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An Outline of the Geology of the Bukit Ibam Orebody, Rompin, Pahang

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Abstract: The Bukit Ibam orebody was the largest single body of iron-ore exploited by the Rompin Mining Co. Ltd. between the years 1962 and 1970. The orebody was intercalated in a sequence of volcanic rocks close to a small granodiorite body. On a regional scale the igneous rocks formed part of an assemblage of volcanic and meta-sedimentary rocks of unknown but probably pre-Jurassic age, cut by numerous small intermediate to basic plutonic bodies. A number of other iron ore bodies of smaller size were mined in the surrounding area which formed a minor iron ore province.

The primary iron orebody could be divided into two distinct zones, an upper oxidized and iron-enriched zone which furnished high grade haematite-magnetite ore after simple processing, and an underlying protore containing mainly magnetite in a complex magnesium silicate gangue which required upgrading by magnetic separation to yield a saleable product. Massive limonite ore of slightly lower grade formed a distinct zone along the hangingwall and and contributed largely, together with the haematite, to a mantle of secondary boulder ore on the flanks of the main hill.

Copper, zinc and bismuth were present in minor amounts and constituted the main commercially significant impurities in the ore. Copper (average concentration 0.08%) was markedly concentrated into the limonitic ore along the hangingwall and in a zone of secondary sulphide enrichment near the ore-protore boundary. Zinc (average concentration 0.07%) was markedly concentrated in the hard limonite ores. It was also present in chloritic rocks along the hangingwall and in manganiferous concentrations. Bismuth was concentrated in the more friable zones of the high grade haematite-magnetite ore and averaged about 0.06% overall. The principal non-metallic deleterious impurity was sulphur, which occurred as pyrite in the lower unoxidized protore zone.

The ore zone lies within a sheath of sheared and chloritized rocks between a hangingwall of deeply weathered unmetamorphosed acid volcanics and a footwall of hard siliceous pyritic hornfels. A short distance into the footwall, but never less than 200 feet from the ore, is the granodiorite. Substantial shearing occurs along the footwall of the ore and along parts of the hangingwall, and at least one strong fault zone cuts obliquely through the ore. Mineralization of a distinct type followed this fault in the hangingwall rocks.

The orebody may have originated contemporaneously with the volcanic series as an exhalative—sedimentary deposit over an intrusive at shallow depth. Subsequent folding and fracturing with further rise of the granodiorite to close below the ore caused considerable thermal metamorphism of the footwall rocks and shearing and recrystallization of the ore zone, with some redistribution of the copper and sulphur. The high grade ore was formed subsequently by supergene processes which upgraded the iron content by removal of magnesium, silicon and sulphur and oxidation of magnetite to haematite and pyrite and chlorite to limonite.

INTRODUCTION

The geology of south-east Pahang between the Pahang and Rompin Rivers is unmapped and the age of the metamorphosed series of sedimentary and volcanic rocks is not known. The well developed cleavage and generally steep dips, together with the frequent small intrusives in the area suggest that they pre-date the deposition of the Tembeling Formation (mainly Jurassic) which occupies a broad syncline in the valley of the Sungai Jeram to the west (MacDonald, 1959; Koopmans, 1968), and they certainly pre-date the deposition of the flat-lying orthoquartzites and shales of the Gagau Group (mainly Lower Cretaceous?) which outcrop extensively south of the Sg. Rompin (Unpublished work of the Geological Survey of Malaysia and Colombo Plan Geologists).

The Bukit Ibam orebody formed, before mining, a well-defined north-south ridge on the eastern margin of the Bukit Sembilan range of hills, and is located 35 miles inland from the coast of the South China Sea and 6 miles north of the Sungai Rompin. The hill ranges of Bukit Sembilan and Bukit Pemandang are built up from metamorphosed acid volcanic and sedimentary rocks and rise steeply to an elevation of 1600–1800 feet above an undulating plain 50–300 feet above M.S.L. Other isolated hills rise to around 1,000 feet from this plain which appears to be mainly built up from unmetamorphosed sedimentary rocks. Within the higher ground of the Sembilan and Pemandang ranges are a number of distinct hollows, clearly visible on the aerial photographs, which mark the outcrops of minor diorite and granodiorite intrusions, while to the north a substantial diorite-gabbro body crops out.

Eight of these minor intrusions are known and their topographic expression together with the widespread metamorphism around them strongly suggests that they are parts of the same more extensive body at deeper levels. The diorite and gabbro intrusions are strongly magnetic with around 5% contained magnetite, and hand specimens can frequently be picked up with a hand magnet. Strong aeromagnetic anomalies are found over these intrusions and the entire area of metamorphic and intrusive rocks is one of considerable magnetic relief. These features are very clear on the private aeromagnetic survey carried out by Huntings for the Rompin Mining Company, and can also be seen on the published small scale maps (Agocs, 1966).

A number of separate iron ore bodies have been located and worked, both recognizable primary orebodies and secondary bouldery residual accumulations contributing significantly to the output of the field, which totals about 15,000,000 long tons to date. The orebodies are grouped around some of the intrusions, and the larger primary orebodies are probably all within 1,000 feet of the intrusive contacts. There appear to be fundamentally two types of primary orebodies: magnetite bodies with calc-silicate gangue, and haematite-pyrite bodies. High grade, dominantly haematite ores have developed by supergene enrichment from both types of primary ore; most of the secondary boulder ore accumulations have probably developed from the haematite-pyrite bodies.

The largest single orebody so far developed is the Bukit Ibam orebody which was opened up for mining in 1962 following the construction of 50 miles of metre gauge railway linking the mine with the coast at Kuala Rompin and the expenditure of M$100,000,000 to establish the mining venture. Shipments of lump and fine ore, with a grade of 60–64% Fe, were rapidly built up to a total of 2,200,000 tons per annum. All the ore produced to date has been exported to Japan.

Very little thin or polished section work was done in this area except for the work of J. Bean which is not available to me. This is regretted as a more detailed knowledge of the ore would assist the geological interpretation.

