ADOLA GOLD PLACERS AND NICKEL-CHROMIUM ORE DEPOSITS

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With 17 photographs, 2 sketch maps, and 9 tables

Introduction

The gold-bearing area of Adola is located in a triangle bounded by the towns of Neghelli, Dilla, and Yavello in Sidamo Province (Ethiopia), and it is situated between the altitudes of 1000 and 2000 meters. The Adola district is a part of Dawa and Ganale rivers drainage system. The territory between the Awata and Mormora rivers has been the most worked, although a few areas on the left bank of the Awata river and on the right bank of the Mormora river, as well as at Dawa, Dawa Cursu, Ujima, and Aflata rivers, are partially worked.

The Adola gold-bearing area, whose center is the town Kebre Mengist (before Adola), is situated 470 km south of Addis Ababa. The road passes through Modjo, Adamitullu, Shashemene, and Wondo towns, and it is an all-weather road. From Kebre Mengist, the road extends for about 720 km to the southeast through Neghelli and Somaliland to Mogadishu. Thirty kilometers of the road to Neghelli are bad; the road then become better, and from Neghelli to Mogadishu it is good and passable throughout the year. The road leaves Dollo, the last town in Ethiopia, and continues to the border between Somalia and Ethiopia. Thus, the mining area is connected with three ports: Djibouti through Addis Ababa by railroad, Mogadishu through Somalia, and Assab through Addis Ababa by road.

The southern part of the gold-bearing area is covered partly by savanna land, and the northern part of it by forest. The climate of the area now being explored is very good. Day temperatures average about 30^{0} C, while night temperatures are usually low.

The nickel-chromium ore deposits are situated along pre-Cambrian schists in alignment striking NNE—SSW. The western alignment strikes through Tulla and Ula Ulu mountains, and the eastern alignment through Budussa, Kenticha and Dubicha mountains.

The nickel-chromium ore deposits have been discovered 1959, most of them during the systematic geological mapping, although the green garnierite staining rock of the Kajimiti area has long been known to the local inhabitants.

Maps of the area available include one on a scale of 1 : 750 000 made by Italians, and another one of 1 : 1 000 000 made by British experts and intended mainly for flight purposes. In 1952 an aerial survey was carried out by the Ethiopian Air Force at the request of the Ministry of Mines. This surface covers about 5000 sq. km. Unfortunately, it remained in the form of photo-mosaic, and it was never transferred into a contour map. The aerophotographs have been the main basis for geological mapping, photogeological interpretation, topography of the area, and geological mapping.

From June 16—July 16, 1956, a map of the area between the Wollabo Dam-Awata pump station and Dembi valley was made by the author's prospecting group. It indicates water drainage system and roads on a scale of 1:5000 for the area being exploited at that time. The survey was based on six triangulation points and a net of polygons. All important altitudes were already leveled.

Geology of the area

The oldest rocks, the proper basement, of the region are gneiss, actinolite schist and mica schist for which the name Gari Boro series is proposed. In the northern part of the area, the gneiss is intersected by many pegmatite, aplite, and quartz veins; in the south near the junctions of the Aflata, Ujima, and Dawa rivers, the gneiss is mostly intersected by pegmatite veins. The grey gneiss grading into mica schist occurs in the form of an elongated block striking north-south.

The pegmatite, aplite, and quartz veins are essentially younger than the gneiss. Their origin is assumed to be due to a recrystallization process in tectonic lines.

Occuring in slight disconformity with highly crystallized Gari Boro series, The Adola series is composed of following rocks:

1. Amphibole schist
2. Conglomerate and sandstone
3. Chlorite-talc-tremolite schist
4. Serpentinite
5. Graphitic quartzite and white quartzite
6. Phyllitic slate
7. Sericite schist.

The mineral composition of amphibole rocks varies widely (Figs 1, 2, 3). The first type comprises hornblende, quartz, and plagioclases, and it belongs to plagioclase amphibolite; it occurs near Chembi in the Ganale river drainage area.

Another association, found further south near Bedakessa, is composed of quartz, zoisite, hornblende and epidote and belongs to zoisite-amphibole schist (Hinterlechner, 1956) (Fig. 1). The most common rock of the area is the amphibolite from Gayo composed of hornblende in a matrix of salic minerals (Fig. 3).

Conglomerate and sandstone are widely developed, and they strike north-south following a line westward from Shakisso. On both sides of this alignment other schist types of the Adola series have been indicated. The alignment predominates in this part of the country, as it is more resistant to erosion than other schists of the Adola series. These rocks form lenses in chlorite and talc schists, building the ridge between Demi Danissa and Kajimiti valley. The conglomerate is composed of quartz and feldspar in a zoisite epidote matrix. The sandstone contains quartz, biotite, and shlorite.

Fig. 1. Zoisite-amphibole schist (quartz, zoisite, hornblende, epidote), × 35. Bedakessa, Adola district. Determination A. Hinterlechner

Fig. 2. Amphibole schist, × 35. Borę basin, upper terrace. Determination D. Jelenc

Fig. 3. Amphibolite (grains of hornblende in groundmass of salic minerals) × 35. Gayo Camp. Determination A. Hinterlechner

Chlorite-talc-tremolite schist forms the next zone of Ula Ulo and farther south in the Ujima area. The rock is composed of an association of talc, chlorite, and tremolite. The size of mineral grains is less than 0,1 mm. Magnetite is accessory only; its crystals range in size from 0,03 to 20 mm. A parallel structure of bands of chlorite and talc could be observed. The rock is a product of the regional metamorphism of the sediments.

Some specimens reflect the transition between amphibole schist and chlorite schist. Tremolite could usually be observed as a constituent of

Fig. 4. Serpentinite (serpentine, talc, magnesite, accessory magnetite), × 35. Kajimiti bore hole I, Adola district. Determination D. Jelenc

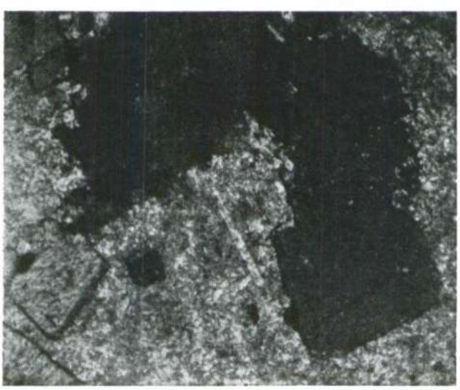

Fig. 5. Serpentinite (the idioblastic mineral grains belong to magnesite), × 35. Ula-Ulo, Adola district. Determination D. Jelenc

this rock type, and the zone has therefore been called the zone of chlorite-talc-tremolite schist.

The next zone belongs to rock types composed of peridotite, and serpentinite (Figs 4 and 5).

Finally, the above-described rocks contain intercalations of graphitic quartzite and white quartzite. They occur near Budussa mountain in Gudba valley and other places. The quartzite of Gudba valley is composed of quartz grains and muscovite.

These rocks occur as isolated dikes in amphibole and chlorite schists. The conglomerate, composed of a zoisite epidote matrix and gneiss pebbles up to 5 cm long and 1,5 cm wide derived from the gneiss of the Gari Boro series. Their position in conformity with the Adola series, forming a part of it, as well as the pebbles of Gari Boro gneiss included in them, prove the conglomerate to be younger than the Gari Boro series.

The less metamorphosed rocks compared with all other above described rocks belonging to pre-Cambrian occuring within Adola series are besides the conglomerate, sandstone, phyllitic slate, graphitic schist, sericite schist, and graphitic quartzite.

Phyllitic slate, graphitic schist, and graphitic quartzite occur in the former Imperial Highway Authority quarry near Kebre Mengist, graphitic schist and graphitic quartzite could be observed on the road between Kebre Mengist-Neghelli some kilometers from Kebre Mengist and near Adadicoto air field some kilometers from Shakisso village. Sericite schist was found near Shakisso village on the new road Shakisso — Kebre Mengist.

A series of conglomerate in disconformity, thus younger than the above-mentioned Adola series, has probably covered larger areas, but is mostly eroded. Only partial remnants have been preserved in the lower part of the Ujima river near its confluence with the Dawa river and in the Anfarara area off the Shashemene-Kebre Mengist main road. Their age could not be determined but they most probably belong to Cenozoic.

Basic and acid rocks intruded into the metamorphosed sediments could be found near Shakisso between the Awata and Mormora rivers. At Laga Dembi, according to Doorninck (1950), the following rocks have been found: diorite, gabbro, pyroxenite, and peridotite. Peridotite rocks were found also at Kenticha, Monissa, Dubicha and Lolotu mountains.

