THE IRON AND MANGANESE ORE DEPOSITS IN ETHIOPIA

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With 18 photographs, 9 sketch maps and 6 tables

Introduction

Ethiopia is still one of the few African countries without a well active Public Geological survey (D i x e y , 1960). Accordingly, the mineral potential of the country is known only partly, and the activity in mineral exploration develops still on occurrences and deposits known for a long time ago. The prospection from the ancient times revealed many of the existing deposits, especially those visible at the surface. Besides gold which was the primary target of the ancient prospector, also iron ore deserved special attention by the native people in its struggle to get provided with weapons and utensils. The native people exploited and smelted iron ore at numerous localities for centuries and still nowadays the primitive technique of smelting by use of charcoal can be seen.

With the beginning of modern time the new-comers became interested in searching for iron and other mineral raw-materials in the country. During the Italian occupation serious efforts have been made to assess and to develop iron ore deposits, but without practical success. No new large and economically important deposit has been discovered and developed.

Also in the post-war time no additional iron ore deposit was found and the assessment of the known deposits was directed to the idea of errection a modern steel-mill industry. Presently, there is only one small steel foundry and rolling mill operating from 1962 at Akaki near Addis Ababa, and having a capacity of 50 tons per day only. Scrap iron is used prevailingly with a small amount of limonite ore from Entoto hill.

Following the suggestions of the Second five year Plan on the urgent priority and special significance for iron prospecting, extensive exploration was undertaken in the last two years by the Ministry of mines, and directed toward verifying the reserves of iron ore in the known deposits. In the Plan, however, the construction of a steel and metal industry based on domestic ore is planned for the end of 1967. The first step of renewed reconnaissance and exploration of the main part of known deposits is in general finished. Further exploration, being in course now, is carried out by specialised groups of foreign contractors and is directed toward the assessment of the eventual economic reserves by means of geophysical and drilling techniques.

The iron and manganese ores hitherto known in Ethiopia are oxidic only. The deposits belong to different types as it will be described in the following.

This article presents a brief summary of essential data on the principal iron and manganese ore occurrences in Ethiopia known till the beginning of 1964. The description of individual deposits is given mainly on the basis of personal field observation as well as own sampling and microscopic examination, supplemented by additional data from published literature and other sources. For each deposit a very short history of exploration is mentioned. The geological mode of occurrences is described and the deposits are classified regarding the origin. The reserves are estimated regarding the type of deposit and the degree of exploration. The measured tonnages have been calculated for some of the deposits. Three of the occurrences treated have not been visited and verified by the author in the field. Several new chemical analyses hav been made in the Chemical laboratory of the Ministry of mines. The other analyses and data used in preparing this article were derived from the listed references.

The author's personal view regarding the economic appraisal of the deposits is not necessarily the opinion of any other person.

GENERAL DATA ON THE IRON AND MANGANESE OCCURRENCES IN ETHIOPIA

Geological setting of the country

About one quarter of Ethiopia's surface consists of pre-Cambrian crystalline rocks of sedimentary and igneous origin. Different lithological types can be distinguished. A highly metamorphosed series, having resulted from high-grade regional metamorphism, is composed of gneisses, mica-shists and amphibolites. An apparently less metamorphosed para-series is composed of different schistose rocks including quartzites and crystalline limestones. Both series are intruded by acid and basic igneous masses. The whole crystalline basement is strongly folded and faulted with the general N—S trend of foliation. Stratigraphically, no exact differentiation has been performed till today, and the correlation of the rocks with metamorphic facies of other parts of Africa is not yet solved (Furon, 1960).

In Africa the metalliferous mineral occurrences are almost all associated with the metamorphic rocks of pre-Cambrian. The same can be expected for Ethiopia. The relatively most important primary iron ore deposits hitherto known in the country are bound to the metamorphic complex.

The pre-Cambrian basement was erroded to a peneplain and overlain unconformably by the sediments of Mesozoic and volcanic rocks of

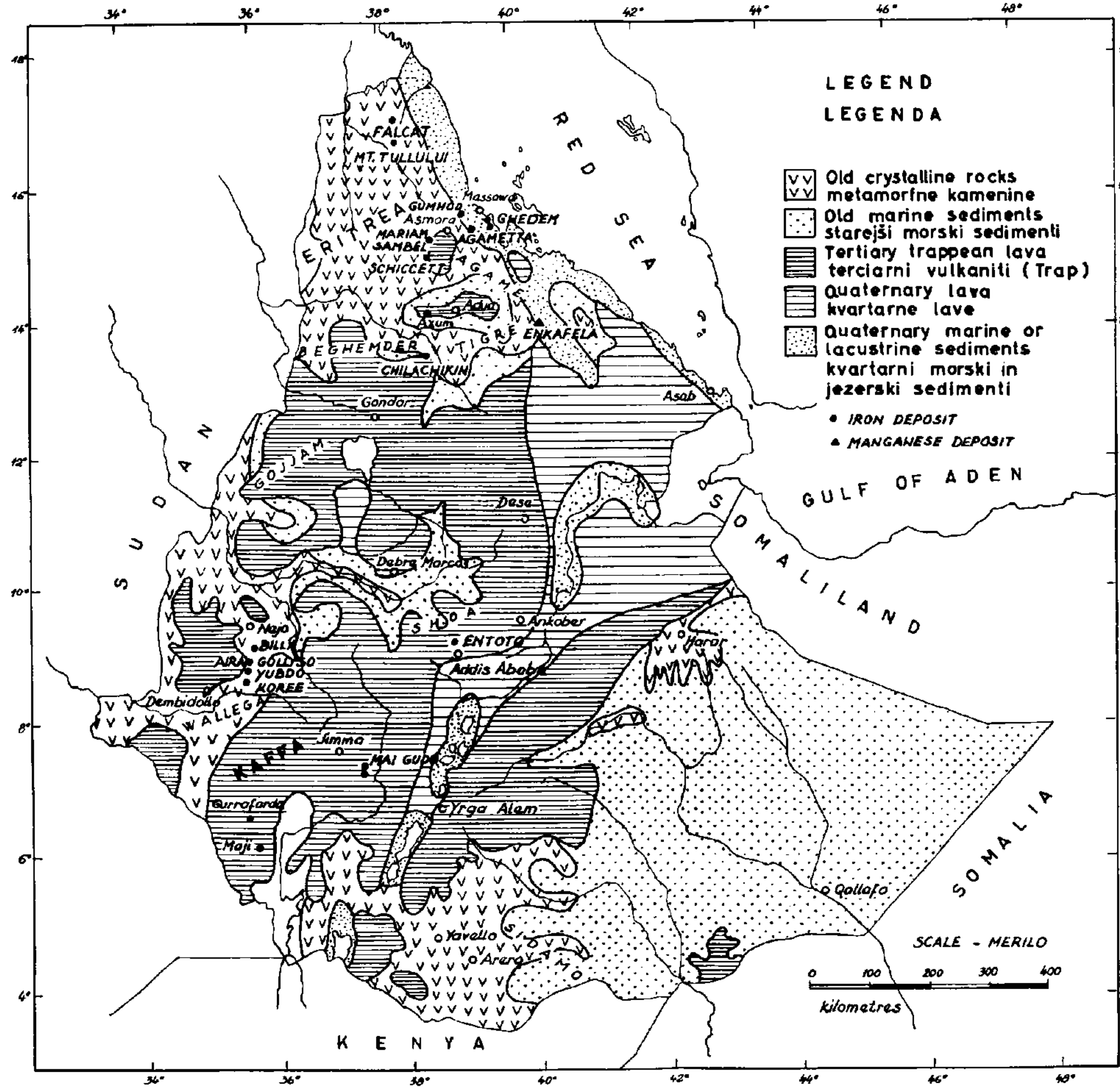


Fig. 1. Generalized geological map of Ethiopia (after P. Mohr), showing principal iron and manganese deposits

Sl. 1. Splošna geološka karta Etiopije (po P. Mohru) z glavnimi nahajališči železa in mangana

Tertiary. Mesozoic sediments spread in general in the eastern part of the country and cover a good another quarter of the country's surface. They are composed of marine sandstones, limestones and evaporitic sediments prevailingly.

Cainozoic is represented by sedimentary rocks of Tertiary which are confined to the extreme east of the country and are of marine origin prevailingly. The most extensive Tertiary formation is represented by extrusive volcanic rocks of Trap series which extend over the Mesozoic and pre-Cambrian formations. Nearly half of the country's surface is covered by thick layers of volcanic rocks of Trap series consisting of basalts prevailingly with some more acid rocks and pyroclastics. These rocks build up the high plateau in the central part of the country. In Tertiary age the upwarping and sinking movements started and shaped the present forms of mountains and rifts.

The volcanism continued during Quaternary in which period also marine, lacustrine and fluviatile depositions were sedimented in local areas and basins. Recent volcanic activity is known in this part of Africa and the youngest volcanic rocks are named Aden series.

During the emersion periods the process of weathering alteration, known as lateritization, took place over the pre-Cambrian complex as well as Mesozoic sedimentary and Cainozoic volcanic formations. The alteration processes played an important part in the formation of secondary iron and manganese accumulations.

Distribution and kinds of deposits

The existing deposits are primary and secondary in origin. As to the geological mode of the occurrences the relatively most promissing and high-grade ores are confined to the pre-Cambrian metamorphic rocks. The primary deposits are known to exist in Eritrea and Wollega provinces. The pre-Cambrian basement complex must be considered as the potentially most favourable environment to contain primary high-grade ore, but also secondary low-grade ore.

The next favourable environment is represented by the volcanic rocks of Trap series. The existing low-grade iron ores are an alteration product and resulted from weathering and leaching under the influence of the descending meteoric waters. In the same way the secondary iron concentrations formed in the clastic Mesozoic sediments cemented by ferruginous cement.

Hydrothermal iron mineralizations in pre-Cmabrian rocks do exist too, being of ascendent katathermal and telethermal or rather hot-spring character.

The depositions of manganese have much less extent in comparison with iron. Only one primary deposit is known to exist in marine sediments of young geologic age. Other manganese occurrences are connected with the secondary iron depositions. Iron and manganese behave in a similar manner in the exogenic cycle and concentrations of both metals in residual deposits are frequent.

The distribution of deposits and occurrences treated is given in the generalized geological map of Ethiopia (Fig. 1.).

The deposits of iron and manganese belong to the varied types of genesis. The iron ores are magnetitic, hematitic and limonitic and the manganese ores are oxidic too, being more or less ferruginous. The following genetical types of deposits have been found in Ethiopia.

Iron

1. Metamorphic type is of primary sedimentary origin and subsequently mineralogically and texturally altered by regional metamorphism.
2. Combined metamorphic-contact metasomatic type was formed by a combination of sedimentation, metamorphism and metasomatism.
3. Residual concentration type, having resulted from decomposition and leaching of extrusive or other ferruginous siliceous rocks.
4. Hydrothermal type is of katathermal and telethermal (hot-spring) character.
5. Magmatic type is inferred only and not cleared enough.

Manganese

1. Residual concentration type is closestly connected with secondary iron accumulations.
2. Hydrothermal type is closestly connected with telethermal iron.
3. Sedimentary type is of marine origin.

DESCRIPTION OF DEPOSITS AND OCCURRENCES

IRON

1. Metamorphic type

Koree — Gollisso — Nejo zone

General. Regarding the possible reserves of high-grade iron ore this zone in Wollega province seems to be one of the relatively most promissing areas in the country. Its center is in the Aira area north of Yubdo. A small primitive smelting activity is reported to have existed there from the former time and exists still nowadays. No published data are available on these occurrences except Murdock (1960), who dropped some lines on these deposits, having considered them as small and irregular replacements in dunite and not persistent at depth. His opinion was that none of the occurrences in Wollega are of any importance except for strictly local use for primitive smelting, such as was formerly carried out there.

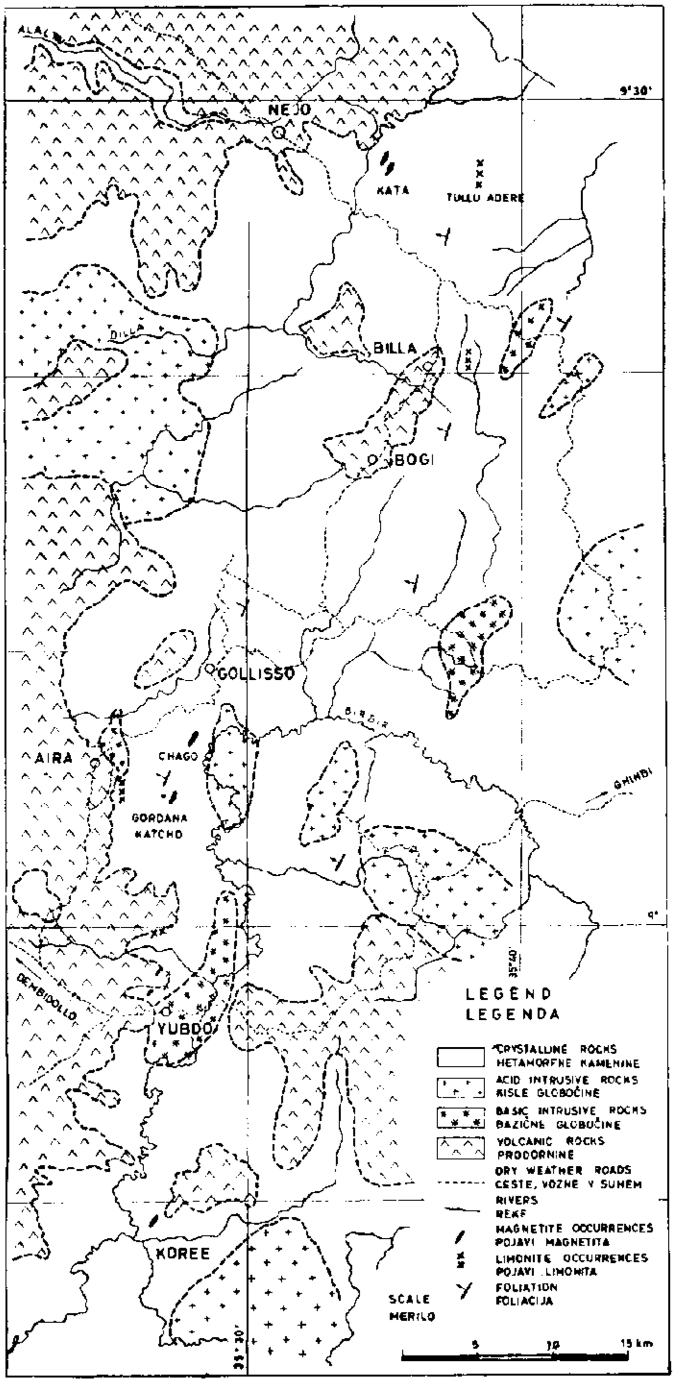


Fig. 2. Geological sketch map of the iron ore-bearing zone Koree-Gollisso-Nejo in Wollega

Sl. 2. Geološka skica nahajališč železove rude v coni Koree-Gollisso-Nejo v Wollegi

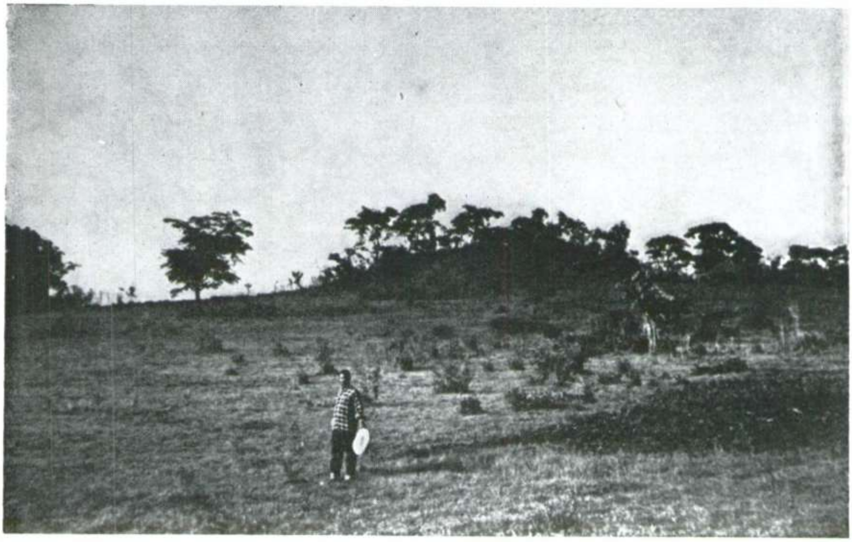


Fig. 3. View of Koree outcrop on the top of hill
Sl. 3. Pogled na izdanek Koree vrh griča

The zone was not searched in the past due to the lack of suitable communications and thus little prospects of economic exploitation. In the season 1963 extensive prospection was carried out by the Ministry of mines. Recently (spring 1964) detailed geological and geophysical (magnetometer survey) exploration started with the aim to assess more exactly the deposits, and to provide the basis for an eventual further drilling program. It was carried out by the Yugoslav RUDIS company.

