THE INFLUENCE OF ROCK PROPERTIES ON MINING TECHNOLOGY AT DEEP LEVELS AT CHIBULUMA EAST

A dissertation submitted to the University of Zambia, in partial fulfilment of the requirements for the degree of Master of Mineral Sciences.

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DECLARATION

This work is submitted in candidature for the award of the degree of Master of Mineral Sciences. I declare that this work has not been accepted for any other degree and is not being submitted concurrently for any other degree.

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Y C Kalasa
SIGNATURE OF CANDIDATE

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Dr M W Chanda
HEAD OF DEPARTMENT

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ABSTRACT

Field and laboratory measurements of rock properties were conducted to investigate the behaviour of rock masses at Chibuluma East deep levels. Intact rock strength was obtained by point load testing, joint spacing, joint condition, separation of joints and the infilling materials were determined by scan line surveys. Groundwater conditions and rock quality designation were also investigated.

These properties are input parameters for an empirical derivation of the insitu rock mass strength from the geomechanics rock mass classification. Necessary adjustments are allowed to the insitu rock mass strenghth to arrive at the design rock mass strength., The latter provides quantitative data for pillar design, rock support and for the selection of mining methods.,

The footwall Quartzite at Chibuluma East is a good competent rock. The Orebody Quartzite is generally of lower competency, and the intensity of jointing in this rock varies and may thus affect its competency. The Hangingwall Quartzite is also of lower competency and its strength is affected by leaching. The Hangingwall Conglomerate is extremely unstable and any break through it must be prevented.

, it is recommended that Hangingwall Benching and in-stope Scraping method be adopted for the extraction of the Chibuluma East flat area deposit

ACKNOWLEDGEMENTS

I would like to acknowledge the Zambia Consolidated Copper Mines Limited for the Scholarship which supported me during my research.

Additionally, I would like to thank some faculty members. First of all my supervisor Prof. G.N. Boukharov who encouraged me throughout all the stages of my work. Further Dr. W.M. Chanda for his constant interest and for many stimulating discussions and suggestions. I also would like to acknowledge all the other people affiliated with the University who assisted me in one way or another, especially my fellow students F. Mondoka and R. Kamanga.

Finally, I would like to extend special thanks to my wife Kabole, my children Chilufya, Chola, Mwaba, and Hellen for their patience and support throughout the undertaking of this research.

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CHAPTER ONE

INTRODUCTION

1.00 INTRODUCTION

Mining and mineral resource development is one of the primary activities on which our civilization is based. In times of rich resources and cheap energy the extraction of these resources was carried out without regard to energy and resource wastage. Those days are gone and society must now address the problem of securing a supply of essential minerals in an economically and environmentally sound manner. A philosophy must be developed in which the total composition and behaviour of the orebody and country rock is identified and individual components classified into valuables, hazardous and inert categories.

To get a realistic idea of the orebody and country rock behavioural impact on ore extration, an area of Chibuluma East with a potential for Copper-Cobalt mining is considered. Of paramount importance are the ground conditions prevailing at current deeper mine excavation levels.

Nkana Division owned by Zambia Consolidated Copper Mines (ZCCM) Limited operates five independent but adjacent underground mines, namely. **Mindola**, Central, South Orebody, Chibuluma West and Chibuluma East. Production at Chibuluma mine is derived from two separate orebodies (West and East) about three Kilometres apart.

Chibuluma East operating since 1956 produces 30,000 tonnes of ore per month. The ore is produced from a gently inclined tabular deposit. The host rocks are sericitic quartizites of slightly variable composition containing scattered pebbles and Conglomerates. These sediments occur around the base of the Lower Roan Group of the Katanga Super Group, and are underlain unconformably by the older Basement Complex.

The Copper mineralization consists of disseminated chalcopyrite, bornite and chalcocite. Pyrite is an essential secondary mineral and is the main source of cobalt at Chibuluma. The ore formation is everywhere overlain by the hanging conglomerate which is an important aquifer.

Overlying the hangingwall conglomerate unit is the Upper Roan Group which consist of considerable thicknesses of dolomite and argillite together with irregular and sometimes large bodies of gabbro (or amphibolites). Important aquifers also occur in this group. The Footwall of the ore formation consists of quartzites of aqueous origin, immediately below the ore quartzites.

This study looks at the influence of rock properties on mining technology at the present deep extraction levels of Chibuluma East. Among the variables which determine and describe the actual complex properties of rock material and the rock mass, limit the usefulness of this method of analysis.

In additional to the use of theoretical and analyical techniques in studying and predicting the behaviour of underground excavations, it is important to use empirical techniques in field and laboratory experimentation. This work further outlines the methods of presentation and analysis of rock properties in terms of observed data and the likely mechanism of rock failure at Chibuluma East. Classification of rock mass conditions surrounding mine excavations into groups of similar behaviour is presented. The importance of establishing a sound understanding of the characteristics of each rock group with respect to mining at depth cannot be over-emphasised.

This study has not been previously undertaken at Chibuluma East.

.10 STRUCTURE OF THE CHAPTERS

Chapter 2 discusses the geological setting and the mining practice of Chibuluma Mine.

Chapter 3 describes the field and laboratory work conducted to investigate rock properties at Chibuluma East deep levels Chapter 4 analyses the influence of rock properties on stope and pillar design.

Chapter 5 illustrates the influence of rock properties on rock support at Chibuluma East deep levels.

Chapter 6 outlines the stoping of the Chibuluma East flat area deposit.

CHAPTER TWO

GEOLOGICAL SETTING/MINING PRACTICE

2.00 GEOLOGICAL SETTING/MINING PRACTICE

2.10 LOCATION OF CHIBULUMA MINE

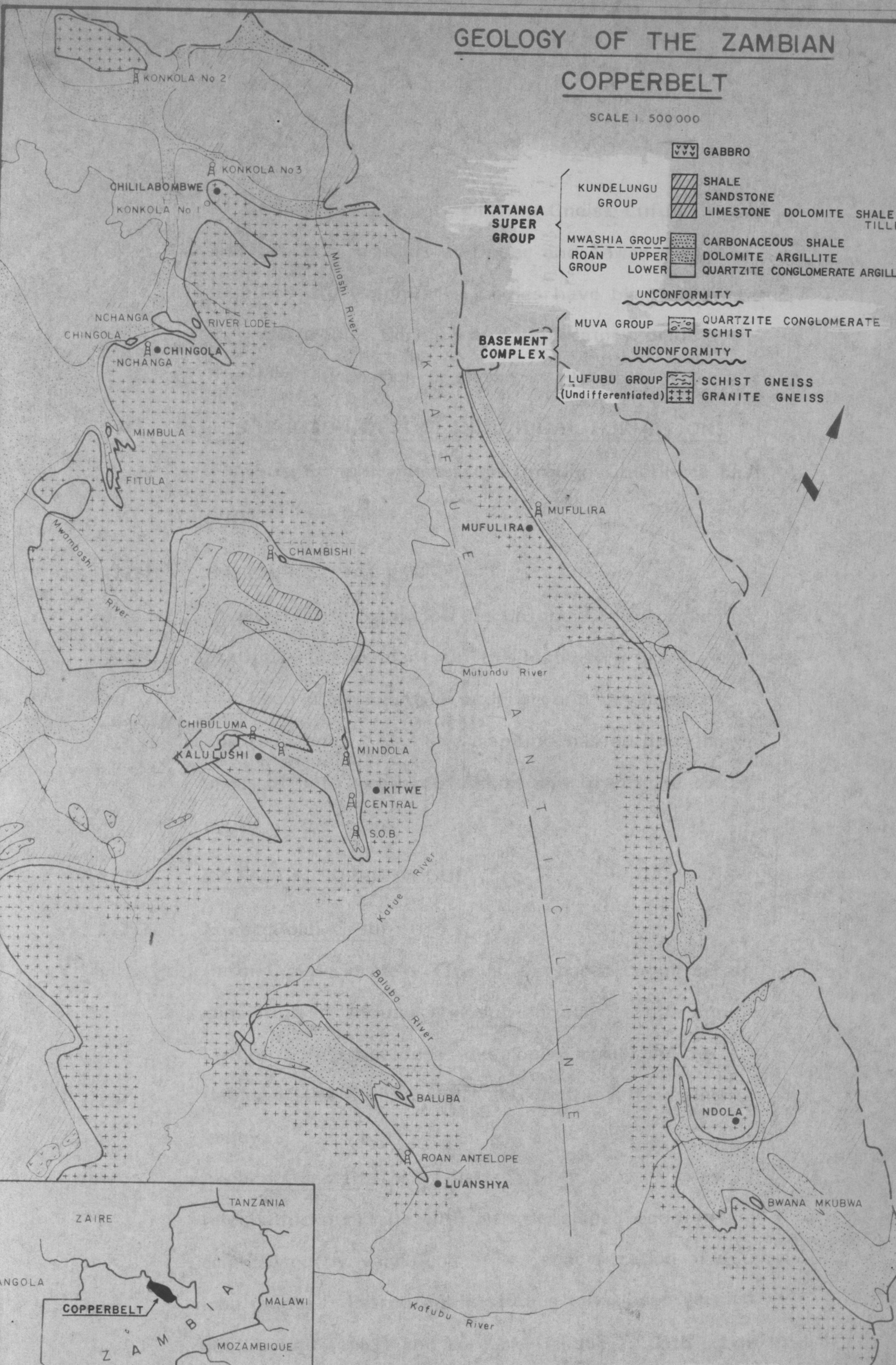
Chibuluma Mine is situated at Kalulushi Township, 15 Km west of Kitwe, the principal town of the Zambian Copperbelt FIG 2.1. The surrounding countryside is flat and is about 1200 metres above sea level. Annual rainfall since records were instituted in 1952 average 1282 mm, most of which falls from October to March, during the remaining months the weather is dry and sunny.

2.20 GEOLOGY OF CHIBULUMA MINE

The general stratigraphy and structure of the Copperbelt and correlation with the stratigraphy of other areas of sub-continent are beyond the scope of this thesis. The writer considered it desirable however that these fields should be discussed briefly in order to present the broad geological setting to which the local Chibuluma stratigraphy and structure can be related.

2.21 STRATIGRAPHY AND LITHOLOGY

The stratigraphy of individual mines and of the Copperbelt in general has been described fully by Mendelsohn (1961) and Fleischer (1976). A broad outline of the Copperbelt geology is shown in FIG 2.1.



GEOLOGY OF THE ZAMBIAN COPPERBELT

SCALE 1 500 000

At Chibuluma East only Granite Gneiss Lufubu Group and Group formations of Upper and Lower Roan, together with amphibolite bodies have been encountered in underground working and exploratory drilling. The local succession is shown in FIG 2.2.

2.22 DESCRIPTION OF THE INDIVIDUAL FORMATIONS

The stratigraphic succession through Chibuluma East is described below.

2.221 BASEMENT COMPLEX

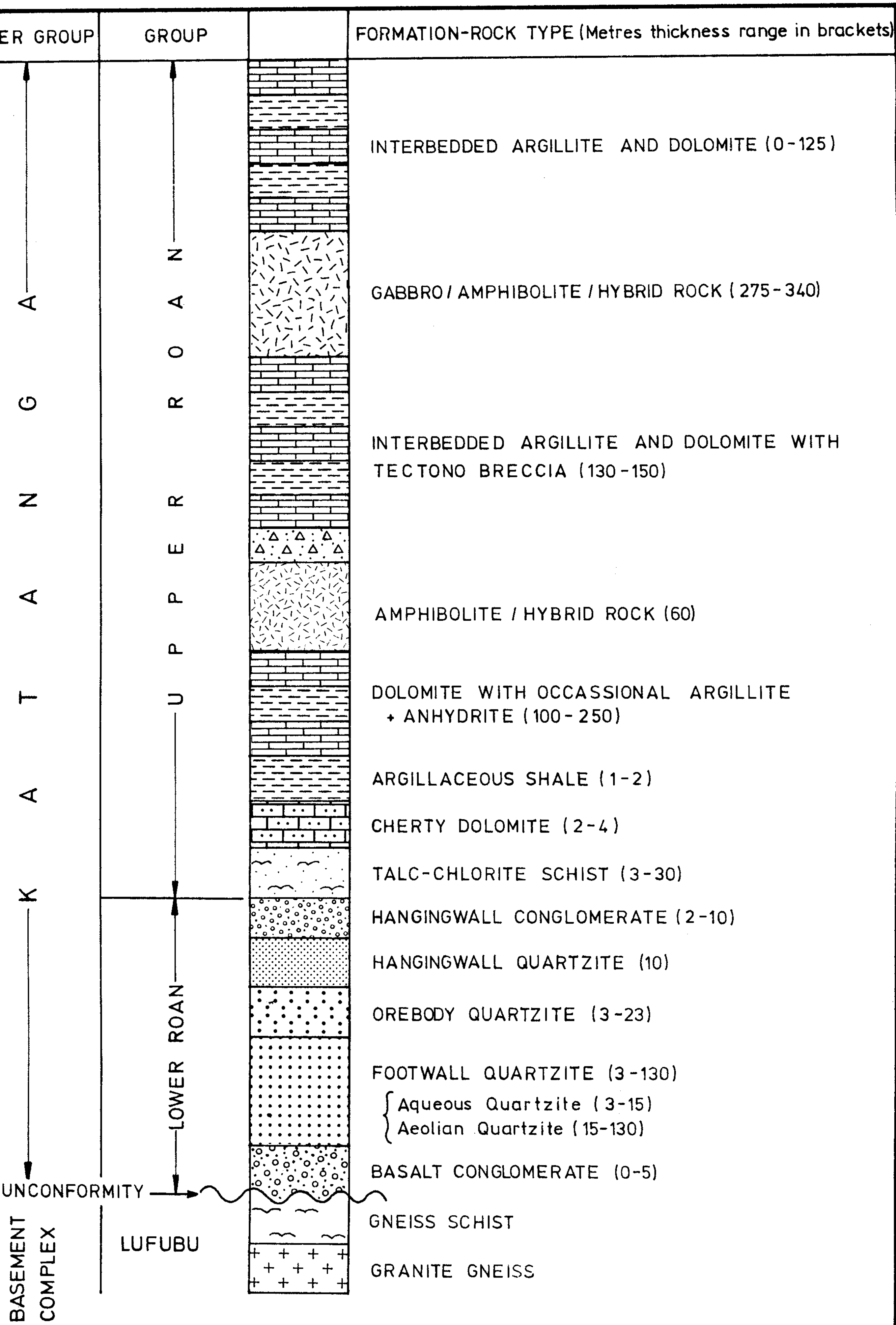
Quartz-biotite Schist of the Lufubu Group occuring as thick roof pendants in the instrusive granite gneiss has been intersected in underground development and drill holes. Surface mapping has outlined large areas of both weathered schist and granite to the south of the mine.

2.222 KATANGA SUPER GROUP

2.2221 Lower Roan Group

Basal Conglomerate - This is a sheared conglomerate consisting of angular and sub-angular granite and Lufubu Schist boulders, developed locally on the flanks of the Katanga hills and in the intervening valleys.

Aeolian Quartzite - This is a grey to dark grey feldspathic quartzite with well developed bedding emphasised by variations in the concentration of detrital iron oxides. Petrographic studies have been carried out by Hall (1963) and Korowski (1984). Both subdivided



GENERALISED STRATIGRAPHIC SECTION THROUGH CHIBULUMA EAST

FIG 2·2

feldspathic quartzite and upper subarkose.

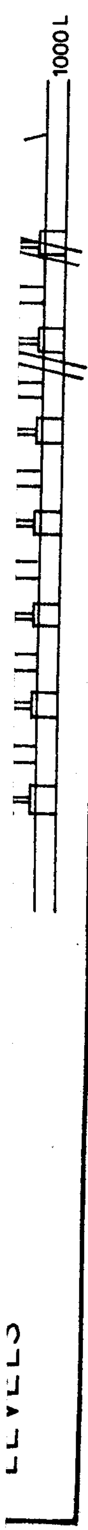
Aqueous Quartzite - Consists largely of coarse arkose with scattered congolomerate bands and inter-bedded with minor shaly horizons. This unit has abundance of tremolite associated with calcite and sphene.

The footwall formation is composed of aeolian and aqueous quartzites.

Ore Bearing Quartzite (orebody Quartzite) - Consists of one or more lenses of chalcopyrite - rich sericitic quartzite intercalated with and enveloped in pyritic albite-quartzite. The contacts between the sericitic and albitic quartzite are gradational and commonly lie within the copperbearing horizon. The quartzite exhibit **blastopsammitic** textures and are commonly cross-bedded. The predominant copper sulphide is chalcopyrite with bornite and chalcocite occuring locally. Cobalt occurs in carrollite and cobaltiferous pyrite, which are commonly confined to narrow bands which lie within and parallel to the main orebody.

Hangingwall Quartzite - This is grey to white poorly bedded rock consisting largely of rounded quartz and albite grains exhibiting blastopsammitic texture. Sericite and biotite occur

FIG 2.5



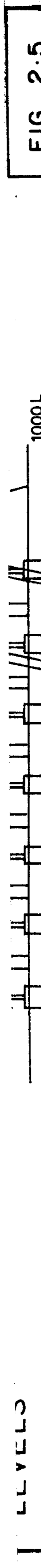
sparsely except in minor argillite bands where they occur with microcline and minor calcite Korowski (1985). Pyrite is common and chalcoprite is less common in the hangingwall quartzite. These minerals are uneconomic in this unit.

Hangingwall Conglomerate - Consists of poorly sorted gritty fragments, pebbles and cobbles of Basement rocks occuring in an albite - quartz - carbonate matrix. Pyrite is the only common sulphide found in the hangingwall conglomerate. This unit is an important aquifer.

.2222 Upper Roan Group

The Upper Roan formation overlying the Chibuluma ore deposit consist of a variety of rock types ranging from almost pure dolomite, through dolomitic shale and dolomitic mudstone to shale and siltstone. Carbonaceous shales occuring in this formation are also of limited distribution. These rock types are randonly intervalated with one another. Regional metamorphism has further diversified the rock types which now include clean dolomitic, marble, scapolite and tremolite bearing dolomite, talcose dolomite and talc-chlorite schist. The Upper Roan Group is

FIG. 2.5

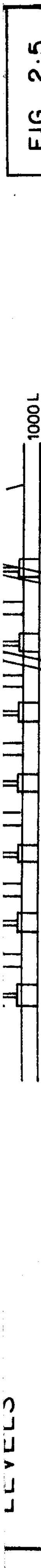


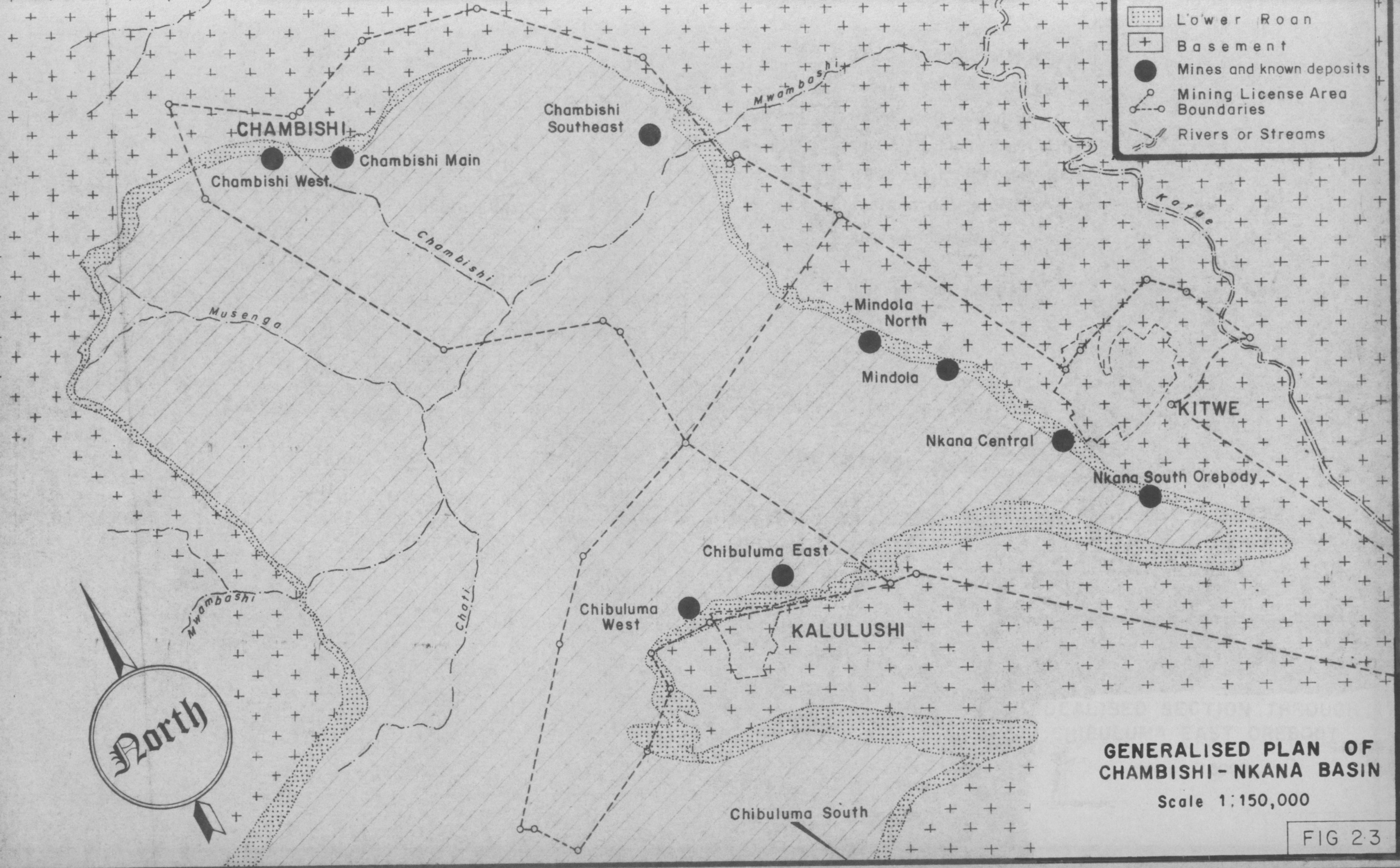
Chibuluma East is located on the Southern flank of the Chambeshi-Nkana basine FIG 2.3. Immediately south of the mine, Basement formation occupy the core of an anticline plunging to the west northwest at a shallow angle.