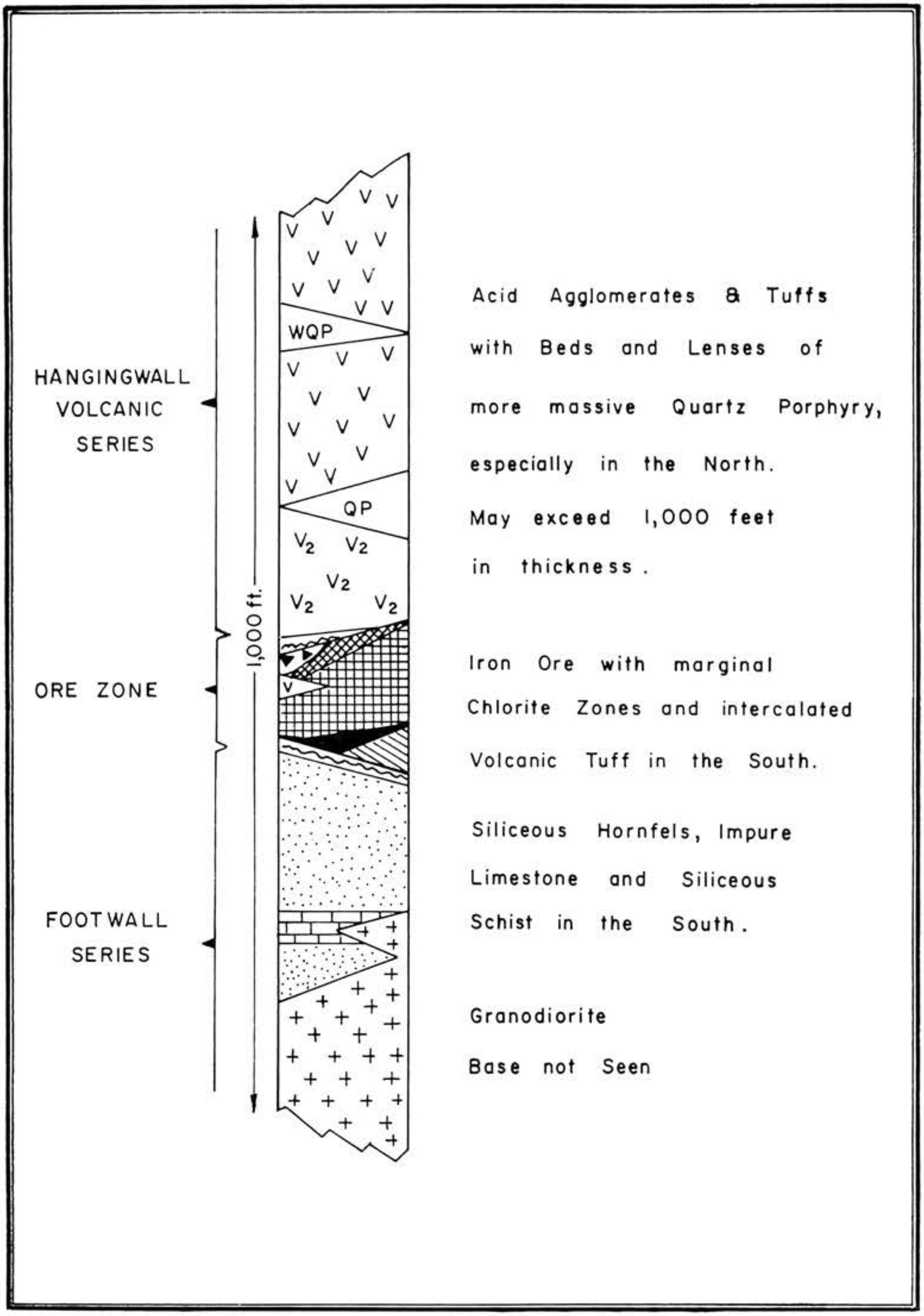

Fig. 1. Stratigraphic succession in the Bukit Ibam mine area.

GEOLOGICAL SUCCESSION EXPOSED IN THE MINE AREA

The apparent stratigraphic succession is shown in figure 1.

Granodiorite

The granodiorite, which forms the base of the exposed sequence, is intrusive into the other rocks. It was intersected by drilling on the 12,000 N section (fig. 6), where it is in contact with impure limestone. Hybrid rocks with chlorite and extensive calcite veining are developed in the contact zone with apparent interbedding of intrusive and limestone. To the south, on the 8000 N co-ordinate, the contact is exposed in the Sungai Mungus, where a siliceous schist not otherwise seen in the mine area is in contact with the granodiorite along a very sharp and steep line conformable with the schistosity.

A specimen of the intrusive from this locality was examined by the Geological Survey of Malaysia and proved to be a true granodiorite, consisting essentially of labradorite and hornblende. In contrast to the dioritic bodies exposed elsewhere in the area, no accessory magnetite was found in this intrusive and no aeromagnetic anomaly was found associated with it.

Siliceous schist

The siliceous schists in contact with the granodiorite are strongly banded rocks consisting largely of quartz with some mica. Both schist and granodiorite are cut by strong joints spaced 2–6 feet apart, which divide the rock into large blocks. The granodiorite weathers along these joints to yield core boulders 2–5 feet in diameter.

Impure limestone

Impure limestone, in contact with the granodiorite on the 12000 N cross-section (fig. 6), has been seen in 6 diamond drill holes but is not known at outcrop. It consists of a very variable amount of white calcite with fine grained siliceous material and abundant chlorite. Fine grained calc-silicate minerals are present but were not identified. Occasional clots of pyrite ocur, but pyrite is not widely disseminated through the rock; magnetite is absent. Similar rocks occur some 3 miles to the south at Bukit Merah, where a surface weathered zone of chocolate brown clay with nodular manganese oxides and hydroxides and crumbly acicular quartz aggregates was proved by drilling to overlie a coarse grained calcite-quartz-tremolite rock.

Siliceous hornfels

Siliceous hornfels varying in thickness from 180–210 feet underlies the ore zone throughout the length of the mine. The typical rock type is a fine grained quartz-feldspar-chlorite hornfels with a little greenish biotite and abundant disseminated pyrite. Variations occur between an almost pure white fine-grained quartzite and a grey-green chlorite rich rock. Some of the rock shows a distinct faintly banded light grey spotting in a darker grey groundmass, but generally no directional texture is visible.

In drill cores from the full thickness of this rock unit and along the exposed footwall of the orebody in the opencut a very strong and intense pattern of joints is to be seen. These cause the rock to break readily into fragments which vary in size from $\frac{1}{2}\times 1\times 1$ inch to $6\times 12\times 12$ inches, and are usually rhombic in shape. In unweathered drill cores these joints are picked out by thin stringers of white powdery calcite or by pyrite. These stringers vary in thickness from $\frac{1}{2}$ inch down to hairline thickness and are