Near Kojowa river an diopside peridotite outcrop has been indicated. Another specimen, containing olivine remnants, has been observed near Ula-Ulo.

It is supposed that the above-mentioned zones of serpentinite are metamorphosed ultrabasic rocks. This may also be confirmed by nickel and chromium contained in those rocks. However, the chlorite-talc-tremolite schist represents the former sediments metamorphosed by regional metamorphism.

The amphibolites also represent products of regional metamorphism of sediments. At the Upper Falls of Mormora river has been indicated an intrusion of grey granitic rock, characterized by the presence of biotite. This intrusion zone has been followed northward, where the same intrusive body occurs west of the road near Anfarara. The Imperial Highway Authority has used this granite for road construction, so an abandoned quarry is to be observed at the spot. Southwards, in the gorge of the Ujima river, another granite outcrop occurs. The name Sawana granite is proposed for this granite occurrence, as it was first known near the Sawana valley, a left tributary of the Mormora river near the Upper Falls (Fig. 6). Pegmatite, aplite, and quartz veins occur in granite. The granite specimens are very similar in their mineral composition, but vary widely regarding the grain size. Feldspars belong to microcline, anorthoclase, and rarely orthoclase. A spectrographical analysis of this granite has shown the presence of Mn, Pb, Sn, Cr, V, and Zn*, and traces of Ba, Sr, and Ni.

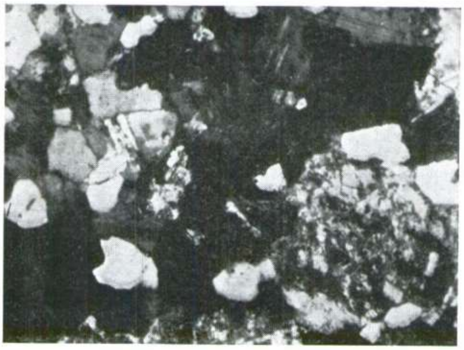

Fig. 6. Sawana granite (microcline, quartz, microcline perthite), × 35. Ujima, Adola district. Determination D. Jelenc

As the granite is overlain by Jurassic sediments, it is assumed to be older than Jurassic. This has also been proved by age determinations by the radiogenic method**. The basis for determination has been biotite, and the results obtained are given in table I.

Table I

THE AGE DETERMINATION OF SAWANA GRANITE

Locality	K %	Radiogenic. 40 Ar.	Age, millions of years	Color
Upper Falls at Mormora river	4,98	0,2013 ppm	495 ± 20	Grey
Ujima gorge near Dawa river	5,07	0,1990 ppm	482 ± 20	Pink

Bearing in mind the experimental errors, there is no significant difference between these two results. They are within the usual 400—650 million years range, which is a characteristic of all micas so far dated from basement rocks along the eastern side of Africa as well as those from Aden, Somalia, and Egypt. The age of biotite is an indication of the last change imposed on the rock, which cannot be younger than the biotite itself.

* The spectrographical analysis was made by A. Kandare in Geološki zavod (Geological Survey) in Ljubljana.

** The age determination was made by Overseas Geological Survey laboratories, London.

The above mentioned age, which ranges from 482 ($\pm$20) to 495 ($\pm$20) million years, corresponds to the period of the late Cambrian or early Ordovician. Thus, the age of Sawana granite is pre-Cambrian, taking into consideration only the last cycle of metamorphism indicated by the biotite. The age is not Mesozoic, as has been assumed by some authors.

Gold Placers

The distribution of gold-bearing placers has proved that the primary deposit extends generally from south to north along the strike of the basement rocks.

The degree of gold content depends on the following characteristics of the geological environment:

1. The Adola series is, as a rule, the bedrock of the commercially important placers.

2. The gold content is proportionate to the percentage of amphibole schist in gravel.

3. The gold content is proportionate to the size of the gravel. Gold-bearing placers occur usually in the areas where the bedrock is composed of chlorite-talc-tremolite schist mainly altered to a type of greenish yellowish clay. Selective erosion caused depressions in chlorite-talc-tremolite schist and elevations in conglomerate, amphibole schist, and serpentinite. In addition, the soft talc-chlorite-tremolite schist has been an excellent trap for gold nuggets, grains and specks.

This distribution of the gold along the north-south trending valleys which intersect the talc-chlorite-tremolite schist, conglomerate, quartz veins, and amphibole schist, renders possible the conclusion that the gold originates from these rocks. The quartz veins and pegmatites genetically connected with Sawana granite, diorite, or other basic rocks intruded in the Adola series may be another possible source of gold mineralization.

The following arguments exist for the theory that the gold is associated with amphibole schist and chlorite-talc-tremolite schist.

1. Gold has been indicated in inclusions of quartz in amphibole schist of Gayo walley.*

2. Gold distribution show no detectable relation to the granitic intrusions.

3. The general distribution of gold entirely follows the north-south strike of the talc-chlorite-tremolite schist and amphibole schist.

The gold might be derived from conglomerate with which the gold could be syngenetically associated. This explanation is however not feasible for the time being as the gold was not found in conglomerate.

As the gold was found only in the quartz inclusions of amphibolite, the explanation might be correct, that the gold originates from this

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* Chemical analysis was carried out by A. Kandare in Geološki zavod (Geological Survey) in Ljubljana in the year 1956.

quartz. The quartz inclusions in amphibolite seem to represent the product of lateral secretion. It is supposed that during the same secretion gold was concentrated in these quartz inclusions.

The existence of conglomerate and quartzite in less metamorphosed Adola series and recrystallized quartz deposits in high crystallized Gari Boro series might be the second proof for the gradual metamorphism of psammitic and pelitic layers essentially composed of quartz grains. Only smaller bodies in the Adola series are found completely recrystallized in form of quartz inclusions. However, the higher stage of metamorphism of Gari Boro series leads to a complete recrystallization.

The other possible derivation of the gold-bearing quartz in Adola series from the granitic, dioritic or other intrusive rocks seems to be less probable as the placers gold distribution follows the metasediments of Adola series and as quartz as possible gold source represents isolated lenses and inclusions in the Adola series. The association of gold placers over large areas with Adola series could be explained due to the angular appearance of gold and therefore its short transportation distance only by syngenetic process and lateral (metamorphic) secretion of quartz and ore minerals.

According to some authors (Kossmat), the amphibole schist represents a product of differentiation of an initially granitic-dioritic magma separated into dioritic and granitic portions, as suggested for the Sokota Island granite-amphibolite succession. The essentially older amphibole schist (compared with granite) does not permit this conclusion for the Adola area, where an extrusive origine of a part of amphibolites is assumed.

The same conclusion could be drawn for Bedakessa, Shanka, Hidi Dimma, Wollena, and Laga Dembi areas, where similar geological conditions have been found.

Economic deposits of gold occur in placers of the second erosion cycle. Detailed investigations have been carried out in Upper Bore basin to find out the relationship between the primary rocks and the distribution of the gold placers. The corresponding geological cross section indicate that the richest deposits follow the areas composed of the chlorite-talc-tremolite schist associated with amphibole schist. Alluvial deposits have been found only in those valleys where the rocks of these groups occur.

The oldest erosion cycle could be recognized in the remnants of the former rivers of the Shakisso, Reji, Megado, and Sillu saddles. The following erosion cycle comprises former rivers with relatively large placers forming meanders of which only a part of the extension is proved by prospecting. The further lowering of the erosion basis created conditions for the third erosion cycle, which is represented by the present erosion systems of the Mormora, Awata, Dawa and other rivers.

The discovery of the economic gold placers was possible since in a portion of the placers, owing to the activity of the third cycle, the overburden has been removed completely (at the Dawa Cursu placer), or partly (at the Bore basin placers). The deposits became thus economically more interesting, as the overburden was thinned considerably or even completely removed.

The thickness of the overburden varies between 1 and 20 meters depending on the distance of placers from the recent local base level of erosion. Generally the placers near river systems have a thin overburden, provided that the creeks carry surface water, and in areas where the placers lack moving surface water and are far from the present rivers, the overburden is thick. Another influence has been the structural movements, which have changed the course of the placers, as well as moved parts of the placers of the second erosion cycle. This is reflected in the strange forms of the creecks, which sometimes have a length of only 1—2 km and a width 0,1—0,5 km, making difficult the identification of the former drainage system. The study of structural movements and geomorphology has cleared up some of the problems in Bore basin; however, further study should elucidate the palaeogeography of the river drainage system of the second cycle.