At Chibuluma East the Katanga Group sediments strike approximately east-west FIG. 2.4. and dip to the north at an average angle of 40 degrees. The dip of the Lower Roan Group is uniform and is affected by only minor undulations. The generalised section through the orebody is slightly concave to the north on all levels possibly as a result of compactional folding in a small depositional basin.

Folding at Chibuluma East is gentle in the arenaceous Lower Roan Group and slightly more severe in the breciated dolomite and argillite of the Upper Roan Group. No major faulting has been recorded in the Lower Roan Group at Chibuluma East.

The present mining level is at 790 metres below surface FIG. 2.4. This is the base of the main Limb and the start of the flat area. In the immediate future, mining will concentrate on the

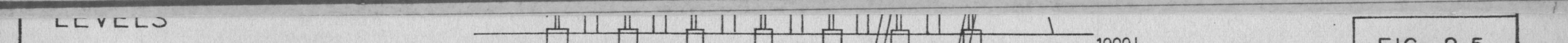




GENERALISED PLAN OF CHAMBISHI - NKANA BASIN

Scale 1:150,000

FIG 2.3



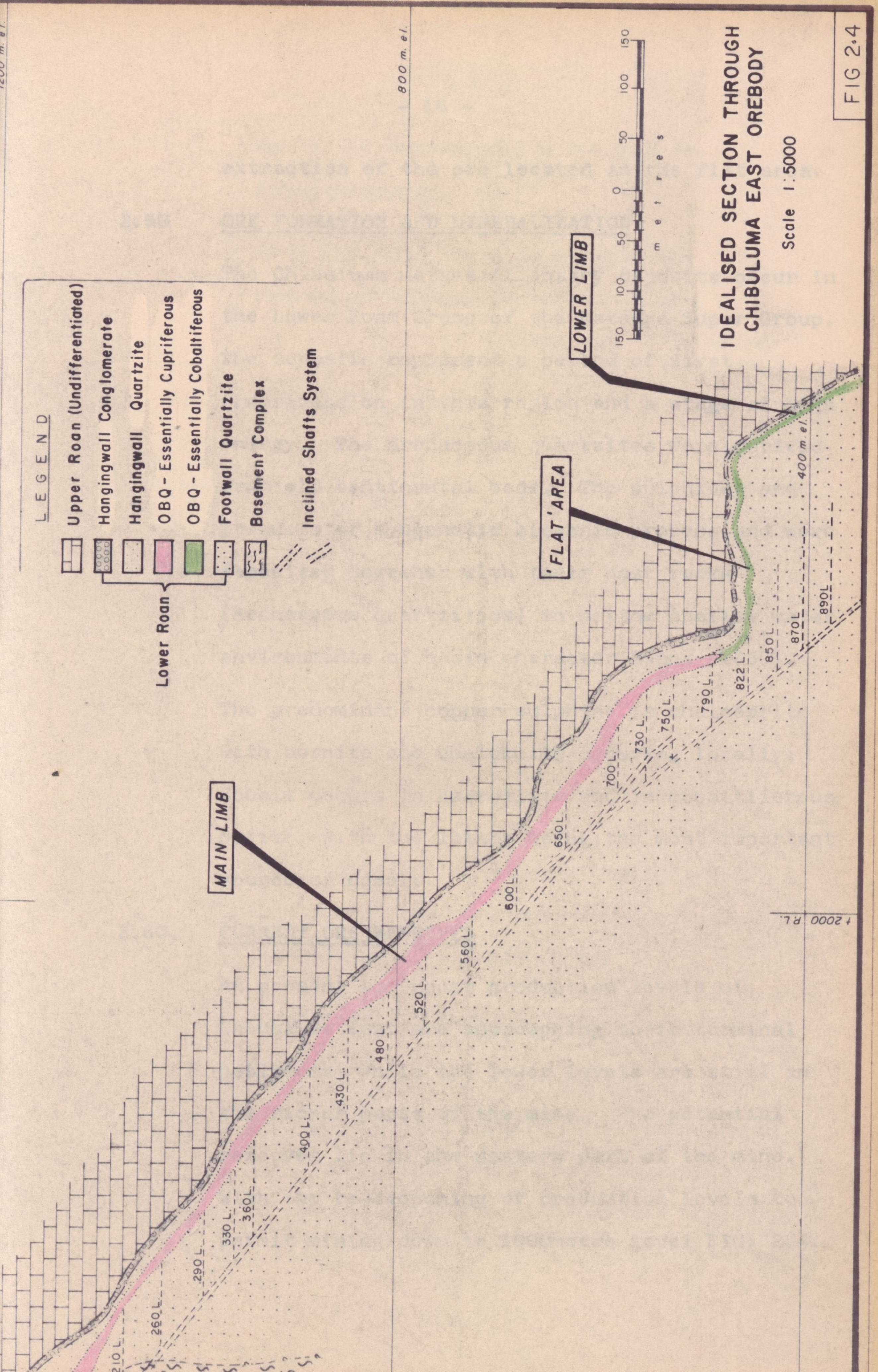


FIG 2.4

IDEALISED SECTION THROUGH CHIBULUMA EAST OREBODY

Scale 1:5000

extraction of the ore located in the flat area.

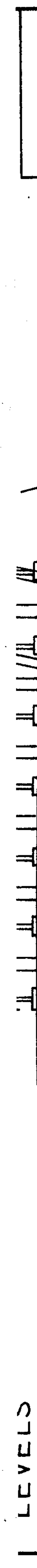
2.50 ORE FORMATION AND MINERALIZATION

The Chibuluma meta-sedimentary deposits occur in the Lower Roan Group of the Katanga Super Group. The deposits represent a period of first transgression in this region and a stage of high energy. The arenaceous quartzites were derived from old continental beds. The sulphides are products of syngenetic biogenic process and were deposited together with their host rocks (Arenaceous quartzities) in bottom shallow water environments of basin character Evans (1980).

The predominant copper sulphide is chalcoprite with bornite and chalcocite occuring locally. Cobalt occurs in carrollite and in cobaltiferous pyrite, with the latter being the most important source of cobalt.

2.60. CURRENT ORE RESERVES

At present the upper production levels of Chibuluma East are approaching their terminal positions, while the lower levels are still in the richer parts of the mine. The potential reserves lie in the western part of the mine. With the re-deepening of production levels to permit mining down to 1000metre level FIG. 2.4.



Further ore reserves will be available for future production.

As at 31st March, 1987, the estimated ore reserves at Chibuluma East are as follows:

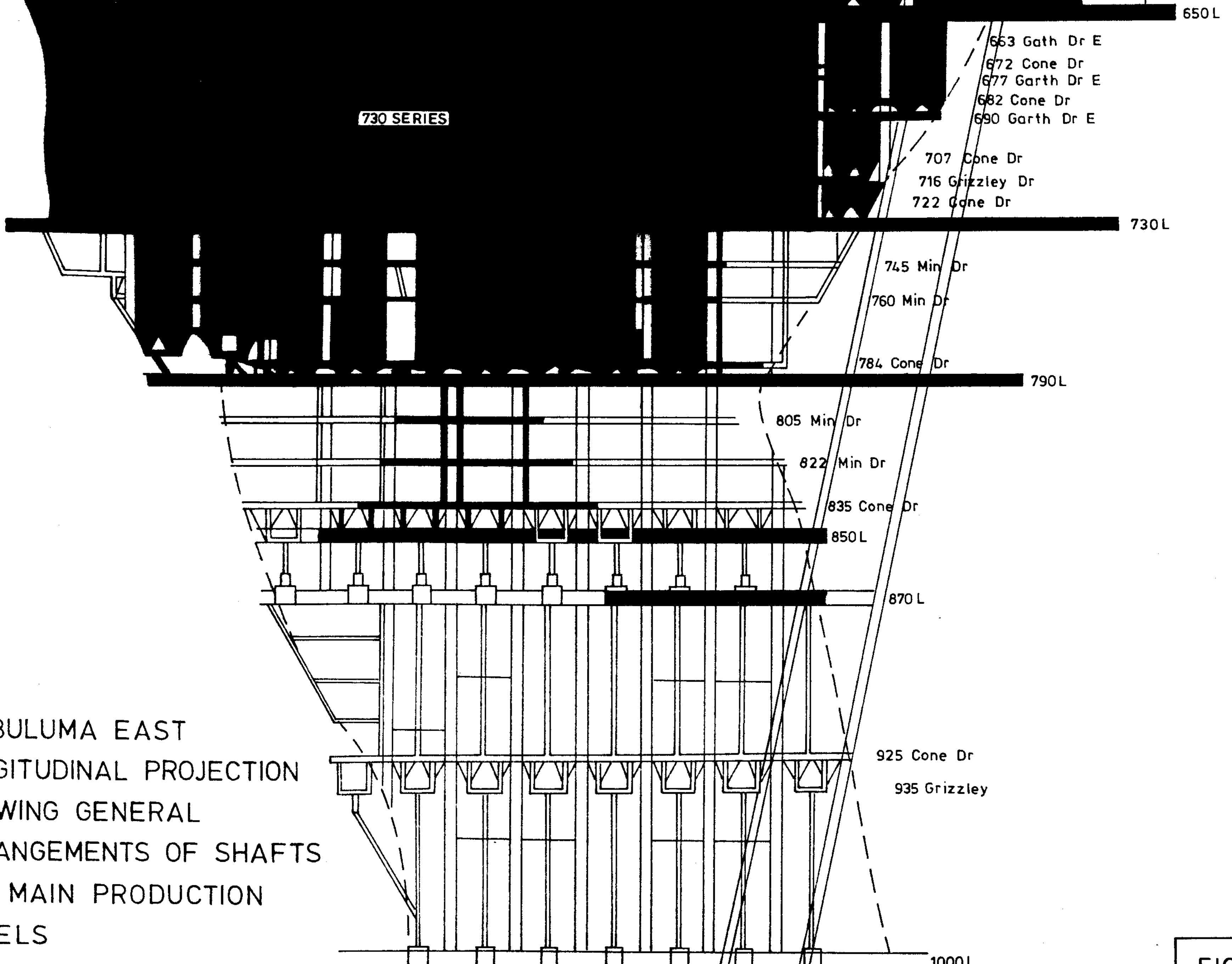
	Tonnage	Percentage Total Copper	Percentage Total Cobalt
Fully Developed	73,000	1.47	0.41
Partly Developed	481,000	2.26	0.29
Indicated and possible ore	2,300,000	1.63	0.29
Total	2,854,000	1.73	0.29

2.70 MINING METHODS

General arrangement of the shafts and main production levels is illustrated in the longitudinal projection FIG 2.5 which shows also present positions of stope faces and lower limits of drilled ore reserves, together with the future five re-deepening production levels below the present 790 metre level.

2.71 SUBLEVEL OPENSTOPING MINING METHODS

Sublevel open stoping methods at Chibuluma East are applied to suit prevailing conditions. In some cases these methods are made applicable with certain modifications. Several



CHIBULUMA EAST
LONGITUDINAL PROJECTION
SHOWING GENERAL
ARRANGEMENTS OF SHAFTS
AND MAIN PRODUCTION
LEVELS

FIG. 2.5

methods have been used, ranging from trailing and benching to cut and fill stoping and to more recently conventional open stoping utilizing hundred millimetre blastholes. Traditionally all open stopes have been back filled with cycloned mill tailing possessing varying percentages of cement addition, using the post-fill technique.

The length of the stope along strike varies from 15 metres to as much as 30 metres depending on geological and geotechnical factors. Normally 3 to 10 metre thick pillars are left between stopes but are extracted as stoping progresses by means of long drill holes, drilled from parallel cross cuts. Sublevels are driven between the upper and lower main haulages at 20 metres interval.

The base of each stope is usually represented by the grizzley levels, where the extraction and sizing of ore takes place. These levels have two parallel crosscuts 15 to 20 metres above the footwall haulage. The cross cuts give access and ventilation to the grizzlies from which gravitational flow of broken ore is controlled.

The main sublevel open stoping, methods applied at Chibuluma East are shown in FIG 2.6.

Presently large diameter blastholes open stoping method is employed at Chibuluma East. FIG. 2.7. This method is suitable for orebodies with a uniform dip at an angle greater than 55° to ensure free running of broken rock.

2.72 DISCUSSION

For viable extraction of the flat area deposit, it requires the adoption in most areas of stoping. mining methods different to those used in the upper levels. Greater emphasis can be placed on selection of mining methods based on a better understanding of caveability of the flat area orebody, so as to minimise dilution of ore and avoid structural damage to pillars.

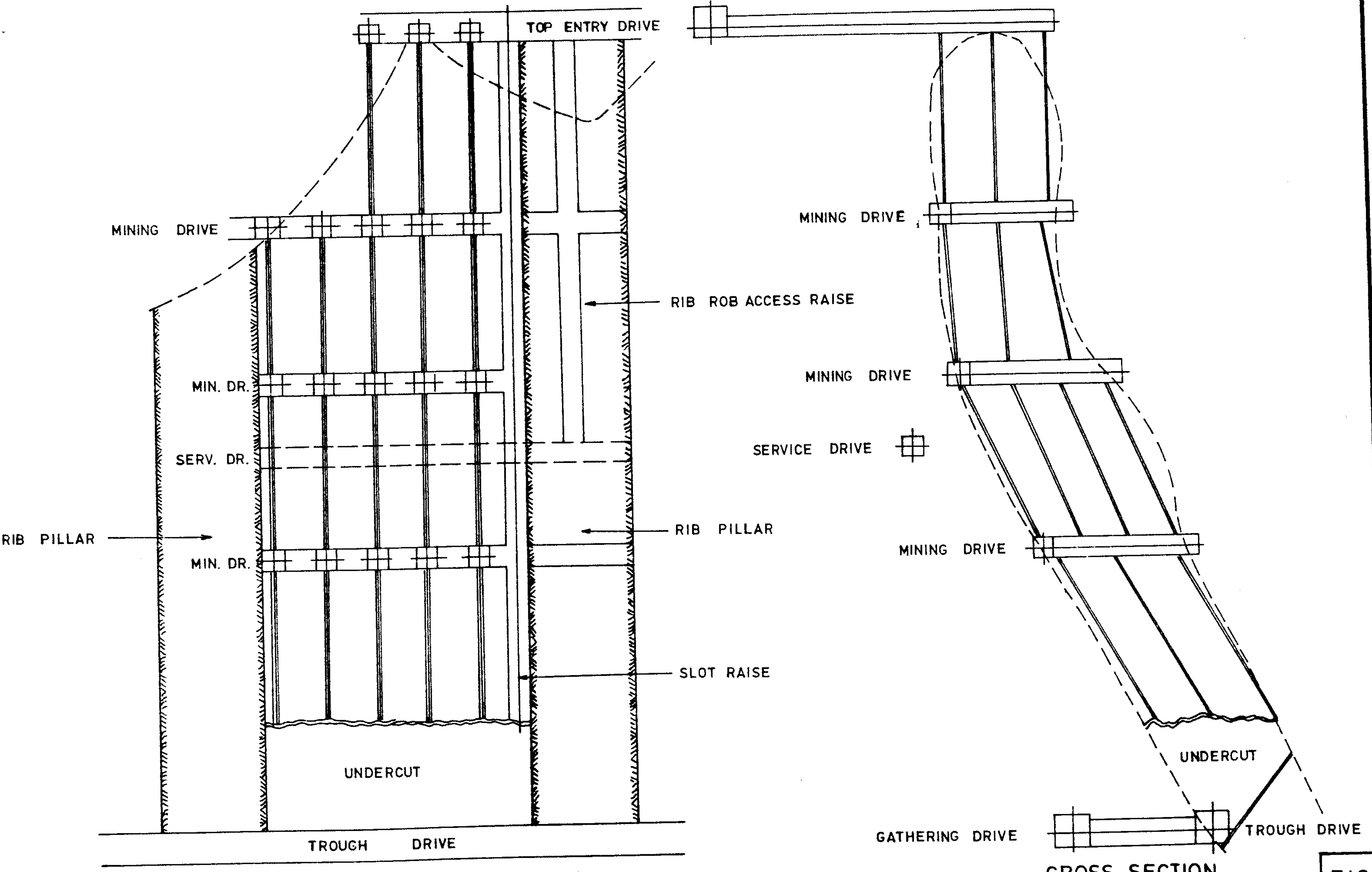
Of paramount importance in this respect are the rock properties of the flat area. Consequently a detailed geotechnical assessment of the rock mass condition of the area is necessary.

