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UNITED NATIONS INDUSTRIAL DEVELOPMENT ORGANIZATION
Vienna International Centre, P.O. Box 300, 1400 Vienna, Austria
Tel: (+43-1) 26026-0 · www.unido.org · unido@unido.org

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GROUP TRAINING IN PRODUCTION OF ALUMINA
VOLUME 1

PRINCIPLES AND METHODS OF BAUXITE PROSPECTING

ALUTERV-FKI

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VOLUME 1

PRINCIPLES AND METHODS OF BAUXITE PROSPECTING

by

Fodor, B., Mrs Gecse-Tóth, É., Mrs Hegedüs-Koncz, M., Horváth, I., Kanuer, J., dr. Komlóssy, Gy., Mindszenty,A., Nyerges, L., Szabó, E., Szantner, F., Tolnay, K., Tóth,K., dr. Vörös, I., Zólomy, M.

editors:

dr. Komlóssy, Gy.
Szantner, F.
dr. Vörös, I.

translation:

dr. Dudich, E.
dr. Komlóssy, Gy.
Mindszenty, A.

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INTRODUCTION

All materials of the UNIDO Group Training - launched under the auspices of the Research, Engineering and Prime Contracting Centre of the HUNGALU - are summarized in an eight-volume series, the first - present - volume of which comprises the Principles and Methods of Bauxite Prospecting, as the first stage of the vertically integrated aluminium industry.

Beside a complete review of geology, mineralogy, petrography and origins of bauxites and the methods of prospecting, the present volume includes also drilling techniques, the know-how of organization of exploration campaigns, the preparation of Exploration Reports and the most up-to-date methods of computerized reserves'calculation.

Lateritic and karstic bauxites are treated separately in most of the text. As far as demonstration is concerned, however, Hungary is in a position to present karstic occurrences only, and this inevitably led to a kind of disproportionateness in some of the chapters. In order to provide for a better understanding of the examples, karstic occurrences, being the subject of demonstration, are discussed namely more profoundly than lateritic occurrences are. Based on international experience of Hungarian experts, the most striking characteristics of lateritic bauxites are also presented, however, with particular emphasize on those which are directly connected to the theory and practice of prospecting.

Bauxite geological mapping, sampling, chemical and mineralogical investigations and some additional questions being of equal importance when prospecting either for lateritic or for karstic occurrences, are treated with special care, because experience proved that - due partly to objective difficulties - they are often neglected or may involuntarily be overlooked in part of the developing countries.

The volume includes also detailed description of certain operations the relation of which to the geologists's duties seems to be rather remote (geophysics, geodetics, drilling methods and techniques). Their treatment is justified, however, by the fact that, in order to control and coordinate the complex of technical and scientific activities comprising a prospecting campaign, the geologist has to be familiar not only with his own problems but also with those of all the adjoining branches of science and technique.

For lack of detailed information concerning the qualification of the participants some elementary problems had also to be discussed to ensure a firm basis for the effective treatment of more complicated problems.

CONTENTS

LIST OF FIGURES

1. DEFINITION OF BAUXITE

GEOLOGICAL DEFINITION OF BAUXITE

Geological definition of bauxite has been made by a number of authors from BERTHIER's first definition in 1821. Based on the results of the exploration and that of the investigations of the last few decades one of the most up-to-date definitions was made by BÁRDOSSY (1976). According to his definition "bauxite is a sedimentary rock in which the total amount of the Al, Fe and Ti-oxides and hydroxides is more than 50 % with the dominance of Al-minerals."

Regarding the characteristics of the two main types of bauxite formed by different geological conditions BÁRDOSSY's definition can be enlarged as follows (VÖRÖS, 1976):

"Bauxite is a sedimentary ore rich in allitic components formed from the rest of different rocks weathered in tropic climate; depending mainly on the morphology, drainage and on the geological-tectonical circumstances bauxite can be found both as part of lateritic profiles or as accumulation in smaller to larger karstic cavities of carbonatic footwall rocks. The total amount of the Al, Fe and Ti-hydroxides and oxides is more than 50 % with the dominance of the Al-minerals."

Based on the ratio of the main minerals the bauxites are grouped by BÁRDOSSY (1976) as Fig. No. 1. shows.

The determination of bauxite from the point of view of genetics, formation and consequently that of the geology of bauxite based only on the presence of the allitic minerals is disputable. Number of examples show this case from hydrothermal dyke formations associated sometimes with gibbsite through the Al-hydroxides of the areas of presently active volcanism up to the allitic components in several cases in the very largely ex-

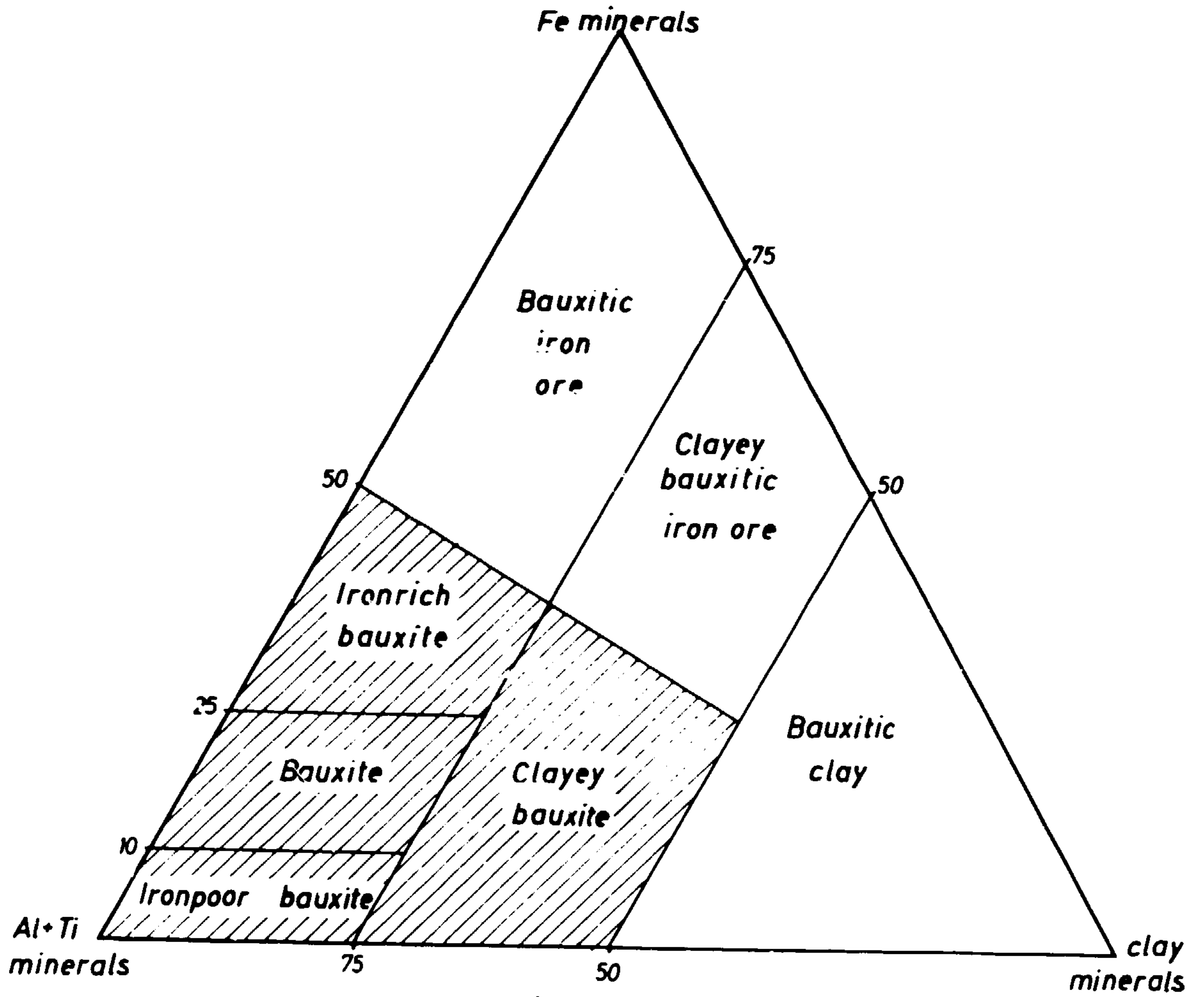


Fig.I. Classification of bauxites after Bárdossy (1977).

tended laterites of the tropics. However in geological and moreover in industrial sense these materials are not bauxites due mainly to the very low percentage of their allitic components which are inadequate to the definition of the bauxite as given above.

INDUSTRIAL DEFINITION OF BAUXITE

Geologically defined bauxites can be industrial or ore--grade types, if they are suitable for economic alumina producing by any actually used technology. However this ore-grade quality cannot be determined by some numerically well-defined value owing to the relatively significant tolerances of these technologies on the one hand and to other effects on the other one which are detailed in Chapter No. 5 (quantity of the estimated reserves, infrastructural questions, mining possibilities, etc.).

Regarding the actual alumina technologies (see also Books No.3. and 7.) these bauxites are ore-grades for the so-called Bayer technology in which the ratio of the allitic minerals is the highest compared with the others; the "pyrogen" technology can economically use the bauxites with lower allitic and higher siallitic contents also. The so-called Grzymek technology does not strictly need the presence of allitic minerals. In other words this technology can use not only low grade bauxites but clays too as raw material with no allitic content.

The question of quality varies also in time: parallel with the development of the technologies - and last but not least with that of the running out of several high ore-grade bauxite reserves - the need of industry has very much varied during the last few decades. The alumina plants (including also the Hungarian plants) process mainly the so-called karstic bauxites and they are already economically producing alumina from lower-grade bauxites too.

Modul is the generally known value, giving simply the quality of the bauxite with quite good exactness; the modul can be calculated as the ratio of the two main components as follows: Al_2O_3/SiO_2

According to the value of the modul bauxite can be classified as follows:

I^{st}	class bauxite, if the value is:	$M \geq 10$		
II^{nd}	class bauxite, if the value is:	$M =$ 7	to	10
III^{rd}	class bauxite, if the value is:	$M =$ 4	to	7
IV^{th}	class bauxite, if the value is:	$M =$ 2,6	to	4
V^{th}	class bauxite, if the value is:	$M \leq 2,6$		

The modul will be more exact by prescription of the lowest Al_2O_3-content, naturally based on the needs of the technology of the alumina plant using this bauxite. According to this method the bauxite can be only geological but not industrial (ore-grade) bauxite, if the alumina content is only 20 % with 2 % of silica, although the modul is 10.

Generally the bauxites are ore-grade for the Bayer technology with a module = 7 or more and with 40 % of Al_2O_3-content or more.

Based on the experiences of the alumina plants some parts of the chemically analysed Al_2O_3-content can never be recovered. This unrecoverable alumina is partly in the sialitic minerals and partly in the insoluble allitic components. Based on the experimental data this Al_2O_3-content is two times (in some cases three times) higher than that of the chemically analysable SiO_2-content, more exactly that of the so-called reactive silica content. Based on these the formula of the Basic Equivalent or Bev can be worked out as follows:

$$Bev = Al_2O_3\ \% - 2\ .\ SiO_2\ \%\quad \text{or:}\ Al_2O_3\ \% - 3\ .\ SiO_2\ \%$$

The Hungarian bauxites contain the SiO_2 mainly as reactive silica (in clay minerals: **predominantly in kaolinite**). If the bauxite contains the SiO_2 as non-reactive silica (e.g. quartz in many bauxites mainly in the lateritic types) the SiO_2-content plays a very small role in the value of the Bev.

In the case of higher percentages of other impurities (CaO, MgO, etc.) the analysed percentage of these also must be derived from the value of Bev. Generally the lowest cut-off of the economy is Bev = 30, but the Bev-value of the I-IInd class (modul) bauxites is much higher.

The factor of recovery is also used for the industrial qualification of the bauxites. This factor practically means the Bev, with no SiO_2 in the formula. This value is calculated not from the average of the results of the chemical analyses but based on the result of a technological test carried out on a given type of bauxite reserve in question.

The value of the absolute Al_2O_3 per cent is still also used in some cases. This method was very widely used 30 to 40 years ago and stated for instance, that a bauxite is ore-grade, if its Al_2O_3-content is higher than 55 %, below which it was low-grade (not an industrial one). This method was based on the earlier undeveloped technology. This practice cannot be used today: calculating only the Al_2O_3-content one can make big mistakes: e.g. a great deposit of the Montenegrian (Yugoslavia) "white bauxite" contains more than 56 % Al_2O_3, simultaneously with 17 % of SiO_2; in other words this bauxite is not ore-grade for the Bayer technology.

In other cases the bauxite can be economically usable for the Bayer process with relatively or significantly lower Al_2O_3--contents too: the average quality of the 980 million tons proved reserve of the Cape Bougainville deposit of the Mitchell Plateaux region (Australia) is as follows:

$$Al_2O_3 = 36\ \%$$
$$SiO_2 = 1.9\ \%$$

The very interesting iron-rich bauxite type of the Nyinahin deposit of Ghana contains less Al_2O_3, only 30 %, but the silica content is also very low (2 to 4 %), consequently this type can be determined as ore-grade bauxite considering mainly the co-existence of an iron-rich and a normal ore-grade bauxite at the same deposit (with more than 40 % of alumina and about 5 % silica).

Summarizing the above detailed things the conclusion is, that - regarding also the actual possibilities of the alumina plants around the World - only those bauxites are presently ore-grade types, from which (supposing sufficient reserves as well) alumina can be economically produced.

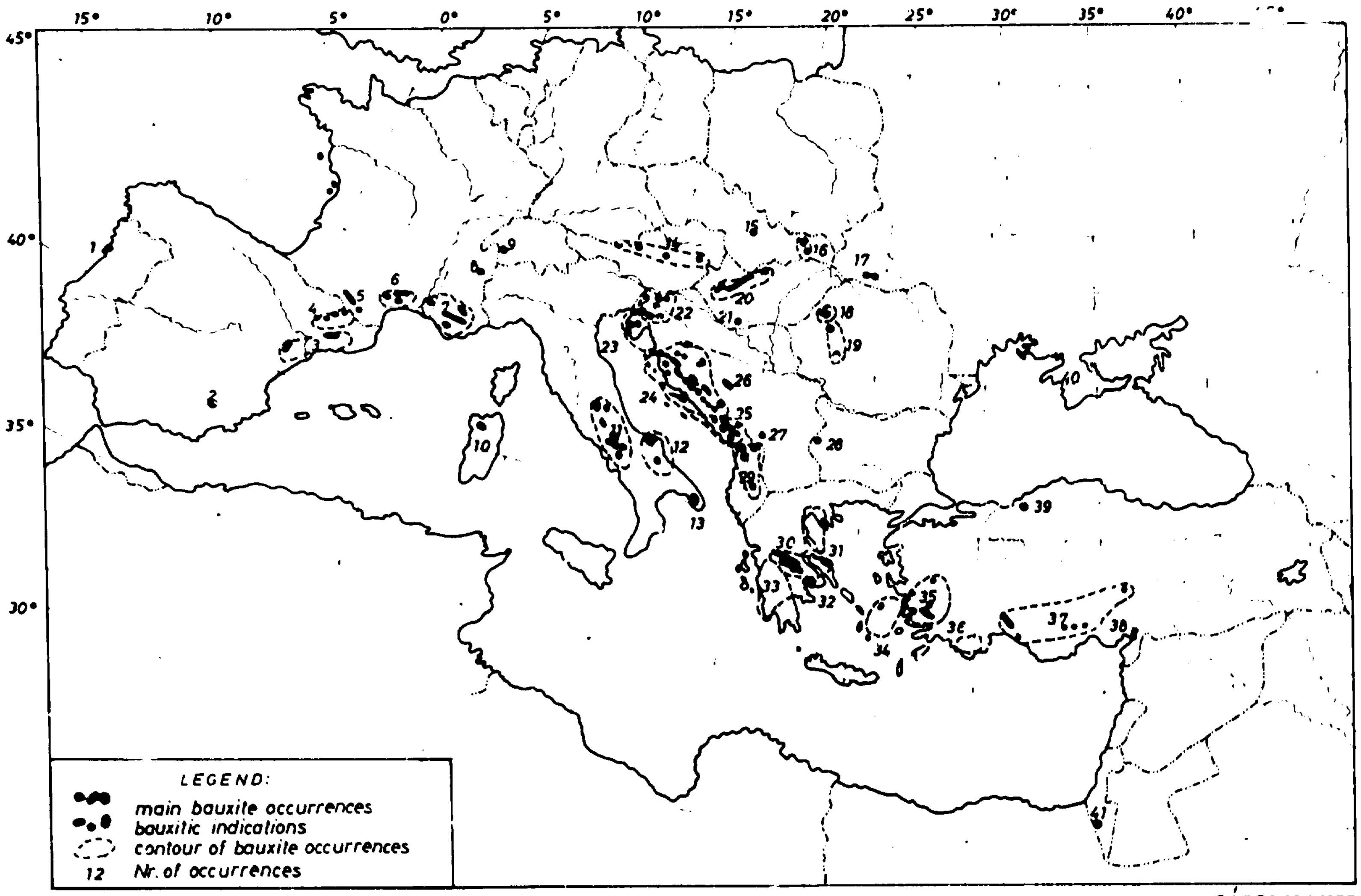
2. THE MAIN GEOLOGICAL CONDITIONS OF BAUXITE FORMATION AND ACCUMULATION; TYPES OF BAUXITE DEPOSITS; LOCATION OF BAUXITE DEPOSITS OF THE WORLD

2.1. KARST BAUXITE DEPOSITS

2.1.1. Characteristics of karst bauxites, types of deposits

The characteristicsof the geological setting of the karst bauxite types are as follows. The footwall is more or less karstified limestone or dolomite, the karstic cavities of which are filled in by bauxite. The predominant allitic mineral can be the gibbsite and/or the boehmite and at several regions the diaspore as well. The karst bauxite deposits (named Mediterranean type, too, due to their commonness around the Mediterranean Sea) are on the surface or they can be covered. The cause of the surface outcropping is mainly the erosion of the original hanging wall rocks; however in some cases (some bauxites of the Carribbean area, or that of some parts of SE-Asia) they had not been covered as yet. The direct hanging wall of the covered bauxites is frequently a clayey, coal-bearing swamp formation, in other cases limestone, marl, or mottled clay. The transition between the bauxite and the direct hanging wall can be continuous, but the limit can also be very sharp. In many areas the bauxite does not fill the karstic cavities and depressions of the footwall directly but it is a part of a complex bauxitic section containing fragmental--sedimentary-clayey horizons and parts too, e.g. Kazakhstan (Soviet Union), or Ariège (France) etc. The footwall of bauxite deposits for example in Yugoslavia and Greece is more deeply karstified and tectonized than that in other countries e.g. lenticular-tectonic deposits are upthrusted or faulted into vertical position or the karstic sinkholes are very deep of well-like forms etc. The stratiform deposits can be traced in 10 kms length or even more than 100 kms. in France, Yugoslavia, Iran, Kazakhstan (SU). The outcrops of the deposits rank along 50-100 km length of strike. These large and of wide spread deposits generally can be characterised with their low grade quality or better the stratigraphical gaps are not filled with bauxite only but they are filled with a bauxite complex in which industrial grade bauxites occur at places only.

MEDITERRANEAN BAUXITE BELT



BÁRDOSSY 1977.

Fig. N°2.

2.1.2. Geology of bauxite deposits of Hungary

By its geographic position Hungary belongs to the so called Mediterranean Bauxite Belt, which extends from the southernmost parts of Spain (and North-Africa) through France, Italy, Yugoslavia, Albania, Greece, Bulgaria and Roumania, down to Turkey and even Israel. See Fig. No.2.

The majority of the Hungarian bauxite deposits is bound to the Transdanubian Central Mountains. Some small-size occurences are known, however, also in North-Hungary adjacent to the NE termination of the Central Mts. (Nézsa, Nagyszál) and in South-Hungary (Nagyharsány).

Bauxite deposits were discovered first in 1910 near the presentday Halimba bauxite mines. Up to 1945 prospecting had been carried on by various private parties mostly of foreign interest. Thanks to the efforts of the pioneers bauxite have played an important role in the economy of the country even at those early periods. True prosperity commenced, however, after the second world war only, when prospecting together with mining, and the production of alumina- and aluminium, became integral parts of the newly consolidated Hungarian aluminium industry. From 1950 on prospecting has been going on systematically and provides for the raw material basis of the continuously growing industry.

The main characteristics of Hungarian bauxite deposits were disclosed during the first decades of prospecting already. (TELEGDI-ROTH,K. 1937., VADÁSZ,E. 1946., 1951, de WEISSE,J.G. 1948., BARNABÁS,K 1961., BÁRDOSSY,Gy. 1961.) The investigations of the sixties and seventies led, however, to several new bauxite geological results which profoundly influenced both the methods and the strategy of further prospecting and exploration. The accelerated rate of discovery of new deposits is demonstrated rather well by the fact, that several yet active staff-members of the present-day Prospecting Company have taken their part in the discovery and exploration of the following important deposits, that are being now under development already:

year of discovery	occurence
1959	Fenyőfő, Bakonyszentlászló
1961	Bittó (in the Mór-graben)
1968	Bakonyoszlop, Dudar
1972	Nagyegyháza-Csordakut-Mány
1974	Iharkut

New discoveries called for new overall bauxite geological interpretations (SZANTNER,F.-SZABÓ,E. 1962., FÜLÖP,J. 1964., DUDICH,E.-KOMOLÓSSY GY. 1969., SZANTNER,F.-SZABÓ,E. 1970., KÁROLY,GY. et.al. 1970.).

As a result of new, detailed investigations, new areas could be declared perspectivic for further exploration, and also areas of accepted perspectivity became enlarged. Since scientific research proved the productivity of the Albian and the Senonian (Lower-Eocene) contact, prospecting had to be extended in the stratigraphic sense, too.

Morphological types of deposits, formerly not observed in Hungary were recognized such as the tectonic graben type, the canyon-filling type and the type of structurally controlled sinkholes combined with karstic forms.

Scientific progress stimulated also the development of methods of prospecting. A new combined geological-geophysical method was developed to prospect for bauxite in areas of shallow or medium depths.

In order to meet the growing requirements of the aluminium irdustry, bauxite prospecting had been the subject of a considerable expansion during 1977. Beside a staff-increase in the geological departments also the annual drilling capacity had been raised to 100.000 meters pro year (an almost doublefold increase when compared to 1976) with an increased proportion of scout-drillings.

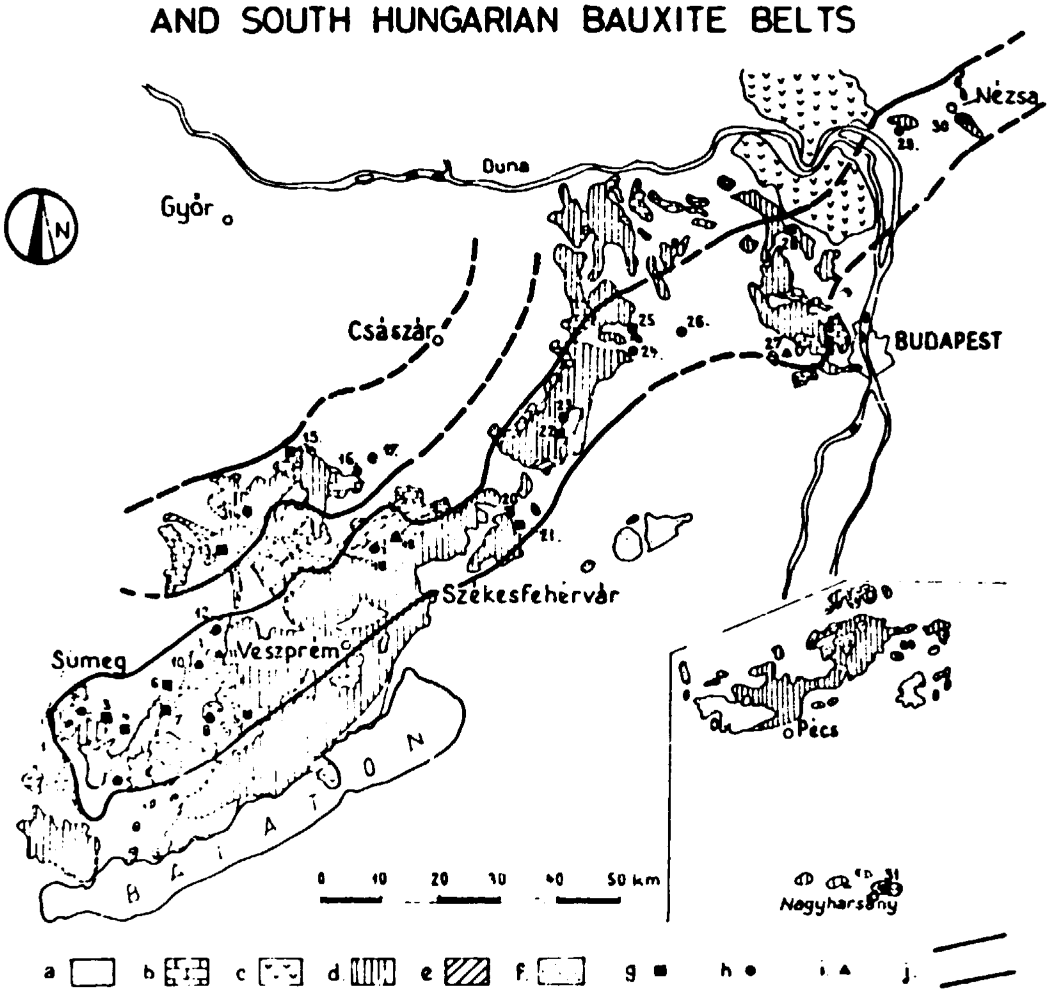
As a cons quence of these developments the amount of geological information concerning both the whole of the Transdanubian Bauxite Belt and the individual occurrences has been greatly increased, and the outlines of a new bauxite geological synthesis will probably emerge in the near future.

2.1.2.1. Stratigraphy

There are two bauxite-belts in Hungary (Fig.No.3.) The northern one extends from the south-western margins of the Transdanubian Mountains up to the isolated Mezozoic Blocks (Nézsa) on the left side of the Danube-bend and is called the Central-Transdanubian Bauxite Belt. It can be divided into two distinct zones. The SE zone is about 180 kilometres long and runs from Sümeg in the south to Nézsa in the north with a transversal extension of 30 to 40 km. The NW zone is represented by an about 35 km long and 15 km wide section extending from the village of Iharkut to Sur in the North-Bakony and some less--important indications near Császár in the Gerecse Forelands.

The only occurrence representing the SE-NE striking South Hungarian Bauxite Belt is Nagyharsány in the southernmost part of Transdanubia. Although no other deposits are yet known in this belt, its existence is undoubtedly proved by several boreholes which penetrated sedimentary rocks similar to those found in the Nagyharsány occurence. In Nagyharsány the bauxites rest on the surface of Upper Jurassic

GEOLOGICAL SKETCH MAP OF THE TRANSDANUBIAN AND SOUTH HUNGARIAN BAUXITE BELTS



a Sedimentary sequences of the Quaternary, Neogene and Oligocene
b Eocene sedimentary rocks
c Neovolcanics
d Lower Cretaceous, Jurassic and Triassic sedimentary formations
e Middle and Upper Cretaceous sedimentary formations
f Palaeozoic formations
g Bauxite deposits under development
h-i Bauxite deposits abandoned or not yet worked
h Industrial grade
i Non-industrial
j Borders of the Northern Zone of the Transdanubian Bauxite Belt

1-31 Bauxite occurrences

1 Sumeg 2 Csabpuszta 3 Nagytárkány 4 Nyirád 5 Zalahaláp 6 Halimba 7 Szóc 8 Öcs 9 Nagyvázsony 10 Ajka-Padragkút 11 Úrkút 12 Kislőd 13 Iharkút 14 Bakonybél 15 Fenyőfő 16 Bakonyoszlop 17 Súr 18 Alsópere 19 Tés 20-21 Iszkaszentgyorgy 22-23 Gánt 24 Óbarok 25 Nagyegyháza 26 Mány 27 Budakeszi 28 Pilisszántó 29 Nagyszál 30 Nézsa 31 Nagyharsány

Fig N° 3. SZANTNER 1979.

(Malm, Kimmeridge-L.Titonian, Lombardia arachnoidea zone) shallow-water oolite limestones and are covered by a Barremian shallow-water limestone sequence (Fig.No.14.). According to French analogies the bauxite itself is probably of Hauterivian age. The Southern Belt can be traced up to the central part of the country.

As to reserves and mineral grade it is the Northern (Central-Transdanubian) Belt that is of economic importance. The stratigraphic gap between footwall and overburden is rather wide here: bauxite is underlain generally by Upper Triassic carbonates while the overlying strata are either of Mid-Cretaceous or of Late-Cretaceous and Eocene age. Since the ore itself contains only scarce remnants of badly preserved Coccoliths and Diatomae its age can mostly be determined by indirect methods and rather uncertainly only. (BÁLDI-BEKE,M. 1974., BROKÉS,F. 1976.).

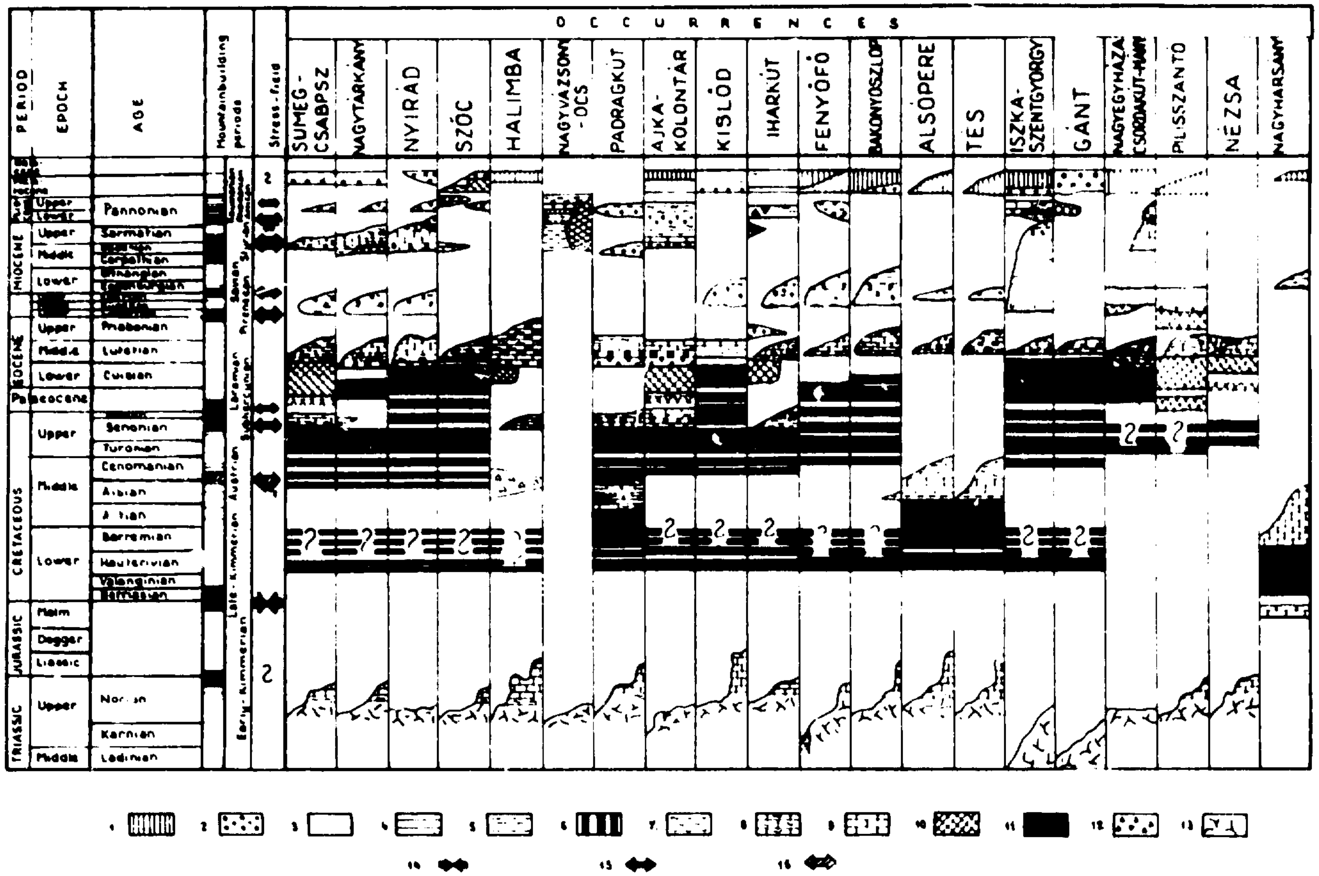
Stratigraphic correlation of the deposits is carried out generally by taking the age of the footwall and the cover into consideration. Deposits bound to the same footwall/cover combination are supposed to belong to the same stratigraphic horizon. Compromise may be effected when due to subsequent denudation parts of one and the same deposit became secondarily covered by younger strata. In this case - irrespective of the age of the cover - adjoining deposits with identical footwall are considered to be synchronous.

E.G. Iharkut: primary cover K_3
secondary cover E_2
E_3
or younger (O_1-Q)

Up to now the following stratigraphic horizons proved to be bauxitiferous in the Central Transdanubian Bauxite Belt (Fig.No.4.).

STRATIGRAPHY AND ELEMENTS OF TECTOGENESIS OF THE MOST IMPORTANT BAUXITE OCCURRENCES OF HUNGARY

(COMPILED BY F. SZANTNER)



1 Loess 2 Pebble conglomerate 3 Sand 4 Sandstone 5 Clay 6 Lignitiferous clay, lignite 7 Marl 8. Calcareous marl 9. Limestone 10. Reworked bauxite 11 Bauxite 12 Bauxitiferous dolomite scree 13. Dolomite 14 Compressive 15 Tensional 16. Tectonism producing potential bauxite traps

Fig N° 4

1st Horizon: footwall: Upper Triassic (Norian) limestone (Dachstein Formation)

cover: Mid-Cretaceous (Albian) shales, clayey aleurolites, marls, limestones (Tés Formation)

E.g. Northern Bakony (Alsópere, Tés, Bakonyoszlop)

Approximate age: Mid-Cretaceous (Early Albian)

2nd Horizon: footwall: Upper Triassic (Norian) dolomites, limestones and (rarely) marls,

Lower Liassic (Hettangian) limestones,

"Hauptdolomit"

"Koessen Strata"

"Dachstein Limestone Formation"

(each may occur "in situ" or in the form of a loose scree)

cover: a) Upper Cretaceous (L.Senonian) paralic coal-seams (=Ajka Formation) and/or reef-limestones (=Ugod Formation)

E.g. Southern Bakony (Halimba-Ajka, Csabpuszta, Sümeg)

b) Upper Craetaceous (L.Senonian) luviatile sequence (=Csehbánya Formation)

E.g. Northern Bakony (Iharkut, Ugod)

Approximate age: Late Cretaceous (Turonian - Early Senonian)

3rd Horizon: footwall: Upper Triassic (Karnian-Norian) - Middle Triassic (Ladinian) dolomite, "Hauptdolomit"

"Nagyszénás Formation"

cover: Mid-Eocene (in the Nyirád area at places also L.Eocene)

a) clay, gravel, carbonaceous clay, marl, limestone (=transgression sequence)

b) dolomitic talus-scree (=fanglomerate) and/or coalseams

E.g. a) Southern Bakony (Nyirád, Halimba, Kislőd)
Northern Bakony (Fenyőfő, Bakonyoszlop, Iszkaszentgyörgy), Vértes-Mts. (Gánt)

b) South Gerecse (Nagyegyháza, Mány)

Approximate age: Late Cretaceous (Turonian-E.Senonian) or Palaeocene-E.Eocene.

(The members of this group are not necessarily all synchronous!)

4th Horizon: footwall: Upper Cretaceous (Upper Senonian) reef-limestones (=Ugod Limestone F.)

cover: Lower to Middle Eocene transgression-sequence built up of sands, gravels, clays, marls and limestones

E.g. Southern Bakony (Csabpuszta, Sümeg)

At places there are also some industrial-grade occurrences interlayered into continuous sequences, or bound to rather short stratigraphic gaps:

Horizon (A) within the Middle Cretaceous (Albian) shallow-water limestone sequence (Urkut Limestones Formation), in the Southern Bakony (Padragkut)

Horizon (B) within the Upper Cretaceous paralic coal-bearing strata (=Ajka Formation) in the Southern Bakony (=Csabpuszta)

Horizon (C) interlayered in the Middle Eocene dolomite-fanglomerate in the South-Gerecse (Nagyegyháza-Mány)

Horizon (D) inbetween the Middle Eocene fanglomerate and the coal-bearing strata overlying it (South Gerecse: Nagyegyháza-Mány)

Bauxite deposits of the horizons B, C and D are no doubt of the reworked, redeposited type while the origins of the probably also reworked bauxites of horizon A is not yet fully disclosed.

Low-grade, partly resilicified bauxites are known in several other stratigraphic horizons of Transdanubia, all bound to wider stratigraphic gaps, such as:

Horizon (a) footwall: Mid-Cretaceous (Albian) limestone
cover: Upper Cretaceous of Middle Eocene
E.g. South-Bakony (Padragkut, Urkut)

Horizon (b) footwall: Upper Triassic dolomite
cover: Upper Eocene lagoon-facies clays
Oligocene blackish strata
E.g. South Gerecse, Buda Hills (Budakeszi, Bicske)

Horizon (c) footwall: Upper Triassic dolomite
cover: Pliocene fresh-water-, or brackish strata, basalt or basaltic tephra
E.g. Bakony-Vértes, Zalahaláp, Öcs, Nagyvázsony, Iszkaszentgyörgy.

2.1.2.2. Depositional characteristics, bedrock-morphology

All bauxite desposits of Hungary belong to the group of karstic bauxites. Apart from some exceptions they unconformably rest on the uneven, karstified and partly also eroded surface of intensely tectonized (block-faulted) dolomites and/or limestones. They are supposed to have been formed by in-situ bauxitization of some siallitic weathered material of uncertain origin.

Geological and morphological characteristics (i.e.: size, shape, etc.) of all deposits vary considerably, sometimes even within one and the same ore body. The possible number of coexisting depositional types is, however, limited by palaeogeographic and geologic factors controlling the deposition of bauxite and cover on the one hand; and subsequent structural displacements on the other. The most common coexisting types are the stratiform and lenticular; or the lenticular and tectonic-graben-filling deposits.

The major depositional types recognized up to now are as follows:

1. stratiform desposits,
2. extensive, blanket-like deposits,
3. lenticular bauxite-bodies
4. sinkhole-fillings,
5. tectonic-graben-fillings,
6. sinkhole-filling combined with tectonic-grabens,
7. canyon-fillings
8. bauxite-pockets.

There are also several additional minor but distinct types, like fissure-filling bauxites or those deposited into karstic cavities or cavern systems; although part of these types are logically compelling only, but not yet analytically proved, i.e. as far as economic accumulations of alumina are concerned.

Lenticular bodies of reworked bauxites interlayered in the overburden are also considered to be a distinct depositional type. It is to be noted, that reworked and/or degraded bauxites may occur in either of the above described types.

The whole system may of course be improved and refined when taking also the age and facies of the cover-beds, the horizontal and vertical extension of the bauxite bodies, and the fine details of bedrock morphology or other characteristic into consideration.

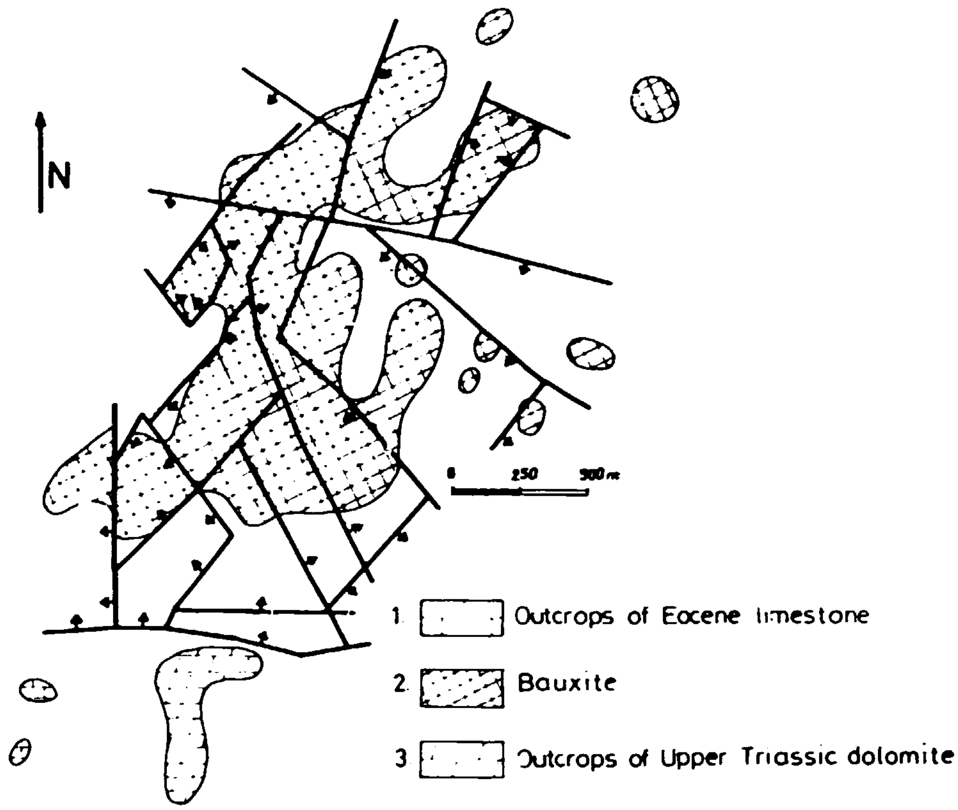
Except stratiform and blanket-like deposits, the formation of any of the above depositional types is controlled essentially by the morphology of the bedrock. It is namely the tectonic-karstic negative (i.e. concave) morphological elements of the underlying carbonates which served as traps during the deposition of the material and provided also effective protection against subsequent erosion.

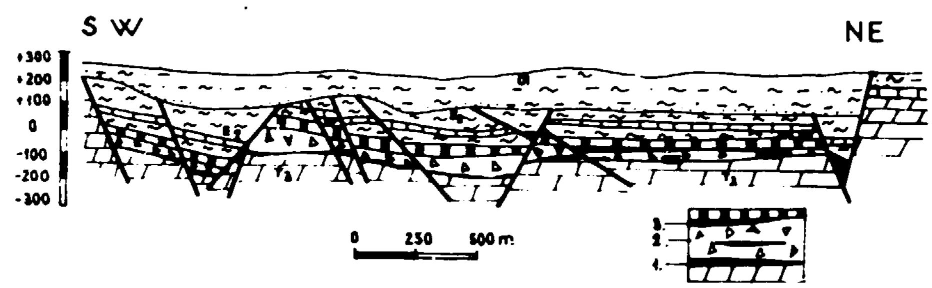
Stratiform deposits

Stratiform deposits are rather common all over the Central Mountains. (Examples are: Halimba, Alsópere, Iszkaszentgyörgy-Kincses-József-Rákhegy, Nagyegyháza, see Figs. Nos.5.-7.

They are of considerable (several sq kilometres) areal extension and contain excessive reserves of the order of several tens of million tons. Of course, the deposition of such enormous masses of bauxite can not be taken for having been controlled by fine morphological elements of the bedrock, more probably they were trapped in large-scale, tectonically "preformed" structures of negative relief. Their shape is therefore generally near-isometric or slightly elongated (according to the orientation of principal lineaments of the one-time topography).

STRATIFORM DEPOSIT. NAGYEGYHÁZA





1. Stratiform deposit underlain by Upper Triassic dolomite
2. Lenticular bauxite bodies comformably interlayered into the Middle Eocene dolomite-scree /fanglomerate/
3. Blanketlike depositions of reworked bauxite along the contact of the dolomite-scree and the overlyng coal seams.

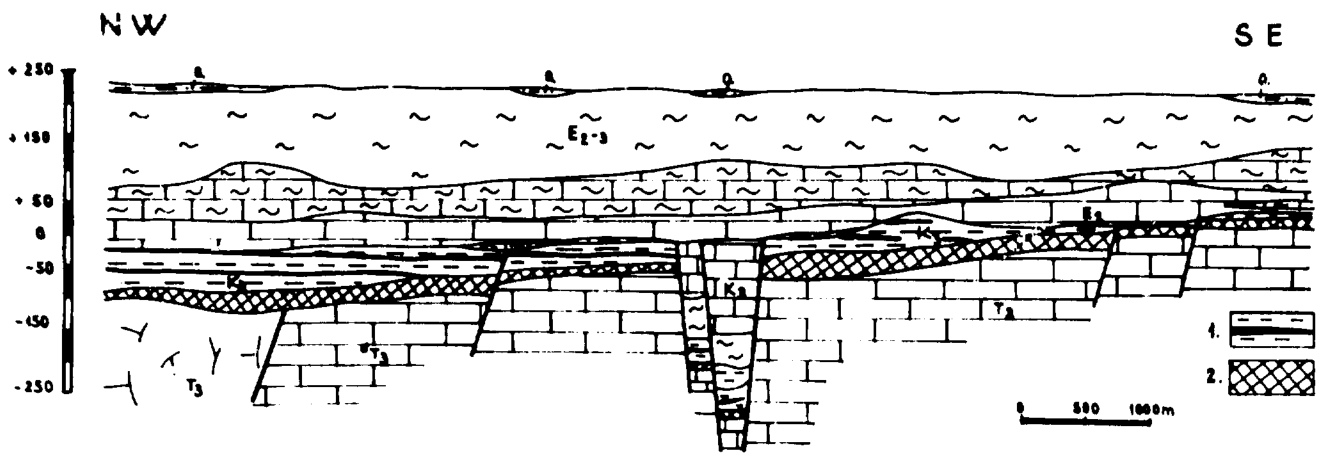
T3 Upper Triassic /dolomite/

E2 Middle Eocene /marl, limestone/

Ol Oligocene /sand clay argillaceous marl, sand, sandstone/

Fig N° 5. SZANTNER 1979

STRATIFORM DEPOSIT
/HALIMBA/



1. Upper Cretaceous coal-seams /Ajka Formation/

2. Bauxite

T_3 Upper Triassic /dolomite/

T_3^d Upper Triassic/Dachstein Limestone and Koessen Strata/

K_3 Upper Cretaceous Jákó Formation /clay and marl/ and Ugod Formation /limestone/

Q Pleistocene

E_2 Middle Eocene

E_3 Upper Eocene

Fig. N° 6.