The age of the first and second erosion cycles could not be established, although the third cycle is certainly younger than the Rift valley volcanism. The essentialy older age of the second and first cycles is supported by the following data:

1. Basalt and volcanic glass gravels have been found only in rivers of the third erosion cycle, i. e., the Awata, Dawa, and Mormora. However, the gold placers of the second erosion cycle do not contain fragments of volcanic rocks.

2. The placers of the second cycle are often disturbed by movements which could be assumed to be associated with the youngest Rift valley structural movements.

The post-volcanic age of the second erosion cycle is supported by explanation that the absence of the gravel originated of volcanic rocks could be explained by a shorter river bed which did not reach volcanics. The absence of volcanic rocks in placers of the second erosion cycle might indicate the older age of these placers, particularly as they are found in abundant quantities in the Awata, Mormora, and Dawa rivers, so in the youngest erosion cycle.

The gold placers associated with the above-mentioned basement rocks occur in the area of the well-known basis of the Ethiopian and Somali plateau. They are situated in the western part of the Somali plateau, which is bounded by the Rift walley in the northwest. The depression of the Rift valley is built of basalt and other volcanic rocks. The gold-bearing area is situated in similar depressions striking northeast-southwest.

The gravels in gold placers are composed of sterile quartz, hydrothermal quartz with gold, quartzite, amphibole schist, and, rarely, of granite which are usually decomposed to clay and sand. The amount of gold is entirely proportionate to the amount of amphibole schist gravel in the placer.

The gold originates from the quartz inclusions occurring in amphibole- and talc-chlorite-tremolite schists.

Prospecting in the new placer areas is based on the experiences in the more or less known area of Adola. A study has been made to determine if there are analogous geological structures in other part of the Sidamo-Borana basement in order to find new gold placers. Systematic geological mapping has been carried out in order to determine favourable structures.

Bore Basin

In the second part of 1955, prospecting and exploration was started in Bore basin. Bore placer, which was first explored, is located on the right bank of the Mormora river. It begins on the other side of Megado mountain at an altitude of about 1730 meters. The Bore placer stretches 10 km downstream in the northwest-southeast direction, and then turns east-west. The last part again turns northeast-southwest. The whole placer has a length of about 36 km and an average width of 80 m. The placer in the first part downstream up to the old waterfall (gorge) has an average depth of 3 m; below the waterfall its depth presumably increases to over 10 m in average.

The Bore basin is now dry and represents the bed of an old river drainage system which existed during the second erosion cycle foregoing the present erosion cycle. Bore valley in the east meets the Mormora river as an elevated terrace. The elevation of the junction is about 1320 meters. The whole Bore basin covering an area of about 200 sq. km,

Fig. 7. Gari boro gneiss with aplitic veins. Ujima, Adola district

Table II

PROSPECTING AND EXPLORATION AT THE LOWER BORE TERRACE

Placer	Line	Pit	Average depth in meters	Gold content g/cu. m.	Remarks
Tulla (Burri)	10	P	11,7	0,58	
		I		0,12	
		G		0	
		J		1,19	
		N		0,25	
		K		0,30	
Tayisso (Ababido)					The whole creek is gold-bearing, but the gold content is low
Lower Bore	300	M	9,7	1,5	
		N		1,5	
		O		2,8	
		P		3,05	
		Q		2,50	
		R		2,10	
	302	M	10,5	2,15	
		N		1,30	
		O		0,40	
		P		0,40	
		Q		1,50	
		R		2,60	
		S		nil	
	304	G	11,2	1,76	
		H		1,50	
		I		0,35	
		J		0,30	
		K		4,80	
		L		4,85	
		M		0,60	
	500	O	11,6	0,8	
		Q		0,57	
		R		0,30	
		S		0,65	
	560	M	12,7	0,97	
Gudba	20		16,6	—	Bedrock was not reached
	24		13,0	—	Location at the Gudba gorge
	60		2,2	0,102	

is built by upper and lower terraces divided by amphibolite. The alternating streams of the Upper Bore placer are the Kajimiti and Demi Danissa placers, which are probably older than the Lower Bore placer. There are also some smaller feeder placers adjoining the Upper Bore placer. Parallel to the Upper Bore placer is the Gagama placer. Gudba valley is also formed of two terraces. The basis of the upper terrace at one of its ends is built by Gari Boro gneiss (Fig. 7), and it is found to be sterile in its lower part. The placers joining the Bore are Tayisso (Ababido), Tulla (Burri), and some smaller placers in the Daba area. To summarize, gold placers have been indicated in the following areas:

Upper Terrace includes:

1. Upper Bore placer
2. Smaller feeder placers of Upper Bore
3. Gagama placer
4. Demi Danissa placer
5. Kajimiti placer.

Lower Terrace includes:

1. Tulla (Burri) placer
2. Tayisso (Ababido) placer
3. Lower Bore placer
4. Smaller feeder placers.

Previous prospecting and exploration gave the following successful results in various areas of the Upper Bore terrace:

Kajimiti placer is about 8 km long, and it contains gold-bearing gravels along the whole length. The end of the placer toward the Bore basin watershed is particularly rich in gold.

Demi Danissa placer with its two main affluent placers has a gold content along the whole length.

Gagama placer has been proved as gold-bearing in a length of 2,5 km.

Many feeder placers are formed in normal position to the main Bore placer, where gold reserves have been proved suitable for handwork operation.

The results of prospecting and exploration works in various placers of the Lower Bore terrace are shown in Table II.

Table III

PROSPECTING AND EXPLORATION OF BORE BASIN TILL THE END OF SEPTEMBER 1962

Location	Number of lines	Number of pits
Upper Basin		
Bore placer	249	1149
Gagama placers	29	210
Demi Danissa placer	105	372
Kajimiti placer	44	864
Lower Basin		
Tulla (Burri) placer	33 (planned)	132 (planned)
Tayisso (Ababido) placer	8	38
Gudba placer	30 (planned)	240 (planned)
Other placers	60 (planned)	360 (planned)

The richest placers are located along upper Bore valley, where the gold occurs continuously. The distribution of gold in Kajimiti, Demi Danissa, and Gagama valley is different as the gold occurs in many paystreaks which are not continuous, but limited to certain areas.

Lower Mormora Basin

Mormora meanders near Lower Bore

Placer examinations were made by the Natomas Co. (1956) from July 27 to October 15, 1956, in connection with geological field work being carried out by a joint prospecting team made up of personnel representing Goldfield Consolidated Mines Co., Newmont Exploration, Ltd., and Natomas.

The primary target in the exploration area was a meander area occupying a narrow flat valley along the Mormora river 60 km air distance south of Kebre Mengist. The area was believed to be physically suitable for dredge prospecting.

In May 1956, three shafts were dug and 0,03, 0,09, and 0,06 g/cu. m of gold were indicated (Table IV).

The deposit would be a potential source of gold if proper prospecting by drilling were to be carried out.

Table IV

EXPLORATION IN MORMORA MEANDER

Shaft no.	Bedrock depth in meters	Overburden thickness in meters	Gravel thickness in meters	Gold content	
				Gravel g/cu. m	Top to bottom g/cu. m
1	7,1	6,3	0,8	0,25	0,03
2	7,7	7,1	0,6	1,10	0,09
3	6,6	6,3	0,3	1,55	0,06

The overburden is stiff red clay containing fine sand locally. The gravel bed is composed of loose quartz sand with well-rounded pebbles up to 70 mm in size mixed with pebbles of amphibole schist and other metamorphic basement rocks. The bedrock is soft micaceous schist.

Lower Mormora basin is located mainly on gneiss and mica schist of the high crystalline Gari Boro series, and it is influenced by the youngest erosion cycle. Thus, the possibility of finding commercial gold placer deposits is very slight. Only the meanders of the Mormora river indicate some gold content which probably originates in the eroded portions of Bore basin and in the Adola series of the Budussa alignment.

Lower Mormora basin could be considered as suitable for the gold placer along the Budussa talc-chlorite-tremolite alignment with serpentinite and amphibolite.

Upper Mormora Basin

The basin, located in the Adola series, is intruded by Sawana granite near Upper Falls of Mormora river. Many placers belonging to this basin have been exploited by handworkers as they are located near the Mormora river for water supply. The main placers are Laga Gesho, Sawana, Hiddi Dimma, and other placers, all left hand side affluents of the Mormora river.