SUBLEVEL OPEN STOPING METHODS APPLIED AT CHIBULUMA EAST

VEL tres)	MINING METHOD	REMARKS
TO		
650	– SEMI-SHRINK (OR BACK) STOPING – BENCH AND TRAIL STOPING – CUT AND FILL PILLAR RECLAMATION	
730	– CONVENTIONAL SUBLEVEL OPEN STOPING – TRACKLESS MECHANISED LONGHOLE OPEN STOPING WITH SAND FILL	
790	– CROSS STRIKE-RETREAT UP-DIP DRILL STOPING	
DATE	– LARGE DIAMETER BLASTHOLE OPEN STOPING (LONGHOLE DRILLING) – SHRINKAGE STOPING	METHOD CURRENTLY IN USE METHOD PROPOSED FOR MINING THE BASE OF THE MAIN LIMB

FIG 2·6

CHIBULUMA EAST LARGE DIAMETER BLAST HOLE OPENSTOPING



LONGITUDINAL SECTION

CROSS SECTION

FIG 2·7

CHAPTER THREE

FIELD AND LABORATORY WORK

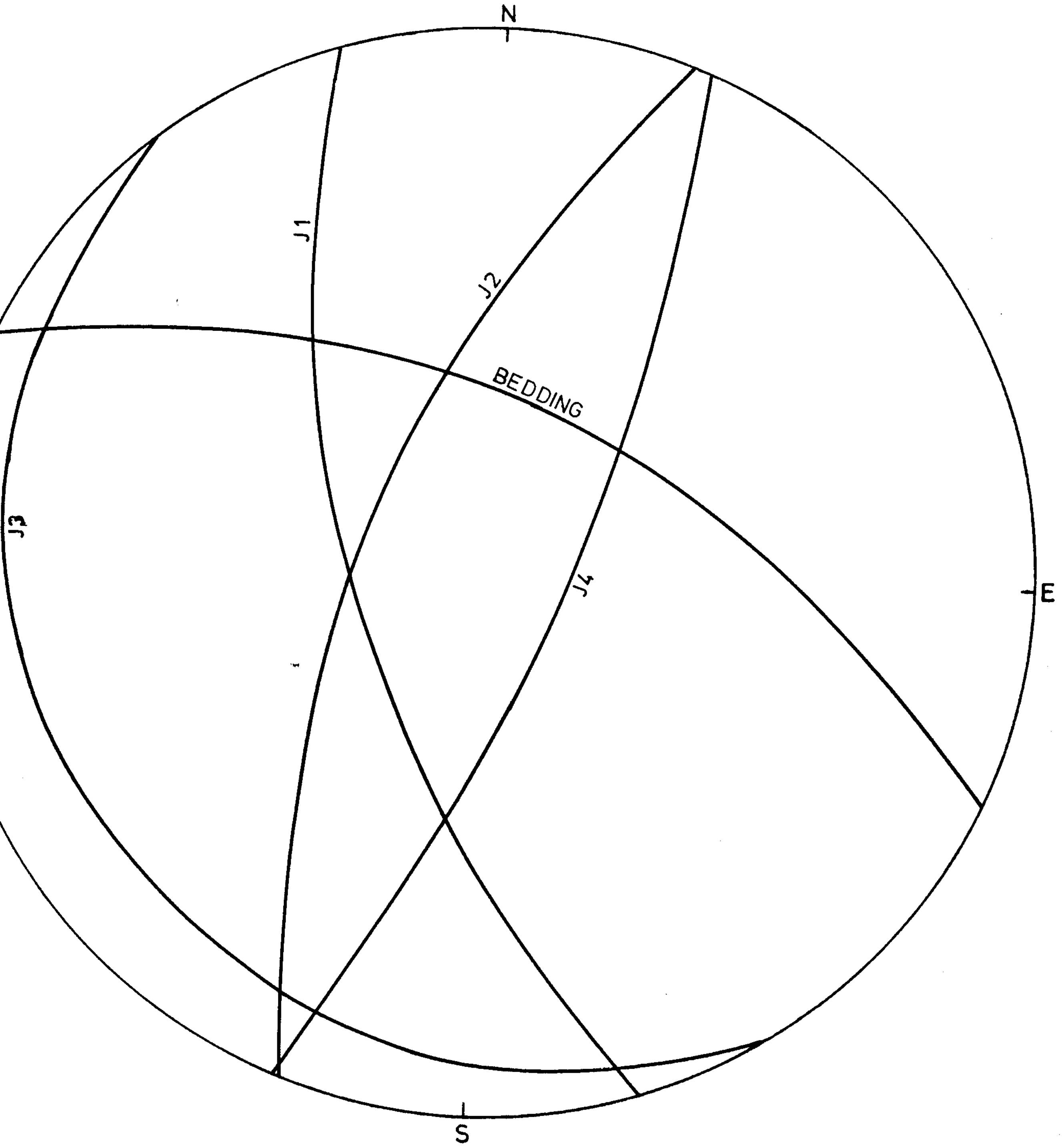
3.00 FIELD AND LABORATORY WORK

3.10 FIELD WORK

Detailed field investigations were conducted and the following rock properties delineated:

JOINT SPACING

Detailed joint surveys were carried out in footwall and orebody developments on the 790, 850 and 870 levels, and the results were plotted using spherical projection techniques, see FIGS 3.1, 3.2, 3.3 and 3.4 which shows stereonets of four independent joint surveys. FIG 3.1 shows the discontinuities measured during a detailed survey of OBQ and FWQ exposures on 790 and 850 levels. Only the prominent joints apparent in different exposures were measured and from this survey the following bedding and joint sets were evident.

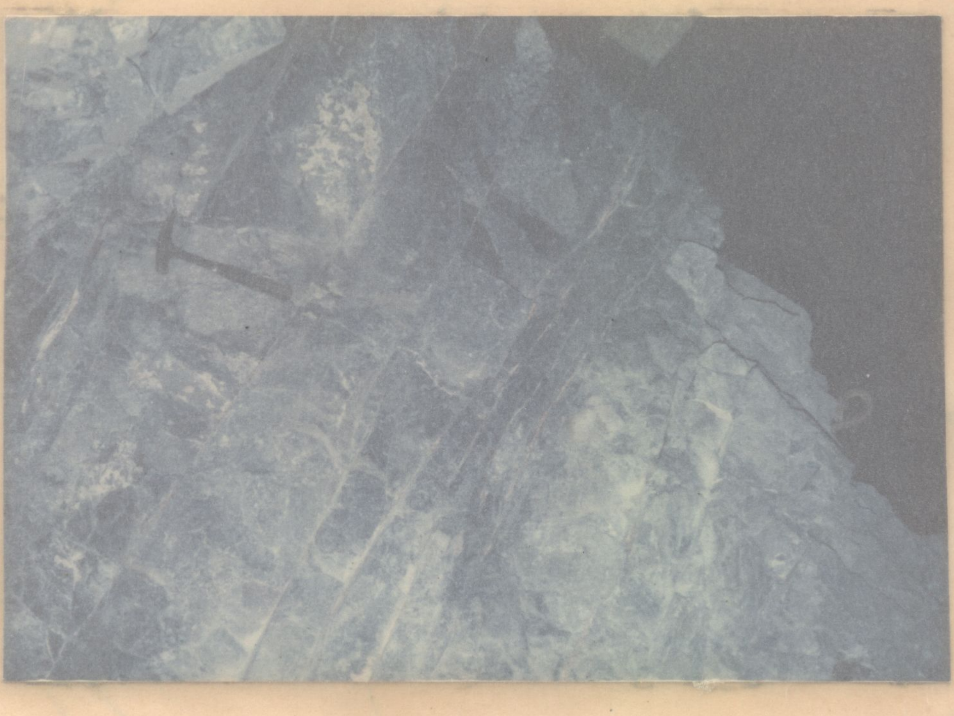


KEY

EDDING	N25/55
J1	N253/62
J2	N300/62
J3	N230/10
J4	N112/74

HIBULUMA EAST MINE: GENERAL JOINT
IRVEY ON 790 AND 850 Levels

FIG 3·1



Westerly dipping closely to widely spaced tight joint sets. Diamond drilling crosscut is noticeable on the right top corner.

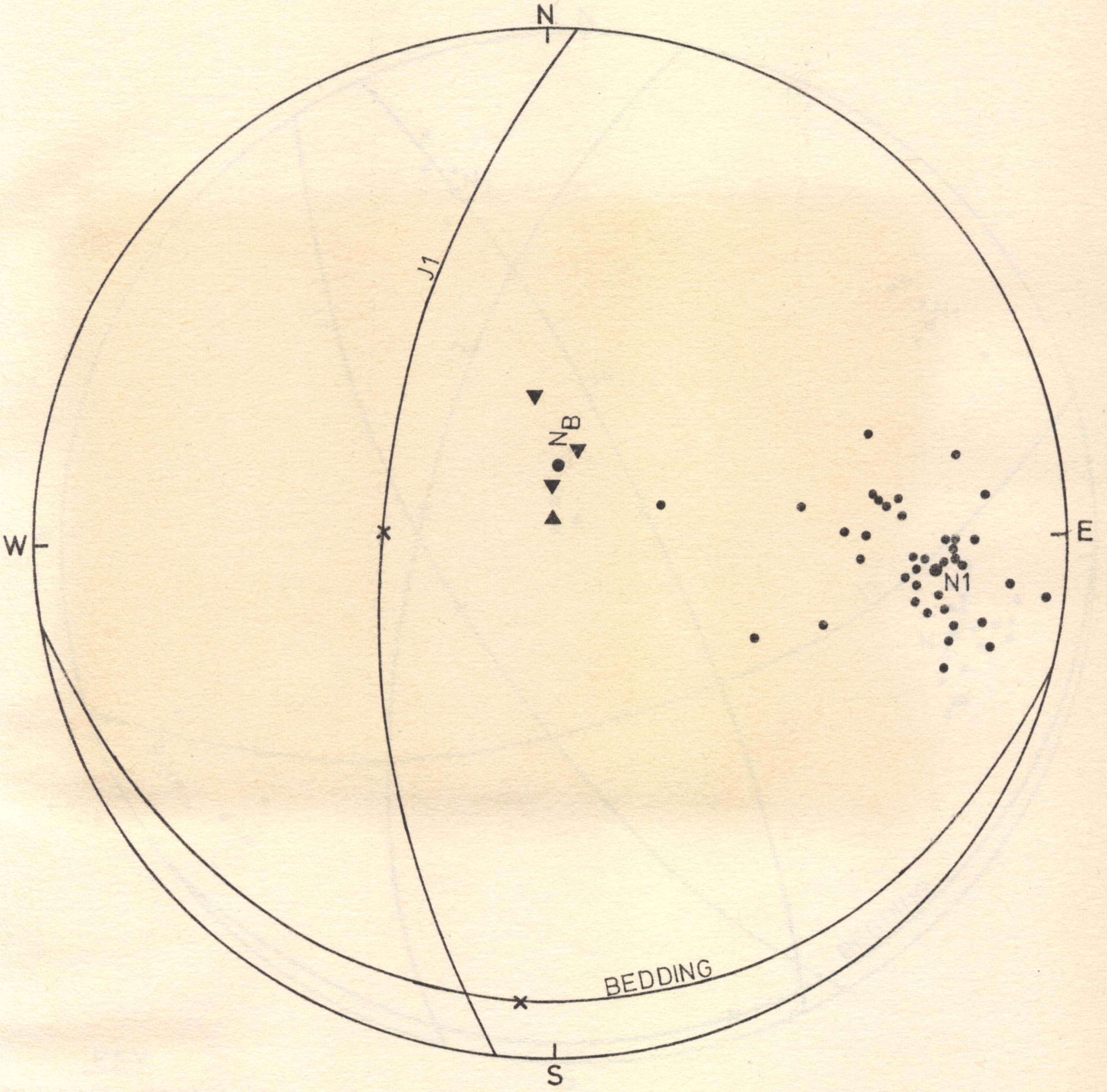
850 GRIZZLEY VENTILATION DRIVE
IN FWQ
150 — SECTION

PLATE 3.1

Westerly dipping closely to widely spaced tight joint sets. Diamond drilling crosscut is noticeable on the right top corner.

850 GRIZZLEY VENTILATION DRIVE
IN FWQ
150 — SECTION

PLATE 3 : 1

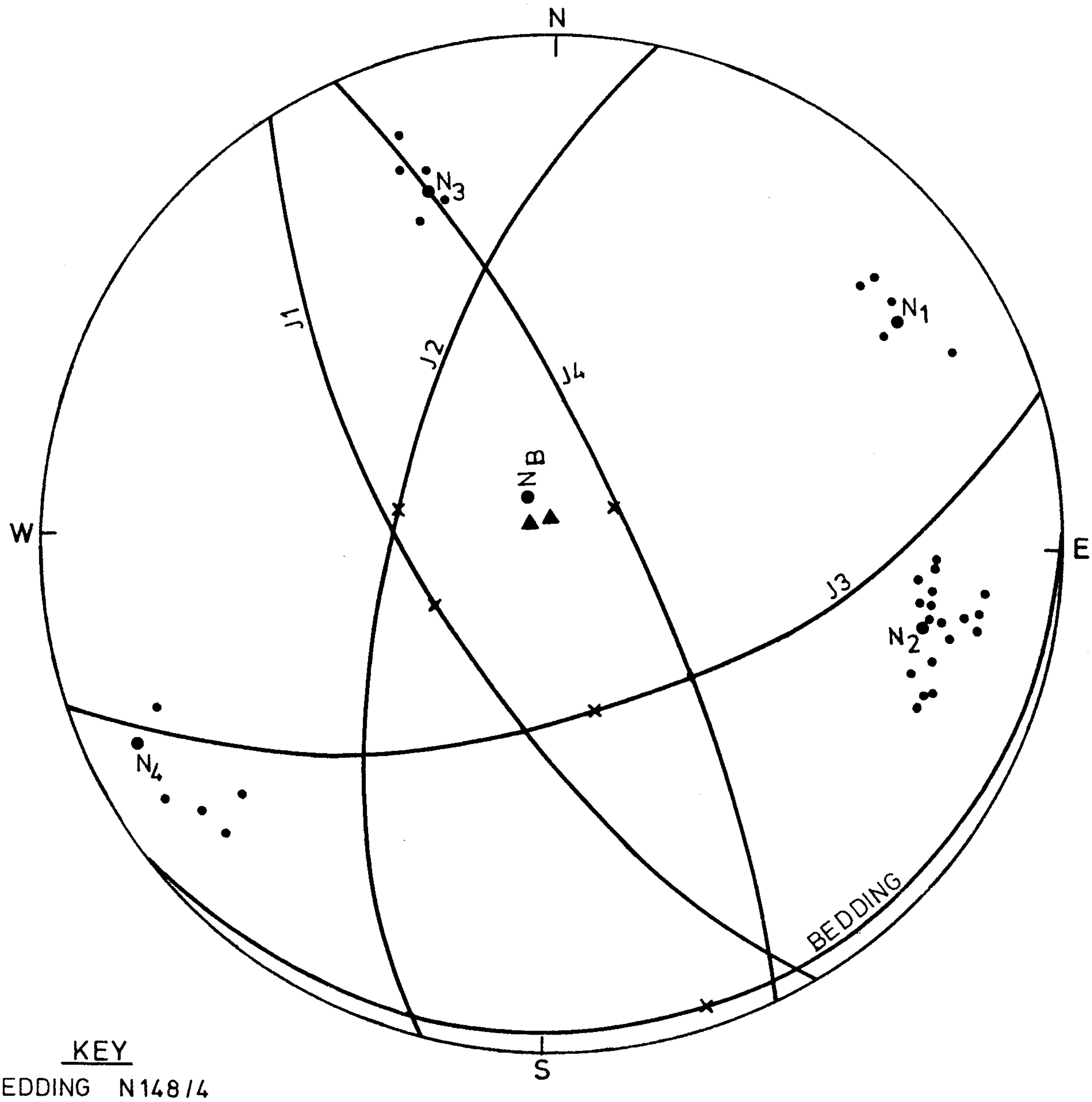


KEY

BEDDING	N 186/14
J1	N 275/62
NB	NORMAL TO BEDDING
N1	NORMAL TO J1

IBULUMA EAST MINE: DETAILED JOINT SUR-

FIG 3·2

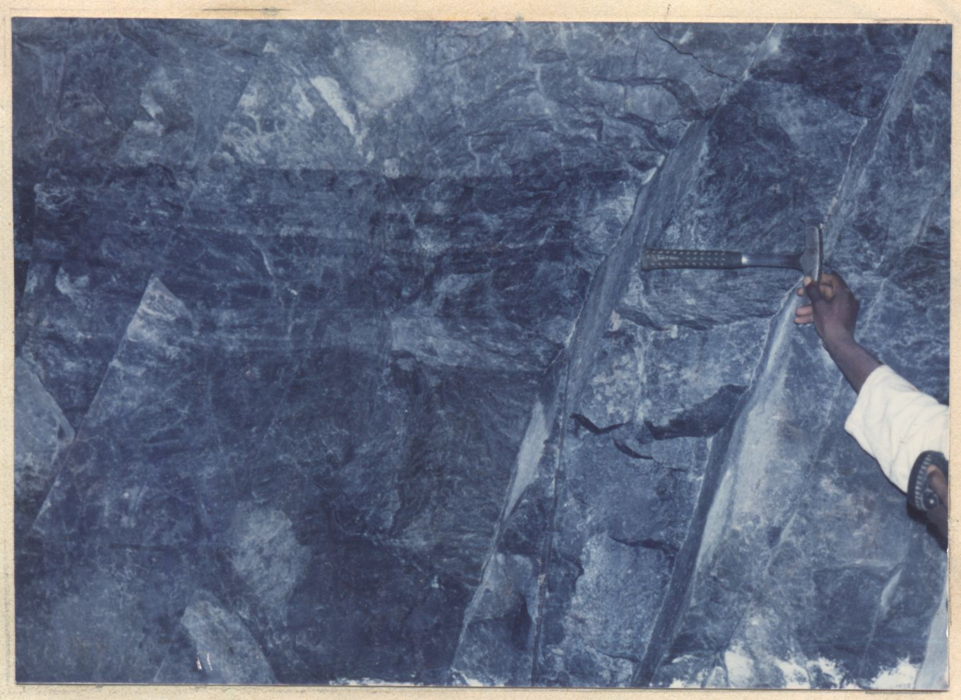


KEY

BEDDING	N148/4
J1	N238/70
J2	N285/64
J3	N160/62
J4	N064/80
NB	NORMAL TO BEDDING
N1	NORMAL TO J1

CHIBULUMA EAST MINE: SCAN LINE
SURVEY IN FOOTWALL HAULAGE ON 370L

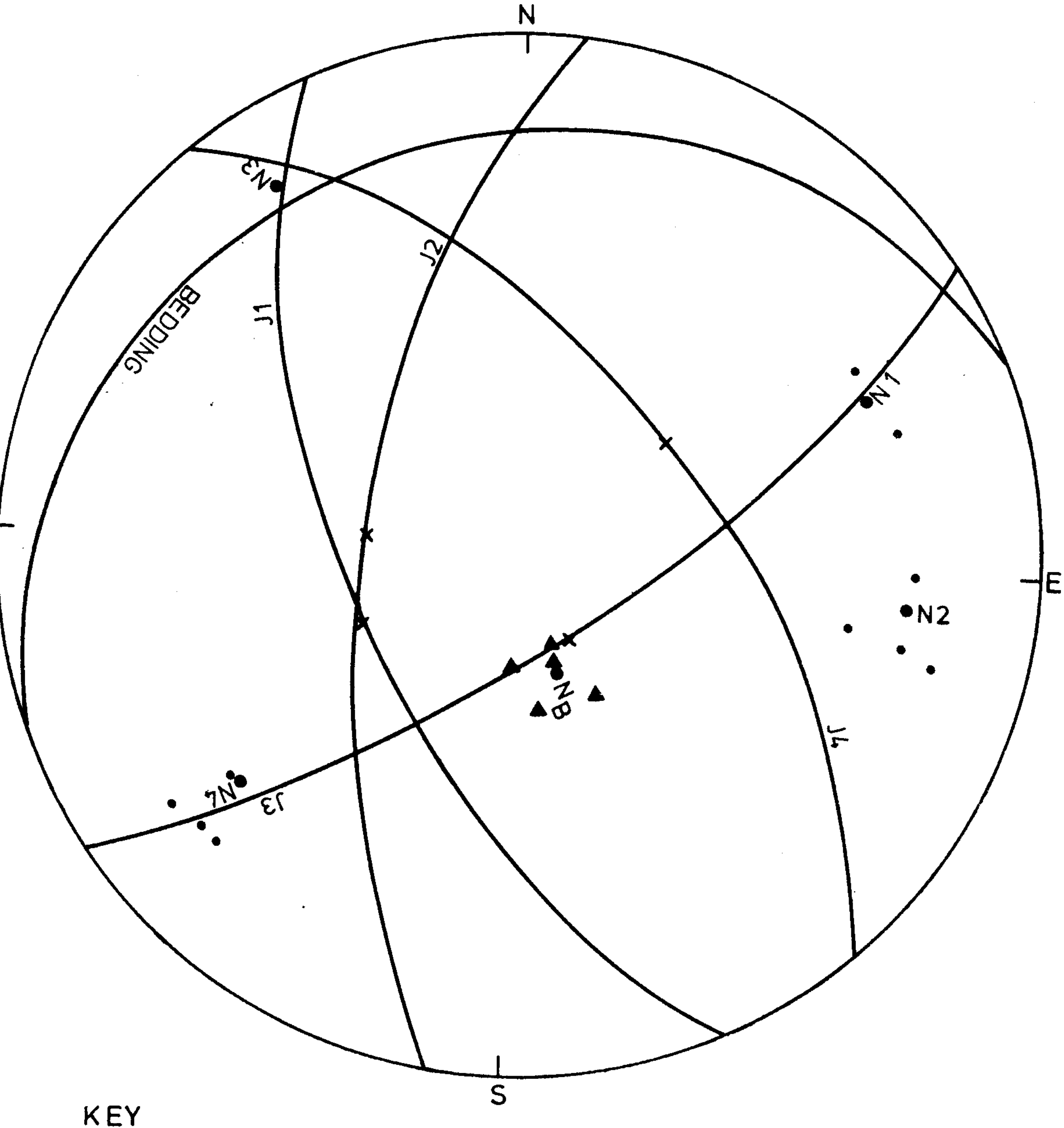
FIG 3·3



Steep westerly dipping widely spaced joint sets.
Competent area not affected by flexure.

870 - HAULAGE IN FWQ
BETWEEN 150 - 182 SECTIONS

PLATE 3:2



KEY

EDDING	N 340/120
J1	N 247/64
J2	N 280/64
J3	N 146/74
J4	N 230/60
NB	NORMAL TO BEDDING
N1	NORMAL TO J1

BULUMA EAST MINE: SCAN LINE
VEY IN MINING DR. ON 790 Level

FIG 3·4

Intense jointing in the area of orebody flexure. Closely
ced steeply dipping joint sets possessing a blocky
earance. A drawpoint raise is noticeable on top left corner.

790 MINING DRIVE IN OBQ
187 - SECTION

PLATE 3:3

STRUCTURAL DISCONTINUITIES

Structure	Dip	Dip Direction	Comments
Bedding	55°	25°	Not prominent in FWQ
J1	62	253	Very prominent generally
J2	62	300	A variation of J1
J3	10	230	Infrequent
J4	74	112	Infrequent

FIG 3.2 illustrates the results of detailed joint surveys carried out in the FWQ exposures on 790, 850 and 870 levels. J1 appears prominently.