SZANTNER 1970.

Since the surface of the karstic bedrock is rather irregular, the thickness of the ore varies capriciously from nil up to 30 metres. Within the marginal zone, where it is already pinching out, the ore may often be "perforated" by protruding clints or sometimes also by larger blocks, and thus the bauxitic stratum becomes discontinuous. The degree of karstification of the bedrock is generally moderate with occasional shallow dolines. The deposit is always flat on the roof-side and thins out gradually towards the margins. Immediately below and above the deposit there is a characteristic thin clay "envelop" consisting of bauxitic clays and argillaceous bauxites. Industrial-grade bauxite may form either a single continuous stratum or several detached thick lenticular bodies (e.g. Alsópere) within this "envelop".

Due to intense erosion preceding the deposition of the bauxitic sediment, the effect of tectonic movements anterior to bauxitization is difficult, if not impossible to decipher. The effects of younger orogenic movements are, however, rather easy to trace all over the occurrences. As far as tectonism is regarded the following main types of bauxite deposits could be distinguished:

1. structurally controlled
2. subsequently block-faulted
3. undisturbed, stratiform

Along the borders of stratiform deposits there may be occasional "satellite" deposits (smaller or larger lenticular bauxite bodies adjoining the main deposit).

Extensive **blanket-like deposits**

They are thin but of large horizontal extension and have elongated or near-isometric but lobate outline in the ground-plan. The most common dimensions are as follows: length (diameter) 0.5 to 1 km, thickness 0.5 to 2 metres on the average with a maximum of 5 to 6 metres. Blanket-like bauxite-sheets are not necessarily bound to negative elements of relief. The bed-rock surface, may it be flat or gently undulating, is uniformly covered by the thin bauxite-veil.

Since - unlike stratiform deposits - they are always thin and closely follow the irregularities of the footwall, they are not horizontal - or more exactly not flat - on the roof--side either.

Due to low percentages of industrial-grade ore in the generally thin blanket, the reserves of blanket-like deposits rarely exceed a few hundred-thousands of tons.

There is an apparent relation between the thickness and the grade of the ore, namely the thinner the deposit, the lower the grade seems to be. Coexistence with lenticular--type deposits or sinkhole-fillings is common.

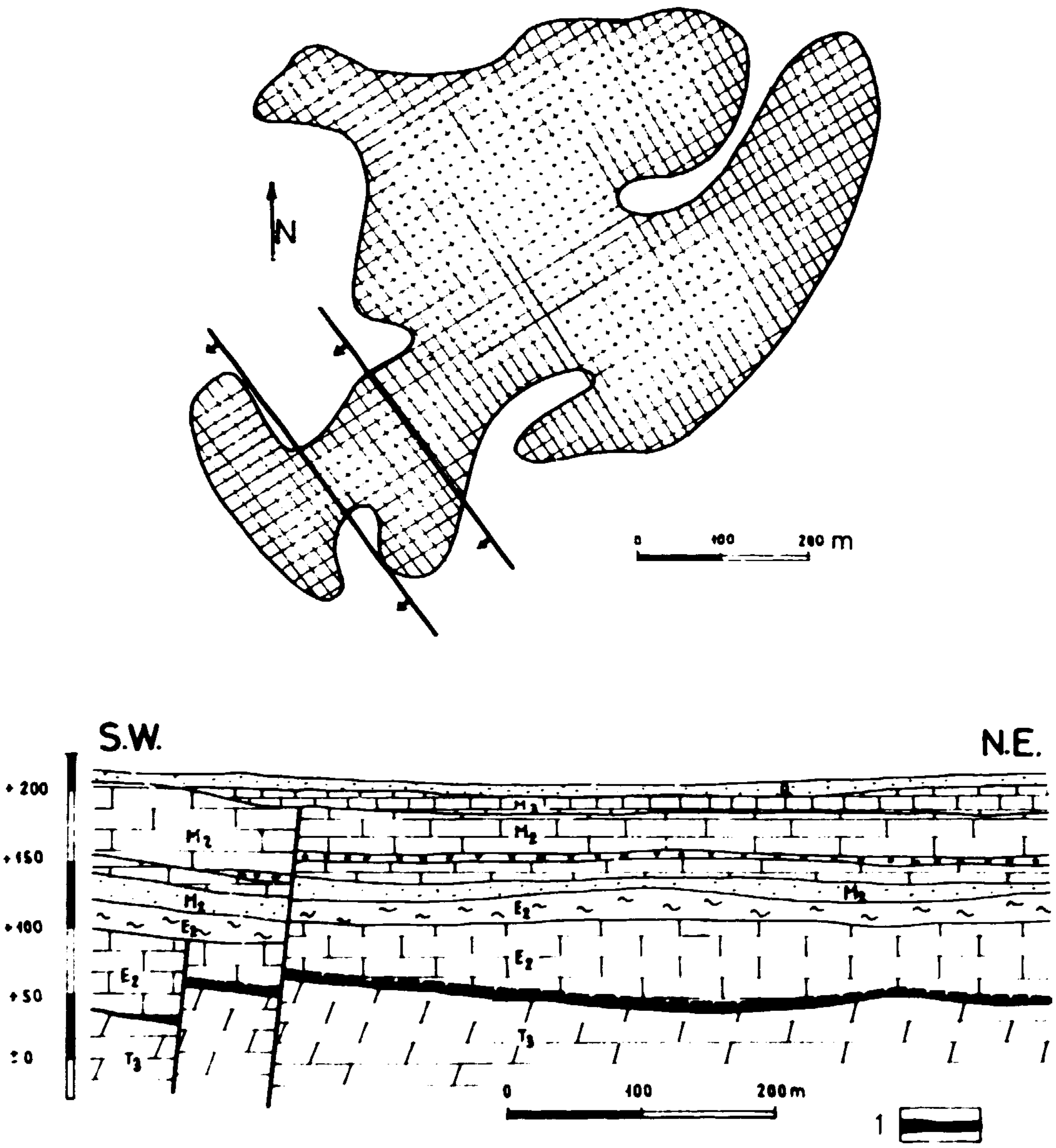
Blanket-like deposits are not very frequent in Hungary; the only examples known as yet are those at Nyiråd and Nagy-tårkåny.

Details of formation of blanket-like deposits are not yet disclosed, It seems to be highly probable, however, that they are the results of fortunate coincidence of circumtances of accumulation and denudation subsequent to the primary deposition of the bauxitic sediment, but preceding the sedimentation of the Eocene cover-beds.

Lenticular deposits

Most of the deposits of the Central Mts. belong to this group. With a diameter rarely more than 50 to 60 metres they are of rather small horizontal extension. In the ground plan they generally have a slightly lobate, roundish, oval or

EXTENSIVE BLANKET TYPE DEPOSIT NYİRÁD.



1. Bauxite
T₃ Upper Triassic/dolomite/
E₂ Middle Eocene /marl, limestone with clay and carbonaceous clays at the base/
M₂ Badenian/limestone, conglomerate and gravel
M₃ Sarmatian/limestone/
Q Quaternary/sand/

Fig N°7.

SZANTNER 1979

elongated outline (see Figs. Nos.8. and 9.).
They are bound to karstic dolines or sinkholes of moderate relative depth. Both grade and thickness of the ore is rather uniform with the thickness rarely exceeding 30 metres (4 to 18 m on the average). Thinning out of the ore towards the margins may be either gradual or abrupt. Grade is best in the center of the deposit, while at the bottom, on the tops and along the side-walls it is moderate to low, i.e. high-grade ore is enveloped by clayey bauxites and bauxitic clays all around.

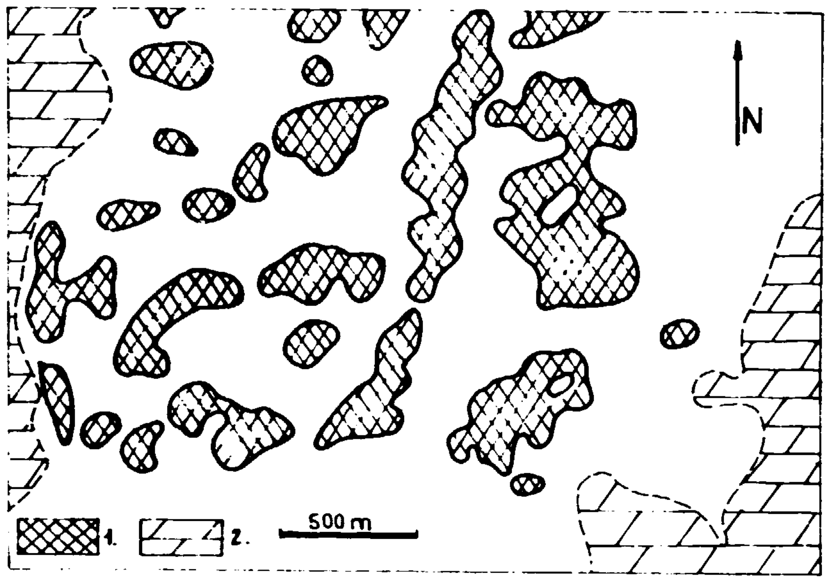
As to fine details of bedrock-morphology, the walls of the dolines, although sloping evenly towards the bottom, may prove to have a jagged outline when inspected closely. Ponors are rather common at the bottom of the dolines.

(It is to be noted, that the term "lenticular" is widely used by mining engineers in a wider sense, to denominate small-size bauxite-bodies of any genetic type, but this has nothing to do with the term used hereabove.)

Sinkhole-fillings

Deposits belonging to this type are of considerable thickness; their horizontal extension is limited and have a characteristic isometric, or slightly elongated outline in the ground-plan. They fill either deep regular funnel-shaped karstic cavities (=sinkholes or dolines) or large irregular depressions, at the bottom of which there may be outstanding steep karst-cones or towers. Sinkholes form generally by dissolution at fault-intersections with the development of ponors as the initial stage. Progressive dissolution may result in the coalescence of several sinkholes or dolines and - when filled with bauxite - to the formation of deposits of the complex sinkhole-filling type.

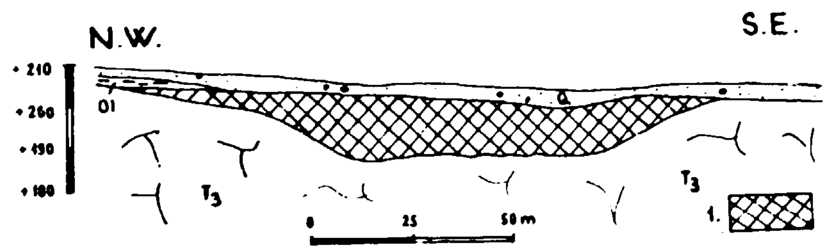
BAUXITE DEPOSIT CONSISTING OF LENTICULAR BAUXITE BODIES NYIRÁD



1. Bauxite
2. Outcrops of Upper Triassic dolomites

Fig. N° 8.

LENTICULAR DEPOSIT /NAGYTÁRKÁNY/



1. Bauxite

T_3 Upper Triassic/dolomite/

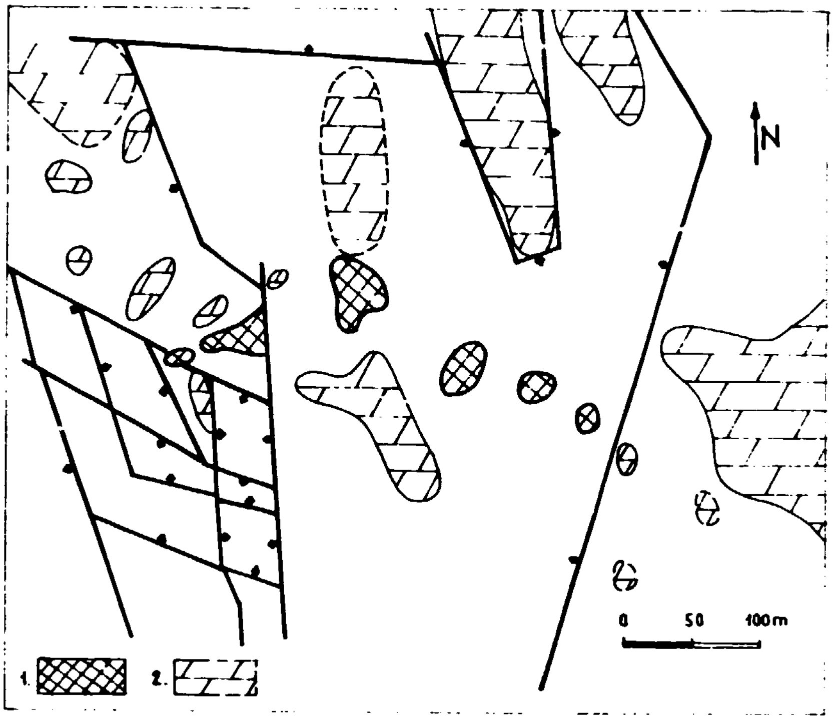
Ol Oligocene /clay/

Q Pleistocene/sand, gravel /

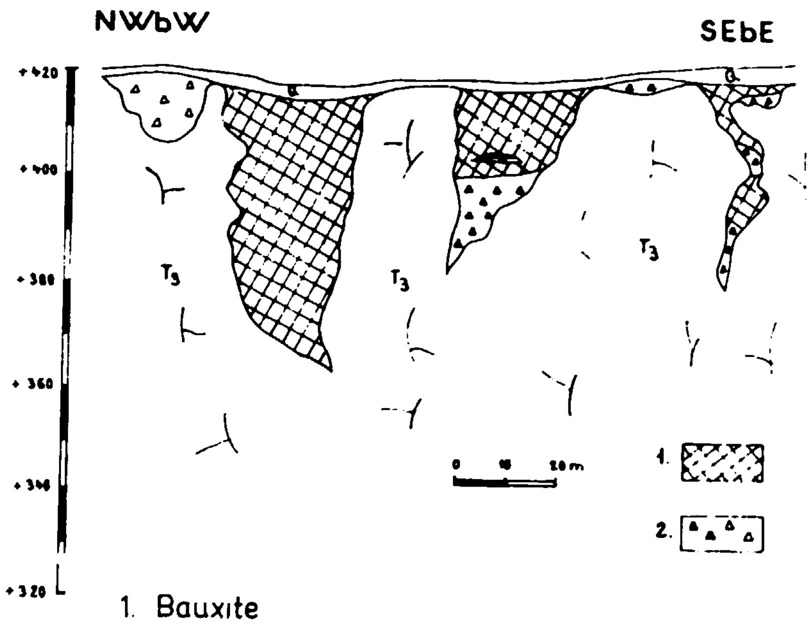
Fig. N° 9

SZANTNER 1979.

SINKHOLE FILLINGS. IHARKÚT



1. Bauxite
2. Outcrops of Upper Triassic /dolomite or dolomite scree/



1. Bauxite
2. Dolomite-scree, clayey dolomite-scree

T_3 Upper Triassic /dolomite/

Q Pleistocene /loess and Holocene reworked loessy soil/

Fig. Nº 10.   SZANTNER 1979.

Interbeddings of carbonate-debris of even several metres are rather common within the bauxite. They are essentially slumped-down blocks or small-size scree-like fragments of the weathered pulverulent bedrock washed in the sinkhole from the higher elevated surroundings. The ore is generally of high grade. Its amount depends on the dimensions of the sinkhole it fills, but rarely exceeds a million ton. When the ore is deposited into vertical chimney-like karst-holes, the deposit is called shaft-filling and is ranked as a subtype of sinkhole-fillings.

Tectonic-graben-fillings

Based on detailed study of orogenic phases preceding bauxite formation this taxon was proposed in 1961 by SZANTNER,F. and SZABÓ,E. (see Figs. Nos. 18., 19.).

The classical example of the tectonic-graben-filling is the Fenyőfő deposit discovered in 1959, but later on deposits of essentially the same appearance became known at several other Hungarian occurences too. (e.g. Bakonyoszlop). There are occurrences where tectonic-graben-fillings are prevalent, at other places, however, they occur occasionally only.

As it was pointed out by SZANTNER and SZABÓ the importance of structural control lies not only in the fact that "preformed" tectonic grabens provide excellent natural traps for the accumulation of bauxite but also in the obvious role that tectonism plays in the protection against subsequent erosion.

Bauxitic material laid down in deep tectonic grabens may survive erosion even if the resistant cover is completely striped off. The presence of bauxite is therefore to be attributed at many places simply to "protective" tectonism. (Further relationships between tectonic graben-like structures and bauxite deposits are discussed in Chapter 2.1.2.3. in details).

Since within the graben conditions are extremely favourable for bauxitization, tectonic graben fillings are generally of high grade, sometimes right throughout the whole of the graben.

The ground space of the grabens is medium-size or small. They are bordered by fault lines on all sides. The transition from bauxite towards the side-walls is abrupt, there is no gradual thinning out at all (see Fig.No.11.).
The thickest of all Hungarian deposits belong to this type.

Despite their small areal extension, deep tectonic grabens, completely filled by bauxitic material, may have reserves as large as several millions of tons.

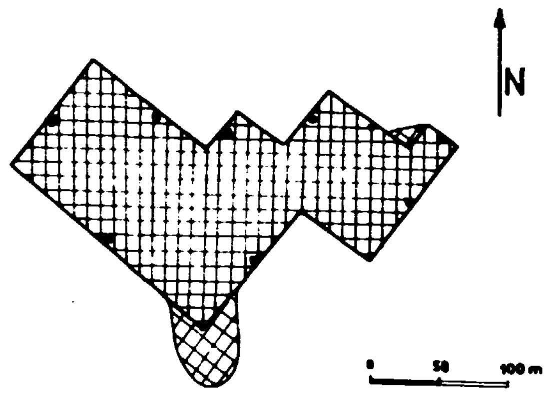
Lenticular deposits may often be bordered by fault lines on one or two sides. These asymmetric structures can be taken for the combination of the lenticular and tectonic-graben--filling deposits. Both thickness and areal extension of deposits bound to these complex structures exceed that of the simple lenticular deposits.

Tectonic-graben-fillings are the results of blockfaulting immediately preceding the deposition of the bauxitic material. At places, where due to denudation, older structures had already been faded when sedimentation began, there were no grabens - i.e. no traps - to receive the bauxitic material, and thus no graben-filling deposits could form.

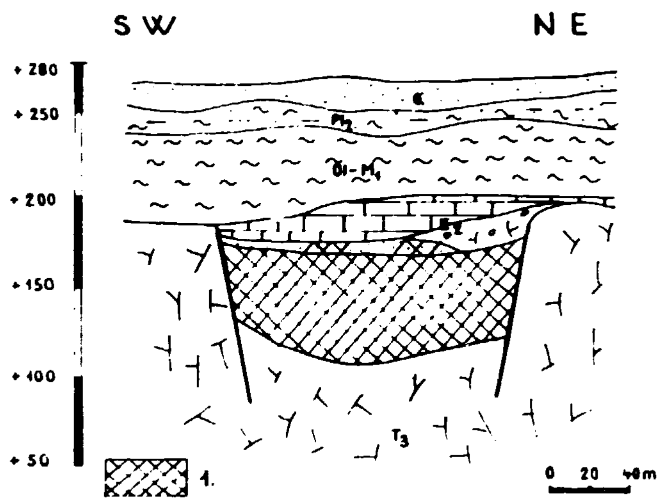
Sinkhole-fillings combined with tectonic-grabens

Deposits belonging to this type are essentially sinkholes coexisting with and partly passing over to tectonic-grabens (Fig.No.12.).
The establishment of the taxon is justified by the fact that deposits connoted by it, do not bear the characteristics of either of the simple types. They differ from those both by

TECTONIC GRABEN-FILLING. FENYŐFŐ.



1. Bauxite
T_3 Upper Triassic /dolomite/
E_2 Middle Eocene



E_2 /bauxitiferous sand, dolomite-scree, with quartzite-pebbles, limest/

$Ol-M_1$ Oligocene-Lower Miocene /varicoloured fluviatile sequence/

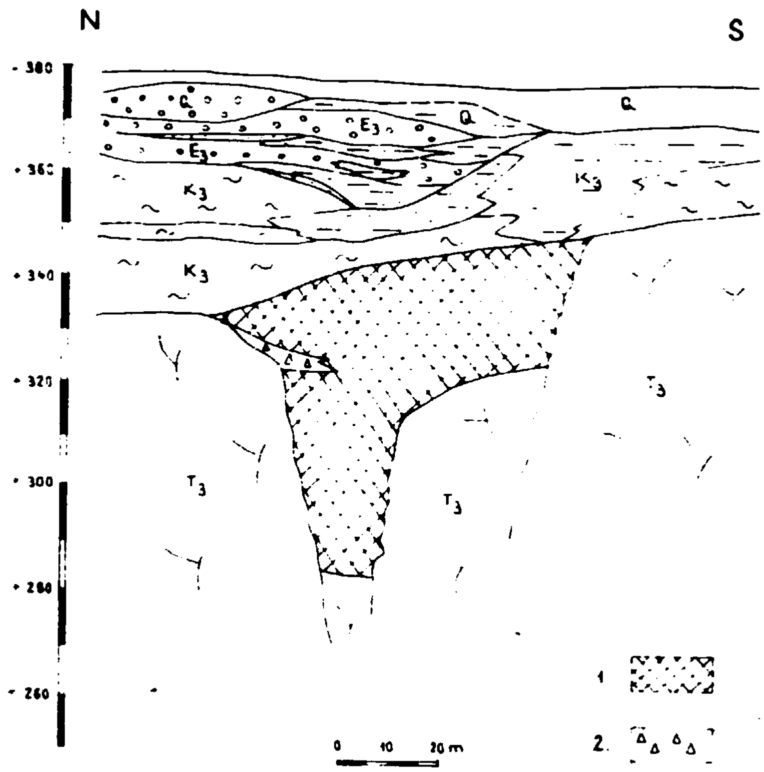
Pl_2 Upper Pannonian /argillaceous marl/

Q Pleistocene /wind-blown sand/

Fig. N° 11.

SZANTNER-SZABÓ 1962.

COMPLEX KARSTIC-TECTONIC GRABEN. IHARKÚT.



1 Bauxite
2 Dolomite-scree
T_3 Upper Triassic dolomite
K_3 Upper Cretaceous fluviatile sequence/Csehbánya Formation/
E_3 Upper Eocene/conglomerates, clays/
Q Pleistocene/gravel, clay and loess/

Fig N° 12

SZANTNER 1979

morphology and general geology, with the difference being brought about by the joint effect of tectonism and karstification.

Classical examples of these complex karstic-tectonic grabens were described at Iharkut, where intensely karstified tectonic grabens filled by high-grade bauxites are known.

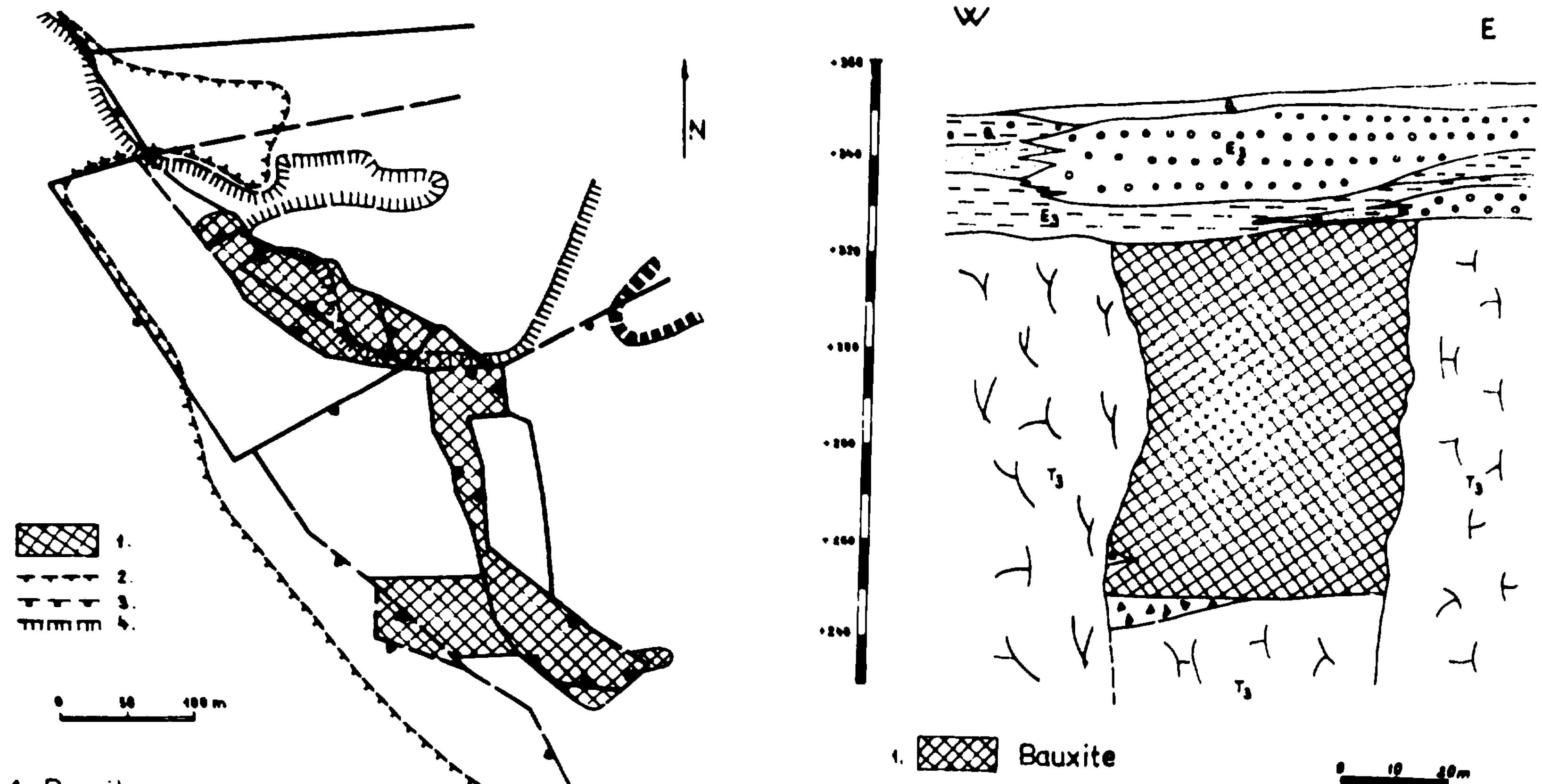
As to areal extension, karstic-tectonic grabens are of medium size, but considerably deeper than any of the simple types. The imprints of tectonics are at most places dimmed by intense partly subsequent karstification. The order of magnitude of reserves bound to karstic-tectonic grabens is around one million ton per deposit.

Canyon-fillings

Deposits filling canyon-like karstic gorges are not very common in Hungary. The only examples were described from Iharkut (Fig. No.13.).
The traps are as narrow as 30 to 80 metres across, here, but as to depth they may exceed even the 100 metres, with the side-walls descending almost vertically to the bottom. In the ground-plan they usually follow a characteristic NW-SE oriented zig-zag pattern, with lobular enlargements or deepenings at places. Their horizontal extension is generally around 500 metres. The distinct NW-SE orientation suggests structural control coupled with the obviuosly intense karstification.

It seems highly probable that part of the karstic canyons enclosing these unique type of deposits were of collapsogenic origin (i.e. they are essentially collapsogenic dolines formed by collapse of structurally controlled underground dissolution--cavities).

CANYON-FILLING. IHARKÚT



1. Bauxite
2-4 Boundary of potential cover-beds
2. Senonian
3. Middle Eocene
4. Upper Eocene

Fig. Nº 13.

1. Bauxite
2. Dolomite-scree

T_3 Upper Triassic /dolomite/

E_3 Upper Eocene /clay, conglomerates, clayey sandstone/

Q Quaternary /clay, gravel, loess/

BAUXITE POCKETS. NAGYHARSÁNY. SOUTH HUNGARIAN BAUXITE BELT

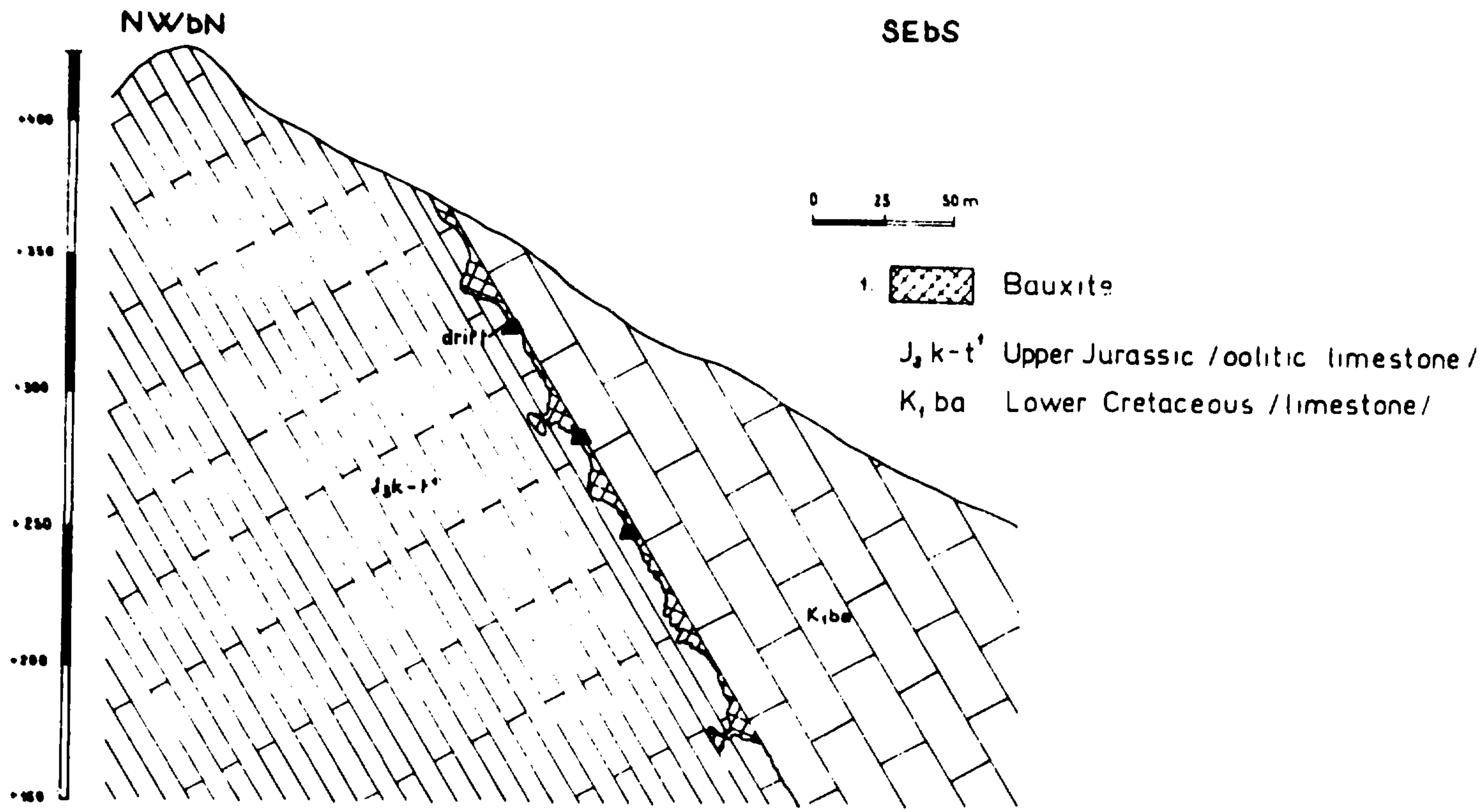


Fig N° 14.

KNAUER 1979.
(After Noszky, Fülöp and Bárdossy)

Bauxite-pockets

Bauxite-pockets are essentially small lenticular bauxite bodies. They fill small-scale (3 to 10 m deep) dissolution holes of an uneven karst-planation surface (practically a rough clint-field). (Fig.No.14.). In the cross section they form disconnected string-like successions but in the ground plan they turn out to be nothing else than a thin veil with randomly scattered 10 to 40 m long and 3 to 10 m deep "pockets" "protruding" into the underlying bedrock.

Bedrock-morphology

All the above described depositional types clearly demonstrate that bedrock morphology is of vital importance in karst-bauxite geology. The surface of the bedrock has been the subject of more or less intense karstification in either of the cases. Grade of dissection of the karstic surface as well as the relative differences of relief or the frequency of the individual morphological elements are different in each group of deposits. There are occurences characterized by deep, almost vertical-sided sinkholes; at other places, however, the ore may fill slight, less than 30 m deep dish-like depressions. Karstic morphological elements of any degree of maturity may well coexist and what is more, they may combine also with pure tectonic forms (like in the group of karstic-tectonic graben--fillings), thus giving rise to an almost infinite number of possible configurations.

Detailed information collected during the last few years of prospecting facilitated the analytical study and tentative classification of the morphotypes of the bedrock (SZABÓ,E. (1975). (Fig. No.15.).

From the point of view of formation of potential bauxite--traps morphological elements of the bedrock can be classified essentially as

convex and
concave

units. According to origin each of these classes can be divided on to a group of

a) erosional-dissoulutional forms, and
b) tectonic forms.

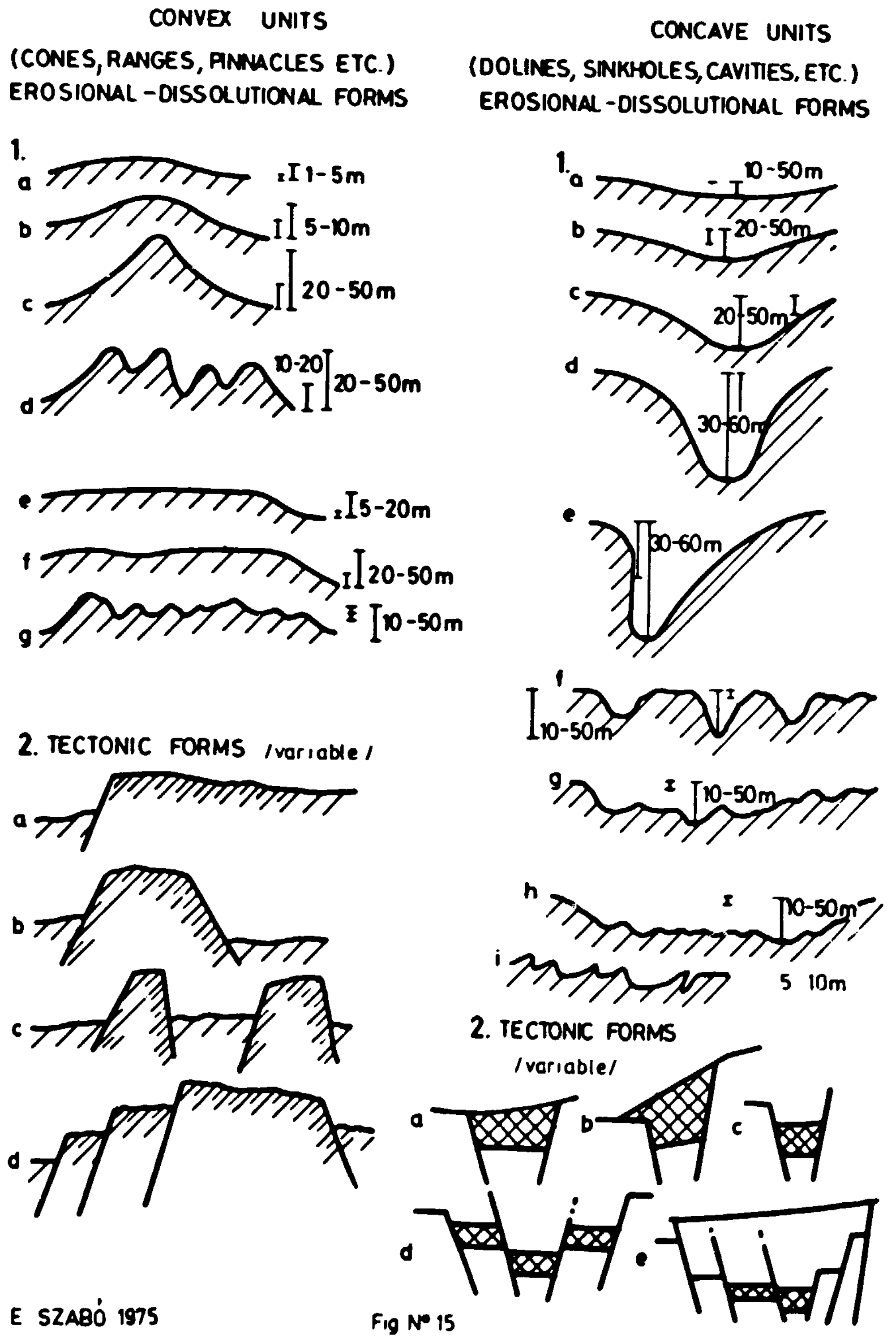
Large scale structures most likely to contain bauxite deposits had already been discussed in the foregoing paragraphs (cf. also with Figs.No.8.-14.). Fine details of bedrock-morphology and small-scale but important morphological units recognizable within, or independent from major structures are shown on Fig.No.15.

2.1.2.3. Tectonics

Today the role of tectonism in the formation of karstic bauxites is a commonplace already, but the exact nature of structural control seeks for explanation in most cases.

As to tectonics on the regional scale structural geological information is produced first of all by the State Oil Company (drill cores) and - subordinately - also by other geological activities (i.e. prospecting for non-bauxitic minerals; small-scale general geological mapping; etc.). Fine details of structure are disclosed, however, by bauxite prospecting itself during the stages of reconnaissance mapping, proving drilling, etc.

THE MOST COMMON MORPHOLOGICAL FORMS OF BEDROCKS BENEATH BAUXITES IN HUNGARY



E SZABÓ 1975

Fig N° 15

The most striking structural feature of Hungary is the zonal character of its underground. It was recognized during the fifties and early sixties by SZALAI,T., VADÁSZ,E., KŐRÖSSY,L., WEIN,GY. and others that the basement of the Pannonian basin is built up of alternating zones of crystalline (igneous and metamorphic) and sedimentary complexes all striking from SW to NE parallel or subparallel to each other. They assumed that this structural make-up cannot be accidental and postulated SE-NW compression and overthrusting from the SE. Since there was no plate tectonics at that time the reasoning stood yet on the basis of classical tectonics.

Based on latest results of geophysical research a new up-to-date tectonical synthesis was elaborated during the last few years. The details of this synthesis will of course be subject to further refinements when additional structural geological information becomes available, but up to now it is the most widely accepted interpretation of the structural features of the country. According to WEIN the tectogenesis of the Pannonian basin took place in five successive stages (Fig.No.16.).

Each zone is divided from the others by major NE-SW striking lines of dislocation which played an important role in the development of the zoning. Bauxite deposits of the Transdanubian Belt are confined to the so called Bakony-North Gömör zone built up mostly of Mezozoic rocks, while the South Hungarian Bauxite Belt falls on to the area of the Bihar-Villány zone. In the easternmost continuation of this zone, where it passes over Roumanian territories there are the Padurea Craiului bauxites which by stratigraphy and mineralogy are very similar to what we have at Nagyharsány in Hungary. The areas of both Bauxite Belts were subject to manyfold tectonic disturbances during the Mezozoic and Cainozoic eras. The effects of orogenic movements that took place from the Mezozoic up to the Quaternary period (Pleistocene) may be studied either

GEOTECTONIC EVOLUTION OF THE TETHYAN AREAS IN THE CARPATHIAN BASIN. THEORETICAL SKETCH (AFTER WEIN, GY.) 1978.

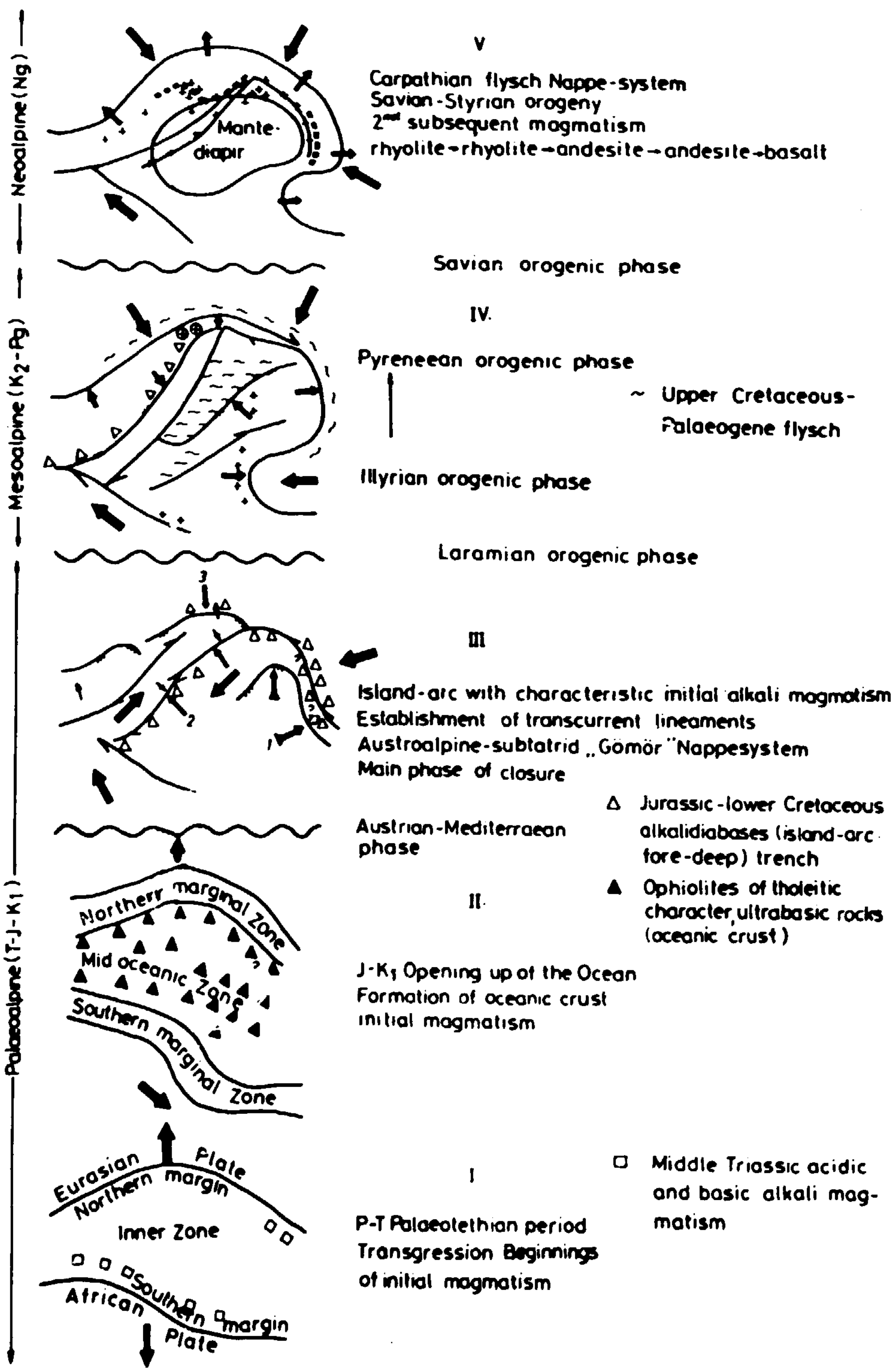


Fig Nº 16

directly in deposits where mining operations are going on, or indirectly by investigating drill-cores or adapting geophysical information.

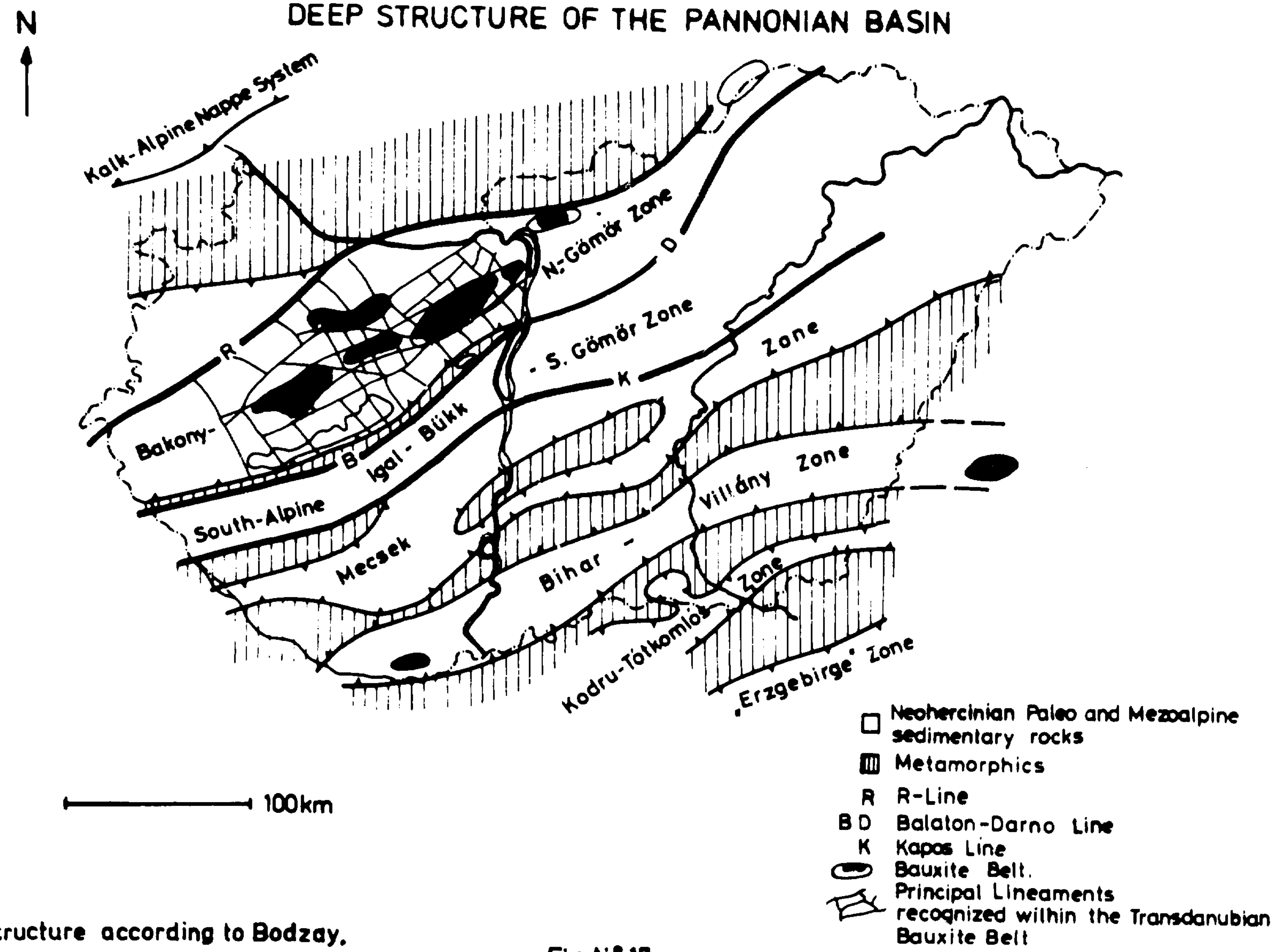
Elements of tectonics recognized within the bauxite occurrences are rather variegated. They undoubtedly worked as controlling agents during both the accumulation and preservation of bauxites. The extent to which tectonism may be held responsible for the actual grade and quantity (i.e. thickness) of the ore is however, much disputed and can be find out in every single case by careful detailed examinations only.