Geologically the region is built up by pre-Cambrian rocks of apparently younger less metamorphosed series and overlain by basaltic cover. Petrographically para-rocks as mica-schist, chlorite-schist, amphibole-schist, phyllites and quartzites prevail, having a constant foliation of abcut 15^0 and dipping steeply west. Igneous rocks of ultrabasic, basic and acid types are included as well as some gneisses. The general situation of the zone is given in the enclosed map (Fig. 2.).

Ore outcrops are known to extend in a zone of several tens of kilometers in lenght. Lenslike ore bodies occur included in the crystalline rocks. Besides outcrops in situ also secondary ore can be found as large boulders. The possibility exists that the zone continues southwards as well as northwards from the prospected and reconnoitred area. No doubt a mineralized zone following the general NNE—SSW trend of foliation in the basement complex is in question.

The magnetitic-martitic ore is coarse crystalline, bluish-black in colour but the strike is reddish due to the high grade of martitization. On the surface rare incrustations with limonite occur sometimes.

D e s c r i p t i o n. The most southern outcrop of ore at Koree some 16 km south of Yubdo is the biggest in dimensions from all existing in the discussed zone. It consists of a lens of about 200 m of visible lenght, having a thickness of several meters. The outcrop forms a well pronounced topographic ridge, striking 35^0 and dipping nearly vertically (Fig. 3.). The prolongation of the ore body for some additional 100 m is assumed, the outcrop being hidden under the thick cover of residual soil. The ore consists of magnetite and martite and appears in big angular blocks with quartzite banding, being more or less impure and limonitized.

About 500 m southeast from the outcrop large boulders of magnetite are scattered on a pretty great surface, several of them of considerable size. The boulders are not in situ. They form secondary deposit derived either from the existing Koree outcrop or another one burried under the soil in the vicinity. Anyhow, the boulders could not have been transported from afar.

The existing reserves at Koree can be estimated to some 150 000 to 200 000 tons of ore, provided the depth of the lens is about one half of the lenght and a lenslike body is supposed. Additionally, several thousands tons of ore are deposited as boulders on secondary place.

The next known outcrop of ore exists about 1,5 to 2 km northwest of Yubdo. On a hill slope just beneath the volcanic cover scattered boulders and pieces of ore can be found on a surface 300 m by 60 m approximately. Some of them are very large in size, weighing several tons each (Fig. 4.). It looks very probable that at least a part of ore is not in situ there,

Fig. 4. Boulders of magnetite at Yubdo outcrop
Sl. 4. Magnetitni bloki na izdanku Yubdo

but due to the very large size of the blocks they could not have been transported from afar. The primary deposit has to be somewhere very near, burried under the residual soil or even basaltic capping. The coarse-grained ore seems to be clean with some inclusions of quartz.

About 650 m northwards from this place iron ore in situ crops out in a trench made by natives, which exploited the ore. The ore body here might be about 30 m in lenght and several meters thick, judging on the dimensions of the trench. Its strike might be about 45° and dip nearly vertical. The ore consists of impure limonitized magnetite intermingled with banded quartzite. It is possible that the lens continues southwards under the volcanic cover, which begins just at the end of the trench.

The form as well as the character of the deposit could not be definitely established by surface examination only. The existing reserves at Yubdo locality might not exceed the general estimate of several hundreds of thousand tons at maximum, taking into consideration the assumption the ore is in situ prevailingly. If this is not the fact the reserves are much smaller.

Several kilometers east from Aira Mission and some 16 km north of Yubdo the Gordana Katcho hill is built up of quartzite, chlorite-schist and mica-schist. On the hill the traces of former exploitation can be seen in form of a trench, striking conformably with the foliation of the metamorphic complex. The trench is about 100 m long and variable in width with several meters on average. Although it is filled up with earth and grown over by vegetation, the blocks and pieces of magnetite can be seen. Bands of magnetite are included in white quartzite indicating the genetic connection of both rocks and minerals. The traces of an exploitation in limited extent can be found also on the western slope of the hill perpendicular to the trend of the mineralized zone.

The exposition of the outcrop is bad and an estimation of probable reserves difficult. It could be assumed that several tens of thousand tons of ore might exist there, depending on the not clear dimensions of the ore body.

The next outcrop at the locality Chago some 5 km south of Gollisso has a lenght of about 300 m and a width of several meters. Former exploitation by natives is evident and remnants of smelting-furnace can be seen too. The area is strongly covered by residual soil and on some places magnetite ore is to be seen in large block, being very compact and of the same appearance as on the other spots described as above. The trench follows the foliation of the metamorphic rocks, being in general 15° to 20°.

The preliminary tonnage estimate of reserves might be analogous to that of Koree, amounting from 100 000 to 200 000 tons of ore.

In the area east of Nejo magnetite boulders can be found at several localities (Gambo, Kata valley, Tullu Adere), but there is also ore in situ in form of smaller lenslike outcrops. The ore is of the same appearance and composition as in the other localities described above. The geological environment is more or less the same and the quartzitic and schistose rocks of the basement prevail. A prospection is in course to establish the position and the dimensions of the existing outcrops. For the time being a very rough tonnage estimate of several tens of thousand tons of inferred ore can be assumed for this area.

Analyses. Several samples of magnetitic-martitic ore from Wollega have been analysed in 1962 (analyst A. Regan). Table 1. gives the composition of the chip samples of selected clean ore from different localities.

Table 1 — 1. tabela

Locality	Fe	TiO_2	SiO_2	P_2O_5	S	MnO
Koree	71,6	0,0	0,82	0,06	0,09	0,09
Yubdo	70,9	tr.	1,2	0,08	tr.	0,12
Gordana Katcho	70,8	tr.	3,1	0,03	0,05	0,23
Chago	68,8	tr.	1,8	0,14	tr.	0,12
Nejo (Kata)	65,2	tr.	8,7			

Several additional chip samples have been analysed in the laboratory, giving the same size-order in the quantity of the components.

In Wollega a rich magnetitic-hematitic ore is in question, very low in sulphur and in phosphorus. The percentage of silica is low in samples of clean ore, but on average it can be expected higher owing to the variable inclusions of quartz and quartzitic mother rock to which the ore is bound.

Polished sections of ore have been examined under the microscope in order to provide additional information about the processes of its formation. The microscope reveals a rather porous coarsegrained ore of largely martitized magnetite (Pl. 1, Fig. 1.). The magnetite is almost completely oxidized to hematite in form of lamellae, following the (111) planes of magnetite. The alteration is more pronounced at margins of magnetite crystals and martite extends irregularly along cracks into magnetite. With progressive martitization the lamellae broaden and very often only residual areas of magnetite remain.

Limonite replaces martitized magnetite here and there, forming rims and irregular bodies .Quartz grains can be found in the ore, concentrated in bands sometimes. An important feature is the exceptional appearance of small roundish inclusions of pyrite and chalcopyrite in the middle of unaltered magnetite grains.

Origin. The intimate connection of ore to the parametamorphic rocks consisting of white quartzite and other schistose rocks is evident at all find-spots where magnetitic ore occurs. The ore zone and the ore bodies run parallel with the foliation of the metamorphic complex. The outcroping portion of the ore lenses is extremely altered to martite due to the supergene oxidation of magnetite.

There is no doubt that the ore is singenetic with the adjacent rocks of originally sedimentary series. This has been strongly folded and metamorphosed by regional and dynamic metamorphism, accompanied by granitic and other intrusions. Metamorphism entailed mineralogical and textural changes of the primary sediments the "bedding" of which is still discernible in metamorphosed rocks. The paragenesis of the present ore is simple and the magnetite as well as the quartz waste is recrystallized. The sulphides might be primary in origin, and the presence of rare small grains of pyrite and chalcopyrite in the ore could be due to the conditions of primary sedimentation rather than having been introduced later by thermal solutions. There is no other evidence of any hydrothermal activity. Accordingly, the iron ore occurrences in this part of Wollega belong to the metamorphic type of deposits, being derived from a former sedimentary accumulation and subsequent concentration of iron.

The question about the primary sedimentary environment and the form in which iron was present originally is difficult to explain. The idea that the original beds of iron formation could belong to epicontinental sediments seems the most probable. Iron may have precipitated and concentrated either as sedimentary oxides or even iron silicates. The attribution of iron to a magmatic source as for instance exhalative activity on the sea floor is less probable. Since the formation the iron-bearing sediments were subjected to extensive metamorphism and recrystallisation, having converted the primary iron concentration into magnetite. The uncertainity as to the details of origin of this ancient deposit is a direct consequence of its long and complex geological history and this shall be kept in mind when considering the genesis of pre-Cambrian deposits.

R e s e r v e s. No accurate tonnage estimate of the whole zone is possible before the full program of detailed survey, including drilling, will be carried out. For the time being the presence of ore is known on the above described localities only. The estimated reserves are given as approximate figures in the Table 2.

Table 2 2. tabela

Locality	Estimated reserves (tons) Measured	Inferred (min.)	(max.)
Koree	50 000	100 000	150 000
Yubdo	20 000	50 000	300 000
Gordana Katcho	10 000	40 000	100 000
Chago	80 000	100 000	200 000
Nejo (east)	—	—	50 000
T o t a l	160 000	290 000	800 000

The quantity of existing reserves for single locality can not be expected more than several hundreds of thousand tons at maximum. The whole zone must be ranged accordingly to small-size iron deposit with a total tonnage of about half a million or so tons of high-grade iron ore. The lenght of the zone is about 70 km and the total lenght of the visible outcrops 750 m only.

Billa

Approximately 2 to 3 km east of the village Billa in Bogi district in Wollega a pronounced barren mountainous ridge extends (Fig. 5). It is composed of compact light grey quartzite, having a strike of about 10^0 and dipping apparently very steep west. On the western slope of the ridge several more or less limonitized quartzitic and schistose rocks can be found in a 100 to 200 m wide zone, containing even pure limonitic

Fig. 5. View of Billa ridge with scattered pebbles of limonite

Sl. 5. Pogled na greben Billa z razmetanimi kosi limonita

pieces and debris. A banding in the metamorphic strata can be seen and the schistose rocks alternate with layers richer in iron oxide. The lenght of this zone is about 1,5 km. The average iron content is relatively low. It is possible that in the series of alternating strata some of them contain a higher content of iron.

Genetically the iron concentrations at this locality are in general bound to the zone of metamorphic rocks as described above. The ferruginous quartzite and schist are of sedimentary origin and subsequently recrystallized by regional metamorphism. The quartzite might be metamorphosed originally arenaceous sediment. The local concentration of limonite found in this place is secondary in origin and has formed by leaching and precipitation of iron out of the primary mother rocks. Chip samples of ore have been analysed, containing even 56 % of iron and 3 to 5 % of silica, but these figures can not be regarded as average. The iron content varies from place to place, being in average very low.

For the time being it is believed that the iron ore occurrence at Billa is of no economical value due to the low iron percentage.

The existence of sedimentary-metamorphic iron occurrences in Wollega is, however, an interesting phenomenon due to the fact that many of the significant world's iron deposits belong to this type, which usually contains high-grade iron ore. In South Africa and especially in recent time in West Africa enormous deposits of this type have been discovered (Finn, 1964).

In the northern prolongation of Billa ridge some 12 km away of it an analogous iron concentration was found at Tullu Bollale, having the same appearance as that of Billa ridge. Hematitic schist was observed also along the main road to Nejo several kilometers before the town. The iron contents is low. The rocks are reddish-brown and well schistose. Ferruginous schist does exist also in the vicinity of Gollisso.

The conclusion can be made that in this part of Wollega several ferruginous schistose horizons appear the iron contents of which is disseminated very irregularly, and here and there concentrated to rich but rather small lenslike ore bodies.

2. Metamorphic — contact metasomatic type

Falcat — Agametta zone

General. Regarding the geological information available for the time being the most interesting and potentially important might be the iron ore occurrences in Eritrea. Lenslike ore bodies of high-grade magnetitic ore were known for many years to extend at several localities, especially in the area Sabub-Agametta about 40 km east of Asmara, and in the extreme northern part of Eritrea in the Falcat area. Several new ore occurrences have been found in the Gumhod area during the prospecting campaign carried out in 1963 by the Ministry of mines. It looks very probable that additional ore bodies could be found by systematic work in the mountainous and partly extremely hard accessible parts of this province.

The data on investigations carried out formerly on these iron ore-bearing areas (Fig. 6.) are summarized by Usoni (1952). In 1919/20 several pits and trenches were dug in Agametta area. Extensive exploration was carried out immediately before War II, applying magnetometer survey too. The reserves were estimated to 2,5 million tons.

In 1956 the German KRUPP company assesed the reserves to be probably beyond the 2,5 million tons. In 1963 the Ministry of mines engaged the Yugoslav RUDIS company to explore definitely the 100 sq. km large area between Sabub and Agametta in the most southern part of the ore-bearing zone. At the same time the reconnaissance, prospecting and preliminary studies in the adjacent areas covering totally over 1800 sq. km were carried out by the Ministry of mines. The aim of this

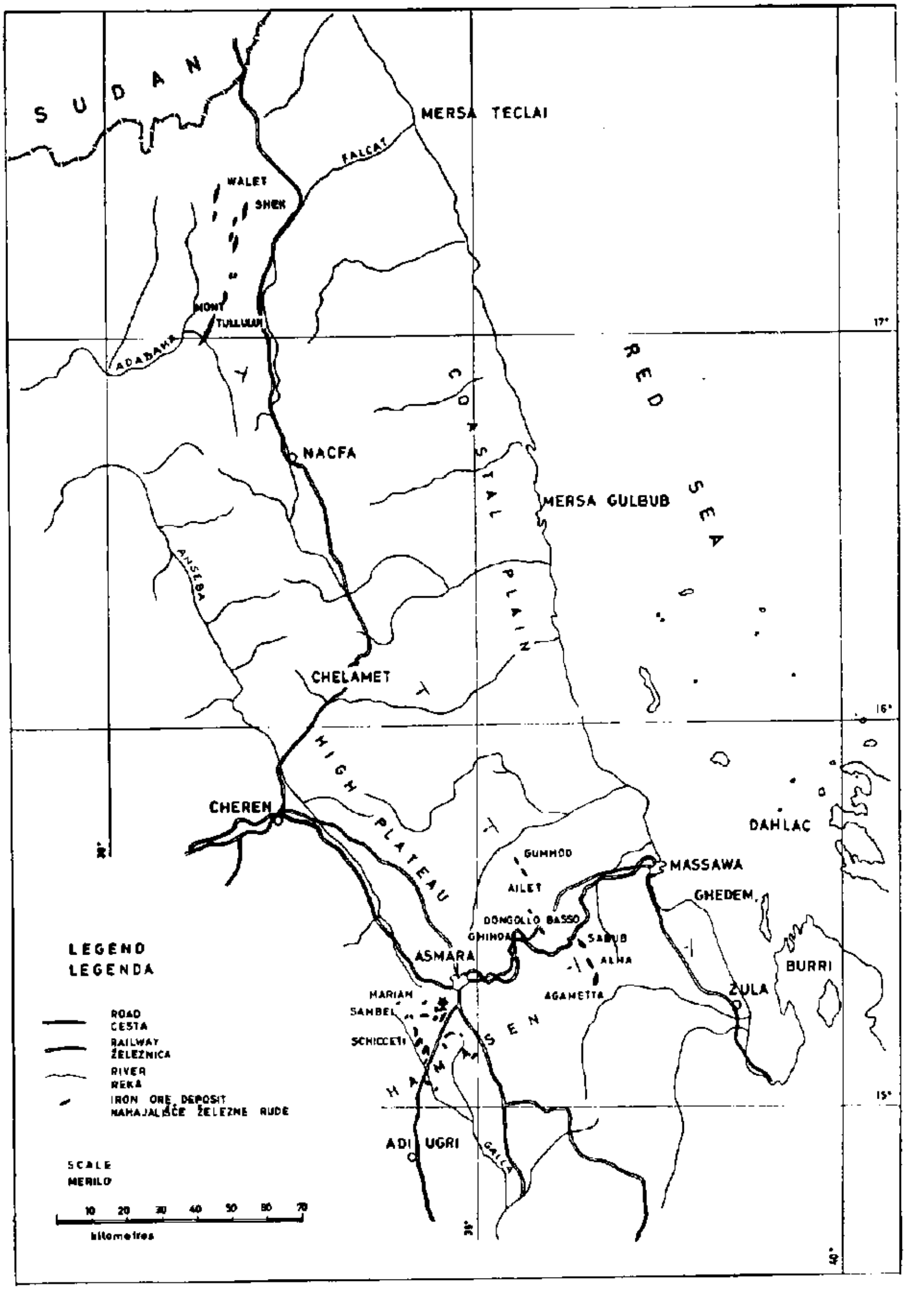


Fig. 6. Sketch map of iron ore-bearing areas in north eastern Eritrea
Sl. 6. Karta območij železovih nahajališč v severovzhodni Eritreji

