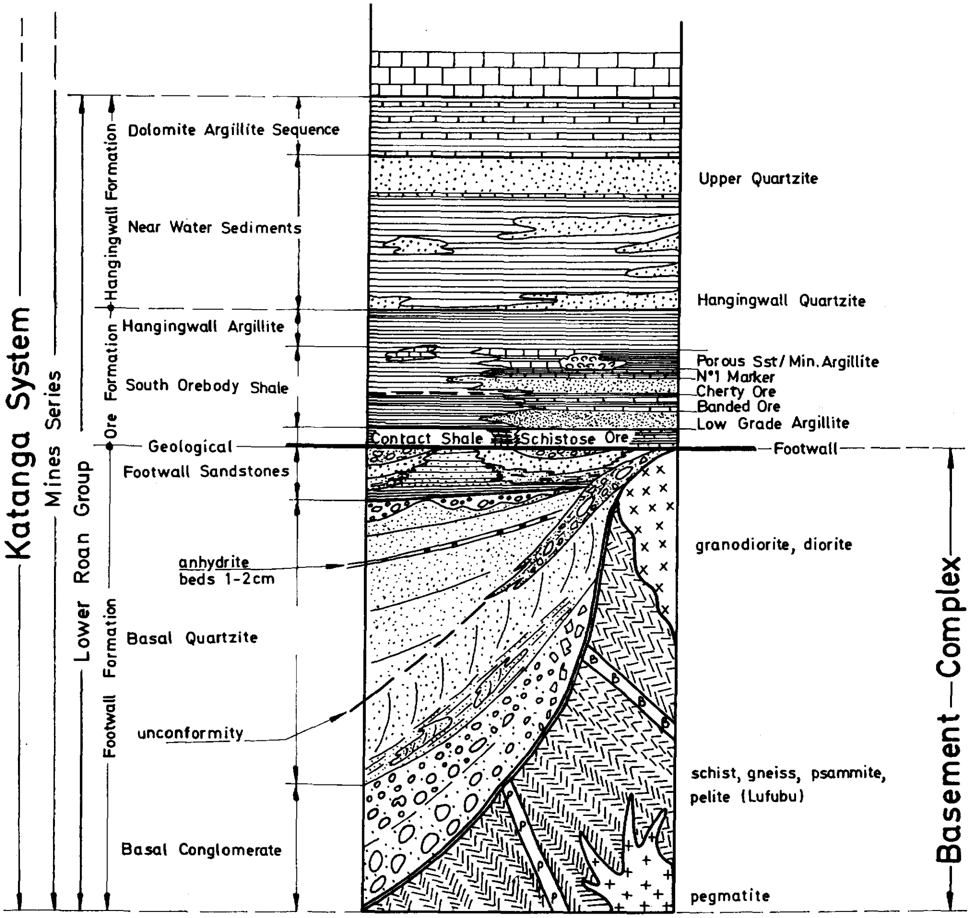

FIG. 2. — *Idealized Stratigraphical Column (not to true scale).*

Mindola Area

This is a cyclical sequence. Units of interlaminated calcareous mud, silt and dolomite alternate with units of calcareous silt; at least nine subunits are recognized.

Schistose Ore

This is the basal unit of the sequence and rests upon the *Geological Footwall.* It consists of thin interbedded dolomites and dolomitic argillites, often flaser bedded. Birds eyes and worm-like carbonate patches are common, often containing regularly ordered ore minerals. The unit is best developed on the southern side of Mindola mine. Northwards the argillite fraction can become more silty and the dolomite banding more diffuse.

Low Grade Argillite

This is a relatively massive, current laminated, calcareous silt with dolomite patches. It becomes more argillitic to the south and down dip. It is the first unit of the sequence to thin laterally and may be absent on the south side of Mindola. The thickest development is in the north.

Banded Ore

This unit is similar to the *Schistose Ore* except that the dolomite/silt banding is coarser and "bird-eye" textures rare. Small scale slumping, load casting and washouts occur in this unit.