Feeder placers of the Mormora river include Laga Dembi, Reji, Wollena, Lago Gesho, Laga Adunia, Hiddi Dimma, and Alona placers.

Wollena placer is 11 km long, and has been partly exploited by handworkers. The placer is now being prospected, and it has been found to be commercially interesting.

Reji and Laga Dembi placers together have a length of 16 km. These creeks have been already exploited by handwork.

Systematic prospecting has indicated gold reserves in the placers large enough to justify dredging.

Upper Mormora basin is located in a similar geological structure as the Bore basin, but in the youngest erosion cycle.

Table V

PROSPECTING AND EXPLORATION OF THE UPPER MORMORA BASIN

Location	Number of lines	Number of pits
Feeder placers	111 (planned)	666 (planned)
Mormora river	50 (planned)	50 (planned)
Wollena placer	24	220
Reji placer	48	288
Laga Dembi placer	166	341

Shakisso Basin

Kalacha placer is 10 km long. Drilling carried out some years ago did not indicate attractive results. Efforts are now being made to find the eventual connection between Shanka placer and Kalacha placer.

Kalacha placer according to Astrup (1948) is a horseshoe-shaped, fairly broad that occurs at the foot of the low hills where Shakisso and Wodo villages are situated. The entire length might be about 9,5 km including only the lower part from the Awata junction and Shakisso. The upper part of the placer is called Laga Gora. The upper and lower ends of the placer are covered with thick forest, but the central part of some 4 km is fairly free from trees and therefore suitable for mining operations. This is where drilling operations were carried out in 1948.

The width of the placer is, on the average, 150 m, but it becomes narrower towards the upper and lower ends. The Kalacha placer has only two principal feeder placers 3 km apart. One comes down from the mountains near Laga Reji and the other from the airfield at Adadikotto.

Fig. 8. Prospecting for gold in Adola district

Prospecting by pits in these valleys allegedly yielded traces of gold. The upper end of the Kalacha valley continues through a narrov gold field. The length of the prospected area was 3650 m (the distance between the prospecting lines A and E). The drilling showed 162 000 cu. m. of gravel with 50 kg gold reserves. Line E near Shakisso has been found to be the richest one.

Shanka-Wollabo placer is about 23 km long. One hundred forty-seven pits have already been dug to prove the presence of gold in upper and lower Shanka creek with favourable results. Dredging vas introduced in 1956 and is still in operation.

Table VI

PROSPECTING AND EXPLORATION OF THE SHAKISSO BASIN

Location	Number of lines	Number of pits
Kalacha creek	20	80
Shanka-Wollabo creek	46	421

Bedakessa placer explorations with drilling equipment have been carried out in lower Bedakessa valley. Fifty-one bore holes were made, three lines by two "Banca" hand drills. Ground water was met at about 3,5 m below the surface. The direction of the lines was 24° northeast and the distance between bore holes 25 m. The explorations started in February 1956. The results of drilling show an average tenor of gold of 0,7 g/cu. m.

The basin is built by the same type of rocks as the Bore basin. A gneiss alignment belonging to the Adola series dominates the basin from Shakisso to the Reji area. Other rocks occurring in the basin are amphibole- und talc-chlorite-tremolite schists of the Adola series with intrusive rocks as pyroxenite, diorite, and serpentinite.

The basin belongs to the second erosion cycle. Many commercially important gold placers have been found in this basin, which has been also the main supplier of the gold in the past from manual operations as well as from the former mechanized project at Bedakessa and the present mechanized project at Shanka placer.

Dawa Basin

The discovery of the Dawa-Cursu gold-bearing area not only made possible to increase gold exploitation in the years 1958—1959, but also increased the possibility of finding gold in southern areas. To prove the reserves in these areas, it is necessary to carry out a systematic prospecting program.

The longest valley is Gambela, which is 22 km long. It is situated on Gari Boro series, and the content of gold found there during reconnaissance prospecting is discouraging.

The Dawa river alluvial deposit near junction of the Cursu and the Dawa rivers was found to be very rich. The area is located geologically in the Adola series, and it is particularly rich in amphibole schist. About 9,5 km from the Cursu junction at Dawa is the junction of a 10 km long valley which seems to be located in Adola series. All the above-mentioned placers belong to the youngest erosion cycle.

Aflata Basin

The main creek of the Aflata basin, which is situated southwest of the Dawa basin, is about 100 km long. This stream has been found to be gold-bearing, and manual operations have taken place in the area (Fig. 9). The basin is located in Adola series, and it belongs to the youngest erosion cycle.

Ujima Basin

A similar erosion basin with a relatively large surface is developed south of the Aflata basin. The length of the main placer, including feeder placers, amounts to 47 km taking into consideration only the area included in the existing aerial photographs. Only a small part of this drainage basin (that belonging to the Adola series) has been found to be gold-bearing. However, in the portion of the placer located on gneiss no gold has been found.

Fig. 9. Hand panning for gold in Aflata placer. Adola district

Makanissa Basin

The Makanissa basin is situated as a peneplained area belonging to the second erosion cycle between the Awata and Mormora rivers east of Ula-Ulo mountain. Large valleys were formed during this erosion cycle. Prospecting for gold in this area started in 1963. The basin is built up of talc-chlorite-tremolite schist on the boundary with gneiss.

Lower Awata Basin

The Awata river flows in its lower course (before its junction with the Mormora) on gneiss. Gold placers have not been reported from this area. The area belongs to the youngest erosion cycle.

Kojowa River Basin

The Kojowa river is flowing in the course included in available topographical base on gneiss. Commercial deposits have not been reported from this area belonging to the youngest erosion cycle.

Placer Mining

Past methods (J e l e n c, 1956) of working in this area include mainly (about 6/7 of the production) the digging of a large number of pits by handwork (Fig. 10). After the pit reaches bedrock, gold-bearing gravel is excavated in all directions as much as the primitive means permit. The distance between the pits is about 5—10 meters. The gold-bearing gravels are handed up from the pits and are carried for washing to the nearest small rivers or water basins which are dug on the surface. Water is transported to the washing basins from the nearest river by

Fig. 10. Hand panning for gold in Dawa placer. Adola district

Fig. 11. Clearing operation for transmission line of Shanka gold operation in forest area in Adola district

trucks or by workers. Some short canals were also constructed to supply water to working places in the valleys wherever convenient.

Dredge-dragline equipment was first installed in Bedakessa creek and later in Shanka creek (Figs. 12, 13, 14). This equipment has a washing capacity of 90 cu. m gravel per hour.

A water-supply system was built to supply water to the dredge and for ground sluicing in Bedakessa, as well as in neighboring valleys. An earthen dam was also built at Wolabo to accumulate water. The dam has a capacity of about 30.000 cu. m. From Wolabo dam, the water is conveyed to another reservoir located some 10 m above the upper Bedakessa valley.

The output of the gold by handwork operations decreased from initial 7395 kg during the 1944-48 period to 5299 kg during the following 1948-1952 period, and to 3023,3 kg during the 1952-56 period mainly due to the exhaustion of gold placers in the affluents of the Awata and the left bank of the Mormora river, as these placers are situated near water suitable for the handwork. The placers situated far from water have remained out of operation as the exploitation of those placers required larger investments for water supply and therefore for prospecting and exploration to find out the reserves. In order to prevent a further decrease in gold output, mechanization has been planned for the Shanka and Bore basin placers. These projects are based on proved reserves of

Fig 12. New power plant 500 kW for Shanka gold dragline-dredge operation

gold, which have been increased from 2000 kg in 1958 to about 11 000 k in 1963. These reserves represent a sound basis for further mine development and gold output, which has already increased owing to the discovery of Dawa Cursu placer and the introduction of a mechanized project at Shanka. Both projects are based on dragline stripping of the overburden of the gold placers, and on dragline dredging of gravel.

A further increase in the gold output is expected with reconstruction of the Shanka and Bore projects. Two pover stations have been built to supply these two projects with power. One Diesel power station of 500 kW is supplying the Shanka mechanization project. A second 1500 kW water power station is under construction at the Mormora river (Figs. 15 a, b). It will supply power to the Bore basin placers mechanization projects.

At the Shanka placer, the mechanization project represents merely a reconstruction project with the main aim of increasing the gold output. The text below describes the main features of the Bore mining project.