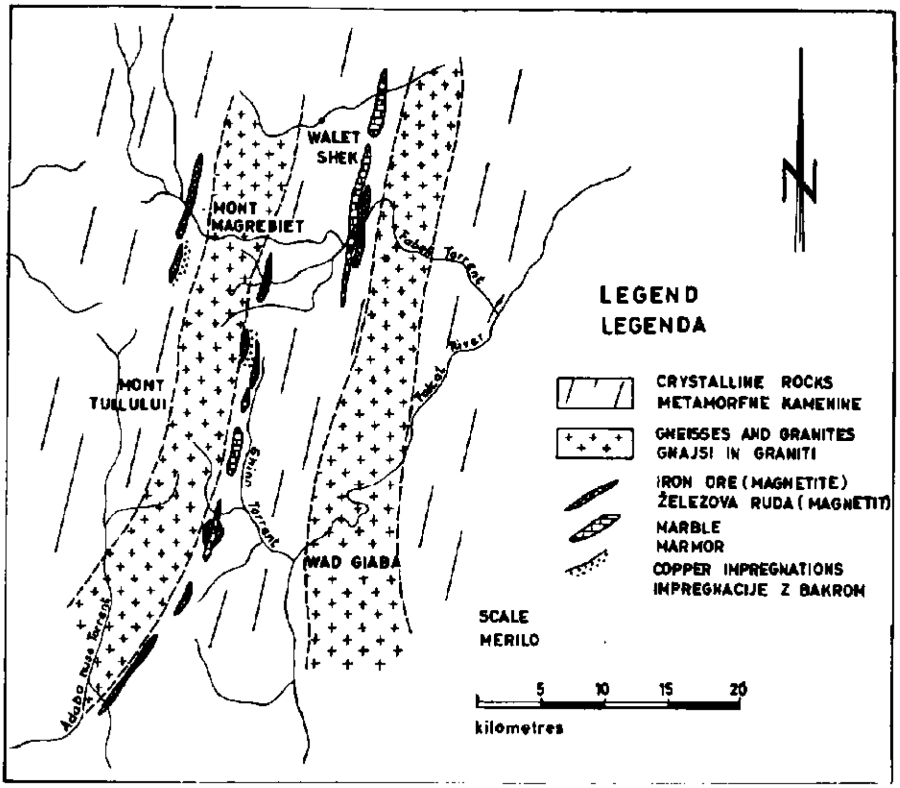


Fig. 7. Provisional geological sketch map of the Falcat area. (After A. Cavagnari, 1919)

Sl. 7. Približna geološka skica območja Falcat. (Po A. Cavagnariju, 1919)

activity was to provide the preliminary basis for the eventual further investigations.

The northern ore deposits in the Falcat region could not be visited by the author in 1963. The deposits were studied in the past mainly by Bibollini (Usoni, 1952). The general geological situation is evident from an unreliable sketch by Cavagnari (Fig. 7.). In 1940/41 the Italian RIMIFER company explored the deposits geologically and geophysically without having discovered new ore bodies. No definite view can be deduced from Usoni's data regarding the economic importance of these deposits, and the reserves were estimated to 200 000 to 300.000 tons only.

In judging the potential possibility of the whole ore-bearing zone the deposits in the Falcat area must be explored and studied definitely in the shortest possible time.

According to the Italian geologists the iron ores of Agametta as well as of the northern deposits in the Falcat area are pyrometasomatic in origin and related to silicic intrusions. KRUPP found obvious indications of the sedimentary character of the ore in Agametta area. RUDIS (1963) interpreted the origin of the ore in connection with the exhalative volcanic processes in the shallow sea. Subsequently hematite was transformed into magnetite by regional metamorphic and contact metamorphic processes.

Description. Geologically the Gumhod-Agametta area in the eastern part of the central Eritrea consists of pre-Cambrian rocks of presumably low-grade metamorphism similar to those in Wollega. The most important rock-types are parametamorphic schistose rocks varying from almost unaltered arenaceous sedimentary rocks to high-grade metamorphosed gneiss facies. The inclusions of calcareous lenses occur often in the basement complex, the foliation of which is in general NNW—SSE in this part of Eritrea. Granitic, pegmatitic and differentiated intrusive rocks are included. On the plateau south of Asmara basalt capping covers the basement rocks, and in the coastal part of Eritrea young Tertiary sediments and basaltic lavas spread locally over them.

The existing magnetitic ore is prevailingly massive and occurs in big angular blocks (Fig. 8.). Texturally it is coarse-grained but also fine-grained or in the form of banded ferruginous quartzite and schist. The latest shows here and there also a well defined banding with quartz-rich layers alternating with iron oxide-rich layers. Also the alternation of magnetite layers with schistose chlorite-schist and other schists is not

Fig. 8. Outcrop of magnetite ore at Agametta
Sl. 8. Izdanek magnetitne rude v Agametti

Fig. 9. Outcrop of sehistose magnetite ore at Dongollo basso

Sl. 9. Izdanek skrilave magnetitne rude v Dongollo bassu

seldom to be seen. This banding is without doubt an original sedimentary layering, accentuated perhaps by metamorphic recrystallization. Also the fine-grained magnetite ore shows a very fine banding parallel to the folliation of the sedimentary complex (Fig. 9.). The coarse-grained ore is more clean and the banding seems to be less pronounced. In the northern part of the zone near Gumhod the ore layers consist of alternating bands of magnetite and schistose rocks. The schistose textured ore is intermingled with green chlorite-schist and quartz layers.

The southern part of the ore-bearing zone between Sabub and Agametta is built up by different low-grade metamorphic rocks, which contain several lenslike iron ore bodies, following the general foliation in the metamorphic series. In general some ten groups of ore lenses exist there, occurring in different levels in the ore-bearing horizon. According to RUDIS (1963) the ore bodies have the predominant lenghts between 5 and 25 m and the thicknesses exceed exceptionally more than 1 m. Schistose metamorphic rocks contact larger bosses of granodiorite and granite porphyry. A narrow zone of older basic extrusive rocks occurs in the basement complex and RUDIS believes these rocks might be genetically related to the granodiorite as well as to the iron ore. An important feature is the presence of skarns, which are not always connected to the calcareous lenses occurring within the metamorphic series. Besides the locally abundant quartz, garnet, epidote and other silicates also grains of sulphides and patches of copper carbonates occur in this type of ore mineralization. Malachite was found also in small quartz veinlets crossing the metamorphic rocks.

Near Dongollo basso a completely isolated lens of banded magnetite ore was found on the Gahar hill, having a lenght of 15 m and a maximal width of 1,5 m. Several kilometers to the north another small outcrop of ore exists near Ailet. Both are included in the foliated schistose rocks.

In the Gumhod area several new magnetite occurrences have been found during prospection. They have the same morphological features as those in Sabub-Agametta area, being characterised by scarse small-

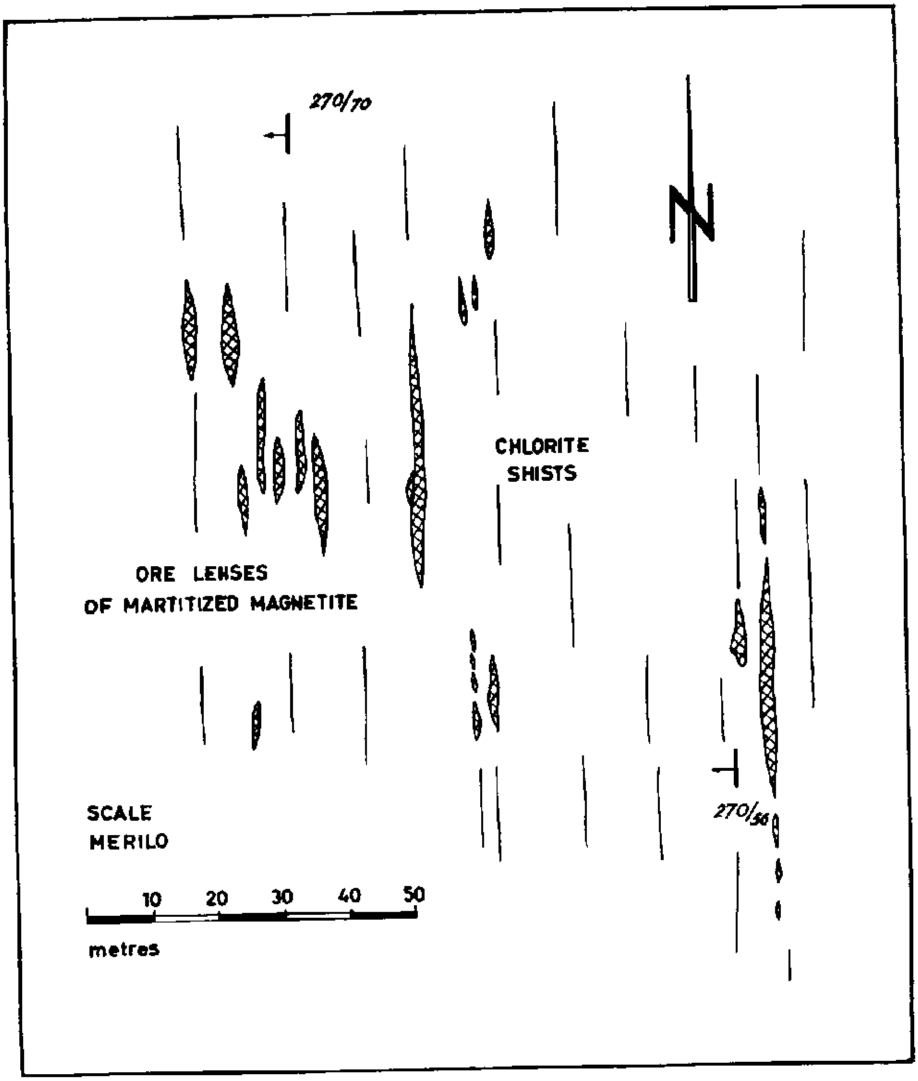


Fig. 10. Field-sketch of lenslike iron ore occurrence near Gumhod

Sl. 10. Terenska skica lečastih teles železove rude pri Gumhodu

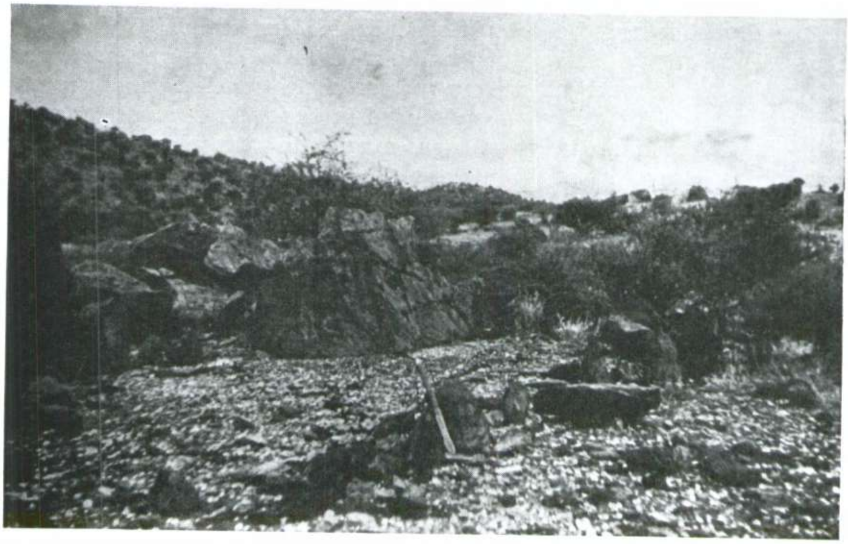


Fig. 11. Outcropping small lenslike ore bodies near Gumhod
Sl. 11. Izdanek majhnih lečastih rudnih teles pri Gumhodu

sized lenslike ore bodies lying in the strike of the metamorphic complex. There is no doubt the occurrences belong to the same ore-bearing zone. Three groups of ore lenses have been found there and the group Gumhod I is shown in the sketch (Fig. 10.) as well as in the photo (Fig. 11.).

The area between Sabub and Gumhod is represented by a plain covered by sands and torrential piedmont gravels. The thickness of this cover can be estimated to several meters on average. The continuation of the ore-bearing zone along this 20 km long area between the northern and southern outcrops is very probable, however, composed of the eventual small groups of ore lenses. The possible existence of ore under this alluvial cover might be partly proved by a 600 m long magnetic anomaly discovered by RUDIS's magnetometer survey near Fort Ambatocan (RUDIS, 1964).

This ore-bearing zone continues in all probability further to the NNW following the general trend of the basement complex. Magnetite sands are known along the sea-shore at Mersa Gulbub in the Northern desert. Future efforts shall be directed towards possible new discoveries of ore in this area. Owing to the fact that this region is far and very hard to access only a well organized and equiped terrestrial prospection could bring results.

In the northern part of Eritrea, about 180 km north of Asmara similar magnetite deposits occur at Walet Shek and Mont Tullului in the region of Falcat river. The iron ore occurrences of Falcat-Mont Tullului area and others are described by Usoni (1952), following mainly Bibolini's data. Considering also additional data on these areas the conclusion can be made, that the geological situation in general does not differ from that in the Gumhod-Agametta area, except perhaps more accentuated skarn character of the deposits. Magnetite lenses occur everywhere in the closest contact with marble, having both the forms of elongate lenslike bodies. The strike of the basement complex might be there NE—SW and the zone of interest several tens of kilometers in lenght. The deposits are described to be typical contact-metasomatic in type with large formation of epidote, garnet and perhaps ilvaite, the minerals replacing calcite. The mineralization is thought to be due to hydrothermal solutions derived from porphyric extrusions as well as granodiorite or other igneous masses in depth in the vicinity. The lenght of lenslike iron ore bodies may vary between 100 m and 300 m, having the thicknesses of about 10 m as maximum. The presence of iron and copper sulphides is indicated (Usoni, 1952). From Cavagnari's sketch (Fig. 7.) the copper mineralizations look to be well delimited. Specular hematite may occur in the Falcat ore too.

Analyses. KRUPP analysed in 1956 seven grab samples of iron ore from Agametta area. The results would give an average composition of ore as follows (in percent):

Fe	58
SiO_2 . . .	14
P	0,047
O	0,018

Additionally, three chip samples of good ore from Sabub-Agametta area have been analysed in the Chemical laboratory of the Ministry of mines. The results are given in the Table 3 (in percent):

Table 3 — 3. tabela

No.	Fe	SiO_2	Ca	Mg	Al_2O_3	P	Ti	MnO	Cu	SO_4
250	47,04	22,82	0,00	0,00	0,53	0,02	0,00	0,54	tr.	tr.
251	47,50	30,70	0,00	0,00	0,23	0,044	0,00	0,40	tr.	tr.
253	68,13	2,30	0,00	0,00	0,20	0,017	0,00	0,35	tr.	tr.