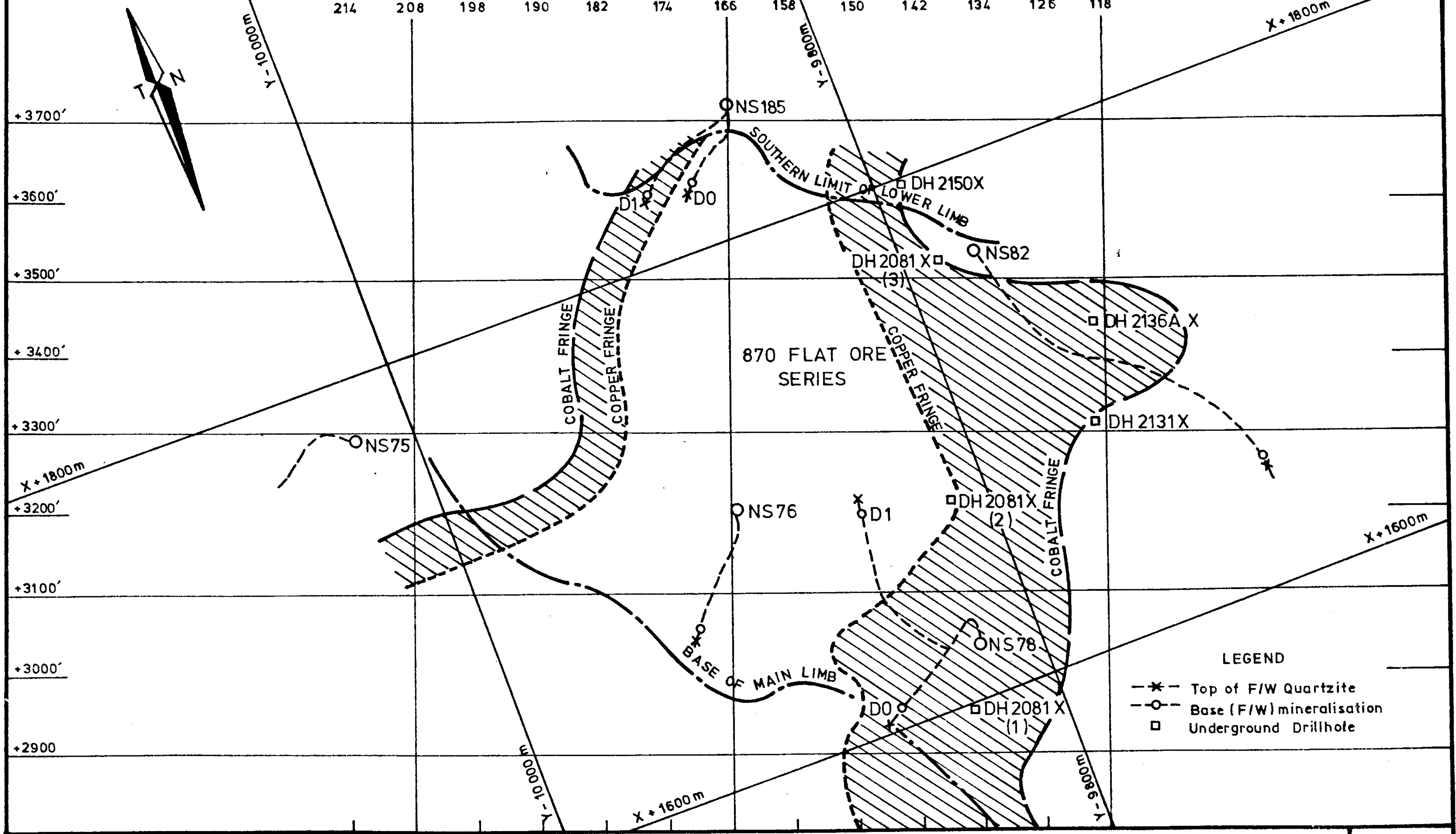
FIG 3.3 indicates the results of a scan line survey conducted on the 870 level in FWQ, as shown in here again J1 along with J2 are Prominent.

FIG 3.4 outlines the results of the survey in the OBQ and HWQ on the 790 level again J1 and J2 are prominent.

The joint spacing was generally found to vary from 0.1 m to 0.3 m between Sections 110 - 150 and 182 - 214 FIG. 3.5. However the area between Sections 150 - 182 showed joint spacing

PLAN OF SURFACE BOREHOLES SHOWING 870 FLAT ORE SERIES
CHIBULUMA EAST

SCALE 1 : 2,000



SCALE 1 : 2,000

PLAN OF SURFACE BOREHOLES SHOWING 870 FLAT ORE SERIES

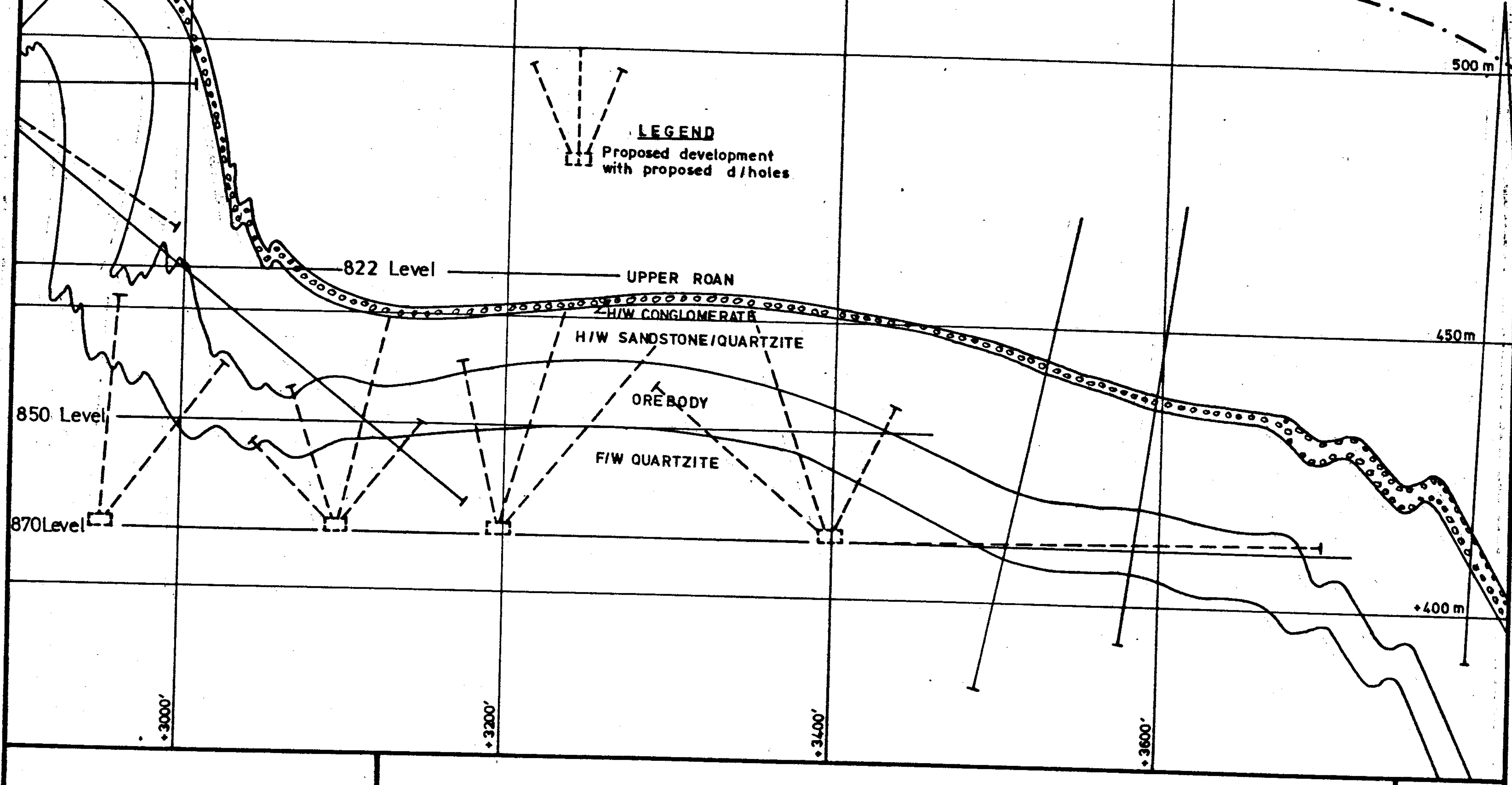
FIG 3·5

ranging from 0.3 to a maximum of 0.9m.

It is likely that more intense jointing could be encountered at lines of orebody flexure. The effect of flexure is shown in FIGS 3.6 and 3.7. The geological interpretation at the base of the 850 levels may infact be a series of closely spaced mini faults or minor displacements resulting in the deteriorating effect on the rock completency because of such faulting.

CONDITION OF JOINTS

From the field observations, it was noted that joint planes are generally tight and without infilling in the FWQ. Except for limited zones of intense jointing the rock is generally competent. The OBQ possesses calcitic infilling and is considered to be more competent and less jointed in the copper-rich centre of the orebody than in the cobaltiferous fringes FIG 3.5. The joint orientation, spacing and rock competency of the OBQ vary from area to area. But the intensity of leaching on joint planes increases towards the HWQ. The HWC is extremely incompetent and the strength of the HWQ beneath it is reduced by leaching for a distance of about 2 metres.



SCALE 1:1000

SECTION 166–CHIBULUMA EAST

FIG 3·7

TABLE 3·1

DISCUSSION

The intensity of jointing varies along strike and it is possible that such condition persists into the flat area.

The highest joint concentration are located to the two places of orebody flexure Sections 118 - 150 and 182 - 214 see FIG. 3.5. These are areas of cobaltiferous fringe and are associated with closely spaced joint sets possessing a blocky appearance.

The third intermediate area between sections 150 - 182 lies in the copper sulphide rich centre of the orebody. This is a more competent area not affected by flexure and has widely spaced tight joint sets.

GROUNDWATER

The sources of groundwater at Chibuluma East *Mine are as follows:-*

FWQ - This source is mainly joint controlled. Volumes are small but pressures high with current measurements indicating that the water table is about 500 metre level. The source is considered to cause problems when initial development takes place but the flow of water is normally blocked or dries out after a short period of time.

OBQ AND HWQ - These formations are generally dry but little moisture is experienced in the HWQ formation.

HWC - This is a weak, feldspar/quartz conglomerate with boulder to pebble grading. The feldspars are frequently kaolinised. The formation containes large volumes of water but is reasonable free draining.

UPPER ROAN DOLOMITE (URD)

The URD series consists of interbedded dolomites and argillites. At least three separate acquifers have been identified, these are not continous and are not located at constant distances from the orebody. The acquifers are probably weathered horizons, they yield large volumes of water for long periods and in addition it is possible for water from URD to recharge the HWC after it has been dewatered. From the pressure measurements the water table in the URD is about the 715 metre level.

3.20 LABORATORY WORK

Laboratory work carried out on Chibuluma East drill core samples is outlined below.

INTACT STRENGTH

Measurements of the uniaxial compressive strength (UCS) of Chibuluma East drill core samples of orebody and country rock were conducted.

Sixty nine core samples from orebody and country rock were subjected to UCS testing by the Material Testing Section of Technical Services of the Zambia Consolidated Copper Mines Limited (ZCCM), and forty core samples were also subjected to UCS testing at the School of Engineering Laboratories of the University of Zambia (UNZA). Details of the test work are listed in Appendix 1.

In addition to UCS testing, detailed diametral Point Load Strength testing was conducted on fifty one AXT size drill core samples to determine an index for the strength classification of rock materials with which the obtained strength index is correlated with the UCS. Results obtained are also shown in Appendix 1 and a summary of intact rock strength values are shown in TABLE 3.1. Average UCS for the four rock types which are encountered in the development and stoping and which are relevant to stoping design at Chibuluma East are

Comparison of results from uniaxial compressive and point-load testing

ROCK MATERIAL	Uniaxial Compressive Strength 7150 DSB Avery Denison Universal Testing Machine				Uniaxial Compressive Strength ZUM-PCY-250 Testing Machine				Point-load index in diametral test				
	No of Specimens	Mean MPa	Standard Deviation MPa	%	No of Specimens	Mean MPa	Standard Deviation MPa	%	No of Specimens	Mean MPa	Standard Deviation MPa	%	Siz
Footwall Quartzite (FWQ)	22	103.11	3.60	3.5	10	92.45	1.09	1.2	16	3.90	0.04	1.02	AX
Orebody Quartzite (OBQ)	20	70.31	2.39	3.4	10	74.34	1.37	1.8	15	3.07	0.20	6.5	AX
Hangingwall Quartzite (HWQ)	16	68.09	3.15	4.6	10	69.79	1.36	1.9	10	3.01	0.23	7.6	AX
angingwall Conglomerate (HWC)	11	33.15	5.22	15.7	10	31.83	2.28	7.2	10	1.17	0.07	6.0	AX

AVERAGE UNIAXIAL COMPRESSIVE STRENGTH FOR THE FOUR ROCK TYPES

FWQ = 98 MPa OBQ = 72MPa HWQ = 69MPa HWC = 32.5MPa tabulated Below:-

ROCK TYPE	COMPRESSIVE STRENGTH MPa	POINT LOAD INDEX MPa
Footwall Quartzite (FWQ)	98	4.00
Orebody Quartzite (OBQ)	72	3.07
Hangingwall Quartzite (HWQ)	69	3.01
Hanginwall Conglomerate (HWC)	32.5	1.17

Eight drillcore samples were submitted for mineral percentages and rock properties determination at the Mineralogy Section of Technical Services. Results obtained are indicated in TABLE 3.2.

The current Chibuluma East stoping and developments are predominantly carried out in quartzitic rocks (FWQ, OBQ, and the HWQ). From the laboratory test results, these rocks appear to have an average strength of about 80 Mpa and a bulk density of 2.70 gm/cm^3.

ROCK TYPE	FOOTWALL QUARTZITE		HANGINGWALL QUARTZITE		HANGINGWALL CONGLOMERATE		OREBODY	
SAMPLE NO	15791	15792	15793	15794	15795	15796	15797	15798
<u>MINERALS</u>								
<u>Gangue</u>								
Quartz	64	56	47	64	50	52	64	69
Feldspar	20	25	35	25	35	30	10	10
Coloured Mica	2	2	1	<1	Nil	Nil	1	1
Dolomite	<1	3	2	<1	–	Tr	<1	<1
Amphibole	–	8	<1	–	–	–	–	–
Barite	–	–	–	–	6	8	<1	2
Apatite	1	–	1	<1	<1	1	<1	<1
Clay	8	2	1	1	5	<1	–	Nil
Fe Oxides	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil
Tourmaline	2	3	4	<1	1	2	3	4
Rutile and Ilmenite	1	<1	1	<1	1	2	1	<1
Zircon	<1	Tr	<1	Tr	–	–	Tr	Tr
<u>Sulphides</u>								
Pyrite	–	–	7	6	2	4	3	0.5
Chalcopyrite	–	Tr	–	–	–	–	16	11
Bornite	–	–	–	–	–	–	1	2
Carrollite	–	–	–	–	–	–	0.5	0.5
S.G. Calculated	2.65	2.68	2.84	2.80	2.81	2.92	3.00	2.91
S.G. Measured	2.67	2.61	2.77	2.82	2.86	2.93	3.02	2.96
Bulk Density	2.50	2.58	2.73	2.70	2.23	2.22	2.91	2.76
Porosity %	5.7	3.7	3.9	3.6	20.6	23.9	3.0	5.1

TABLE 3·2

SCALE:
N.T.S.

CHIBULUMA EAST MINE
CORE RECOVERY IN SURFACE HOLES
THROUGH 870 SERIES

FIG 3·10

The competency of the HWC is poor. This is due to the kaolinisation of the feldspar in the weathered areas of the HWC. This formation is generally leached and decomposed.

ROCK QUALITY DESIGNATION (RQD)

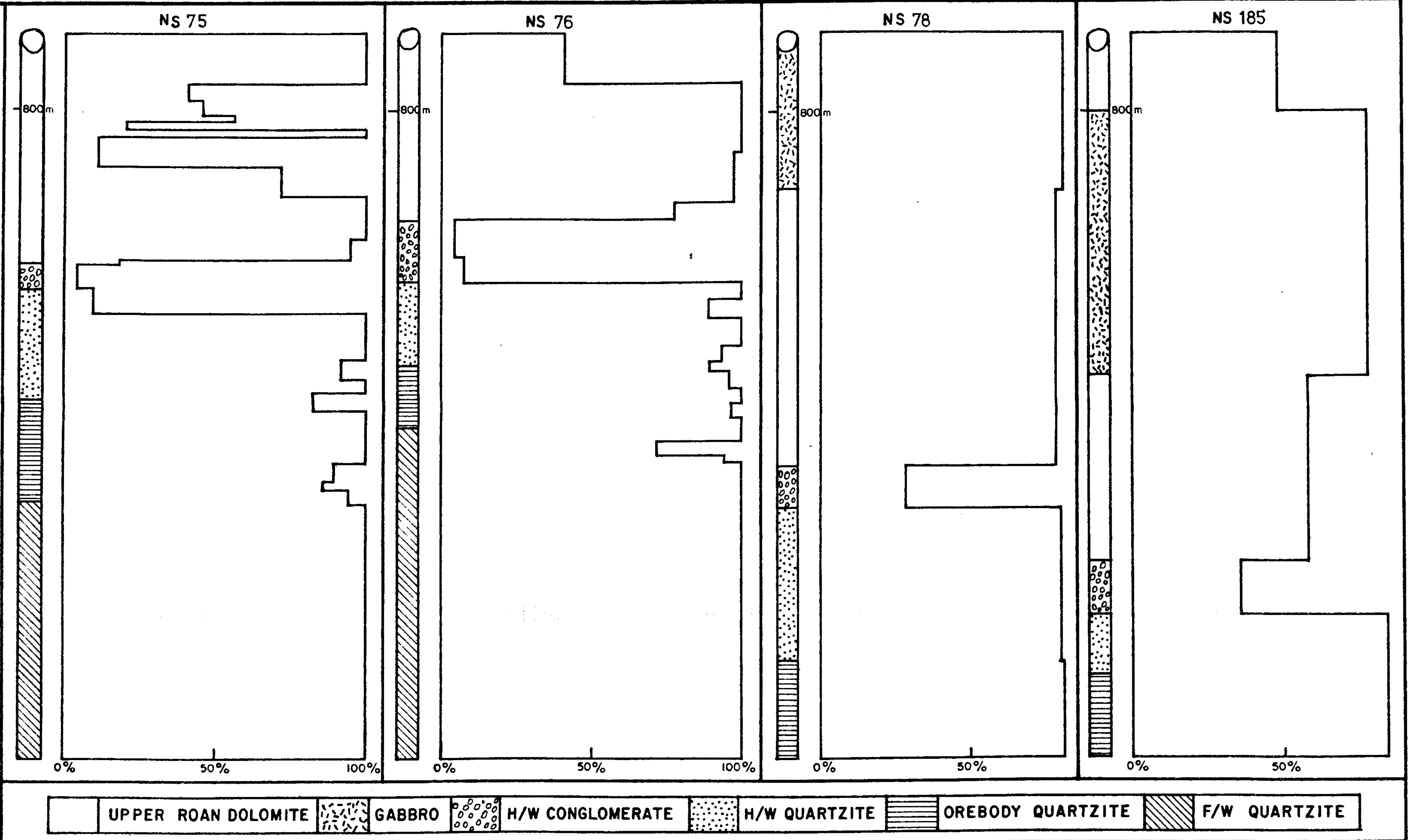
RQDs were determined by examination of core from the areas of 790, 822, 850 and 870 levels (Drill holes NS75, NS78 and NS185 see FIGS. 3.5 and 3.8. Only core of BX size recovered using a double-tube core barrel was considered with results averaged for the three geological sectional areas and the four rock types. The results are tabulated below:-

ROCK TYPE	RQD PERCENTAGE OF SECTION		
	118 - 150	150 - 182	182 - 214
Footwall Quartzite (FWQ)	70 - 75	70 - 80	75 - 80
Orebody Quartzite (OBQ)	60 - 70	65 - 75	60 - 70
Hanginwall Quartzite (HWQ)	60	65	60
Hangingwall Conglomerate (HWC)	30	30 - 35	30

FIG 3·10

CHIBULUMA EAST MINE
CORE RECOVERY IN SURFACE HOLES
THROUGH 870 SERIES

SCALE:
N.T.S.



SCALE:
N.T.S.