Despite the overall compressional character of the basement complex of Hungary (cf.Fig.No.17.) most tectonic elements to be recognized within the tectonic framework of the bauxite occurrences are of tensional origin. This apparent contradiction can be elucidated by taking the followings into consideration. The principally compressive structure has been subject to several stages of younger tectogenesis, part of which was clearly of tensional character, and it was the effect of these younger movements that produced the structures we recognize and study as bauxite traps.

Faults are dipping rather steeply (50 to 85^{o}), and being arranged nearly at right angles with respect to one another (NE-SW; SE-NW) give rise to a characteristic trellis pattern almost all over the Central Mountains. At places also fault-strikes of N-S or E-W direction occur but subordinately only. Of course the elements of compression are also recognizable, in fact they may become even predominant at places. They are represented mostly by thrust-faults and high-angle reverse--faults resulting in characteristic imbricate (shingle-block) structures.

Most bauxite deposits of Hungary are bound to moderately or intensely faulted structures. The intensity of tectonic

DEEP STRUCTURE OF THE PANNONIAN BASIN



Deep-structure according to Bodzay.

Fig. N° 17

Compiled by Szabó, E.

movements giving rise to block faulting can be demonstrated by the frequency of recognizable faults per unit area. In the Central Mountains this figure may reach even the 250 per square kilometres at places.

The throw of most faults varies between 10 to 200 metres but throws as much as 500 metres were also observed at some places (=mostly major fault-lines along the margins of deposits that fill structural traps).

Since the majority of faults has been subject to several renewals during younger phases of tectogenesis, their age is rather difficult - if not impossible - to establish.

Due to repeated dislocations the structural setting of most Hungarian deposits is intricate enough to raise severe difficulties to both prospecting and mining. To overcome these difficulties detailed structural investigations and the analysis of the effect of the individual orogenic phases are inevitable during the early stages of prospecting already. Structural analysis is facilitated by the fact that - justified by the capriciously changing grade and thickness of the ore - proving drilling has to go on sometimes with a spacing as close as 50 metres. Areas of detailed exploration are therefore in an exceptional position: the amount of structural information is mostly sufficient here to allow the identification of the imprints of both older and younger orogenic movements; the exact location of faults, and the establishment of the intensity of the individual orogenic phases. The quality of structural information provided by any stage of exploration depends, however, also on the geological make-up of the area concerned. It is quite natural therefore that, as to reliability, the results of structural geological studies carried out on different deposits will be fairly different. Similarly also the possibilities of differentiation between the effects of the individual orogenic phases will not be equal either.

The effects of orogenic phases recognized up to now within the most signficant Hungarian bauxite deposits are demonstrated by Fig.No.18. (SZANTNER,F. and SZABÓ,E. 1970).

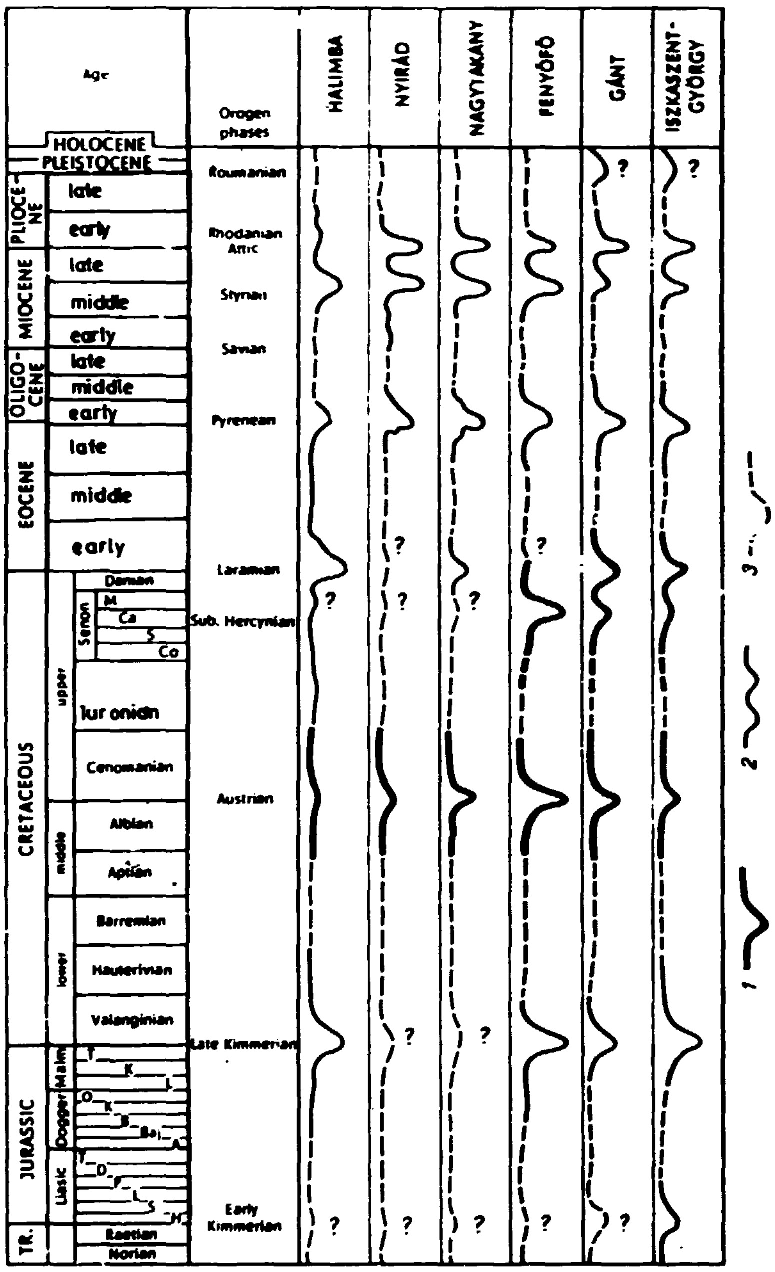
During the last few years systematic investigations were carried out in order to analyse the effects of block-faulting on the accumulation of the bauxitic sediments; on the size, shape and structural position of the bauxite bodies; on the grade and amount of reserves and on the chances of protection against subsequent erosion.

Fig.No.19. summarizes the principal instances of simple tensional block-faulting during various stages of tectogenesis of the main bauxite occurrences, and the possible combinations of block structures.

From the point of view of the formation of bauxite traps it is the "prebauxitic" orogenic phases (preceding the accumulation of bauxitic sediments) which are of crucial importance. They surely have exerted a profound influence also on the grade and amount of reserves trapped in the "pre-formed" block-structures, and helped to preserve them from subsequent erosion.

The above statements are demonstrated by selected geological profiles across some important Hungarian deposits and by two block-diagrams shown on Figs.Nos. 20.-23. and 24. respectively.

OROGENIC PHASES AND THEIR INTENSITY RECOGNIZED IN THE PRINCIPAL BAUXITE OCCURRENCES OF HUNGARY

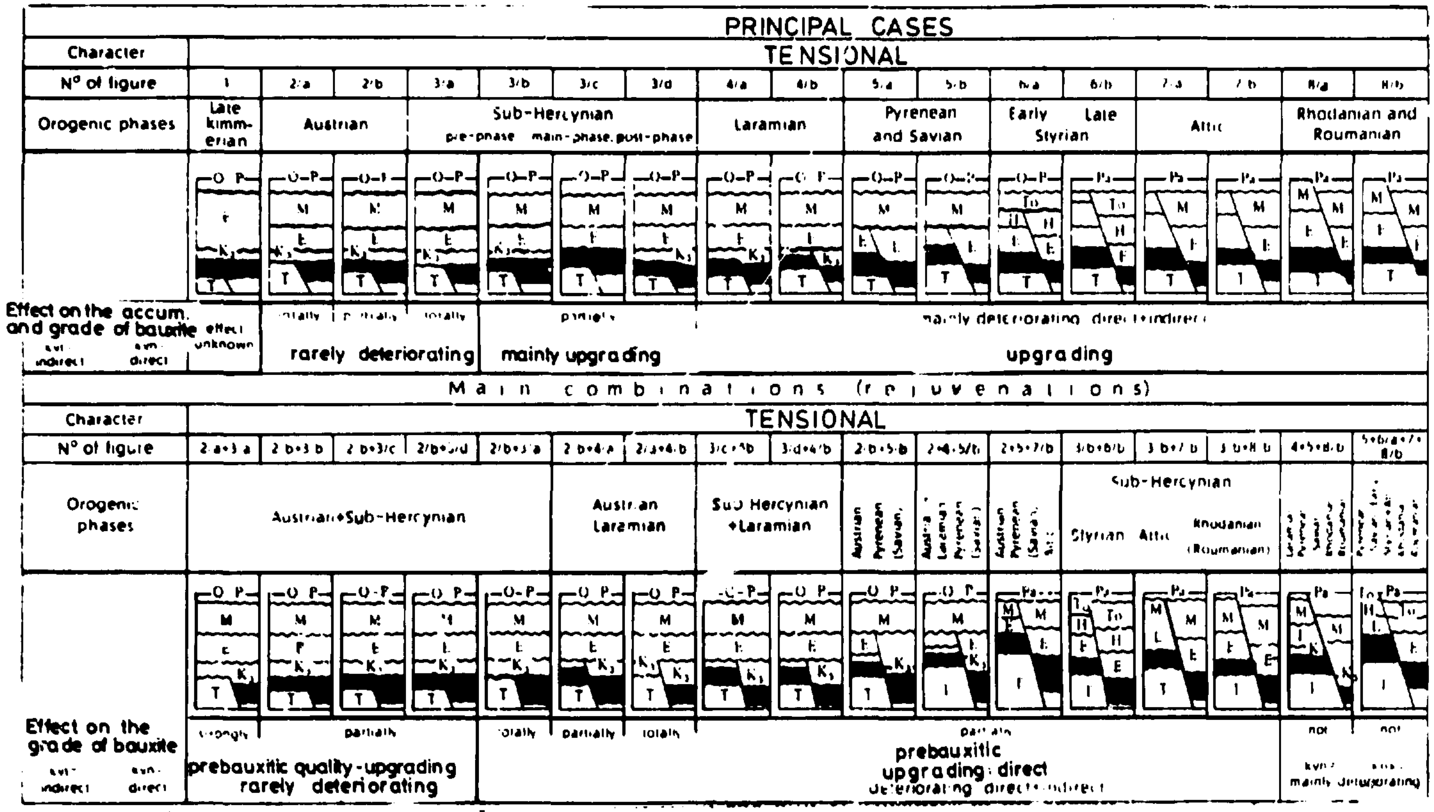


1. PREBAUXITIC OROGENIC PHASE
2. OROGENIC PHASE WITH NO EFFECTS ON THE ACCUMULATION OF BAUXITES
3. UNCERTAIN OROGENIC PHASE

Fig Nº 18.

F. SZANTNER- E. SZABÓ. 1970.

PRINCIPAL CASES OF SIMPLE TENSIONAL BLOCK FAULTING AND THE POSSIBLE COMBINATIONS OF BLOCK-STRUCTURES

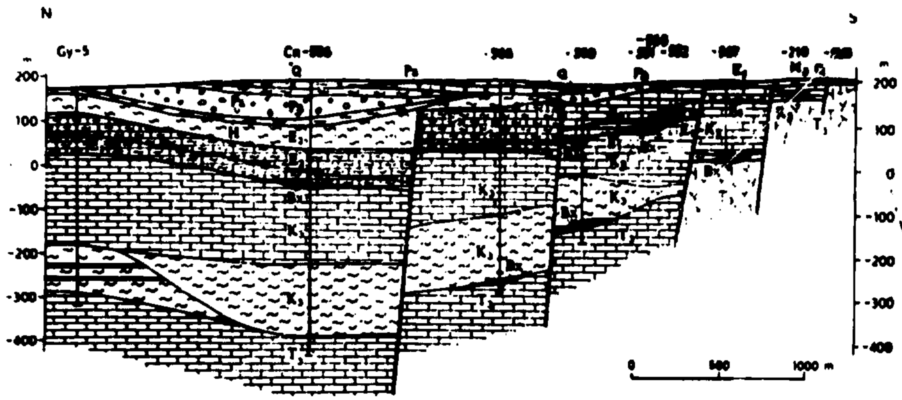


O–P = Pleistocene and Pliocene formations, Pa = Pannonian formations, M = Miocene formations, To = Tortonian formations, H = Helvetian formations, E = Eocene formations, K = Upper Cretaceous formations, black = Bauxite complex, T = Triassic formations, sinuous line = unconformity

Fig N° 19

F SZANTNER-E SZABÓ 1970

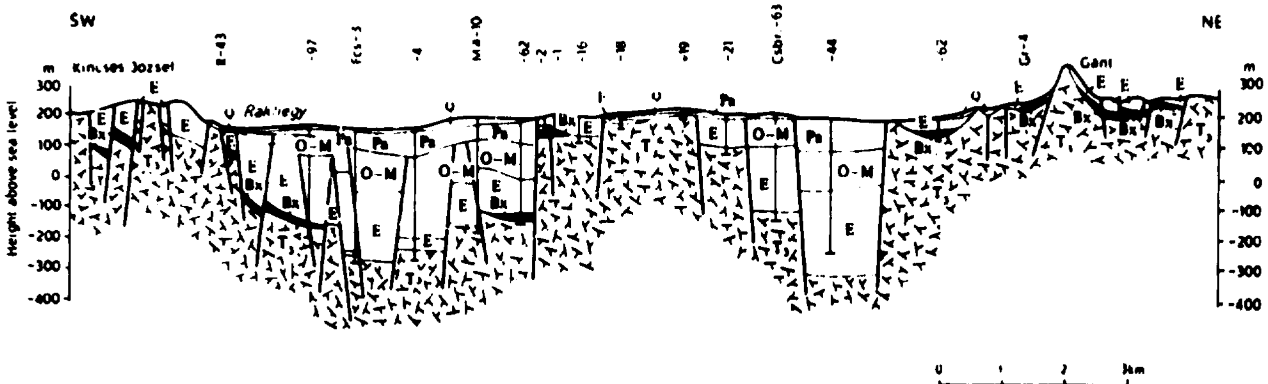
GENERAL GEOLOGICAL SECTION ACROSS THE NAGYTÁRKÁNY-CSABPUSZTA BAUXITE OCCURRENCE



Q = Pleistocene clay. Pa = Pannonian marl. M = Miocene gravel, clay, limestone detritus. E_2 = Middle Eocene marl, limestone, marly limestone, E_1 = Lower Eocene limestone, marly limestone, lignitic clay. K_3 = Upper Cretaceous limestone, marl, coal-bearing complex, black: bauxite. T_3 = Upper Triassic limestone, dolomite

Fig.No.20.

GENERALIZED TECTONIC PROFILE ACROSS THE ISZKASZENTGYÖRGY AND GÁNT BAUXITE AREAS



Q = Pleistocene sandstone, loess, gravelly clay, Pa = Pannonian clay, O-M = Oligo-Miocene clayey marl, sandy clay, sandstone, marl, E = Eocene clayey marl, limestone, Bx = Cretaceous bauxite, T_3 = U = Upper Triassic dolomite

Fig.No.21.

GENERALIZED TECTONIC PROFILE ACROSS THE HALIMBA BAUXITE AREA

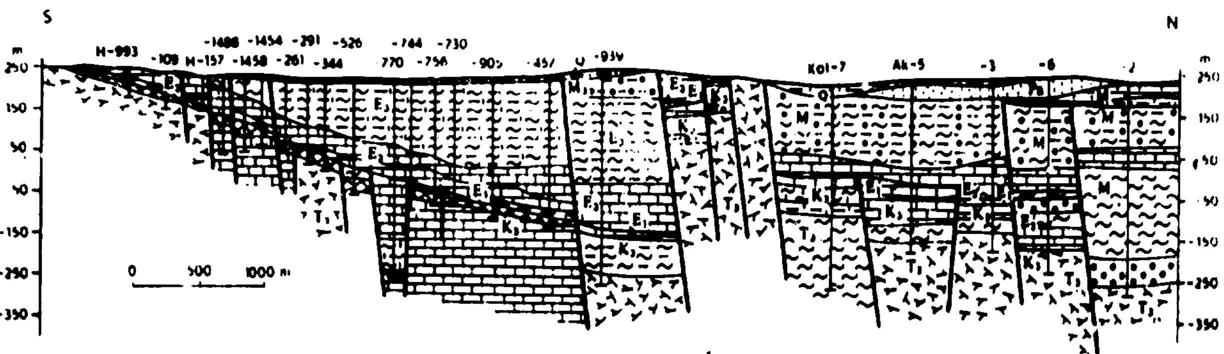
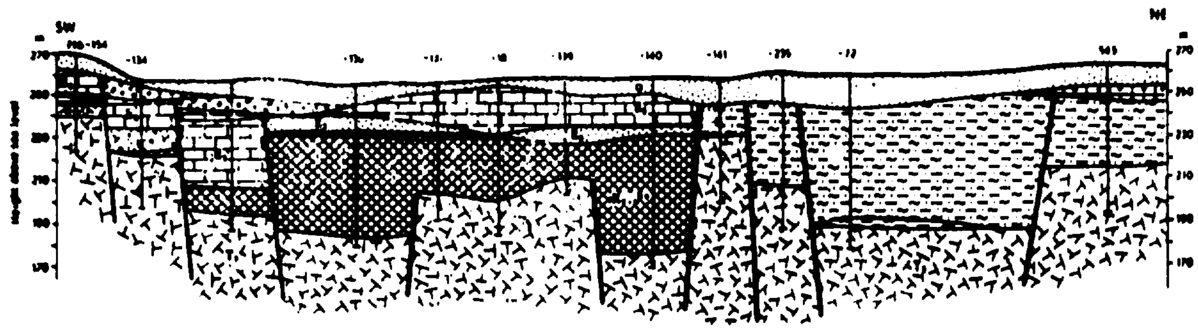


Fig.No. 22.

SZANTNER, 1970.

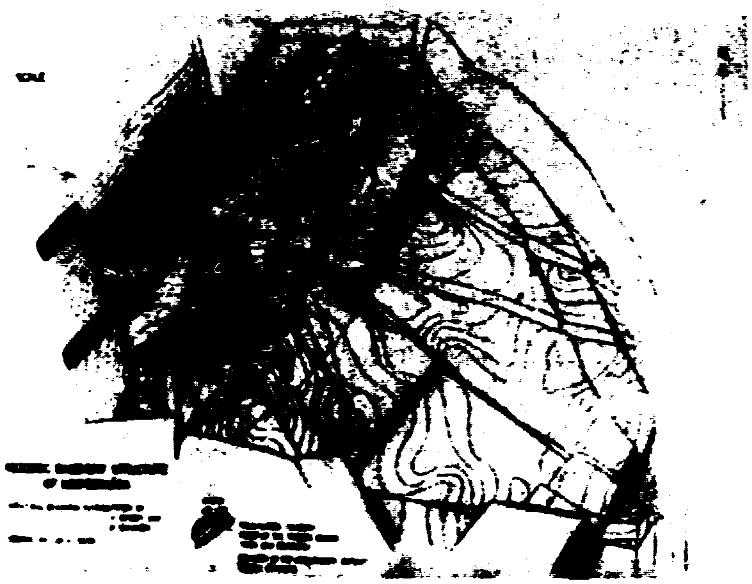
PREBAUXITIC AND YOUNG FAULTS AND THE COMBINATIONS OF THE TWO

FENYŐFŐ BAUXITE OCCURRENCE



Q = Pleistocene sand, Pa = Pannonian clayey marl, clayey sand, gravel, M_3 = Upper Miocene silt, grit, E_2 = Middle Eocene limestone, sand, limestone blocks, limestone debris, K_{2-3}^{bx} = Cretaceous bauxite, T_3 = Upper Triassic dolomite, dolomite debris

Fig.No.23.



2.1.2.4. Grade and thickness of the ore

As it was mentioned in the foregoings, both grade and thickness vary capriciously throughout the deposits. Despite the apparent capriciousness close inspection may, however, reveal some logic in the variations in most ore-bodies. In the case of lenticular and stratiform deposits variations of thickness for instance can be taken for a consequence of a gradual pinching out towards the edges on the one hand and of the hollow-filling nature of the ore resting on the uneven (alternately convex and concave) surface of the bedrock on the other. When subject to denudation short before the deposition of the cover beds, bauxites, especially the more resistant (harder) ones, may gain a lofty appearance and thus their contact towards the roof may become distinctly convex.

Variations of thickness of deposits filling tectonic--grabens or deep canyon-like structures are generally structure-controlled (=abrupt changes along fault-lines). The ore, although often extending over the bordering fault-lines, thins out abruptly above the upthrown block and forms thin tongues adjoining to the main ore-body. Abrupt changes of thickness, especially along the margins of the deposits are common also in the sinkhole-filling types. Changes of thickness due to the undulating bedrock-surface are also common in this groups.

Variatons of thickness are even more capricious in deposits built up of adjoining bauxite-bodies of different depositional types.

The situation seems to be even more complex when considering the variations of grade as a function of thickness. Grade is - in general - lower along the margins than in the centre of the deposit, and this is true both in the lateral and in the vertical sense, although the deterioration of grade of the uppermost parts of the deposit is mostly of secondary origin. Degradation by secondary pyritization, may occasionally permeate the whole section, right down to the footwall-contact.

It seems to be a general rule that the grade of stratiform deposits decreases only where the stratum is pinching out. Occassionally, however, rather mighty uninterrupted intercalations of low-grade ore were also observed right within the interior of stratiform deposits. There are also examples of high-grade ore occuring in the form of smaller or larger lenticular bodies, within extensive strata of low-grade bauxite (e.g. Alsópere).

In some deposits of the Szőc occurrence a rather exceptional pattern of distribution of high-grade and low-grade ore can be observed: it is only the uppermost 1 or 2 metres of the 10 to 20 metres thick bauxite body which by grade reaches the limits of industrial utilization here. Deposits filling tectonic-grabens or belonging to the combined tectonic-karstic graben-filling type are generally high-grade right throughout the ore-body. Deterioration of grade is restricted to a rather narrow (1 to 2 m) zone along the bordering fault-lines.

Degradation of the ore along young fault-planes seems to be an unescapable aftermath of faulting in any of the depositional types discussed in the previous chapter. The pattern of grade variations in reworked deposits is generally similar to that of the primary ones especially when contamination with non-bauxitic material and resilification had not been too intense. There are also some exceptions however; lower but yet industrial-grade ore may occur in the form of lenticular bodies or pockets embedded in the low-grade matrix of reworked deposits. At some places high-grade ore occurs as boulder-, pebble-, or sand-size contamination in a predominantly kaolinitic clayey matrix. The pebble- or sand-size material may consist of loose detached pisolithes or ooids of the primary bauxite. Depending on the amount and grade of the clastic material the average grade of admixtures like this may be at places even equal to that of some industrial-grade primary bauxites. The grade of conformable lenticular bodies of reworked bauxites deposited into continuous marine sequences may be devoid of any deterioration (partly because the distance of transportation of these materials had probably been less than 1 km).

As to the relation between grade, thickness, morphology and genesis of the deposit the following general rule can be established:
The more favourable the conditions of accumulation and leaching-out had been within the given structural, karstic or combined structural-karstic trap, the better and thicker the deposit could have grown in it.

Because of the multivariable nature of the function, mathematical modelling of the above interrelation is rather difficult, if not impossible. Graphic representation of statistical amounts of data collected during the exploration of one or another of the large occurrences may however reveal some trends in the variations of thickness and grade. As an example see the thickness vs grade diagram of five lenticular ore-bodies of the Iharkut occurrence, compiled by SZABÓ, E. (1978). (Fig.No.25.).

DIAGRAM SHOWING THE CORRELATION BETWEEN THE AVERAGE THICKNESS AND GRADE OF BAUXITE /IHARKÚT/

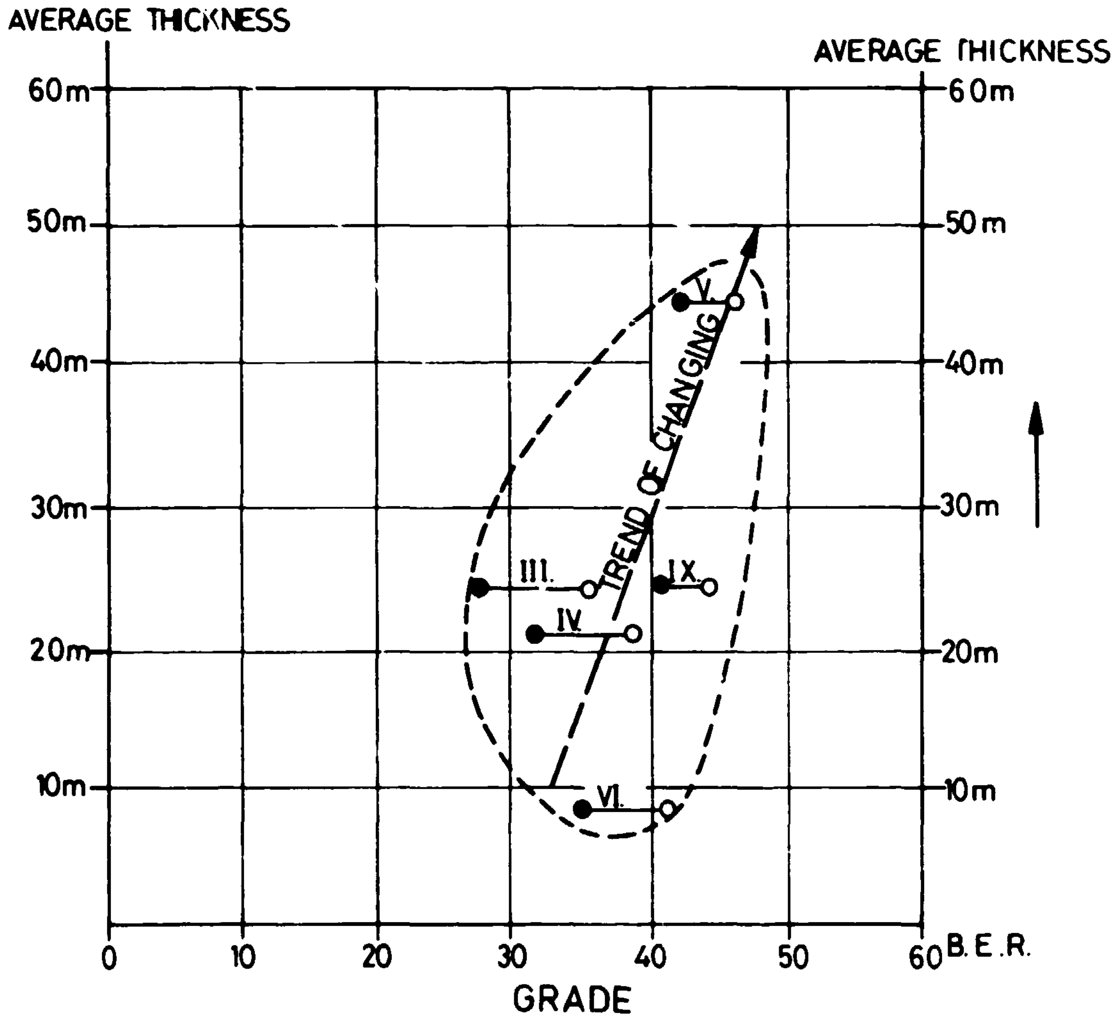


FIGURE OF MERIT: 1.-2.

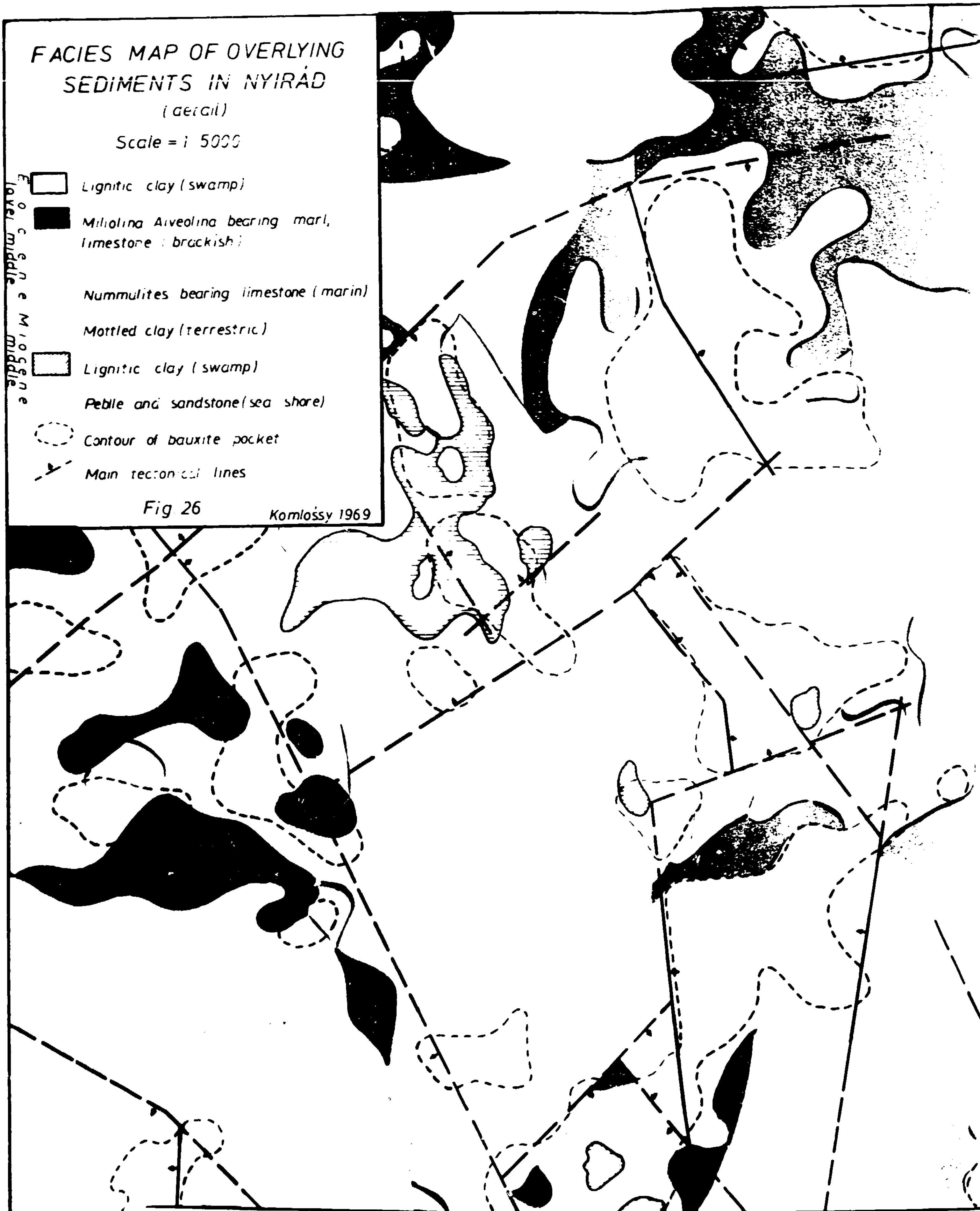
1- o "OLD BASIC EQUIVALENT VALUE" = $Al_2O_3 - 2SiO_2 - (CaO + MgO)$

2- ● "NEW BASIC EQUIVALENT VALUE" = $Al_2O_3 - 3SiO_2 - (CaO + 2MgO)$

I...... IX. NUMBER OF BAUXITE LENSES

COMPILED BY : E. SZABÓ 1978

Fig. 25


FACIES MAP OF OVERLYING
SEDIMENTS IN NYIRÁD
Scale = 1 : 5000
Eocene middle level
Lignitic clay (swamp)
Miliolina Alveolina bearing marl, limestone (brackish)
Nummulites bearing limestone (marin)
Miocene middle
Mottled clay (terrestric)
Lignitic clay (swamp)
Peblle and sandstone (sea shore)
Contour of bauxite pocket
Main tectonical lines
Fig 26
Komlóssy 1969

SECTION 1

SECTION 2

Grade seems to be correlated, however, not only with thickness but also with the facies of the immediate overburden. Because of their role in protecting the ore against subsequent erosion primary coverbeds (i.e. Cretaceous and Eocene Formations) had always been subject to careful investigations of the explorers, right from the beginnings of prospecting on. At first these investigations were restricted to the establishment of the presence or absence of the Eocene formations only. Later on, however, when it turned out that the age of the immediate cover is by far not indifferent from the point of view of the grade and quantity of the ore beneath (the sooner the ore became buried the lesser the probability of subsequent erosion had been) also the precise stratigraphic position of the overburden became important to determine.

In the proving drilling stage the interval of the drilling grid is already close enough to compile detailed facies-maps on the basis of drill-core information. It was the Iszkaszentgyörgy Rákhegy Final Report on the basis of the facies maps of which the authors realized first, that some well-pronounced correlation seems to exist between bauxite and certain overlying formations (namely the coal-seams of the Eocene coverbeds): the inner parts of the ore-bodies were covered invariably by coal-seams, while above the margins there was nothing but yellowish or mottled clays in the roof (BKV 1965. unpublished reports). According to KOMLÓSSY,GY. not only the presence but also the grade of the ore can be predicted on the basis of the facies of the coverbeds. His Nyirád investigations proved namely that high-grade reserves are found always beneath the Lower- or Middle Eocene coal-seams, whereas the lower- or medium-grade ore is covered generally by non-lignitiferous formations. Facies and age of the immediate cover beds are shown by Fig.No.26.

Based on careful investigation of core-samples of several bore-holes at the Bakonyoszlop area KNAUER,J. and TÓTH,K. realized that all bauxite traps are characterized by a well-defined facies-climax in the coverbeds. The Eocene sequence above the traps proved to be quite different from that above the bare unperspective dolomite surface (in KNAUER,J. - PÓPITY,J. 1972.).

Stimulated by the above results systematic research began in the Sümeg-Csabpuszta and at the Bakonyoszlop-Dudar areas. At Sümeg-Csabpuszta the interrelation between the location of bauxite-traps and their Upper Cretaceous (Senonian) coverbeds was investigated by KNAUER,J. and Mrs.KNAUER-GELLAI,M.B. (1978), while at the Bakonyoszlop-Dudar and Nagytárkány areas (where the ore is covered by Eocene sequences) facies analysis were carried out by TÓTH,K. Detailed methodological description of these facies analitycal work was published in the proceedings of the IVth International Congress of the ICSOBA (Szantner et al.) in 1978.

For the sake of better understanding the results and significance of some of the referred facies-analytical work will briefly be presented in the followings.

<u>Example No.1.</u> <u>Sümeg-Csabpuszta area</u>

Deposits of the Senonian sequence (Ugod Limestone Formation) were laid down on to an uneven karstic dolomite terrain here, which was the result of some long-lasting process of denudation during Pre-Senonian times. Based on careful microfacies analysis the Senonian sequence could be divided on to several facies such as the reef-fore slope facies the organic-reef, the lagoon-, the lagoon-back, the winnowed platform-edge-sand, the abrasion-breccia, etc.). As transgression commenced, at first lagoon-facies clay and limestones were laid down into the bauxite-filled depressions of the carbonate terrain. They buried the ore and extended also slightly over the surrounding carbonate area and, as such, they are excellent indicators of the bauxite beneath. As to petrology they are essentially loose bauxitiferous limestones, they are pale-coloured purple or russet and contain numerous pisoids and round-grains of bauxite, but no detritic Pachyodont-fragments. The deposition of typical reef-limestones and all reef-bound limestone facies took place at a later stage of the transgression only, when the advancing sea occupied also the higher-elevated bare, interdepressional dolomite-"hills".

Example No.2. Dudar-Bakonyoszlop

The area of the Dudar-Bakonyoszlop occurrence had been a part of some platform-like neritic region surrounded by deeper basins both from the South and the North. On the platform, shallow-water Alveolina-limestones and biodetritus limestones were laid down. The former can be considered essentially as an open shelf-lagoon-facies while the latter is a kind of the platform-margin sand facies. At places, however, where the lowermost members of the Eocen sequence were laid down on to the surface of bauxite traps a well-pronounced change of facies can be observed as compared with the bauxite-free parts of the platform. Above the ore at first finely laminated limestones were laid down, with coal-seams at places. The ore bodies of the one-time margin of the open shelf-lagoon are covered, however, by a pale-coloured, purplish or red Alveolina-Miliolina limestone which contains also some fine-grained bauxitic detritus. Occasionally also Nummulite-limestones can be found in the immediate cover, but they are always closely associated with the above mentioned finely-laminated limestones.

Example No.3. Nyiråd-Nagytårkåny

Bauxite is covered by Eocene strata deposited in an archipelag-like environment here, the once low-lying parts of which had been sites of temporary swamp sedimentation. Accordingly the immediate overburden consists of brackish lagoon-facies clays, argillaceous marls and lignitiferous clays in the depressions. Positive elements of the one-time relief are, however, covered by Alveolina limestones and there are no or only scarce indications of bauxite at these places.

The geology of the cover-beds of all the other occurrences are very similar to what was described under Examples Nos 1, 2, and 3. The immediate overburden consists almost always of lagoonar clays, argillaceous marls, marls and lignitiferous clays, thus demonstrating the one-time brackish, temporarily uliginal environment (e.g. Iszkaszentgyörgy, Fenyőfő, etc.).

Based on recent investigations it is suggested nowadays that the apparent facies-climax above the bauxite traps (as compared to the sediments laid down on to the bare non-perspectivic dolomite surface) can be attributed to basic environmental differences between the dolomitic and the bauxitic basement. Reaching beyond the scope of the present booklet this matter will not be detailed here, however.

Based on careful faciological investigaion of the coverbeds, the following interrelations could be established:

Brackish - temporarily even uliginal - lagoonar formations, or sediments laid down in some closed lateral lagoon or in inlet-lakes are most favourable from the point of view of the protection of the underlying bauxite. Apart from hypergenic reduction effect of organic-rich solutions descending from the lignitiferous clays, the essentially undisturbed sedimentary environment of the lagoon- or the swamp has namely little or no influence upon the underlying ore.

At places where on trasgression the bauxite-traps became part of some open shelf-lagoon, the uppermost horizons of the ore may have been carried away by wave action when falling into the one-time zone of abrasion. According to the latest palaeogeographic reconstructions this was exactly the situation in the Northern and Southern margins of the Dudar-Bakonyoszlop "plateau", and at some places of the spot-reef belt of the Ugod Limestone Formation in the Csabpuszta area.

It is clearly demonstrated by the above example that the role of environmental factors such as pre-bauxitic relief and the conditions of sedimentation of both bauxite and overburden must have been determinative as far as grade and quantity of the reserves are concerned. That is: there is a well defined correlation between the grade of the ore found in a trap and the facies of the overburden covering it, and this correlation can be used as a guiding principle of the exploration.

2.1.2.5. Origin

Conditions of formation of karstic bauxites (including climatological and physicochemical criteria) are supposed to have been identical with the conditions of presentday and subrecent lateritisation (details discussed in para No.2.3.2.

To avoid repetitions only the problem of the parent-material, and the prerequisites of accumulation and retention of karst-bound deposits will be discussed here.

It is to be emphasized, however, that the details of formation of karstic bauxites are yet far from being fully disclosed. All that can be taken for sure is that karstic bauxites are fine-grained sedimentary rocks formed on drylands of the one-time tropical or subtropical climatic zones. Deposition of their parent material (essentially some chemical weathering product) took place in permanent or intermittant pools of a lacustrine or near-shore continental environment. Their footwall is always some neritic carbonate rock, the cover-beds are various members of some transgression sequence and there is always a longer or shorter stratigraphic gap between footwall and hanging wall. As to the nature of the parent material, it is a question fiercely disputed in almost all occurrences. The enumeration of all arguments and counter arguments of long scientific debates is outside the scope of the present booklet, all the more because the exact chemical and mineralogical composition of the parent rock is by far unimportant from the point of view of the strategy of systematic prospection.

Having been the subject of debates in Europe since 70 years; the question of origins is still under discussion, but no generally accepted conclusion could be reached up to now. One thing is for sure, however, namely that "possible" is not to be taken for a synonim of "inevitable", not even in this branch of geology. It is hoped that by the understanding of global tectonics and its bauxite geological consequences, the whole question will get nearer to the solution.

Of the numerous theories elaborated up to now the following deserve attention:

a) According to HILL (1955), HARTMANN (1955), HOSE (1961), de WEISSE (1964, 1976), BURNS (1961), SINCLAIR (1966), KOMLÓSSY (1967), VENDL-KISHÁZI--BOLDIZSÁR (1971), etc. karstic bauxites are autochtonous or parautochtonous accumulations of the weathering product of the karstic bedrock. Formation of bauxites on carbonate-weathering may take place directly, or indirectly - through an interim stage of residual clays ("terra rossa").

b) The other side assumes that the parent material should have been the alumina-rich weathering product of some non-carbonitic rock, and that it reached the karstic surface after a considerable transport only. As to the origin of this weathering product, any kind of igneous, sedimentary or metamorphic rocks may be reckoned with, with the only requirement of the fresh rock having an average alumina content higher than that of the ordinary carbonates.
As far as the medium of transportation is concerned most authors agree that the parent material was brought on the karstic surface by permanent water--courses. Opinions greatly differ, however, regarding the state of the transported material. HABERFELNER (1951), RUTTNER (1970) and CAILLERE and POBEGUIN (1964) claim that the transport had been essentialy chemical, that is the material was transported in the form of true inonic solutions. NEMECZ and VARJU (1967) JURKOVIC and SAKAC (1964), VÖRÖS (1965) and VALETON (1965) are of the opinion that the parent material reached the carbonate terrain in the form of some finely dispersed colloidal suspension. According to NICOLAS

(1970) and BÁRDOSSY (1961) transportation in the form of thick muddy water-courses is most probable. SZABÓ (1976) claims that the material deposited on the karstic surface was essentially bauxitic, that is, some fine-grained high-alumina weathering product of lateritic origin might have been washed in the morphological traps of the bedrock.

c) Lately a new conception seems to emerge from the combination of the above two. The most substantial argument of this conception is that a rock - be it of any chemical or mineralogical composition, when exposed to humid tropical climates invariably becomes the subject of lateritic weathering. Only the extent to which this weathering affects it, differs slightly according to various local conditions (see Para No.2.3.2.). Supporters of this conception are of the opinion, that the parent material of karstic bauxites might be an admixture of weathering products of all the rocks that had actually been exposed during the period of accumulation of the bauxitic sediment. Nevertheless all authors concerned are clearly inclined to prefer igneous rocks or metamorphics as an original source material. BONTE (1970), NICOLAS (1970), MARIC (1966), ZANS (1955), etc.

Formation of karstic bauxites as related to tectonism on the regional scale was already discussed under Para No.2.1.2.3. In the present Chapter the most important historical geological events of a single geological unit will be analysed from the point of view of the accumulation of karst-bound bauxites.

1st stage Large-scale subsidence within the neritic zone of the shelf; marine sedimentation (=neritic carbonate facies).

2nd stage Uplift of orogenic or epeirogenic character followed by more or less intense denudation (e.g. intense erosion: Pannonian Internid Mass Transdanubian Central Mts.
slight denudation: Geosynclinal zones of the Dinarids and Hellenids).

3rd stage Atectonic period
Development of karst morphology; bauxite formation. It is highly probable, that in this stage karstification and bauxitization are going on simultaneously. As a consequence of the peneplain character of the gently undulating low-relief, terrain, the role of mechanical disintegration becomes subordinate to chemical weathering. Corrosion and karstic erosion may proceed at the bottom of karstic dolines as deep as the karstic water-table itself. Old fault-lines often turn into deep karstic canyons with circular enlargements at fault-intersections. It is this kind of karst morphology that facilitates accumulation and retention of bauxitic sediments.

4th stage Subsidence (generally of epeirogenic character)
Rejuvenation of older marginal faults along the contact of rigid and mobile crustal units; formation of tectonic graben structures; deposition, reworking and local transportation of the bauxitic material on the karstic surface; filling up of karstic depressions with reworked and redeposited bauxitic material.

Although at places sedimentation may have reached an end during the atectonic period already, the material of most lenticular- karstic-tectonic graben type deposits were laid down just before the deposition of the immediate cover-beds. This is especially true in the case of deposits having a thickness considerably greater than the amplitude of the karstic undulations of the bedrock.