The percentages of iron and silica are variable and depend on picked samples. It could be estimated that an average contents of iron would vary between 50 and 65 % and that of silica between 10 and 20 % respectively in the representative samples, which, however, have not yet been systematically taken and examined. Small contents of phosphorus, sulphur and other admixtures make the composition of ore excellent.

Many samples of ore as well as other rocks were examined under the microscope as polished and thin sections. As to the ore there are two types to be distinguished: banded magnetite-martite ore and magnetite with skarns. It can be said, in general, that the banded ore consists of granoblastic recrystallized agregate of magnetite and quartz prevailingly. Magnetite in form of allotriomorphic fine grains is concentrated in bands but also dispersed in quartz matrix (Pl. 1, Fig. 2.). Magnetite is always martitized, and martite spreads along the grain boundaries and fissures or follows the planes (111) of magnetite in form of lamellae. Some rare inclusions of chlorite, mica, amphibole, epidote and calcite are present. The blastic grain structure of the rocks, which vary from magnetite-bearing quartzite on one side to dense granular magnetite on the other, is due to the metamorphic recrystallization.

Big crystalls of epidote occur in the banded rocks sometimes and later quartz fills the cracks and fissures, proving additional hydrothermal processes in the ore. Besides very advanced martitization of magnetitic grains distinct lamellar hematite occur too and can be seen even by unaided eye. The impression is got the lamellar hematite might be due to a special crystallization phenomenon undipendent from that of martitization of magnetite. Lamellar hematite is distinguished by very porous texture.

The presence of sulphides in banded ore is another important feature. Rare isometric crystals of pyrite are spread allong banding in quartz matrix. They are much bigger than the average size of magnetite crystals. The great part of these grains appear already completely altered to zoned limonite which spreads also along fine fissures in the ore. Homeoblastic fine-grained quartz matrix gets disturbed along the margins of these crystals and longish quartz grains are oriented perpendicularly to the margins of sulphide grains. Pyrite crystals, having more than 1 mm in size, occur in the bordering zones with marble too. Normally they are pseudomorphoses after pyrite which can be found within limonite in form of small relicts only. It looks that the sulphides have been introduced with a later generation of quartz due to the hydrothermal processes which produced skarns.

On the other side small roundish and elongate grains of chalcopyrite occur in the magnetite grains as well as in the martitized parts of it (Pl. II, Fig. 1.). The small gold-yellow bodies are distributed very scarcely and irregularly. Their direction seems to be here and there parallel to that of the martite lamellae. The size of these grains which are well delimited from the surronding magnetite, is generally less than 0,01 mm, and the maximum not more than 0,03 mm.

Malachite is concentrated as secondary filling in fissures and cracks together with the supergene iron oxides.

There is no certainity regarding the textural relation of copper and iron minerals. The intimate relation of both minerals could point out that copper might be primary in origin and syngenetic with iron. This relation is not yet studied in details and sufficiently explained for the time being.

The skarn type of ore consists of garnet, epidote, amphibol, prevailing quartz and magnetite (Pl. II, Fig. 2.). The microscope reveals the idiomorphic garnet and epidote cemented by magnetite and a later quartz.

The idiomorphic garnet crystals show often skeletonlike forms with oriented bandsgrowth in quartz. This is a proof of more or less simultaneous crystallization whereupon magnetite crystallized apparently as the last of the components. Magnetite is always allotriomorphic. It can be found also in the center of garnet crystals.

O r i g i n. The information gathered hitherto points out to the explanation of the origin of deposits in the following way. The main part of iron in the existing ore bodies is of primary sedimentary origin. It was deposited in the ancient marine basin where the metasediments of the present pre-Cambrian complex originated. A small amount of copper might have been deposited simoultaneously with iron. The original form in which these two metals might have been precipitated is unknown. According to RUDIS (1963) some indications for an exhalative iron origin might exist.

Regarding sedimentary copper minerals there are occurrences in the world known where this metal is associated with sedimentary rocks, having originated in the conditions of shallow-water sedimentation. In general there iz much uncertainity as to the sedimentary environment in which the sediments were deposited. The copper mineralization of apparent sedimentary origin seems to be present in Eritrea also at the new discovered occurrence Mont Sacar in the vicinity of Gumhod.

The primary depositions containing iron were subsequently subjected to several periods of metamorphism and deformation. They were extensively metamorphosed and recrystalized and iron concentrated to lenslike ore bodies of granoblastic texture.

The next hydrothermal replacement mineralization followed, the result of which was the formation of skarns. The mechanism of these events as well as the origin of solutions is not cleared. The components could be either newly brought from magmatic sources or may be simply a remobilization of elements from sedimentary sources already present, without introduction of new material. The solutions may have been derived from the batholitic activity, connected to granodioritic intrusions, younger than the metasediments.

The process of martitization is believed to be of supergene origin. As already pointed out a part of hematite is possibly due to hydrothermal activity too.

R e s e r v e s. The reserves for the most southern part of the iron-bearing zone between Sabub and Agametta have been calculated by RUDIS (1963), and summarized to a global sum of 425 000 tons. Some nine groups of ore lenses in the zone of about 15 km lenght may contain about 124 000 tons of visible and probable ore, and several hundreds of thousand tons of potential possible ore. The enlargement of reserves on account of inferred ore in the depth is not hopeful due to small dimensions of the ore lenses and their scarce displacement in the terrain.

As to the visible and probable reserves in the Gumhod area they are calculated to 8530 tons only. The inferred tonnages can be estimated to several tens of thousand tons (H a m r l a, 1964).

On the basis of the known geological situation in both areas, and on the assumption that the ore might be present in the plain area covered by alluvial sands the tonnage estimate is possible by statistical method. Hence, the reserves of the whole 40 km long zone might amount to about 1 million tons, related to twelve known occurrences and additional nine supposed to exist under the alluvial cover. A depth to 60 m under the surface was considered and the actual relation between the proven and inferred reserves is about 1 : 7 (Hamrla, 1964).

More promising in reserves might be the Falcat region. The Italian sources report much greater dimensions of the ore bodies from those established in the Gumhod-Agametta area. On the other hand these data seem to be doubtful if compared with the Italian data for Agametta. Additionally the great distance from potential industrial centres as well as from the shore (60 km air-line to Red-sea port Mersa Teclai) makes the immediate economic proficiency of these deposits doubtful even if larger reserves exist. The deposits should be, however, reconnoitred and well assessed in light of experiences gained through detailed geological and geophysical examination of Gumhod-Agametta area. Moreover the whole 180 km long zone between Gumhod and Falcat valley should be prospected and assessed.

Other deposits

Similar iron ore deposits are reported to exist in Sidamo province in the area of Yavello and Irbi as well as in the zone of Arero and Metacapersa (Murdock, 1960). Magnetitic and hematitic ore is reported to contain 60 to 68 % of iron. These localities would be worth to be explored to such an extent that the eventual significance could be assessed.

3. Residual concentration type

The occurrences of residual ores are due to the decomposition of silicate rocks in the process of weathering. During the decomposition some leached components go into solution and are carried away, others remain and precipitate in convenient environment. Under conditions characterised by alternating dry and wet seasons, the decomposition is more complete and results in a lateritic soil composed of limonitic and bauxitic components, meanwhile silica is extensively removed.

Under favourable climatic and other conditions iron and also manganese may accumulate in this way to form even economic deposits. The concentration of iron in lateritic residue forms residual — lateritic deposit. If the leached components precipitate in open spaces residual — infiltration type originates.

Regarding the nature of mother-rock the iron has been leached from the extrusive volcanic rocks and ferruginous siliceous rocks can be distinguished.

Extrusive rocks as source of iron

Mai Gudo

General. The Mai Gudo area is situated about 60 km to SSE from Jimma in the upper drainage pattern of the Odonitta river. The mountainous area is difficult to access. A 65 km long old road in very bad condition presently connects the locality with the highway some 30 km before Jimma.

The deposit consists of many small iron ore occurrences, the most important of which are shown in the enclosed map (Fig. 12.). There is no persistency among the isolated accumulations.

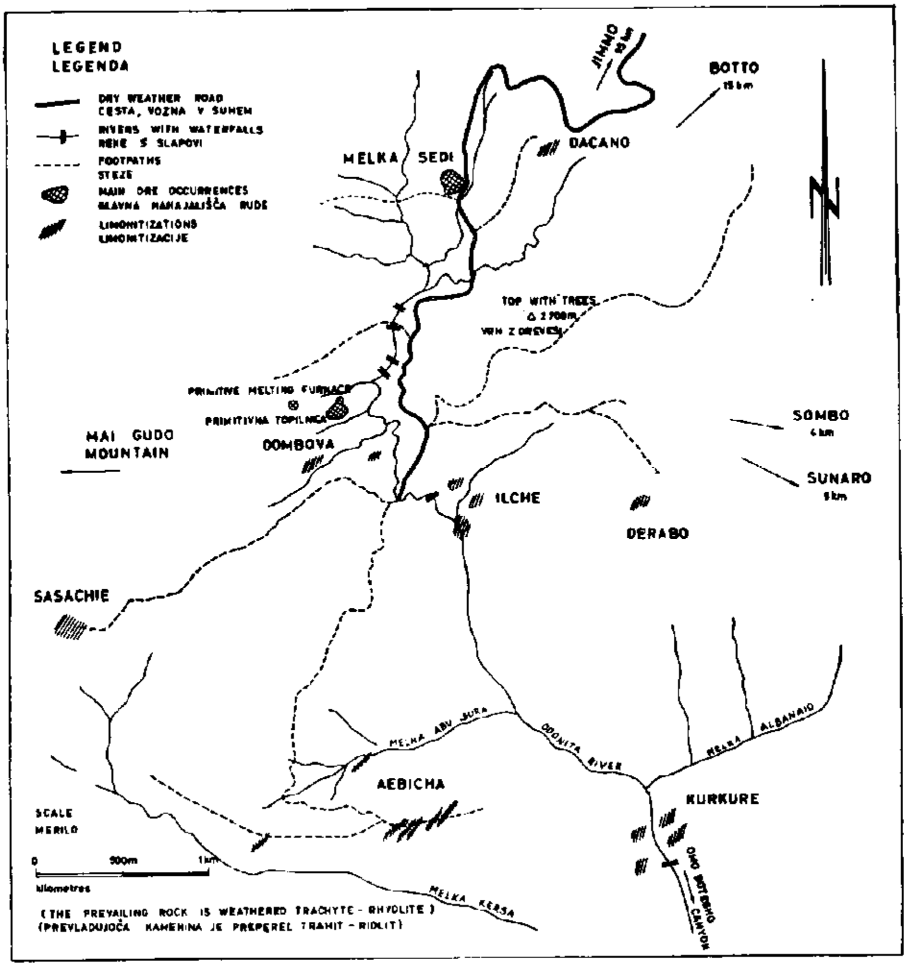


Fig. 12. Sketch map of Mai Gudo iron (and manganese) ore occurrences

Sl. 12. Skica nahajališč železove (in manganove) rude Mai Gudo

The ore has been exploited by natives and smelted in a primitive way for a long time ago for the manufacture of tools and weapons. During the Italian occupation considerable mining activity has been carried out and about 20 000 tons of ore were mined. In that time V i l l a m i n a r estimated the ore reserves, which are cited by U s o n i (1952) to amount to 1,2 million tons totally.

In 1945 M u r d o c k visited the area and estimated the reserves to 120 000 tons (M u r d o c k, 1960). He pointed out the guess has been made without any real basis. In 1956 an expert of the German KRUPP company reconnoitred the area and found it not worth of any further exploration.

At the end of 1962 the Ministry of mines explored the area by pitting and trenching. The occurrences have been found practically without economic importance, being very small in size and insignificant in reserves of ore of medium and low quality (H a m r l a, 1963). Additionally, the position of the area is very unfavourable regarding transportation facilities.

D e s c r i p t i o n. The large region of Mai Gudo is built up of volcanic rocks of Trap series. Dolerite and olivine-basalt are reported to build the highest parts of the mountains. The prevailing rocks are trachyte-rhyolite. The rocks are extremely weathered and characteristically violet-reddish coloured. Residual soil covers the surface and locally accumulates in considerable thickness. Yellowish-brownish bands and crack-fillings by compact ore could be stated everywhere in the soft weathered country rocks which contain often yellow ochreous and black manganiferous inclusions. The traces of former exploitation in limited extend can be locally found.

Melka Sedi is the most important locality among all occurring in this region. Supergene iron ore occurs in the lowest part of a pretty steep slope. Old ditches and trenches are evident in the outcropping area which may have a surface of about 120 m by 100 m. Residual soil covers the weathered rocks, being ferruginous and intensively yellowish-reddish-brown coloured. Thin veins and bulby inclusions of compact ore are frequent. Small bodies of compact limonite are included in yellow earthy ochre containing bluish-black manganese hydroxides as well as layers of grayish-black earthy wad. The structure of ore is breccious and it passes here and there to the residue. It looks that the more compact ore is concentrated in the lowest part of the mineralized zone near the bottom of the slope. The quantitative relation between the compact ore and the waste is in general unfavourable.

At Dacano ferriferous concentrations occur in weathered rocks accompanied by manganese oxides. They are quantitatively unsignificant.

The outcroping area at Dombova extends on a roughly estimated area 100 m by 80 m. The ore occurrence is similar to Melka Sedi in appearance but smaller and poorer in degree of mineralization. An old trench reveals the prevailing yellowish weathered rocks and banded soil with irregularly concentrated limonite in form of small bulbs and veinlets other than greater blocks and lenses.

At Ilche only scarce traces of mineralization exist in residual soil as proved by several pits.

At Sassachie weathered yellowish-brown rocks prevail, containing small crack-fillings of iron and manganese oxides.

No remarkable ore concentrations exist also at the localities Kurkure, Derabo, Sunaro and Botto, where unimportant local concentrations of compact ore are accumulated in cracked weathered country rock.

Veinlike iron ore occurrences were signaled from the locality Aebicha. Iron and manganese oxides are concentrated in tectonically crushed zones, striking 200° to 250° and dipping vertically. They have 10 cm to 40 cm in width. The breccious weathered rocks are cemented with iron oxides as well as with silica, indicating in this way the forms of apparent veins.

At the locality Sombo a several centimeters thick lenslike seam of manganese ore was found underlying the clayey overburden. This residual manganese concentration is of theoretical interest only.

In general the Mai Gudo ore can be described as mostly unclean and more or less breccious with admixtures of weathered rocks. It consists of hydrated oxides of iron in all varieties from brown hydrohematite on one side to high porous ochre of earthy nature on the other side. The same passes for manganese ore which exhibits stalactitic and spongy masses, but also earthy wad of high porosity can be often observed.

Analyses. For Melka Sedi and Dombova ore twelve chip and channel samples have been analysed by KRUPP (1956), indicating the average iron content about 40 %. The average manganese contents for Melka Sedi iz 8,6 % and for Dombova 3,8 %. Phosphorus and sulphur range about 0.03 % and silica between 6 and 17 %.

Several chip samples from different localities were analysed also in the Chemical laboratory of the Ministry of mines. The samples did not represent the average of the existing ore but rather relatively rich ore was taken. The results are shown in Table 4 (in percent):

Table 4 — 4. tabela

Locality	Fe	Mn	SiO_2	Al_2O_3	Remarque
Ilche	37,9	0,3	36,0	4,7	Siliceous ore
Kurkure	45,0	1,64	20,0	3,15	Rich compact ore
Aebicha I	45,6	tr.	21,9	1,0	Siliceous breccious ore
Aebicha II	34,8	0,1	41,0	0,0	Unclean breccious ore
Sunaro	58,8	0,3	3,5	0,0	Clean compact ore
Sombo	7,7	44,5	5,4	2,7	Rich manganese ore

The microscopic examination of polished sections of ore specimens reveals the porous texture of limonitic ore composed of goethite prevailingly. The admixtures of impurities are often (Pl. III, Fig. 1.). Psilomelane occurs intimately intergrown with iron oxide but also in form of fine banding.

Microscopic examination of the country rock reveals no mafic phenocrysts in hollocrystalline porphyritic rock. Minute mafic components are disseminated in the matrix only. Decomposition begins in the matrix which get to be impregnated by yellowish pigment. The limonitic products fill up also the cleavages in sanidine phenocrysts, which get to change to products of kaolinization.