Cherty Ore

This is a less calcareous repeat of the *Low Grade Argillite* lithology. Toward the top of the rock dolomite filled subaqueous shrinkage cracks and birds eyes are common.

No. 1. Marker

This unit shows great lateral variation. In the north it is a regularly interbanded

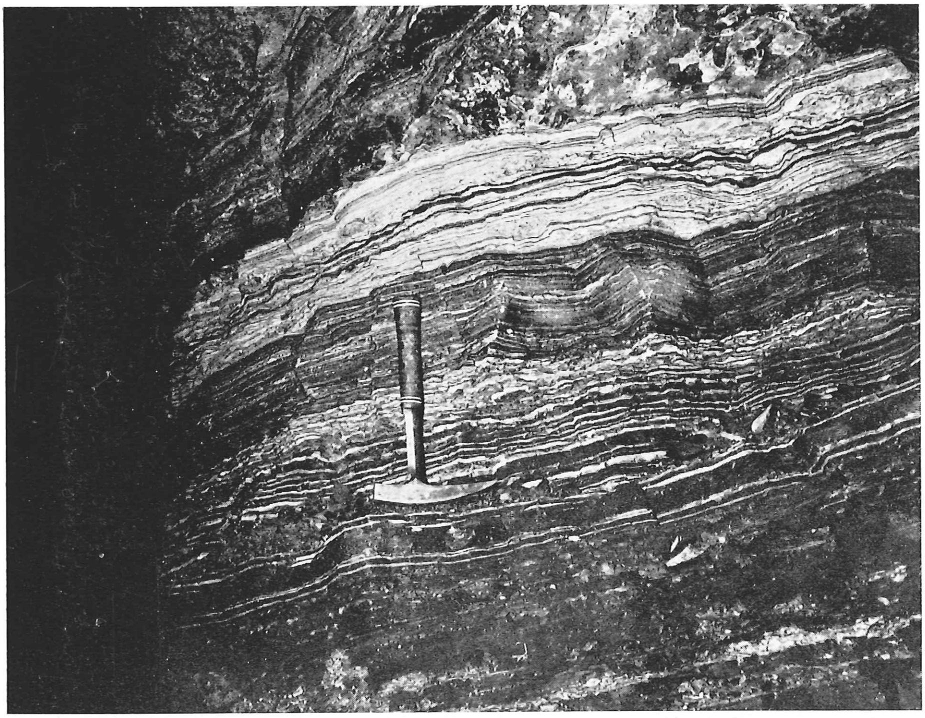

Plate 1. — *Showing the gradual vertical transition from subtidal sediment* (Cherty Ore) *through intertidal (No. 1 Marker) to supratidal (Porous Sandstone). The sharp transgressive contact of the overlying subtidal sediment, to complete the cycle, is in evidence (top left).*

dolomite and argillite rock (plate 1). Southwards, bedded anhydrite begins to appear at the expense of the argillite fraction, the change usually commencing toward the top of the bed (plate 1). Eventually it merges with the overlying *Porous "Sandstone"* to form a dolomite/anhydrite rock. Birds eye structures, desiccation cracking and nodular anhydrite are a feature of this unit.

Porous Sandstone

This unit is the most laterally variable in the Ore Formation. It varies from a massive siliceous khaki dolomite, through dolomite anhydrite rock, to algal dolomite with well preserved growth forms. These algaldolomites vary from individual growth and small bioherms (plate 2) to large bioherms up to 6 m thick. The bioherms are arranged in a zone plunging east-west on the north side of the property. Desiccation cracks, birds eyes, washouts, nodular and bedded anhydrite characterize this unit.

Mineralized Argillite

This is a silty khaki coloured unit, mainly developed on the south side of the mine. Current laminations often enhanced by chalcopyrite "dust" are typical. The unit is often present as washout infillings and thin beds associated with the algal dolomites (plate 2).