CHIBULUMA EAST MINE
CORE RECOVERY IN SURFACE HOLES
THROUGH 870 SERIES

FIG 3·10

The results show a generally decreasing trend in RQD from footwall to hangingwall with HWC displaying low quality.

A summary of geotechnical rock properties obtained from the field and laboratory investigations are shown in TABLE 3.3. This data is of great importance for use in rock mass classification and subsequent pillar design at present deep underground excavation of Chibuluma East.

TABLE 3.3

GEOTECHNICAL DETAILS OF THE FOUR ROCK TYPES AT CHIBULUMA EAST

ROCK TYPE	INTACT ROCK STRENGTH MPa	RQD %	JOINT SPACING (m)	JOINT CONDITION	INFILL THICKNESS AND TYPE	GROUND WATER	POROSITY %	BULK DENSITY gm/cc
Footwall Quartzite (FWQ)	98	80	0.30-0.90	SR/C/NG	0.1mm tight	Dry to moist only	4.70	2.54
Orebody Quartzite (OBQ)	72	65	0.10-0.30	SR/C/WG	2 to 5mm open Calcite in fill	Dry	4.05	2.84
Hangingwall Quartzite (HWQ)	69	70	0.1-0.30	SR/C/WG	5 to 10mm open Kaoline and Calcite in fill	Moist only	3.75	2.71
Hangingwall Conglomerate (HWC)	33	30	None	S/SW	Leached and decomposed	Recognised acquifer	22.25	2.22

KEY SR - Slightly rough, S - Smooth, C - Continuous, NC - Not Continuous, SW - Softwall, WG - With Gouge, NG - No Gouge

TABLE 3.3

CHAPTER FOUR

INFLUENCE OF ROCK PROPERTIES ON STOPE AND PILLAR DESIGN AT CHIBULUMA EAST DEEP LEVELS

.00 INFLUENCE OF ROCK PROPERTIES ON STOPE AND PILLAR DESIGN AT CHIBULUMA EAST DEEP LEVELS

The basis of stope and pillar design presented here is largely a theoretical review of ground conditions and an empirical assessment of rock mass strength at Chibuluma East deep levels.

Empirical assessments of rock properties provide a useful supplement to future detailed analytical work. Firstly an empirical derivation of the insitu rock mass strength from the geomechanics rock mass classification (RMR) Laubscher (1977) is obtained and secondly an application of the necessary adjustments to the insitu rock mass strength in order to arrive at the design rock mass strength is made. Lastly the method then allows an establishment of a relation of the above data to the mining induced stresses.

0 Rock Mass Classification

The principle of rock mass classification is that a numerical assessment is made of the physical properties of a rock mass and a single index is derived to represent the different properties.

In 1964 Tarzaghi proposed a single rock mass classification for use in estimation of the loads to be supported by steel arches in tunnels. But this was or is still applicable only for steel arch support system and it is not so suitable for modern tunneling methods using shotcrete and rock bolts.

In 1958 Lauffer suggested another classification and introduced a new parameter of performance, the stand up time. According to Lauffer, it is the average time that unsupported rock span takes to failure.

The system was not widely used but it had a significant influence on the development of rock mass classification. In 1966 Deere and Miller proposed an index on rock hardness and fracture frequency, which could be obtained by an examination of rock cores. This modified core recovery the rock quality designation (RQD), expresses as a percentage the length of intact core over 100mm compared with the core run.

Bieniawski recognised the need to quantify all the parameters in a common mode and in 1973 proposed a geomechanics classification which used rock-strength, RQD, joint spacing, joint condition, joint orientation and ground-water. Each parameter is assigned a rating to give a rock mass rating (RMR), as a percentage. Five classes of rock mass were than identified TABLE 4.1. excavation support

4·1 GEOMECHANICS CLASSIFICATION OF JOINTED ROCK MASSES (BIENIAWSKI 197

ASSIFICATION PARAMETERS AND THEIR RATINGS

PARAMETER		RANGE OF VALUES						
ngth	Point load strength index	>8 MPa	4 - 8 MPa	2 - 4 MPa	1 - 2 MPa			
ct rock erial	Uniaxial compressive strength	>200 MPa	100 - 200 MPa	50-100 MPa	25 - 50 MPa	10-25 MPa	3-10 MPa	1-3 MPa
	Rating	15	12	7	4	2	1	0
rill core quality RQD		90% - 100%	75% - 90%	50% - 75%	25% - 50%	<25%		
	Rating	20	17	13	8	3		
Spacing of joints		>3m	1-3m	0.3-1m	50 - 300m	<50m		
	Rating	30	25	20	10	5		
Condition of joints		Very rough surfaces Not continuous No separation Hard joint wall rock	Slightly rough surfaces Separation < 1mm Hard joint wall rock	Slightly rough surfaces Separation < 1mm Soft joint wall rock	Slickensided surfaces OR Gouge < 5mm thick OR Joints open 1-5mm Continuous joints	Soft gouge > 5mm thick OR Joints open > 5mm Continuous joints		
	Rating	25	20	12	6	0		
und er	Inflow per 10m tunnel length	None		<25 litres/min	25-125 litres/min	>125 litres/min		
	Ratio joint water pressure / major principal stress	OR 0		OR 0.0-0.2	OR 0.2-0.5	OR >0.5		
	General condition	OR Completely dry		OR Moist only	OR Water under moderate pressure	OR Severe water problems		
	Rating	10		7	4	0		

TING ADJUSTMENT FOR JOINT ORIENTATIONS

Strike and dip entation of joints		Very Favourable	Favourable	Fair	Unfavourable	Very Unfavourable
ng	Tunnels	0	-2	-5	-10	-12
	Foundations	0	-2	-7	-15	-25
	Slopes	0	-5	-25	-50	-60

K MASS CLASSES DETERMINED FROM TOTAL RATINGS

Rating	100 ← 81	80 ← 61	60 ← 41	40 ← 21	<20
Class No.	I	II	III	IV	V
Description	Very good rock	Good rock	Fair rock	Poor rock	Very poor rock

ANING OF ROCK MASS CLASSES

Class No.	I	II	III	IV	V
verage stand-up time	10 years for 5m span	6 months for 4m span	1 week for 3m span	5 hours for 1.5m span	10 minutes for 0.5m span
esion of the rock mass	>300 kPa	200-300 kPa	150-200 kPa	100-150 kPa	< 100 kPa
n angle of the rock mass	> 45°	40° - 45°	35° - 40°	30° - 35°	< 30°

EFFECT OF JOINT STRIKE AND DIP ORIENTATIONS IN TUNNELLING

Strike perpendicular to tunnel axis				Strike parallel to tunnel axis		Dip 0° - 20° irrespective of strike
Drive with dip		Drive against dip				
5° - 90°	Dip 20° - 45°	Dip 45° - 90°	Dip 20° - 45°	Dip 45° - 90°	Dip 20° - 45°	
ry ourable	Favourable	Fair	Unfavourable	Very* Unfavourable	Fair	Unfavourable

recommendations were made for each class and an estimate of the stand up time after Lauffer was given for various sizes of excavation.

From the point of view of mining, the modification of the RMR system by Laubscher in 1977 is highly significant. TABLE 4.2 shows the significancy. In this method five parameters, rock-strength, RQD, joint spacing, joint condition and ground water are used to obtain first insitu rock mass rating (IR). The method then allows modification of this to an adjusted rating (AR) by consideration of weathering, joint orientation, blasting effects and field induced and changed stresses.

From the geotechnical rock properties on TABLE 3.3 and using TABLE 4.2 the respective RMR of each rock type is indicated in TABLE 4.3.

(LAUBSCHER 1977)

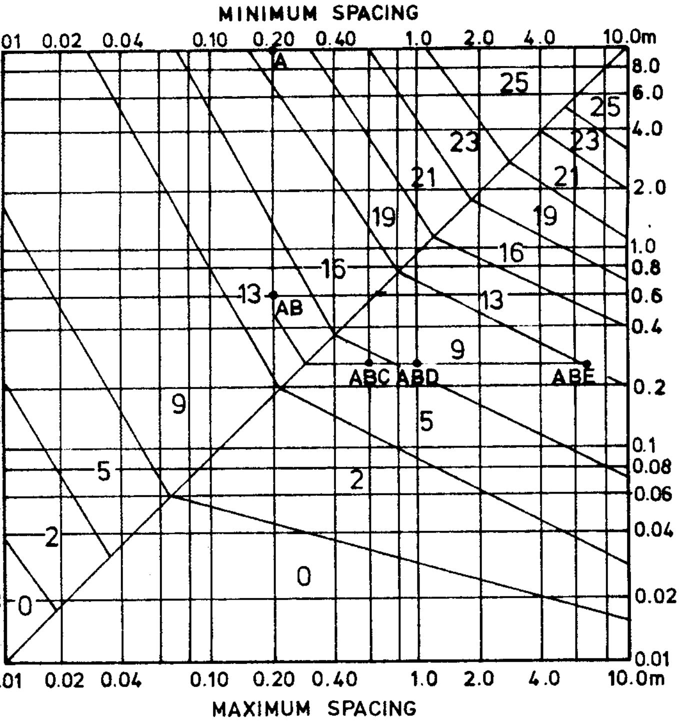
A. MEANING OF THE RATINGS

CLASS	1		2		3		4		5	
	A	B	A	B	A	B	A	B	A	B
RATING[Σ1-4 OF B]	100 — 81		80 — 61		60 — 41		40 — 21		20 — 0	
DESCRIPTION	VERY GOOD		GOOD		FAIR		POOR		VERY POOR	

B. BASIS OF THE CLASSIFICATION

1	RQD %	100 — 97		96-84	83-71	70-56	55-44	43-31	30-17	16-6	3 — 0	
	RATING (= RQD% × 15/100)	15		14	12	10	8	6	4	2	0	
2	UCS (MPa)	>185	184-165	164-145	144-125	124-105	104-85	84-65	64-45	44-25	24-5	4-0
	RATING (= 0.1 × MPa)	20	18	16	14	12	10	8	6	4	2	0
3	JOINT SPACING	REFER C (BELOW)										
	RATING	25 ← → 0										
4	JOINT CONDITION INCL GROUND WATER	REFER D (BELOW)										
	RATING (40 × A × B × C × D / 10^8)	40 ← → 0										

C. RATINGS FOR MULTI JOINT SYSTEMS



XAMPLES

PACINGS A = 0.2m, B = 0.45m, C = 0.5m, D = 1.0m, E = 7m
ATINGS A = 79, AB = 13, ABC = 5, ABD = 9, ABE = 13

FIELD DATA ON JOINT SPACING IN METRES (REF. TABLE 3.3)

ROCK TYPE	MINIMUM	INTERMEDIATE	MAXIMUM
FWQ	0·3	0·6	0·9
OBQ	0·1	0·2	0·3
HWQ	0·1	0·2	0·3
HWC	NONE	NONE	NONE

NOTE: THE MINIMUM AND INTERMEDIATE SPACINGS WERE USED FOR RATINGS INDICATED ON TABLE 4·3

TABLE 4·2 CONTINUES

D. ASSESSMENT OF JOINT CONDITIONS

ACCUMULATIVE % ADJUSTMENT OF POSSIBLE RATING OF 40

PARAMETER	DESCRIPTION		DRY COND.	WET CONDITIONS		
				MOIST	MOD PRESSEY PRES	
					25-125 1/m	125 1/m
A JOINT EXPRESSION (large scale irregularities)	WAVY	MULTI-DIRECTIONAL	100	100	95	90
		UNI-DIRECTIONAL	95 90	95 90	90 85	80 75
	CURVED		89 80	85 75	80 70	70 60
	STRAIGHT		79 70	74 65	60	40
B JOINT EXPRESSION (small scale irregularities or roughness)	VERY ROUGH		100	100	95	90
	STRIATED OR ROUGH		99 85	99 85	80	70
	SMOOTH		84 60	80 55	60	50
	POLISHED		59 50	50 40	30	20
C JOINT WALL ALTERATION ZONE	STRONGER THAN WALL ROCK		100	100	100	100
	NO ALTERATION		100	100	100	100
	WEAKER THAN WALL ROCK		75	70	65	60
D JOINT FILLING	NO FILL SURFACE STAINING ONLY		100	100	100	100
	NON SOFTENING + SHEARED MATERIAL (CLAY OR TALC FREE)	COARSE SHEARED	95	90	70	50
		MED SHEARED	90	85	65	45
		FINE SHEARED	85	80	60	40
	SOFT SHEARED MATERIAL (eg TALC)	COARSE SHEARED	70	65	40	20
		MED SHEARED	65	60	35	15
		FINE SHEARED	60	55	30	10
	GOUGE THICKNESS < AMPLITUDE OF IRREG		40	30	10	
	GOUGE THICKNESS > AMPLITUDE OF IRREG		20	10	FLOWING MATERIAL 5	

TABLE 4.3

CHIBULUMA EAST LAUBSCHER (1977).

ROCK TYPE	RQD	UCS/IRS	JOINT SPACING	JOINT CONDITION INCLUDING GROUND WATER	TOTAL RATING	CLASS
FWQ	12	10	16	40X1X1X1X1=40	78	II
OBQ	10	8	9	40X1X0.99X1X0.99 = 36	63	III
HWQ	10	8	9	40X1X0.99X1X0.90 = 36	63	III
HWC	4	4	0	40X1X0.60X1X0.60 = 14	22	IV

Average quartzitic rocks total rating = 67.3

Average quartzitic rocks UCS/IRS rating = 8.7

Based on **TABLE 4.3.** a geotechnical description of each rock group is described below:

4.11 Strength Characteristics of the FWQ

This is a grey to dark grey feldspathic quartzite mainly composed of detrital quartz and feldspar. This is good competent rock. Support requirements in this rock can be occasional spot bolting.

4.12 Strength Characteristics of the OBQ

This is a sericite rich medium grained light to dark grey quartzite with disseminated sulphide mineralization.

This is a fair rock generally competent but from the field observations mentioned earlier, the strength of the OBQ may in limited areas be affected by leaching and jointing of higher than average intensity.

Support needs in this group should include systematic grouted bolts spaced

1.5 to 2m length plus mesh and 100mm thick shotcrete. However minimal support is applied in the OBQ as most of the rock is drawn.

4.13 Strength Characteristics of the HWQ

This is a light grey glassy feldspathic quartzite. The HWQ is equally a fair rock and support needs in this unit are similar to that indicated in the OBQ.

4.14 Strength Characteristics of the HWC

This is composed of unsorted clasts and rounded pebbles of quartz and feldspar in a calcite cement. The condition of this rock is poor, it is generally leached and decomposed. It is also a recognised acquifer. Any exposures in this group result in running ground, and therefore any break through into the HWC must be avoided by supporting of the underlying HWQ, through optimum design of stope spans, by rapid stope extraction and finally by filling of the voids.

4.20 IN-SITU ROCK MASS STRENGTH (RMS)

Current underground stoping and developments at Chibuluma East are conducted in quartzitic rocks of the lower Roan Group (FWQ, OBQ and the HWQ). Only the average quartzitic rock values are considered.

The procedure that is used to calculate the insitu IRMS is as follows;

1. The intact rock strength (IRS) or the uniaxial compressive strength (UCS) rating of the rock (TABLE 4.3) is subtracted from the total rating. And therefore the balance rock quality designation (RQD), joint spacing, joint condition and groundwater will be a function of the remaining possible rating of eighty percent.

   The average total rating of quartzitic rocks is 67.3 (TABLE 4.3.). And the average rating of the intact quartzitic rock strength is 8.7. Therefore the reduction factor is as follows

$$\frac{67.3 - 8.7}{80} = 0.7325$$

2. The intact rock strength (IRS), represents the strength measured in megapascals of the intact rock Specimen (UCS). The average UCS of the quartzitic rocks is 80 MPa as shown in TABLE 3.3. In this case

the corrected strength is as follows:

$$\frac{80 \times 80}{100} = 64 \text{ MPa}$$

3. The corrected IRS value is multiplied by the reduction factor to obtain the insitu rock mass strenth (RMS)

   Thus 64 x 0.7325 = 46.88 MPa

   RMS = 47 MPa

4.21 DESIGN ROCK MASS STRENGTH (DRMS)

The DRMS is the unconfined rock mass strength in a specific mining environment. A combined empirical adjustment factor of ninety five per cent laubscher (1984) for the effects of weathering, joint orientation, blasting and field induced and changed stresses is considered to be reasonable for the Chibuluma East situation.

The following individual factors have been adopted.

a) Good conventional blasting = 95%

b) Weathering/Alterations = 100%

c) Joint condition = 100%

Total adjustment factor is

0.95 x 1 x 1 = 0.95

Therefore the design rock mass strength of Quartzitic rocks at Chibuluma East is as follows:-

47 x 0.95 = 44.65 MPa

DRMS = 45 MPa

The respective insitu rock mass strength (RMS) and the design rock mass strength (DRMS) of individual rock units is tabulated below:

ROCK TYPE	RMS MPa	DRMS MPa
FWQ	65	61
OBQ	40	38
HWQ	38	36
HWC	6	5

4.30 PILLAR STRENGTH

The determination of pillar strength predominantly depends on geometrical parameters (width to height ratio and the shape of the pillar), and the strength of the rock mass (DRMS).

The effect of width to height ratio on the strength of coal pillars has been determined based on South African case histories by Salamon and Oravecz (1976) Salamon (1976) and the following formular applies

$$\text{Pillar strength} = \frac{KW^{0.46}}{H^{0.66}} \text{ KPa}$$

Where K = strength of one metre cube of coal as measured in the laboratory.

W = Pillar width in metres.

H = Pillar height in metres.

The factors of 0.46 and 0.66 are applicable to coal mines.

But other authors Wagner (1980) have ascribed values of 0.50 and 0.75 as being applicable to hard rock mines. The latter values are used in this work.

The above formular is only applicable to square pillars and if rectangular pillars are used such as the case for Chibuluma East flat area, then the effective width (Weff) is used instead of the actual width Kersten (1984)

$$\text{Weff} = 4 \times \frac{A}{C}$$

Where A = Pillar area

C = Pillar circumference

The ratio A/C is also known as the hydraulic radius and is the ratio of the excavation area to the excavation perimeter. Therefore for rectangular pillars, the pillar strength can be calculated as follows;

$$\text{pillar strength (Ps)} = \frac{K\ (Weff)^{0.5}}{H^{0.75}}$$

Where H = pillar height

K = constant = DRMS.

The flat area of Chibuluma East is a flat lying stratiform tabular deposit with a uniform thickness averaging 10 metres and dipping approximately 10 to 15 degrees north-west for a distance of about 200 metres. The deposit has a strike length of 240 metres in the east-west direction and lying at an average depth of about 350 metres below surface.

The following optimum stope and pillar dimensions have been designated for the stoping of the flat area deposit by Chibuluma Mine Management

The vertical stress at a point below ground surface is normally assumed to vary linearly with depth (Z) and the density of the rock (ρ)

$$\sigma_v = \rho g Z$$

Where $g = 9.81\ m/sec^2$ = Gravitational Accelaration

Chibuluma East flat area has a small orebody width (10 metres thick) and hence the variations of the virgin stress across the plane of the orebody is negligible. Owing to the fact that the width of the orebody is small when compared to other linear dimensions (the strike length and the dip length), the stope and pillar design regions can be viewed as single plane surfaces.

In the case of deep level mining as at Chibuluma East the depth of mining can be assumed to be at 850 metres below surface.

The tributary area method (Brady 1985) provides a simple method of determining the average state of the axial pillar stress for a tabular deposit. The prediction of the insitu performance of

a pillar requires a method of assessing the strength of peak resistance of the pillar to the axial compression. This analysis suggest that the strength of a pillar is related to both its volume and its geometric shape.

The pillar stress (σp) for Chibuluma East can be calculated using the current stope and pillar width as follows:

$$\text{Pillar stress } (\sigma p) = \frac{\sigma v(Sw + Pw)}{Pw}$$

Where Sw = stope width

Pw = Pillar width

σv = Vertical normal stress of the pre-mining field stresses

$$\sigma_p = \frac{\sigma v(15 + 15)}{15}$$

$$\sigma_P = 2\sigma v = 2\rho g z$$

The Orebody Quartzites at Chubuluma East have a bulk density of 2.84 gm/cc (as presented in TABLE 3.3).

Therefore ρ = 2840 Kg/m^2

g = $9.81 m/sec^2$

z = 850m

σp = $2 \times 2840 \times 9.81 \times 850$ Pa

σp = 47.36 MPa

Where A = Pillar area

C = Pillar circumference

The ratio A/C is also known as the hydraulic radius and is the ratio of the excavation area to the excavation perimeter. Therefore for rectangular pillars, the pillar strength can be calculated as follows:

$$\text{pillar strength } (Ps) = \frac{K\,(Weff)^{0.5}}{H^{0.75}}$$

Where H = pillar height

K = constant = DRMS.