Origin. Genetically the accumulation of iron and manganese can be explained through principles of supergene mineralogy of both elements. The mineralization is the result of chemical weathering of the country rock. Iron and manganese have been leached out of mafic minerals in the fine-grained matrix and precipitated more of less in situ, having accumulated in residuals and different openings in the rock where iron and manganese-bearing solutions have penetrated. Silica, alkalies and alkaline earths have been removed in solution and carried away. There is no doubt on the descending origin of the solutions. Also the morphology and the superficial character of the occurrences reveal a secondary enrichment only.

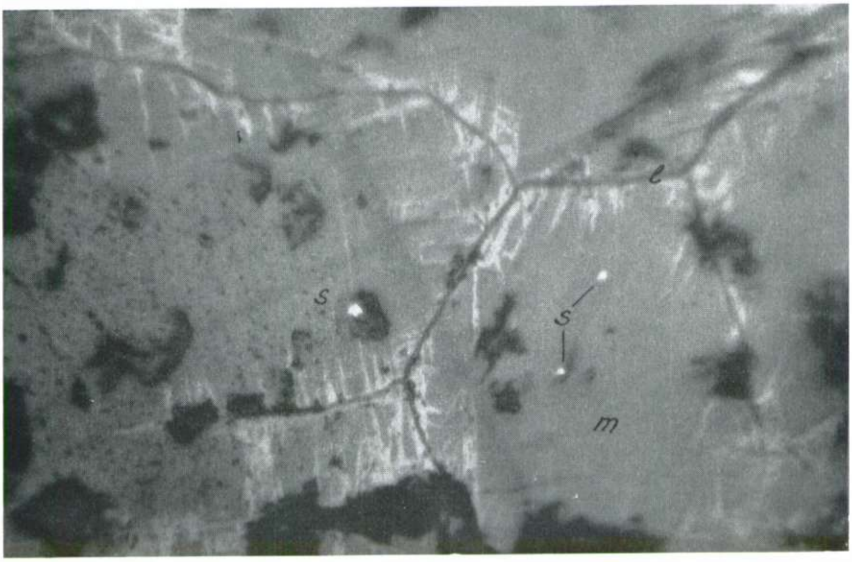
Iron and manganese might have originated partly perhaps also from more basic rocks the presence of which is indicated in the area. However, the percentage of iron and manganese in acid rocks is low. Economically important iron ores of this genetical type are normally bound to more basic rocks.

Reserves. Regarding the reserves Melka Sedi and Dombova deserve limited attention only. At both localities the quantity of useful compact ore does not exceed 20 % of the volume of the layers of altered ochreous decomposed rocks prevailingly. Hence the measured reserves of compact ore have been calculated to 65 000 tons for Melka Sedi and 12 000 tons for Dombova, having an average of about 40 % of iron and several percents of manganese. The additional inferred tonnages could be estimated to 25 000 tons only. From the point of view of smelting industry the reserves as indicated above have a very limited significance. An additional unfavourable factor regarding the mining is high compact ore — to — waste ratio, ranging about 1 : 5.

For all other localities the conclusion is due, that no reserves of economic importance were detected and can also not be expected. Taking into consideration also the transportation difficulties the reserves of Mai Gudo have very small economic importance for the time being.

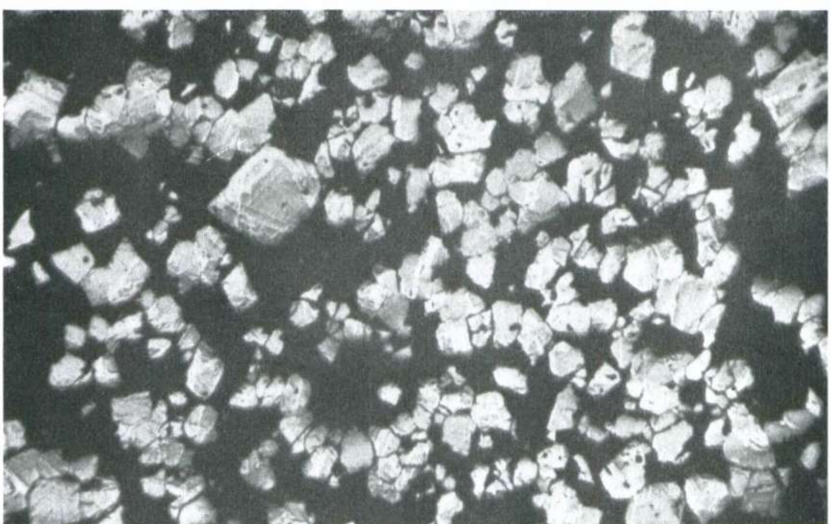
Entoto

Entoto hill several kilometers north of Addis Ababa is known for a long time to yield iron ore. Old trenches and overgrown pits give evidence of former mining activity. Small isolate lenses and veinlike accumulations of hard limonitic ore are exploited in very reduced scale presently to meet local requirement of the Akaki smelting factory. The ore is used as extra-charge to the scrap iron.



Pl. I, Fig. 1. Koree ore; — oil immersion, 600 ×. Martitized magnetite (m), limonite (l) in cracks and small grains of sulphide (s)

I. tab., 1. sl. Ruda Korree; — oljna imerz., 600 ×. Martitiziran magnetit (m) z limonitom (l) v razpokah in drobnimi zrni sulfida (s)

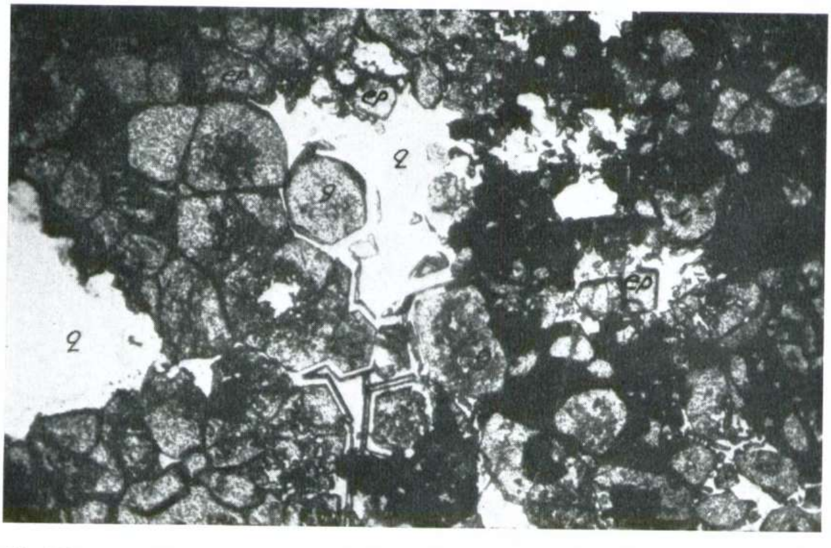


Pl. I, Fig. 2. Dongollo basso ore; — oil immersion, 135 ×. Granoblastic agregate of partly martitized magnetite in quartz matrix

I. tab., 2. sl. Ruda Dongollo basso; — oljna imerz., 135 ×. Granoblastičen agregat delno martitiziranega magnetita v osnovi kremena

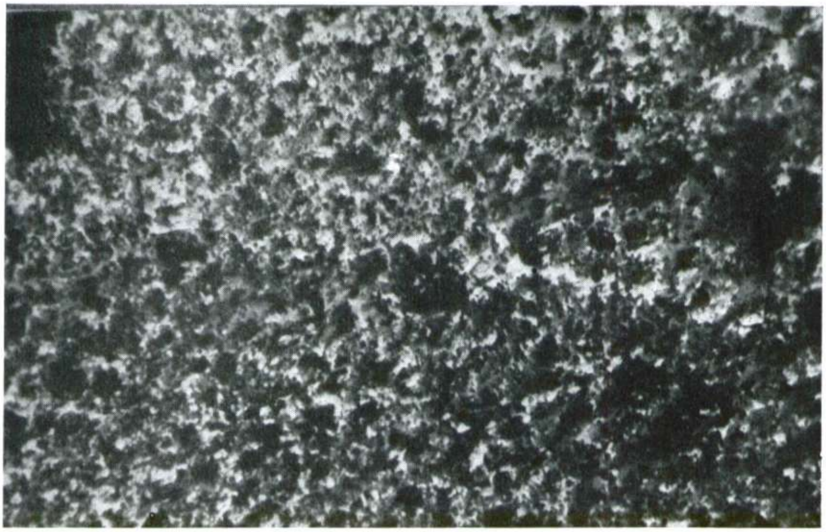
Pl. II, Fig. 1. Gumhod ore; — oil immersion, 600 ×. Martitized magnetite (m) with small grains of chalcopyrite (ch) and malachite (ml)

II. tab., 1. sl. Ruda Gumhod; — oljna imerz., 600 ×. Martitiziran magnetit (m) z drobnimi zrni halkopirita (ch) ter malahitom (ml)



Pl. II., Fig. 2. Agametta ore; — thin section, 40 ×. Skarn ore: magnetite (m), garnet (g), epidote (ep) and quartz (q)

II. tab., 2. sl. Ruda Agametta; — zbrusek, 40 ×. Skarnova ruda: magnetit (m), granat (g), epidot (ep) in kremen (q)



Pl. III., Fig. 1. Mai Gudo ore; — oil immersion, 135 ×. Porous impure limonitic ore

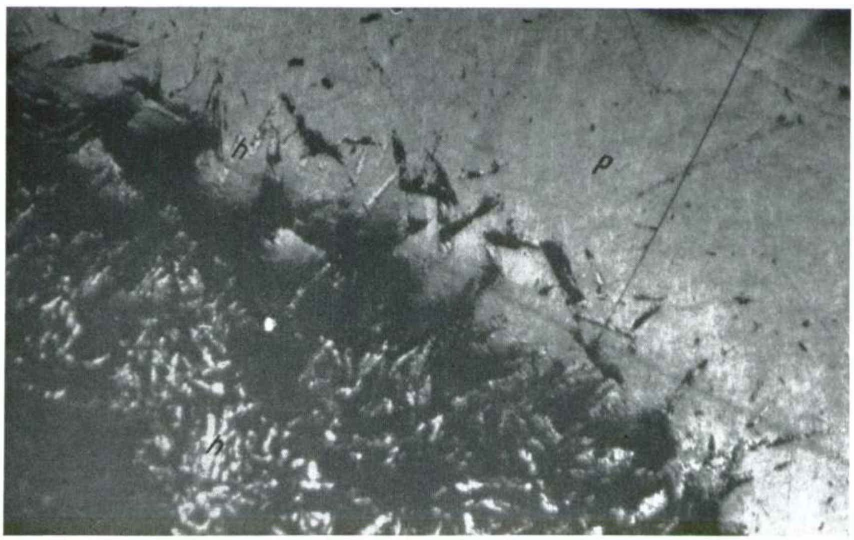
III. tab., 1. sl. Ruda Mai Gudo; — oljna imerz., 135 ×. Porozna nečista limonitna ruda

Pl. III., Fig. 2. Ghedem ore; — oil immersion, 135 ×. Zonal texture of ore, consisting of alternating bands of iron oxide (g), manganese oxide (m), silica (s) and calcite (c)

III. tab., 2. sl. Ruda Ghedem; — oljna imerz., 135 ×. Conarno strukturirana ruda sestoji iz izmeničnih pasov železovega oksida (g), manganovega oksida (m), kremenice (s) in kalcita (c)

Pl. IV., Fig. 1. Ghedem ore; — oil immersion, crossed nicols, 135 ×. Fine-crystalline agregate of pyrolusite

IV. tab., 1. sl. Ruda Ghedem; — oljna imerz., navzkrižni nikoli, 135 ×. Drobno kristalast agregat piroluzita



Pl. IV., Fig. 2. Enkafela ore; — oil immersion, 135 ×. Psilomelane (p) and needleshaped hollandite (h)

IV. tab., 2. sl. Ruda Enkafela; — oljna imerz., 135 ×. Psilomelan (p) in igličast holandit (h)

The Entoto mountain is built up of trachytic-rhyolitic rocks prevailingly. The ore occurrences are known on the southern slope of St. Raquel church's hill. The rocks are altered and decomposed on the surface and residual soil is accumulated in thick cover locally. The limonitic ore is found as fillings of fractures and cracks in the weathered rocks or as small isolated inclusions in decomposed rock. The ore is compact, glassy limonite prevailingly but sometimes soft and banded ochreous parts can be found too. The width of "veins" is several decimeters at the maximum.

The origin of the ore is due to the leaching of iron by rain water during the weathering of country rock. Other leached components were carried away but iron precipitated in fractures and other openings in the rock. The colloidal ferric hydroxide hardens subsequently into amorphous glassy limonite with more or less obviously banded texture.

The estimation of reserves is difficult. The quantity, however, can be expected very small and no economic importance might be attributed to the locality for the time being. On the other hand an accurate search of the whole mountainous complex would possibly reveal several new ore concentrations, however, of limited dimensions. The reserves of inferred ore can be estimated not exceeding several thousands of tons only. Nevertheless, the tranportation situation of this area is favourable and a smelter is near.

Aira — Yubdo

In the Aira-Yubdo area in Wollega volcanic Trap series overlays the pre-Cambrian metamorphic rocks. The volcanic cover is relatively thin and reduced partly only to the tops of the hills. The rocks are largely composed of olivine-basalt. Along the border of the Trap capping the presence of thin layers of ferriferous rocks of oölitic and spongy texture is evident on many places in the volcanics' marginal zone. Near Aira Mission the ferriferous rocks are composed of quartz sandstone and conglomerate witch limonitic cement. At the magnetite occurrence near Yubdo an oölitic limonitic layer can be observed in the basis of the basaltic cover overlying the metamorphic schists.

Genetically the mineralization is a residual concentration of supergene iron oxides. The pre-Trapean residue, having resulted from the weathering of the basemnt rocks, was hardened by limonitic cement. The iron was dissolved by meteoric waters out of the basaltic rocks during the decomposition. The solutions percolated down and infiltrated the underlying residuals or other clastic rocks, having found a favourable place for the precipitation and deposition of dissolved minerals, and transforming them in oölitic and spongy ferruginous rocks. It is obvious that silica was leached and transported too due to the ferric-siliceous character of the existing ore.

In this way also the long discussed "birbirite", a special spongy ferric-siliceous rock known from Yubdo platinum deposit, might be explained as limonitized and silicified former lateritic crust of ultrabasic rocks which, however, contain platinum too. An additionnal proof for this explanation is the fact that "birbirite" can be found prevailingly along the western border of ultrabasic mass where it is still more or less in contact with basaltic cover.

Sands and gravel near Aira Mission may have originated as young lacustrine sediments deposited before the extrusions took place. Porous clastic sediments were cemented subsequently by ferric oxides transported in solutions from the overlying volcanic rocks (H a m r l a , 1963).

The observed phenomenon of iron accumulation in the marginal zone along the volcanic capping occurs surely also on other places, where the geological conditions are favourable. The residual limonitic concentrations occurring in this way may be of theoretical interest only. At least in the Aira-Yubdo area the conditions as observed do not allow any hope for depositions of commercial value.

Ferruginous siliceous rocks as source of iron

H a m a s e n

G e n e r a l. The large occurrences of low-grade iron ore of residual type exist in Eritrea in the waste area south of Asmara, known by regional names Hamasen and Serae. Also there the natives smelted the ore to prepare the utensils and weapons. There is some descriptive information about the deposits of "nodular limonite" scattered in the waste area south of Asmara and also on other places in Tigre province. D a i n e l l i (1943) described the phenomenon and later U s o n i (1952) gave detailed information on the results of explorations carried out particularly during 1930/31. According to the Italian investigator T i s s i the ore might extend on a large surface, and the thicknesses of layer are reported between 0,15 m and 0,6 m only.

Geologically this part of Eritrean high plateau is built up by schistose rocks of pre-Cambrian age overlain by volcanic capping. The pre-Cambrian surface was erroded to a peneplain before the Triassic transgression took place. The subsequent denudation removed the greatest part of the uncomformably overlying Triassic and Jurassic sediments before the Tertiary volcanic cover spread over the weathered surface of the basement complex.

The pre-Cambrian rocks of this area are predominantly phyllites, chlorite-schist and sericite-mica-schist streaking generally NNE—SSW, and containing gold-bearing quartz reefs. Granite bosses crop out at several places. The volcanics are built up by basalts, trachytes and rhyolites.