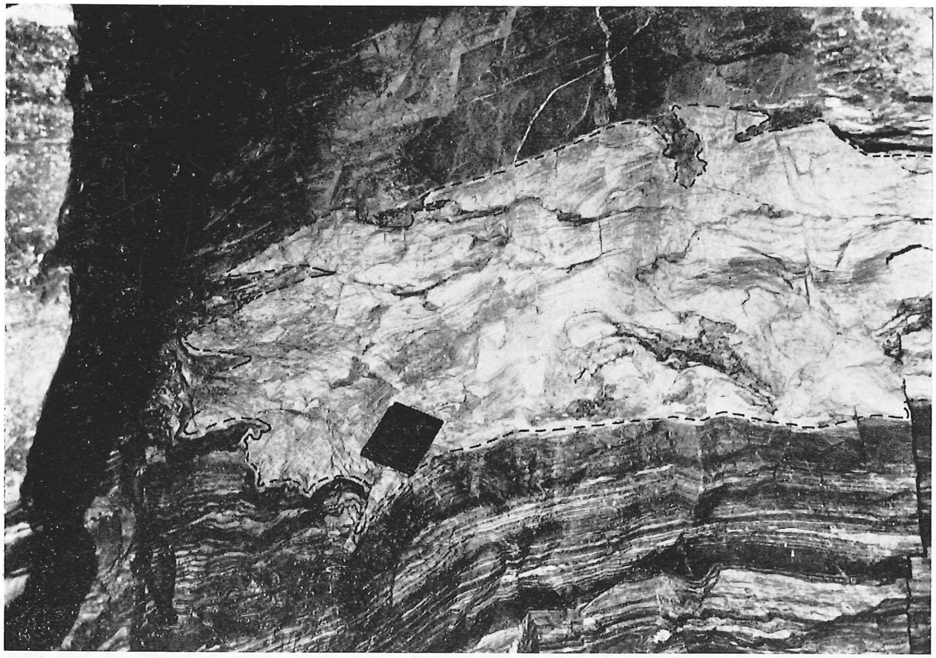

Plate 2. — *A small algal bioherm displaying open growth forms. Base of reef in intertidal (No. 1 Marker) facies top in subtidal (Mineralized Argillite) facies. Note book 15 cm.*

CHERTY ARGILLITE AND DOLOMITE BANDS

This consists of diffuse (1-4 cm) interbeds of siliceous dolomite and silts. It is generally absent from the south side, occurrences in the north being controlled by the presence or absence of the *Porous Sandstone*.

HANGINGWALL ARGILLITE

This unit is not part of the mined "orebody" but is an integral sedimentological part of the "Ore Formation." It is a coarsening upwards sequence of fine clastics. The lower part is often a true shale with very fine (10 to 1 cm) current laminations. This coarsens upwards to a massive coarse silt with rare laminations. In some areas a silt grade "arkose" is developed. Sedimentary features include small scale washout infilling, wispy small scale cross stratification and nodular anhydrite.

South Ore Body Area

The following units comprise the type lithological assemblage (fig. 4).

CONTACT SHALE

This is the lowermost member, resting on the *Footwall Formation.* It comprises interlaminated dolomites and argillites and is regarded as the lateral equivalent of the *Schistose Ore* of the Mindola area. The main lithological difference being the more carbonaceous nature of the muddy interbeds.

SOUTH ORE BODY SHALE

This is typically a blue black carbonaceous shale, comprising a lower banded and an upper more massive unit. Dolomite is common as veins, flasers and laminae but tends to decrease upwards. The main lateral variations are due to less carbonaceous varieties developed in the vicinity of paleohills and dolomitic "Barren Gap" (q.v.) areas.

HANGING WALL ARGILLITE

This unit is a grey pyritic silt with current laminations (*cf.* Mindola).