The flat area of Chibuluma East is a flat lying stratiform tabular deposit with a uniform thickness averaging 10 metres and dipping approximately 10 to 15 degrees north-west for a distance of about 200 metres. The deposit has a strike length of 240 metres in the east-west direction and lying at an average depth of about 350 metres below surface.

The following optimum stope and pillar dimensions have been designated for the stoping of the flat area deposit by Chibuluma Mine Management

Pillar height	=	6 metres
Pillar width	=	15 metres
Pillar strike length	=	20 metres
Stope width	=	15 metres

The Pillar excavation area is pillar width X pillar strike length.

Area (A) = 15 x 20 = $300m^2$

Excavation perimeter (C) = 2(15+20)=70m

$$\text{Hydraulic radius } (A/C) = \frac{300m^2}{70m} = 4.286m$$

Effective Width (Weff) = 4 x 4.286m

Weff = 17.144m

Therefore the average pillar strength of the Orebody Quartzite (OBQ) at Chibuluma East flat area is as follows;

$$Ps = \frac{DRMS \times (17.144)^{0.5}}{6^{0.75}} \text{ MPa}$$

$$Ps = \frac{37.620 \times 4.1405}{3.834} \text{ MPa}$$

$$Ps = 40.627 \text{ MPa}$$

0 PILLAR STRESS

The flat area deposit of Chibuluma East is almost horizontal and of uniform thickness. In this regard the principal stresses can be taken to be vertical (σ_v) and horizontal (σ_h)

The vertical stress at a point below ground surface is normally assumed to vary linearly with depth (Z) and the density of the rock (ρ)

$$\sigma_v = \rho g Z$$

Where $g = 9.81 \ m/sec^2$ = Gravitational Accelaration

Chibuluma East flat area has a small orebody width (10 metres thick) and hence the variations of the virgin stress across the plane of the orebody is negligible. Owing to the fact that the width of the orebody is small when compared to other linear dimensions (the strike length and the dip length), the stope and pillar design regions can be viewed as single plane surfaces.

In the case of deep level mining as at Chibuluma East the depth of mining can be assumed to be at 850 metres below surface.

The tributary area method (Brady 1985) provides a simple method of determining the average state of the axial pillar stress for a tabular deposit. The prediction of the insitu performance of

a pillar requires a method of assessing the strength of peak resistance of the pillar to the axial compression. This analysis suggest that the strength of a pillar is related to both its volume and its geometric shape.

The pillar stress (σp) for Chibuluma East can be calculated using the current stope and pillar width as follows:

$$\text{Pillar stress } (\sigma p) = \frac{\sigma v(Sw + Pw)}{Pw}$$

Where Sw = stope width

Pw = Pillar width

σv = Vertical normal stress of the pre-mining field stresses

$$\sigma p = \frac{\sigma v(15 + 15)}{15}$$

$$\sigma P = 2\sigma v = 2\rho gz$$

The Orebody Quartzites at Chubuluma East have a bulk density of 2.84 gm/cc (as presented in TABLE 3.3).

Therefore ρ = 2840 Kg/m^2

g = 9.81m/sec^2

z = 850m

σp = 2 x 2840 x 9.81 x 850 Pa

σp = 47.36 MPa

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σp = 47.36 MPa

4.50 FACTOR OF SAFETY

The factor of safety in pillar design is defined as follows;

$$F.S = \frac{\text{Pillar Strength}}{\text{Pillar Stress}} = \frac{Ps}{\sigma_P}$$

The factor of safety for pillars at Chibuluma East flat area has been determined as 0.36. A structure is defined as stable when a factor of safety is greater than one. The above factor of safety indicates a sign of an area requiring active support.

CHAPTER FIVE

INFLUENCE OF ROCK PROPERTIES ON SUPPORT SYSTEMS AT CHIBULUMA EAST DEEP LEVELS

.00 INFLUENCE OF ROCK PROPERTIES ON SUPPORT SYSTEMS AT CHIBULUMA EAST DEEP LEVELS.

The design of rock support system depends on the geotechnical properties of rock masses, the size and shape of the excavation, the resultant magnitude of the distributed stresses and the degree of deformation acceptable in the completed excavations.

Most support and reinforcement design systems are based on practical experience or on observations made and experience gained in earlier excavations.

The simply commonly adopted support system is an empirical approach in which the rock is expressed in terms of continuity and its stability to withstand stress. An empirical support design system utilizing rock properties and based on Laubscher (1984) is outlined, for support requirements in deep excavation areas of Chibuluma East flat area.

10 MAXIMUM AND MINIMUM COMPRESSIVE STRESSES

Underground excavations in rock masses leads to redistribution of stress around the excavation. of great significance are the maximum (σ_1) and minimum (σ_3) stresses which are expressed as follows

$$\sigma_{max} = K1 \rho gz \qquad \text{(Grebenyoka (1983)}$$
$$\sigma_{min} = K2 \lambda \rho gz$$

where K1 and K2 are co-efficients of stress concentration, λ is the co-efficient of lateral thrust and where V is the poisson ratio

$$\lambda = \frac{V}{1 - v}$$

ρ = rock density

g = gravitational acceleration

z = excavation depth below surface.

At Chibuluma Mine the poisson ratio is taken to be equal to 0.25 Pentz (1972). In this regard the co-efficient of lateral thrust is then equal to 0.33. The respective co-efficients of stress concentration are indicated in TABLE 5.1.

TABLE 5.1 COEFFICIENTS OF STRESS CONCENTRATION

Grebenyoka (1983)

EXCAVATION SHAPE	K1	K2	PROTODYAKONOY STRENGTH NUMBER $F = \frac{UCS}{10}$
Dome	2	0.4	$F \geq 12$
	2	0.3	$F \leq 12$
Trapezium or Rectangular	2	1.0	

Therefore the average maximum and minimum stress currently encountered in quartzitic rectangular excavation at Chibuluma East area are:

σ_1 = 45.03 MPa

σ_3 = 7.43 MPa

Stress difference $(\sigma_1 - \sigma_3)$ = 37.6 MPa

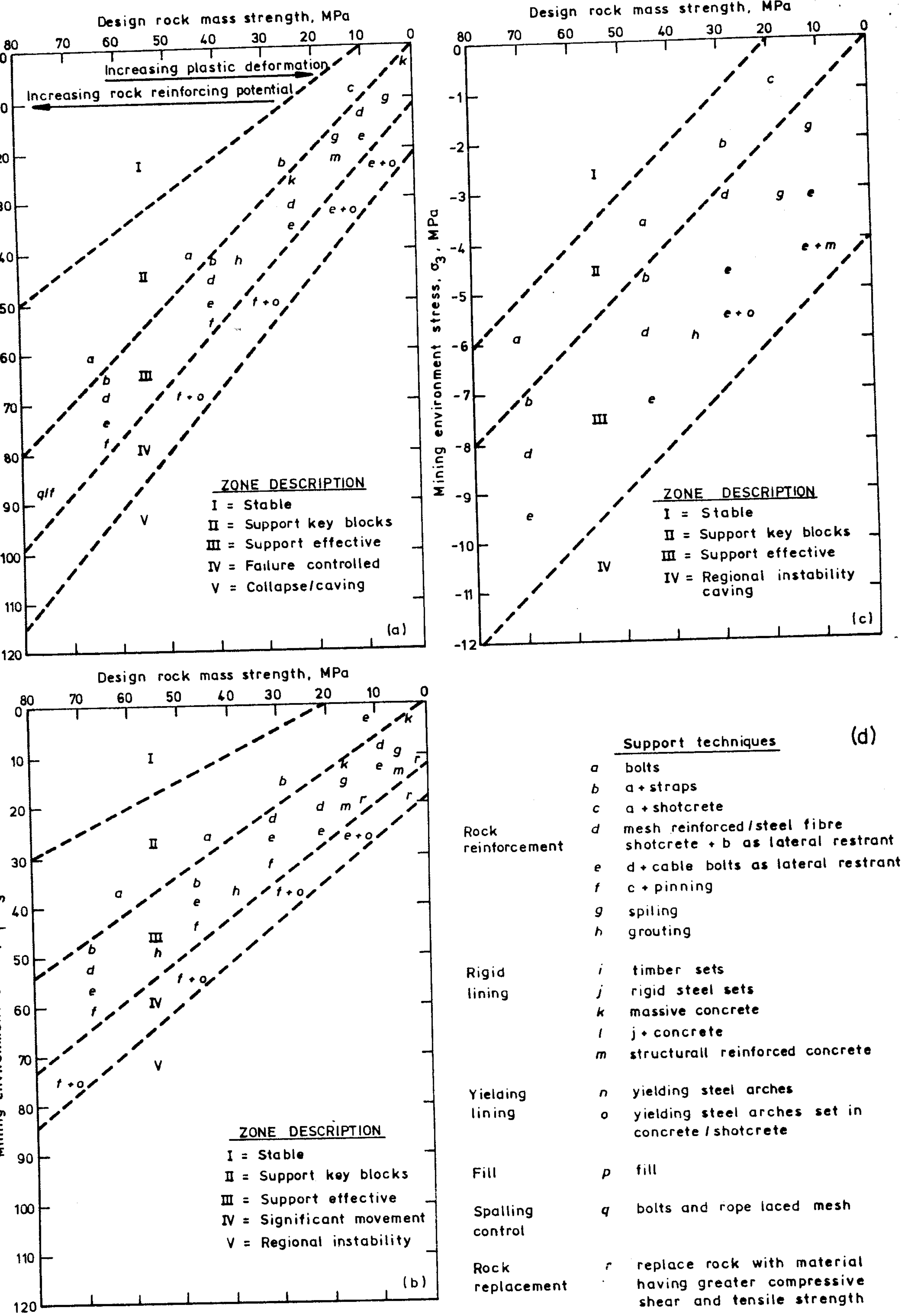
The maximum and minimum stresses for individual rock units are shown in TABLE 5.2

5.20 SUPPORT SELECTION

The DRMS of the quartzitic rocksat Chibuluma East was found to be equal to 45 MPa (see 4.21). Support charts by Laubscher (1984) have been prepared that relate DRMS to maximum stress (σ_1) FIG.5.1 a to the stress difference

SUPPORT SELECTION CHARTS

(LAUBSCHER 1984)



		Support techniques
Rock reinforcement	a	bolts
	b	a + straps
	c	a + shotcrete
	d	mesh reinforced / steel fibre shotcrete + b as lateral restrant
	e	d + cable bolts as lateral restrant
	f	c + pinning
	g	spiling
	h	grouting
Rigid lining	i	timber sets
	j	rigid steel sets
	k	massive concrete
	l	j + concrete
	m	structurall reinforced concrete
Yielding lining	n	yielding steel arches
	o	yielding steel arches set in concrete / shotcrete
Fill	p	fill
Spalling control	q	bolts and rope laced mesh
Rock replacement	r	replace rock with material having greater compressive shear and tensile strength

FIG 5·1 Support selection charts in which DRMS is related to (a) maximum stress, (b) difference between maximum and minimum compressive stresses and (c) minimum stress. Support techniques and symbols are shown in (d)

$(\sigma_1-\sigma_3)$ FIG 5.1b and to the minimum stress (σ_3) FIG 5.1c. Appropriate Support requirements are listed in FIG 5.1d. Below is a brief description of each individual zone.

Zone 1 - is a stable zone where no support is required.

Zone 2 - comprises key blocks (pontentially unstable blocks) that required support.

Zone 3 - is a zone in which spalling rock falls.

Zone 4 - represents an area in which significant spalling, unravelling movement on joints and deformation are expected.

Zone 5 - is characterised by regular collapses and caving. Using FIG 5.1 and based on the values of DRMS and mining environment stresses, the average quartzitic rocks at Chibuluma East fall in Zones 2 and 3. Support needs for these zones consists or rock bolting, shotcrete and reinforced wire mesh.

Support requirements for individual rock units at Chibuluma East can be determined in a similar

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FOOTNOTE: <u>ROCKBOLT</u> — A REINFORCING ELEMENT MADE OF SOLID OR TUBE FORMED STEEL INSTALLED UNTENSIONED OR TENSIONED IN THE ROCK MASS.

GROUTED DOWEL — A REINFORCING ELEMENT MADE OF WIRES LAYED TO ASTRAND OR AROPE CONFIGURATION AND INSTALLED UNTENSIONED OR TENSIONED WITH CEMENT GROUTING IN THE ROCK MASS.

manner. Necessary data for the four rock types is presented in TABLE 5.2.

5.30 DISCUSSION

A comparison of the strength properties of the rock mass (DRMS) and the resulting stress difference ($\sigma_1 - \sigma_3$) indicated above gives an indication as to whether failure can be expected around an excavation.

The FWQ is generally competent with tight widely spaced joint planes. No ground problems can be expected in the FWQ since the level of the total stress difference ($\sigma_1 - \sigma_3$) is lower in relation to the design rock mass strength.

The total stresses in the OBQ and the HWQ are almost equal to the DRMS. These units are generally of lower competency and their strengths are affected in certain areas by jointing of higher than average intensity, and by leaching especially in the zone below the contact with the overlying Hangingwall Conglomerate. The OBQ and the HWQ are the units requiring effective support.

The DRMS of the HWC is less than the total stresses in the rock and in this regard failure can be expected. The HWC is extremely unstable and therefore any break through it

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FOOTNOTE: ROCKBOLT — A REINFORCING ELEMENT MADE OF SOLID OR TUBE FORMED STEEL INSTALLED UNTENSIONED OR TENSIONED IN THE ROCK MASS.
GROUTED DOWEL — A REINFORCING ELEMENT MADE OF WIRES LAYED TO ASTRAND OR AROPE CONFIGURATION AND INSTALLED UNTENSIONED OR TENSIONED

SUPPORT REQUIREMENTS FOR CHIBULUMA EAST DEEP LEVELS

ROCK TYPE	DRMS MPa	σ_1 MPa	σ_3 MPa	$\sigma_1 - \sigma_3$ MPa	ZONE	Support Requirements
FWQ	61.00	42.36	6.99	35.37	1 and 2	Occassional Spot bolting
OBQ	38.00	47.36	7.81	39.55	3	Bolting, shotcrete, reinforced wire mesh and grouted dowels
HWQ	36.00	45.20	7.46	37.74	3	
HWC	5.00	37.02	6.11	30.91	4 and 5	Zones of regional instability Support in this area is not likely to be successful.

TABLE 5.2

FOOTNOTE: ROCKBOLT — A REINFORCING ELEMENT MADE OF SOLID OR TUBE FORMED STEEL INSTALLED UNTENSIONED OR TENSIONED IN THE ROCK MASS.

GROUTED DOWEL — A REINFORCING ELEMENT MADE OF WIRES LAYED TO ASTRAND OR AROPE CONFIGURATION AND INSTALLED UNTENSIONED OR TENSIONED WITH CEMENT GROUTING IN THE ROCK MASS.

must be prevented by supporting the overlying HWQ. It is equally important to control blasting in order to keep the extent of induced damage to a minimum.

Lastly damage to underground structures results from over or under estimating the rock mass properties or mining induced stresses. Geotechnical assessment deficiencies which lead to rock mass failure often originate from using inappropriate values based on limited population samples. Calculations mentioned above are based on empirical descriptions and further analytical work is essential for extra support recommendations.

CHAPTER SIX

STOPING OF THE CHIBULUMA EAST FLAT AREA DEPOSIT

6.00 STOPING OF THE CHIBULUMA EAST FLAT AREA DEPOST

Stoping methods selected for extraction of the Chibuluma East flat area deposit must be amenable to several factors and orebody characteristics. Of paramount importance are the rock properties at present deep extraction levels.

The average thickness of ore is about ten metres and much of it is flat dipping. Therefore the current gravity sublevel open stoping methods in use would generally be unsuitable.

Because of the ten metre width and the flat dipping nature of the deposit, development, requirements must be minimized. The OBQ is generally of lower competency and the intensity of jointing is likely to vary and may thus regionally affect its competency. The HWQ is also of lower competency and its strength is affected by leaching especially in the zone immediately below its contact with the overlying Hangingwall Conglomerate. The HWC is extremely unstable and any break through it must be prevented.

In view of the above, it is essential to minimize dilution and maximize recovery in any possible adopted mining method.

Room and pillar stoping methods are generally recommended for flatlaying stratiform orebodies

Brady (1985). However these methods are most suitable for naturally supported thick and large deposits. In the present Chibuluma East Context, room and pillar stoping would be difficult to be applied

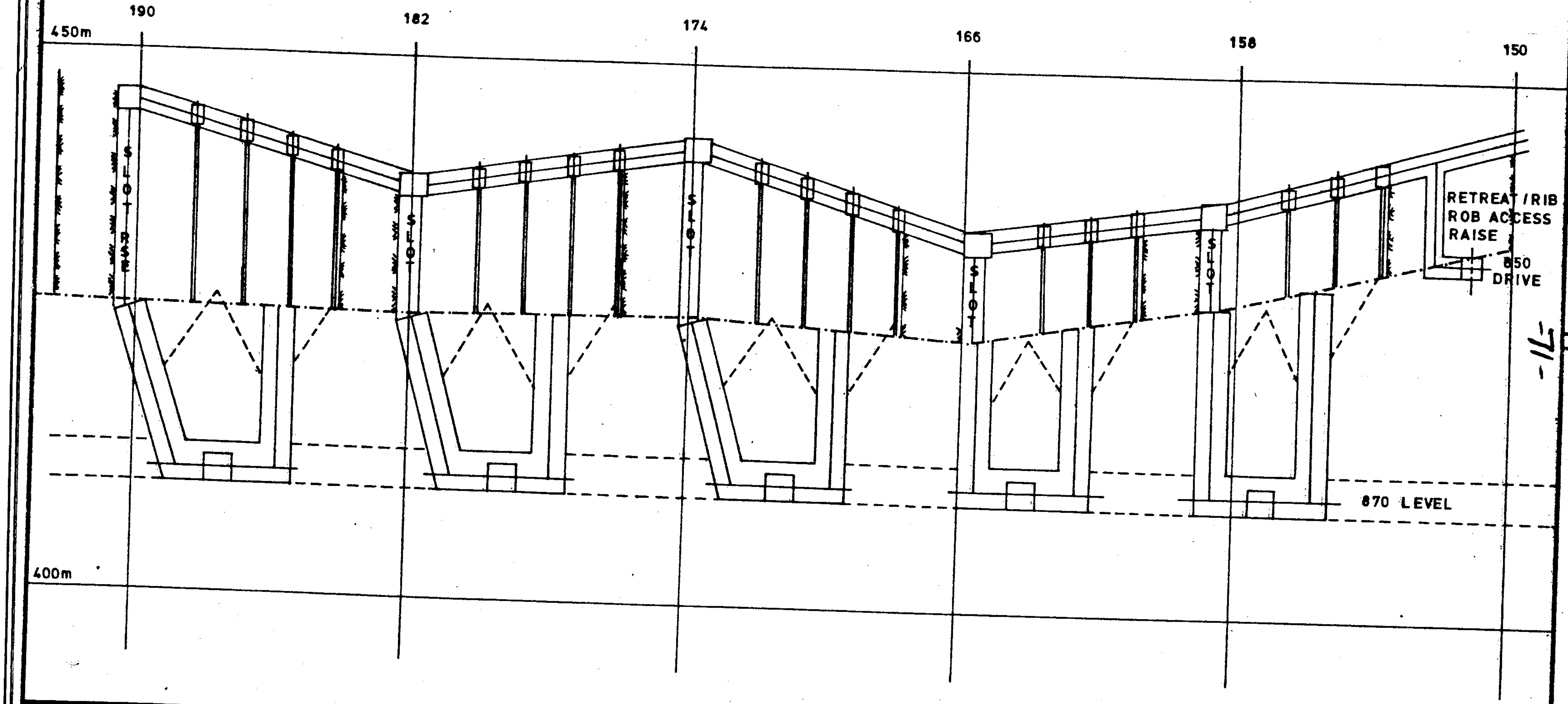
Clean stoping of the Chibuluma East flat area deposit could be impossible without the use of post-fill technique. This is mainly because of the narrow width and folding of the orebody with major flexure occurring in some areas. In addition the flat area possesses fairly intensive jointing of the OBQ and the HWQ particularly in the cobaltiferous fringes. Also of great importance is the existence of the weak HWC bed immediately overlying the HWQ.

Inview of the outlined rock properties and in order to optimise future mine developments with respective mining at depth, it is therefore recommended that Hangingwall Benching with in-stope scraping method be adopted for Chibuluma East flat area. Major aspects of the method are discussed below.

6.10 HANGINGWALL BENCHING

It is proposed that the Hangingwall Benching FIGS 6.1 and 6.2 could proceed in a series of panels that comprise stope and pillar dimensions. Stoping of the panels should be conducted alternatively with adjacent excavated backfilled.