D e s c r i p t i o n. The concentration of iron oxides is connected to the zone of alteration on the old levelled surface of the schistose pre-Cambrian rocks. The reddish layers of ferriferous rocks are to be seen everywhere, where the errosion removed or cut the basaltic covering. The largest areas of exposed reddish ferriferous rocks extend in the surroundings of Mariam Sambel just westwards of the new airport of

Fig. 13. Scattered pebbles of low-grade iron ore at Mariam Sambel
Sl. 13. Razmetani kosi nizkoprocentne železove rude pri Mariam Sambel

Asmara (Fig. 13.), and westwards of Schicceti on the Asmara-Adi Ugri road. There are many additional more or less exposed occurrences along the whole margin of volcanic capping, and isolated islands occur on the basement where the volcanic cover was already removed.

The approximate situation of the iron-bearing localities is given in the enclosed sketch (Fig. 14.).

At Mariam Sambel low-grade iron ore can be found on a surface of about 3 sq. km. It is compact with a nodular and breccious appearance. The thickness of existing layer is difficult to estimate but it is thought to reach several meters at maximum. The limonitic-hematitic ore is low-grade by appearance and should contain a relatively great percentage of silica.

Near Schicceti between the highway and the river Mareb there are large surfaces covered by reddish ferruginous products confined to the contact zone between the basement complex and overlying volcanics. The oxidized and secondary enriched ferruginous zone shows an obvious schistosity and represents the upper weathered part of the basement rocks, consisting locally of ferruginous and other schists (Fig. 15.). Irregular or lenslike inclusions of white siliceous staff are not seldom and might result from the precipitation of leached silica. The highest part of the secondary enriched zone is a breccious brownish-reddish rock of nodular and spongy appearance, similar to ferruginous concentrations observed by the author in Wollega and described above.

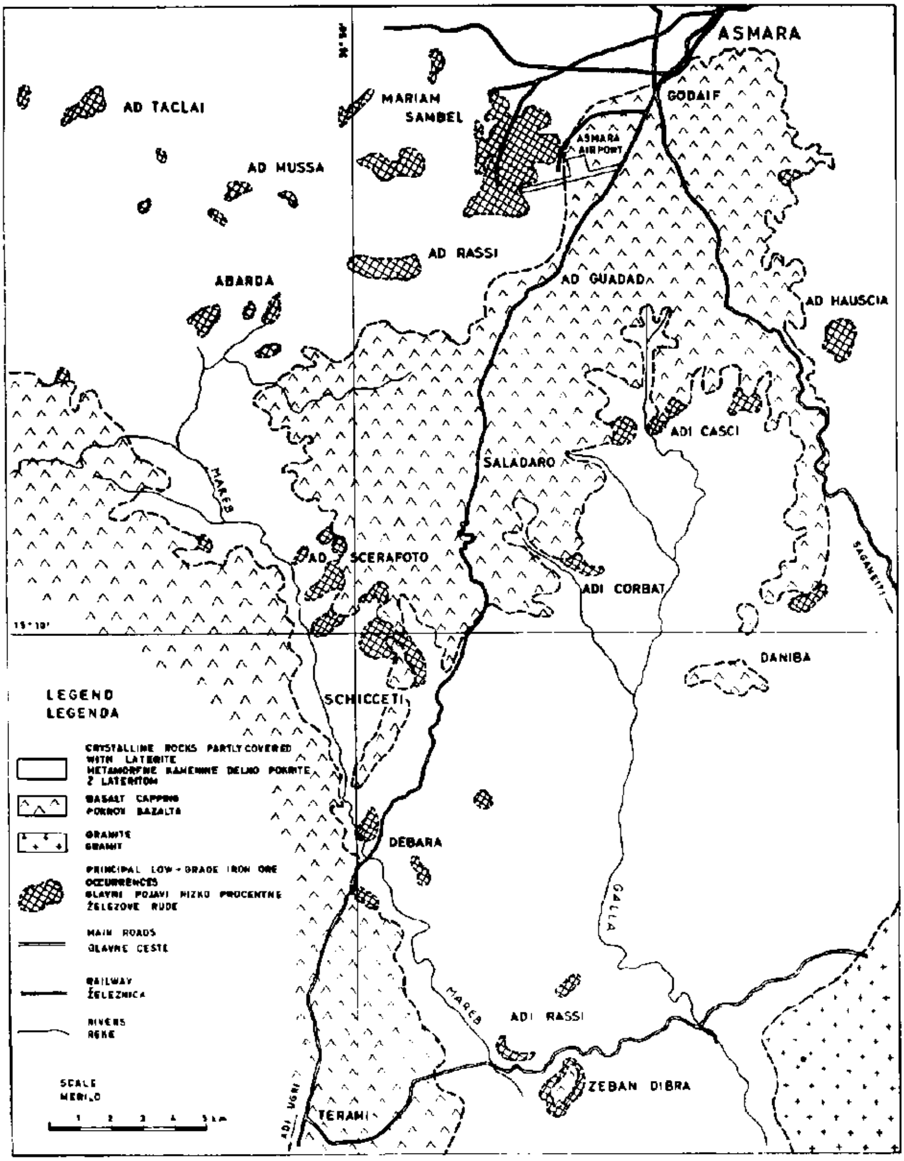


Fig. 14. Provisional geological sketch map of Hamasen. (After L. Usoni)

Sl. 14. Približna geološka skica Hamasena. (Po L. Usoniju)

There are many other localities in this region where the occurrences of iron oxides appear in the altered weathering zone immediately on the surface of crystalline basement rocks.

In general, the ore appears mostly unclean, breccious and schistose textured, cemented with reddish cement. It consists of weathered rock and iron oxides and hydroxides. The passages from ferriferous concentrations to the schistose basement rocks can be observed especially in the lowest part of the layer.

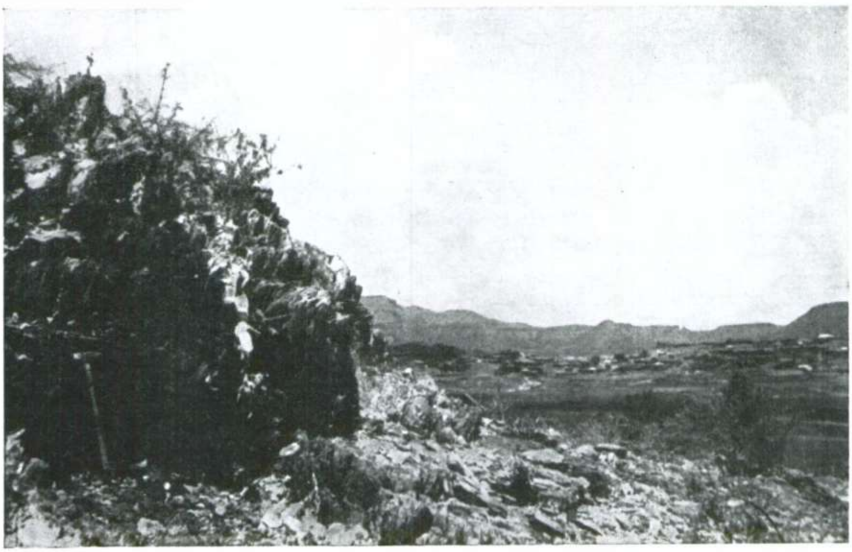


Fig. 15. Schistose low-grade iron ore with quartz inclusions near Schicceti

Sl. 15. Skrilava nizkoprocentna železova ruda z vključki kremena blizu Schiccetija

A n a l y s e s. As to the percentage of iron the low-grade ore contains there are large variations estimated visually to range between 5 and 6 % but averaging rather low. For the time being the data of several chemical analyses given by U s o n i (1952) are available only. The iron contents is reported to vary between 30 and 56 % and silica 13 to 18 %, averaging accordingly to 40 % of iron and 16 % of silica. The contents of other admixtures like phosphorus and sulphur is very low. These values can be accepted as a rough orientation only because no garanty exists on the correctness and precision of sampling and analysing performed. The visual estimation of an average percentage of metal in the ore is much lower. It is possible, however, that parts in the mineralized zone exist which might yield a higher average in iron.

O r i g i n. The supergene enrichment of iron is due to the weathering of the pre-Cambrian basement rocks in the period of emersion before the lawa flows dispersed over the peneplained and levelled surface. According to M o h r (1961) the age of weathering and decomposition can be dated as belonging to the Portlandien-Eocene interval. The basement rocks were oxidated and leached during that interval and the rain-water removed different constituents of the rocks other than iron which remained and enriched in situ. The aspect of the mineralized layers is thus an argilaceous and breccious. A part of supergene iron could be leached also out of the overlying basaltic capping and after percolating the fractures and cracks it precipitated and accumulated in the upper part of the weathered and decomposed basement rock.

R e s e r v e s. According U s o n i (1952) T i s s i examined the deposits in 1931 by 219 shallow pits and trenches. He estimated the total reserve of low-grade iron ore might be about 15 million tons, a half of this tonnage being situated in the immediate surroundings of Asmara. Supposing the continuity of the ferriferous deposit under the volcanics, T i s s i estimated the inferred reserves to 200 million tons.

Nothing more definite is possible to say about the reserves existing in this area as well as the quantity of ore with a satisfactory chemical composition for the time being. It could be expected that several tens of million tons of ore might be potentially important regarding the quality as well as other factors influencing the eventual exploitation. Anyhow, the deposits must be regarded as a potential second- or third-order source due to the low contents of metal. Regarding the transportation facilities their situation is good. The future of these deposits might be perhaps in blending with high-grade ores.

To asses the existing ore detailed exploration is necessary. It is being carried out by the Ministry of mines for the time being in order to detect richer and thicker parts of the layers.

T i g r e

Many explorers observed the ferriferous lateritic formations in Tigre province and reported upon the existence of iron deposits. An old primitive exploitation on a small scale as well as smelting for local requirements is known in different parts of the province. Quite exhaustive description of these and Eritrean deposits is summarized by D a i n e l l i (1943). U s o n i gives some general information concerning the most important localities between Adua, Axum and Enticcio (U s o n i , 1952). The iron occurrences are reported to be "ferriferous laterites" similar to those in Eritrea, and connected to the basement rocks as well as to the Mesozoic formations of Adigrat and Upper sandstones. The interesting appearance of nodular and pisolitic limonite concentrations is known to exist at many of those places where clastic sandstones crop out. M e r l a and M i n u c c i give some detail on mineralization indicating that the prevailing limonitic "lateritic crust" has a thickness of 5 to 6 m at maximum, but the weathered zone of the sandstones is much thicker (M e r l a , M i n u c c i , 1938). According to V i l l a m i n a r the grade of metal averages about 45 % (M u r d o c k , 1960).

As to the genesis of iron accumulation Merla and Minucci considered it as a result of lateritization of sandstones during the pene-plaination which preceeded the Trappean eruptions (Merla, Minucci, 1938). The ferruginous cement of sandstones might be of primary authigene origin. On the other hand, Dainelli considered the presence of the opaline-limonitic sediments as to have been transported in the Uper Jurassic or Cretaceous period from the lateritized emerged basement rocks and sedimented in the sea (Dainelli, 1943).

According to Mohr (1961) there is obvious evidence of the lateritic weathering on the top of Upper sandstone. The lateritic crust found in Eritrea upon the basement complex passes further south into the sandstone formations. The alteration takes the form of a limonitic enrichment of the topmost strata to a depth of some ten meters.

It is probable that the enrichment of iron might be locally sufficient to form an economic iron-ore deposit. No figures for the reserves are known, but it can be expected that perhaps several million tons of low-grade ore might be available.

Other residual occurrences

The phenomenon of iron concentration as described above for different more known localities occurs in the whole region of the Ethiopian plateau where similar petrographic, morphologic and climatic conditions exist, being in general convenient for leaching and transportation of iron and its accumulation either in residual lateritic soil or other favourable environment.

There is some information on local iron ore occurrences at different localities of Ethiopia, but the details are rather limited and up to now no one of them deserved larger interest regarding the economic importance. Dainelli (1943) gives an overlook of find-spots of ore and these localities are indicated or described many times in several other reports.

Residual deposits are known from Beghemder west of Tana lake and north of Gondar as well as near the town itself. The occurrences are reported from Gojjam some 100 km north of Debra Marcos, and from Ankober in Shoa. A small lateritic-infiltration type occurrence is reported to exist near Yavello in Sidamo province (Murdock, 1960).

To the same type belong probably the occurrences reported to exist at Maji and Gurrafarda in Kaffa province.

4. **Hydrothermal type**

Ghedem

General. The sole more important known deposit of hydrothermal origin is situated some 7 km southeast of Massaua, occupying the extreme northern part of the Ghedem mountain. The deposit was visited and explored many times in the past as described by Usoni (1952), who summarized all what was knovn about it. The main exploration and exploitation of the ore took place immediately before the War II. Several trenches, pits and bore-holes were executed and a limited tonnage of ore was exported to Italy.

There was no certainity about the origin of this iron and also manganese accumulation and M o h r even in 1961 ranged the deposit as a probably pre-Cambian sedimentary one. In 1963 preliminary prospection and studies were carried out by the Ministry of mines (H a m r l a , 1963). Early in 1964 the deposit was searched geologically and geophysically by the Yugoslav RUDIS company on behalf of the Ministry of mines in order to establish definitely its eventual economic signification.

The mineralizations are located on a hill confined on three sides by dislocations and surrounded by alluvial sands and gravels. The prevailing direction of the faults is about 30° and the dip is more or less vertical but dislocations run also about 150°. Here and there along the borders of the hill the slickenside fault surfaces can be clearly seen with traces of oblique movements. The faults are accompanied by tectonic breccias. The main ore bodies are bound to these dislocation (Fig. 16.).

The area is built by metamorphic crystalline rocks. Micaceous and gneissic schistose rocks prevail, dipping generally 75° to 80° west. Pegmatitic veins and dikes in various directions are often. Greenish porphyry rocks appear at some parts of the hill. Gray-black crystalline carbonate rock appears along the borders of the hill following the main tectonic directions. It forms elongated ridges like dikes on the hill and it fills the cracks and fissures in pegmatites and other rocks, being directly

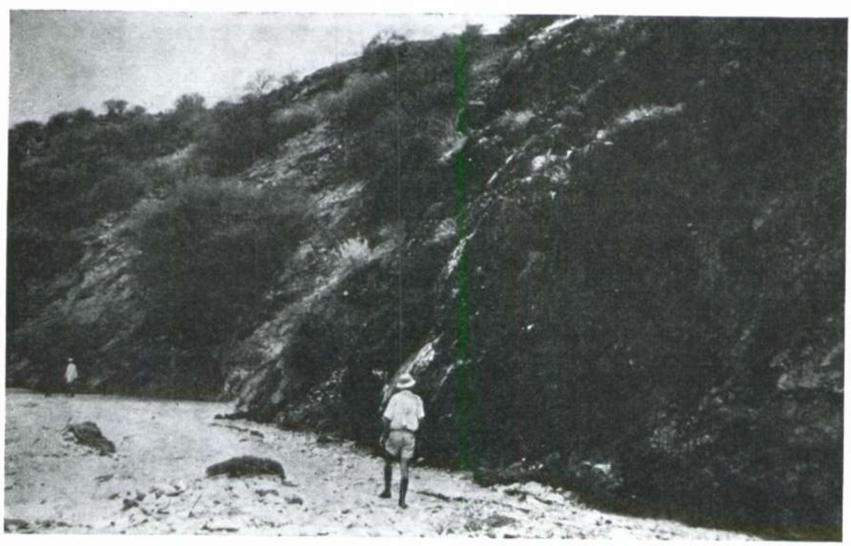


Fig. 16. Ore body No. 3 along the torrent Ghedem

Sl. 16. Rudno telo št. 3 vzdolž hudournika Ghedem

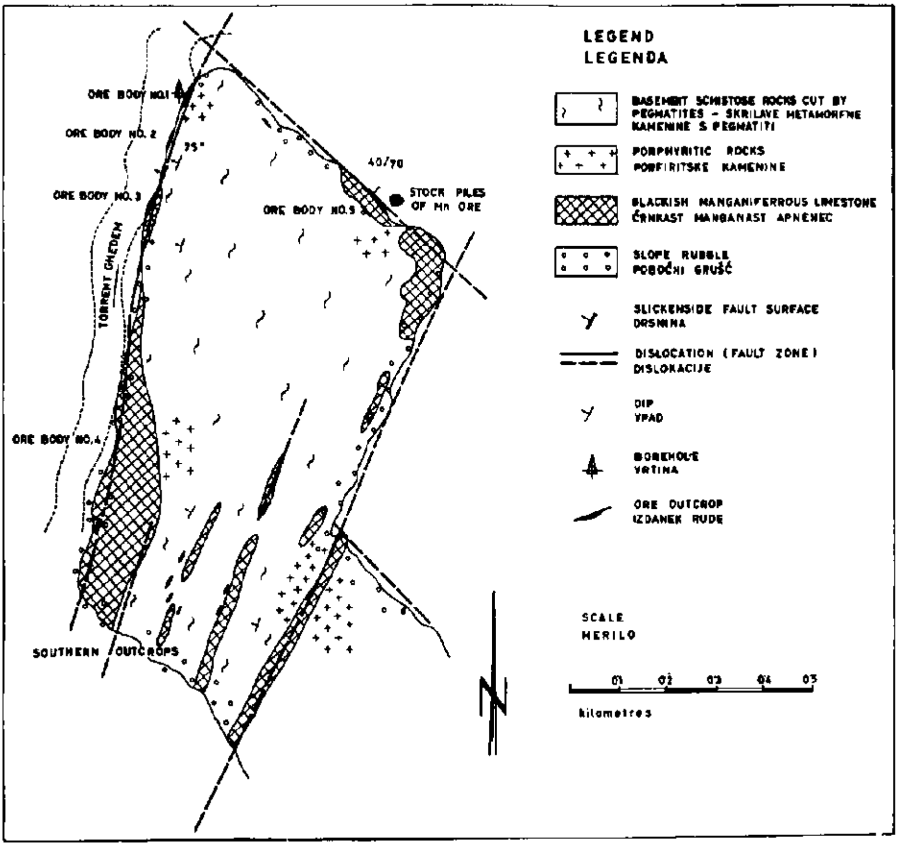


Fig. 17. Provisional geological sketch map of Ghedem deposit
Sl. 17. Približna geološka skica nahajališča Ghedem

connected with iron and manganese mineralization (Fig. 17.). Carbonate gangue alternate with iron and manganese oxides in bands, indicating in this way the obvious genetic connection.