From the morphogenetic point of view it is the last period immediately preceding the burial of the bauxite-traps which is of decisive importance. Primary morphology and in fact the survival of any given deposit depends closely - if not exclusively - on the intensity of erosion during this last period. On further subsidence at first fresh-water sediments are laid down, which later on give way to swamp- or lagoon-facies clays, brakish formations and at the end to a normal marine limestone or marl. At places of rapid transgression the succession begins with coarse-grained clastic sediments, laid down primarily into deep karstic depressions or tectonic grabens (e.g. Jajce, Yugoslavia). At places of intense denudation bauxites may completely be striped off by erosion and the eroded material may be redeposited, together with the coarse grained scree coming from the surrounding, higher-elevated blocks. Scattered remnants of larger bauxite bodies may survive erosion, but if so, their grade invariably becomes deteriorated.

It can be taken for a general rule that optimum conditions of retention of bauxitic accumulations are attained when the deposition of the immediate cover-beds takes place in an environment of slow ingression, characterized by the formation of smaller or larger lagoons and inlet lakes, along the shores of the advancing sea. There are also some evidences of high--grade bauxite being connected to lignitiferous cover-beds, while under semi-halin brakish sediments only lower-grade deposits are to be expected. When the immediate roof of the bauxitic horizon is built up of some marine formation (like Nummulite-limestones for instance) the probability of finding high-grade bauxite is low (marine cover-beds indicate namely that the deposit became buried at a later stage of transgression only, thus having had more chance of both grade-deterioration and denudation).See also in Para No.2.1.2.4.

Recurrence of the above described historical-geological events during the development of a given area is theoretically.

unlimited, thus bauxite formation may be repeated several times within a given sedimentary sequence. In the Mediterranean for instance, in Yugoslavia, there are not less than 10 separate bauxite horizons, showing the above set of events having taken place at least 10 times during the Mesozoic from the Middle Triassic right up to the Mid-Eocene (GRUBIC 1970). (And what is more: there is an additional horizon of reworked bauxites even in the Oligocene sequence.)

In Hungary however the number of bauxitic horizons is restricted to 3, - a difference that can be attributed most probably to palaegeographic reasons:

Bauxite deposits of Yugoslavia were formed in a near--shore environment, closely adjoining to a highly mobile crustal unit: the true geosynclinal zone of the Dinarids. The area of presentday Hungary was however the integral part of a more stable unit, the so called Pannonian Internid Mass. Repeated slight uplifts and subsidences could more easily lead to the formation of alternating bauxite,and marine sediments within the sensitive geosynclinal environment than in the rigid internid mass where not all subsidences have necessarily resulted in complete inundation of the area of bauxitization.

Due to climatic changes bauxitization ceased in he Mediterranean with the end of the Mesozoic. As a consequence of intense erosion following the main phases of orogenic uplift, denudation of bauxites began soon and - regarding the reworked, redeposited material - lead to a considerable degradation. Redepositon in a hydrous environment frequently caused almost complete resilification of the bauxitic material whereby hydrous alumina became combined with silica to form kaolinite. At some places only scarce pebbles of the original high-grade ore were able to survive deterioration, with the rest of the material converted into a red kaolinitic matrix.

At other places degradation was due mainly to mechanical processes (i.e. the admixture of large amounts of sand-size non-bauxitic material during reworking and redeposition). Reworked and redeposited remains of eroded deposits adjoining to larger contiguous bauxite bodies are rather frequent in almost all occurrences. They may be present every now and then also further away, thus delineating the area of the one-time bauxitic belt.

2.2 EXERCISES

On-the-field study of the stratigraphical-tectonical, and depositional characteristics of some typical Hungarian bauxite occurrences: Gánt, Iszkaszentgyörgy, Szőc, Nagytárkány and Iharkut. Itineraries are related to descriptions in Paragraph No.2.1.2.

2.3. LATERITIC BAUXITES

According to the latest estimates world bauxite reserves and resources (proved and inferred) are total up to 45 milliard tons. Most of them (38 milliard tons) are bound to the lateritic type of deposits while the rest belong to the karstic occurrences. About 95 percent of all industrial-grade lateritic bauxites (proved and inferred reserves) are situated within the tropics where tropical red and yellow soils are widely distributed along both sides of the Equator.*

2.3.1. Main characteristics. Types of deposits

The total area of the drylands of the world is 149 million sq kilometres, about 12 million sq kilometres of which are situated within the tropics and subtropics. These tropical and subtropical landmasses are covered mostly by various kinds of lateritic soils and laterites. They occur on or near the surface and - at places under the present cilmatic conditions - their formation is going on continuously even today.

As to the exact definition of laterites and lateritic bauxites, confusion prevailed right through the last century, and even the attempts of the first 50 years of the 20th century, (LAPPARENT /1930/, FOX /1932/, LACROIX /1913/) have failed in this context. As a result of developments in mineralogy, chemistry and geochemistry, the solution seems to be somewhat nearer today. According to our presentday terminology, all the residual soils covering the weathered surface of igneous, metamorphic, or sedimentary rocks of the intertropic

*Remark: Bárdossy distinguishes an additional group of bauxites namely the Tichvin-type. Tichvin bauxites consist essentially of reworked, redeposited bauxitic material interlayered into marine sedimentary sequences. In fact, the differences between this type and ordinary karstic bauxites are not so sharp than those between k rstic and lateritic bauxites.

region (i.e. the tropical weathering crusts) are called laterites in a wider sense. Strictly speaking, however, laterites are those non-bauxitic members of the lateritic weathering profile, which - due to processes of decomposition, selective leaching and neomineralization - are enriched in hydrous oxides of alumina, iron and titania, contain practically no K, Na, Ca and Mg, and their principal clay mineral is kaolinite. Weathering products consisting principally of 2:1 clay minerals and found generally in the lowermost zone of the profile are called lithomargic clay. They represent the transition from resh rock - towards the lateritic profile.

Fig.No.27. represents one of the most typical examples of the complete lateritic profile, showing at the same time a direct connection between the bauxitic and iron-rich lateritic parts of the profile. It has to be mentioned that one or more parts of the section may be absent (not developed or eroded).

When due to dissolution of silica and relative accumulation of alumina the alumina/silica ratio reaches the limits of industrial utilization in the weathering product, the laterite is called bauxite.

This is the general way of laterite-and/or lateritic bauxite formation which is mentioned as "indirect lateritization" (lateritic bauxitization)" by many authors.

IDEALIZED LATERITE PROFILE OF WESTERN GHATS

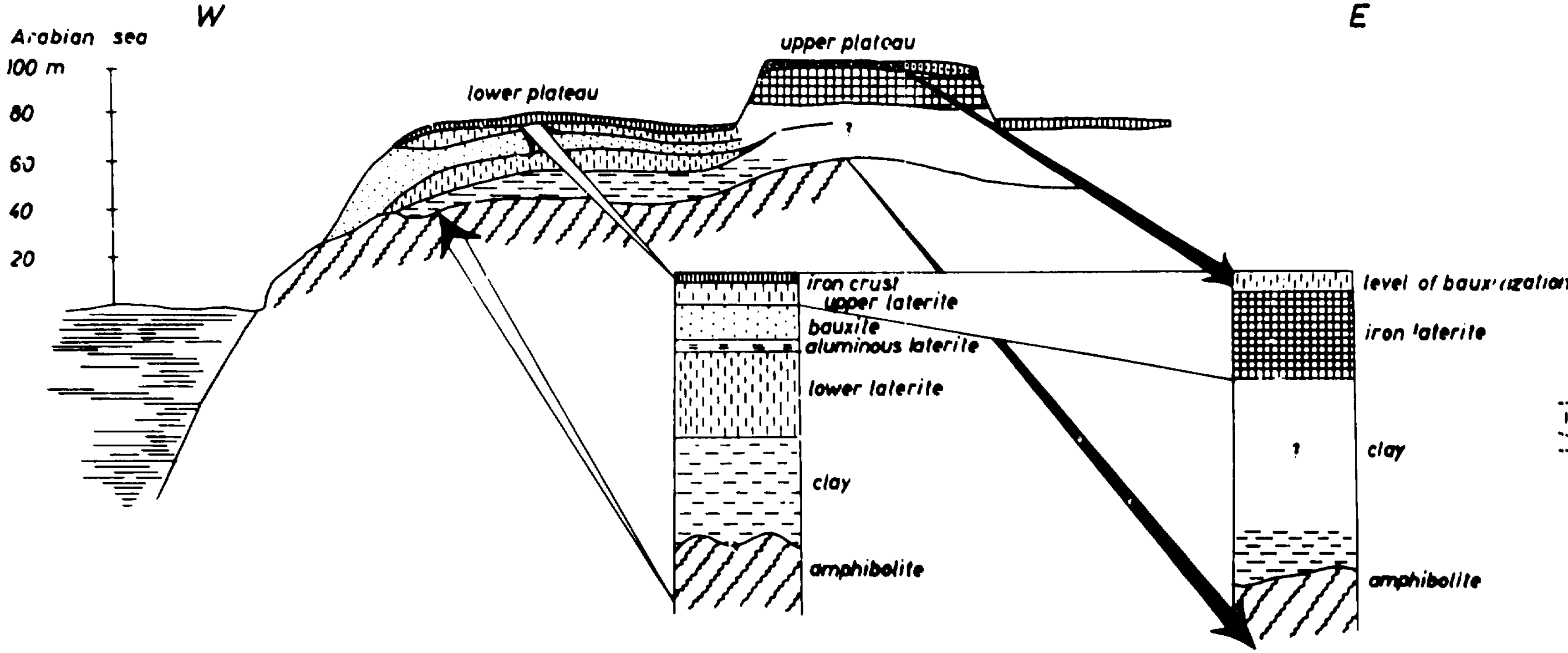


Fig. N° 27.

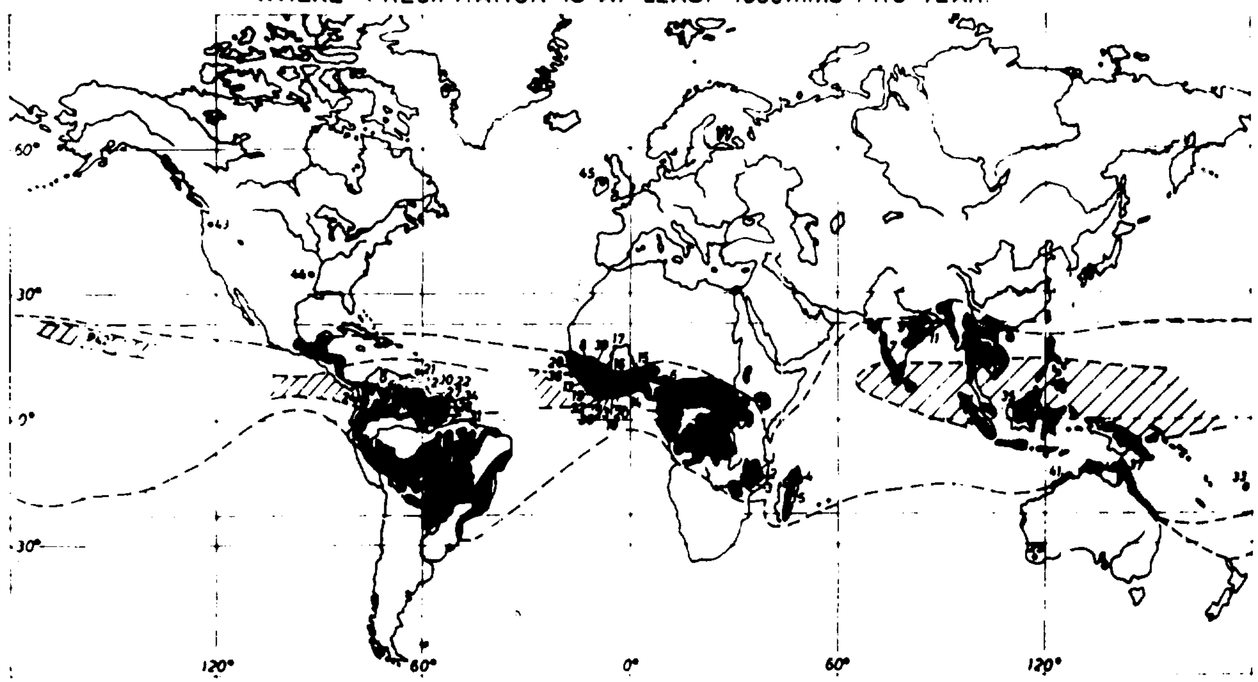
GY KOMLÓSSY 1971.

"Direct lateritisation" especially when coupled with gibbsitization and the formation of thin layers of extremely leached-out, porous bauxites, can not, however, be taken for a result of any long-lasting process. Weathering crusts of even greater thickness would have been carried away by erosion when exposed during hundred thousands or millions of years. Direct lateritisation implies much shorter periods of weathering. It can be effective only when its penetration rate exceeds the rate of overall denudation. Depending among others on the nature of the parent rock, on the inclination of the terrain and on microclimate this penetration rate is between 0.01 and 1 mms pro year in the humid tropics. Thus direct lateritisation of 0.1 to 0.2 metres of the parent rock may take not more than a few thousands of years.

Since lateritization is a process bound to tropical (subtropical) conditions, the occurence of laterites and lateritic bauxites is restricted to the tropical (and subtropical) climatic zones which are characterized by a mean annual temperature of 20 centigrades and are bordered by the 20 ^{o}C isotherms. There are also older laterites, formed during past eras of the Earth's history, the areal distribution of which does not conform to the presentday tropics. Old laterites are known for instance in the temperate zones as well as in the Polars (Oregon, Antrim, Arkansas, Tajmir, etc). Their distribution is the joint result of processes of polar-wandering, continental drift and plate tectonics (Fig.No.28.).

Within the zones of presentday lateritization there are several types of parent rocks the weathering of which is known to produce lateritic soils, laterites or lateritoids. The nature of the weathering product is the joint result of a number of different factors which will be discussed later on in details. Of the wide variety of laterites it is the lateritic

ZONES OF PRESENT-DAY ALLITIZATION, ALFERRITIZATION AND FERRALLITIZATION WHERE PRECIPITATION IS AT LEAST 1000 mms PRO YEAR.



Recent / Subrecent — Areas of optimum bauxitization-conditions

E. Szabó 1976.

Lateritic bauxite occurences

1 Lichenya-Plateau
2 Mt. Zomba
3 Penhalonga
4 Morangaka-Plateau
5 Analavory-Plateau
6 Ngaoundal Plateau
7 Kolhapur-District
8 Dabola
9 Palamau-Kalahandi Dis.
10 Gran Sabana
11 Ranchi District
12 Pacaraima Mts.
13 Kindia-Friguiagbé
14 Kibi Mts.(Atewa Range)
15 Mt Ejuanema
16 Nyinahin
17 Yaoure-Plateau
18 Vanfoue-Plateau
19 Benene Plateau
20 Affoh Group
21 Upata-Nuria
22 Bakhuis-Nassau Mts
23 Digo-Orumba-Boka
24 Morales-Caibio
25 Darling Range •
26 Kaw-Mts.
27 Blue-Oko Mts.
28 Boké
29 Lakota-Plateau
30 Babokon-Plateau
31 Roura Mts.
32 Badi Konkoruė
33 Viti Levu
34 Mahury-Plateau
35 Bukit-Gebong
36 Los-..ls
37 Weipa
38 Trombetas
39 Sitadina
40 Gove
41 Mitchell-Plateau
42 Hawai-Kauai
43 Oregon •
44 Arkansas •
45 Antrim •

(43–45) Outside the recent • tropical belt

The most important occurrences are underlined

N^{os} 1-37 are compared in fig N° 29

Fig. N° 28

iron ores, bauxites, and nickel-manganese ores which are most frequently of industrial importance.

As to classification, although several attempts were made by authors of repute, nc universally accepted system has emerged up to now. According to GRUBB (1973) laterites and lateritic bauxites can be divided into two main groups ("high-level" and "low-level" laterites) while on the basis of hawaiian (Kauai) examples ABBOT and ALLEN proposed an additional taxon of slope-type laterites and lateritic bauxites to count with. In the US PATTERSON (1971) speaks of ground-water-laterites and -bauxites. The system developed by the Soviet geologists uses the term plateau-laterites. Similarly to GRUBB's classification "low--level" and "high-level" laterites are distinguished in India.

Since the consistent system and nomenclature of laterites is yet far from being worked out, for convenience, the following simple grouping will be used in this booklet.

1. Plateau-type lateritic bauxites
   (about 80 to 85 per cent of the total figure of lateritic bauxites belong to this group)
   They may be the results of direct or indirect lateritisation. (In the case of direct lateritisation the boundary between fresh rock and its lateritic cover is abrupt, decomposition of the primary silicates and neomineralization of the residue commences within a range as narrow as a few centimetres or millimetres (BONIFAS /1959/, BALKAY and BÁRDOSSY /1967/, and others). Indirect lateritisation is characterised by a well-defined transition zone (between fresh rock and true laterite) which consists principally of lithomargic clay.)
2. Slope-type and colluvial (valley) laterites
   (The occurrences in this group are generally small--size and of less importance)

3. Polygenic laterites
(They are supposed to have been reworked and partly re-bauxitized; and unlike true "in situ" laterites, exhibit no direct genetic connection with the underlying rocks. This group was distinguished also by I.VALETON).

Thickness of laterite (lateritic bauxite)

The thickness of bauxitiferous plateau-type laterites is determined by the joint effect of accumulation and denudation. It is important to discriminate between the age of a few centimetres of lateritic crust and that of a full 30 to 50 m thick weathering profile. Depending on thickness, the former may be not more than 10 to 100 or at most a thousand years old while the formation of the latter may have taken several tens of millions of years of favourable climatic, morphological and drainage conditions. It should be noted, that lateritisation including bauxitization is generally an intermittent phenomenon. Climatic changes must have been namely more frequent and more common in the past than they are today (e.g. 4 to 5 thousand years ago large areas of presentday Sahara were inhabited and covered by dense vegetation). The imprints of past climatic changes can of course be followed in the zones of recent lateritisation, too. They are thought to be called forth by polar-wandering and the shifting of principal climatic belts as compared to geographic latitudes.

2.3.2. Factors controlling the formation of bauxitic laterites

It is generally accepted now that lateritisation (including the formation of bauxite as final product) is the complex result of the interaction of a series of elementary processes controlled by different, simultaneously acting, geological, physico-chemical, climatic morphological and other (e.g. biological) factors.

The importance of the individual factors is, however, much disputed. Part of the authors is of the opinion that the nature of the parent rock, above all its chemical composition, is the most significant controlling factor while others believe that climatic conditions are much more important in this context. Biological factors, as well as physical properties of the rock, or geomorphological agents are also frequently thought to be of utmost importance, and the whole question is yet full of contradictions. As a matter of fact lateritisation, including bauxite formation is a process influenced by simultaneous and/or successive action of all the above mentioned factors.

Part of the promoting factors act within certain optimum ranges only, and when exceeding the limits for long, they may become a hindrance to or may cause even the reversal of lateritisation. That is - within certain limits - all the factors discussed in the followings have an equal importance from the point of view of lateritisation.

Being the subject of all weathering processes, the parent rock was decided to be discussed at first.

Parent rock

As to petrology, the investigation of 37 of the most important lateritic bauxite occurences of the world (mainly of the plateau type) proved that there are not less than 22 different kinds of igneous, volcanic, metamorphic and sedimentary rocks which may serve as a parent rock for lateritisation (see Fig. 29/A).

These occurrences include about 22 per cent of the world total reserves (9.5 vs 45 milliard tons in 1978) thus - as far as the nature of the parent rock is concerned - they are fairly representative. The tonnage versus parent rock diagram of these 37 representative occurrences demonstrates also the "physico-chemical susceptibility for laterization" of the various rocks (see Fig.No.29/B).

According to SCHELLMANN,W. (1975), when comparing the average chemical composition (i.e. Al_2O_3, Fe_2O_3, SiO_2) of the weathering profile with that of the parent rock the following principal chemical trend emerges:

Lateritisation of quartz-free rocks results in simple desilification and total loss of alkalies and alkaline earths, with the ratio of Fe_2O_3 to Al_2O_3 remaining unchanged. Quite different from that, weathering of granites, gneisses, clays and shales which are rich in alumina but poor in iron leads to the formation of laterites rather than bauxites and to a definite increase of the iron content at the expense of alumina in the weathering product. Due to migration and reprecipitation of the iron-compounds, iron becomes concentrated in the form of absolute accumulations, as a consequence of which the relative percentages of alumina decrease.

Lateritization of parent rocks having different lithological properties leads always to more or less pronounced differences in the chemistry of the weathering product even if taking place under identical climatic conditions.

Also the intensity or the rate of weathering and the depth to the lower limit of the weathering zone is subject to some changes according to the nature of the parent rock. The latter is influenced by the physical state of the rock (i.e. relative percentage of joints and fissures) on the one hand and the position of bedding planes relative to the position of the exposed rock surface on the other. (It is namely the bedding planes that provide channelways for the infiltration of rainwater.) Near-vertical bedding planes of tectonized thin-bedded or schistose rocks, when having a hor-

SOME PLATEAU TYPE BAUXITE OCCURRENCES OF THE WORLD

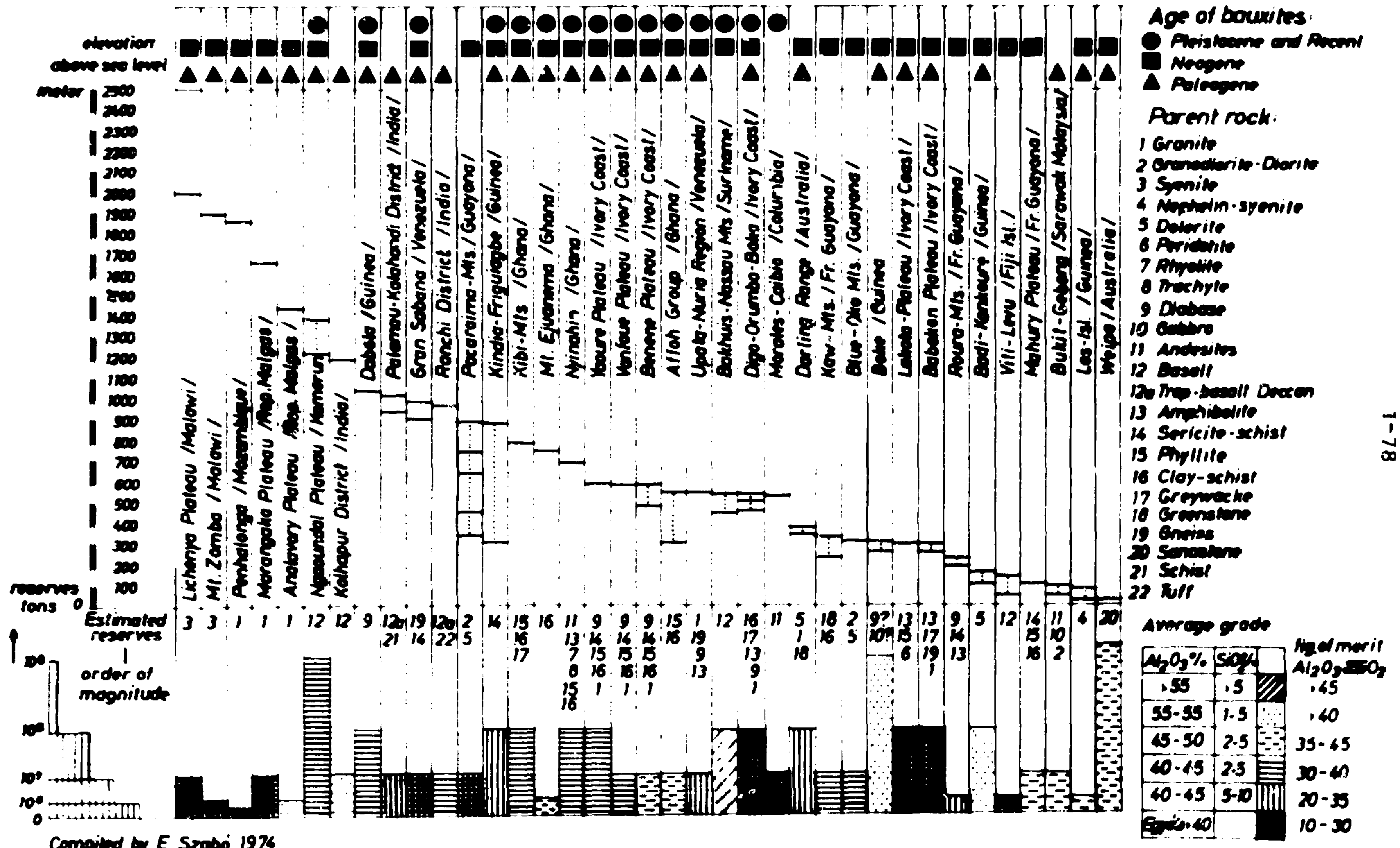


Fig. Nº 29/A

TONNAGE VS PARENT ROCK DIAGRAM
OF 37 SIGNIFICANT LATERITIC BAUXITE
OCCURRENCES

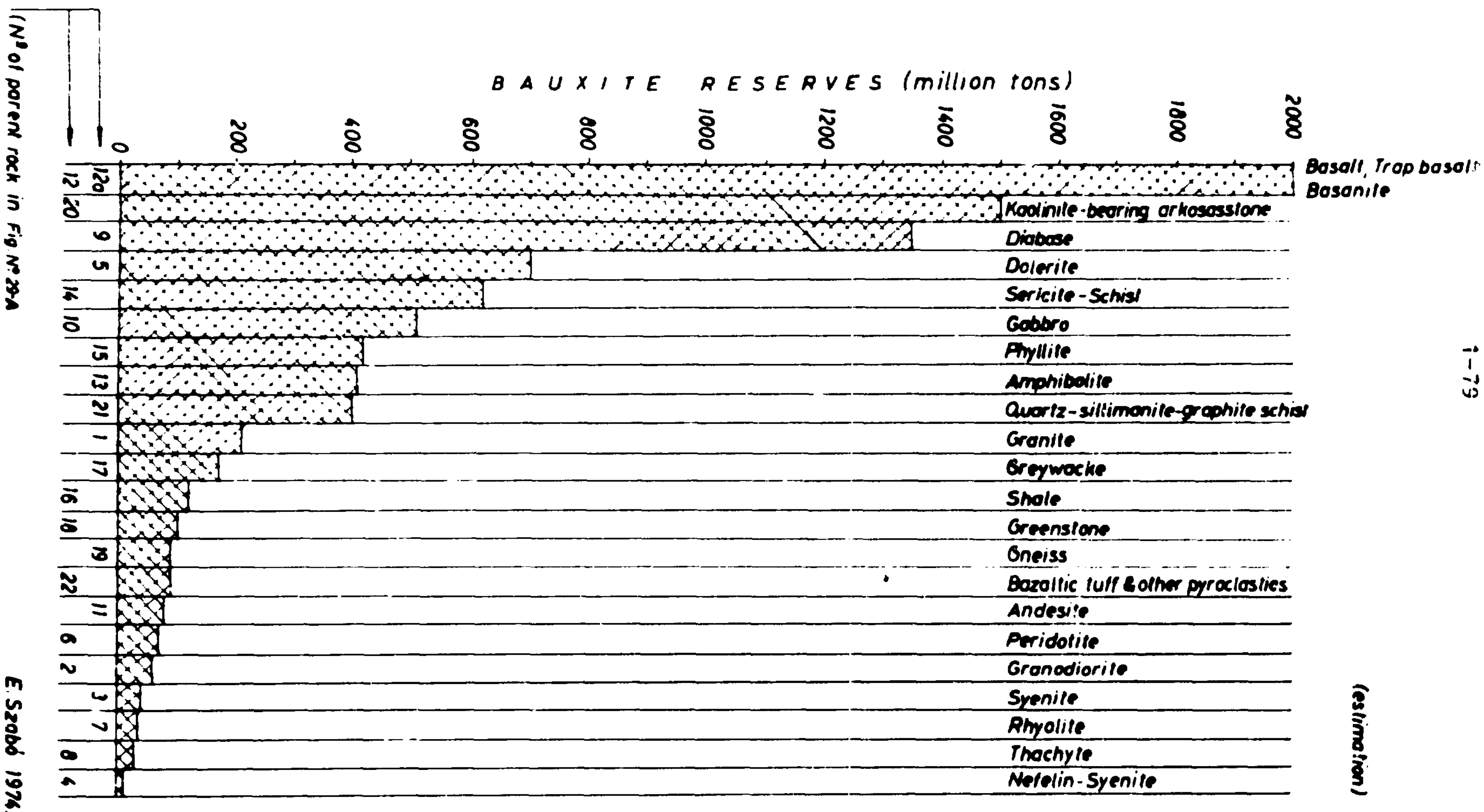


Fig. 29-B

E. Szabó 1974

izontal intersection with the surface, provide excellent waterways for downward percolating meteoric waters, thus enabling the weathering front to penetrate rather quickly to rather great depths. Situations like that may lead to the formation of weathering crusts as thick as 20 to 30 metres (Affoh Group, Kanaiyeribo Hill, Ghana).

When plateaux built up of easily laterizable rocks are exposed to humid tropical conditions at considerable lengths of time (10 thousands to some millions of years) a characteristic weathering zone forms on their surface.

Under identical or near-identical climatic conditions and identical elementary lateritisation processes lateritic weathering of fairly different rocks (like basalts, granites, diorites, andesites, trachydolerites, shales, phyllites, sericite-schists, kaolinite-bearing arcosa sandstones, etc.) may lead ultimately to the formation of materials of near--identical chemical composition (i.e. bauxites).

On the basis of field survey in Goa (India) and laboratory investigations KOMLÓSSY (1976) established that the type of laterization is controlled by the alumina iron oxide ratio of the parent rock rather than its absulute Al_2O_3 and ΣFe_2O_3 content. In the case of this value being higher than 1 bauxitization is most likely. At values lower than 1 both bauxite and iron ores may develop. The occurrences of Goa where at the same topographic level parent rocks having very different chemical composition are covered by bauxitic laterite suggest that the quality of bauxite does not depend strictly on the chemical composition of the parent rocks:

		whole lat. section	bauxite zone	whole lat. section	bauxite zone	whole lat. section	bauxite zone
Al_2O_3	%	38.09	48.66	39.94	45.52	-	46.27
SiO_2	%	10.11	5.35	7.65	5.77	-	6.18
Fe_2O_3	%	25.03	15.17	20.80	15.45	-	19.23
TiO_2	%	1.99	2.11	-	1.46	-	2.00
L.O.I.	%	25.53	27.26	21.63	24.65	-	22.22

		amphibolite	granite	mica shist
Al_2O_3	%	16.32	10.96	2.50
SiO_2	%	46.36	77.06	90.45
Fe_2O_3	%	15.06	3.06	1.63
TiO_2	%	0.82	0.24	0.07
L.O.I.	%	2.98	0.80	0.59
CaO	%	8.30	0.72	0.72
MgO	%	7.91	0.31	0.00

Local variations of morphology, water-balance or other factors, thought to be of minor importance, may result in the formation of fairly different materials even if climatic conditions and the petrology of parent rock are essentially unchanged. This is why the grade of lateritic bauxites may vary considerably even within one and the same deposit.

As to porosity rocks may be permeable or impermeable, with the loose or silghtly cemented coarse grained sandstone and the claystone as the two extremes. Between them, however, there are large numbers of rocks with permeabilities less than the optimum but better than nil.

As to the relation of lateritisation to parent-rock porosity most of the authors (SCHELLMANN /1964/, STEPHEN /1963/, LOUGHNAN /1969/, BALKAY, BÁRDOSSY /1967/) agree that high but not too high porosity is by experience, the optimum, i.e. ground-water movement in the pores should be slow but unhampered both in the vertical and in the lateral sense. To provide the necessary conditions for the dissolution of silica and other mobile constituents it is important that losses on evaporation and adhesion be not significant throughout the lateritic profile, i.e. the total amount of water retained in the form of pore water adhesive water or chemically-bound water should not exceed 50 per cent of the percolating rain-water. The recognition of this ratio is of crucial importance from the point of view of the water-balance of the weathering rock, although it is yet far from being understand in details.

When rocks of extreme high permeability (for instance porous sandstones consisting of hard, resistant grains of quartz) are in a steeply dipping position, rain-water rushes unimpeded down the near-vertical channel system of the bedding planes and pores; and due to high flux rates it can not display any effective solvent action. Instead of bauxite the weathering product will be of the iron-rich ferruginous laterite-type, or - in some cases, on ultrabasic rocks exposed to dry climates - also manganese may be enriched in the weathering crust. (Gabon; Pacaraima Mts, Guayana; Kwahu - Plateau on the surface of the Volta sandstone, Ghana).

When the porosity of the sandstone is reduced by accessory felspars, kaolinite or other clay minerals, an internal drainage system, providing slow but steady rates of ground--water flux, may be established and thus also the weathering of arcosa sandstones may lead to formation of bauxitic laterites (e.g. Weipa, Australia).

Climatic conditions

Being formed by deep weathering on the surface of tropical landmasses under conditions of alternating wet and dry seasons, laterites are indicators of tropical (and/or subtropical) climates and dryland conditions. Fossil laterites and their global distribution provide therefore a useful tool for the geologist in the reconstruction of past climatic changes of the Earth's history (BÁRDOSSY,Gy. 1975.).

The area of presentday lateritisation, (including allitization and economic concentration of alumina) is confined to the intertropics - a zone bordered by the tropic of Cancer in the North and the Tropic of Capricorn in the South. Part of this zone along both sides of the Equator is humid throughout the year while the rest is characterized by alternating wet and dry seasons.

On the northern haemisphere this area falls within the range of the +28 °C (July) and +24 °C (January) isotherms and has a precipitation figure of 1000 to 5000 mm pro year.

On the southern haemisphere the borders are less consistent. In most of South Africa they are represented for instance by the +24 °C (January) and +20 °C (July) isotherms.

In South America alumina-rich weathering crusts occur in areas adjacent to the drainage system of the Amazon river. They are bordered by the +24 °C isotherms in the North and the +16 °C isotherms in the South. Both the eastern and the western limits of the lateritic zone is marked by the +24 °C (January) isotherms.

In Australia lateritic bauxites of the Cape York peninsula, the Arnhem-land and Kimberley are bound partly to the belt of tropical rain-forests and partly (-at higher altitudes) to the savannah belt. They are bordered by the +24 °C and +20 °C (July) isotherms in the North and in the South respectively, while in the East and West they terminate at the +28 °C (January) isotherms. Similarly to other occurrences of the Southern haemisphere, the laterites of India and Indonesia are confined also to the area inbetween the +24 °C and +28 °C isotherms.

As to the distribution of precipitation, the southern haemisphere is quite similar to the northern one: mean annual rainfall is around 1000 to 5000 mms all over the lateritic belt.

Conditions of presentday lateritization has been subject to manyfold investigations of numerous authors of repute during the last two decades. Lateritisation process as related to climatic conditions were studied by ALLEN and SHERMAN (1965) at Kauai and Maui (Hawaii Isl.). On the basis of the study of laterites and lateritic bauxites of the Ivory Coast, ZANONE,L (1971) suggested that the climatic factor is of primary importance in this context. He emphasized above all the role of temperature, the distribution of rainfall and relative humidity.

The formation of bauxites, however, is not an overall phenomenon within the zones of lateritisation. Beside various non--climatic factors this restriction can partly be attributed to local variations of climate. Although strict limits could not have been established as yet, on the basis of complex solubility, temperature, etc. investigations of the last few years, the optimum climatic conditions necessary for desilification and bauxitization of plateau-type laterites can be summarized as follows:

Mean annual temperature: 20 to 25 °C
Annual rainfall: 1500 to 2500 mms

Distribution of precipitation: alternating wet and dry seasons (best if the completely dry periods do not last longer than one to one-and-a-half months a year, because soft laterites harden on exsiccation, the iron-crust, consisting of goethite-needles grows thicker and thicker and the ultimate weathering product formed under dry conditions will be ferruginous rather than aluminous laterite. The duration of the so-called dry-season- (with a rainfall less than 30 to 35 mms) should not exceed three months a year).

Relative humidity is favourable when within the range of 80 to 100 per cent (-mean annual figures). The optimum lies between 90 and 100 per cent.

As an example let us cite the mean annual figures of Kibi and Kumasi (both in Ghana) on the one hand, and the same figures (with an altitude correction) for the bauxite-plateaux of the Atewa Range and Mt Ejuanema (also in Ghana) on the other. (See Figs. 30 and 31.).

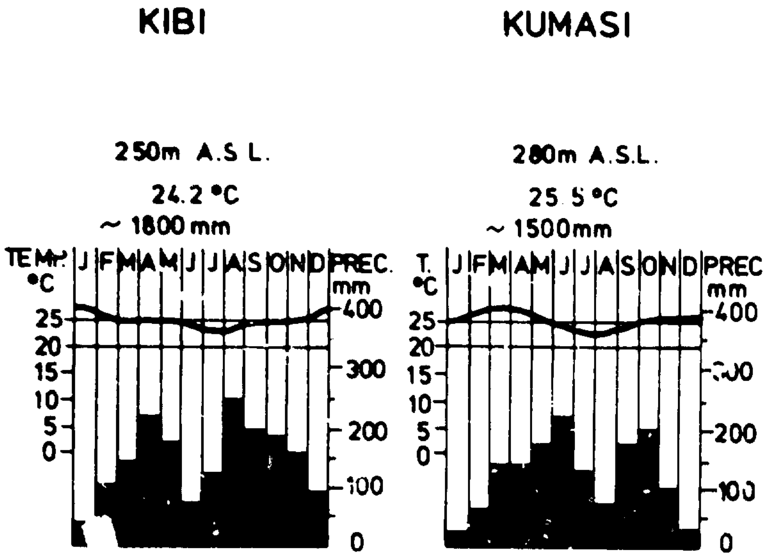


Fig N° 30.

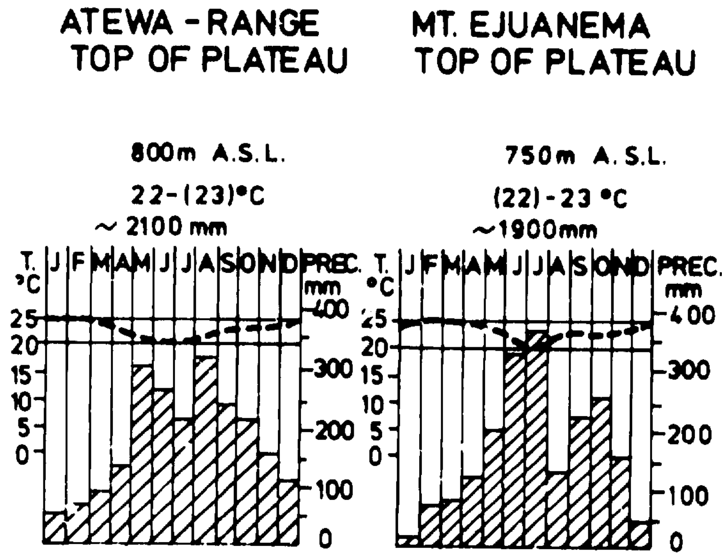


Fig N° 31

Lateritic bauxite profile
in a cut near Pepiasi, GHANA

View of escarpment of
a lateritic plateau
Kwahu Plateau, GHANA

Dissected lateritic
plateau.Mt.Tutuojiram,
GHANA

CLIMATIC CONDITIONS OF SOME SELECTED
LATERITIC AREAS OF EQUATORIAL AFRICA
(a comparison)

Observatory	Elevation above sea level	Characteristic mean values			weathering product	
		mean ann. temp. in centigrades	annual rainfall in millimetres	relative humidity per cent	ferral-litic	si-allitic
Debunja (SW Cameroons)	800	22.1	10,680	90	+	+
Freetown (Sierra Leone)	40	27.6	3,800	88	+	+
Boké (Rep.du Guinée)	30	26.6	2,940	84	+	
Kumasi (Ghana)	285	25.5	1,486	88	+	
Accra (Ghana)	20	26.4	732	81	+	
Tamale (Ghana)	150	27.4	1,200	67	+	

Within the optimum range of latitude-dependent regional climatic factors lateritic weathering, at any given point of the tropics, is determined by the microclimate of the immediate surroundings (e.g. lee or luv position of the hillsides relative to rainfall, etc.).

Morphology

Beside climate, morphology is one of the most important factors affecting lateritisation. The elements to be considered are as follows:

a) relief, especially the so called plateau-morphology (flat-topped hills) including minor relief of both small- and large-size plateaux and plateau-complexes

b) altitude (elevation above sea level)

a) Plateau morphology

Since apart from permeability both the infiltration : runoff ratio and the direction of sheet wash depend primarily on the inclination of the terrain, relief is a factor of high importance in weathering. The intensity of erosion is determined essentially by the angle of slope and the percentages of rain-water running off the surface. Experience proves that outstanding plateaux of gently undulating surface are the most favourable.

Field evidence shows that there is a bilateral connection between the inclination of the slopes and the degree of bauxitization of the lateritic cover.

High-grade bauxites form always on flat (inclination: 0 to 5^{o}) laterite-covered plateaux, the drainage conditions of which promote the dissolution and leaching out of silica by maintaining optimum groundwater flow-rates throughout the section.

On the near-horizontal terrain the rate of accumulation of the weathering product exceeds the rate of denudation and thus in addition to the optimum conditions of chemical weathering also an optimum accumulation/denudation ratio is attained i.e. the thickness of the weathering crust is continuously being increased.

The reverse is true in respect of slopes steeper than a certain limit of inclination.

When drainage is too effective, water "runs through" the section; iron accumulates rather than alumina and except some isolated alumina-rich blocks or boulders there is no high-grade bauxite in the laterite cover of such steep slopes.

When denudation exceeds accumulation, no considerable thicknesses of weathered materials can be retained "in situ" on the surface of the weathering bedrock.

In the terms of morphogenetics this means erosion of the once established thick weathering crust on the one hand, and the degradation or ferruginization of the originally high-grade sections on the other.

Plateau morphology and laterite facies

The composition and structure of the weathering products is not uniform throughout the lateritic cover of a given plateau. There are slight faciological variations to be traced according to undulations of the relief.

Relief	Laterite facies
Uppermost, near-horizontal areas of the flat hill-top	considerable thicknesses of high-grade bauxite
water-logged depressions	kaolinite; occasionally bauxitiferous clay
receding valley-heads along the plateau-margins	concentrations of iron; ferruginous laterite, ferruginous bauxite
flat marginal "tongues" of the plateau-complex	generally high-grade bauxite
indistinct, convex plateau-margins (with a gradual transition into the slope)	ferruginous bauxite, iron-crust
escarpment	iron-laterite, ferruginous bauxite; large boulders and debris of iron-crust; formation of talus-scree

Relief	Laterite facies
ordinary slopes with an inclination of 10 to 30°	laterite, iron-laterite; occasionally also redeposited, cemented bauxite
steep slopes with an inclination more than 30°	fresh or slightly altered bedrock

As to extension, flat-topped, laterite-capped hills can be classified as follows:

1. Small plateaux (extension not more than 10 sq. kilometres).
   Obviously it is the small plateaux which are best drained, because the ratio of areas of marginal position (i.e. places of good drainage) to the total area of the plateau is the highest here, and thus conditions of dissolution of all mobile constituents (including silica) are most favourable for bauxitization.
2. Medium-size plateaux (extension: 10 to 100 sq.km
3. Extensive plateaux or plateau complexes (larger than 100 sq.kms) see Fig.No.32.

As to elevation it seems to be useful to distinguish

a) over-cloud and
b) under-cloud

plateaux in either of the above groups.

Over-cloud plateaux are elevated above the horizon of precipitation of atmospheric water (they are above the mist--level), while under-cloud plateaux are below the cloud-horizon.

When looking for large reserves of lateritic bauxites, extensive plateaux high above the mist-level (600 m or higher above sea level) are most promising, when having a flat top, with slight or no depressions (see plateaux of Orissa of Madhya Prades in India).

SCHEMATIC BLOCK DIAGRAM OF A LATERITIC PLATEAU-COMPLEX

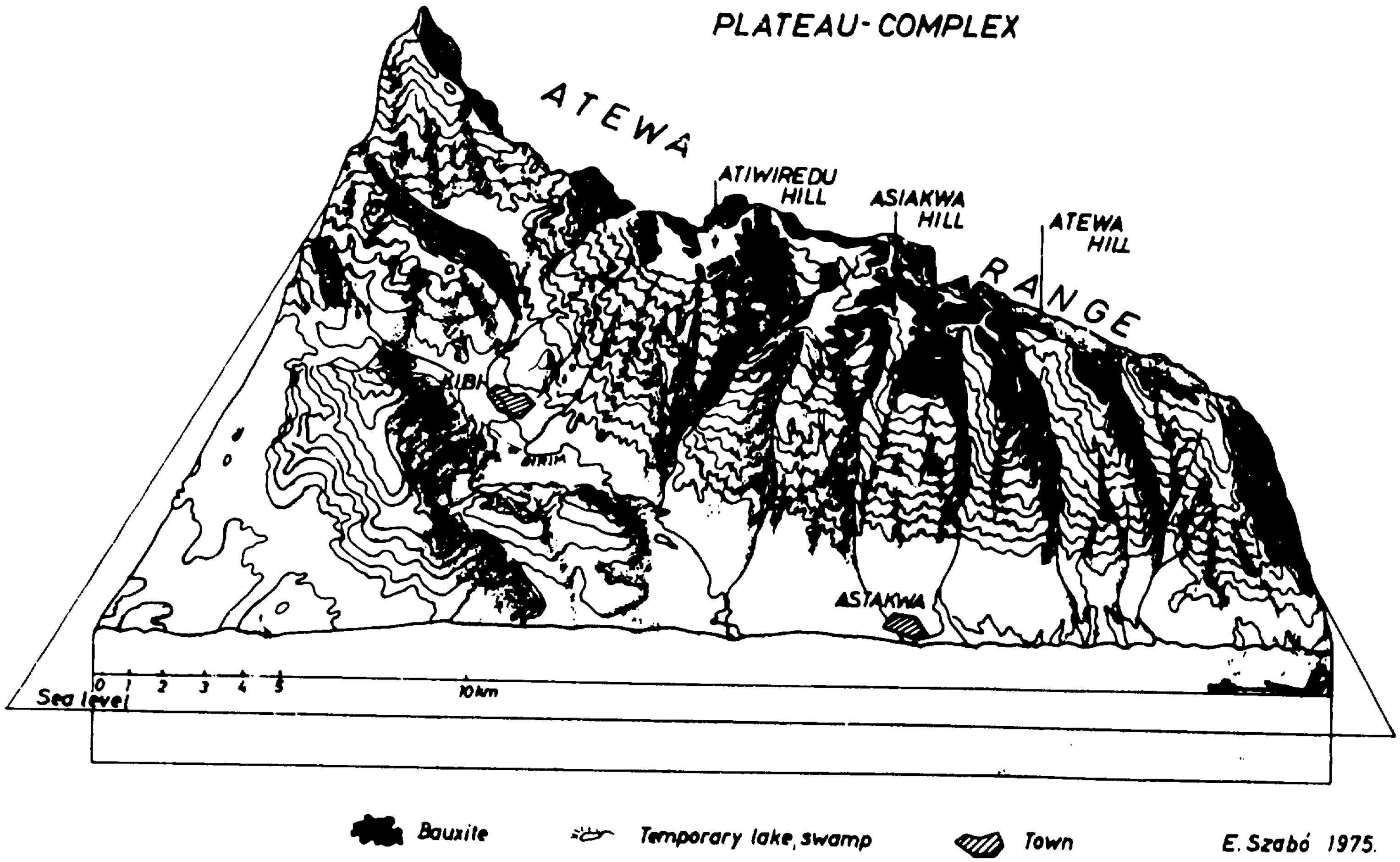


Fig N° 32.