Fig. 13. Mechanization project Shanka. Two draglines of the Dragline-dredging operation. Adola district

Fig. 14. Mechanization project Shanka. Washing plant for gold of the Dragline-dredge operation. Adola district

Bore Placer Project

It has been proved (J e l e n c, 1956) that the handwork method of mining is not profitable from a national economic point of view. Therefore mechanization of work and treatment is needed. The large investment could only decrease the cost and increase profits and the repayment of invested capital.

An additional motive for the mechanization of projects is stabilization of production. The gold production from manual labor in the

Fig. 15. Construction of the power plant 1500 kW at Mormora river for Bore Dragline-dredge operation

last ten years has varied from 1662 to 310 kg annually. A constant production is possible only if it is based on reserves which would assure a more or less constant output for many years in advance. Certainty as to proved reserves of gold is the only way of making the investment possible and enabling the repayment of capital on equipment and machinery.

The renewed efforts at surveying in 1959 and at prospecting in 1960 were some of the most important prerequisites for starting the Bore placer project.

Intensified work has been started 1959 to prepare all requirements and preparations for the mechanization project started. The main features of the work were:

1. Surveying and prospecting in 1959-1961.
2. The approval of the investment program of 1959, which included a power station, workshop, mining equipment, water supply, and mining camp and subsequent elaboration of Bore placer project.
3. Selection of electricity as the source of power and the starting of the constructing for a power plant and pumping station workshop in 1962 and 1963 respectively.

The above-mentioned basic data enabled the starting of the placer project, which was completed during the second part of 1960 and in the first part of 1961.

The area in which the traces of gold occur covers about 10 000 sq. km while the drainage basin of the Upper Bore, on which the project is based, covers a surface of only about 100 sq. km.

The present project represents the first attempt to exploit the virgin gold gravel without foregoing handwork operation on the basis of proved gold reserves. Observations of water losses from the exploration pits organized by the author have made possible an estimate of leakage during exploitation as the dredging has been selected from among many alternatives as the cheapest one.

In order to determine the upper limit of possible losses of water from the pond, Kleindienst (1960) considered the specific discharge of pit No. 28/K with a 7 cm decrease in water level during 10 minutes of observation after getting the stabilization of water losses to 0,0136 lit./min. × sq. cm.

Applying the results of the above experiment to the actual case of the possible leakage in the widest cross section of the exploitation area without regard to different conditions leads to the following result: discharge of 367,5 liters per minute.

This result is based on the highest observed discharge from the pits during the experiments. The major portion of the results showed only one-third to a maximum of one-half of the value taken into account above.

On the basis of the results in test pits and theoretical considerations, it can be concluded that the expected leakage from the pond for the dredging does not represent any problem, and for this reason it presents no hindrance to the proposed dredge project.

Nickel-Chromium Deposits

The nickel-chromium primary deposits are confined in general to magma of basic and ultrabasic provenience. Basic magma which generally displays pronounced differentiation was intruded into the metasediments of Adola series, and it has split into peridotite, pyroxenite, and diorite. The serpentinite which predominates is derived from ultrabasic rocks of an originally peridotitic composition. Less altered specimens still show some relic cores of the earlier mafic minerals, mainly olivine. Serpentinite is composed of lizardite, a serpentine-type mineral (Baines and Duesing, 1963).* Metamorphic equivalents of the ultrabasic rocks and their altered products as they occur in the Adola series have shown traces of nickel and chromium minerals both in primary and secondary mineral occurrences.

Chromite is found as an accessory mineral of the serpentinite, and due to magmatic segregation it seems to be concentrated in lens-shaped bodies, whose existence is proved by eluvial chromite, a product of erosion of the former primary chromite deposit mostly near or on the surface of the serpentinite. As large serpentinite bodies are found, there exist a fair possibility of finding chromite deposits in this type of rock. The content of chromium in the serpentinite amounts to 0,01—0,03 %.

In one case at Budussa (Fig. 16), eluvial chromite was found associated with anthophyllite schist some kilometers from serpentinite. This could be explained by postmagmatic injections into intrusive rock surrounding metasediments, or by complete erosion of serpentinite body. In Dubicha Gudda the chromite was found as primary constituent of serpentinite, however, in antophyllite coating in lenses 3 m long and maximum 20 cm thick striking EW and here and there NE—SW.

Chromite deposits associated with talc-carbonate and talc schists are known from South Africa and southern Rhodesia respectively. In the future prospecting both possibilities of primary chromite deposit shall be considered.

In general, some nickel- bearing rocks contain considerable quantities of sulphur which gives rise to nickel sulphides deposits. As the occurrences of Sidamo do not contain sulphur, the nickel was originally combined with silica, and when it congealed a rock containing nickeliferous silicate (olivine) was formed. Laboratory experiments show according to Kitaisky (?) that a molten mass consisting of various metals, sulphur and silica constitues not one, but two hot liquids. These liquids are as immiscible as water and oil. When the magma chamber cools, the molten sulphide mass begins to crystallize later than the molten silicate. As the sulphur did not exist in the ultrabasic and basic magma of Sidamo Province, nickel deposits are of silicate type. There were no indications of sulphidic nickel minerals in this province. Therefore it is hard to

* I am thankfull to Baines T. V. of International Nickel Comp. Ontario for friendly communication about petrographic determination made by Duesing C. M. in 1963.

expect that sulphidic nickel minerals will be found as the sulphur content was determined to be very low (less than 0,01 %) in the serpentinite cf this area. The ultrabasic and basic magma which has given rise to nickel deposits was therefore a nickeliferous silicatic magma

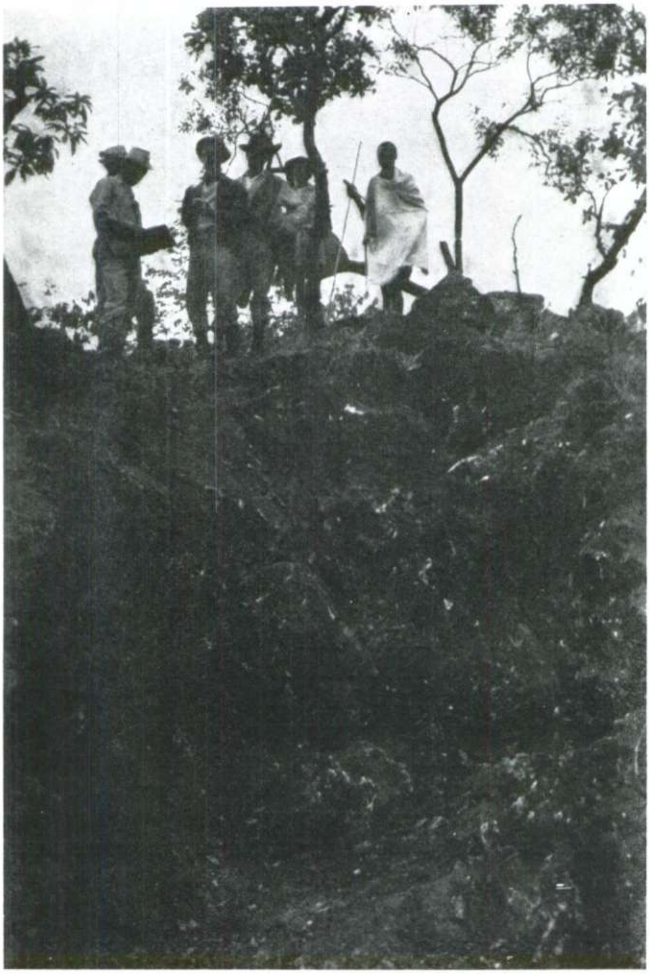


Fig. 16. Eluvial chromite deposit at Budussa. Adola district

Thus, nickel is genetically probable assocciated originally with olivine and other silicates whose lattices were altered during the process of metamorphism. Nickel compounds of unknown chemical structure were formed together with serpentinite.

The main accessory mineral of the compact rock zone is crystalline magnetite, which is partly replaced by amorphous magnetite. The amorphous magnetite is younger than the crystalline magnetite, and it seems to be replaced partly by trevorite (?), as the analysis of amorphous magnetite has indicated a content of 0,96 % of Ni and 0,44 % of Cr.

The magnetite occurs in veins 2—5 mm thick as well as in the form of grains dispersed in the primary rock, i. e. in the serpentinite.

Serpentinite forms lens-shaped and irregular bodies of various sizes in the talc-chlorite-tremolite schist. The Tulla serpentinite body is about 800 m long and about 100 m wide on the average. The Dubicha Gudda and Mika serpentinites have a total length of a few kilometers and a width of several hundred meters. The serpentinites of Burjiji and of Budussa are a few hundred m long and about 50 m wide. The Kenticha serpentinite, which is composed of many bodies, indicates various sizes. The serpentinite of Ula-Ulo is round with a diameter of 300 m. The T'Allo serpentinite is similar to a layer parallel with the Adola series.