Description. The main ore bodies appear allong the borders of the hill in form of lenslike outcrops, having an average lenght of several ten meters and thickness of several meters only. The best exposed outcrops are situated along the torrent Ghedem due to its errosive activity. Many smaller ore outcrops are occurring in the southern part of the hill, accompanied by calcareous gangue which includes more or less of metal oxides as incrustations or inclusions.

Iron ore is limonite prevailingly, having a porous and spongy texture. The breccious ore is composed of particles of country rock, cemented by iron and manganese oxides. Manganese ore appears generally fine-banded mammillary or as crusts, being intimately mixed and intergrown with iron oxide. The ore is generally composed of both iron and manganese oxides.

The main ore body, a part of which is already removed by excavations, shows visible dimensions 75 m by 15 m by 5 m approximately. The porous limonitic ore seems to be crushed and mylonitized and subsequently cemented again with iron oxides. In the vicinity of the ore body many thin veins of ore intersect the adjacent country rocks.

The visible dimensions of the other ore outcrops are smaller. The ore is in general more breccious and impure with increased contents of manganese. The breccious texture gives obvious evidence of a tectonically effected mineralized zone. Blackish manganiferous limestone everywhere accompanies the ore. The separation of the ore outcrops on the western side of the hill along the torrent Ghedem was thought to be due to errosion, but this hope was disproved by RUDIS' survey in 1964.

On the southern part of the hill several mineralized limonitic zones and small ore outcrops can be observed at many places. No traces of exploitation can be seen there.

On the north-eastern border of the hill there are two outcrops of ore which have been mined in the past. The ore is breccious and manganese oxides prevail. Also this border is obviously tectonically effected and fragments of ore can be found intermingled with slope-rubble.

Analyses. All transitions between calcareous waste and rich either iron or manganese ore can be observed in the field. The results of analyses of several chip samples of ore and of two average samples of ore shipped in 1940 to Italy are given by Usoni (1952). The chemical composition of Ghedem ore might result accordingly as follows (in percent):

Fe	about 54	S	0,055 to 0,13
SiO_2	about 12	P	0,027 to 0,04
Mn	0,2 to 0,45		

This quality, however, can not be expected as an average one because the ore from diverse outcrops differs in great extent due to the varying mineralogical composition and admixtures of impurities. The iron ore — to — manganese ore ratio might be in general about 18 : 1 relating to the Italian sources (Usoni, 1952).

No new chemical analyses of ore are available presently. The carbonate gangue was chemically examined only in order to clear its composition which is the following (in percent):

$CaCO_3$	94,0	SiO_2	0,3
Fe_2O_3	1,86	S	0,00
Al_2O_3	1,64	Mg	0,00
MnO	3,1		

The admixtures of manganese oxides cause the black colour of the carbonate rock. Besides the calcite the elongate shaped crystals would point to aragonite.

Microscopic examination of the ore reveals the prevailing concentric texture of oxidic minerals in form of fine curved bands and zones (Pl. III, Fig. 2.). Radial crystallization is common, and the fibrous radially arranged agregates with long axes normal to the bands show continuous transition through bands and zones with fine needle-shaped free surfaces.

Goethite is the prevailing iron mineral. Bandlike ochreous inclusions seems to be replaced by goethite. Manganese oxides are represented by fine-grained psilomelane and fine fibrous pyrolusite (Pl. IV, Fig. 1.). Some yellow bands might belong to hollandite. Small flaky inclusions of pyrolusite are found in goethite. Silica occurs in form of irregular cryptocrystalline masses and alternates in bands with other oxides. It contains more or less fine dispersed oxides and forms a jasper-like cherty rock. Calcite is present in relatively big crystals and never as fine banding. Small irregular inclusions of manganese oxides are always present in it. More "generations" of iron and manganese oxides are evident.

Origin. The accumulations of iron and manganese oxides, accompanied by gell quartz and carbonate gangue, have originated from thermal solutions. The mineralization might be classified as epithermal or rather hot-spring deposition and was caused by a relative young thermal cycle. The deposition took place as filling of holes and cavities along the dislocations, cementing the tectonically crushed zones under the formation of breccious ore. There is no doubt of an ascendent character of the solutions which must have been loaded with CO_2. About the origin of these acid solutions nothing can be said with certainty. They were very probably bound to the young (Pliocene or Pleistocene) volcanic activity in the region, being either of juvenile or surface provenience as ascending heated meteoric waters.

The alternating bands of different oxides were caused by variations of physico-chemical conditions during the precipitation. The fine banding is, however, normally the proof of deposition in a colloidal state. The zonal structures observed develop mostly by minerals of supergene origin which are deposited as alteration products from cold aqueous solutions. Such textures, however, are found also in hypogene minerals and iron and manganese oxides are known to originate also as hydrothermal low-temperature products.

As to the mechanism of precipitation the constituents might have been transported in molecular solutions as bicarbonates, and after oxidation transformed partly to more stable colloidal state and precipitated as gels. Carbonate crystallized probably from bicarbonate solution. Other components precipitated subsequently as gels and acquired later more or less expressed crystallinity.

It can be assumed that the acid solutions percolated the deeper parts of the earth's crust, having leached iron, manganese, silica and calcium out of different rocks of metamorphic basement series. Another possibility is the solutions are derivatives of a magmatic source.

R e s e r v e s. According to U s o n i the reserves of ore were estimated in the years before the War II by T a z z e r who calculated the visible part to 80 000 tons, the probable one to 32 000 tons, and the possible one to 540 000 tons. M i n u c c i estimated the visible tonnage to 85 000 tons, and the possible one to 265 000 tons (U s o n i , 1952).

On the basis of recalculation of reserves in the field the conclusion can be made that the visible part of the outcrops amounts to about 36 000 tons. Some additional 40 000 tons of possible ore may exist in the immediate prolongation of the outcrops to the depth. According to the type and form of the deposit some hundreds of thousand tons might be additionally considered as inferred possible tonnage (H a m r l a , 1963). These figures practically coincide with those given by Italians. The deposit has to be classified accordingly as a very small one. Altogether about 30 000 tons of ore have been excavated only (U s o n i , 1952).

The RUDIS' estimate of the total quantity of ore is about 650 000 tons, and it should be considered as possible reserve only.

The prospection of the surroundings of Ghedem, carried out in the season 1963 by the Ministry of mines, did not find any additional mineralizations of the same type.

C h i l a c h i k i n

According to KRUPP's report (1964) the Chilachikin iron ore occurrence is situated near the Asmara-Gondar road, about 30 km southeast of Enda Selassie and some 270 km from Asmara. The area is composed of pre-Cambrian phyllites and sericite-schists, traversed by numerous young quartz veins which in a few cases show marginal iron mineralizations. Mesosoic sandstones form isolate cappings on the tops of hills and mountains.

No information is available of any former investigation in this area. KRUPP executed several trenches which exposed quartz veins in schistose rocks. The thicknesses of the veins are between 0,1 m and 0,5 m, but in many cases under 0,1 m. The 1,5 m thick quartz vein is marginally mineralized with coarse-grained hematite, the width of mineralized band being 5 cm or about 5 % of volume only.

The iron mineral is specular hematite. Its connection to quartz veins can be interpreted as apparently katathermal derivative of a magmatic source. Veins of this kind are rarely of economic importance, and also this occurrence is interesting from a mineralogical point of view only.

As much as it is known until now there are very few iron ore occurences in the country formed by ascending solutions. U s o n i guesses some iron ores connected to quartz gangue at Agame region could be of hydrothermal origin (U s o n i , 1952). There are no other data available on the existence of other hydrothermal iron ore occurrences in Ethiopia and this genetical type is unimportant as potential source of iron ore.

5. Magmatic type

There are no precise data available refering to the iron ore occurrences of magmatic origin. The suspection that iron ores of magmatic origin might exist in the country is due to a sample of granular magnetitic ore gathered during the prospecting campaign in 1963 in the area north of Nejo in Wollega (Hamrla, 1963).

The microscopic examination of ore specimen revealed a granular intergrowth of allotriomorphic magnetite and ilmenite with an idiomorphic axial mineral, belonging probably to the group of orthopyroxenes, and amounting to about 50 % by volume. Magnetite shows the initial martitization. The composition of ore sample is 39 % of iron, 5,9 % of titanium beside silica and a small percentage of magnesia.

This ore might be a product of magmatic crystallization differentiation. No other data are available for the time being. The find-spot was not yet examined and the geologic feature of the occurrence is not yet known.

MANGANESE

1. Residual concentration type

All known residual occurrences of manganese are bound to the concentrations of supergene iron oxides described above. It is well known that manganese is very similar in behaviour of transportation and precipitation to iron. In supergene deposits they are normally both found together. Manganese can be easier removed in solution in comparison with iron, but it does not precipitate as easy as iron. The manganese hydroxides are normally deposited as gels from colloidal solutions and solidify as psilomelane. They undergo subsequently further dehydration and crystallize as pyrolusite which acquires more or less expressed crystallinity and exhibits radial texture.

The accumulations of manganese oxides in described residual iron deposits have no economic importance. In Mai Gudo area manganese oxides are closestly connected to iron oxides as inclusions or intergrowings. Local concentration of manganese ore was found at the locality Sombo in form of several centimeters thick lenticular ore seam, the composition of which is given in Table 4.

Mineralogically, psilomelane in colloform banding and zoning prevails and earthy wad is common too.

In general, the contents of manganese in Mai Gudo iron ore ranges from 4 to 12 %. The conditions for formation of richer and larger depositions were not favourable in this area, because the content of manganese in trachytic-rhyolitic rocks is to small to give rise to more important residual manganese concentrations.

Similar small and scarce accumulations of supergene manganese minerals are known from different other places, and their formation is due to the weathering phenomenon of volcanic rocks.

2. Hydrothermal type

The only occurrence of manganese ore of hydrothermal origin is known at Ghedem. The geological side of the deposit is described above. Manganese oxides in form of psilomelane and pyrolusite occour in general closestly connected to iron oxides, forming colloform textured ore of alternating bands and zones or as incrustations within breccias and carbonate waste. Manganese oxides are fine-crystalline prevailingly (Pl. IV, Fig. 1.). The black colour of the accompanying manganiferous calcstone is due to the fine admixtures of manganese oxides which are displaced in calcite crystals following the rhomboeder directions, but also among calcite grains.

The prevailing manganese ore occurs along the north-eastern border of the hill, as evidenced in several outcrops or trenches. The contents of manganese in this ore might be about 40 %. The rich manganese ore was exploited separately in the past, and there is still a quantity of about 800 tons stored in piles near the working places for the time being.

The mineralization can be explained by a young thermal cycle, having originated either from leaching of deep-lying rocks or from solutions of magmatic origin. There are outcrops of more of less manganiferous ore or ferruginous manganese ore or even pure manganese ore. This very pronounced and quick change in the composition of ore regarding the contents of oxides as well as carbonate gangue could be explained by very unstable physico-chemical conditions of deposit's formation.

The reserves of manganese ore from Ghedem can be estimated to about 4000 tons of visible and probable ore. The inferred tonnage could be expected to reach some tens of thousand tons at maximum.

3. Sedimentary type

Enkafela

General. Enkafela is the only known manganese ore deposit of sedimentary origin. The locality is situated about 20 km southwest of Dallol on the border of the Salt plain in the Danakil depression, and was discovered incidentally several years ago. A prospection licence and lease for exploitation was given in 1955 covering an area 300 m by 350 m only, and in 1958 primitive mining started under a private licence. The ore is transported by truck to the port of Mersa Fatma on the Red sea coast, and exported via Massaua to USA. The production is small and altogether not more than 40 000 tons of ore have been exploited and shipped to Massaua till the end of 1963.

The geology of the Salt plain depression is characterized by an early Pliocene sea ingression which deposited during Plio-Pleistocene marine beds composed of conglomerates, sands, clays and evaporites. All around the Salt plain conglomeratic and gypseous sediments occur which were formed in the shallow sea along the former coastline. Along the whole western margin of the Salt plain thick layers of terrassed pluvial torren-

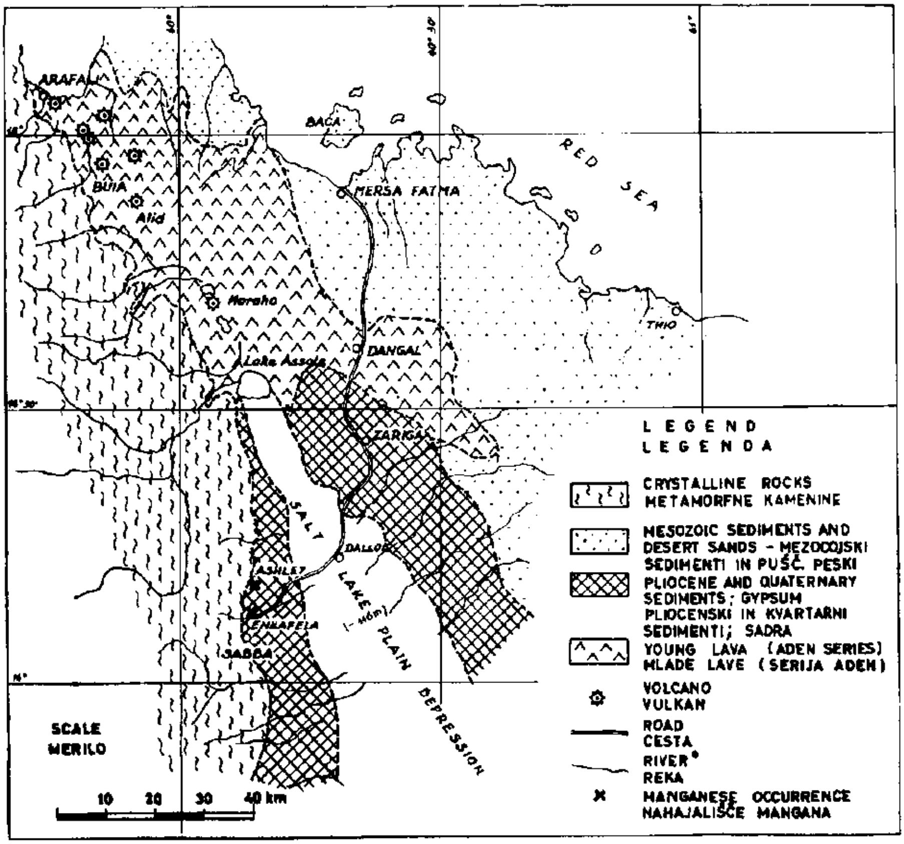


Fig. 18. Provisional geological sketch map of the northern Salt plain depression. (After various sources)

Sl. 18. Približna geološka skica severnega dela depresije »Salt plain«. (Po raznih virih)

tial gravel rest unconformably on marine sediments which are well exposed only in young wadi-cut valleys. In such a valley of the Handeda river the manganese ore became erroded and the layer exposed. The manganese ore is interstratified in the clastic marine succession, and its sedimentary nature is evident.