A central hangingwall raise as presented in FIG 6.2 and large blastholes drill drives on strike should



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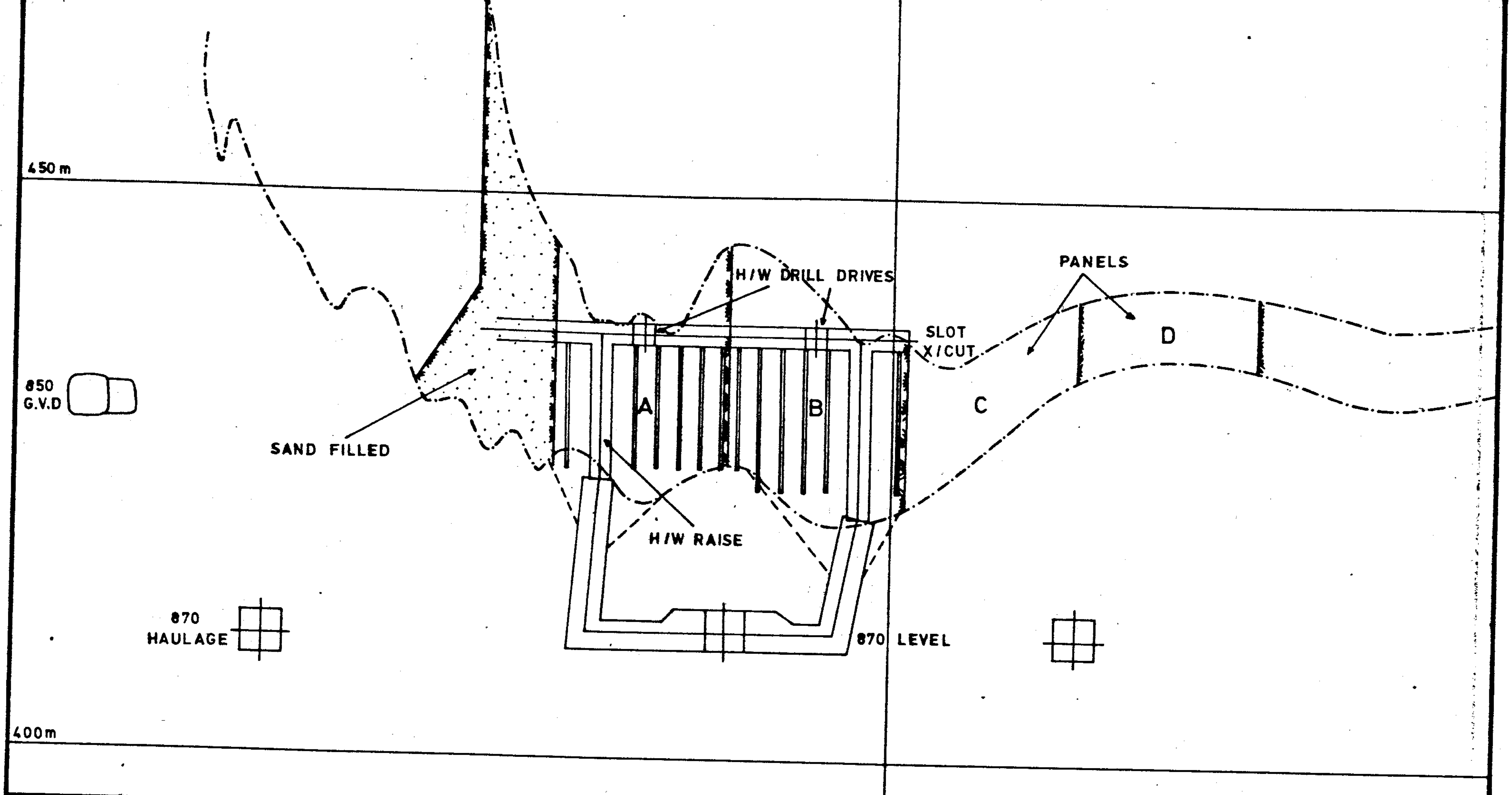
CHIBULUMA EAST MINE
870 FLAT SERIES. LONGITUDINAL SECTION

FIG 6·1



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CHIBULUMA EAST MINE

PROPOSED HANGINGWALL BENCHING.

SECTION 182

FIG 6·2

be placed at about four metre centres and developed. Pre-support of the stope hangingwall prior to post-fill would be done from the raise and the drill drives. This is necessary to prevent hangingwall failure before post-fill is introduced.

The slots should be blasted on dip and the direction of ring blasting done on strike. A slot raise and a slot drive are also required at the base of the stope. Stope drilling should be done from the hangingwall to footwall from a hangingwall raise and large hole drilling drives.

The base of the stope should be served by grizzley levels where the extration and sizing of ore can be done. The grizzley levels should have parallel crosscuts above the footwall haulage from which gravitational flow of broken ore can be collected.

CONCLUSIONS/RECOMMENDATIONS

Rock properties at present deep extraction levels of Chibuluma East have a significant influence on the stability of underground openings. Among the properties which possess great influence are; the intact rock strength (IRS/UCS), the nature of **discontinuities** , such as joint spacing, joint condition, separation of joints and the infilling material, groundwater conditions and rock quality designation (RQD).

The above properties can easily be determined by relevant tests quickly and cheaply in the field and laboratory. In addition these properties are important input parametres for an empirical derivation of the insitu rock mass strength from the geomechanics rock mass classification (RMR).

Necessary adjustments are allowed to the insitu rock mass strength to arrive at the design rock mass strength (DRMS). The DRMS provides quantitative practical data for pillar design, rock support and for the selection of mining methods.

At Chibuluma East, the footwall Quartzite is a good competent rock. The Orebody Quartzite (OBQ) is generally of lower competency with an average thickness of about ten metres and much of it is flat dipping. The intensity of joining in the (OBQ) varies and may thus affect its competency. The Hangingwell Quartzite is also of lower competency and its strength is affected by leaching especially in the zone below its contact with the overlying Hangingwall Conglomerate (HWC). The HWC is extremely unstable and any break through it must be prevented.

In the current Chibuluma East Context, it is recommended that Hangingwall Benching with in stope scraping method be adopted for the extraction of the Chibuluma East flat area deposit.

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APPENDIX ONE

EOMECHANICS CLASSIFICATIONS (RMR)

DATA ANALYSIS

.00 ZAMBIA CONSOLIDATED COPPER MINE LIMITED (ZCCM)

TECHNICAL SERVICES ENGINEERING DEPARTMENT KALULUSHI

TEST RESULTS ON COMPRESSIVE STRENGTH DETERMINATION OF CHIBULUMA EAST DRILL CORE SAMPLES

SAMPLE NO.	DIAMETER (M)	HEIGHT (M)	MEAN BREAKING LOAD (N)	COMPRESSIVE STRENGTH MPa	REMARKS
15631	0.04700	0.0705	146969	84.7	
15632	0.03500	0.0373	103924	108.0	
15633	0.04100	0.0533	128535.6	97.4	
15634	0.04100	0.0525	46830.8	35.5	Surface covered with voids
15635	0.05500	0.0703	132521.2	55.8	
15636	0.05500	0.0705	288956	121.6	
15637	0.05500	0.0710	96650.8	40.7	
15638	0.03200	0.0366	60780.4	75.6	
15639	0.03200	0.0373	45834.4	57.0	
15640	0.03200	0.0377	60083	74.7	
15641	0.03200	0.0360	63769.6	79.3	
15642	0.03200	0.0357	58787.6	73.1	
15643	0.03200	0.0360	46830.8	58.2	
15644	0.03200	0.0363	51812.8	64.4	
15645	0.03200	0.0373	73733.6	91.7	
15646	0.03200	0.0370	68751.6	85.5	
15647	0.03200	0.0367	66758.8	83.0	
15648	0.03200	0.0367	42845.2	53.3	
15649	0.03200	0.0370	87683.2	109.0	
15650	0.03200	0.0370	66758.8	83.00	
15651	0.03200	0.0370	47827.2	59.5	
15652	0.03200	0.0373	60780.4	75.6	
15653	0.03200	0.0367	106614.8	132.6	
15703	0.04200	0.0513	91668.8	66.2	
15704	0.04200	0.0523	122557.2	88.5	
15705	0.03200	0.0357	57791.2	72.1	
15706	0.03200	0.0350	71740.8	89.2	
15707	0.03200	0.0360	53798.4	69.4	
15708	0.03200	0.0363	51812.8	64.4	
15709	0.03200	0.0363	58787.6	73.1	
15710	0.03200	0.0363	43841.6	54.5	
15711	0.04200	0.0530	153445.6	110.8	
15712	0.04200	0.0530	124550.0	90.0	

TEST RESULTS ON COMPRESSIVE STRENGTH (CONTINUED)

SAMPLE NO.	DIAMETER (M)	HEIGHT (M)	MEAN BREAKING LOAD (N)	COMPRESSIVE STRENGTH MPa	REMARKS
15713	0.04200	0.0537	152449.2	110.0	
15714	0.04200	0.0520	169985.8	122.7	
15715	0.04200	0.0537	104622	75.5	
15716	0.04200	0.0537	141488.8	102.2	
15717	0.04200	0.0477	136506.8	98.5	
15718	0.04200	0.0530	85690.4	61.9	
15719	0.03200	0.0353	58787.6	73.0	
15720	0.03200	0.0363	14946.0	18.9	Honey combing on the surface
15721	0.03200	0.0387	68751.6	85.5	
15722	0.03200	0.0380	61776.8	76.8	
15745	0.03200	0.0360	57791.2	71.9	
15746	0.03200	0.0387	46830.8	58.2	
15747	0.03200	0.0393	75726.4	94.2	
15748	0.03200	0.0370	30888.4	38.4	Surface covered with voids
15749	0.03200	0.0370	25906.4	32.2	Surface covered with voids
15750	0.04200	0.0503	152449.2	110.0	
15751	0.04200	0.0510	107611.2	77.7	
15752	0.04200	0.0500	89676	64.7	
15753	0.03200	0.0380	62773.2	78.1	
15754	0.03200	0.0357	84694	105.3	
15755	0.03200	0.0363	42845.2	53.3	
15756	0.03200	0.0395	3487.4	4.3	Honey combing on the surface
15757	0.03200	0.0363	46830.8	58.2	
15758	0.03200	0.0357	43841.6	54.5	
15759	0.03200	0.0353	47827.2	59.5	
15760	0.03200	0.0360	72737.2	90.5	
15761	0.03200	0.0367	25904.4	32.2	Surface covered with voids
15762	0.03200	0.0357	37863.2	47.1	
15763	0.03200	0.0363	76722.8	95.4	
15764	0.03200	0.0363	86688.8	107.8	
15765	0.03200	0.0357	61776.8	76.8	
15766	0.03200	0.0363	6974.8	8.8	Honey combing on the surface
15767	0.03200	0.0360	47827.2	59.5	
15768	0.03200	0.0360	46830.8	58.2	
15769	0.03200	0.0363	40852.4	50.8	
15770	0.03200	0.0357	111596.8	138.8	

.10 DATA ANALYSIS OF UCS TEST RESULTS OF CHIBULUMA EAST DRILL CORE SAMPLES USING ZCCM-7150 DSB UNIVERSAL TESTING MACHINE:

FOOTWALL QUARTRITE (FWQ)

NO.	SAMPLE NUMBER	DIAMETER (M)	HEIGHT (M)	BREAKING LOAD N	COMPRESSIVE STRENGTH MPa (X)	X-$\bar{X}$	$(X-\bar{X})^2$
1	15631	0.0470	0.0705	146969	84.7	-18.41	338.9281
2	15632	0.0350	0.0373	103924	108.0	4.89	23.9121
3	15633	0.0410	0.0533	128535.6	97.4	-5.71	32.6041
4	15636	0.0550	0.0703	288956	121.6	18.49	341.8801
5	15641	0.0320	0.0360	63769.6	79.3	-23.81	566.9161
6	15645	0.0320	0.0370	73733.6	91.7	-11.41	130.1881
7	15649	0.0320	0.0370	87683.2	109	5.89	34.6921
8	15653	0.0320	0.0367	106614.8	132.6	29.49	869.6601
9	15709	0.0320	0.0363	58787.6	73.1	-30.01	900.6001
10	15711	0.0420	0.0530	153445.6	110.8	7.69	59.1361
11	15712	0.0420	0.0530	124550.0	90	-13.11	171.8721
12	15713	0.0420	0.0537	152449.2	110	6.89	47.4721
13	15714	0.0420	0.0520	169985.8	122.7	19.59	383.7681
14	15716	0.0420	0.0537	141488.8	102	-1.77	3.1329
15	15717	0.0420	0.0477	136506.8	98.5	-4.61	21.2521
16	15721	0.0420	0.0387	68751.6	85.5	-17.61	310.1121
17	15747	0.0320	0.0393	75726.4	94.2	-8.91	79.3881
18	15750	0.0420	0.0503	152449.2	110	6.89	47.4721
19	15754	0.0320	0.0357	84694	105.3	2.19	4.7961
20	15763	0.0320	0.0363	76722.8	95.4	-7.71	59.4441
21	15764	0.0320	0.0363	86680.8	107.8	4.69	21.9961
22	15770	0.0320	0.0357	111596.8	138.8	35.69	1273.7761
TOTAL					2268.4		5722.999

MEAN = 2268 ÷ 22 = 103.11 MPa $\bar{X}$ = 103.11 MPa

STANDARD DEVIATION $\sigma = \sqrt{\sum (X-\bar{X})^2} \times \frac{1}{n-1}$

(Standard deviation is the measure of data dispersion about the mean) $\sigma = \sqrt{5722.99} \times \frac{1}{21} = 3.6$ MPa

.11 DATA ANALYSIS OF UCS TEST RESULTS OF CHIBULUMA EAST DRILL CORE SAMPLES USING ZCCM-7150 DSB UNIVERSAL TESTING MACHINE:

OREBODY QUARTRITE (OBQ)

NO.	SAMPLE NUMBER	DIAMETER (M)	HEIGHT (M)	BREAKING LOAD N	COMPRESIVE STRENGTH MPa (X)	$X-\bar{X}$	$(X-\bar{X})^2$
1	15638	0.0320	0.0366	60780.4	75.6	5.29	27.9841
2	15639	0.0320	0.0373	45834.4	57.0	-13.31	177.1561
3	15640	0.0320	0.0377	60083.0	74.7	4.39	19.2721
4	15642	0.0320	0.0357	58787.6	73.1	2.79	7.7841
5	15644	0.0320	0.0363	51812.8	64.4	-5.91	34.9281
6	15646	0.0320	0.0370	68751.6	85.5	15.19	230.7361
7	15647	0.0320	0.0367	66758.9	83.0	12.69	161.0361
8	15651	0.0320	0.0370	47827.2	59.5	-10.81	116.8561
9	15707	0.0320	0.0360	53798.4	69.4	- 0.91	0.8281
10	15715	0.0420	0.0537	104622	75.5	5.19	34.9281
11	15718	0.0420	0.0530	85690.4	61.9	-8.41	70.7281
12	15719	0.0320	0.0353	58787.6	73.0	2.69	6.8121
13	15722	0.0320	0.0380	61776.8	76.8	6.49	42.1201
14	15746	0.0320	0.0387	46830.8	58.2	-12.11	146.6521
15	15758	0.0320	0.0357	43841.6	54.5	-15.81	249.9561
16	15759	0.0320	0.0353	47827.2	59.5	-10.81	116.8561
17	15760	0.0320	0.0360	72737.2	90.5	20.19	407.6361
18	15765	0.0320	0.0357	61776.3	76.8	6.49	42.1201
19	15767	0.0320	0.0360	47827.2	59.5	-10.81	116.8561
20	15751	0.0420	0.0510	107611.2	77.7	7.39	54.6121
TOTAL					1406.1		2065.858

MEAN $= \bar{X} = 1406.1 \div 20 = 70.31$ MPa

STANDARD DEVIATION $= \sigma = \sqrt{\sum(X-\bar{X})^2 \times \frac{1}{n-1}}$

(Standard deviation is the measure of data dispersion about the mean) $\sigma = \sqrt{2065.858 \times \frac{1}{19}}$

$\sigma = 2.39$ MPa

.12 DATA ANALYSIS OF UCS TEST RESULTS OF CHIBULUMA EAST DRILL CORE SAMPLES USING ZCCM-7150 DSU UNIVERAL TESTING MACHINE:

HANGINGWALL QUARTRITE (HWQ)

NO.	SAMPLE NUMBER	DIAMETER (M)	HEIGHT (M)	BREAKING LOAD N	COMPRESSIVE STRENGTH MPa (X)	$X-\bar{X}$	$(X-\bar{X})^2$
1	15635	0.0550	0.0703	132521.2	55.8	-12.29	151.0441
2	15643	0.0320	0.0360	46830.8	58.2	-9.89	97.8121
3	15650	0.0320	0.0370	66758.8	83.0	14.91	222.3081
4	15652	0.0320	0.0373	60780.4	75.6	7.51	55.4001
5	15703	0.0420	0.0513	91668.8	66.2	-1.89	3.5721
6	15704	0.0420	0.0523	122557.2	88.5	20.41	416.5681
7	15705	0.0320	0.0357	57791.2	72.1	4.01	16.0801
8	15706	0.0320	0.0350	71740.8	89.2	21.11	445.6321
9	15708	0.0320	0.0363	51812.8	64.4	-3.69	13.6161
10	15710	0.0320	0.0360	43841.6	54.5	-13.59	184.6881
11	15745	0.0320	0.0360	57791.2	71.9	3.81	14.5161
12	15752	0.0420	0.0500	89676.0	64.7	-3.39	11.4921
13	15753	0.0320	0.0380	62773.2	78.1	10.01	100.2001
14	15757	0.0320	0.0363	46830.8	58.2	-9.89	97.8121
15	15768	0.0320	0.0360	46830.8	58.2	-9.89	97.8121
16	15769	0.0320	0.0363	40852.4	50.8	-17.29	298.9441
TOTAL					1089.4		2228.4976

MEAN $= \bar{X} = 1089.4 \div 16 = 68.09$ MPa

STANDARD DEVIATION $= \sigma = \sqrt{\sum (X-\bar{X})^2 \times \frac{1}{n-1}}$

(Standard deviation is the measure of data dispersion about the mean) $\sigma = \sqrt{(2228.4976) \times \frac{1}{15}}$

$\sigma = 3.15$ MPa

.13 DATA ANALYSIS OF UCS TEST RESULTS OF CHIBULUMA EAST DRILL CORE SAMPLES USING ZCCM-7150 DSB UNIVERSAL TESTING MACHINE:

HANGINGWALL CONGLOMERATE (HWC)

NO.	SAMPLE NUMBER	DIAMETER (M)	HEIGHT (M)	BREAKING LOAD N	COMPRESSIVE STRENGTH MPa (X)	$X-\bar{X}$	$(X-\bar{X})^2$
1	15634	0.0410	0.0525	46830.8	35.5	2.35	5.5225
2	15637	0.0550	0,0710	96650.8	40.7	7.55	57.0025
3	15648	0.0320	0,0367	42845.2	53.3	20.15	406.0225
4	15720	0.0320	0,0363	14946.0	18.9	-14.25	203.0625
5	15748	0.0320	0.0370	30888.4	38.4	5.25	27.5625
6	15749	0.0320	0.0370	25906.4	32.2	-0.95	0.9025
7	15755	0.0320	0,0363	42845.2	53.3	20.15	406.0225
8	15756	0.0320	0.0395	3487.4	4.3	-28.85	832.3225
9	15761	0.0320	0.0367	25904.4	32.2	-0.95	0.9025
10	15762	0.0320	0.0357	37863.2	47.1	13.95	194.6025
11	15766	0.0320	0.0363	6974.8	8.8	-24.35	592.9225
TOTAL					364.7		2726.8475

MEAN $= \bar{X} = 364.7 \div 11 = 33.15$ MPa

STANDARD DEVIATION $= \sigma = \sqrt{\sum(X-\bar{X})^2 \times \frac{1}{n-1}}$

(Standard deviation is the measure of data dispersion about the mean) $\sigma = \sqrt{(2726.8475) \times \frac{1}{10}}$

$\sigma = 5.22$ MPa

1.20 DATA ANALYSIS OF UCS TEST RESULTS OF CHIBULUMA EAST DRILL CORE SAMPLES USING UNZA-ZUM-PCY-250 TESTING MACHINE:

FOOTWALL QUARTRITE (FWQ)