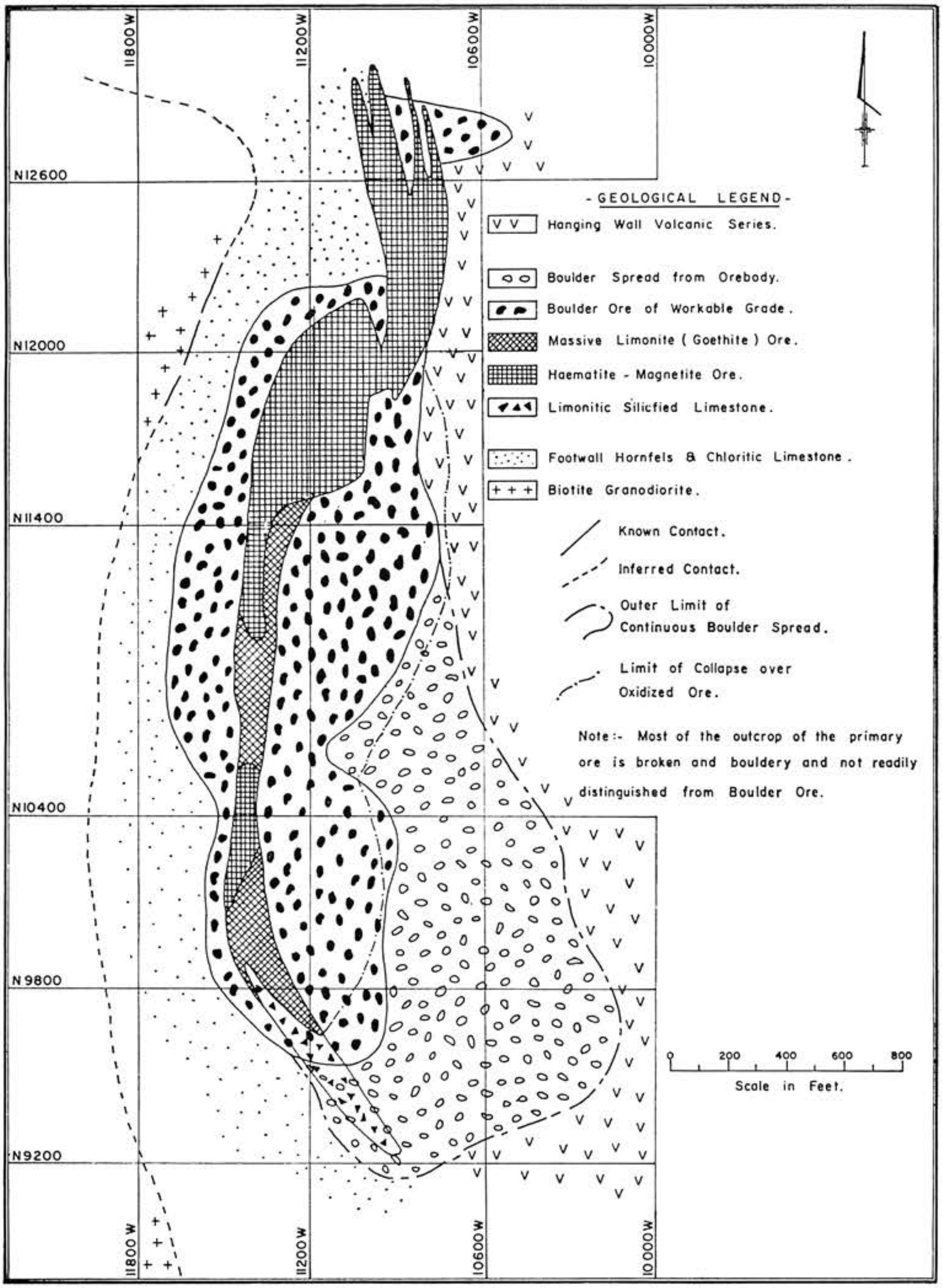

Fig. 2. Surface geological plan of the Bukit Ibam orebody before mining.

found throughout the rock unit outlining the three joint directions. The entire body of this rock unit has been shattered and veined but with no movement of the shattered fragments relative to one another.

This rock weathers in two distinct stages with oxidation and leaching of the joint fillings preceding the breakdown of the pyrite and feldspar of the body of the rock. As a consequence of normal weathering pyrite and feldspar are replaced by limonite and sericite-kaolin, softening the whole rock and converting it to a varicoloured clay, usually grey-white to purplish brown. Usually the pyrite and feldspar decay together and the rock changes in a short vertical distance from hard to soft. In some places, where the rock is more feldspathic, the destruction of the feldspar precedes the oxidation of the pyrite and the rock alters to a white clay with fresh to tarnished pyrite.

Chloritic footwall and hangingwall rocks

The immediate footwall of the orebody is a distinctive lithological unit consisting mainly of chlorite and talc. The first sign of this unit appears 10–40 feet below the orebody where slickensided shears with abundant chlorite are found lying parallel to the footwall. The intensity of this shearing increases rapidly towards the ore and immediately below the ore the rock consists almost entirely of greasy chlorite and talc, heavily sheared and slickensided parallel to the contact and containing abundant sulphides, mainly pyrite with locally a little chalcopyrite and patchy magnetite. When exposed to weathering this material alters to a brown limonitic clay.

Very similar material follows the hangingwall for part of its length and caused much difficulty when prospecting adits were driven through it, with heavy caving and large inflows of water. Substantial amounts of calcite also occur in the hangingwall zone together with local concentrations of chalcopyrite.

Quartz porphyry and agglomerate

Along the greater part of its length the hangingwall is made up of highly decomposed rocks which are very difficult to identify. North of 12100 N and locally to the south, unweathered rock is seen in boreholes, and can be identified as agglomerate, tuff and quartz porphyry. The unweathered quartz porphyry is more massive and hard than the other rocks and is made up of a fine grained quartzofeldspathic matrix with numerous quartz phenocrysts and sparsely disseminated pyrite. There are no signs of lava-flow structures and the rock is probably a welded crystal tuff. Large blocks up to two feet in diameter are found in the coarser agglomerate members. All are weakly cemented and somewhat decomposed and are acid and feldspathic in composition. Except where obliterated by deep secular weathering the primary textures of these rocks are clearly visible and no noticeable metamorphic effects can be discerned in them, in marked contrast to the footwall rocks described above.

NATURE OF THE MAIN BUKIT IBAM OREBODY

The main primary orebody at Bukit Ibam consisted essentially of a single lens of ore 3,000 feet in length striking north-south and dipping generally to the east with a maximum vertical extent of about 800 feet and a maximum true thickness of 220 feet Several million tons of detrital boulder ore spread over the flanks of the hill below the main outcrops indicated that the orebody had suffered considerable erosion, particularly at the south end and that one quarter, perhaps as much as one third, of the original orebody had been removed by erosion. The surface plan of the area before mining is shown in figure 2. Four main types of ore occurred within the ore lens itself. These were