MINERALIZATION

The main ore minerals of the deposit are *chalcopyrite, bornite* and *carrollite.* Pyrite is very common often in association with the *chalcopyrite.* Other copper minerals present include chalcocite, native copper and, in the near surface zone, a range of copper carbonates, phosphates and silicates. It is not the purpose of this paper to deal with the ore mineralogy but to illustrate that it forms an integral part of the primary sedimentary facies distribution and thus, was subject to the same paleogeographical influences, paleoenvironmental controls and diagenetic processes as the host rock. The following points are presented:

(1) Involvement in sedimentary structures such as slumping, load casting, current laminations and washout infillings.

(2) Copper mineralization is antipathetic to receptive hosts such as dolomites and coarse clastics.

(3) Presence of barren bioherms with high copper content in intercalated argillites and washout channel infillings.

(4) Low grade carbonate mats in the *No. 1 Marker* unit with high Cu concentrations in the interbedded argillite.

(5) Marked facies control of mineralization e.g. the *Mineralized Argillite/Hangingwall Argillite* can pass in 2 cm from economic (+2 % Cu) to subeconomic (−0.5 % Cu).

(6) Occurrence of Barren Gaps in the orebody due to topographic facies controls (q.v.).

BARREN GAPS

Described here are four facies assemblages which have a marked bearing on the paleogeographical reconstruction and which exert a detrimental effect on copper grades. They are presented also as further proof of the contemporaneous nature of copper mineralization.

Kitwe Barren Gap (figs. 1 and 3)

This is a fringing "reef" of dolomite around a paleo "Island." The northern fringe displays crossbedded dolomite conglomerates (wave debris). The dolomite interdigitates and then replaces the *Ore Formation* attaining a thickness of some 20 m and is barren or has only traces of copper mineralization. Small argillite pockets within the reef can run to several percent copper. The reefs northern edge is in excess of 800 m long.

No. 4 Shaft Barren Gap (figs. 1 and 3)

This gap starts opposite No. 4 shaft (fig. 2) and plunges south at 30° to meet the Kitwe Gap. The facies replacing the Ore Formation are mainly arkose and conglomerate. The deposit is linear, being some 450 m down plunge and 50 m across. The interpretation is of an offshore bar (Garlick, 1941). The "back bar" facies of sandy dolomite was host to the now worked out Mindola Uranium deposit (Garlick) (fig. 3).

No. 3 Shaft Barren Gap (figs. 1 and 3)

Barren arkose and conglomerates replace the *Ore Formation* as it "shoals" on to a paleohill (Garlick, 1941). It is large in exposed extent forming a triangle with the base at surface being 600 m and the down dip extent some 300 m (fig. 3).

South Ore Body Type Barren Gaps

This term is used to describe a whole suite of barren gaps. They are developed as dolomites, again over paleohills. The dolomite in this type of gap, unlike the Kitwe Gap usually extends into the *Footwall Formation*, the hill never having been exposed during "Ore formation" times. The occurrences of this white dolomite in a sapropel (*South Ore Body Shale*) often with a mantle of less carbonaceous grey shale, is interpreted as carbonate (Algal?) patch "reefs" developed over a sea bed swell. Thus lifting localized areas up into oxygenated environments and away from the muddy sediment bottom.

GRADE TRENDS

Lateral Grade Trends (fig. 3)

During ore reserve calculation a marked down dip decrease in copper grade became evident. The grades were contoured using a bias obtained from paleoslope observations and a pattern emerged of ore "shoots" mainly parallel to the paleo-valley in the footwall. Predictions of down dip grades using this method have been accurate.

It is suggested that this lineation was caused by tidal ebb and flood trends. This point is vividly illustrated by figure 4 where the grades are aligned along circular paths. This tidal flow pattern was probably due to the baffling effect on ebb and flood direction by a reef and an offshore bar (Kitwe Gap and No. 4 shaft gap respectively).