Monissa serpentinite which strikes north-south is composed of three bodies cut by erosion of two brooks flowing in east-west direction. The total length of serpentinite is about 7000 m being 200—500 m wide. Lolotu serpentinite is about 1000 m long, being about 300 m wide. Near Budussa there occur two serpentinite bodies Tulan Chebi being about 20 m long and 10 m wide and Aragessa, being composed of four separated bodies covering totally about 400 sq. m of surface. Chabessa serpentinite is situated between Monissa and Dubicha Gudda serpentinites being about 1000 m long and about 250 m wide.

Morphologically the serpentinite builds elevated, round, elliptical, or irregular bodies which can be easily recognized in the field. The serpentinitic mountains dominate over wide areas, i. e. Ula-Ulo extends over the Bore drainage basin, as do the Dubicha Gudda and Dubicha Mika mountain ridges over the Kebre Mengist plane. They are mostly devoid of forest.

According to the assumed primary content of chromium and nickel minerals in the serpentinite, the above areas may be divided into two groups. The first group comprises serpentinite bodies where eluvial chromite was not found. The second group comprises serpentinite where eluvial chromite was found to be either associated with the serpentinite or near it.

In the first group are Burjiji, Ula-Ulo, and Tulla. They are barren of eluvial chromite, but they contain, however, small amounts of chromite as accessory mineral, as indicated by chemical analysis. Owing to the small content of nickel (0,2—0,5 %), the serpentinites have no commercial value as mineral deposits, as the nickel was not found in sulfidic form.

The second group of primary occurrences of chromite has been indicated by eluvial chromite debris at Budussa, Kenticha, Dubicha Gudda, Dubicha Mika, and the Wollabo area (where chromite debris were found, but no serpentinite). The commercial value of these deposits can be determined only by extensive prospecting and exploration.

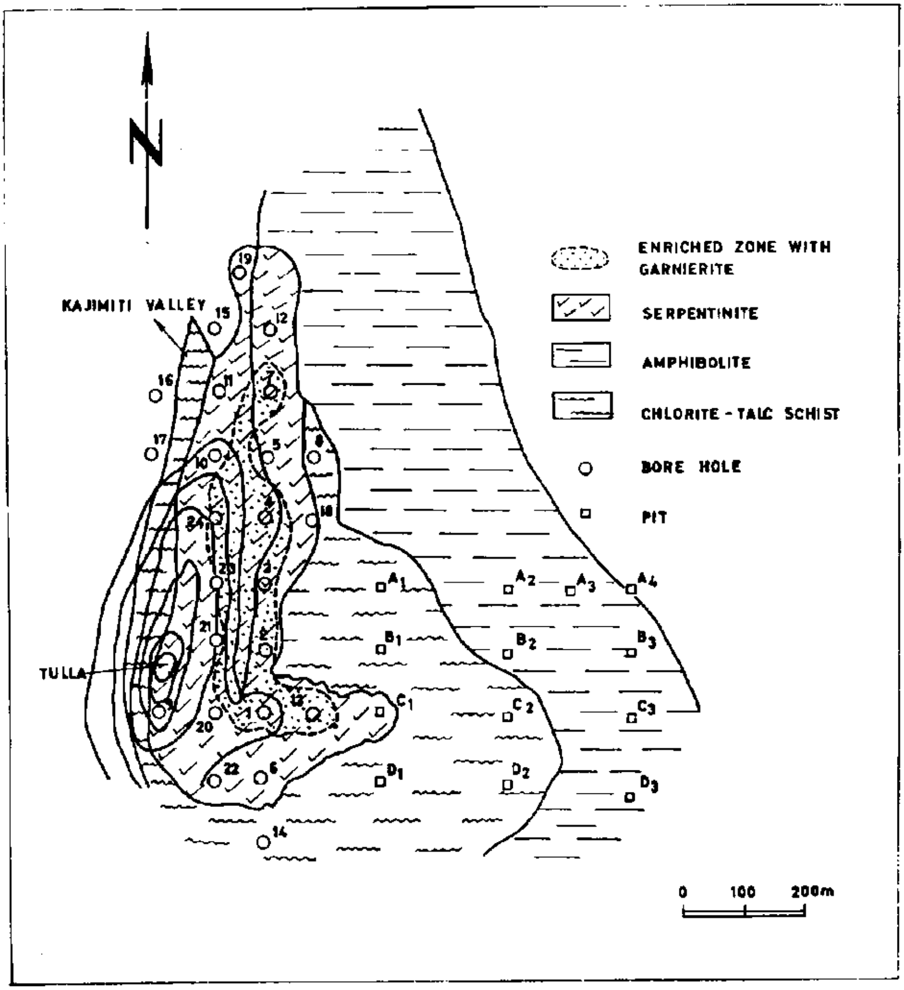


Fig. 17. Geologic sketch map at Tulla

Stronger indications of the eluvial chromite were found at Budussa, associated with talc-chlorite-tremolite schist; smaller indications associated with serpentinite, however, were found at Dubicha Gudda and T'Allo valley. At Wollabo valley, only a few pieces of chromite were found.

Nickel mineralization

The decomposed zone has been enriched in nickel in the altered zone of serpentinite of Tulla, Ula-Ulo, Ketta, Kenticha, Dubicha Gudda, Dubicha Mika and other deposits of this area. The nickel content in the zone of the compact, fresh rock amounts to less than 0,5 % and chromium to about one tenth of this percentage, which corresponds to the normal geochemical content of these metals in the family of the ultrabasic rocks.

Nickel deposits of Tulla, Ula-Ulo, and others as well as the deposits along the Mormora—Awata watershed at Kenticha are associated with residual soil of altered serpentinite. Residual soil of the upper zone of the formation is enriched in garnierite and probably in other nickel compounds.

Tulla

The numerous garnierite veins dip 20—30° E. They follow the fissures of the altered serpentinite, which are parallel to the slope of the Tulla Saddle.

Residual nickel deposit in Tulla has been drilled systematically. Table VII shows the depth and Table VIII the petrographical and chemical section of residual soils. The situation of the holes drilled and pits dug is given in the **Fig.** 17.

The highest content of nickel follows the line 13 — 1 — 2 — 3 — 4 — 24 — 7; however, the volumes do not show commercial quantities.

These petrographical and chemical characteristics indicate that the nickel deposit is associated with residual soils. The constituents such as magnesium salts and silica are washed out of the serpentinite. The decomposed superficial zone in the Tulla deposit has been enriched in various nickel compounds.

Prospecting based on the above chemical analysis has proved around 6500 tons of nickel in 583 000 tons of nickel ore with 1,14 % of nickel, considering only that part of the cores of the bore holes with nickel content higher than 1 %.

The average depth of the deposit was found to be 6,57 m. The deepest mineralization with nickel content above 1 % is found in the bore hole 1.

Table VII

THE DEPTH OF RESIDUAL NICKEL DEPOSITS IN THE TULLA AREA AS DETERMINED BY DRILLING

Number of the hole	Depth of the hole m	Depth considered for reserves m	Residual soil with serpentinite m	Serpentinite m	Average nickel content %
1	79,60	18	24,70	54,90	1,14
2	6,50	1	1,00	5,50	1,03
3	4,00	1,2	2,20	1,80	0,92
4	13,00	9,0	10,10	2,90	1,45
7	6,00	5,00	6,00	—	1,14
24	3,0	3,0	—	—	1,18
13	8,80	8,8	8,80	—	0,89

Table VIII
SECTION OF THE BORE HOLE № 1 AT TULLA

Bore hole 1 Depth in meters	Petrographical composition of core	Nickel content %
0,0— 0,7	Brown, argillaceous, decomposed serpentinite with white spots	1,58
0,7— 1,4	Pink, decomposed serpentinite	0,98
1,4— 3,0	Pink, sandy, decomposed serpentinite	1,80
3,0— 3,5	Pink, argillaceous, decomposed serpentinite	1,42
3,5— 6,5	Pink, argillaceous, decomposed serpentinite	0,84
6,5— 8,0	The same as 3,5—6,5	1,58
8,0— 9,5	Pink, sandy, argillaceous, decomposed serpentinite	1,58
9,5—10,0	The same as 8—9,5	1,10
10,0—12,5	The same as 9,5—10,0	0,70
12,5—13,0	The same as 10,0—12,5	1,07
13,0—13,8	The same as 12,5—13,0	1,01
13,8—15,6	Brown, sandy, argillaceous, decomposed serpentinite	
15,6—18,0	The same as 13,8—15,6, but at the lower portion with transition to compact, fresh serpentinite	0,73
18,0—21,0	Sandy, pinkish, argillaceous, decomposed serpentinite in the upper part; green spots in the lower layers of compact rock	0,44
21,0—24,0	Pink, sandy, argillaceous, decomposed serpentinite	0,56
24,0—24,7	Shaly, sandy, grey to reddish layer of decomposed serpentinite	0,64
24,7—79,6	Compact, fresh rock with yellow and green veins impregnating the rock, but with intercalations of grey sandy layers; weak reaction to HCl.	Less than 0,5

Ula-Ulo

The numerous gernierite veins occur in the western slope of the Ula-Ulo hill, discovered along the road cut in the slopes. They dip 30° W and are mostly parallel to the western slope of the hill, filling fissures of the altered serpentinite.