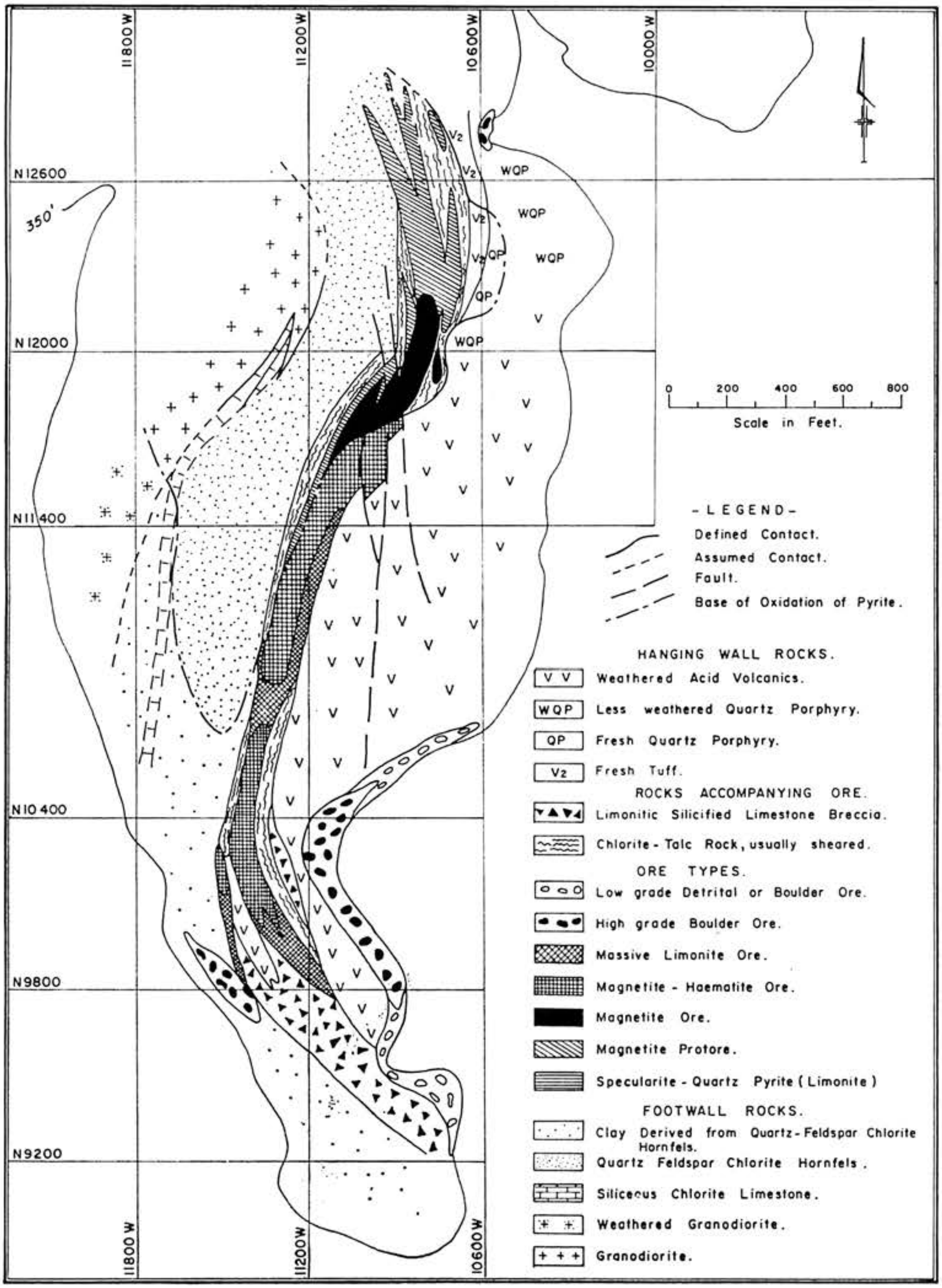

Fig. 3. Bukit Ibam orebody horizontal section on the 350 foot level.

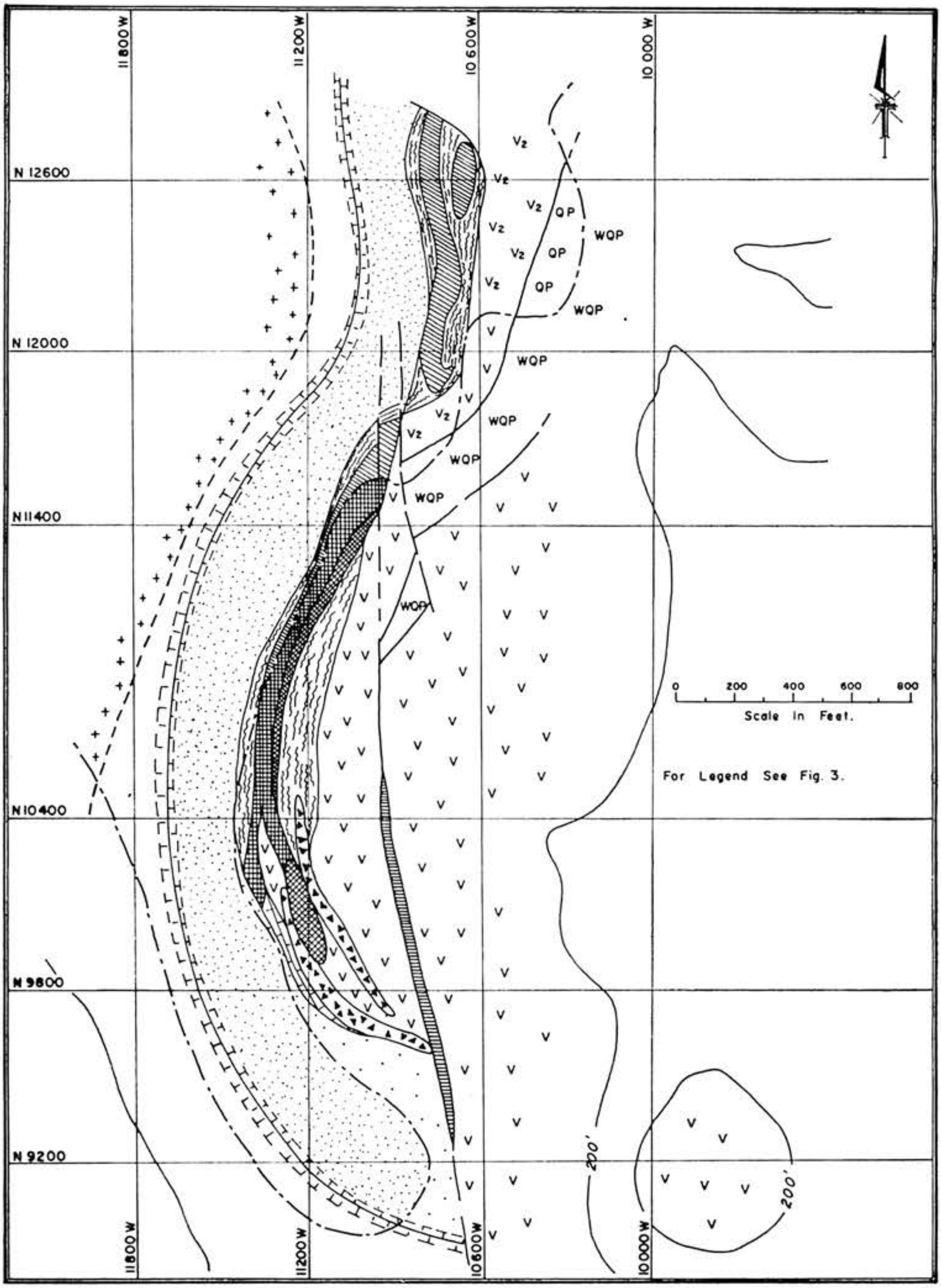

Fig. 4. Bukit Ibam orebody horizontal section on the 210 foot level.

systematically distributed from south to north and from surface to depth in the following manner:–

South & top levels:	4.	Massive hard limonite ore with a little haematite.
	3.	Friable haematite with residual magnetism.
	2.	Massive martite and magnetite.
North & lower levels:	1.	Magnetite ore and magnetite-protore.

The magnetite protore is the only type unaffected by tropical weathering and as it is thought to be the parent material for types 2 and 3 it will be described first.