Division of lateritic plateaux according to the relief of the plateau surface can be summarized as follows:

1. slightly convex plateaux
2. flat-topped plateaux
3. flat-topped plateaux with occasional depressions filled temporarily (or sometimes permanently throughout the year) by swamps
4. plateaux dissected by steep incisions of V-shaped valleys.(cf.Fig.No.33.)

Each of the above groups represent also a certain set of drainage conditions characteristic of the given relief.

b) Altitude

It is undeniable that as to the nature of the weathering crust formed on a given terrain, altitude is more or less important. Whether its role is determinative or not, is much disputed, however. All the same, one thing is for sure: there is a certain altitude-limit above which conditions become unfavourable for bauxitization, even within the zones of present-day lateritization. In West-Africa, for instance, this altitude-limit is between 1500 and 1700 metres. The role of the altitude factor is demonstrated very well by the bauxite deposits of the 2000 m high Mt Zomba (Lichenya-Plateau, Malawi, Eastern-Africa). According to STEPHEN (1963) these bauxites are in the state of a gradual kaolinitization (resilification) already, because at these altitudes, conditions do not promote bauxitization any more. Mean annual temperatures are namely rather low (16 to 20 ^{o}C) here, thus they can not provide the necessary chemical environment for the silica to be dissolved and separated from alumina.

Thus the altitude affects lateritisation and bauxitization indirectly by modifying the climatic criteria of bauxitization.

EVOLUTION OF LATERITIC PLATEAUX (SKETCH)

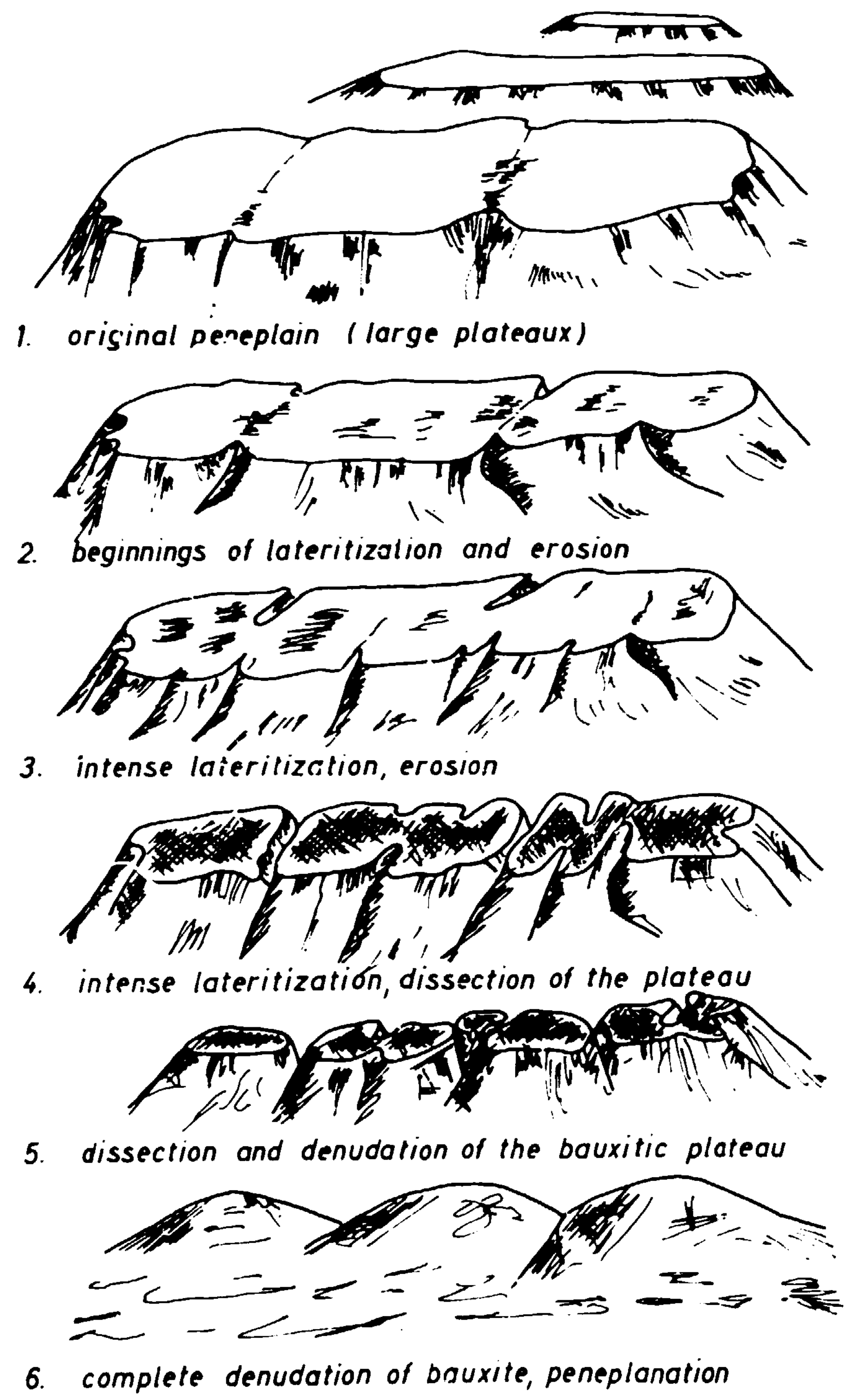


Fig N° 33

E. Szabó 1975

Hydrogeological factors

The role of water in the formation of lateritic bauxites

The presence of water is one of the principal prerequisites of chemical weathering, especially of lateritisation. Decomposition of the primary minerals, leaching out of their mobile constituents, the formation of secondary minerals from the weathered material and the nature of the final residuum are all controlled by water, its presence and its movements within the rock. The role of water has been subject to investigation of several authors of repute such as PETROV (1962), PEDRO (1966), LISITSINA-PASTUCHOVA (1973), etc.

Water-balance of plateau-type laterites

Because of higher humidity and abundant rainfall the intensity of chemical weathering is considerably higher in the tropics than in the temperate zones. Allitization and kaolinization depends, however, not only on the abundance and distribution of precipitation. The way of infiltration of rain-water is of equal importance in this context. In the initial stage of weathering, when the parent rock is yet more or less compact and thus almost impermeable, the movement of ground-water within the rock is negligible. Later on, however, when due to humid tropical conditions, a thin soil-cover has already been established, permeability increases. In this stage morphology (relief), and consequently also the infiltration evaporation ratio gain importance and lead to considerable ground-water movements. The following types of ground-water movements can be distinguished within the top-soil and the altered zone:

a) continuous downward percolation
b) alternating downward percolation and stagnation
c) alternating downward and upward movements
d) upward movement
c) intermittent upward movement

Whether one or another of the above types of ground-water movements becomes predominant depends partly on morphoclimatological partly on geographic factors (including also orography).

On the basis of ground-water studies of some Guinean plateau-laterites and bauxites BALKAY (1973) distinguished the following three characteristic zones of the lateritic profile:

a) zone of under-saturation
b) zone of fluctuation
c) zone of saturation

Of course there is some moisture also in the under-saturated zone, because depending on the abundance and distribution of rainfall, the relief, the porosity of the rock and also on certain biological factors, it is penetrated both vertically and laterally by infiltering rain-waters. Every zone can be distinguished by characteristic mineral assemblages. High above the ground-water table the undersaturated zone is characterized for instance by the formation of ferruginous laterites (goethite--hydrohematite), while in the saturated zone conditions favour kaolinization and resilification. (Resilification is essentially a process of degradation: it means synthesis of kaolinite and other clay minerals at the expense of hydrous alumina.)

The under-saturated zone is practically nothing else than the uppermost part of the profile including some leached-out boulders of high-grade bauxite scattered on the surface. The zone of fluctuation (i.e. the temporarily saturated zone) includes the lower and middle parts of the upper horizon, while the lowermost part represents the zone of saturation.

Due to subsequent denudation one or more of the above zones (mainly the upper two) may be absent. Sudden changes of the drainage conditions (increasing discharge; opening up of crevices of the bedrock, etc.) may upset the water-balance, as a consequence of which - although rarely - the lowermost zone may gradually be converted into bauxite and ultimately disappears.

Favourable drainage conditions alone do not lead to bauxitization. Percolating rainwaters must be of sufficiently high solvent capacity and temperature to promote the dissolution of mobil constituents so that the residuum be enriched in sesquioxides, expecially in hydrous alumina.

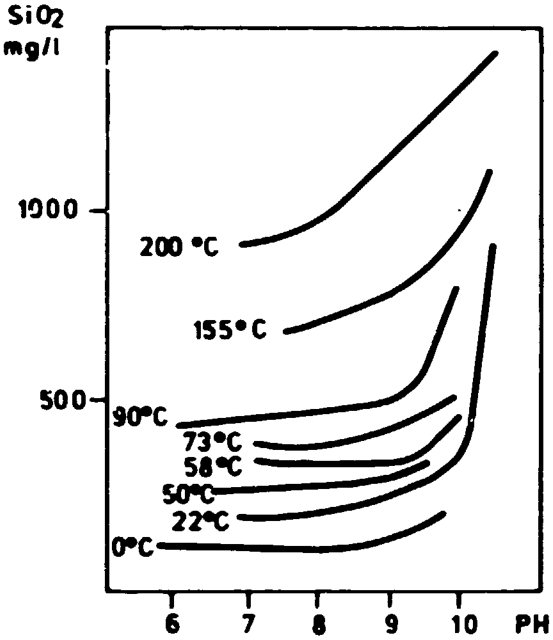
Solubility and ground-water temperature

The solubility of the chemical components of the parent rock as related to the H-ion concentration of the ground-water was investigated by several authors. According to MASON (1952) in natural environments (pH 4 to 9) $Ca(OH)_2$, $Mg(OH)_2$ and all the alkalies are mobile; the hydrous oxides of titania, iron and alumina are essentially insoluble, while silica shows a nearly constant but low solubility all along.

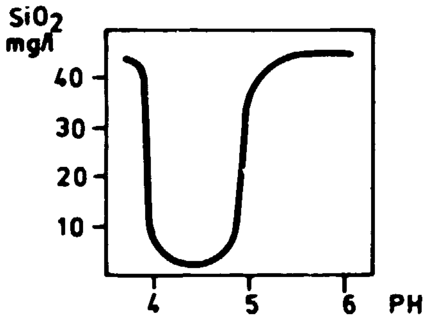
The above relation is demonstrated very well by OKAMOTO'S solubility vs pH diagram (Fig. 34.).

It can be seen at the first glance that within the said range of pH 4 and 9 alumina is practically insoluble - its solution begins below pH 4 in acidic or above pH 9 in alkaline media. The solubility of silica - in accordance with what was said earlier - is steady but low.

Alumina needs a hydrogen ion concentration lower than pH 4 to be dissolved. Acidic media like this can be attained only in soils rich in organic matter. Lowering of the pH is an effect of the luxurious vegetation of the tropical forest. Organic acids produced in the course of biological breakdown of rotting leaves and other plant-remnants provide namely an extremely acidic environment and thus promote the dissolution



SOLUBILITY OF SiO_2 AS THE FUNCTION OF PH (OKAMOTO ET AL. 1957)



PRESENCE OF OTHER IONIC COMPONENTS(EG. Al) DECREASE THE SOLUBILITY OF Si

SiO_2 = 45 mg/l
Al = 1 mg/l (OKAMOTO ET. AL. 1957)

Fig. N° 34.

GEOCHEMICAL SECTIONS OF THE WESTERN GHATS (INDIA)

DISTRIBUTION OF ALUMINA

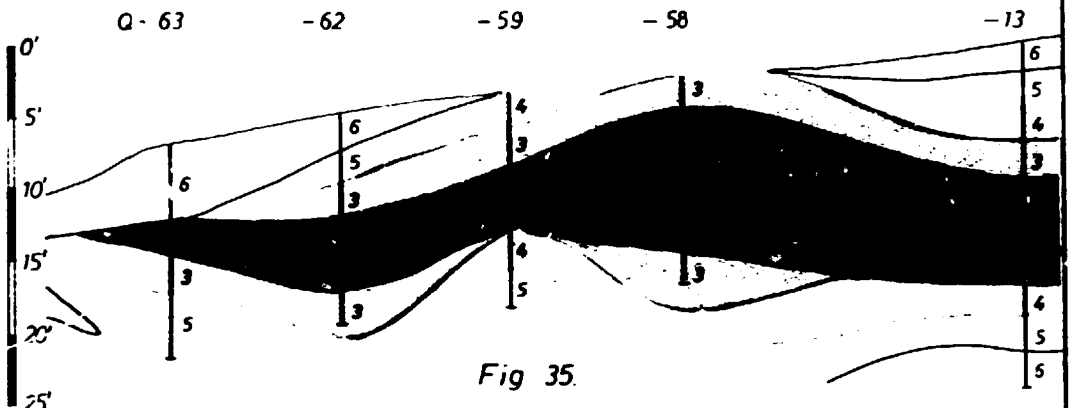


Fig 35.

Legend:

Al_2O_3

1 > 50% 4 35-45
2 45-50 5 30-35
3 40-45 6 25-30%

0 20 40 60 80 100m

GY. KOMLÓSSY 1976.

DISTRIBUTION OF SILICA

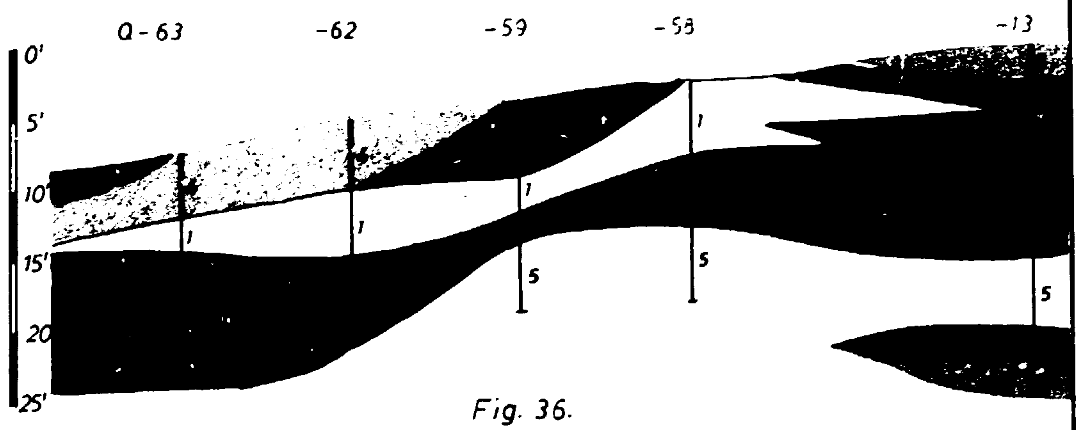


Fig. 36.

Legend:

SiO_2

1 < 5 percent 4 15-20
2 5-10 5 20< percent
3 10-15

0 20 40 60 80 100m

GY. KOMLÓSSY 1976.

of alumina. Ultimately this dissolution leads to a kind of depletion of alumina from the uppermost horizons of the lateritic profile, but it promotes also lateral and vertical movement and thus the absolute accumulation (reprecipitation) of alumina compounds at the same time.

Distribution of the alumina and silica content in a typical lateritic profile is shown by Figs. 35. and 36.

The solubility of colloidal and clay-bound silica increases slowly but steadily up to pH 8 but beyond 8 the increase becomes suddenly sharp and at pH 9 the solution may have a silica concentration as high as 4 millimols pro litre already. This is why a ground-water pH near 9 is so essential to be reached - at least temporarily - during bauxitization.

According to KRAUSKOPF (1967) the solubility of quartz is 0.1 times that of the chemically-bound silica. This is why intact quartz grains occur frequently not only in laterites but also in lateritic bauxites formed on the surface of quartz-bearing rocks (e.g. granites or sandstones).

The behaviour of iron-oxide is somewhat different from that of alumina. Experience shows that it occurs mostly in the form of ferric iron (Fe^{3+}) while the role of bivalent iron - apart from scarce local concentrations - is insignificant. Iron-hydroxides precipitated in an alkaline medium become unstable when submerged into acidic solutions. Beyond pH 4 a slow dissolution commences. In acidic media bivalent iron may rather soon be completely lost from the system while part of the ferric compounds - being present always in larger quantities - may remain intact for considerable lengths of time.

Due to high temperatures evaporation is rather intense within the tropics, thus solutions of hydrous iron become

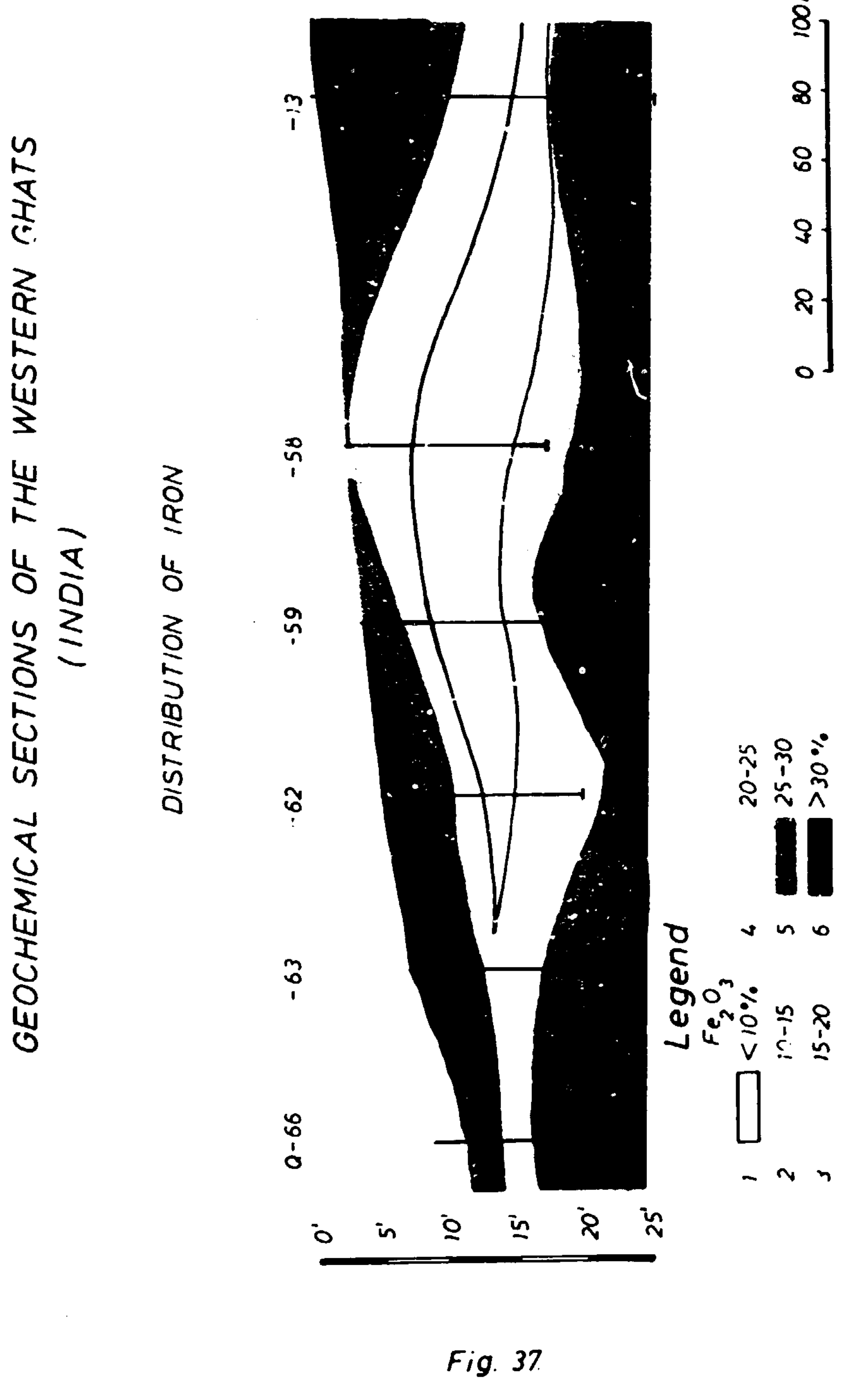

GEOCHEMICAL SECTIONS OF THE WESTERN GHATS
(INDIA)
DISTRIBUTION OF IRON
a-66
-63
-62
-59
-58
-13
0'
5'
10'
15'
20'
25'
0
20
40
60
80
100m
Legend
Fe2O3
1 < 10%
2 10-15
3 15-20
4 20-25
5 25-30
6 >30%

Fig. 37

soon concentrated. By concentration the pH of the solution is increased and ironhydroxide reprecipitates within short distances.

According to STEVEN (1964) under constant humidity conditions, increasing insolation and temperature decrease the proportions of nitrogene and other organic materials in the soil. Accumulation of considerable amounts of organics is possible - as a rule - only when mean annual temperatures do not surpass +25 °C. Above +25 °C the rate of decay exceeds the rate of accumulation. Since lateritization is a process going on in zones of high annual temperatures, laterites are generally poor in organics. Decrease of the organic content results in an incrase of the pH as a consequence of which also the solubility of silica increases. At pH 8.5 precipitation of ferro-hydroxides commences.

Hot climates with mean annual temperatures higher than 25 °C are generally characterized by scarce (500 to 1200 mms pro year) or moderate (1500 to 3500 mms pro year) seasonal rains. Instead of large uninterrupted rain forests, hot and dry areas like this, are covered only by open woodlands or grasslands of savannah-type vegetation. The role of insolation and evaporation is of course much more important here than in the forest belt and considerably accelerates the decay of organic matter. The lack of organics is one of the main factors held to be responsible for the prevalence of iron-laterites over bauxites in the "hot zones".

The distribution of the iron-oxide content of a typical lateritic complex is shown by Fig.No.37.

When rainfall exceeds 5000 mms pro year erosion by heavy torrential rains leads to a rate of denudation higher than the rate of lateritisation, however intense it is. Sometimes a thin layer of ferruginous laterite demonstrates the unstable equilibrium between weathering and denudation, but in most of the cases the weathering product is striped off completely by erosion. Of course as a consequence of the absence of a thick laterite-cover bauxitization is out of the question here.

Biological factors

Lateritization - including bauxitization - is a process affected to a considerable extent also by biological factors. Biocoenosis consisting of plants and lower animals are most important in this connection. Depending on climate, topography and soil conditions their global distribution exhibits a clear zonal character (cf. belts of deserts, savannah grasslands, savannah woodlands and rain forests). Soil, vegetation and bacterial life are in continuous interaction and may vary locally within each of these regional zones, however.

The 700 to 800 m high Atewa Range (Ghana) is covered for instance by a dense rain forest with all the characteristic strata developed completely (Triplochiton scleroxylon, Entandophragma utile, Khaya ivorensis, Ceiba pentandra, etc.). It consists of various kinds of palm trees, luxurious colonies of epiphytes, parasites, ferns and an underwood of shrubs and short-trunk trees. The root-system of tropical trees is strong but rather shallow and consists mainly of laticostate pillars and near-surface prop-roots. Deep roots occur occasionally only.

Humification is restricted to a rather narrow zone (down to about 2 metres below ground surface) where humic acids produced by decaying leaves and other plant litter are yet present. Below this zone an equilibrium is established between the downward percolating acidic waters and the ground-water, thus soil-formation can not be maintained any more.

Swamp vegetation - be it temporary or permanent always differ from its surroundings. Due to frequent fluctuations of pH (alternating acidic and alkaline environment) it is characterized by euryecious uliginal plants such as the Borassus palms, the Pandanus candelabra, Marantacloae and various species of sedges.On decay plant cells are dissolved by water and carried away by overflow during the rainy season. Despite large masses of plant litter produced by the luxurious vegetation there is no notable fossilization in the swamps. This apparent contradicton is probably due to frequent fluctuations of the oxidation potential and to high temperatures throughout the year.

Dense forest together with the abundant rainfall, humidity, high temperatures and large amounts of decaying leaves, produce an environment favourable for various cultures of soil bacteria. Most important of all is the effect of chemotrophic bacteria such as the Ferrobacillus group or the nitrogen-fixing bacteria. By destruction of plant litter they keep the organic content of the soil generally at a constant level. When the state of equilibrium between formation and destruction of organic matter is disturbed by any extraneous factor, an increase in organics may occur, however. Although the role of bacterial life in soil formation and lateritization is yet far from completely understood and needs further careful investigations to be explained, one thing is for sure already: formation of iron-rich "hardpans" (cuirassee) is due - in a great part - to the action of soil-bacteria. This means that - although indirectly (by promoting the formation of iron hard-caps) - bacterial life helps also to protect the soft bauxitic complex against subsequent erosion.

Soil biota affect the alteration of minerals both mechanically and chemically. Chemical weathering of rock fragments and mineral grains is considerably enhanced in the soil zone by various acidic compounds produced during the assimilation-dissimilation processes of micro-organisms. They equally promote the destruction of organics and anorganics and take their part also in alteration of the clay minerals.

Chemical weathering is preceded as a rule by mechanical disintegration, which may also be effectuated partly by biological factors, especially by soil fauna. The activity of insects like termites or burrowing bugs and cast-making earth--worms may considerably increase the porosity of the soil and promote the penetration of roots toward greater depths. By prising apart joint blocks of the parent rock roots contribute also to the advance of chemical weathering and thus to lateritisation.

Structural geological factors
The role of epeirogenic uplift and subsidence

It was mentioned already that presentday lateritization is possible within the tropics only and that it necessitates also favourable morphological conditions. In other words this means that laterites are generally bound to flat terrains of certain well-defined topographic horizons. (The optimum altitude is thought to be between 500 and 1500 metres above sea level). They may however be removed from this optimum position by subsequent regional uplift or subsidence, and if so, they may undergo of course also the corresponding climatic--microclimatic variations (change of temperature, insolation, rainfall, humidity, vegetation cover, etc.). When uplifted, for instance, they may enter altitudes of lower temperatures where resilification of the bauxitic members of the lateritic profile commences (see Lichenya Plateau in **Malawi**).
To sum up all, bauxites of old plateau-type laterite caps may either be upgraded or degraded when subject to epeirogenic movements.

Regional uplift may increase also the intensity of denudation and by so doing, it may influence morphological evolution as well as the drainage system. All this may be of profound influence on the evolution of both the lateritic profile and the lateritic plateau itself (see Fig.No.33.).

Effects of plate-tectonic movements

The only feasible explanation of bauxitic palaeo-laterites of the temperate and polar zones of the Earth (e.g. Tajmir) lies in assigning them to continental drift or plate-tectonic movements. Using the DIETZ-HOLDEN reconstruction as a base map BÁRDOSSY (1975) elaborated a new geotectonic model that explains rather well the distribution of Palaezoic bauxites. According to this model the formation of Palaezoic bauxites was controlled primarily by the position of the continents as related to the climatic conditions (i.e. major climatic zones) of the Palaezoic era. Karstic bauxites were formed for instance in orogenic belts of the tropics and subtropics, where collision of large continental masses had been realized by breaking up of the large plates on to several micro-continents (cf. with the Mediterranean or the Caribbean region).

Effects of polar-wandering

The effects of polar-wandering can not be neglected either when looking for an explanation of global distribution of laterites. As evidenced by Carbonian coal-seams of the Spitzbergen or Permian glacial sediments of the tropical areas of the southern drylands,there must have been several major climatic changes during the Earth's hystory. Since these changes can not be explained by plate-tectonic movements alone, it is inevitable to count also with the variations of the position of the polars throughout the Earth's history. The extent to which these variations may have influenced the global distribution of laterites is, however, not yet fully understood. It is suggested, that climatic changes due to polar variations have most probably affected the old laterites of Tajmir, situated right beyond the Arctic Circle (discovered in the early seventies) or the deposits of the Northern Ural and Tyihvin.

The well-known Quaternary advance of the Sahara on to the areas of presentday Upper Volta is supposed to have been the effect of a southward-drift of the humid climatic zone, which might have been caused also by polar variations. As a matter of fact lateritic profiles formed under more humid conditions of the Tertiary and Early-Quaternary periods are dead or being resilified now because the climate is too dry to facilitate allitization here.

Local structural factors

As to the formation of bauxitic laterites, local structural factors, that is, tectonics on the small scale may be at least as important as plate-tectonics on the global scale.

Block-faulting of extensive lateritic plateaux results in dissection on to smaller units, which subsequently may undergo a highly differentiated morphogenesis. Disjointed downthrown blocks become then sites of accumulation of eroded material coming from higher elevated remnants of the original plateau. The result is a complex system of small, bauxitiferous or lateritic plateau-remnants representing various stages of denudation.

Age

It was generally accepted during the past decades that bauxitization needs long lasting - at least some millions of years long - atectonic periods. Today it is beyond question that laterites as young as a few hundreds of thousand years may exist. As evidenced by the age of the parent rock the age of subrecent laterites covering the Quaternary basalts of Hawaii, Panama and Columbia is less than a million year.

Although the weathering profiles of these occurrences (Koloa Series, Popayan Series, etc.) are yet far from being mature, they contain considerable amounts (millions of tons) of bauxite-grade material already. According to the latest mineralogical investigations (NEMECZ 1973) reversible transition of kaolinite into gibbsite is a process that may go on rather quickly on the elementary scale. When under ideal conditions it does not take much time on the regional scale either: several metres of silicate rocks may be transformed into clayey weathering products within ten-thousands of years only.

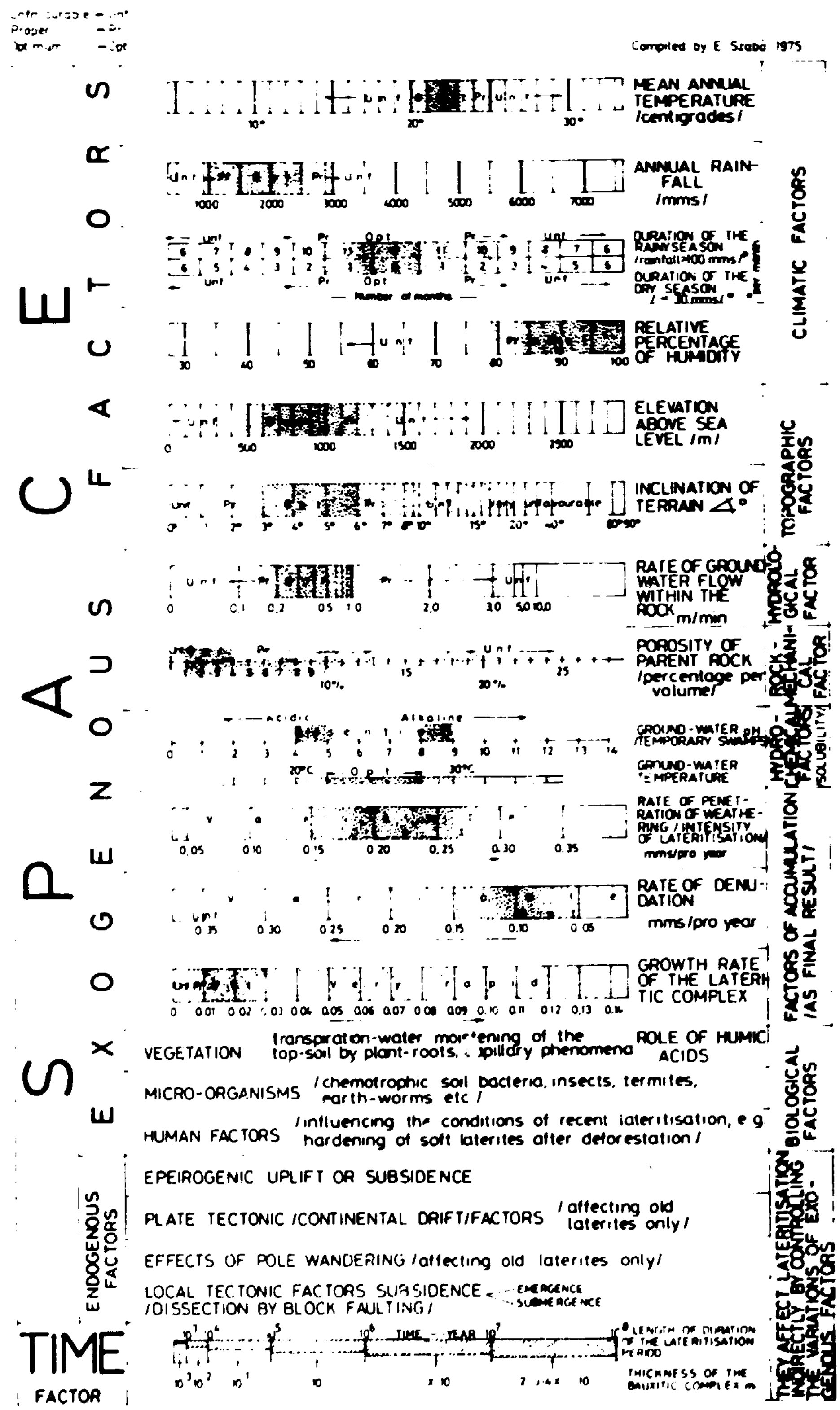
SUMMARY

As to the optimum conditions of lateritization, the following intervals could be established on the basis of the investigation of the effect of all influencing factors: (Table No.1.).

This table may serve as a usable reference when prospecting for bauxitic laterites in remote areas. Selection of the most promising areas and drawing up of preliminary reserve forecasts may be carried out easily by systematic analysis of the prerequisites of lateritization and bauxitization. (For convenience, optimum intervals - i.e. figures most favourable for accumulation of alumina and depletion of silica - are marked by deep colourings in every column of the table.)

Table N° 1

FACTORS OF BAUXITIZATION OF PLATEAU TYPE LATERITES



It should be emphasized, however, that field observations can not - under no circumstances - be substituted simply by using the table. Field checks and sampling including also laboratory analysis of the collected samples are inevitable to obtain reliable results. The table should be relied on at the very first stage of reconnaissance only; in remote areas; and merely with the aim of ruling out the unpromising terrains.

3. PHYSICAL PROPERTIES, CHEMISTRY AND MINERALOGY

Planning of any proper mining method or processing technology requires profound knowledge of both the chemical and mineralogical composition and the physical properties of the ore in question.

The proportion of bauxites to the total volume of sedimentary rocks of the Earth is less than 0.001 per cent. This means that bauxites do not belong to the commonest mineral resources. As to chemical composition their main constituents are hydrous oxides of alumina, iron, to a lesser extent titania and various percentages of kaolinite and quartz. They may contain also accessories: 0.01 to 1.0 per cent of Ca, Mg, P, S, Mn, V, Cr, Fe^{2+}, Zr and RE-compounds; carbonates and organics.
The most important "bauxitophil" trace elements are: Ga, Be, Mo, Zn, Ni, Cu, Co, As, Na, K, Ba, Pb and B, the amount of each of which is between 0,1 and 100 ppm. As to mineralogy: boehmite, gibbsite, haematite, goethite and kaolinite are to be mentioned as principal minerals (see also Para No.3.3).

3.1. PHYSICAL PROPERTIES OF HUNGARIAN BAUXITES

Macroscopically bauxites are fine-grained (seemingly amorphous) compact rocks, generally rather soft (closely resembling clay). They have an inhomogenous appearance, with various colourings from white through shades of yellow and red to purple and even green. The most common bauxites are red-coloured or russet with light patches or strikes. All shades of red and yellow are attributed to the presence of iron-compounds. Tint and brightness of the colours depends on relative percentage, nature and grain-size of the iron--minerals. Spherical, often concentric textural elements (pisolithes or oöides) are rather common in bauxites. They are mostly pea-like but sometimes reach even the size of a small nut. Their iron-content is usually higher than that of the groundmass, they are darker-coloured and have a shiny appearance. As to structure and texture bauxites may be earthy, brecciated or clastic, sometimes they may form even true conglomerates consisting of large bauxite-boulders; but there are hard, homogenous-looking, compact varieties, too. (see also Ch.3.4.2.).

The hardness of bauxites varies on a rather wide scale, from soft (plastic) up to 7 or 8 Mohs-degrees. The hardness of Hungarian bauxites is generally around 1 to 2 with the exception of the diasporic Nézsa deposit where the ore is as hard as 6 to 7 on the Mohs-scale.

Hardness is determined essentially by the mineralogy of the sample; the role of chemical composition is subordinated in this context. (Diasporic bauxites are always harder than boehmitic ones, even if having identical chemical composition.) Since mineralogy may profoundly be influenced by tectonic movements, tectonics - although indirectly - also affects hardness. The fracture-surfaces in soft, compact bauxites are "earthy", while in the hard varieties they may be conchoidal with a characteristic soapy lustre.

The run-of-mine ore has generally 10 to 20 per cent adhesive moisture. Specific gravity is 2.0 to 2.6 grams pro cubic centimetres (wet!). The highest figures were recorded in the Nagyegyháza deposit. Bulk density of the dryed ore is 1.7 to 2.0 only (see also 3.6.1.).

3.2. CHEMICAL COMPOSITION

3.2.1. Main constituents

The five main components are alumina, silica, ironoxide, titania and "loss on ignition" (i.e. combined water obtained by calcination of dried sample). According to the geochemical classification set up by SZÁDECZKY-KARDOS,E. (1955), aluminium belongs to the so called litho-oxyphil group of elements, silicium is lithophil, iron is siderophil while titania is light--pegmatophil.

Concentration-factors representing the relative enrichment of these elements in Hungarian bauxites with respect to the Earth's crust averages are as follows:

Table No.2.

Elements	Earth's crust averages (ppm) (VINOGRADOV)	Concentration factors
Al	88,000	3.0
Si	276,000	0.3
Fe	51,000	2.5
Ti	5,000	2.5

These concentration factors fall well within the range of typical karstic bauxites. From the point of view of alumina production the decisive components are alumina and silica. Economic specification of bauxites is based essentially on the ratio of these two ($M=Al_2O_3/SiO_2$) but lately - especially in the case of high percentages of impurities, also the so called "figure of merit" ($B=Al_2O_3-3SiO_2-CaO-2MgO$) became widely used as a criterion of economic utilization.

Chemical composition of hungarian bauxites as expressed by the concentration factors of four of the five main components are shown in Table No.3.

Table No.3.

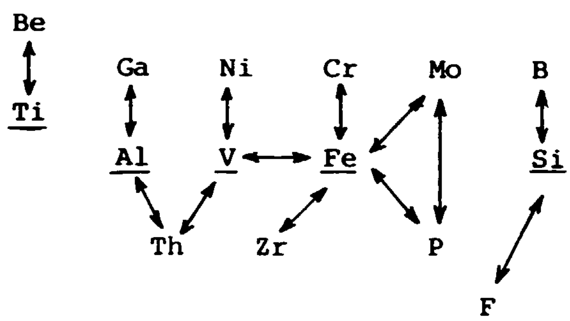
Occurrence	Al	Si	Fe	Ti
Halimba	3.0	0.15	3.2	2.2
Nyirád-Nagytárkány	3.1	0.10	2.9	2.3
Fenyőfő	2.9	0.15	2.3	2.2
Bakonyoszlop	2.9	0.16	3.5	2.2
Iszkaszentgyörgy	3.1	0.16	2.4	3.2
Iharkút-Németbánya	3.2	0.10	3.2	2.5
Nagyegyháza-Csordakut-Mány	3.0	0.07	3.5	3.3
Gánt	3.0	0.24	2.4	2.3

Frequency-distribution curves of the above main components, together with those of the trace elements and "impurities" can be classified as follows:

1) normal-distribution with one distinct maximum
   (Al, Ti, Mn and at places also V, Fe and Be belong here)
2) elongated curve with one maximum
   (V, Fe, (P) /=the latter only rarely/)
3) two-maximum curves
   (Cr, P, partly Ga and Zr)
4) curves with several maxima
   (Si, Ga, Zr, Ni)
5) irregular curves
   (Ca, Mg, S)

Detailed geochemical investigations and statistical evaluation of industrial grade reserves of a number of various occurrences proved that most of the important chemical components are closely correlated. The strong negative correlation between alumina and silica is an overall rule, and the positive correlation of Al with Ti, Be and Ga is also rather distinct. The correlation of Fe and Cr is distinctly positive. The relatjonship of Al to Fe and either of these to Ti, V or Ga is uncertain, correlation coefficients of both positive and negative sign were observed. Ga generally follows the trerd of Al while V seems to be a "satellite" of iron.

The above interrelations are demonstrated by the following tripartite diagram:



(Ca, Mg and S are not included in this scheme, because their distribution is irregular and they are obviously so unlike to all the other elements that they may even be called "bauxitoxen" elements that is, they are "foreign" in the geochemical environment of bauxitization.)

The close resemblance of geochemical behaviour of bauxitophil elements can be explained by near-identical figures of their ionic potentials (=ratio of ionic radius to ionic charge or valency), which are demonstrated very well on the diagram of SCHROLL and SAUER (1964). (See Fig.No.38.).

IONIC POTENTIALS OF BAUXITOPHIL ELEMENTS

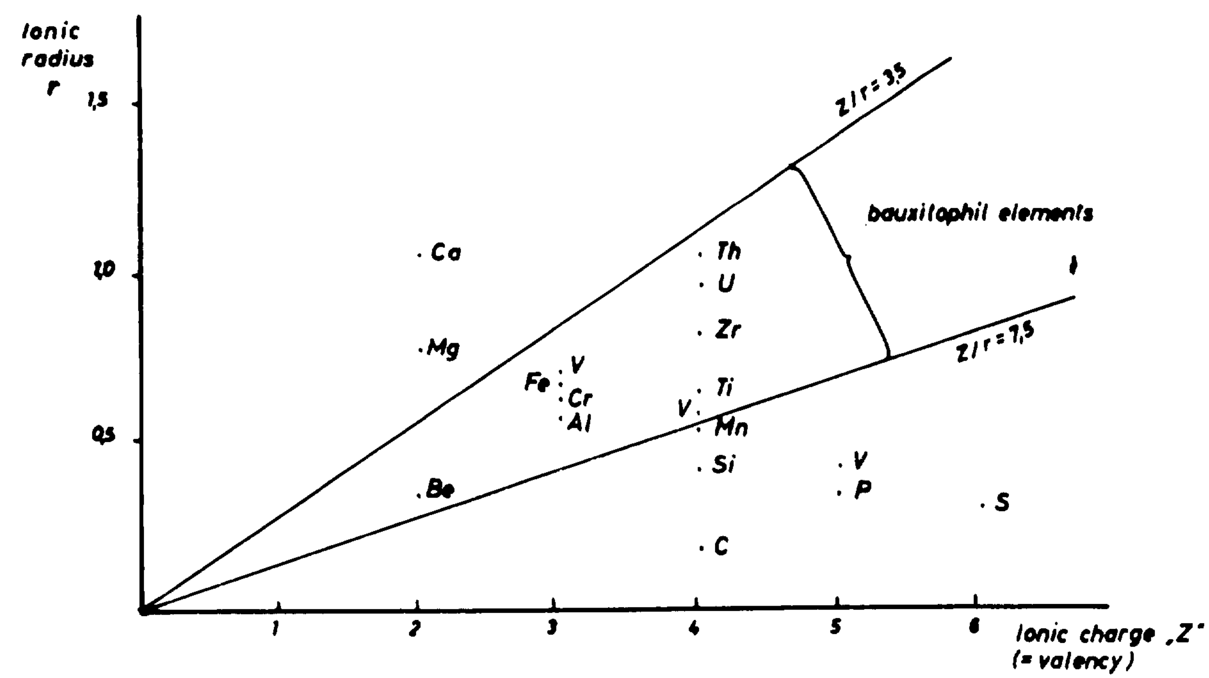


Fig. N° 38.

3.2.2. Impurities

Beside the five main components bauxites may contain considerable amounts of accessory elements part of which are undesirable for the alumina production. All constituents resulting either in losses of caustic soda or in deterioration of the end--product of the Bayer-process and thus in raising the costs of alumina production are called impurities.The economic value of any given bauxite is considerably decreased when impurities are present in percentages higher than a certain limit of tolerance. The most common impurities of Hungarian bauxites are carbonates (dolomite, calcite, siderite), phosphates (crandallite, apatite), sulfides (pyrite, marcasite) and organics, obtained by various calculations from the percentages of CaO, MgO, $FeCO_3$, P_2O_5, total sulphur and organic carbon of the chemical assay.

As to origin, impurities can be divided into two distinct groups:

- impurities of primary origin (their accumulation can probably be attributed to some synsedimentary process)
- impurities of secondary origin (deposited during post--sedimentary processes)

The accumulation of impurities belonging to either of the above groups is controlled essentially by geological and environmental conditions of the deposition of the bauxitic sediment on the one hand and of the immediate overlying strata on the other.

In Hungary bauxites rest on the surface of Triassic carbonates (dolomites and limestones, (cf. with 2.1.2.1.) and are covered generally by various members of an Eocene swamp-sequence consisting of lagoon-facies clays, argillaceous marls, lignitiferous clays and, at places, of coal--seams. Redeposition of reworked bauxites mixed with dolomite and limestone debris coming from the eroded surface of higher elevated dolomite and limestone blocks resulted in the accumulation of considerable amounts of carbonatic impurities in some of the occurrences (e.g. in Halimba or parts of Nagyegyháza).