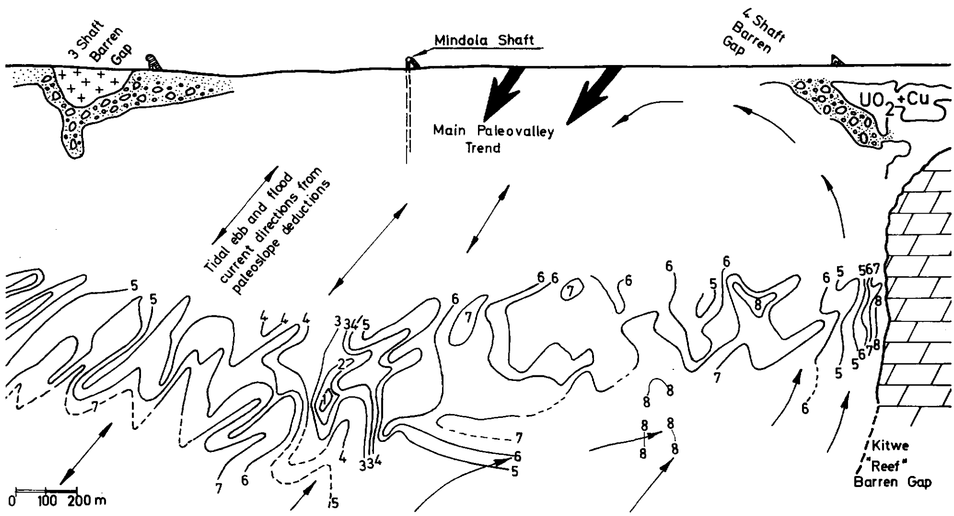

FIG. 3. — *Profile of south side of Mindola Mine showing Barren Gaps, Copper Isogrades and postulated tidal current pattern. Isogrades numbered 1 to 8 in order of decreasing grade.*

Vertical Grade Trends

In the Mindola area the grades tend to increase upwards reaching a marked peak in the *Cherty Ore* then dropping fairly sharply. The *Low Grade Argillite* usually contains the lowest grades. In a *South Ore Body Shale* orebody the distribution, although peaking in *Contact Shale*, shows a more even trend.

FACIES RELATIONSHIPS AND INTERPRETATION

This is best explained by figure 4 (Barren Gaps omitted for clarity). The information on the "West Limb" of the syncline was obtained from drill core only.

It may be noted here that in the Mindola area to the north, the lithologic units often pass down dip into a fairly homogeneous khaki silt with little or no carbonate. Ore body grades show a drastic reduction in this type of facies. The facies has only been mapped north of the zone of algal bioherms.

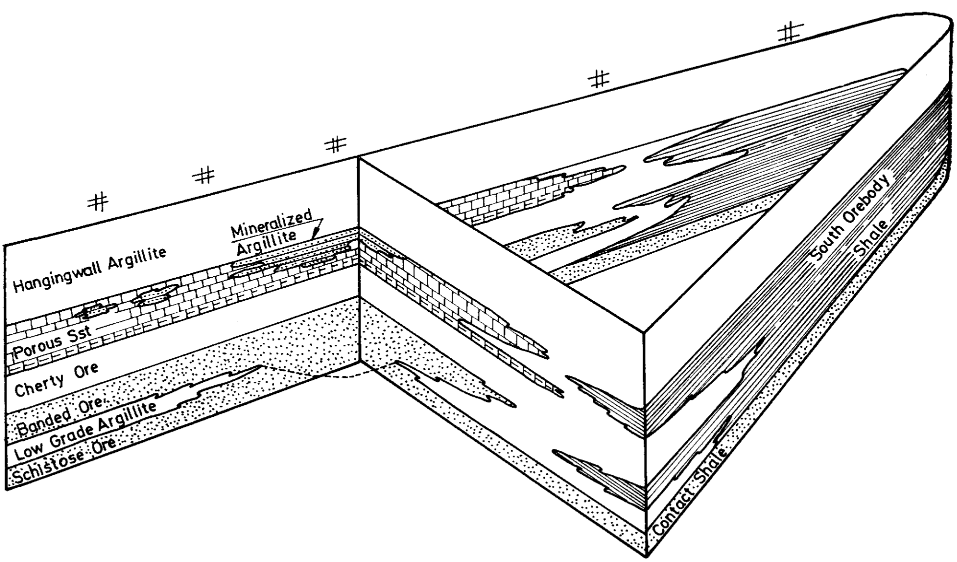

FIG. 4. — *Ore Formation facies relationship diagram of Nkana Syncline (Barren Gaps omitted). Not to scale.*