Magnetite ore and protore

The distribution of these materials can be seen from the plans of the 210 and 350 foot levels (figs. 3 & 4) and from sections 11400 N, 12000 N and 12600 N (figs. 5, 6 & 7) and it lies below and to the north of the high grade magnetite-haematite. Some of this material had a grade of better than 60% Fe *in situ* and constituted high grade direct shipping ore but the grade of the protore could be as low as 25% Fe. The overall bulk grade was around 45% Fe and the great majority of the iron was present as magnetite (Fe_3O_4) in well crystallized aggregates or single crystals within a highly magnesian gangue made up essentially of a felted mass of anthophyllite ($Mg_7Si_8O_{22}(OH)_2$) and talc $Mg_3Si_4O_{10}(OH)_2$) with lesser amounts of tremolite-actinolite ($Ca_2Mg_5Si_8O_{22}(OH)_2-Ca_2(Mg, Fe)_5Si_8O_{22}(OH)_2$). A little pyrite was present, segregated near the margins of the ore with very minor chalcopyrite. The magnetite, which occurred as single crystals up to 4 inches in diameter, was extremely pure, and primary haematite was essentially absent. No trace elements appeared to be incorporated in this magnetite, in marked contrast to that from Bukit Batu Hitam 4 miles to the north which contained $2\frac{1}{2}$% Mn and 0.3% Zn. The bulk chemical composition of this material was approximately determined as:–

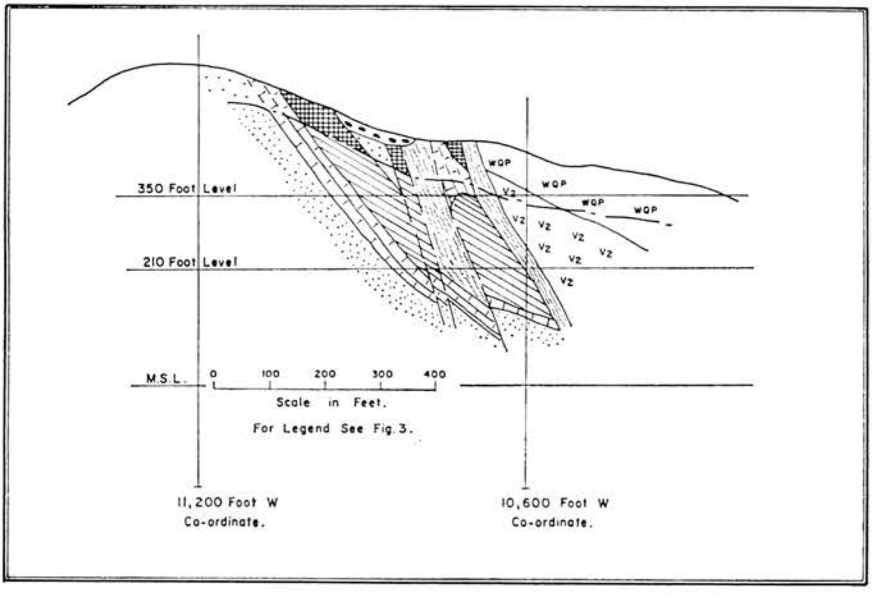

Fig. 5. Vertical cross section along the 12,600 foot north co-ordinate.

Fe_3O_4	64%
SiO_2	18
MgO	11
Al_2O_3	3
CaO	2.5
S	0.5
	99.0%

The porosity was very low and the tonnage factor was around 10 cubic feet to the long ton (S.G. = 3.6).

Massive martite and magnetite high grade ore

This material, grading around 65% Fe, is found in lenses and irregular masses within the main orebody, in intimate association with more friable ore. It consists essentially of feebly magnetic to strongly magnetic haematite derived from and locally grading into massive magnetite with subordinate amounts of limonite and a little clay. Maghemite was present but rare and the great bulk of the material had the red streak of haematite. Empty vugs and cavities were common, with frequently a little clay, and the porosity was 10%–15%, with a tonnage factor of around 8½ cubic feet to the long ton (S.G. = 4.2). It is almost certainly derived by weathering of the more massive magnetite primary ores with oxidation of the pyrite and almost complete removal of the calcium and magnesium silicates.

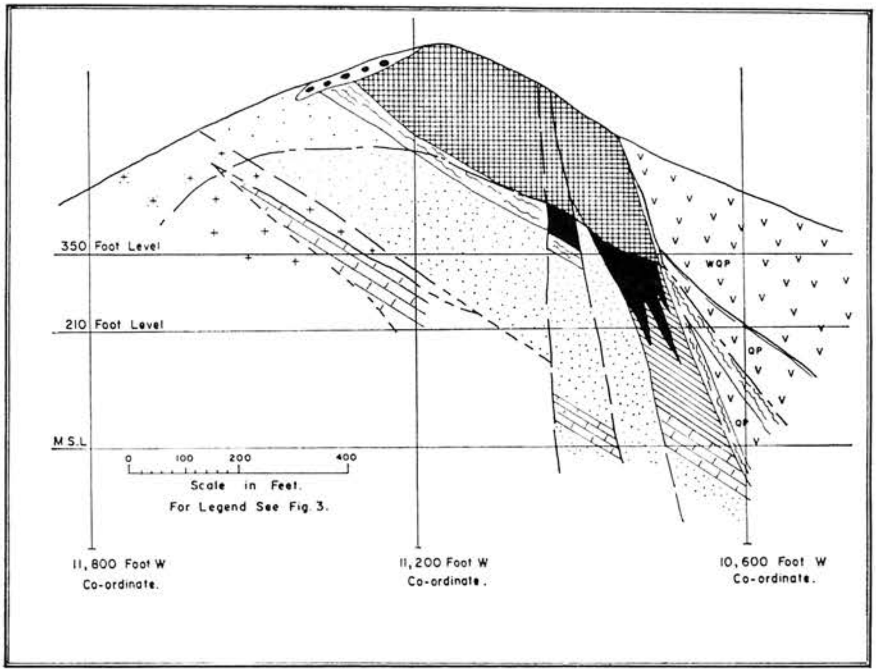

Fig. 6. Vertical cross section along the 12,000 foot north co-ordinate.

Friable haematite with residual magnetism & magnetite

Interdigitated with the massive martite and forming a substantial part of the central parts of the orebody were friable ores of very similar mineralogy. The major constituents were feebly to strongly magnetic haematite (martite) and some magnetite occuring as free crystals of varying size, either embedded in a grey-white or yellow kaolinitic clay or occurring quite free and loose. This latter ore, when dry, constitutes a free running iron sand. Locally very coarse magnetite crystals in the form of rhombdodecahedra up to 4 inches in diameter were found embedded in clay together with limonite replacements of pyrite cubes up to the size and shape of house bricks.

Ores of this type varied in grade from 55% to 66% Fe, depending essentially on the clay content, but the higher grade ores had a porosity of up to 30%, and the average tonnage factor was only 11 cubic feet to the long ton (S.G. = 3.3). The overall average grade of this ore was probably only 60—61% Fe but it was readily amenable to upgrading by simple washing to 64—66%.

The *in situ* grade of the massive and friable haematite ores was of the order of 62—63% Fe and they had an approximate bulk compostion as follows:–

Fe_2O_3	90%
Al_2O_3	3.5—4.0
SiO_2	3.5—5.0
CaO	0.05
MgO	0.05
S	0.05

The balance was minor elements and combined water.

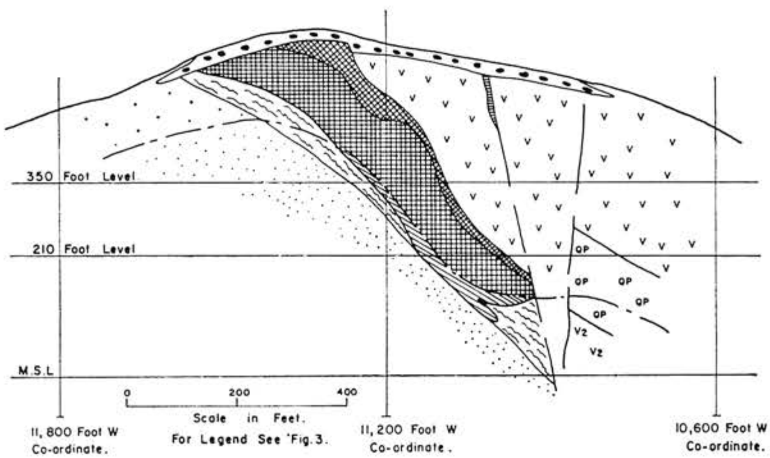

Fig. 7. Vertical cross section along the 11,400 foot north co-ordinate.