Grey bauxites form on reduction by acidic solutions coming from the overlying swamp or lagoon. Ferric iron of the primary bauxite minerals is transformed into ferrous iron, which combines with the sulphur content of the descending swamp-water to form finely distributed pyrite and hence the grey, greenish--grey colour of the bauxite.

The partly diagenic partly epigenic sideritization of the Nagyegyháza bauxites can be attributed also to secondary physico-chemical processes, set off by the presence of swamp--waters.

The formation of crandallite (P!) and the accumulation of organics in bauxites are also due partly to secondary processes, but - as far as organics are concerned - syngenetic temporary pools formed during longer or shorter breaks of deposition of bauxite may also have played an important role.

Reworking and redeposition of the uppermost parts of the bauxite deposits and the admixture of dolomite or limestone debris observed in several occurrences are the results of secondary, mechanic processes such as wave-action along the shorelines of the advancing sea, etc. At places there are also lenticular bodies of quartz-sands and pebbles interbedded in the upper parts of the bauxitic complex. Impurities of mechanical origin like these are bound, however, always to deposits covered by sedimentary sequences of near-shore litoral origin, and are the signs of a particularly "high-energy" environment.

Concentration-factors of the most important impurities of Hungarian bauxites are presented in the followings:

Table No.4.

Occurrence	Ca	Mg	P	S
Halimba	0.24	0.12	0.75	3.2
Nyirád-Nagytárkány	0.16	0.11	0.68	3.8
Iharkút-Németbánya	0.14	0.06	2.75	0.8
Bakonyoszlop	0.16	0.06	0.62	1.8
Fenyőfő	0.06	0.03	1.5	1.2
Iszkaszentgyörgy	0.12	0.07	2.0	3.4
Gánt	0.18	0.10	1.5	1.2
Nagyegyháza	0.18	0.09	4.4	2.2
Csordakút	0.20	0.08	5.9	1.8
Mány	0.17	0.08	5.62	2.8

3.2.3. Utilizable accessory components

There are accessories e.g. V, Ga, F or As - which unlike impurities may be even of economic interest. Part of these "useful" accessories become available during the digestion phase of the Bayer process and are dissolved in the aluminate-liquor in the form of complex sodium-accessory salts. For technological reasons they are to be regularly removed from the cycle (the presence of any accessory, be it even so useful, is namely a disadvantage from the point of view of the balance of the liquor-circuit). While the extraction of the undesired compounds is a compulsion on the one hand it may, however, provide valuable materials of commercial interest on the other. In Hungary at present only Ga and V are being extracted from the aluminate liquor (the former is a byproduct of the Ajka Alumina Plant the latter is that of Mosonmagyaróvár).

3.2.4. Trace elements

The geochemical behaviour and the distribution pattern of trace elements can be disclosed by systematic investigation and evaluation of the trace element content of representative samples(or representative sections) collected from deposits of various geological setting.

Up to now spectrography proved to be the most suitable analytical method for this purpose. During the preliminary stage of prospecting trace element content of the samples is determined by a semiquantitative spectrographic method (for 20 to 23 elements) while in the detailed exploration phase the most important trace elements are assayed quantitatively.

Trace elements exceeding the Erath's-crust average ("Clark") in Hungarian bauxites are Mo, B, V, Ga, Zr, Cr, Ni, Mn, Nb and at places Be and Sr. Concentration factors shown by Table No.5. below were obtained by calculating with Earth's crust averages established by SZÁDECZKY-KARDOSS,E. (1955).

Table No.5.

Elements	concentration (max.)	factors (max.)	Concentration factors (averages)					
			Nyirád	Fenyőfő	Gánt	Halimba	Iszka	Nagy-egyháza
Be	0.37	37.0	1.0	0.9	0.83	0.9	3.0	1.3
B	3.10	93.3	-	-	-	25.0	25.0	-
V	0.73	10.0	5.4	3.2	4.8	4.1	4.4	6.9
Cr	0.07	4.0	2.4	1.2	1.2	1.6	1.4	2.3
Mn	-	36.6	0.7	3.0	0.7	1.4	1.4	1.6
Ni	0.47	3.1	1.8	-	1.3	-	-	2.5
Ga	0.42	8.6	2.5	2.7	2.8	2.6	2.4	1.9
Sr	0.04	8.7	-	-	-	0.8	6.8	-
Zr	0.35	9.0	2.8	1.9	2.7	1.7	1.7	2.7
Nb	1.70	10.o	-	3.5	-	4.9	7.7	-
Mo	1.65	21.5	-	-	-	9.5	16.0	-

As to the details of frequency distribution of the trace elements and their correlation with the five main components see Chapter 3.2.1. on page 115.

3.3. MINERALOGY

Mineralogy of the ore is one of the most important properties both from the miners'and from the alumina technologists'point of view. Identification of the bauxite-minerals had, however, been an unsolved problem for long, because the details of the extremely fine-grained structure were impossible to study under the conventional petrographic microscopes. Mineral percentages were calculated from the figures of chemical analysis. The introduction of thermal analytical methods resulted in a revolutionary change of the situation. Using the ERDEY-PAULIK-PAULIK system (=Derivatograph) quantitative mineralogical analysis of any fine-grained crystalline substance became a routine procedure.

Methods of X-ray diffraction had widely been used for the solution of bauxite-mineralogical problems right from the twenties on, the exact quantitative assay of the bauxite--minerals, however, became possible during the mid-sixties only when BÁRDOSSY,Gy. and co-workers elaborated the combined method of quantitative bauxite analysis (calculation of mineral percentages by combined evaluation of the DTG-curve the X-ray diffractogram and the chemical assay of the sample).

As to chemical composition most bauxite-minerals are essentially oxides and hydroxides of various metals but considerable amounts of silicates, carbonates, sulphides, phosphates and sporadically sulphates and vanadates may also be found in most bauxites. The four main rockforming elements are Al, Fe, Si and Ti.

Oxides and hydroxides of alumina

Boehmite AlO(OH)

Its amount is around 40 to 60 per cent on the average. It is the most common Al-mineral of Hungarian bauxites.

Gibbsite $Al(OH)_3$

With 20 to 30 per cent on the average it is the second commonest Al-mineral of Hungarian bauxites.

Diaspore AlO(OH)

After boehmite it is the second-commonest mineral of karstic bauxites. With 1 to 2 per cent on the average, in Hungary it is subordinated, however. (The only exception is the diaspore-bearing bauxite of the abandoned Nézsa open-pit in North Hungary).

Iron minerals

The scope of iron minerals is much wider than that of the minerals of alumina. Except in kaolinite Al is almost exclusively bound to oxygen and water, while among the iron--compounds we can found a wide range of various sulphides, carbonates and silicates as well.

Oxides and hydroxides of iron

Haematite Fe_2O_3

The most common iron mineral of all karstic bauxites (also of the Hungarian ones). In part of the cation positions ferric iron may be substituted by the isomorphous aluminium (=alumo-haematite). The limit of tolerance is 14 molar per cent for the haematite structure.

Goethite $FeO(OH)$

The second-commonest iron mineral of karstic bauxites. The average goethite content of Hungarian bauxites is around 5 to 10 per cent with a maximum of 20 to 25 per cent at Iszkaszentgyörgy. Similar to what was discussed under haematite, part of the ferric iron may be substituted by Al (alumo-goethite) here, too. Recent investigations show that there is a positive correlation between the percentages of goethite in a given sample and the rate of Al-substitution in the goethite-structure (the higher the relative percentages of goethite are, the more ferric iron is substituted by Al. The Al-content of the Iszkaszentgyörgy-goethites reaches even the 30 per cent).

Maghemite γ-Fe_2O_3

It is a scarce but steady constituent of bauxites of several karstic occurrences. In Hungary 1 to 4 per cents of maghemite were recorded in most of the deposits. It seems to be present more likely in grey or secondarily reoxidized, pyritiferous bauxites, than in the ordinary red ones.

Minerals of titania

The scope of Ti-minerals is by far not so wide than that of the iron-minerals and also the percentages of Ti--minerals are rather low in most bauxites.

Anatase TiO_2

The most common Ti-mineral of karstic bauxites (70 per cent of the Ti-content is bound to anatase). It forms very fine, submicroscopic crystalline aggregates in the groundmass of the bauxite.

Rutile TiO_2

The second-commonest Ti-mineral. (30 per cent of the Ti content is bound to rutile in the Hungarian bauxites.)

Ilmenite $FeTiO_3$

Third-commonest Ti-mineral. Mainly of clastic origin. Average concentration: 0.0X per cent with a maximum of above 1 per cent in the Nagyegyháza deposit.

Oxides and hydroxides of manganese

The most common Mn-mineral of karstic bauxites is lithiophorite ($Li_2Al_8Mn_2^{2+}Mn_{10}^{4+}O_{35}.14H_2O$). In Hungary it was identified first in the Bakonyoszlop and Fenyőfő deposits.

Silicate-minerals

Kaolinite $Al_2Si_2O_5(OH)_4$

The most common clay mineral in karstic bauxites. According to the degree of crystallinity there are several structural variations of kaolinite to be distinguished. The kaolinite of the Hungarian bauxites is generally of the partly disordered fire-clay type. 90 per cent of the silica content of Hungarian bauxites is bound to kaolinite.

Quartz SiO_2

Mainly of clastic origin, and not more than 0.X per cent.

Carbonates

Calcite $CaCO_3$

It is rather common in most hungarian bauxites, but its amount rarely exceeds a few per cents and generally remains within the order of O,X per cent. Percentages exceeding 10 per cent observed in the uppermost parts of the Alsópere bauxites are considered to be exceptional.

Dolomite $(Ca, Mg) CO_3$

In the form of minute rock-debris or pebbles it is a common constituent in nearly all bauxite deposits of Hungary; individual crystals are, however, rather rare.

Exceptionally high concentrations of dolomite were recorded during the early sixties in the large Halimba deposit.

Siderite $Fe(CO)_3$

The siderite content of hungarian bauxites does not exceed O,X per cent on the average. Maximum figures as high as 20 per cent were recorded only in the uppermost horizons of the Nagyegyháza-Mány-Csordakút deposits. As evidenced by a sharp downward decrease, this exceptionally high siderite content is obviously the result of some secondary (descendent) mineralization.

Sulphides

Pyrite FeS_2

The most common sulphide mineral of karstic bauxites. It is concentrated as a rule in the grey reductive varieties, but there are also exceptions (red, high-sulphur bauxites). The sulphur content of grey bauxites is 5 to 10 per cent on the average but at places figures as high as 15 to 20 per cent were also observed. The most significant occurrences of pyritiferous bauxites are those at Nyirád-Nagytárkány-Darvastó, but clear signs of pyritization are known also from Iszkaszentgyörgy, Halimba and Nagyegyháza as well.

Marcasite FeS_2

When occurs, it is almost always closely associated with pyrite. Isolated patches of marcasite are rare; percentages low.

Sulphates

Alunite $(K,Na)Al_3(OH)_6(SO_4)_2$

Most common sulphate mineral of karstic bauxites. Forms isolated pockets or concretions several millimetres or even centimetres across. It is mostly a product of pyrite-oxidation.

Phosphates

Crandallite $Ca,Al_3H(OH)_6(PO_4)_4$

Most important phosphate mineral of Hungarian bauxites. It is finely dispersed, mostly of submicroscopic size. The average percentages are around 0.1 to 1.0 with exceptionally high concentrations in the Nagyegyháza-Csordakút-Mány and Iharkút deposits. The amount of crandallite-bound P_2O_5 may be as much as 2 per cent of the total P_2O_5-content.

3.4. STRUCTURE AND TEXTURE

Since the german-russian concept of structure and texture differs basically from what is called texture and structure in the anglo-saxon sense, it seems to be useful to make clear that in this booklet hereinafter we use the terminology of BREWER,R. (1964), that is:

"structure is the physical constitution of the" rock "material as expressed by the size, shape and arrangement of the solid particles and voids; fabric is the element of structure which deals with arrangement" while "texture is the physical constitution of the" rock "material as expressed by its structure and by the degree of crystallization (=crystallinity) of the "rock" particles. Fabric is a part of structure which is a part of texture in this context" (italics mine).

The term primary rock- or sediment-structure includes all morphological properties of the rock arising from regular or irregular association of rock materials of different physical constitution (texture, structure, fabric), and/or composition. "Primary rock structure" refers always to properties brought about directly by the processes of sedimentation (e.g. primary bedding (regular or irregular), turbidite-like mud-flow structures), etc.

The concept of secondary rock structures refers to all morphological properties resulted by processes posterior to sedimentation. They may be of atectonic or tectonic origin. (Examples are: shrinkage cracks, foliation (=atectonic); joints, fissures, or fault-planes, etc. (=tectonic).

3.4.1. Megascopic structural- and textural features

Lateritic bauxites

Since aluminous laterites are invariably bound to lateritic weathering products and occur in the form of more or less continuous layers or lenticular bodies connected to certain horizons of the lateritic profile, their most striking primary structural and textural features are of course controlled by the processes of lateritic weathering.

Depending on the rate of weathering and the nature of the elementary processes of lateritization (direct or indirect alteration of the primary silicates) the weathering product may exhibit either "inherited" or "diagenic"* structural characteristics. Whether one or the other of the two becomes predominant depends on local petrological hydrogeological and geomorphological factors (see also 2.3.2.).
Since every horizon of the lateritic profile is characterized by a certain set of elementary processes (leaching out of bases; decomposition; neomineralization; absolute accumulation of sesquioxides; etc.) it is quite natural that lateritic bauxites bound to different horizons are somewhat different also from the structural point of view. Similarly there is a more or less pronounced structural difference also between lateritic bauxites formed above different parent rocks (this difference can be attributed to the petrochemical control of the weathering environment).

In order to provide a rapid glance over the most common megascopic textures and primary structures of lateritic bauxites a short glossary is presented below:

*since the differentiaiton between diagenic and epigenic structures is quite illusory, they will be referred to hereinatter simply as diagenic.

<u>Most important inherited ("relic") structures</u> (=structures of the parent rock retained in the weathered material).

1) sedimentary structures, like bedding, lamination, etc.
2) metamorphic structures, like schistosity, gneiss--structures, etc.
3) granular structures (holocrystalline)
4) porphyric structures (basaltoid)
5) amygdaloidal structures (basaltoid)
6) brecciated structures

Bauxitic laterites built up of relic-structures are generally of higher porosity but less hard than the bedrock; they are pale-coloured (whitish, yellow or reddish) and the boundaries of the elementary structural units they consist of, are faint. They are generally more common in lateritic profiles found on the surface of easily laterisable rocks (such as basic volcanics or intrusives) than on the surface of acidic or intermediate rocks. That means that the weathering of acidic and intermediate rocks may lead to the formation of bauxite-grade Al-laterites under extremely favourable climatic and morphological conditions, and locally only (e.g. at places of extraime--good drainage).

<u>Diagenic structures</u>

1) "clayey", soft
2) earthy
3) porous
4) spongy
5) vesicular (vesicles are smoothed, regular voids
6) alveolar (having small cellular units like honey-comb)
7) vermicular (vermiform)

} (items 5–7) the pores or vesicles may or may not be filled (lined with various kinds of earthy or crystalline material)

8) nodular (nodules are globular, three-dimensional units with an undifferentiated internal fabric)
9) concretionary pisolitic, oölitic (consisting of concretions, concentric pisolits, or oöids, loose, or cemented)
10) indurated (bauxite-pisolites and -pebbles in a light to dark grey or brown cherty-looking matrix which consists of kaolinite, halloysite or gibbsite)
11) brecciated, gravelly
12) laminated (with Liesegang-rings formed by dissolution-reprecipitation processes taking place within the colloidal-size gel-like material).

Structural features specified under 1 to 7 are characteristic of bauxites bound to the uppermost horizons of complete, in-situ weathering profiles; while structures detailed under 8 to 11 and 12 are typical of illuvial bauxites bound either to horizon "B" of in-situ weathering profiles or to the so-called low-level, or "valley-laterites". In the latter brecciated structures mentioned under 11 may also be frequent.

It is to be noted, that neither of the above features can be taken for an exclusive symptomatic of one or the other of the horizons of the weathering profile. In most cases, horizons can be distinguished on the basis of the principle of predominance only. (Due to a kind of superposition of the elementary processes of weathering, a structural superposition prevails namely right throughout the profile.)

Secondary structures

Lateritic bauxites - by nature - are less likely to be exposed to revolutionary tectonism than karstic ones. (One of the most important prerequisites of lateritisation is namely the epeirogenic style of tectonic evolution of the area concerned.) Joints and fissures of tectonic origin - if any - are therefore restricted mostly to "fossil" laterites of old buried peneplains.

Atectonic displacements are rather frequent, however, especially along the edges of dissected plateaux covered by hard, resistant, high-level type aluminous or ferruginous "cuirasses". Cutting back along the scarps results in the development of outstanding hard cliffs with no or inadequate support below. When support is completely lost by erosional outwash of the loose parts of the section, cliffs may collapse and slumpe down by gravitation in the form of large blocks and scree to the base of the slope. The resulted structures are clastic, brecciated or fragmentary.

Shringkage-craks. In the uppermost horizons where the weathering product is particularly often exposed to repeated wetting and drying; tensional forces, generated by contraction on drying may result in the opening up of shrinkage cracks which may or may not be subsequently filled by some reprecipitated material.

Structures produced by the well-known phenomenon of "hardening on exposure" belong also to the group of secondary structural features. When due to some natural or human factor, such as soil-erosion or bush-cutting, the vegetation-cover of a laterite-complex is removed, the uppermost part of the profile will soon become extremely hard and resistant thus effectively protecting the remainders of the complex from further erosion. What happens on hardening is nothing else than a kind of irreversible mineralogical alteration (mostly dehydration) of the weathering product induced by intense aeration and the heating effect of sunshine. Alterations affect mainly the iron-minerals, and lead to the formation of a hard, cemented, but cellular (aluminous) iron-crust often called the "hardpan" in english-speaking Africa (french: cuirasse).

Since hilltops are never perfectly horizontal, erosion on the minor scale and local transport may lead to the accumulation and cementation of clastic material in the depressions. Brecciated and gravelly structures are rather common therefore in the hardcap-facies.

Karstic bauxites

Karstic bauxites are essentially fine-grained sedimentary rocks consisting of particles, the size, shape and arrangement of which is the joint result of the threefold process of sedimentation (i.e. weathering - transportation - deposition), diagenesis and epigenesis. These and the fact that deposition and diagenesis take place in a karstic carbonate-environment (=pH on the alkaline side; good centripetal drainage, etc.), seem to be of utmost importance from the point of view of the rock structures resulted.

Since bauxitization on a karstic terrain is a diagenic process meaning profound rearrangement of the constituents not only in the chemical but also in the mechanical sense, primary sediment structures are hard to recognize in most karstic bauxites. Of course this is particularly true with respect of high-grade "diagenic" bauxites, but independent from grade refers also to bauxites having been subject to intense epigenesis. More or less preserved sedimentary structures can be recognized in low-grade bauxites when for some reasons bauxite-forming diagenesis has been blocked at an earlier stage and no notable epigenesis took place.

A short summary of the most important primary sedimentary structures and megascopic textures are presented in the followings:

Primary sedimentary structures

bedding

- parallel
- tilted
- graded-bedding
- lamination
- mud-flow structures (turbidites, convolutions, etc.)

Diagenic structural features and megascopic textures

- porous structure
- homogenous structure
- inhomogenous
  - brecciated
  - pseudo-brecciated
  - clastic (- with bauxitic intraclasts and extraclasts or with non-bauxitic extraclasts)
  - gravelly (intraformational, or with extraneous pebbles)
  - oölitic
  - pisolitic
  - nodular
  - vesicular
  - mottled, patchy, etc.

They all may be hard and compact, soft, loose or even of earthy or clayey consistence.

Secondary structural features and megascopic textures

- compaction triggers small-scale slumps in the fine--grained (colloidal-size) material, hence the presence of numerous slides and slump-planes in bauxites
- gradual loss of water trapped in the pores of the sediment, or electrostatically bound to the surface of the individual minerals (adsorption phenomena) leads to a certain volume-contraction which results in the formation of shrinkage-cracks on the large-scale
- slides, slicken-sides, fault-planes and fissures may be resulted also by tectonic deformation
- parallel orientation of clay-size particles due to tectonic reasons is also quite common along fault-planes
- chemical rearrangement of part of the constituents caused by descendent solutions may result
  - in decoloration by deferrification (e.g. "tigre"--textured bauxites)
  - in the formation of Liesegang-rings on the large scale
  - and in the formation of secondary concretionary structures

3.4.2. Micromorphology

The role of optical micropetrography in bauxite micromorphology

Similar to large-scale structural features, fine details of rock structure (i.e. micromorphology) also contain a certain set of genetic information, the decoding of which may help the geologist to find out about fine details of the formation of the rock in question. Disclosing the interrelations between geometry of the orebody and the variations of grade within it, this kind of information may provide a useful tool to the explorer or the mining engineer, too.

Since structural features available at different levels of maginfication (such as under the conventional microscope or under the electron microscope) contain different sets of genetic information, neither of the above methods can be taken for a substitute for the other.

The petrographic microscope has the great advantage of being simple, cheap and available even for the field geologist. The trouble is that because of the extremely fine-grained, often crypto-crystalline nature of the subject, micropetrographic observations can not be used for mineral diagnostics without some instrumental aid. This problem may and can freely be overcome when X-ray diffractograms or scanning electron-micrographs of the most typical samples are available for the petrographer to rely on. All the same, the main purpose of micropetrography is not to make mineralogical statements but rather to read the details of petrogenesis out of the microstructures accessible for the normal optical microscope.

Methods of bauxite- micropetrography

Determined by instrumentation and the techniques of sample-preparation, the following methods of bauxite micropetrography are used in the practice:

1) Investigation of "undisturbed" planparallel preparates
   a) in reflected light (i.e. polished sections under the ore-microscope)
   b) in transmitted light (i.e. thin-sections under the ordinary petrographic - polarization - microscope)
2) Investigation of heavy-mineral size-fractions under the binocular microscope (by means of conventional micromineralogy); under the normal petrographic microscope (by means of sand-size material embedded into synthetic resin or canada-balsam and mounted on a glass slide); and by means of X-ray diffraction methods.

It should be noted, however, that micromineralogy in the classical sense represents the transition to the methods of mineral-diagnostics already, and the sedimentological information it provides is indirect (i.e. obtainable by statistical analysis of grain-size distribution data only).

Further detailes of bauxite micromorphology will be given during the practicum.

Micromorphological features accessible for the optical microscope

For didactic reasons microstructures observable by means of classical transmitted-light polarising microscopy were decided to exemplify all micromorphological features, because at the moment it is the only method having a reasonable interpretability. It should be emphasized however, that the examination of polished sections under the reflected-light polarising microscope (=ore-microscope) leads also to adequate results and that almost all microstructures - especially the iron-rich ones - described in thin sections can be recognized and examined without trouble in polished-surface preparates, too.

Lateritic bauxites

Just like megascopic textures also micromorphological features of lateritic bauxites are determined principally by the processes of chemical weathering. All the observed microstructures can be taken for the spatial reflection of the stages of lateritic weathering manifested in characteristic mineral assemblages. That is: size, shape and arrangement of the mineral constituents in one or the other of the pedological horizons are the direct results of elementary processes of weathering predominating the horizon in question. In horizon "A" the controlling factors are decomposition and leaching, in "B" beomineralization (zone of saturation!) while in horizon "C" - below the zone of groundwater fluctuation - the processes of decomposition gain importance abain with the intensity of weathering rapidly decreasing to nil.

Since there are basically two ways of allitic lateritisation: direct and indirect alteration of the primary minerals into oxides and hydroxides of alumina (GIDIGASU, DELVIGNE-BOULANGE, VALETON, etc.) it is quite natural that the micromorphological features of horizon "A" (deluviation horizon) of the residuum be divided also into two main groups, namely the group of micro-sctructures representing direct allitization, and the group of microstructures formed by indirect allitization.

The essence of direct allitization is as follows:
In the case of extraim-good drainage conditions or of some highly laterisable parent rock, primary silicates are transformed into crystalline alumina-minerals (mainly gibbsite) but retain the morphological framework of the parent mineral. As to the chemistry of this direct alteration it is essentially a kind of desilification on leaching combined with on-site neomineralization of the residuum. The result is a loose pseudomorph-like mass of crystalline gibbsite - the inherited structural features of which can be seen only because of iron-oxide precipitations laid down along cleavage-planes and grain-boundaries.

Indirect allitization is the transformation of primary silicates into hydrous oxides and hydroxides through a transitional mixed-Al-Fe-gel phase (DELVIGNE-BOULANGE). Dehydration and recrystallization on ageing induce seggregation processes in this mixed-gel-phase as a result of which finally crystalline aggregates of oxides and hydroxides of alumina and iron appear. (BÁRDOSSY, MINDSZENTY)
As long as the gel is amorphous it possesses a certain mobility as a consequence of which it is able to migrate within the voids of the porous weathering product. As a result of the above phenomena, bauxites formed predominantly by indirect

allitization are characterized by an intricate network of pore-space filling collomorphous structures of the mixed-Al-Fe-gel phase, each at different stages of dehydration, recrystallization and seggregation. Syneresis cracks filled with mosaics of pure crystalline gibbsite and remnants of relic structures of the parent rock embedded into the collomorphous gel phase are also rather common.

The horizon of illuviation (horizon "B"), that is the horizon where the concentration of dissolved elements in the downward percolating water reaches the point of saturation, and thus precipitation and/or flocculation and coagulation begins, is predominated by absolute accumulations of the sesquioxides. In terms of micromorphology this means incrustations, cutans, films, pore-space fillings, fissure-sillings built up of rhytmically alternating "layers" of Al and Fe oxides and hydroxides etc. Oöids, pisoliths and various other kinds of rhytmical concretionary structures with syneresis cracks and various mineral "aggregates" formed on seggregation are also characteristic of this horizon.

Horizon "C" i.e. the zone of transition towards fresh--rock is represented by pseudomorphous structures consisting of 2:1 clay minerals but retaining the morphology of the primary silicates. Brecciated structures representing the stage of mechanical disintegration immediately preceding chemical weathering are also common with the brecciated fragments being optically isotropic and mostly also atextural. As to grade, the weathered material is generally of non-bauxitic composition in this horizon. It is to be emphasized here that just like in the case of the megascopic structural and textural festures, neither of the above described microstructures can be taken for an exclusive symptomatic of one or the other of the horizons of the weathering profile. Due to fluctuations of the groundwater table and to the regional geomorphological evolution of the area concerned a kind of micromorphological superposition prevails right throughout the profile. This superposition of the microstructures is the micromorphological manifestation of superposition of the elementary processes of weathering itself, as a consequence of which horizons can be distinguished on the basis of the principle of predominance only. High-grade bauxites may exhibit for instance clear signs of processes normally characteristic of horizon "C" (transition) when due to ground-water fluctuations at the B/C interface absolute accumulations of iron or alumina became superimposed into the pores or over the transitional relic structures of horizon "C". (Details will be submitted during the practicum).

Karstic bauxites are built up generally of well defined elementary structural units (microstructures) embedded into some fine-grained matrix, called the groundmass.

Primary sedimentary microstructures can be observed usually within the groundmass only. Low-grade bauxites, bauxitic clays or bauxites of certain reworked deposits are exceptions to this rule, however, since sometimes they may exhibit well-defined sedimentary structures of primary character. The most common primary sedimentary microstructures and textural features recognized up to now are as follows:

lamination with parallel bed-surfaces
bedding or lamination with wavy bed-surfaces
small-scale graded-bedding
mud-flow structures

Microtextural units to be distinguished within the above structures are:

fine-grained (1 to 60 μ diameter) relics of primary minerals (partly allite-pseudomorphs after various silicates)
fine lamellae of clay-minerals
needles or lamellae of allitic minerals

fine organic detritus
aleurite-size relic minerals (mostly well-rounded fragments of chemically resistant grains of zircon, rutile, tourmaline quartz and less frequently also felspar - partly altered into kaolinite- and opaque minerals)

Micromorphological features of early diagenic origin:
In karstic environments the processes of diagenesis and supergenesis taking place after the deposition of the fine--grained "prae-bauxitic" sediment are rather intense and lead to radical changes as to both chemistry and mineralogy of the original sediment and what is more also the physical constitution (i.e. structure and texture) of the material alters considerably during diagenesis and supergenesis.

Microstructures formed during this period of bauxitization generally conceal all primary sedimentary structures. That is why the primary microclastic texture of the material can be traced within the fine-grained groundmass and under high-resolution microscopes only.
The most important diagenic microstructures and microtextural features are as follows:

1) Formed by mechanical rearrangement of materials:
angular intraclasts (bauxite-fragments)
more-or less rounded grains (bauxite round-grains, bauxite-pebbles)

2) Formed on chemical rearrangement of material:
oöliths
pisoliths
spastoliths
part of the atextural round-grains
collomorphous (fluidal) pore-space filling structures
consisting of - iron hydroxides
- Fe-Al mixed hydroxides
- siderite, etc.

It is the fabric that serves primarily as a basis for identification of diagenic structures embedded into the fine--grained groundmass. The identification may be difficult, however, particularly in the case of bauxitic intraclasts having a composition almost identical with that of the groundmass. The degree of diagenesis, that is, the degree of recrystallization of the fine-grained partly colloidal material is, however, usually different and thus they can be identified all the same. (Clastic constituents the fabric of which is obviously different from that of the groundmass are considered to be extraclasts and belong therefore to structures of late-diagenic or supergene origin already).

Diagenic structures formed by chemical rearrangement of materials (i.e. oöids, pisoliths, spastoliths) are very characteristic, and easy to indentify. They are partly of accretional origin; while part of them exhibit clear signs of seggregation processes, and are built up almost invariably of regular or irregular concentric shells. Internal fabric of the collomorphous (fluidal) pore-space fillings demonstrates the one-time movement of the gel-like material. The distribution of their elementary structural-textural units are mostly subparallel or parallel, banded.

Supergene microstructures

Microstructures formed by mechanical rearrangement (i.e. reworking-, local transportation-, redeposition) of the bauxitic material are called supergene clastic microstructures, while those formed by chemical action of "secondary", descendant solutions are called simply supergene microstructures. The most common supergene clastic microstructures are: intraclasts of bauxitic composition, the fabric of which is different from that of the bauxitic groundmass. Non-bauxitic extraclasts (i.e. pebbles or fragments of extraneous origin) are also frequent in some deposits.

Microstructures resulted by supergene chemical processes are various kinds of iron-migration structures (impregnations, patches of deferrification, etc. pore-space fillings and fissure-fillings), representing different stages of recrystallization. Patches of fissure-fillings of kaolinite formed by resilification (degradation) of the bauxitic material are also common. Pyritization and sideritization caused by chemical action of descendant CO_2-rich acidic waters seeping down from the overlying swamp are also considered to be supergenic. Characteristic microstructures are: supergene metasomatic enrichments of pyrite consisting of finely distributed idiomorphous crystallites replacing the original bauxitic material, spherolitic aggregates of siderite (also in the form of pore--space fillings).

Microstructures formed after the deposition of the cover--beds are called "post-bauxitic". In most cases they are bound to tectonically active zones where micromorphology could be altered along the fault planes both mechanically and chemically. As an example of mechanic alteration induced by tectonic movements, oriented microstructures consisting of well-developed, parallel or subparallel oriented crystallites of kaolinite (fault-plane facies) can be mentioned, while postbauxitic chemical alterations max be exemplified by zones of decoloration formed by descending solutions seeping down along fault-planes and leaching out most of the iron content of the ore. As to micromorphology these pale-coloured zones are characterized by iron-migration structures and clear signs of resilification (secondary kaolinite pseudomorphs).

3.4.3. Bauxite-geological and sedimentological implications Uses in the prospection routine

Most conclusions drawn from micromorphological observations are to be treated cautiously and they can be taken for valid only when being in accordance with all the other geological and mineralogical parametres of the bauxite body regarded. There are some microstructures however, the genetic significance of which seems to be obvious even at the present state of research. A short summary of them is given in the followings with reference to their possible practical use.

Lateritic bauxites

1) The phenomenon of micromorphological superposition is considered to be the direct result of the poliyciclic development of the lateritic weathering profile (MAIGNEN, VALETON, MINDSZENTY). It can be taken therefore as an indicator of the polycyclic nature of the profile. In other words: superimposed microstructures identified in random samples of some extensive laterite sheet covering a given area may be interpreted as clear signs of the polycyclic nature of the laterite sheet in question, which invariably means that conditions of bauxitization may have prevailed some time during the geomorphological history of the area in question. Although not yet proved it seems to be logically compelling that also the problem of differentiation between "high-level" and "low-level" bauxitic laterites will be resolved - if ever - by micropetrographical means, that is, under the petrographic microscope.

2) The use of micromorphological examinations in the identification of minerals of silica (their size, shape and mineralogy in bauxites) is an old routine. The results serve for a basis for the establishment of any proper beneficiation technology.

In the case of karstic bauxites micromorphological research has two purposes:

1) one is the solution of genetic problems, and the identification or partly also the definition of various macro- and micro-facial units within the bauxite body. This may help to improve our understanding and the definition of

some of the depositional types; to decide the age of the most important morphotectonic elements as related to the deposition of the ore (prae-, syn- and post-sedimentary faults, etc.) and to elaborate a more succesful prospecting-strategy.

Undesired impurities of diagenic or supergene origin may also be detected and - as to nature and grain-size - also closely investigated by micromorphological methods. Based on micromorphological observations, the approximate distribution of highly contaminated parts of the ore-body may be predicted as early as during the prospecting phase already.

2) The other purpose of applied micromorphology is to supply adequate information for the alumina-technology. The elaboration of any proper processing or beneficiation method should be based on reliable data concerning the size, shape and mineralogical nature of both the principal bauxite minerals and the impurities.

3.5. EXCERCISES

In the laboratories of the Bauxitkutató Vállalat (Bauxite Prospecting Co.) Balatonalmádi and ALUTERV-FKI (Research Engineering and Prime Contracting Centre) of the Hungarian Aluminium Corporation Budapest. Related to paragraphs Nos. 3.1., 3.2., 3.3. and 3.4.).

3.6. MATERIALS TESTING FOR RESERVE CALCULATION PURPOSES

3.6.1. Bulk density tests

When calulating the reserves of any mineral raw material its bulk density is at least as important to know as grade and tonnage are. Bulk density is a parameter determined by the chemical, and mineralogical composition, texture, structure, degree of compaction, and to a certain extent also by the age of the mineral occurrence in question, and the degree of metamorphism it has been subjected to, during geological ages. Percentages of adhesive moisture and the position of the ore body as related to the karstic water-table may also have a profound influence on the bulk density of the ore. Lower and upper extremes of the bulk density of bauxites cover a range as wide as 1,3 to 3,5 therefore. Different kinds of bauxites exhibit different figures of bulk density, with considerable variations sometimes even within one and the same deposit. Mean bulk density is therefore a figure to be obtained by calculating the average of several representative samples in every occurrence.

In the case of karstic bauxites expecially when the deposits are situated at greater depths, specific density of the wet "in situ" ore is determined by measuring the density of several core-samples under laboratory conditions and by calculating the arithmetical mean of the figures. As to the number of core-samples necessary to get reliable results the followings can be taken for a normative: bulk density tests carried out on 20 to 50 small-size core-samples taken from 5 to 10 representative boreholes are generally sufficient to stand for the bulk density of a medium-size occurrence containing 1 to 2 million tons of mineable reserves. Of course larger (5 to 10 million ton) occurrences need accordingly larger amounts of samples to be tested.

When the ore is exposed on the surface, or - being under development - is disclosed by exploration shafts or drifts, laboratory-scale density tests can be substituted by the following field method:

Symmetrical cuboid, brick-shaped or prismatic samples (so called "bulk samples", of a volume not less than 1/4 cubic meter pro sample are taken from the shaft or - in the case of surface exposures - from pits. The volume of the bulk sample is established with a cubic-centimeter-accuracy by repeatedly measuring and then multiplying the depth, width and length of the cube. After weighing the sample the weight of one cubic decimeter of wet ore - that is the wet-basis bulk density - can be calculated. Samples may be taken also from several pits when necessary and in this case the characteristic (representative) bulk density of the deposit can be established again by calculating the arithmetical mean of the results.

The average (wet-basis) bulk density of an ore body is obtained by calculating either the arithmetical mean or the proportioned or weighted average of the volume weight of the bulk samples and of the small core-samples. Adhesive moisture of the crude samples should be established, too. Thus in addition to the wet-basis volume-weight also a volume weight figure referred to the dry basis (sample dried at 105 ^{o}C under laboratory circumstances) can be obtained. The difference between the two, facilitates the establishment of a conversion factor by which the recalculation of the wet--basis volume-weight to the dry-basis one can be carried out simply and easily. Both the bulk density tests and the arithmetical operations provide basic data for the reserve calculation, thus they are to be carefully documented and the documents to be attached to the report.
In the case of lateritic occurrences bulk density tests are carried out generally on samples taken from exploration pits, shafts or - occasionally - also from outcrops. (Outcrops should be carefully cleaned off before sampling). When taking bulk samples and carrying out bulk density test the following main rules should be kept in mind:

1) The shape of the pit should be simple and easy to determine.

2) The sample should be of industrial grade (best if representative of the average grade of the deposit in question).

3) Both the ore itself and the area immediately adjoining the sampling site should be free of contaminants. Uncontrolled caving in of lumps from the pit-wall and mixing of the sample with any extraneous material are to be avoided.

4) Not any of the steps of the bulk density test (sampling, measuring the parameters of the pit, and weighing of the sample) are to be undertaken in, or immediately after rain.

5) In order to avoid the distortion of weight figures by sticked-on material, weighing pots, pans, baskets, etc. should be carefully cleaned before and after the weighing of each sample.

3.6.2. Recovery factor

The determination of the recovery factor in the in situ weathered or redeposited bauxite complex is to be carried out simultaneously with the sampling. The percentage of recovery must be weighed and calculated for each interval sampled for routine analysis.

Prospecting of bauxite complex (consisting of larger of smaller hard bauxite boulders, debris or nodules and relatively softer clayey matrix), just in order to have a reliable value of recovery it is advisable to carry out, by pitting or in depending on geological setting by drillings as well, with the largest possible core diamater. The French Pechiney in Malgas Rep. for the prospection of a nodular type laterite bauxite exposed on surface, applied drilling with one meter core diameter.

The weight of bauxite recovered either by manual separation or by washing-screening system, is to be compared with the theoretical volume of the core. It is expected that during the drilling mainly the clayey matrix will be flushed out from the complex. Consequently if the core recovery is less than 100 %, the core, is alredy a beneficiated sample which differs from the in situ concentration.

In pitting, besides the weighing of the bauxite fragments, the most important task is to measure exactly the excavated volume. In the bouldery type bauxite it is very difficult to form a geometrically regular body. That is why each edge is to be taped, measured at 0.5 m interval.

The volume of the pit given in Fig. No.39. is limited by 1.5 m x 1.0 m x 1.0 m edges. Altogether 21 measurements are needed between the points in

DETERMINATION OF EXCAVATED VOLUME OF THE PIT

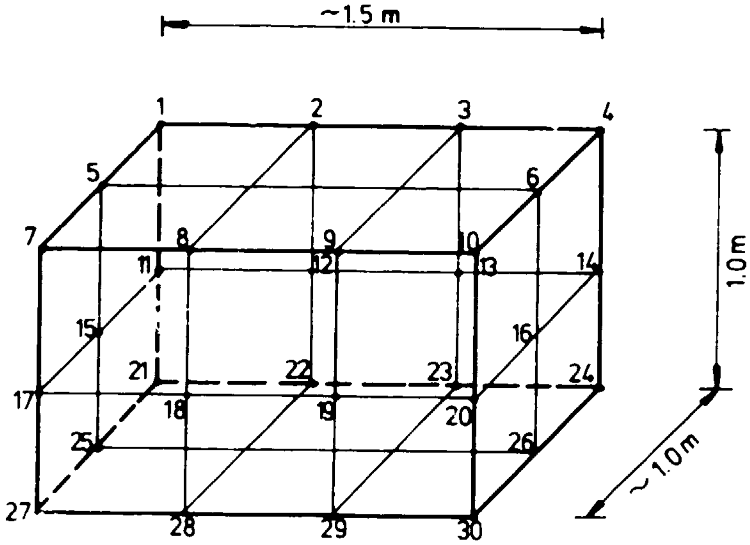


Fig. 39

SAMPLE TREATMENT OF BOULDERY BAUXITE

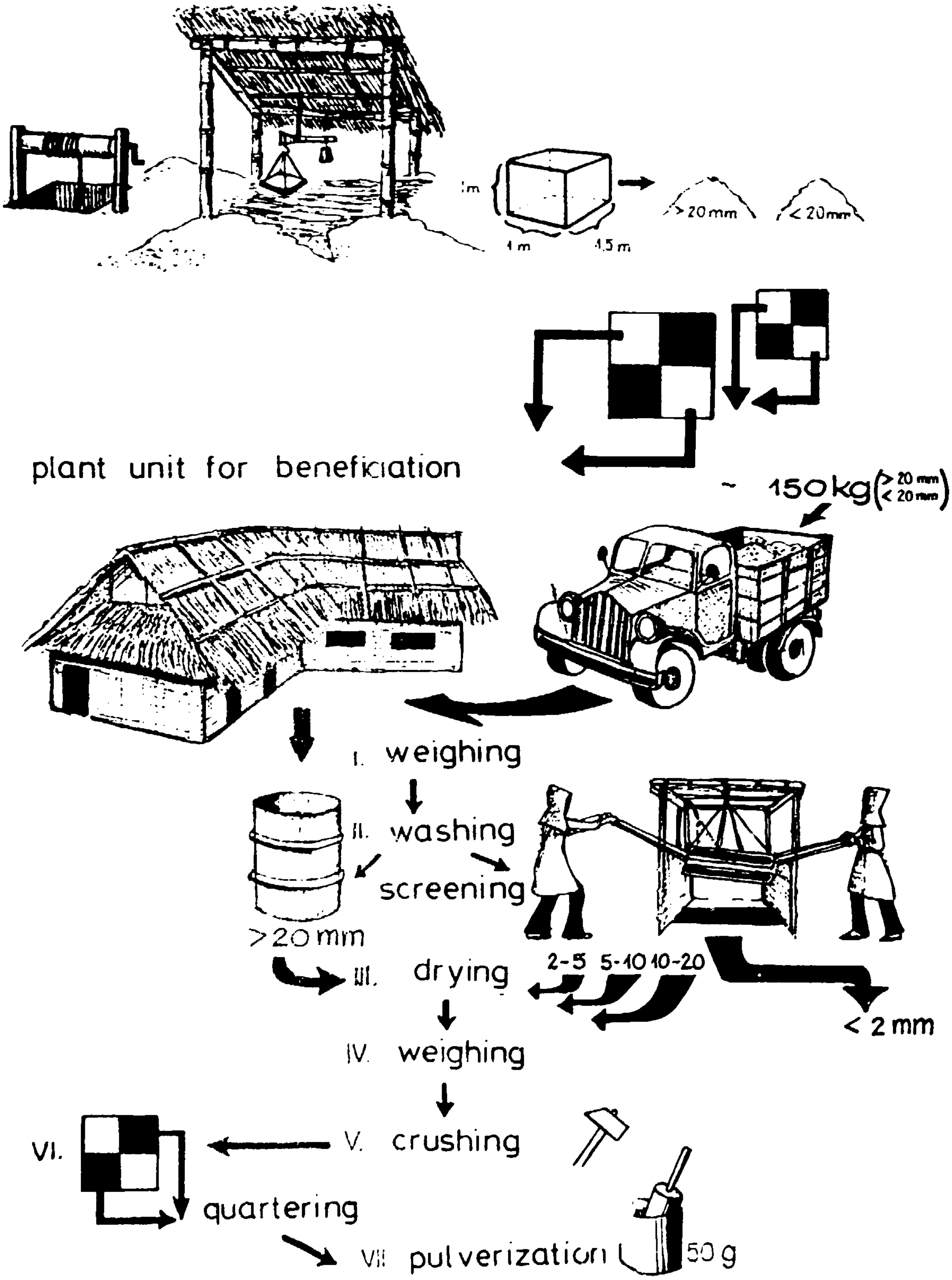


Fig. N°40

diagonal direction: 1-' 4-6 7-10 11-14 15-16
17-20 21-24 25-26 27-30

longitudinal direction: 1-7 2-8 3-9 4-10 11-17 12-18
13-19 14-20 21-27 22-28 23-29
24-30

By the arithmetical means of the diagonal and longitudinal directions, the volume of the excavation is calculated.

The determination of the grain-size of bauxite lumps, extracted from the clayey matrix, is achieved on the basis of size frequency diagrams. At the exploration as we have it learned the cut off is at 1-2 cm. Recovery factor is to be referred to grains larger than one or two cm.

When in the complex, the bauxite lumps of less than 1 cm play an important role both in quality and quantity. The beneficiation test on pilot plant scale, gives the cut off (see details in para No.3.9.).

The method used for determination of recovery factor depends on the litho-sediment character of the bauxite complex.

- In the case of lateritic bauxite, parallel sampling and analysis are needed, to be convinced about the necessity of beneficiation. If we find a remarkable difference between the quality of the complex and lumps the beneficiation or recovery factor determination is to be taken into consideration.
- At the prospection of laterite bauxite deposits - under favourable conditions - the bauxite lumps can be separated easily from the clayey matrix, by very simple dry screening. All of the quantity of excavated complex is to be turned on a screen of one or two cm mesh or the material can be transported to a central vibro-screen system.

- The determination of recovery factor in the case of karstic bauxite deposits is much more complicated, and the construction of a very simple beneficiation plant at the prospected region, is inevitable as the recovery factor determination is an every day task of prospection. The installation of the beneficiation plant is necessary because the clayey matrix is adhered to the uneven surface of the bauxite boulders and the clay can be removed by washing-screening procedure only.