Mindola Sequence

This is interpreted as a series of tidal flat/subtidal regressive and transgressive sequences. In plate 1, for example, the subtidal *Cherty Ore* has a gradual transition into the intertidal *No. 1 Marker* which passes gradually into the supratidal dolomite/anhydrite (*Porous Sandstone*). The sharp erosive contact of the overlying transgressive subtidal sediment completes the cycle.

South Ore Body Sequence

This sequence is interpreted as having been laid down in stagnant reducing conditions in an area of reduced circulation. The transition through grey shale to dolomite over sea bed swells reinforces this interpretation.

PALEOGEOGRAPHY AND GEOLOGICAL HISTORY

Paleogeography

A picture is emerging of a shoreline to the north-east (up dip) based on paleo-slope deductions and the facies of the 3 and 4 shaft Barren Gaps. At least one major "island" has been indicated by the *Kitwe Barren Gap reef*. The pre *Ore Formation* topography of the syncline east of the Kitwe "Reef" was fairly rugged. It is suggested that this gave rise to an undulating sea floor (viz. evidence of dolomite cappings over buried hills). The climate would have been fairly arid (viz. the evaporite minerals and their sabkha-like mode of occurrence). The sea floor probably always shallow.

Geological History

After a period of mainly fluvial basin infilling, the transgressive sea advanced from the south over a flat expanse of terrestrial sediments. This period produced the *Schistose Ore* and *Contact Shale* intertidal deposit over the whole basin.

The sea continued to transgress during *Low Grade Argillite* times producing the type deposit as a subtidal rock at Mindola. During this time it is suggested that the swell and/or island over which the Kitwe "Reef" was developing asserted its presence and reduced tidal circulation in what was a distal arm of the basin to the east. This produced reducing conditions in the arm and deposition of the laminated *South Ore Body Shale* commenced.

The first regression was marked at Mindola by the *Banded Ore* but this tidal flat did not extend as far over as the West Limb (fig. 4). The Kitwe Reef reached its maximum extent in *Banded Ore* times. Laminated shale continued to be deposited in the South Ore Body "*Lagoon*."

A transgression, marked by the *Cherty Ore* and probably by commencement of massive *South Ore Body Shale* deposition then took place.

The following regression (No. 1 Marker and Porous Sandstone times) was a major one and probably lengthy, allowing the growth of a "bioherm barrier" on the edge of the flat and shelf. This could explain the relationship between the bioherms and the *Khaki Silt* facies. Behind the bioherm barrier, further landward (east) tidal flat deposits and supratidal evaporite sequences were forming. Washout channels in the barrier were filled with marine silts (*Mineralized Argillite*). This barrier broke down first in the south, allowing marine silts to invade the supra-tidal flats in this area giving a semi-lagoonal deposit (*Mineralized Argillite*). Again this flat did not extend to the West Limb but traces of it remain in up dip areas in the South Ore Body area.

A further major transgression then took place during *Hangingwall Argillite* times. An indicated increased energy of environment in this unit may have some bearing on the fact that copper values are reduced to uneconomic levels.

The detailed chemical origins of the mineralization are beyond the scope of this paper but the following comments are pertinent.

(*a*) Copper grades are highest towards the land (east) and decrease away from it (down dip).

(*b*) The alignment of copper grades is in shoots parallel to deducted ebb and flood tidal directions.

(*c*) Sedimentation and mineralization were contemporaneous.

(*d*) Copper grades are controlled by facies distributions.

(*e*) Copper mineralization is antipathetic to receptive hosts such as dolomites and clastics on both large and small scales (e.g. No. 1 Marker).

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