Massive hard limonite ore with a little haematite & magnetite

Forming a well marked strip along the hangingwall of the orebody from 11400 N (fig. 7) to 10600 N and building up the bulk of the orebody south of 10200 N (see fig. 3) was a sharply defined zone characterized by massive hard brown limonite with local strips of yellow clay. Well crystallized haematite and occasionally magnetite were found in this zone, together with some earthy haematite. There was no evidence that the limonite was an alteration product of either haematite or magnetite.

At the south end of the orebody both laterally and in depth the massive limonite ore gave way to an angular breccia of siliceous fragments around one inch in diameter set in a limonite matrix (figs. 3 and 9). Relict rhombic cleavage boxworks preserved in some of the fragments in the breccia indicated that the siliceous fragments had originally been carbonate. At the extreme south end of the orebody the limonite cement was locally replaced by black manganese oxides which contained significant percentages of zinc, the zinc content being roughly proportional to the manganese with a Zn/Mn ratio of 1 to 6 (the highest sample was 36% Mn and 6% Zn).

Hard limonite ore was mainly found where the zone of sheared chlorite was absent along the hangingwall and massive limonite was only found in the more deeply and thoroughly oxidized southern parts of the ore zone. The most likely origin of the limonite is from the weathering and concentration of the iron content of the ferruginous chlorite of the hangingwall sheared zone where this was exposed longest to weathering.

Minor specularite—pyrite mineralization

Within the hangingwall of the orebody were irregular patches of coarse specular haematite and gossan apparently derived from pyrite. These occurred within a belt of shattering which cuts obliquely through the orebody and appears to post-date the main period of iron mineralisation. There is no base metal associated with this mineralization, which does not give rise to workable ore at Bukit Ibam. Immediately to the south on Bukit Sanlong and Bukit Pesagi similar mineralization gives rise to small workable orebodies of haematite which in depth are mixtures of specular haematite and pyrite.

DISTRIBUTION OF TRACE ELEMENTS IN THE MAIN OREBODY

Several hundred samples from the first phase of widely spaced diamond drilling and from adits were analysed for a wide range of elements to determine which minor and trace elements were present in sufficient quantity to require care in quality control. It was known from earlier Japanese work from before the Second World War that copper was present in significant quantities, locally reaching several percent (Unpublished reports to the Mines Department by Ishihara Sanyo Kaisha, 1939–1941). The preliminary assay work showed that Cu, Zn and Bi were present in significant amounts and that P, As and S were locally present. TiO_2, SiO_2 and Al_2O_3, while present, were well within the normal limits for iron ore, and Sn, a major contaminant in iron ores in Malaysia (e.g. Bukit Besi, Trengganu), was essentially absent.

Subsequently all drill hole and adit samples were assayed for Cu, Zn, Bi, P, As and S in addition to iron. The distribution of each element was plotted on cross sections and level plans and the key to the geological association of each element sought. The ore reserves were calculated in detail for each element and routine production quality control was instituted for Fe, Cu, Zn and Bi. All blast holes were assayed for these four elements and mining was controlled to even out the variations on a day-to-day basis. Lump and fine ore products were sampled and assayed before being loaded onto trains, and individual train loads were further blended by selective stock piling and reclaiming at the coastal shipping point, while further sampling took place during shiploading in Malaya and unloading in Japan. As a result of this work a detailed knowledge of the impurity distribution and associations was worked out.

Distribution of copper

In the unweathered parts of the orebody the only copper mineral found is chalcopyrite, usually associated with pyrite, in coarse to medium grained blebs and stringers markedly concentrated in the chloritic sheared marginal zones of the orebody. Subordinate amounts of sphalerite were locally found intergrown with the chalcopyrite but assays showed little zinc to be generally associated with the sulphide phase. One specimen examined showed a trace of free gold but limited assays showed no gold associated with the copper.

In the central zone of the orebody between 11600 N and 12400 N relatively high copper values were obtained at and for a short distance below the base of oxidation of pyrite. Covellite (CuS) chalcocite (Cu_2S) and native copper (Cu) were found replacing the chalcopyrite upwards, with the zone of highest copper assays coinciding with the visible native copper. Above the base of oxidation, copper values were less and the visible copper minerals were cuprite (Cu_2O) and malachite ($CuCO_2.Cu(OH)_2$). Secondary sulphide enrichment was indicated, and had been assisted by the ready migration of water along the marginal sheared zones of the orebody where the primary copper mineralization was concentrated.

South of 11600 N the oxidation of the orebody was much more thorough and was essentially complete on the hangingwall side. Small amounts of sulphide copper were found along and within the footwall. On the hangingwall side the massive limonitic ore had a higher than average copper content (about 0.15% Cu) fairly evenly distributed through it. The copper appeared to be lattice-held and no independent copper minerals were found in this limonite ore during examination of polished sections at Australian Mineral Development Laboratories, Adelaide.

The copper which is held in limonite naturally follows the massive limonite into the lump ore product. The other copper-bearing minerals, being generally softer and more friable, are segregated preferentially into the fine ore product. The form of the copper was therefore very important in predicting the behaviour of the copper in the treatment plant and was an important factor in the quality control of the product.

Distribution of zinc

Two primary modes of occurence of zinc are known in the immediate mine area. Sphalerite occurs as a minor constituent of the copper sulphide phase within the orebody and as very occasional pure sphalerite veinlets in the footwall rocks. Zinc also occurs in significant amounts of 0.1%–1% in massive chlorite-epidote rock along the hanging wall of the ore south of 11,400 N. The absence of sulphur precludes sphalerite as the responsible zinc mineral, and the precise form of the zinc is unknown. The zinc may be present as a molecular substitute for iron in the chlorite.

The high zinc content of the chlorite rock is matched by the zinc content of the limonite ore which appears to be derived from it by weathering and this is the main mode of occurrence of zinc in the orebody. Like the copper in the limonite the zinc appears to be evenly distributed through the massive limonite ore and no independent zinc minerals are known. It is probably also lattice-held and assayed 0.30% zinc on average. A high zinc content in manganese oxides is a regional feature in Ulu Rompin where all manganese oxide material assayed shows zinc levels of several hundred to a few thousand parts per million. High-zinc limonites are however not widespread in the area and no other limonites as zinc-rich as those at Bukit Ibam were found.

Because of its association with massive limonite the zinc was markedly concentrated into the lump ore product during processing and quality control for zinc was mainly needed for the lump product.

Distribution of bismuth

Bismuth did not occur in significant quantities in the remaining unoxidized portions of the orebody and the primary form of the bismuth is unknown. High bismuth values were restricted to friable haematite and magnetite zones and the highest bismuth contents of all (over 1%) were found in earthy white or grey clays within the friable ore zones. It was probably a hydrated oxide or carbonate (the precise minerals have since been identified by J. Bean, working at Durham University, England).