The procedure is as follows:

- At the pit the lumps are screened and kept dry. The fractions of +2 cm, is weighed.
- After crushing and quartering, 100-200 kg of bauxite lumps is to be washed on a screen in the beneficiation plant. After drying it is weighed.
- The -22 cm fraction is weighed at the pit too. 100-200 kg is supplied to the plant, where it is weighed exactly. Then comes the beneficiation by a simultaneous washing--screening process. The recovered part is dried and weighed again. The weight of extracted material is to be related proportionally to the whole weight measured at the pit. The recovery can be calculated as follows:

Example: Total weight of bauxite lumps of +2 cm is 1800 kg
Volume of excavated interval is: 1.65 m^3
Bauxite lumps before beneficiation is 150 kg
after beneficiation is 130 kg
150 : 1800 = 130 : x
x = 1560 kg
recovery factor = 1560/1.65 = 0.94 t/m^3

In the case of grains less than 2 cm the calculation is similar, to this method. To get the overall recovery this quantity is to be added to the former result. If we are interested in the quality of the two fractions, we send them for analysis separately.

3.7. SAMPLING - SAMPLE TREATMENT - QUARTERING

In this chapter we deal with sample collecting from the bauxitic complex only. The kinds and numbers or quantity of samples needed will vary greatly with the purpose of a project, the methods depend on the geological conditions and the heterogenity of the bauxite complex.

3.7.1. General aspects of the sample collecting

a) Samples must be taken from the whole interval between hanging wall and footwall. In the case of karst bauxite deposits this means virtually that the clayey-looking formations accompanying the ore body must be sampled too, because chemical analysis is the only efficient method to produce appropriate data about the different parts of the bauxitic complex. In the case of laterite bauxites the interval between the top-soil or the iron crust overburden and the lithomarge must be sampled and analysed. This is so even if the bauxite body is sandwiched in sensu stricto laterite too. It turned out many times that in the lack of chemical analysis industrial grade bauxites were regarded as laterite or lateritic bauxite and the field geologist took these formations out of consideration. We carry out our bauxite explorations, the data will be build in the reserve calculation while the mining and technological strategy will be worked out in the far future. That is why during the exploration the most complete sampling and analysis are needed.

b) Both in the case of cores and sections of pits and escarpments the intervals to be sampled must be marked on the petrographic basis. Petrographically homogenous bauxites are sampled generally by one meter intervals. In the course of detailed prospections, however it can be permitted also to take the samples by three meters if the petrographically homogenous bauxite is homogenous also from the chemical point of view.

c) Sampling and analysis of obviously barren inter-layers are an important task, mainly when the barren layers (i.e. red bauxitic-clay or clay) can not be separeted from the ore in the course of modern (mechanised) mining. These inter-layers form more or less extended lenses or stratiform layers occuring in karst bauxite deposits, or they form pockets, fissure filligs or dissected layers, consisting of ferruginous clay, bauxitic laterite, iron rich bauxite etc, in the laterite complex. Knowledge of the chemical composition and extent of these non-productive layers is advisable because of the necessity of calculation of dilution (see chapter No.5.2.2.).

d) All efforts should be made to obtain representative material from the sampled interval independently of its heterogenity in hardness.

3.7.2. <u>Sampling from outcrops</u>

3.7.2.1. Sampling from surficial bauxite deposits

Mainly in laterite regions, but in karst regions too, it happens that bauxite deposits are exposed on surface. Apart from the fact that we can win suitable data from the quality and quantity of bauxite bodies, if we penetrate the whole section by pitting or drilling, sometimes superficial sampling is needed, to work out our exploration project. For this purpose the procedure given by Robert R.Compton (1962) can be used very well. (See Fig.No.41.). In the case of karst bauxite deposits we propose to establish triangles of 100 m side length, in the case of laterite bauxite triangles of 300 m side length are recommended. In case of necessity side length can be divided into two or three equally spaced intervals (Group No. 2 or No. 3.).

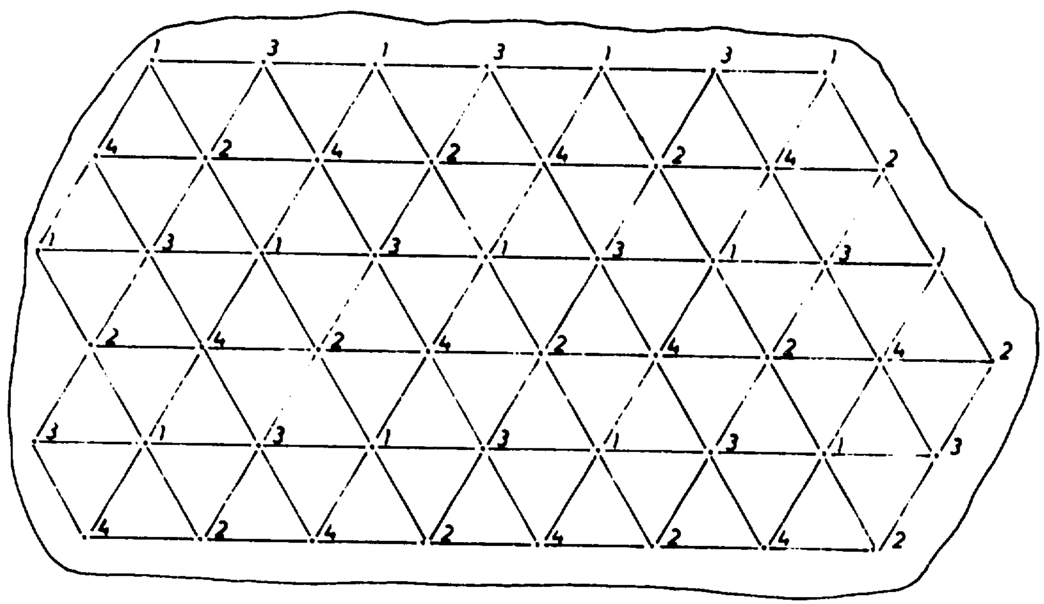


Fig. N°41.

Sampling plan for determining the bulk composition of the outlined body using four groups of equi-spaced samples.

It is obvious that the surface should be cleaned before cutting or chipping out the samples. The bauxite detritus or soil is to bee removed. From each point equal quantity of samples are needed. After homogenisation and minimalisation a good average can be got from the surface of bauxite lenses.

The localisation of such bauxite lenses or bauxite outcrops belong to the tasks of geological mapping, marking the sampling sites on the map.

3.7.1.2. Linear outcrops and escarpments

Linear outcrops of karst bauxite deposits are sampled in general at 100-200 m intervals and escarpments of lateritic bauxite at 300-500 m intervals before detailed exploration. When the explored intervals are short all outcrops are to be sampled.

Karst bauxite outcrops are usually covered by alluvial deposits in more or less significant thickness. This detrital material must be removed together with the altered clayey bauxite as well. Sampling can be carried out by trenching. The trenches are to be planned always perpendicular to the strike. Method of sample collection from trenches is described in chapter No. 3.7.2.

Escarpments in stream valleys or along the edeges of lateritic plateaux are sampled by channeling. Surfaces to be sampled are to be cleaned over 1 m width and 5-10 cm deep even if the walls seem absolutly clean. This is necessary because of the tropical climate where the original elementary composition on the surface of the bauxite outcrops is being modifed rather quickly (silica is being leached out while iron and manganese precipitate on the surface.

Channels must be cut downward from the top. The aspects of this method are given before.

The channels are cut in the middle line of the previously cleaned strip. It is 5-8 cm wide and approximatly 5 cm deep. Geometrically perfect channels exist on the figures of manuals only. The lateritic bauxites are very heterogenous in hardness and that is why forming of channels is a very difficult task. The reliable sample collecting needs the presence of a geologist who pays strict attention to the collection. From the given interval the bauxites of different hardness shall be represented in proportional quantity. The samples cut down are collected on a tarpaulin. The material is crushed, homogenized, reduced by quartering as described in chapter 3.7.4.
The sampled linear outcrops are plotted on the bauxite-geological map and sites of sample collection are marked on the maps too. It is advisable to compile a special map for sampling. If the bauxite complex is exposed on the surface from its cover to the footwal and the data of sampling and analysis can be used in the reserve calculation too, the sampling site must be localised by surveying, just like the pits or bore holes.
The sampling units are given in accuracy of 0.1 m measured by tape. In our note book we note down the sampling site exactly, with the units of sampled intervals.

3.7.3. Sampling from trenches, pits and bore holes

Trenches

Depending on local circumstances and expected depth the trenches are planned approximatly with 1 m width. Supporting the trenchwalls deeper than 1.5 m, is advisable mainly, in the case of crumbling formations. Supporting can be avoided by forming graded walls.

Sampling is advisable from the middle line of the bottom of trench by channeling, accordi. j to the points, given before. Trenching falls within the scope of geological mapping (see chapter No. 4.4.).

Pits

Sampling is carried out by two methods as follows:

a) Channels are cut in the middle line of four walls or in the four corners. Consequently the bauxitic complex is explored at first. The intervals to be sampled are determined on the basis of petrography. The material from each interval is crushed, homogenized, and reduced separately (see chapter 3.7.4.). There are no difficulties in the case of karst bauxite, because it is obvious that the pits are excavated till the footwall. Although not customary, in our opinion, it is advisable to take samples from the formations regarded as footwall in the case of lateritic bauxite. At any rate the bottom of the pits is to be sampled by channeling diagonally or transversely. If we are convinced by the analysis, that the excavation of pit was stopped in industrial grade bauxite, we shall have the possibility to continue the pitting.

b) Sampling the whole bauxite complex excavated from pits: in the case of homogenous bauxite complexes, this procedure gives the same result as the channelling. It is a labourious method, because large amount of bauxite must be crushed, while due care is to be taken of the separate handling of various types of bauxite.

There are detrital or pseudodetrital (weathered in situ) type bauxite deposits which practically consist of hard bauxite boulders, pebbles or nodules and softer cementing (clayey) matrix. As the samples will be won by manual separation or beneficiation by screening, it is necessary to calculate the recovery of bauxite as well. (See chapter 3.6.2.) This detrital type bauxite can be prospected by pitting or by drilling of large diameter (at least 1 m) bore-holes. Sampling of detrital type bauxite is carried out by processing the whole material. Because of the significant inhomogenity of the bauxite complex channelling does not give reliable samples for routine analysis.

Pits are surveyed on the field and marked on our map of exploration. Besides the description of the sequence explored by pits the sampled intervals are marked in our note book. We have to emphasize the fact again that a pit is negative, only when it is proven by analysis too. Consequently when a pit seems to be barren on petrographic basis, it must be sampled, documented, analysed, and surveyed just as if it were a productive point of the bauxite pocket.

Bore-holes

The cores of bauxite complex are stored in one m long, partitioned cases made for this purpose. After drying, the samples are cleaned with a wire brush. The core samples are divided into two equal parts along the axis of the cores. Description of the texture and structure of the bauxite samples is due at this time and the intervals of sampling (analysis) are determined on the basis of petrographic properties of bauxite. One half of the sample should be preserved in a good paper or cotton bag in order to have sufficient material for additional (chemical, petrographical, mineralogical e.t.c.) analysis or checking purposes that would be carried out in the future. The other half of the sample is crushed, homogenized and quartered as follows:

3.7.4. Homogenization, quartering, and storage

In the course of sampling much more material is worked down than the routine analyses needs. The sample must give a proportional representative average of each interval. We carry out this task by crushing, quartering and minimisation according to Richards-Cherchette's formula.
Analysing actual sampling data, Richards concluded that reliable weights are more or less directly proportional to the square of diameters of largest particles and compiled a table for determining the size to which the samples should be crushed depending on their weights. Later Cherchette expressed this rule in the following formula:

$$Q = K \cdot d^2$$

Where Q = reliable weight of the worked down sample in kg
d = diameter of the largest particles mm
k = factor depending on the nature of mineral, recomended for ores of different types

According to our experience k = 0.05 in the case of any bauxite. Consequently if we want to win 1 kg of bauxite sample from any bigger quantity, the samples must be crushed to less than five mm in diameter.
It is obvious that the quartering can be carried out in more steps; by crushing to finer and finer fractions. For example the material excavated from a pit consists of 10 cm pieces; we can minimise them by quartering till 500 kg. In order to have less material we continue the crushing.

We don't deal with the general rules of quartering, but we have to mention it again that in order to have a proper sample, the quartering is to be done on a tarpaulin or on any other suitable material. Two samples at least 1-1 kg are needed from each interval.

The samples are to be marked on the bag with the No. of the pit, escarpment or trench, interval (from m to m) and name of locality. One bag is to be stored in a good sample stock at the exploration location (group). It is very necessary to provide for the samples being undamaged, that the sample could be used for analysis even in the far future. Well stored samples will save the company a lot of costs of reprospection. The other part of the sample is crushed, minimised and analysed. The remaining pulverized samples are stored with the first (lumpy) samples together.

3.8. REPRESENTATIVE SAMPLES FOR ALUMINA TECHNOLOGICAL TESTS

The developing countries make an effort to improve their national industry by establishing aluminium industry based on their more or less prospected bauxite deposits. The first step on this long way is the compilation of a feasibility study, which, beside the elaboration of many technological and economic questions, gives a proposal for the process of most economic utilization of the bauxite in an alumina plant.

For the elaboration of alumina technology, the technologist turns to the geologist to assort a sample which can be regarded as a representative one.

The assorting of the representative sample entails a scrupulous responsibility because the economics of the alumina industry depends mainly on the chemical and mineralogical composition of the bauxite in hand; practically it depends on the samples derived from the bauxite deposits.

Here we can give some general aspects only for this sampling procedure because the method of sampling is determined in detail by the nature of deposits and their mineralogical and geochemical characters.

For the sampling, the geologists, have to know:

- The quality and quantity of the workable reserves, taking into consideration the local economic conditions as well.
- Mineralogical composition of the bauxite deposits and the distribution or trends of the most important minerals in horizontal and vertical directions.
- Requirements of the alumina industry.

The assorted representative sample should be representative, in point of chemical view and simultaneously it should be characteristic in its mineralogical constitution.

The difficulties of this task originate from this double demand. While we have information about the chemical constitution of the bauxite on the basis of sufficient data, it may happen that we do not have even a single reliable quantitative mineralogical analysis of the deposits.

We can regard a deposit as mineralogically known if we have two or three mineralogical tests per one million tons of bauxite which is homogenous in alumina bearing minerals, while from the heterogenous bauxite deposits, 10-15 samples are needed per million tons. From the point of view of alumina bearing minerals, bauxite can be regarded as homogenous, in which at least 95 per cent of total available alumina content is only in gibbsite or in boehmite or in diaspore.

When we do not have adequate mineralogical data, necessary sampling is to be commenced according to the aspects given below:

- Each sampled interval has to be extended for the whole thickness of the industrial grade section.
- Within one occurrence we determine the number of samples proportionally to the reserves of deposits, lenses or pockets, taking into consideration all of the less important pockets too, having more then half million tons of reserves.
- Within one geologic or mining unit the samplimg sites should be evenly distributed.
- Processing the data of chemical analysis of the intervals sampled for technological test, we choose them in such a manner that their quality in 60-70 per cent of cases should be around the average quality of the reserves.

20 per cent of the samples has to be of higher grade, while 10-20 per cent of samples has to be of lower grade, than the average of the deposits. It is needed to have samples from non--industrial grade bauxite too, if the selective mining of this unproductive intercalations can not be avoided and it gets into the alumina plant.

Samples at least one kg of each needed. Samples prepared for mineralogical analysis are to be analysed for 14 components too.

Assorting the representative samples can be achieved if we have got mineralogical and chemical data of each individual sample. The "know-how" of the assorting is presented in the example given below:

The bauxite occurrence consists of three deposits:

Deposit	Al_2O_3	SiO_2	Fe_2O_3	TiO_2	Loss on ignition	Reserves million tons
I.	50.8	5.1	26.4	3.2	12.5	10.0
II.	50.1	6.6	26.5	3.2	12.8	7.2
III.	49.9	4.0	30.8	3.6	11.6	2.8
Average and total	50.4	5.4	27.1	3.3	12.4	20.0

On the basis of the chemical composition of deposits, the bauxite seems to be homogenous. At first we send 50 samples for mineralogical test. The X-ray diffractions revealed that the deposits are very heterogenous from the point of view of mineralogy. Then we send 150 more samples for mineralogical analysis. On the basis of these tests the mineralogical composition on average, weighted with reserves is as follows:

Deposits		I.	II.	III.	Weighted average
Gibbsite	%	5.3	10.1	5.3	7.0
Boehmite	%	2.7	38.4	2.4	15.5
Diaspore	%	40.9	6.4	43.7	28.[illegible]
Kaolinite	%	14.5	13.0	13.2	13.8
Quartz	%	0.8	0.5	0.1	0.6
Hematite	%	19.7	17.4	21.6	19.1
Goethite	%	10.1	9.6	6.1	9.4
Anatase	%	2.2	2.1	2.4	2.2
Rutile	%	1.0	1.1	1.2	1.1

These results were checked to see whether the theoretical chemical composition of the samples, calculated from mineralogical data is in harmony with the chemical composition of reserves or not. It was calculated on the basis of the molecular weight of the minerals as follows:

Al_2O_3 x 1.18 = boehmite, diaspore
Al_2O_3 x 1.53 = gibbsite
Al_2O_3 x 2.53 = kaolinite
SiO_2 x 2.13 = kaolinite
Fe_2O_3 x 1.11 = goethite

The theoretical chemical composition, derived from the mineralogical make-up is as follows:

Deposit	Al_2O_3	SiO_2	Fe_2O_3
I.	49.2	7.6	28.8
II.	49.7	6.6	26.0
III.	52.2	6.3	27.1

The chemical composition of the reserves is in harmony with that of the samples of deposit No.II. Consequently the samples of this deposit could be blended proportionally to its reserves. In the cases of deposit No I. and No III. the samples had lower quality than required. From the sample series we excluded proportional quantities of the low grade samples in order to attain 5.1 SiO_2 and 4.0 SiO_2 resp. We calculated the proportional weight of each sample to be blended. We mixed the samples of each deposit separately and checked them by chemical analysis. In our example they were corresponding to the chemical composition given in the reserve calculation. Then we blended the average samples of the three deposits proportionally to their reserves. For technological tests we needed 5 kg of bauxite.

Deposit No I.	2.5 kg	(10 million tons of bauxite)
Deposit No II.	1.8 kg	(7.2 million tons of bauxite)
Deposit No III.	0.7 kg	(2.8 million tons of bauxite)
Total	5.0 kg	(20.0 million tons of bauxite)

When both the chemical and mineralogical analyses were exact and in each case we paid adequate attention to homogenization and reduction of the samples, the chemical and mineralogical compositions of our sample has to correspond to that of the occurrence. That way we shall have a sample which is representative from the point of view of the chemical components and simultaneously characteristic of the mineralogical composition. In any case if the samples of the deposits do not comform with the reserve calculation we should modify them to the appropriate grade.

3.9. BAUXITE BENEFICIATION AND ITS ECONOMICS

In chapter No 3.6.2. we have dealt with the determination of recovery factor in the bauxite complex. This determination is an ore dressing process: bauxite beneficiation is to be carried out simultaneously with exploration, as an every day task of the geological activities. Here below we deal with the question of bauxite beneficiation in industrial scale.

Not speaking about the fact that the alumina production can be essentially regarded as a process of beneficiation (chemical) we speak about bauxite beneficiation when we separate the bauxite lumps of better quality from the clayey matrix of relatively lower grade.

Whether this separation must or can be applied economically between the mining operation and alumina production is determined by many factors, among them the most important being:

1. Geology: in the reason of geology: the litho-sedimentological character of the bauxite complex (run of mine ore) or in the reason of technology: the physical properties of the complex, the possibility of beneficiation.
2. Grade: whether there exists significant difference in quality among the fractions to be separated. It can happen that the bauxite at disposal is not suitable for alumina production without beneficiation. It is then necessary.
3. Economics: cost of beneficiation depends on the applied technology and the nature of bauxite (the quantity and quality of extractable bauxite). We have to make an assessment whether the cost of ore dressing can be won back by the loss of caustic soda consumption of alumina plant, or better by the higher value of bauxite.

For the elaboration of beneficiation technology and costs benefication tests are to be conducted in pilot-plant scale. For these tests approximately 150 kg representative samples are needed. The suitable sampling sites representing well the deposits(s) or types of deposits can be determined on the basis of the thorough knowledge of the deposits. Samples are taken in the function of various grain size frequency depending on its genesis. For illustration of this question, a figure series is presented (Fig.No.42.), which represent three characteristic samples of a bouldery type karstic bauxite complex. The figure shows the chemical composition of each fraction as well. The in situ weathered detrital complex - localised on hill-top only - is given in Fig.A. The bauxite complex is being reaccumulated, reworked on hill--side as shown in Fig.B. while the bauxite being accumulated on the bottom of valleys is presented in Fig.C.

The distribution of fractions is in harmony with the most important litho-sediment character of the three different types of formation. Meanwhile it reveals the possibility and necessity of bauxite benefication. On the basis of these curves the optimal cut off can be given, taking into consideration the quantity and quality of fractions. It is remarkable that the beneficiation is the most efficient in the case of type A, because the overwhelming quantity, concentrates in the coarse fractions.

Let us investigate a bauxite complex of low grade, which on the average and on the basis of its grain size frequency belongs to type A. Results of test is given in table No.6. on page 169. According to this table the complex, on the average contains 44.2 % Al_2O_3 and 10.4 % SiO_2. After the separation the quality was improved to 47.7 % Al_2O_3 and 4.7 % SiO_2 while 73.9 % of the whole material was recovered, with application of 0.5 mm mesh screen.

Bauxite Quality and Quantity in the Function of Grain-Size

Table No.6.

Fraction mm	Weight %	Al_2O_3 %	SiO_2 %	Mod.	Weight % cumulative	Al_2O_3 cumulative	SiO_2 cumulative	M cumulative
20	34.4	50.9	2.7	18.9	34.4	50.9	2.7	18.9
13-20	8.6	49.4	4.0	12.4	43.0	50.6	3.0	16.9
6 -13	12.7	46.6	4.7	9.9	54.7	49.7	3.3	15.1
4 - 6	6.7	39.3	12.3	3.2	61.4	48.6	4.3	11.2
2 - 4	8.7	42.6	6.6	6.5	70.1	47.9	4.6	10.4
0.5-2	2.2	43.4	6.5	6.7	72.3	47.7	4.7	10.0
0.071-0.5	1.6	35.6	24.6	1.4	73.9	47.5	5.1	9.3
0.020-0.071	8.3	33.8	25.7	1.3	82.2	46.1	7.1	6.5
0.005-0.020	4.5	33.6	25.6	1.3	86.7	45.4	8.1	5.6
0.005	13.3	34.6	25.8	1.3	100.0	44.2	10.4	4.3

CHEMICAL COMPOSITION V.S. GRAIN SIZE
DISTRIBUTION DIAGRAM

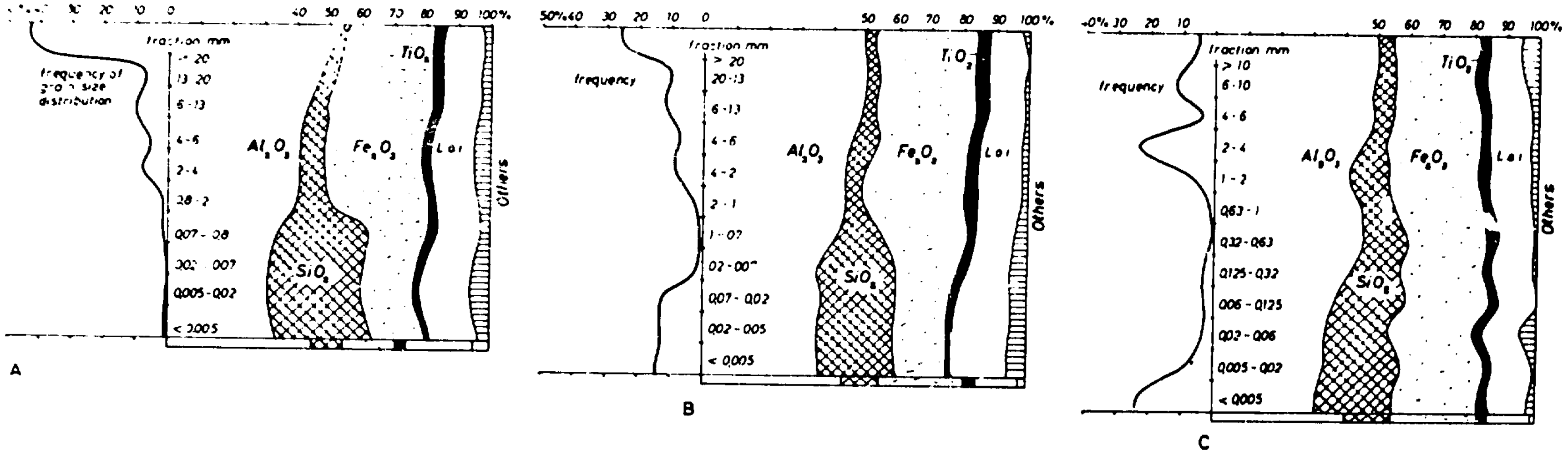


Fig. N°42

It is not the geologist's task to know the technology of beneficiation, but we think it is not superfluous tc mention that regarding the cost of beneficiation process it is learnt that independently of the frequency of grain size, screen less than 1 mm mesh, can't be economically used in the benefication plant.

The possibility of beneficiation is given in lateritic bauxite deposits too. For the sake of an example we present the Malgas bauxite. The parent rock is leptinite, composed of perthitic microcline, quartz, cordierite, garnet and sillimanite. This facies is very resistant to weathering. The SiO_2 content is represented by sandy impurities in non reactive form mainly in the laterite. The alumina accumulates in gibbsitic nodules. The complex is fairly loose. In situ bulk density is 1.75 t/m^3 on the average.

Chemical analysis of the fractions:

Fraction mm	Component % Al_2O_3	SiO_2	Weight %
> 50	48.5	11.5	0.27
10-50	49.5	12.9	24.68
2-10	46.6	14.8	26.60
0.5- 2	43.2	23.4	13.49
< 0.5	22.0	53.4	33.14

The +2 mm fraction contain 13.2 % total SiO_2, out of which only 1.7 % SiO_2 is reactive. Consequently, with 50 % recovery, very good bauxite can be von by extraction.

The economics of beneficiation has been worked out in detail by ALLIQUANDER-BALKAY-SOLYMÁR in 1974.

Their study is based on the comparison of various - more or less hypothetical situations; including and not including a step of benefication. Such comparison require a figure of merit, a single figure expressing the worth of a beneficiated or unbeneficiated bauxite, in terms of money or otherwise.

Such a figure of merit is available alumina:

$$Av.Al = Al_2O_3\ \text{tot.}\ \% - Al_2O_3\ \text{non reactive}\ \% - 0.85\ Re.SiO_2\ \%\ (- Al_2O_3\ \text{losses in plant}).$$

Another figure of merit is the price of bauxite on the open market on the basis of transactions between 1955 and 1970.

$$P = (B-29) \cdot 0.40\ \$\ \text{per ton.}$$

where: $B = Al_2O_3 - 2SiO_2$

Assuming consistant bauxite prices the cost limit of mining plus beneficiation is:

$$(m + d) = KP_b$$

where: m = cost of mining per ton bauxite complex (run of mine ore)

d = cost of beneficiation, ditto

K = recovery factor of beneficiation

P_b = sales price per ton of the beneficiated bauxite fob.

If the bauxite complex can be sold also without beneficiation, the cost limit of beneficiation is the sale price difference between the raw and beneficiated bauxite. When the loss on beneficiation is too heavy and the tailings produced are too high-grade the beneficiation is worthless. According to ALIQUANDER-BALKAY-SOLYMÁR's estimations the cost of beneficiation of one ton of raw bauxite should typically be less than 0.50 $. This means that a well designed and well run crushing-washing-drying operation should be profitable in most cases.

4. EXPLORATION

4.1. PRINCIPLES OF DELINEATION OF POTENTIAL AREAS. ESTIMATION OF INFERRED RESERVES

4.1.1. Karstic bauxites

The delineation of potential areas should be based on sound scientific considerations. It necessitates all geological and economical information related to the areas in question to be revised and interpreted carefully. The revision is to be regularly repeated and complemented with the latest results of both exploration and methodological research. With the estimation of inferred reserves added it is essentially an appraisal conveying the geologist's judgement about the mineral potential of the area in question, at the moment of the date of the appraisal.

It is the sine qua non of any respectable judgement to set up a reasonable geological model, on the basis of which all known factors, controlling the formation and preservation of the mineral in question can be examined minutely.

As for an example the short methodological description of the estimation of the bauxite potential of Hungary will be presented in the followings.

Since the conditions of formation and preservation of the ore are included in Chapter 2.1.2. under heading of

- stratigraphy
- depositional characteristics, and
- formation

of Hungarian bauxites, neither the geological model nor the system of criteria will be detailed here. Only one thing is to be emphasized namely that the mineral potential of any given area is to be estimated by using these conditions as the criteria of delineation of the potential areas. Set up on the basis of well-known occurrences, these criteria are essentially analogous: they are extrapolated on to areas the geology of which is known to be similar to those where the analogous criteria were defined.

There are several means and ways of estimating the mineral potential of a given area but all of them can be included in one or the other of the following three groups:

1) statistical methods
2) analogous methods
3) multicoefficient methods

Neither of the above three is without some element of analogy, however. Even the statistical method is essentially analogous, but instead of working with a simple geological analogy, it extrapolates the mineral potential of known areas on to the potential ones by using the so called productivity factor (potential resources per unit area of known occurrences or of the bauxitiferous stratigraphic complex). The results are mostly subject to certain corrections reflecting the geologist's personal opinion of the reliability of the estimation.

When using the method of analogy not the productivity but the geology of the analogous area is extrapolated on to the less-known potential area. Depending on the differences between the two, correction may be necessary here, too. The reliability of the estimation is a function of the degree of the analogy.

The multicoefficient method is based on a sophisticated point system, in which - depending on the supposed degree of fulfillment - every criterium has its point value. Points are summarized according to some special formula and the results are taken for the numerical basis of the estimation of the bauxite potential of the area in question.

Considering the amount of available bauxite-geological information, the method of geologically differentiated analogies was decided to be used to estimate the bauxite potential of the country. This is a method developed by combining the most important elements of the above described three basic methods. It is essentially analogous but has its productivity indices and, in ranking the areas according to their bauxite-potential, uses a system similar to that of the multicoefficient method (it is the degree of fulfillment of certain combinations of criteria which serves as a basis of ranking). In addition it takes also the amount of available geological information per unit area into consideration, when establishing an order of rank.

According to grade and amount of proved and inferred reserves involved, potential areas can be divided into the following main groups:

a) areas immediately adjoining to proved reserves of considerable economic significance, and with scarce indications of industrial-grade bauxite,

b) isolated areas with scarce indications of industrial--grade bauxite,

c) isolated areas with scarce indications of low-grade bauxite,

d) isolated areas without any positiv indication of bauxite but with the presence of stratigraphic horizons which - by analogy - can be considered as potentially bauxitiferous.

Of course, grade and amount of reserves involved are not the only aspects of the division, and the rank of the above groups may be subject to considerable changes when taking also other criteria or combinations of criteria into consideration.

Estimation of the bauxite potential of selected areas

Mineral potential estimations are carried out generally in two subsequent steps:

1) delineation of potential areas
2) estimation of inferred reserve

The availability of all previous geological and geophysical information is a sine qua non of both steps. The best if the data are summarized in comprehensive charts, preferably all of one and the same scale.

Maps required for the theoretically perfect estimation are as follows:

Geological maps
- geological base map
- special maps such as
- facies map of the potential basement
- facies map of the potential cover
- contour map of the potential basement
- relative depth of the potential basement (the latter two containing also geophysical information)
- detailed facies-map of the immediate cover
- tectonical maps
- hydrogeological maps

Be on account of scarce or inadequate geological information any of the above maps imperfect or actually impossible to compile, the reliability of the estimation would proportionally decrease.

How to realize the estimation

1) First thing is to set up the geological model. Based on geological, stratigraphical and tectonical grouping of all known occurrences this means the invention of several standard occurrence-types, and the detailed description of the combinations of criteria characteristic of every standard type.

2) Then the investigated area should be divided on to several units distinguishable either by geology and tectonics or by the amount of available geological information per unit area.

- Careful analysis of all known geological features of the above units is the following step (with the criteria of formation and preservation of bauxite in mind).
- Fictious standard occurrence-types (types which are logically compelling but not yet realized on the field) are also to be set up if necessary.

3) Then, at the end, the geology of the said units is to be analytically - step by step - compared with that of the standard occurrence types. Potential areas are delineated then by seeking for a standard analogy for every unit (always best fitted to the geology of the unit in question). The rank of order of potential units should be established according to the degree of analogy between the units and the corresponding standard types.

The delineation of potential areas is realized mostly by graphical means.

- At first combination maps are compiled from the cartographical representations of the fulfillment of the individual criteria (criterium maps = essentially those special maps required for the "theoretically perfect estimation" referred to in the previous paragraph).

- The next step is the delineation of those areas which - by geology - are to be excluded from further investigation (="unperspectivic" areas).
- Then the division and ranking of the remaining - potential - areas on to several, geologically coherent units follows.

As demostrated by the following rank of order the most common aspects of ranking are reserve-oriented:

- potential areas with proved reserves
- potential areas with probable reserves
- potential areas with inferred reserves (that is, with reserves supposed, but of not very high probability, or more exactly: areas, the improductivity of which can not be decided on the basis of the available (scarce) information.

The final rank of order of potential areas can be established, however, on the basis of economic considerations only. This calls for numerical information concerning the expectable economic parametres (grade, amount, thickness, etc.) of the potential (inferred) reserves.

The possibilities to estimate these parametres are as follows:

- In the case of positiv indication(s) in the area, the parametres of that (or the average of the parametres of those) particular indication(s) are to be taken for characteristic of the whole area.
- When no indications are yet known; probable parametres are to be estimated by calculating the average of the parametres of known deposits belonging to that particular standard occurrence-type which - by geology - is considered to be analogous with the potential area in question.

The reliability of the estimated parametres depends essentially on the correctness of the analogy (grade and amount are namely direct functions of the depositional type, and thus the "type of occurrence").

Neither grade nor amount are extrapolated mechanically, however. All analogous parametres are increased or decreased according to the degree of analogy or more exactly according to the differences between the geology of the potential and of the corresponding standard area. It is this "adjustment" of the analogous parametres which is called the "geological differentiation".

In addition to grade and amount also all the other parametres of inferred reserves necessary for planning of the mining operations are to be estimated (at least roughly) already in this preliminary stage of prospecting. These are: probable depth and thickness; expectable hydrogeological conditions; petrology and mechanical properties of the cover beds; certain technological parametres of the inferred ore; probable amount of impurities, if any, etc. The only way of estimation of these parametres is of course to use the method of analogies: based on parametres valid for the correspondent standard types, the parametres of inferred reserves are calculated by decreasing or increasing the analogous parametres according to differences between the geology of the potential areas and the standard occurrence types, just as it was pointed out above.

Being the most important element of the economic assesment of any potential area, the methodics of estimation of the amount of inferred reserves was decided to be presented here in details.

First thing is to assign a proper productivity index to every standard occurrence type. Productivity indices are calculated by taking the average of the amount of reserves per unit area of all known occurrences belonging to the particular standard type in question. Productivity indices are thereafter decreased or increased according (1) to the amount of available geological information per unit of the potential area and (2) to the degree of analogy between the potential units and the corresponding standard areas.

Potential units built up of several parts of slightly different geology and supposed to contain therefore potential reserves belonging to more than one standard type are called combined units. Productivity indices of such combined units are calculated by taking the area-weighted average of the productivity indices of those standard types which are considered to be analogous with one or the other of the parts of the combined units.

Analogies concerning small, insignificant parts of one or the other of the combined units may be neglected when their probability is low (even if logically compelling).

(In fact the final decision about the numerical definition of the productivity indices is one of the most biased elements of estimation of inferred reserves; and the only guarantee of its correctness is the personal experience of the geologist.)

Inferred reserves are then calculated by multiplying the area of the potential units with the appropriate productivity indices, and then by summarizing the reserves of all units of the potential area in question.

It should be emphasized that since the estimation is - by nature - merely a rough estimation of the expectable facts, all figures are better be rounded before and after every calculation to avoid the unfounded impression of exactness.

4.1.2. Lateritic bauxites

The lateritic bauxite deposits of the present tropics form two groups. The first group contains the deposits formed by polycyclic surface formation of the old peneplaines. These are on the remains of the old equalization surface, consequently they can only be found upon a determined level of surface. The second group contains the bauxites developed by non-polyciclic formation of the areas characterized by very suitable conditions for the bauxitization (e.g. Indonesia); these deposits were formed in a relatively late (young) phase of the surface formation.

In the case of genetically plain surface of a given geological formation (volcanites, well-bedded sedimentary rocks, etc.) the erosion is not the main factor of surface formation. Naturally these types can also be re-formed by polyciclic evolution later on.

General regularities of the preservation of the lateritic bauxites

The complete lateritic profile can also be eroded by the bauxite-forming rejuvenated erosion, if the rate of the erosion is high. In favourable cases the fragments of the eroded laterite (lateritic bauxite) can be found at lower levels, in the valleys and at terraces; but based on actual analogies only very near to the original lateritic (lateritic bauxitic) plateaux. If the area is not uplifting but sinking, then the laterite or the lateritic bauxite can be destroyed by the chemical weathering enlarged by the uprisen ground water level: this is the resilification. In the case of constant sinking the profile can be covered and can be protected through a long geological period, too. This case is very rare, e.g. the lateritic bauxites partly covered by Eocene limestone in Gujarat Stata (India).

Grading the criterium of the prognostization

Regarding the practical usability the most important criterium of the prognostization of lateritic bauxites is the morphology, mainly the characteristic plateau-morphology.

Large areas are known (e.g. India: lateritic bauxites of the Deccan Plateau), where each of the plateaux are perspectivic for bauxite above a certain level even before the evaluation of any other criterium!

Moreover, the morphologic criterium can be relatively easily and exactly investigated by the interpretation of topographic maps and mainly by aerial photos at a suitable scale (plateau morphology, dip of the slopes, dissection of the plateaux, etc.).

The climatic criterium is only second after the morphology compared with its dominant role in the bauxite formation. In most cases meteorological data can be collected; consequently data of the precipitation and temperature can be relatively well used. The infiltration, evaporation and permeability have little worth in practical prognostization and they need special field works too, for which there is generally no possibility during the first phases of the prognostization.

The lithological and structural (tectonical) criterium are also relatively easily to work with during the prognostization, but the lithological one has no top priority. It can have a practical role, e.g. in the case of two - climatically and morphologically very similar - areas to determine the more prospective one for lateritic bauxite.

Grouping of the prognostizations

Depending on the aim the prognostizations can be grouped as follows:

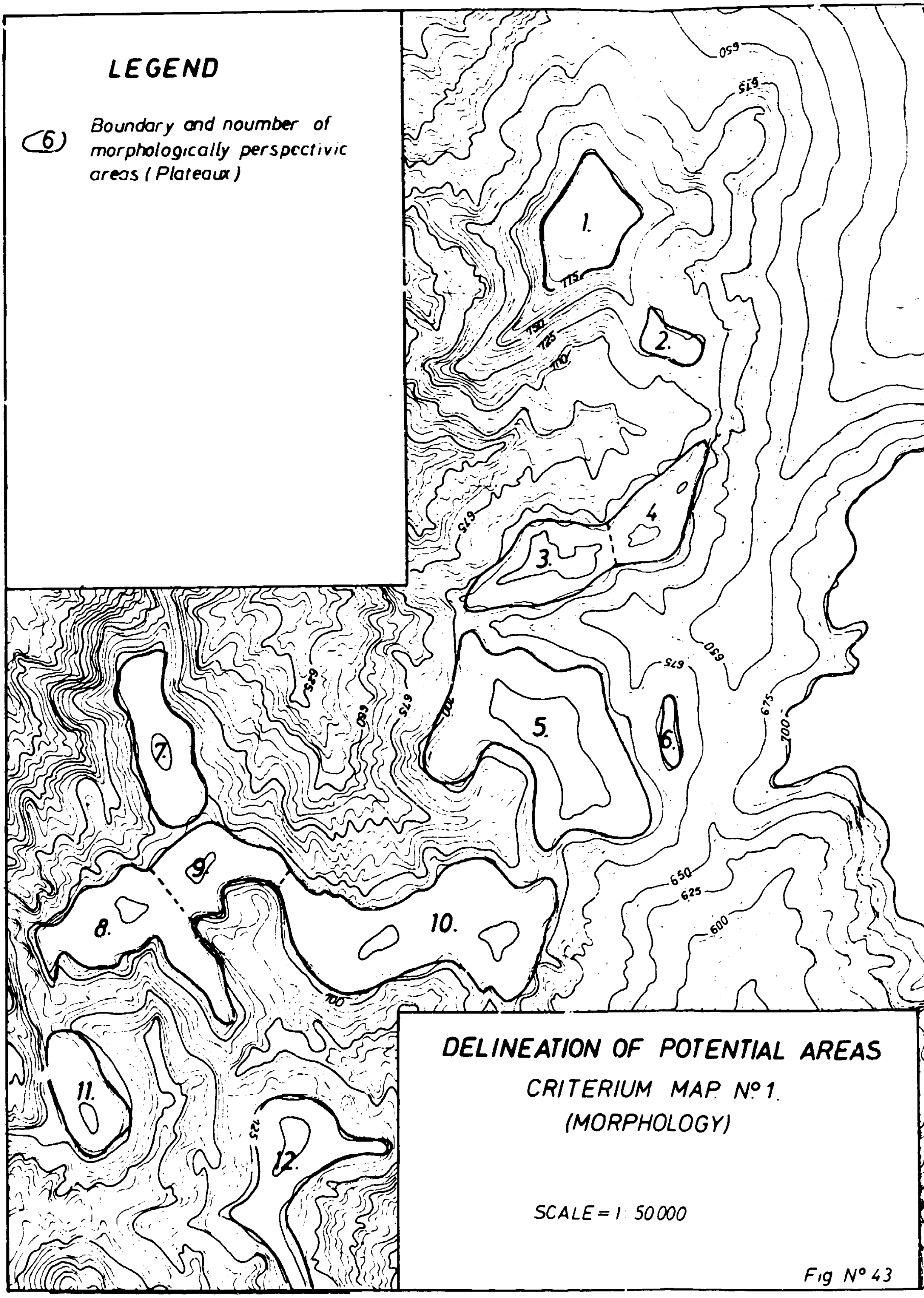
- prognostization for area
  - regional prognostization
  - local prognostization
- prognostization for reserve

Prognostization for area can be made without reserve prognostization, but prognostizacion for reserve always needs a previously made prognostization for area.

The task of the regional prognostization is to complete the prognostization of a bauxite-geologically or totally (geologically) unknown area. Here the importance of the climatic criterium can be similar or higher than that of the morphologic one, mainly in the case of the interpretation of topo-sheets and/or aerial photos at 1:100 000 or smaller (e.g. at 1:1 000 000).

The task of the local prognostization is to prognostize a smaller prospective region of an earlier regional prognostization. The local method can also be used in the neighbourhood of an already explored bauxitic area. This second case naturally means that there are no concrete data for the bauxite geological setting of the prognostized area.

The last phase of the prognostization is the reserve prognostization the task of which is the quantitative estimation (probably an uncertain qualitative estimation, too.) of the reserves. This phase always includes a "factor of uncertainty" which contains all the uncertainties of the data available at the time of the prognostization. Naturally this factor's value is always less than 1.0 and depending on the ideas mentioned above can be also near zero - mainly in some cases of the regional prognostization of geologically unknown areas.



LEGEND

(6) Boundary and noumber of morphologically perspectivic areas (Plateaux)

DELINEATION OF POTENTIAL AREAS

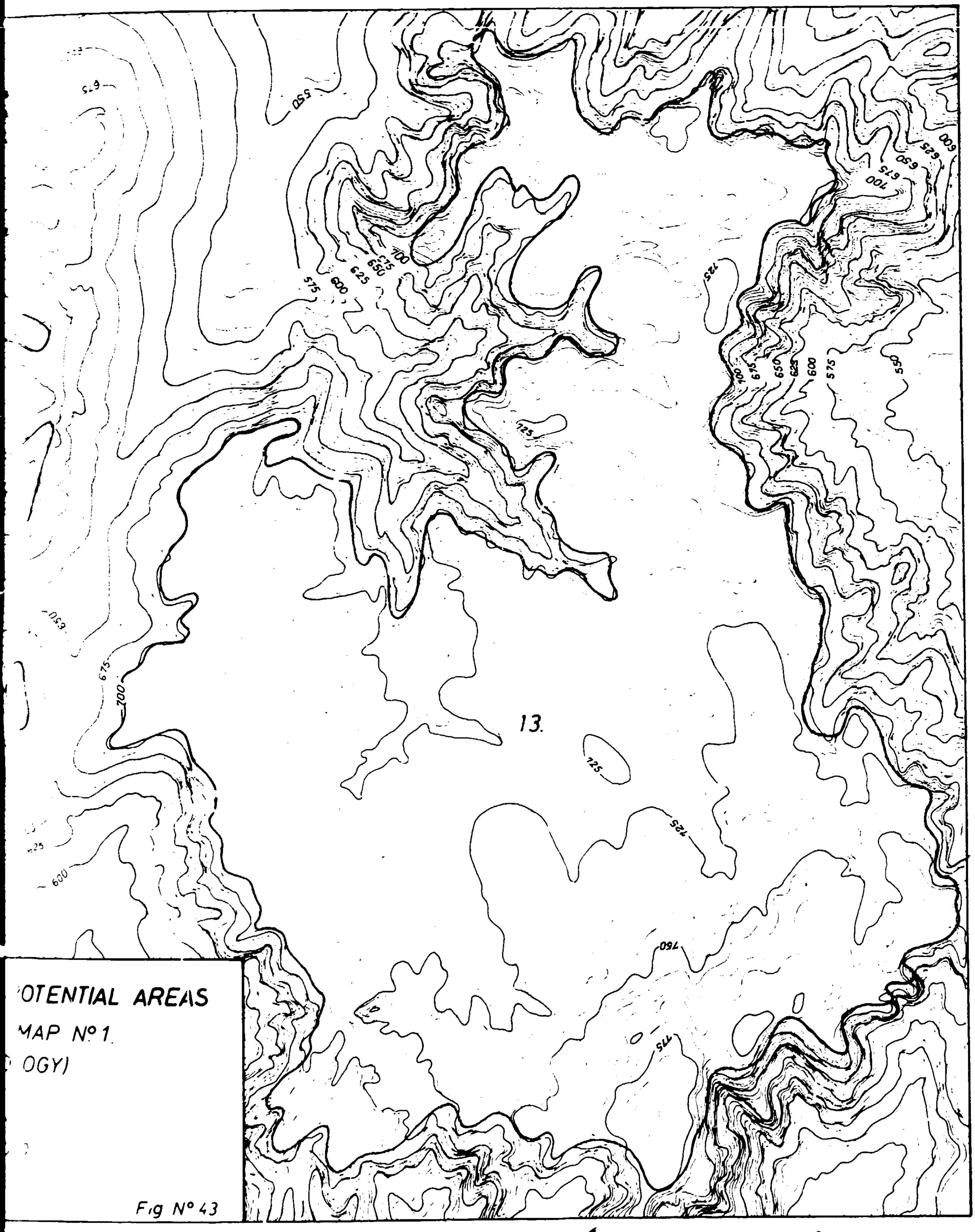
CRITERIUM MAP Nº 1.