SAMPLE NUMBER	DIAMETER (M)	HEIGHT (M)	MEAN BREAKING LOAD Kg	COMPRESSIVE STRENGTH MPa	$X-\bar{X}$	$(X-\bar{X})^2$
1	0.042	0.084	13200	95.30	2.85	8.1225
2	0.042	0.084	12900	93.10	0.65	0.4225
3	0.042	0.084	12800	92.40	-0.05	0.0025
4	0.042	0.084	12600	90.93	-1.52	2.3104
5	0.042	0.084	12000	87.76	-4.69	21.9961
6	0.042	0.084	13000	95.07	2.62	6.8644
7	0.042	0.084	12500	90.21	-2.24	5.0176
8	0.042	0.084	13500	97.43	4.98	24.8004
9	0.042	0.084	12000	87.76	-4.69	21.9961
10	0.042	0.084	13100	94.54	2.09	4.3681
TOTAL				924.5		95.9006

MEAN $= \bar{X} = 924.5 \div 10 = 92.45$ MPa

STANDARD DEVIATION $= \sigma = \sqrt{\sum (X-\bar{X})^2} \times \frac{1}{n-1}$

(Standard deviation is the measure of data dispersion about the mean) $\sigma = \sqrt{95.9006} \times \frac{1}{9}$

$\sigma = 1.09$ MPa

1.21 DATA ANALYSIS OF UCS TEST RESULTS OF CHIBULUMA EAST DRILL CORE SAMPLES USING UNZA-ZUM-PCY-250 TESTING MACHINE: OREBODY QUARTZITE (OBQ)

SAMPLE NUMBER	DIAMETER (M)	HEIGHT (M)	MEAN BREAKING LOAD Kg	COMPRESSIVE STRENGTH STRENGTH MPa	$X-\bar{X}$	$(X-\bar{X})^2$
11	0.042	0.084	11100	80.11	5.77	33.2929
12	0.042	0.084	10500	75.78	1.44	2.0736
13	0.042	0.084	9800	70.73	-3.61	13.0321
14	0.042	0.084	9700	70.00	-4.34	18.8356
15	0.042	0.084	11000	79.39	5.05	25.5025
16	0.042	0.084	10000	72.17	-2.17	4.7089
17	0.042	0.084	11100	80.11	5.77	33.2929
18	0.042	0.084	9800	70.73	-3.61	13.0321
19	0.042	0.084	10000	72.17	-2.17	4.7089
20	0.042	0.084	10000	72.17	-2.17	4.7089
TOTAL				743.36		153.1884

MEAN = $\bar{X}$ = 743.36 ÷ 10 = 74.34 MPa

STANDARD DEVIATION = $\sigma = \sqrt{\sum (X - \bar{X})^2} \times \frac{1}{n} - 1$

(Standard deviation is the measure of data dispersion about the mean) $\sigma = (153.1884) \times \frac{1}{9}$

$\sigma = 1.37$ MPa

1.22 DATA ANALYSIS OF UCS TEST RESULTS OF CHIBULUMA EAST DRILL CORE SAMPLES USING UNZA-ZUM-PCY-250 TESTING MACHINE:

<u>HANGINGWALL QUARTZITE</u> (HWQ)

SAMPLE NO.	DIAMETER (M)	HEIGHT (M)	MEAN BREAKING LOAD Kg	COMPRESSIVE STRENGTH MPa	$X-\bar{X}$	$(X-\bar{X})^2$
21	0.042	0.084	9200	66.40	-3.39	11.4921
22	0.042	0.084	10000	72.17	2.38	5.6644
23	0.042	0.084	10200	73.61	3.82	14.5924
24	0.042	0.084	9800	70.73	0.94	0.8836
25	0.042	0.084	10500	75.78	5.99	35.8801
26	0.042	0.084	9800	64.95	-4.84	23.4256
27	0.042	0.084	9400	67.84	-1.95	3.8025
28	0.042	0.084	10200	73.61	3.82	14.5924
29	0.042	0.084	8800	63.51	-6.28	39.4384
30	0.042	0.084	9600	69.28	-0.51	0.2601
TOTAL				697.88		150.0316

MEAN = $\bar{X}$ = 697.88 ÷ 10 = 69.79 MPa

STANDARD DEVIATION = $\sigma = \sqrt{\Sigma(X-\bar{X})^2 \times \frac{1}{n-1}}$

(Standard deviation is the measure of data dispersion about the mean)

$\sigma = 150.0316 \times \frac{1}{9}$

σ = 1.36 MPa

.23 DATA ANALYSIS OF UCS TEST RESULTS OF CHIBULUMA EAST DRILL CORE SAMPLES USING UNZA-ZUM-PCY-250 TESTING MACHINE:

HANGINGWALL CONGLOMERATE (HWC)

SAMPLE NO.	DIAMETER (M)	HEIGHT (M)	MEAN BREAKING LOAD Kg	COMPRESSIVE STRENGTH MPa	$X-\bar{X}$	$(X-\bar{X})^2$
31	0.042	0.084	5500	39.69	7.86	61.7796
32	0.042	0.084	6000	43.30	11.47	131.5609
33	0.042	0.084	4600	33.20	1.37	1.8769
34	0.042	0.084	4000	28.87	-2.96	8.7616
35	0.042	0.084	3800	27.42	-4.41	19.4481
36	0.042	0.084	2600	18.76	-13.07	170.8249
37	0.042	0.084	4400	31.76	-0.07	0.0049
38	0.042	0.084	4200	30.31	-1.52	2.3104
39	0.042	0.084	4000	28.87	-2.96	8.7616
40	0.042	0.084	5000	36.08	4.25	18.0625
TOTAL				318.26		423.3914

MEAN = $\bar{X}$ = 318.26 ÷ 10 = 31.83 MPa

STANDARD DEVIATION = $\sigma = \sqrt{\sum (X-\bar{X})^2} \times \frac{1}{n-1}$

(Standard deviation is the measure of data dispersion about the mean) $\sigma = \sqrt{423.3914} \times \frac{1}{9}$

σ = 2.28 MPa

1.30 POINT LOAD INDEX TEST RESULTS OF CHIBULUMA EAST DRILL CORE SAMPLES:

- FOOTWALL QUARTZITE (FWQ)

NO.	SAMPLE NUMBER	LOAD KN	POINT LOAD INDEX IN DIAMETRAL TEST $Is(50) = \frac{P}{D^2}$ (D=32MM)		$X-\bar{X}$	$(X-\bar{X})^2$	CORRELATED UCS = 24Is MPa
			Is(50) - ACTUAL MPa	Is(50) - CORRECTED MPa			
1	DH2262	5.4	5.3	4	0.10	0.01	96
2	DH2280	5.2	5.1	4	0.10	0.01	96
3	DH2275	5.3	5.2	4	0.10	0.01	96
4	DH2264D	5.3	5.2	4	0.10	0.01	96
5	DH2211	5.5	5.4	4	0.10	0.01	96
6	DH2227	4.6	4.5	3.5	-0.40	0.16	84
7	DH2209	5.6	5.5	4	0.10	0.01	96
8	DH2225	5.1	5.0	3.9	-	-	93.6
9	DH2269	5.4	5.3	4	0.10	0.01	96
10	DH2269A	5.1	5.0	3.9	-	-	93.6
11	DH2267	5.3	5.2	4	0.10	0.01	96
12	DH2275	5.5	5.4	4	0.10	0.01	96
13	DH2274	4.7	4.6	3.6	0.30	0.09	86.4
14	DH2208	5.0	4.9	3.9	-	-	93.6
15	DH2273	5.4	5.3	4	0.10	0.01	96
16	DH2210	5.4	5.3	4	10	0.01	96
	16			62.8		0.36	1507.2

Is(50) = STRENGTH INDEX CORRELATED TO A 50MM DIAMETER CORE

Is - MEAN = $\bar{X}$ = 62.8 ÷ 16 = 3.9 MPa

STANDARD DEVIATION = $\sigma = \sqrt{\sum(X-\bar{X})^2 \times \frac{1}{n}}$

$$\sigma = \sqrt{0.36 \times \frac{1}{15}}$$

$$\sigma = 0.04 \text{ MPa}$$

CORRELATED UCS MEAN = $\bar{X}$ = 1507.2 ÷ 16 = 94.2 MPa

1.31 POINT LOAD INDEX TEST RESULTS OF CHIBULUMA EAST DRILL CORE SAMPLES:

ORE BODY QUARTZITE (OBQ)

NO.	SAMPLE NUMBER	LOAD KN	POINT LOAD INDEX IN DIAMETRAL TEST $Is(50) = \frac{P}{D^2}$ (D = 32MM)		$X-\bar{X}$	$(X-\bar{X})^2$	CORRELATED UCS = 24Is
			Is(50)- ACTUAL MPa	(Is(50)- CORRECTED MPa			
1	DH2262D	3	3	2.4	-0.67	0.4489	57.6
2	DH2262E	5.3	5.2	4	0.93	0.8649	96
3	DH2262D1	5.5	5.4	4.1	1.03	1.0609	98.4
4	DH2280	4.7	4.6	3.6	0.53	0.2809	86.4
5	DH2275	4.5	4.4	3.5	0.43	0.1849	84
6	DH2211	4.3	4.2	3.4	0.33	0.1089	81.6
7	DH2227	3.9	3.8	2.9	-0.17	0.0289	69.6
8	DH2209	5.1	5.0	3.9	0.83	0.6889	93.6
9	DH2225	3.2	3.1	2.5	-0.57	0.3249	60
10	DH2275	3.8	3.7	2.8	-0.27	0.0729	67.2
11	DH2074	1.6	1.6	1.2	-1.87	3.4969	28.8
12	DH2273	4.6	4.5	3.5	0.43	0.1849	84
13	DH2273A	3.3	3.2	2.6	-0.47	0.2209	62.4
14	DH2208	3.7	3.6	2.8	-0.27	0.0729	67.2
15	DH2210	3.7	3.6	2.8	-0.27	0.0729	67.2
	25			46		8.1135	1104

Is(50) = STRENGTH INDEX CORRELATED TO A 50MM DIAMETER CORE

Is - MEAN = X = 46 ÷ 15 = 3.07 MPa

STANDARD DEVIATION $= \sigma = \sqrt{\sum (X-\bar{X})^2} \times \frac{1}{n} - 1$

$$\sigma = \sqrt{8.1135} \times \frac{1}{14}$$

$$\sigma = 0.20 \text{ MPa}$$

CORRELATED UCS MEAN = 1104 ÷ 15 =73.6 MPa

1.32 POINT LOAD INDEX TEST RESULTS OF CHIBULUMA EAST DRILL CORE SAMPLES:

<u>HANGINGWALL QUARTZITE</u> (HWQ)

NO.	SAMPLE NUMBER	LOAD KN	POINT LOAD INDEX IN DIAMETRAL TEST Is(50) = $\frac{P}{D^2}$(D = 32MM)		$X-\bar{X}$	$(X-\bar{X})^2$	CORRELATED UCS = 24Is
			Is(50)- ACTUAL MPa	Is(50) - CORRECTED MPa			
1	DH2262D	3.5	3.4	2.7	-0.31	0.0961	64.8
2	DH2262E	5.4	5.3	4	0.99	0.9801	96.0
3	DH2264D	4.4	4.3	3.4	0.39	0.1521	81.6
4	DH2211	4.0	3.9	3.0	-0.01	0.0001	72.0
5	DH2227	4.0	3.9	3.0	-0.01	0.0001	72.0
6	DH2209	3.3	3.2	2.6	-0.41	0.1681	62.4
7	DH2225	2.1	2.1	1.7	-1 31	1.7161	40.8
8	DH2274	3.5	3.4	2.7	-0.31	0.0961	64.8
9	DH2273	5.4	5.3	4	0.99	0.9801	96
10	DH2208	4.0	3.9	3.0	-0.01	0.0001	72
	10			30.1		4.189	722.4

Is(50) = STRENGTH INDEX CORRELATED TO A 50MM DIAMETER

Is - MEAN = $\bar{X}$ = 30.1 ÷ 10 = 3.01 MPa

STANDARD DEVIATION ÷ $\sigma = \sqrt{\Sigma(X-\bar{X})^2} \times \frac{1}{n} - 1$

$$\sigma = (4.189) \times \frac{1}{9}$$

$$\sigma = 0.23 \text{ MPa}$$

CORRELATED UCS MEAN = $\bar{X}$ = 722.4 ÷ 10 = 72.24 MPa

1.33 POINT LOAD INDEX TEST RESULTS OF CHIBULUMA EAST DRILL CORE SAMPLES:

HANGINGWALL CONGLOMERATE (HWC)

NO.	SAMPLE NUMBER	LOAD KN	POINT LOAD TEST IN DIAMETRAL TEST $Is(50) = \frac{P}{D^2}$ (D = 32MM)		$X-\bar{X}$	$(X-\bar{X})^2$	CORRELATED UCS = 24Is
			IS(50)-ACTUAL MPa	Is(50)-CORRECTED MPa			
1	DH2262D	1.4	1.4	1.1	-0.07	0.0049	26.4
2	DH2262E	1.6	1.6	1.2	0.03	0.0009	28.8
3	DH2264	1.8	1.8	1.4	0.23	0.0529	33.6
4	DH2275	1.6	1.6	1.2	0.03	0.0009	20.8
5	DH2209	1.5	1.5	1.1	-0.07	0.0049	26.4
6	DH2275	1.4	1.4	1.0	-0.17	0.0289	24.0
7	DH2273	2.1	2.1	1.7	0.53	0.2809	40.8
8	DH2208	1.0	1.0	1.0	-0.17	0.0289	24.0
9	DH2210	1.4	1.4	1.0	-0.17	0.0289	24.0
10	DH2211	1.4	1.41	1.0	-0.17	0.0289	24.0
	10			11.7		0.4610	280.8

Is(50) = STRENGTH INDEX CORRELATED TO A 50MM DIAMETER CORE

Is - MEAN = $\bar{X}$ = 11.7 ÷ 10 = 1.17 MPa

STANDARD DEVIATION = $\sigma = \sqrt{(X-\bar{X})^2 \times \frac{1}{n-1}}$

$\sigma = \sqrt{(0.461) \times \frac{1}{9}}$

σ = 0.075 MPa

CORRELATED UCS MEAN = 280.8 ÷ 10 = 28.8 MPa

Rock Masses (BIENIAWSKI 1976)

STRUCTURAL REGION

ROCK TYPE AND ORIGIN

DRILL CORE QUALITY R.Q.D.

Excellent quality	90-100%	....
Good quality	75-90%	....
Fair quality	50-75%	....
Poor quality	25-50%	....
Very poor quality	<25%	....

R.Q.D. = Rock Quality Designation

WALL ROCK OF DISCONTINUITIES

Unweathered ....

Slightly weathed ....

Moderately weathed ....

Highly weathered ....

Completely weathed ....

Residual soil ....

GROUND WATER

INFLOW per 10m of tunnel length   litres/minute ....

or

WATER PRESSURE   kPa ....

or

GENERAL CONDITIONS (completely dry, damp, wet, dripping or flowing under low/medium or high pressure

....

STRENGTH OF INTACT ROCK MATERIAL

Designation	Uniaxial compresive strength, MPa	OR	Point-load strength Index, MPa
Very high	Over 250		>10 ....
High	100 - 250		4-10 ....
Medium high	50 - 100		2-4 ....
Moderate	25 - 50		1-2 ....
Low	5 - 25		<1 ....
Very low	1 - 5		

SPACING OF DISCONTINUITIES

		Set 1	Set 2	Set 3	Set 4
Very wide	Over 2m	....	....	....	....
Wide	0.6-2 m	....	....	....	....
Moderate	200-600mm	....	....	....	....
Close	60-200mm	....	....	....	....
Very close	<60mm	....	....	....	....

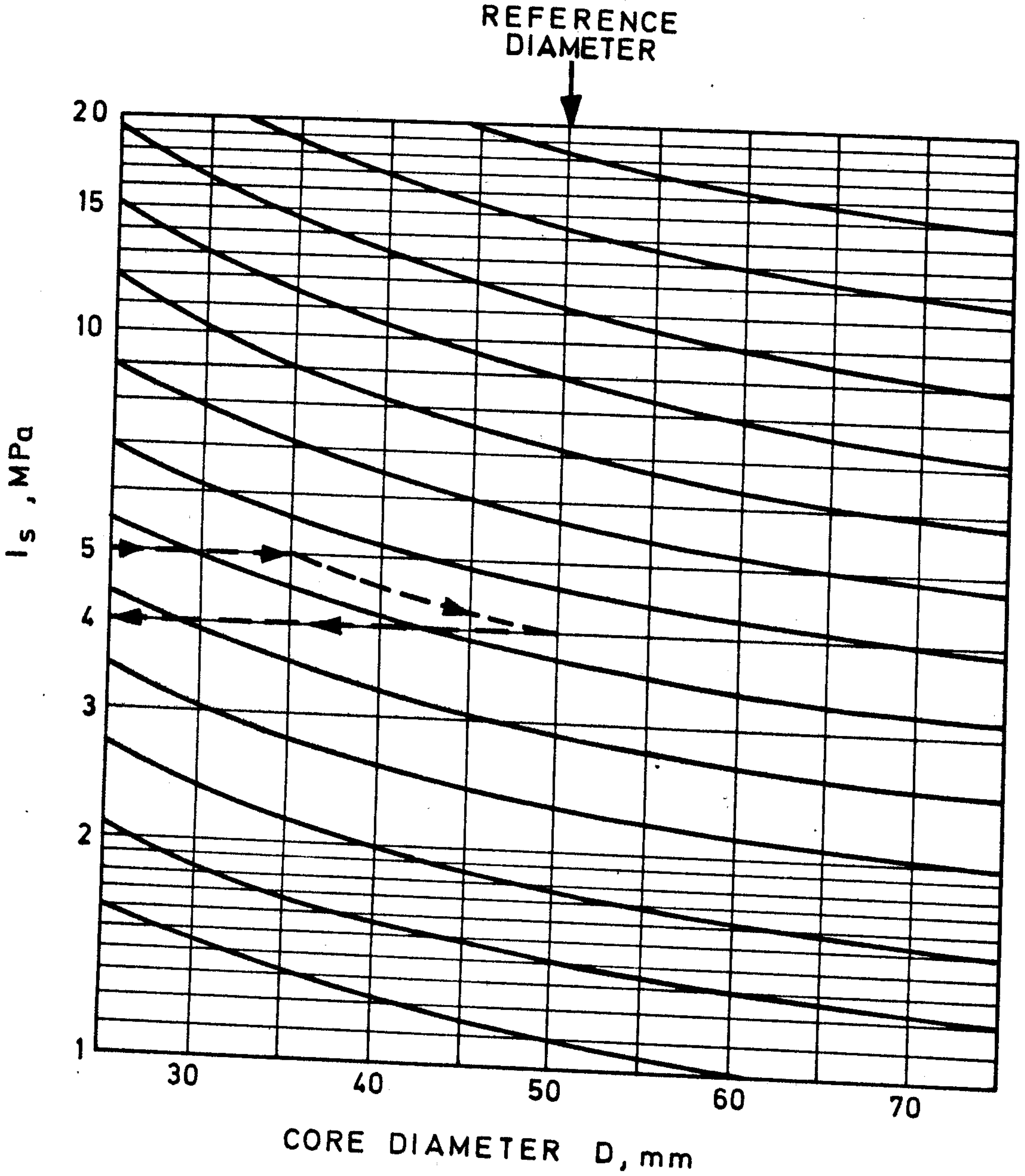
STRIKE AND DIP ORIENTATIONS

Set 1	Strike	(from .... to ....)	Dip .... (angle)	.... (direction)
Set 2	Strike	(from .... to ....)	Dip	....
Set 3	Strike	(from .... to ....)	Dip	....
Set 4	Strike	(from .... to ....)	Dip	....

CONDITION OF DISCONTINUITIES

		Set 1	Set 2	Set 3	Set 4
PERSISTENCE (CONTINUITY)					
Very low.	<1m	....	....	....	....
Low.	1-3 m	....	....	....	....
Medium	3-10 m	....	....	....	....
High	10-20m	....	....	....	....
Very high	> 20m	....	....	....	....
SEPARATION (APERTURE)					
Very tight joints	<0.1mm	....	....	....	....
Tight joints	0.1-0.5mm	....	....	....	....
Moderately open joints	0.5-2.5mm	....	....	....	....
Open joints	2.5-10mm	....	....	....	....
Very wide aperture	> 10mm	....	....	....	....
ROUGHNESS (state also if surfaces are stepped, undulating or planar)					
Very rough surfaces		....	....	....	....
Rough surfaces		....	....	....	....
Slightly rough surfaces		....	....	....	....
Smooth surfaces		....	....	....	....
Slickensided surfaces		....	....	....	....
FILLING (GOUGE)					
Type		....	....	....	....
Thickness		....	....	....	....
Uniaxial compressive strength, MPa		....	....	....	....
Seepage		....	....	....	....

GENERAL REMARKS AND ADDITIONAL DATA



1·50 SIZE CORRELATION CHART FOR POINT LOAD INDEX PROPOSED BY BROCH AND FRANKLIN (1972)