The mountains bordering the Enkafela area to the west are composed of volcanics, meanwhile to the east huge deposition of piedmont gravels form the passage to the Salt plain (Fig. 18.).

D e s c r i p t i o n. The Enkafela mining area covers a surface of about 250 m by 300 m for the time being. Several lenslike ore outcrops can be observed in the wadis. The layer exploited has a maximal thickness of 1,4 m in center and decreases to 0,1 m towards margins. The total volume of the known ore might be thus not more than 10 000 cubic meters only. Marginal passages of ore to the waste can be observed. The greyish black cavernous ore is pure and occurs as botryoidal and spongy mass composed of hard oxides. A very fine crystalline texture can be seen along the cavities. The ore bed is overlain by thin irregular ferriferous breccious layer. The footwall of the ore body consists of coarse clastic sediments containing sands and gravels, and cemented in the upper part with manganese oxides. The hanging wall consists of tuffic aglomerates with corals and other marine fossils.

Fig. 19. Interstratified layer of manganese ore at Enkafela
Sl. 19. Med plasti vključen sloj manganove rude v Enkafela

The following succession of the ore-bearing marine sediments was observed in the eastern part of the open pit (Fig. 19.), from bottom up:

0,5 to 0,8 m	Middle-grained sandy breccia, including small nodules and vertical thin veinlets of manganese oxides;
0,1 to 1 m	Coarse gravel and sand, cemented with manganese oxides (pebbles and grains of volcanic origin prevailingly);
0,5 to 0,8 m	Banded manganiferous impure sandy bed of loose consistence;
0,5 to 0,9 m	Compact manganese ore;
5 to 6 m	Tuffic aglomerates with corals and other marine fossils;
8 to 10 m	Marly sandstones, well banded;
10 to 15 m	Torrential gravel.

Another outcrop of manganese ore was found at the locality Ashley some 7 km north of Enkafela. Several thin earthy layers of manganese ore can be observed, having a thickness not more than 0,3 m totally. The geological environment corresponds entirely to that described for Enkafela. Thin-bedded marine sediments prevail, being covered by a thick layer of torrential gravel.

Analyses. The average chemical composition of the Enkafela ore which was shipped from Massaua to USA between 1960 and 1964 is as follows* (in percent):

Mn (dry basis)	51,26
Moisture	0,68
SiO_2	1,81
Al_2O_3	0,80
Fe_2O_3	1,50
BaO	7,70
S	0,029
P	0,021
Pb	0,000
Cu	0,000
As	traces

The quality of ore is good although the admixture of barium is significant.

Under the microscope manganese minerals can be seen only. The ore show mild zoning. Microcrystalline agregate of psilomelane in mixture with some pyrolusite prevails. Hollandite occurs too and yellow relatively bigger prismatic crystals are concentrated in thin zones (Pl. IV, Fig. 2.).

Origin. The deposit of relatively recent geologic age is of sedimentary origin and was formed in the shallow sea-shore zone rich in oxigen. The manganese might originate from the decomposition of different volcanic rocks in the western hinterland of the Salt plain, and was transported by flowing waters into the littoral sea. It precipitated as manganese hydroxide and was diagenetically transformed to psilomelane-pyrolusite compounds. Iron oxides are normally admixtured to the primary oxidic ore and they are found in Enkafela immediately on the top of the manganese bed. It is believed for the time being that in sedimentary deposits manganese was precipitated directly from sea-water by the activity of microorganisms. Another possibility about the source of manganese could be the connection with hot-spring volcanic activity of that time. More detailed investigation of facial environment as well as the mechanism of precipitation of ore could provide useful hints for the eventual further finding of new accumulations in the vicinity.

Reserves. The total amount of ore which was yielded from the deposit hitherto ranges not more than several tens of thousand tons totally. At the end of 1963 the still existing visible reserves have been estimated not more than about 5000 tons only. Due to the sedimentary

* Personal communication by Mr. L. Zingoni (Technical Officer of the Mining Office in Asmara).

character of the deposition in the former littoral zone, the further economic findings in the immediate vicinity are possible. The known and exploited lenslike ore bodies pass laterally to the sterile or low-grade mineralized clastic rocks. In the case the source of manganese were the volcanic or other rocks of the hinterland, the western border of the Salt plain's sedimentation basin could be a large geological environment which might have favorized the deposition of manganese, and the lateral persistency of the ore-bearing horizon is probable. This assumption is supported by the appearance of the ore at Ashley. Hence, it would be advisable to explore the marginal part of the western piedmont area of the Salt plain depression in order to find out the eventual new manganese ore concentrations.

IRON AND MANGANESE DEPOSITS IN THE NEIGHBOURING COUNTRIES

For the reason of comparison, and following the available sources, the iron and manganese deposits of the neighbouring East African countries are described in the shortest way.

There are several iron deposits existing in Sudan. The country's geological setting is similar to that of Ethiopia, being composed of pre-Cambrian rocks and Mesozoic and younger sediments.

In the Red-Sea zone north of Port Sudan the Sufaya and Fodikwan deposists consist of massive magnetite-hematite ore. The ore bodies extend in conformity with the folliation of the metamorphic rocks dipping steeply east. The layered deposits might seem to be genetically similar to those of Eritrea, or might even belong to the same ore-bearing zone which extend between Falcat and Agametta. More accurate data point to the genetic interpretation of deposits by magmatic differentiation.* Accordingly, the ore bodies originated as ore injections bound to diorite-lamprophyres at Sufaya and porphyrites at Fodikwan. The reserves of high-grade ore are reported to range over 10 million tons for each of the deposits, and there is a large quantity of low-grade ore in addition. The position close to the Red-Sea coast is favourable, and plans have been prepared to exploit the ore at a rate of several hundreds of thousand tons yearly.

At Abu Tulu in Northern Sudan a similar deposit consists of high-grade magnetite-hematite ore. It extends in the nort-eastern strike of the metamorphic complex. The reserves are reported to amount to 36 million tons.

A deposit of resigual type exists at Kutum in Western Sudan. It might be bound to the process of weathering of Nubian sandstone. The ore is concretionary hematite and the reserves total 2 million tons.

A small deposit of probable hydrothermal origin at Fadlab north-east of Khartoum originated as replacement of marbles by hematite. The reserves are several hundreds of tons only.

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* Personal communication by Mr. M. Dolenc, Chief geologist of the Geological Survey of Slovenia, Yugoslavia.

Manganese ore is reported to occur at two localities in the northern part of Sudan near the sea shore. Smaller sedimentary deposits of relatively young geologic age might be in question.

In general the Sudanese iron and manganese deposits look to be genetically very close to the deposits in Ethiopia expect the larger dimensions and the reserves reported to exist. It seems that these occurrences, while interesting, offer little chance of a commercial development for the time being.

In Somalia iron deposits exist between the rivers Shebeli and Giuba westward of Mogadisco and 200 to 300 km from the shore. This large ore-bearing Bur region is described in short by Usoni (1952). In a large area of about 200 by 50 km many important outcrops of rich iron ore occur. The area is built up by crystalline schistose rocks which are intruded by numerous granite bosses and basic differentiates. The ore consists of magnetite, ilmenite and quartz waste. The contents of iron in the ore is not less than 55 % in average.

The Bur deposits are considered to be magmatic in origin and might have formed by segregation. The visible reserves are estimated over 200 million tons. Provided this estimation is not far from the truth the Bur deposits may be the most important potential sources of iron in East Africa.

Small and unimportant deposits are known to exist in Somaliland. A limonite occurrence of very restricted dimensions is known at Galan Galo near Candala on the northern coast. It is a residual deposit in calcareous strata of Lower Eocene, formed by action of meteoric water (Usoni, 1952). A similar very small residual occurrence of limonitic crustifications exist at Timassoh south of Candala. There are also reports on the veinlets of siderite included in phyllitic schists of pre-Cambrian.

According to the data available no important deposits exist in Kenya (Pulfrey, 1960).

Metamorphic and residual lateritic iron ore deposits are explored in Malagasy,- totaling in 170 million tons of 28 to 62 % ore (Murdock, 1963). Only a small part of these reserves belong to high-grade ore.

ECONOMIC APPRAISAL OF THE TREATED ETHIOPIAN DEPOSITS

There is large interest in Ethiopia to find out reserves of iron ore for establishment of metalurgical industry. The errection of national mining and stell-mill industry is suggested in the Second five year Plan of overall country's development. It depends on different factors of economics influencing the final price of hot metal, but the quantity and quality of ore available is of primary importance.

The estimated reserves of iron ore, referring to the principal to-day known and above treated deposits, are summarized in the Table 5.

Table 5 5. tabela

Locality	Average ore-grade estimate (% Fe)	Measured	Category of reserves (tons) Inferred (min.)	(max.)
Koree-Gollisso-Nejo	60	160 000	290 000	800 000
Agametta-Gumhod	58	132 000	....	500 000
Falcat-Tullului	55	—	300 000	1 000 000
Mai Gudo	40	77 000	—	25 000
Entoto	40	—	—	10 000
Aira-Yubdo	25	—	—	100 000
Hamasen	35	—	5 000 000	50 000 000
Tigre	30	—	—	5 000 000
Ghedem	54	36 000	40 000	500 000

Taking into consideration that an economic iron ore deposit of to-day shall contain at least several million tons of high-grade (over 60 %) ore, the conclusion may be made that there is little chance of economic development of known iron ore deposits for the time being even if the maximum of inferred reserves do exist. It is a well known fact that an up-to-date mining production requests large capacities and big reserves, particularly if there are cheap raw-matters in question like iron ore.

From the point of view of establishing big industry the reserves of high-grade iron ore from Eritrea as well as from Wollega are not sufficient. For a planned production of 300 000 tons of pig iron annually the proved reserves should amount to 15 million tons of 60 % ore to guarantee the raw-matter for 30 years. Also the fuel should be in all probability imported. The searching for coal carried out in the country and aimed to find out the eventual adequate fuel for metallurgic industry does not show much prospects.

Regarding the development of export markets small tonnages known for the time being and high transportation costs do not give much prospect. However, world market is governed today by cheap high-grade iron ore, and it would be difficult to find ready markets.

It shall be pointed out, that the degree of geological information for the iron ore potential is far from being satisfactory, and also the known deposits have been explored only partly as this can be seen from the ratio of categories of reserves. However, new discoveries are possible although there is little probability that large and rich deposits exist in the country still undetected. But the possibility of finding new smaller high-grade or middle-grade deposits still exists in the unexplored and remote parts of the country.

On the other hand it looks possible that low-grade iron ore could be found in larger quantities. Its value should be measured in terms of proved quantity and quality as well as technology of mining, beneficiation and metallurgy. There is not much prospect to make from these deposits any larger profit presently, provided the exploration now in course will be negative.

At this time the known iron ore reserves of the country are such that a very modest development could be realized only. Local small-scale exploitation of ore connected with smelting and manufacturing in situ might prove perhaps economically feasible. First of all the sources in Eritrea and Wollega could make a contribution to the local economy.

The Eritrean deposits deserve priority due to favourable communications. The endeavour to appraise the feasibility to use the ore of several existing deposits in Eritrea for the eventual errection of a single plant might be perhaps useful. For this reason the exploration of the known and potential iron ore deposits in Eritrea shall continue in order to clear definitely the tonnages available.

As to the manganese deposits known at present the reserve estimate is given in the Table 6.

Table 6 | 6. tabela

Locality	Average ore-grade estimate (% Mn)	Category of reserves (tons)		
		Measured	Inferred	
			(min.)	(max.)
Mai Gudo	40	—	—	—
Ghedem	35	1000	3000	30 000
Enkafela	50	5000	—	200 000

The Enkafela deposit is the single one which deserves attention and its ore could be placed successfully to world market. Small proved reserves are unsignificant. The finding of eventual new reserves in the Salt plain's marginal areas is due to systematic geological exploration.

In Ethiopia today the contribution of the mineral industry to the national economy shall be enlarged. To reveal the mineral potential of the country, including the final appraisal of the iron and manganese ore deposists, a well organized and equiped governmental Geological Survey shall perform well programmed and supported field campaigns in large scale. The comparatively modest economic mineralizations in the light of discoveries up to this time should not discourage the starting of intensive efforts to asses and develop mineral resources. There can be little doubt that the potential possibilities of finding mineral raw-materials well exist in the country.

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NAHAJALIŠČA ŽELEZOVE IN MANGANOVE RUDE V ETIOPIJI

Milan Hamrla

z 18 slikami, 9 skicami in 6 tabelami

Doslej poznana nahajališča železove in manganove rude v Etiopiji so razvrščena po nastanku v 5 tipov oziroma v 3 tipe. Vsako nahajališče je kratko opisano, upoštevaje poleg prevladujočih avtorjevih podatkov tudi druge vire, zlasti za lokalnosti, ki niso bile preverjene na terenu. Naveden je večinoma le grobo ocenjen velikostni red rezerv. Kjer pa so bile rezerve določene podrobneje, so poleg možnih rezerv podane tudi ostale kategorije (5. in 6. tabela). Stopnja raziskanosti nahajališč je močno različna. Analizni podatki so vzeti iz razpoložljivih virov, novejše analize pa so bile izvedene v kemičnem laboratoriju Ministrstva rudarstva v Addis Ababi.

Relativno najbolj pomembna so metamorfna in metamorfno-metasomatska nahajališča bogate rude v provincah Eritreji in Wollegi. Gre za metamorfozirana prekambrijska prvotno sedimentarna ležišča. Dimenzije rudnih teles so skromne in zaloge relativno majhne.

Številčno prevladujoči tip predstavljajo nahajališča nastala z delovanjem meteorskih voda, ki so izluževale vulkanske ali druge železo vsebujoče kamenine. Železo se je v glavnem koncentriralo v lateritskih preperinah ali v drugem primernem okolju. Najbolj obsežna nahajališča tega tipa so v Eritreji ter utegnejo biti zaloge nizkoprocentne rude znatne.

Zanimivo nahajališče železove in manganove rude Ghedem je nastalo z delovanjem vročega vrelca v bližnji geološki preteklosti. Zaloge so majhne.

Visokotemperaturna nahajališča so brez vsakega pomena, pojav rude domnevno magmatskega izvora pa je še nepreverjen.

Visokoprocentna ruda je magnetitno-hematitna, sicer pa prevladuje bolj ali manj onečiščen limonit.

Manganovo rudo najdemo povsod v zvezi z eksogenimi železovimi rudami pa tudi na Ghedemu. Vsi ti pojavi so ekonomsko zelo malo pomembni. Doslej je znano le eno nahajališče morskega sedimentarnega nastanka, vendar zelo skromnih dimenzij in rezerv. Ni izključeno, da je rude več.

Za primerjavo je nanizanih nekaj podatkov o analognih nahajališčih železove in manganove rude v sosednjih deželah.

Zaradi majhnih količin zalog in drugih neugodnih faktorjev je na podlagi sedaj znanih podatkov le malo možnosti za ekonomsko upravičen razvoj železarstva v Etiopiji v obsegu, predvidenem v drugem 5-letnem planu dežele. Razvoj majhnih lokalnih rudarskih in topilniških obratov, predvsem privatnih, pa je možen.

V splošnem pa je Etiopija geološko malo raziskana ter je njen pravi mineralni potencial še precej neznan. Dokončna ocena tudi železovih in manganovih nahajališč bo možna šele, ko bodo izvedene vse potrebne geološke in druge raziskave.