In consequence of this distribution bismuth was concentrated in the fine ore product and rarely occurred in significant amount in the lump ore. In fact significant quantities of bismuth were washed out of the iron ore products and into the slime tailings.

Other minor element impurities

Small amounts of phosphorous and arsenic occurred in the massive limonite ore. Separate quality control was not needed as the control of the zinc and copper content effectively controlled the phosphorous and arsenic.

Sulphur occurred exclusively in the primary unoxidized parts of the orebody as pyrite and minor copper sulphides. Sulphur was not a contaminant until the deeper parts of the orebody were reached, and the use of magnetic separation to upgrade the magnetite protore from the primary zones eliminated the sulphur, as pyrrhotite was absent.

RELATION OF ORE TO OTHER GEOLOGICAL FEATURES

Relationship to the granodiorite and metamorphic aureole

The ore with its associated envelope of chloritic rock and breccia was aligned in both plan and section parallel to the granodiorite, and was everywhere separated from it by a layer of pyritized metamorphic rock, probably contact metamorphosed tuff. The primary orebody itself was composed of minerals normally considered medium to high temperature—anthophyllite, tremolite, talc and magnetite—and the coarse texture of the ore indicated crystallization, or recrystallization, at elevated temperature. The hangingwall rocks, by way of contrast, showed little or no sign of recrystallization or contact metamorphism and were only sparsely pyritized, except at the northern end of the ore zone.

Substantial drilling into the footwall for engineering and pit stability studies clearly indicated that nowhere did the granodiorite come into contact with the ore zone, while deep drilling from the hangingwall side proved the main orebody to pass into chlorite and breccia zones in depth as well as along strike (see sections 10400 N, fig. 8, and 11400 N, fig. 7). The footwall drilling indicated limestones in the footwall in contact with the granodiorite (see section 12000 N, fig. 6) and proved the actual contact zone to be devoid of mineralization.

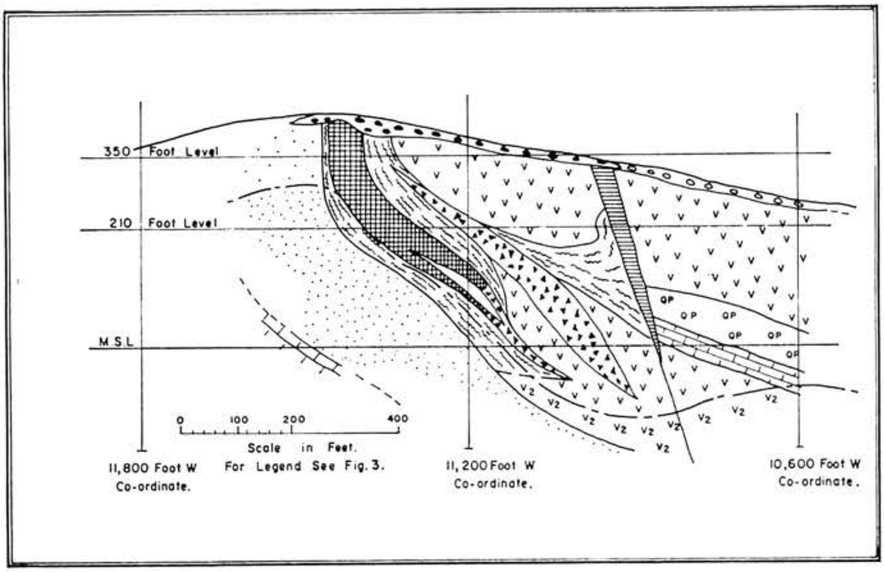

Fig. 8. Vertical cross section along the 10,400 foot north co-ordinate.

The copper, bismuth and zinc were distributed zonally within the orebody with copper in the north and in the footwall and zinc in the south and in the hangingwall, with a bismuth-rich zone between. These minor element patterns therefore also broadly parallel the granodiorite contact and the metamorphic aureole.

What evidence there is indicates that the granodiorite contact is locally concordant with the dip and strike of the footwall of the ore (see 12000 N, section fig. 6). It is likely therefore that both granodiorite and ore are locally concordant, but the lack of sedimentary structures makes this difficult to prove. The hangingwall, where parallel to the footwall, i.e. in 10400 N and 11400 N sections (figs. 7 & 8), appears likewise to be concordant. In section 11400 N (fig. 7), ore types and minor element zones, the orebody as a whole, and the hangingwall rocks appear to be bedded, and this appearance of concordance persists to the south (figs. 8 & 9). To the north the appearance of concordance disappears and the hangingwall becomes markedly discordant and sheared (figs. 5 & 6).

Faulting in and around the orebody

For much of its length the chloritic footwall of the orebody showed considerable evidence of shearing parallel to the footwall, with frequent well formed slickensiding indicating that the massive footwall rocks had moved upwards relative to the ore. These shears generally dip east at angles of 35°–50°. In the northern third of the orebody the hangingwall was marked by a very well defined sheared zone which dips to the east at 60°–80° and forms a sharp contact between ore zone and "quartz porphyry". A second zone of steeply dipping fractures cut through the orebody between 11600 N

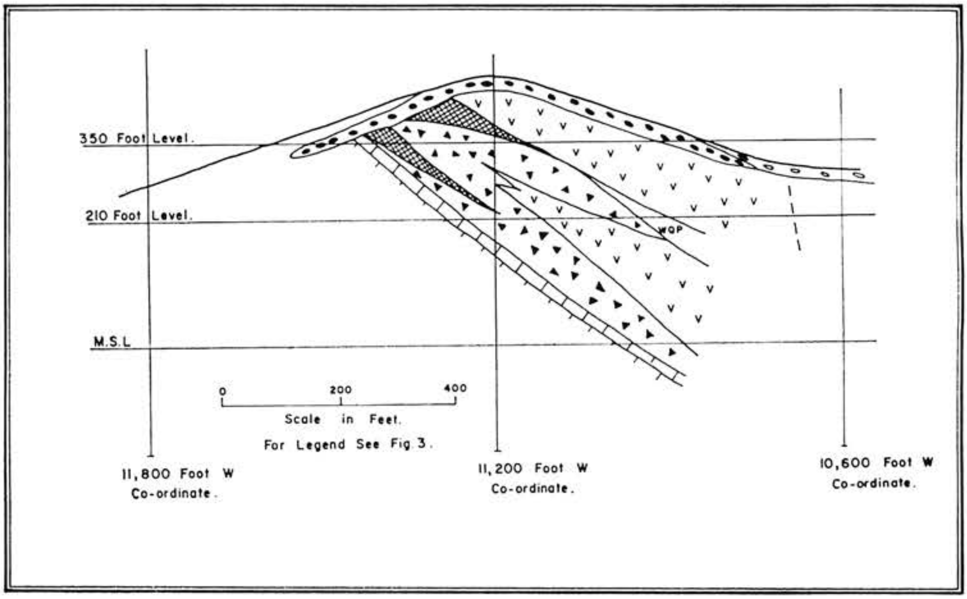

Fig. 9. Vertical cross section along the 9,800 foot north co-ordinate.