The Ula-Ulo zone was drilled in 1963 (May—December). About 1500 m of shallow bore holes were spotted. Some of them are shown in Table IX. Chemical analyses have been carried out for each meter of the core in the laboratory of the Ministry of Mines. Considering only those portions with nickel contents over 1 %, the average content of this deposit was found to be 1,5 %. Taking into consideration only the contents over 0,8 %, the average nickel content was found to be 1,35 %. The tonnage of nickel ore was about 2 000 000 tons at the end of 1963.

This deposit contains an enriched ore zone with the highest grade of nickel (4,53 %) indicated by garnierite.

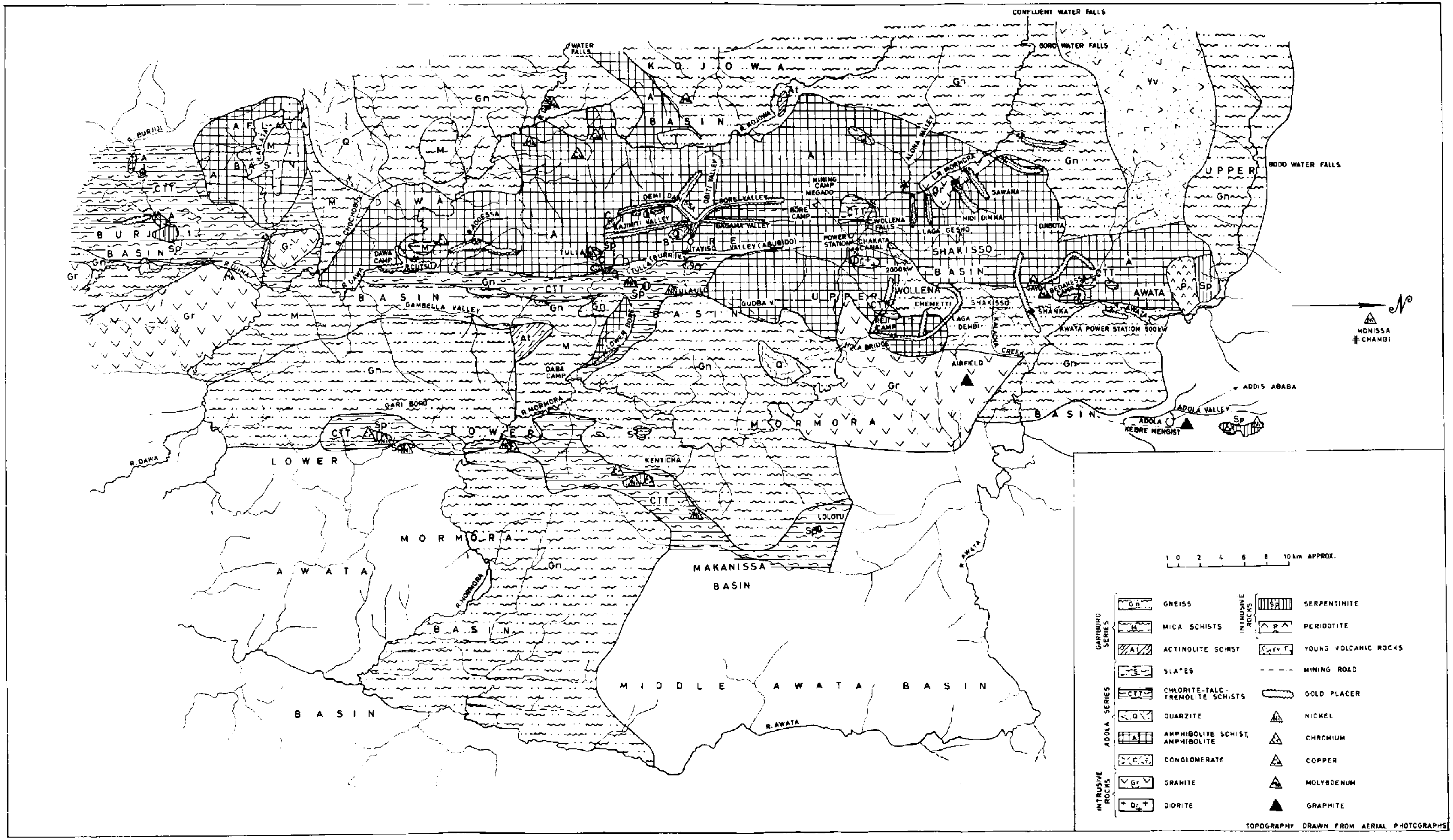
Table IX

SOME OF THE ULA-ULO NICKEL CONTENTS

Number of the hole	Depth of the hole, m	Average nickel content, %
36	6,7	1,22
59	3,0	1,27
0/F	6,5	1,77
0/B	9,5	1,76
0/E	6,0	1,39
1/B	3,3	3,70
2/B	13,0	1,40
2/A	11,5	1,09
0/C	0,3	1,69
1/A	20,4	1,95
2/C	3,0	1,08
3/B	6,3	1,41
4/A	12,0	1,88
4/B	5,0	1,77
5/A	5,0	2,31
5/B	10,8	1,90
5/C	4,0	1,35
12	9,6	0,96
13	8,9	0,92
14	8,8	1,45
15	4,2	1,06
16	7,5	1,38
17	5,0	1,13
18	12,0	0,84
19	8,3	1,43
20	6,0	1,54
21	2,0	1,06
22	4,7	1,39
23	4,0	0,93
26	4,5	1,15
27	8,7	1,11
40	11,2	1,54
41	6,6	2,23
43	3,0	1,05
45	2,0	1,30
47	2,3	1,45
62	5,0	1,12
72	3,4	0,95
95	5,0	1,21
97	5,4	1,98
Average depth	6,61	1,35

Kilta

Another deposit of the same type is found 2 km to the south of Ula-Ulo. This serpentinite also shows enrichment of nickel in residual soil of the alteration zone.



GEOLOGIC SKETCH MAP SHOWING THE ADOLA GOLD PLACERS AND SOME OTHER ORE DEPOSITS

Dubicha Gudda and Mika

This serpentinite residual soil shows enrichments of nickel. The prospecting in this area is carried out at present on a large scale.

Monissa

Monissa weathered serpentinite and subordinate lateritic soil with nickel contents within 0,5 and 1,1 % is situated in extreme north of the Sidamo-Province pre-Cambrian rocks area situated about 16 km west of Meleka village, which is in turn about 35 km from Kebre Mengist village at the road to Addis Ababa. It could be visited also from Chambi village along the path about 7 km long in northern direction. Chambi village could be reached from Kebre Mengist by road constructed for the gold-bearing areas of Ababa river drainage basin.

The nickel-bearing area which is more or less identical with the serpentinite is about 5000 m long and 100—500 m wide. The serpentinite is embedded in talc-chlorite-tremolite schist bounded mostly by gneiss.

Lolotu

Lolotu is located about 32 km south-eastwards of the Adadicotu airfield. The nickel-bearing area is associated with weathered serpentinite and subordinate lateritic soil. The nickel content of samples got by preliminary prospection gave similar results as the samples collected in Monissa.

Chabessa

Chabessa serpentinite body is similar to Dubicha Gudda serpentinite and is situated between Monissa and Dubicha Gudda about 3 km to the north from Dubicha.

The available surface of serpentinite is smaller than in Monissa and Dubicha mountains. Its nickel content in weathered serpentinite is similar to that of Monissa.