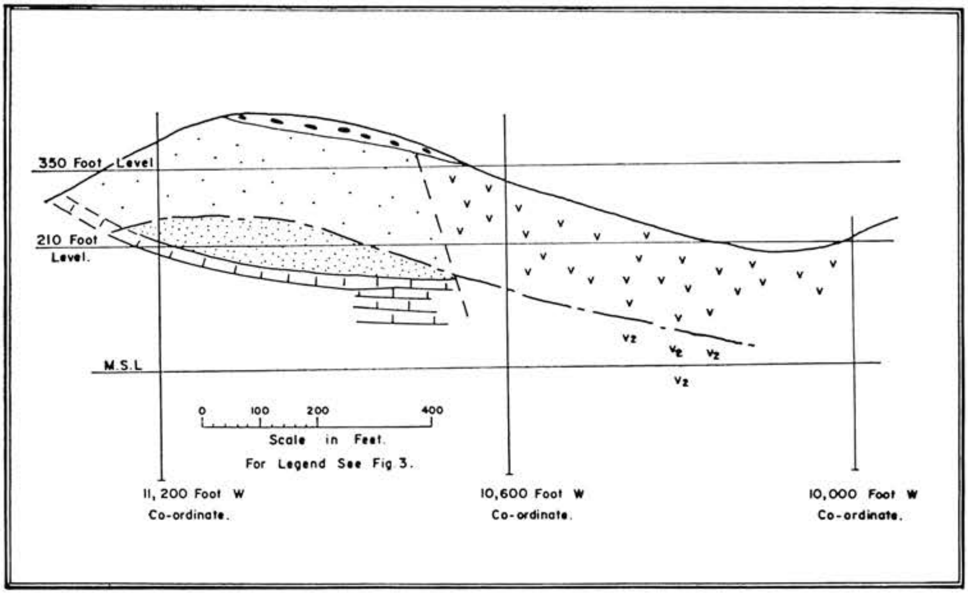

Fig. 10. Vertical cross section along the 9,200 foot north co-ordinate.

and 12200 N, where it caused substantial dislocation and complexity, and could be followed southwards through the hangingwall rocks where it was marked by brecciation and weak quartz-haematite-pyrite mineralization.

The evidence for the age of the shearing is ambiguous; it clearly cuts the ore zone but is itself mineralized. The general effect of the faulting is to downthrow the hangingwall relative to the ore and the ore relative to the footwall. The last phase of movement, postdating formation of the orebody, may be related to the final stage of emplacement of the granodiorite, which with its contact altered rocks was uplifted relative to the hangingwall, most of the movement taking place along the chloritic margins of the orebody.

The small pyrite-specularite orebodies of Bukit Sanlong and Pesagi 6 a few miles to the south were cut by a number of small, closely spaced post-ore faults which cut the ore at a large angle, but such faulting was not found at Bukit Ibam itself.

POSSIBLE MODE OF ORIGIN OF THE ORE

Most descriptions of orebodies or mineralized districts end, or sometimes begin, by giving the genesis of the orebody in question in terms of a currently fashionable hypothesis. For the Rompin district, and for Malayan iron ores in general, the question of the ultimate origin of the iron mineralization is rendered more difficult than usual by the final phase in their formation: deep tropical weathering. At Bukit Ibam roughly 75% of the primary iron mineralization had been thoroughly oxidized and in the process upgraded to ore amenable to simple beneficiation .In much of the surrounding area the proportion of such supergene ore was higher, frequently 100%, and the true primary ore sources (or protore) either unknown, unimportant or unworkable. At Bukit Ibam the primary iron mineral was magnetite, and unweathered mineralization was present in sufficient quantity to make ore, the iron concentrate being extracted magnetically.

In considering the mode of origin of the primary iron mineralization at Bukit Ibam the following features of the orebody are important:–

1. The orebody forms a single lens with maximum dimensions of 3000 by 800 by 200 feet.
2. It is in part concordant with and in part discordant to the surrounding rocks and is cut by faulting parallel or sub-parallel to the ore.
3. The ore is within the contact metamorphic aureole of a minor intrusive and the texture of the ore may well be metamorphic, or modified by metamorphism.
4. It is interbedded into a volcanic sequence with impure calcareous intercalations.
5. The gangue of the orebody is highly magnesian.
6. The granodiorite in the footwall is free of magnetite (in marked contrast to neighbouring stocks) and where in direct contact with limestone does not give rise to ferruginous skarn minerals.
7. The minor elements are distinctly zoned both laterally and across the thickness of the orebody.
8. The ore passes laterally, in depth and across the thickness, into ferruginous and zinciferous chlorite or limonitic silicified carbonate breccia, and is locally interbedded with volcanics in the south.

With the evidence as it stands it would be possible to argue in favour of a number of hypotheses of origin, chief among them being:

(1) a metamorphosed sedimentary ironstone,

(2) a magmatic segregation and injection, or volcanic exhalation,

(3) a contact metasomatic replacement of a favourable bed,

and (4) a hydrothermal replacement of a sheared zone,
with suitable combinations and permutations to explain special features of the ore.

If we assume that the ore is a natural product of the entire geological environment within which it occurs, and not an incidental late feature to be explained only by the last geological event we can detect, then a complex multiple origin in keeping with the complexity of the geological history may be invoked. The local geological succession consists of a thick series of coarse locally erupted volcanic rocks of acid type accumulating at least in part in water. Periods of non-supply of volcanic material were marked by the accumulation of carbonate sediments indicative of a local lack of clastic sediment. Eventually the pile of volcanics and sediments was intruded by the partly differentiated parent magma from which the volcanics were derived, with contact metamorphism and much faulting and shearing. The orebody can be fitted into this geological environment by considering it as the iron-rich fraction of the parent magma, which elsewhere in the region crystallized in the diorite as accessory magnetite. At Bukit Ibam this iron-rich fraction gained access to the surface during the development of the volcanic sequence and was trapped and concentrated as a carbonate-silicate sediment amongst the volcanics, with a primary fractionation of trace and minor elements amongst the various facies of the sediment.

Subsequent intrusion of the iron-impoverished magma, following earth movement, and associated faulting dislocated and contact metamorphosed the primary iron-rich sediment to give the present orebody. Mobilization of the minor sulphide phase took place leading to a concentration of pyrite and chalcopyrite along fault zones and the hangingwall and footwall contacts.

Exposure to surface weathering during the present erosion cycle was accompanied by an extensive mobilization and redistribution of elements, both major and minor. The major elements magnesium, calcium and silicon, originally combined as silicates, were leached out and dispersed; the silica made available in this way probably contributed to the observed silicification of the carbonate breccias. The iron content of the silicates was retained *in situ* as limonite, together with the zinc and copper originally associated with the silicates. The minor sulphide phase was destroyed by weathering and the bulk of the copper transported downwards to enrich the sulphide phase at and below the oxidation base. The magnetite was converted slowly to haematite and finally to limonite in the surface zone. In contrast to the leaching of the silicates and sulphides this oxidation and hydration of the magnetite is very slow, and some magnetite persists into the boulder ore.

The net result of these supergene processes was a very marked residual enrichment of iron in the oxidized zone. Peak iron enrichment was developed in the intermediate zone where the silicates had been removed but the iron oxides were not yet hydrated. In the top 20 feet or so impoverishment due to the hydration of the oxides was seen, and this lower grade material was also found in the weathered mantle of boulder ore surrounding the deposit. The grade of the boulder ore declined steadily away from the outcrop because of the combined effects of the continuing hydration and the increasing admixture of lateritic material derived from the weathering of the country rock.

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