Tulan Chebi and Aragessa

In extreme south of the serpentinite outcrops south of Kenticha the nickel content in weathered serpentinite of two samples amount to 1,5 %.

*

The above described nickel ores of Sidamo have been discovered by nickel bloom. The rock outcrops were attacked by meteoric water, oxidized by air, and decomposed by organic acid deriving from the metabolic activity of plants and animals, a process which may be compared with the oxydation of metals. Prolonged oxidation of nickeliferous minerals on the earth surface, particularly at Tulla, produced nickel green, which could be a hydrous oxide or a hydrosilicate. The apple green tint stain is in contrast against the pink-grey background of serpentinite. Particularly at Tulla serpentinite outcrops nickel green occurs on the surface of serpentinite as sinters, incrustations, coatings, also as small veins or network of veinlets extending some distance into the serpentinite from its surface. The typical apple green tint staining gave rise to inhabitants of this region to pay attention to the occurrence on which samples have been sent to the Ministry of Mines.

Based on favourable result of analysis, prospecting started in the year 1963 at Tulla. The first structural bore hole proved the distribution of nickel in the depth (Table VIII). This hole show that the highest concentration of nickel was found in the depth of 1,4 m — 3,0 m with 1,8 % of nickel. In the depth the content of nickel decreases up to 18 m. Small variations within 0,44 and 0,64 % have been found in content of nickel in deeper parts of the core, but the content was less than 0,5 % of nickel below 24,7 m. The drilling proceeded up to 79,6 m in serpentinite and proved that any concentration of nickel could be expected in the depth. Based on this bore hole, a large drilling program was set up and carried out in Tulla area, partly with mechanized drilling, partly with pitting and hand boring as the small depths requested to reach serpentinite with less content than 0,5 % of nickel vary within 3 m and 13 m.

At Ula-Ulo and other serpentinite nickel staining was hidden until the prospecting started. It appeared along the road to the top of Ula-Ulo mountain which cuts the slopes of this mountain.

It was mentioned in the primary nickel deposit chapter that the nickel compound originates from the disintegration of the olivine lattice during the process of metamorphism and concentration of nickel in the product of metamorphism. Serpentinite is an alteration product of olivine and pyroxene. The serpentinite is chemically composed of metals (magnesium, iron, nickel) linked with silica in a definite order. Serpentinite contains a very minute amount of nickel which replaces a part of magnesium and iron, and which is probably uniformly distributed throughout the mineral. It represents the initial material from which silicate nickel ore was derived.

In order to get the nickel deposits of higher concentration (over 1 % of nickel) compared with the average content of serpentinite (less than 0,5 %) of nickel, process of weathering must take place.

During the process of weathering the first element leached out was magnesium, followed by more magnesium together with iron and nickel. The last to be weathered was the silica matrix. All these elements were dissolved by water, which infiltrated underlying rocks through cracks and pores.

First precipitated at the very surface of the earth was iron which accumulated in the upper crust between 0 m and 1 m forming a type of brown laterite, being loose if dry, and argillaceous if wet. A part of the iron went farther down to be deposited in the fissures of the rock

Veins of crystalline magnetite and amorphous magnetite occur within this layer. These veins usually limit the second layer and introduce the third layer which consists of light partly weathered serpentinite of lower density than fresh serpentinite which has not been decomposed into clay. A characteristic of this zone is the magnesite occurring as white veins in fissures, and minute grains of calcite, as this layer shows weak reaction of hydrochloric acid. The leached serpentinite is nickeliferous only at the upper part near to the second layer where increased contents have been noticed compared with the lower parts of the layer. Farther down, as the above mentioned carbonates begin to appear, the amount of nickel decreases until it reaches the unaltered serpentinite.

The Tulla deposit represents a transition type to the fissure type of nickel deposit, where the zoning is not so clearly expressed. However, deposits as Ula-Ulo, Dubicha Mika and Gudda belong to the clearly zoned types of weathered nickeliferous deposits.

The subsequent erosion influenced the entire nickeliferous deposit, as it is composed of comparatively loose and easily erodable argillaceous material. Therefore, at some places (Dubicha Mika and partly Dubicha Gudda) the upper layer and a part of second layer were eroded, as the serpentinite with magnetite veins appeared at the surface. In some places only the upper layer is eroded (part of Tulla and Ula-Ulo), as the highest contents of nickel have been found at the surface or near of it.

After weathering of serpentinite nickel in the solution was carried deeper compared with iron to be precipitated in the depth of 0,7—1,3 m.

Magnesium, however, infiltrated deeper layers of the rock, and it deposited after iron and nickel. Therefore, fissures filled with magnesite were observed. This layer represents the root of the weathering process.

Silica began to dissolve only when the serpentinite was completely free of above mentioned metals. While a part of silica remained in situ, the leached parts were gradually deposited in the pores and fissures.

The above process gave rise to the following sedimentation characteristics, which are found in all deposits prospected and explored in details (Tulla, Ula-Ulo, Dubicha Mika and Gudda) in more or less clear forms.

The lateritic iron layer with transition to ochre occurs in the upper part of the weathered zone. This zone is mostly eroded and only partly preserved. The middle part of the weathered zone is mainly composed of pink, sometimes sandy argillaceous material (clay) with remnants of original serpentinite.

This clay is of low plasticity, it is waxlike and greasy if touched. Minute inclusions of octahedra of magnetite and probably of other spinels with traces of platinum could be detected in it, if the material was panned as at Tulla and Ula-Ulo in form of fine black sand (clay which originates from other rocks usually does not yield black sand). By means of the microscopic analysis of Ula-Ulo material veins and stringers of chalcedony were determined in this layer. These veins result from silica deposited in cracks by descending solutions.

Secondary (eluvial) chromite deposits

The largest residual deposit of chromite was found in Budussa 100 km south of Kebre Mengist. The serpentinite in this area occurs in the environment of the chlorite-tremolite schist and antophyllite rocks (with asbestos) in form of two bodies. Chromite boulders occur in blocks up to 0,5 cu. m in size.

Trenching carried out in the year 1960-61 has proved that the eluvial chromite blocks are isolated from mother rock. They have been brought to the surface by gradual erosion of the mother rock which could be talc, as relics of this rock have been found associated with chromite boulders.

The reserves of residual chromite amount to maximum 2000 metric tons. The relation between iron and chromium is very favourable and could be considered as a high-grade chromite in respect of its low iron content. As the reserves are too small, the residual deposit has no commercial value.

According to Bentor (1963) who visited in the year 1963 the Budussa chromite occurrence, the chromite boulders could not have been transported from afar, as evidenced by their very large size and by the fact that on the highest part of the trench chromite pebbles occur without any admixture of other materials. According to this visitor, there are three possibilities of the origin of the chromite blocks. The first one explains the boulders being formed from at a present eroded primary chromite deposit near the present eluvial deposit. The second possibility assumes the boulders having rolled down from the higher part of Budussa mountain, what seems to be remote, as a survey showed that neither rocks usually associated with chromite nor chromite occur on this hill. The third possibility assumes the chromite blocks derived from an exposure of ultrabasic rocks occurring about 4 km to the NNE.

A very small number of chromite pieces occurs at Dubicha Gudda and Dubicha Mika; therefore, the residual chromite deposit has no commercial value. The same may be concluded for Wollabo Valley chromite occurrences.

Genesis of nickel-chromium deposits

Taking in consideration the above mentioned field data and laboratory investigation, the chromium and nickel are derived from peridotitic magma. The forming of the deposit was as follows:

Peridotitic magma

Peridotite-magmatic concentration
(Olivine with nickel and chromite was formed)

Metamorphism
(Nickel went into solution and formed various compounds)

Serpentinite
(Concentration of nickel as well as chromite in serpentinite)

Alteration and erosion

(A residual clay with garnierite and other nickel compounds is formed. Eluvial chromite deposits near serpentinite were formed by erosion of serpentinite).

Summary

To improve the mine development and increase the gold production in Ethiopia, in Sidamo province a complex geological-mining development project is being carried out by the Ministry of Mines of the Imperial Ethiopian Government. The main method used was a systematic prospecting in order to increase the gold reserves, planning of mine development, construction of water supply and power supply system, and acquisition of new mining equipment.

During geological mapping metamorphosed ultrabasic rocks have been found, and a systematic prospecting and exploration for nickel and chromium minerals is actually carried out.

The result will be the increase of gold production by mechanized projects and the limiting of handwork production on placers unsuitable for mine development.

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