(MORPHOLOGY)

SCALE = 1: 50 000

Fig Nº 43

SECTION 1



'OTENTIAL AREAS
MAP N°1.
OGY)

Fig N° 43

SECTION 2

Practice

The model detailed below can be used both for regional and local prognostizations. The collection and evaluation of all available data of earlier exploration is the initial step of the work, but the completion of this is already supposed for the undertaking of the following practice.

Regarding the fact discussed in Chapter No. 4.2.2. that the morphology is the most important criterium for the prognostization of the lateritic bauxites of the tropics the first and most important phase of the work is to interprete the topographic sheets and/or aerial photos (see also Chapter No. 4.3. Let us suppose the climatic criterium to be favourable at the small area of our present example.

How to interprete the topographic sheets (the morphological criterium)?

The characteristic plateau morphology can be evaluated only on the topo-maps at a scale 1:50 000 (in some cases at 1:100 000 too) or higher (e.g. at 1:25 000). Although the dip slopes and escarpments of the prospective plateaux are more or less levelled even by the newest automatic construction method of the topo sheets (using aerial photos), the morphology can be interpreted at these scales.

Let us imagine an area of about 240 km^2 at a scale 1:50 000, in other words let us carry out local prognostization (besides this example naturally there are at many areas of the tropics laterite or lateritic bauxite-capped plateaux with smaller relative difference in height to the valleys, e.g. 10 to 30 meters, etc.). Based on the density of the contour lines and on the easily measurable dip of the flat, plateau-like parts of the map, a number of morphologically prospective smaller or larger areas can already be determined (Fig. No. 43

ser. number of prospective plateaux from 1 to 13). The extent of these plateaux can also be easily defined by the approximative delimination of them at a contour line lower than the rim of the plateau. This contour line can be choosen by the thickness of the lateritic (lateritic-bauxitic) profile, which is generally 10 to 20 meters. It is well observable, that the western part of the sheet shows different morphology with smaller plateaux than that of the eastern part with only one, but a more extended plateau. Some of the small plateaux of the western part already indicate the signs of further dissection, therefore these are separately numbered.

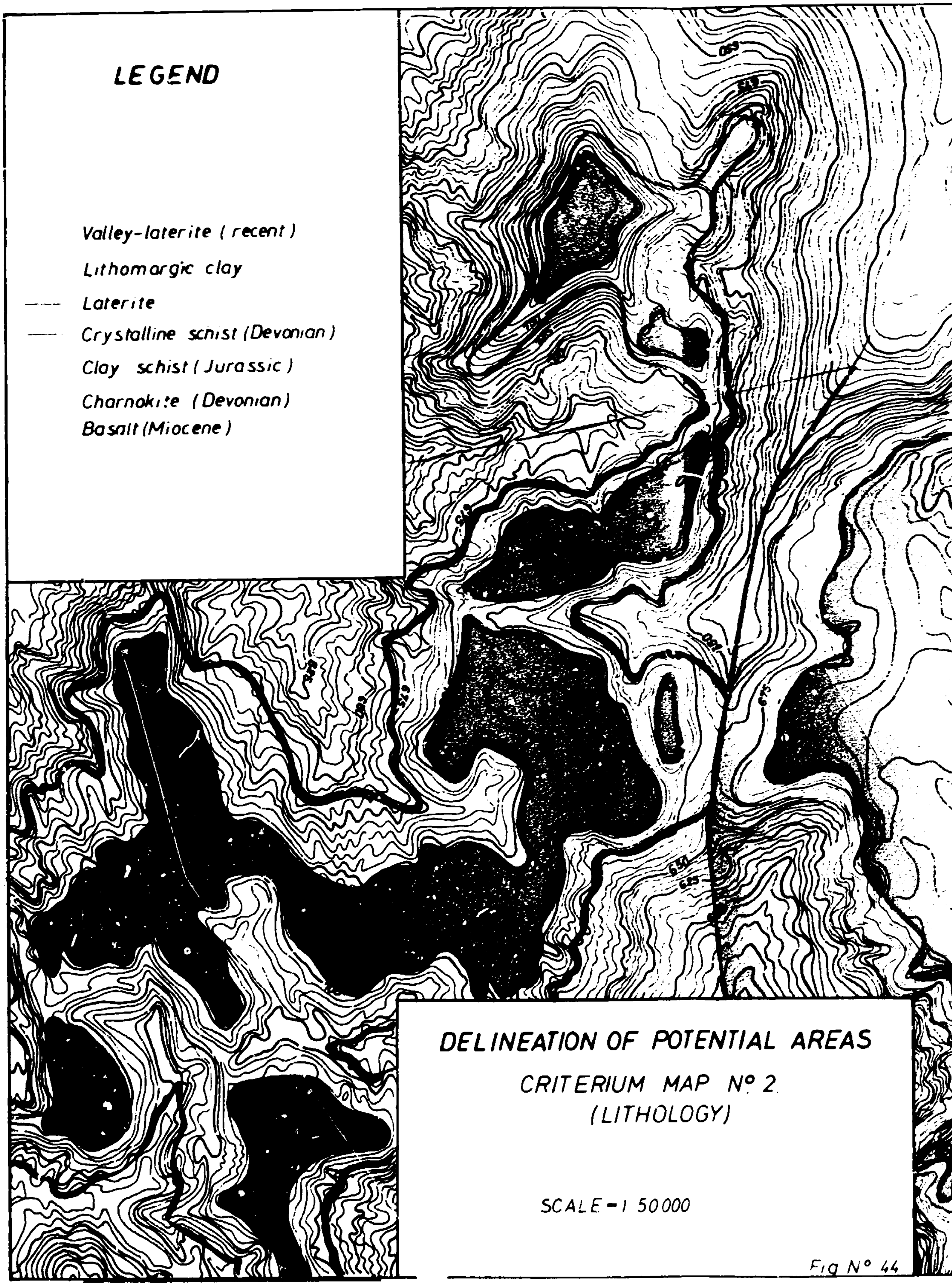
The small plateaux of the western part indicate more favourable conditions for the bauxitization due to the excellent circumstances of leaching owing to the relatively high ratio of the "rim position" against the "in-plateau position". Regarding these conditions the eastern single great plateau has a far less favourable situation, excluding the near-to-the-rim parts of it. However, this plateau No.13. still cannot be excluded from the prospectivity in this phase of the prognostization.

Based only on the morphological criterium an order can be determined by the prospectivity of different sizes and positions of the areas as follows:

most prospectives are:	the small plateaux
prospectives are :	the near-to the-rim parts of the great plateau
less prospective is :	the inner part of the great plateau

How to evaluate the lithological criterium?

Fig.No. 44 shows the results of an earlier geological mapping and sampling work. Regarding the lithological criterium the geological setting produces different parent rocks (shale,



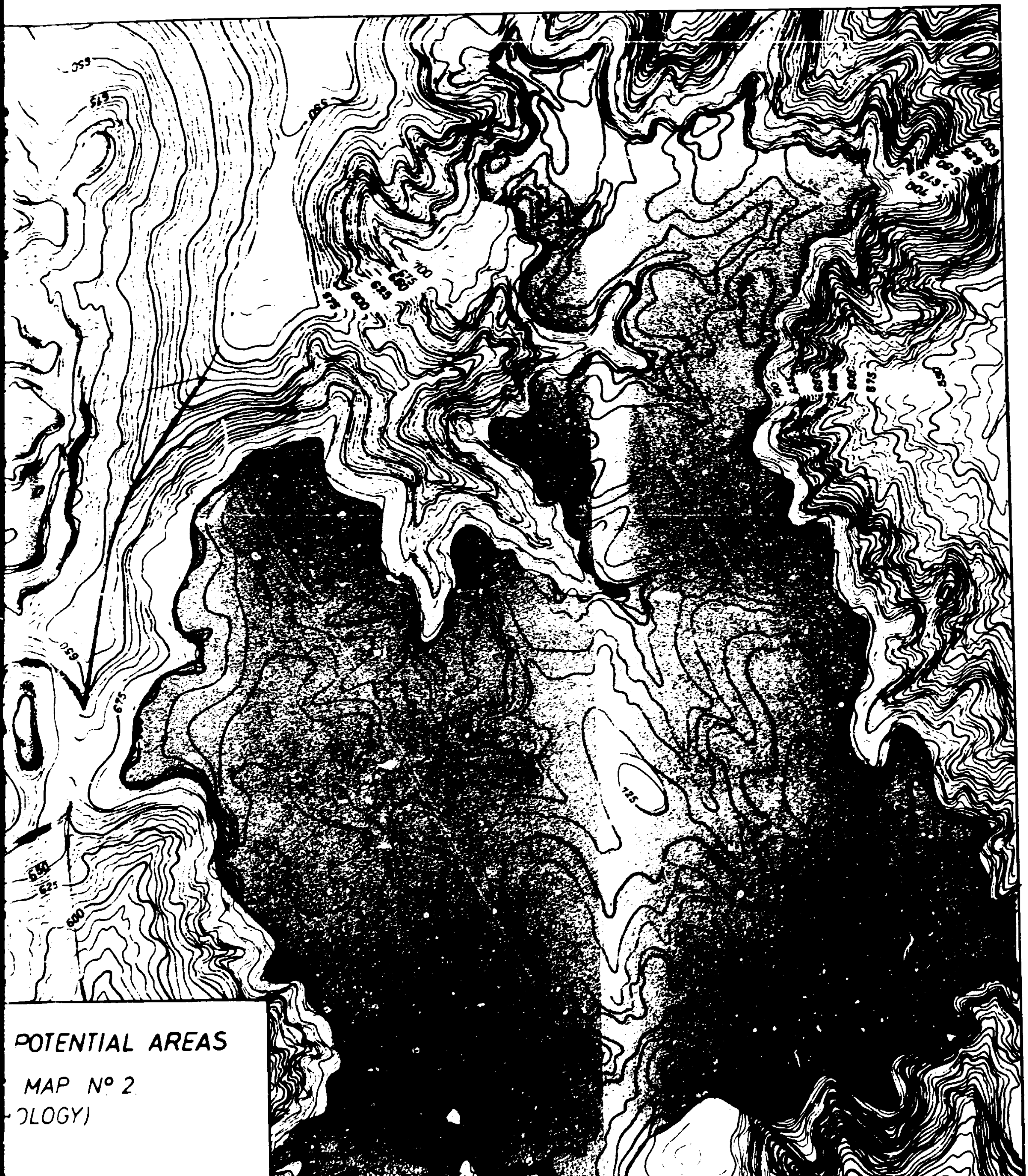
DELINEATION OF POTENTIAL AREAS

CRITERIUM MAP N° 2
(LITHOLOGY)

SCALE – 1 50000

Fig N° 44

SECTION 1



POTENTIAL AREAS
MAP N° 2
-)LOGY)
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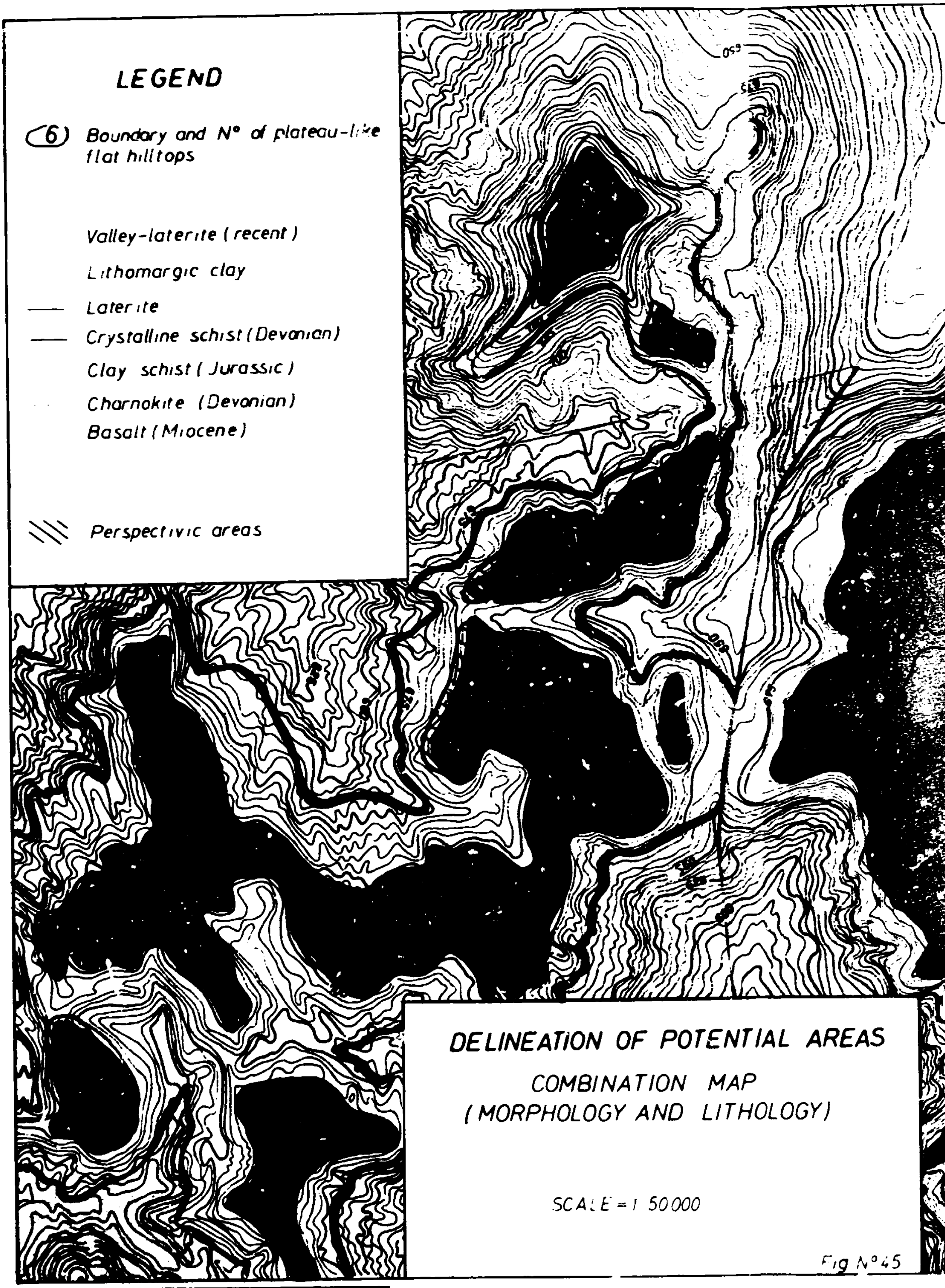
Fig N° 44

SECTION 2


LEGEND
(6) Boundary and N° of plateau-like flat hilltops
Valley-laterite (recent)
Lithomargic clay
Laterite
Crystalline schist (Devonian)
Clay schist (Jurassic)
Charnokite (Devonian)
Basalt (Miocene)
Perspectivic areas
DELINEATION OF POTENTIAL AREAS
COMBINATION MAP
(MORPHOLOGY AND LITHOLOGY)
SCALE = 1 50000
Fig N°45

SECTION 1

SECTION 2

basalt, charnockite). The laterites of the valleys were separately mapped from that of the plateaux and the laterite-covered lithomargic clay was also separately determined. Due to the physico-chemical circumstances the valley-type laterite is obviously unprospective for bauxite. The geological mapping mentioned above did not indicate the visual (observable) presence of the bauxite. The chemical analyses of the samples (see the sampling sites on Fig. No. 44) show the following results:

Sample number	Al_2O_2 %	SiO_2 %	Fe_2O_3 %	$\frac{Al_2O_3}{SiO_2}^x$	Note
9/123	22.7	33.4	39.5	0.68	
14/123	29.8	37.0	44.9	0.80	
15/123	24.2	22.9	44.1	1.05	
19/123	30.5	36.6	5.4	0.83	Lithomargic clay
32/123	31.0	25.8	43.8	1.20	
33/123	48.2	6.0	22.4	8.03	Bauxite
44/123	27.3	30.4	43.5	0.90	
46/123	25.0	33.3	40.4	0.75	
51/123	17.1	42.1	24.3	0.41	
52/123	24.5	35.0	32.3	0.70	

The laterite of the western area is proved to be in a "mature" stage: the value of the Al_2O_3/SiO_2 ratio is higher than 0.8. The sample No. 33/123. collected at a small plateau is already bauxite, moreover an ore-grade one. The sample of the laterite of the eastern great plateau indicates the "unmatured" phase of the lateritization of this area. Considering the favourable lithological criterium of this plateau (due to its composition, basalt is a suitable parent rock for bauxite formation), but against of this is the young geological age (Miocene) of the basalt (criterium of geological age!) this plateau No.13. will be less prospective from the point of view of the geological age criterium.

Conclusions of the prognostization

Summarizing the phases of the local prognostization made till now the following statements can be concluded (see also Fig. No. 45.

- regarding the morphology, the western part of the area is more prospective than that of the eastern one (small plateaux against the large one)
- the lithological criterium is favourable for all plateaux, but the geological age is not that for the eastern large plateau (plateau No.13.)
- the climatic criterium is favourable (as it was supposed at the beginning of this practice) for the whole area

Based on these statements the result of the local prognostization (for area) is the following.

The small plateaux of the western area are prospective for bauxite exploration; no difference in rank can be detected among the plateaux underlain by various parent rocks (shale and charnockite).

Prognostization for reserve

The theory of the method is very simple and needs only the following data:

e = extent of the area in m^2
t = supposed thickness of the bauxite in meters
s = specific density of the bauxite (tons/m^3)

Based on these, the reserve (R) is in metric tons:

$$R = e \cdot t \cdot s$$

This reserve estimation is still optimal (or ideal) as it supposes the presence of bauxite with a constant thickness for the whole area. Therefore the formula must be corrected by the "factor of uncertainty" mentioned on page 186.

Finally the result of the prognostization for reserves will be as follows:

- the extent of the prospective area is 13.9 km^2 (13 900 000 m^2)
- based on worldwide bauxite geological experiences the estimated thickness of the bauxite is: 4.0 meters
- according to similar data the average of the specific density is: 2.4
- the factor of uncertainty (the most subjective data of the estimation) is: 0.5

$$R = 13.9 \times 4.0 \times 2.4 \times 0.5 = 66.7 \text{ million tons of bauxite}$$

which result doubtless proves a proposal for a bauxite exploration programme.

As it was already mentioned above, a reserve prognostization for quality is very uncertain. In the example detailed above the presence of a good ore-grade bauxite can be supposed: the <u>modul</u> of the sample No. 33/123 is more than 8.

The morphological interpretation of aerial photos

The question of the usability of aerial photos for the prognostization of laterites has already been investigated by number of authors (cf. Chapter 4.3.).
The essence of the method is, that the morphology of the typical laterite- (or lateritic bauxite-) capped plateaux is the best observable and interpretable by aerial photos. The drainage system can also be perfectly determined and

there are favourable possibilities to show the differences among different rocks and structural elements as well.

Using either black and white or colour aerial photos the presence of the lateritic bauxite cannot be identified only by the aerial photos method, but it is the most practical and exact one.

The basic theory of the prognostization of laterites by aerial photos was defined by Persons (1970). Liang (1964) proved that the different laterite types can be identified on the aerial photos by characteristic morphology, drainage system and vegetation; on the basis of these he tabulated his experiences as shown on page 243. Chapter 4.3. (for black and white aerial photos).

4.2. PRINCIPLES AND METHODS OF PROSPECTING. SYSTEM OF EXPLORATION OF KARSTIC OCCURRENCES. PLANNING AND EXECUTION OF THE INDIVIDUAL STAGES OF EXPLORATION

Despite their chemical and mineralogical composition being almost identical, as to geology, there are basic differences between karstic and lateritic bauxites and these differences require fairly divergent methods and systems to be used when prospecting for bauxites in tropical and in temperate (or mediterranean) regions of the world.

The differences are mainly direct results of certain elementary processes of formation.

Material supply can be assigned in both cases to weathering (the source from which the material of the ore can be derived is some kind of weathering rock).

The factors of accumulation and economic concentration of this material are, however, different: they are of chemical nature in lateritic weathering crusts, but mainly mechanical in the case of karstic bauxites. Differences become less pronounced again during diagenesis: apart from some subordinated mechanical agents working primarily in karstic environments, the factors of consolidation are mainly of chemical (colloid-chemical) character in both cases.

To sum up all, lateritic bauxites can be considered as "in situ" residual deposits bound to a certain stage of the evolution of a given relief, while karstic bauxites are practically fine-grained clastics i.e. ordinary sediments bound to karstic carbonate terrains (cf.Chapter 2.1.2.5.).

Accordingly there will be basic differences between the principles of prospecting for karstic and for lateritic bauxites.

When prospecting for lateritic bauxites erosion remnants of old dissected peneplains are considered to be perspectivic, with special attention focussed on to weathering crusts preserved on flat hilltops. In other words, prospecting activity is to be concentrated on to positiv elements of the one-time erosion surfaces. Karstic bauxites are bound, however, to areas of optimum accumulation, that is, to the depressions of the one-time karstic carbonate terrain. Prospecting activity should concentrate therefore on to the negative elements of karst-morphology in this case.

An additional difference of primary importance arises from the fact that lateritic bauxites are found mostly in a surface or near-surface position, while karstic bauxites are generally covered by a thinner or thicker overburden. (This is quite natural, since karstic bauxites are formed always in relatively mobile crustal regions of overall accumulation character, thus they are literally predestinated to burial.)

Accordingly when planning of prospecting for lateritic bauxites direct methods of geomorphology (such as aerophoto--interpretation, detailed topo-sheet based geomorphological analysis, etc.) are preferred while the planning of karst--bauxite prospecting relies always on various methods of indirect geomorphology (faciological, stratigraphical, and/or geophysical tracing of the relief of the potential footwall).

Similarly also the details of execution of prospecting in karstic areas differs substantially from what is known to be effective in lateritic regions.

The exploration of lateritic occurrences is carried out mainly by pitting, with additional drilling by hand-operated Empire-drills or light-weight portable power-driven equipments. Pitting and Empire drilling are, however, subordinated when prospecting for karstic occurrences - they are drilled mostly by normal power-driven units of a medium depth-capacity.

Due to the above specified differences, further details of prospecting for karstic and lateritic bauxites will be discussed separately.

4.2.1 Prospecting for karstic bauxites

The ultimate target of every prospecting activity is to prove economic reserves of mineral resources demanded by the mining and processing industry.

Independent from the nature of the mineral in question, the principles of this activity are essentially the same: prospecting and/or explorations as a process of cognition should be

- comprehensive and complex,
- gradual (or progressive), and
- economic,

and the distribution of the new information produced by this process of cognition should be as well-balanced as possible.

1) The principle of comprehensive prospecting and/or exploration requires the extension, grade and all other parametres of the deposit to be known at the end of the given exploration campaign as perfectly and completely as possible. In certain circumstances this requirement, can be - or should be - neglected, however. Within the tropics for instance, where large areas are covered by potentially bauxitiferous laterites, precise delimitation of the deposit within the course of a single exploration campaign being an illusory anyway, prospecting is - or should be - mostly restricted merely to prove the reserves required to cover the needs of the future processing industry for at least the years of return of the invested capital.

The principle of complexity of a given prospecting campaign organized for proving the presence of a particular mineral raw meterial requires also other mineral indications, revealed during that particular campaign, to be recorded and documented carefully so that the information thus accumulated be satisfactory to serve as a basis for planning any further operations or for any preliminary economic assessment concerning these indications. (E.g. coal-seams immediately above karstic bauxites; or economic concentrations of nickel or other metals other than alumina in lateritic weathering crusts).

2) The principle of progressivity requires the amount, exhaustivness and reliability of geological information to be progressively increased in the course of the exploration. This is attained by exploration carried out in three or four successive stages.

The first (or prospecting) stage, immediately adjoining to the preliminary step of delineation of perspectivic areas, is aimed at the investigation of the bauxite potential of the area in question. It has to decide whether there are any disqualifying circumstances concerning the geological possibilities of bauxite, and whether the costs of planning and execution of the next stage are justified. It is required during this stage to review - and possibly also check - all the available previous information. Reserves estimation (surmised reserves, category "D") is based in this stage largely on analogies and on the broad knowledge of the geological character of the area in question. (It is essentially the simple multiplication of the estimated areal productivity (t/km^2) with the extent of the potential area.)

The second stage has to prove the possibility of economic reserves (i.e. reserves able to be mined and processed profitably) within the area of exploration, and by doing so, to justify the costs of planning and execution of the next stage.

As to methods, drilling (and/or pitting) is already an indispensable requisite in this stage. Since the area on to which exploration is concentrated is mostly a tenth or only a hundredth of that of the previous stage, of course the area-specific costs of exploration (Ft/km^2) may be ten times or hundered times more than they had been in the first stage. Total expenditure referred to the second stage is, however, generally the same or only slightly more than it was during the first stage.

As far as costs are concerned the situation is fairly similar also during the third stage. The proportion of drilling (and/or pitting) is, however, considerably increased in this stage, and bore-holes (and/or pits) are to be sited according to some systematic grid already. The target is to prove the presence of the ore, and - in order to facilitate the planning of the mining operations - to get as much information as possible, concerning the geometry and grade of the orebodies indicated. When either of the two is changing too capriciously, a fourth stage of exploration may be necessary in order to provide "measured" reserves for the planning of the mine.

Principles of division of the exploration on to sucessive stages, as well as the essence of each stage depends closely on the amount of geological information available at the beginning of prospecting. In addition, the whole scheme is to be properly fitted also to the geology of the area in question.

There are substancial differences for instance between the first stage of exploration of an already more-or less known, and a completely unknown area. When having sufficient amount of reliable previous information, delineation of potential areas and planning of the first set of bore-holes can be carried out by some simple office-work and without any factual prospecting. That is strictly speaking actual drilling and mapping belong to the second stage of prospecting already.

In unknown territories, however, delineation of potential areas necessitates some preliminary operations, including mapping and some scout drilling at the most problematic points. When as a result of these preliminary operations the outlines of geology of the area become diclosed, only then the situation becomes ready for the estimation of surmised reserves and the planning of the first stage of actual drilling for bauxite.

Of course these diffferences have their financial consequences. At places where the actual drilling work is to be preceded by extensive field-work (mapping), and the delineation of potential areas can not be carried out on the basis of previous information, the costs of the first stage of prospecting will necessarily be higher than in the case of more-or less known areas, where the costs of basic information (general geological maps, results of previous research, etc.) are not imposed on that particular stage alone, but are shared out among earlier, non-exploratory operations.

Higher costs do not necessarily lead, however, to higher risks in the exploration. Surplus costs are to be referred namely not only to bauxite, but to all other potential mineral resources likely to be found during the mapping stage of the unknown area; thus risks are of course shared among them. (Cf. with the principle of complexity!)

As for an example the system of progressive exploration and the essence of the individual stages, according to Hungarian standards will be presented in the followings:

During the 1st (preliminary or prospecting) stage.

Outlines of stratigraphy
lithology and
tectonics

of the potential areas are to be disclosed; the possibilities of economic reserves within the area of exploration should be investigated; rank of order of the potential areas is to be established; and areas to be ruled out of further exploration - if any - should be delineated.

During the 2nd (detailed exploration) stage the presence of bauxite within the area of exploration is to be definitely proved. All or almost all important bauxite bodies of the potential areas are to be indicated by mapping, drilling and/or pitting. Outlines of geology and grade of the deposits should be disclosed, to an extent sufficient for preliminary estimation of the main alumina-technological properties of the ore.

3rd (proving drilling) stage of exploration. It has to provide full-scale information necessary for planning of the mining, that is, in addition to precise data on the geometry and grade of the ore also hydrogeological, rock mechanical and other special characteristics of the deposits (fire- and gas hazards, etc.) should be fully disclosed. Sampling, and laboratory-scale and pilot-plant tests, in order to establish the proper processing technology, belong to the most important tasks of this stage.

4th (or auxiliary-drilling) stage. Facultatively, under particularly difficult geological conditions,execution of the 3rd stage (according to the standards), may turn out to be inadequate to proviede "measured" reserves for the mining, and in this case, some additional drilling may become necessary.

It is to be emphasized, that the above scheme should by no means be interpreted dogmatically. System of division and the essence of the stages of the exploration are to be worked out according to local specialities of that particular country where they will be applied. The only general principle is that all information (i.e. outcrop-data; core-information; laboratory analysis results, etc. provided by the exploration as a whole (and also by the successive stages) should be as well-balanced as possible. In other words the amount of information referred to the unit area should possibly be equal throughout the area prospected; and is to be increased during the subsequent stages of exploration gradually and evenly. By resulting in data evenly distributed throughout the area of exploration (in later stages also throughout the ore-bodies indicated) this is the guarantee for the calculation of reliable and representative averages of all the important parametres of the mineral in question.

In order to attain well-balanced sets of information, exploration and/or prospecting is carried out mostly by bore-holes arranged according to some more-or less regular grid pattern. Drilling grids are not necessarily geometric, however, geological considerations are generally preferred rather than mechanical applications of some strict quadratic or hexagonal pattern. (The requirement is namely to have a more-or--less uniform spacing of information-sources (including both bore-holes and places of reliable and informative field-observations/.)

As for some reference, let us cite the Hungarian standards for the "grid"-interval, recommended for the individual stages:

1st and snd stage: 1 km
250 m
500 m (depending also on geology of the mineral occurrence and of the area in question)

3rd and 4th stage: 100 m
70 m
50 m

The scheme is of course not compulsory: deviations are allowed, and are common expecially in the 1st stage (based on the results of the first set of holes, additional holes may be sited by closing the grid-points along some selected lines (preferably parallel with the general trend of strike and dip of the main rock units indicated). The only thing is to provide comparable and reliable information.

The principle of economic prospecting and/or exploration calls for maximum results by minimum investment, that is an optimum ratio is to be maintained between invested costs, labour, time-consumption (kept as low as possible), and the useful information (aimed as much as possible) provided by the exploration.

Minimum time-consumption is required in order to provide /1/ for the rapid feed-back of field data into the process of exploration, and /2/ proved reserves to be drawn into production at a rate demanded by the industry.

The above requirements can be met only by rational concentration of all prospecting efforts both in time and space.

The guarantee for the success of any prospecting or exploration campaign is a rational but flexible adherence to the above described principles ("prospecting should be comprehensive, progressive, well-balanced and economic") within the bounds of possibility and always with the geology of the area of exploration as the decisive moment in mind.

Methods of prospecting for karstic bauxites

Due to geological reasons the planning of prospecting in karstic areas relies always on sedimentary petrology, stratigraphy and geomorphology (direct and indirect) while execution is a matter of drilling with shallow- and medium-capacity equipments (supplemented by subordinated pitting, trenching and drilling with hand-operated machines).

The proportion of the above methods during a given campaign depends partly on the amount of geological information available at the beginning of the exploration (or the stage of exploration) concerned, and partly on the geology of the area in question.

Since the most important methods of exploration are discussed in details in Chapters 2.1., 4.3., 4.5., and on pages 211-218 they will be referred here in the form of a short glossary only:

Methods of planning and bore-hole siting

Stratigraphical and sedimentological methods are used mainly in outlining the potential areas and in planning of the details of the 1st stage of the exploration.

By careful analysis of available geological and stratigraphical data they have to reveal all gaps of marine sedimentation which can be assigned to longer or shorter periods of emergence and thus may be considered as perspectivic for bauxite.

The delineation of potentially bauxitiferous zones in the preliminary stage of prospecting is also based partly on stratigraphical and sedimentological results of previous research, as bauxitic zones can be outlined on the basis of palaeogeomorphological and genetical considerations (confirmed by scarce indications).

Geomorphological methods. The possibility of application of geomorphological methods in karstbauxite prospecting is based on the fact that accumulations of karstic bauxites are generally connected to negative elements of the relief. Detection and tracing of such negative morphoelements are the target of all geomorphological methods (either direct or indirect) when applied for bauxite prospecting purposes.

Methods of direct geomorphology can be used in shallow areas only, where near-surface accumulations of commercial--grade ore are covered by a thin blanket of some loose sedimentary formation or by top-soil only.

The most important means and ways of direct geomorphological tracing of bauxite traps are those of the simple geomorphological mapping:

It is the smaller or larger temporary pools (=undrained depressions) which are to be recorded, as potentially bauxitiferous structures. According to the geological model, these pools form namely above negative morphological elements of the underground; and may be filled with more or less impermeable strata of bauxite. Due to compaction the ore does not fill the depressions completely and has a definitely concave upper surface. Being impermeable it slows down or even prevents vertical drainage, thus water flowing in along the slight periclinal slopes accumulates in the depression and forms smaller or larger pools. Such depressions can be detected either by aerophoto interpretation or by simple contour-analysis or by personal inspection on the field.

Indirect geomorphological methods

Geophysics

When the ore is covered by thicker and more compact layers of overburden, the relief of the basement can not be traced directly from the surface but needs more sophisticated instrumental methods.

Under favourable geological conditions reasonable approximation of the bedrock-relief can be attained by various geoelectric methods combined with the drilling of some bore-holes at the most problematic points (=Underground Potential Mapping).

The details of this method are described in Chapter 4.5 on Geophysics.

Faciological investigation of the immediate cover

Tracing the bauxite traps by means of faciological investigation of the cover is a method based on the fact that the facies characteristics of sediments laid down immediately on top of bauxite-filled depressions are unmistakably different from those deposited on to the bare interdepressional dolomite surface. The nature of these differences and the role of systematic faciological investigations in bore-hole siting is discussed in details under 2.1.2.4.

It is to be noted, that of all geomorphological methods it is the faciological one that provides for the maximum "number of hits". Being rather sophisticated, however, it demands also the maximum precision in sampling and sample treatment, and gains real importance generally during the 3rd or 4th stage of exploration only. The other two methods (=direct geomorphology and geophysical tracing of the bedrock-relief) although applicable right from the beginning of prospecting on; prove the presence of "potentially bauxitiferous structures" in the terms of descriptive geomorphology only. That is, negative morphoelements are detected without any reference to their age, origin, or to the nature of the material filling them. The results of indirect geomorphological analysis are to be accepted therefore with precaution. When submitted to careful geological- and geomorphological examination part of the potential structures may prove to be namely unworthy of drilling.

When prospecting in covered areas of characterless low relief they are of crucial importance, however, because by marking the places of negative morphoelements of the bedrock they present the only basis for any reasonable bore-hole siting.

Methods of execution

It was mentioned already in the foregoing paragraph that in shallow areas, where the ore is covered only by a thin layer of loose sediments or by some top-soil, bore-hole siting is based mainly on the results of geomorphological mapping and/or of geoelectric measurements. Every point supposed to be perspectivic should be checked, however, before the beginning of the actual drilling campaign. Checking of the proposed sites is undertaken by digging pits, shafts or trenches, or drilling check-holes by hand-operated portable drilling machines. Expensive power-driven equipments are to be put into action only where no disqualifying moments have turned up during the check--procedure. In the case of particularly shallow occurrences sometimes power-driven machines may completely be substituted by handoperated equipments or by pitting, and this leads to considerable savings on the total expenditure.

Having rather compact and thick cover sequences over the ore, in Hungary, prospecting is being undertaken generally by using power-driven equipments of a depth-capacity of 150 to 300 and 500 metres (made by Wirth Co.).

The quarantee for any systematic prospecting activity is the well prepared project which is essentially a repertory of instructions concerning bore-hole-siting, drilling, sampling, laboratory analyses etc., together with technical details, schedule and coordination of all these activities. In addition it includes also the comparison of the estimated costs of all geological technical and other auxiliary operations and the probable in situ value of the expected reserves, and thus it provides basic data for a preliminary decision concerning the economy or viability of the projected campaign.

Every project consists therefore of two inseparable parts: a "manual" and a "viability study".

The firm basis for each is the reliable "prognosis" of the geology and the reserves of the area of exploration. Volume and costs of drilling are estimated and the "manual" part of the project is prepared on the basis of the "delineation of potential areas", while the total costs of exploration and the in situ value of the deposit to be drilled (i.e. the estimation of the expectable specific costs of the exploration) are compared by using the results of preliminary reserve forecasts. The viability of the project is decided with the concept of the limit--costs in mind. This is the highest yet economic specific cost (in Ft/to) calculated with the maximum permissible expenditure and minimum reserves referred to the area of exploration. Since the limit is established always by considering local commercial, infrastructural and industrial conditions, its specification is pointless here.

It is quite obvious that the reliability of the "prognosis" has a direct influence upon the risks of the exploration. Risks are highest in the 1st stage when projecting is based mostly on surmised information with only scarce factual data. The 2nd and 3rd stage are not so risky since here the target is mostly to get further detailed information about the already indicated reserves only.

In order to illustrate the structure of the exploration project, the layout of a project prepared according to Hungarian standards is presented in the followings:

INTRODUCTION

Description of stage, target and area of the exploration, name and motives of the person or institution who proposed to launch the campaign and the expected results, concerning

a) general geological information
b) mineral potential, such as
  ba) mineral resources before and
  bb) after completion of the relevant campaign
  bc) expected requalification of known reserves as resulted by the relevant campaign
  bc) other potential resources with in the area of exploration (e.g. water, thermal-waters etc.)

Projected duration and proposed date of beginning and closing the campaign.

Proposed date of presentation of the Exploration Report.

GEOLOGY

1. Critical review and evaluation of previous research (Table No.1.)
   1.1. Topography
   1.2. Geological mapping
   1.3. Geophysical survey
   1.4. Drilling
      1.4.1. Drill-hole survey (well-logging)
   1.5. Mining geology (if any)

2. Outlines of geology of the area in question
   2.1. Stratigraphy
   2.2. Lithology
   2.3. Tectonics
   2.4 Palaeogeography
   2.5. Hydrogeology
   2.6. Petroleum geology (if any)

3. Outlines of the known mineral bodies

   3.1. Depth
   3.2. Geometry
   3.3. Size
   3.4. Grade
   3.5. Origins

Expectable particulars of geology of the surmised ore bodies and probable changes of grade.

4. Detailed and controllable description of the estimation of potential reserves

5. Proposed methods of exploration

6. Sampling methods, probable volume and specification of laboratory analyses and materials testing projected

   6.1. Planned core recovery - from roof
        - from the ore and
        - from the footwall
   6.2. Means and ways of sample storage
   6.3. Laboratory investigations of the ore and the wallrocks
   6.4. Description of circumstances justifying geophysical measurements other than the standard well-logging procedure

TECHNICAL-ECONOMIC DETAILS OF THE EXPLORATION

1. Technical details of the proposed methods of exploration
2. Recommended type of drilling equipments to be used
3. Sampling methods
4. Description of all special tasks (such as geophysical measurements, hydrogeological observations or tests, etc.)

5. Justification of all technical parametres of the campaign
6. Economic parametres

TABLES, APPENDICES

1. Specification of volume and costs of all the planned operations
2. Specification of the proposed materials testing (engineering geological tests included!)
3. Economic and technical parametres
4. References cited

ILLUSTRATIONS

1. Small -scale geological map of the occurrence and its surroundings (1:25 000 or 1:50 000)
2. Exploration-map (=detailed geological map) of 1:25 000 scale in the 2nd, and 1:10 000 scale in the proving drilling stage, with
   2.1. all geological features and
   2.2. all bore-holes drawn up
3. Profiles (at least one along the strike and another along the dip of the most important formations, including some of the proposed bore-holes
4. Probable stratigraphic columns of the proposed bore--holes with the most important technical details (such as progress rate and core-recovery required, casing, flushing, etc.) indicated

It is to be emphasized, that the above layout is not the only correct one; deviations - in order to meet local demands - are permitted, and the whole system is to be accepted as flexibly as possible. The individual paragraphs are for instance never elaborated with equal minuteness: when preparing the project of the 1st stage, chapters dealing with general geology and those describing the results of previous research, and discussing the reliability of previous information are worked out with greater care and more precisely than in the case of the 2nd or 3rd stage of exploration.

When planning the proving drilling stage, however, instructions concerning the system of sampling for special technical engineering geological and hydrogeological investigations; sample-treatment; etc. become of utmost importance and are discussed in minute details because they provide basic data for the mining engineer.

The key-question of every project is to select the sites for would be bore-holes. Methods of bore-hole siting and also the system of execution of the actual drilling work varies of course from stage to stage.

Bore-holes to be drilled during the 1st stage are planned according to the concept of individual bore-hole siting. That is: plan-points are selected on the basis of general geological and geophysical considerations. Part of these points are planned simply with the intention of solving general geological or tectonical problems, having arisen during the mapping stage, or during reinterpretation of previous information. Part of the points are suggested to be drilled already in areas of surmised productivity either in order to check the information provided by scarce and unreliable indications or to check the possibility of bauxite in geophysically detected depressions of the bedrock within the potentially bauxitiferous stratigraphic horizons.

Since most 1st-stage-projects (expecially those regarding the exploration of shallow occurrences) prescribe also the completion of detailed geological and geomorphological maps, and the execution of large-scale geophysical measurements (by ground-survey or by the UPM method); and these operations ...

invariably result in a series of new areas orth of drilling - it is quite obvious that most of the plan-points of the project-map can not be taken for fix but according to the suggestions of the mapping geologist or the geophysicist are necessarily subject to slight spatial deviations in the course of the campaign.

The feed-back of field information into the process of prospecting is of particular importance therefore during the 1st and 2nd stage of exploration.

When planning the 2nd stage of exploration the geologist has already much more factual information to rely on. In addition to individual bore-hole siting, the planning of more or less regular drilling grids gains also some importance here, particularly in characterless areas covered by thicker layers of overburden. Beside using the results of large-scale geophysics, geomorphology and general geology, individual bore-hole-siting may be based now partly on the results of facies analysis already. (Although the main task of faciological investigations in this stage is to prove the applicability of facies analysis in bore-hole-siting rather than to select perspectivic points actually on the faciological basis.)

Rational schedule and co-ordination of drilling operations and laboratory investigations are of crucial importance here, because they are the guarantee for the said steady and effective feed-back of field- and laboratory data into the process of prospecting, and for the success of the so called "operative" (that is "on-the-field") control of the operations.

Promt and proper on-site interpretation of core information may result namely in cancellation of part of the projected bore-holes nearby, and thus may facilitate rational redistribution of the expenditure prescribed in the project.

The target of the 3rd and 4th stage is basically different from that of the 1st and 2nd stages. Geometry and boundaries of all indicated ore bodies are to be disclosed with the greatest possible precision; and all technical, geological, mineralogical and chemical details, necessary for planning the mining and processing technology, are to be revealed. This can be attained by drilling along some regular grid pattern, the spacing of which may be 50, 25 or even 12.5 metres (depending on the variations of the geometry and grade of the ore).

Depending on local geology, bore-holes may be sited either individually or mechanically, according to the pre-established grid pattern. In addition to drilling also detailed geophysics may be put into action in order to attain higher precision in determining the geometry of the deposits.

In addition to technical details also all geological information produced during the 3rd and 4th stage are to be recorded with the greatest possible care, because it is the interpretation of core-data, arising from closely spaced, systematically sited bore-holes of the proving drilling stage, that gives a firm analogical basis for further prognosis operations. Thus the risks of further exploration campaings may be decreased considerably.

4.2.2. Prospecting for tropical, plateau-type bauxitic laterites

From the bauxite-prospector's point of view the following two kinds of unexplored tropical areas can be distinguished:

a) those with no bauxite indications at all, and

b) those with some indications of commercial-grade bauxite

a) At places where no indications are yet known, prospecting should start with a kind of reconnaissance. This reconnaissance includes

1) general review of the lithology of the area in question (by means of small-scale /1:200,000/ geological maps)
2) climatological review with the climatological and microclimatological criteria of bauxitizaton in mind
3) outlines of geomorphology of the area in question (drawn on the basis of the 1:62,500 or 1:50,000 topo-sheets and of the results of previous geomorphological research, if any)
4) acquisition and critical evaluation of all available previous information (special maps, aerophotographs, published and unpublished reports, etc.)

(Airphotos may be of great help to the geologist in the recognition of lateritic plateaux. In fact sometimes even the first stage of detailed exploration may properly be planned on the basis of geological and geomorphological informataion obtained by the common means of aerophoto-interpretation.)

Short field-check of the most important previous geological data or statements is an indispensable element of this first - reconnaissance - stage of prospecting. Every statement of previous authors should be checked by personal observation and random sampling at some properly selected critical points. Field observations and sampling points should be recorded carefully on <u>traverse-maps,</u> which together with the available - and now already checked - previous information will serve as a firm basis for planning the next stage of prospecting.

Samples collected in the course of the reconnaissance survey are to be analysed normally for the standard five components (alumina, silica, ironoxide, titania and loss on ignition) but sometimes - when terrain conditions are exceptionally rough and/or transport facilities are inadequate, the alumina content of the laterite may be estimated also on-site, by determining simply the "loss on ignition" of the material. (see SCHELLMANN,W. 1975)

b) In areas where the presence of bauxite-grade laterite was previously proved by indications, field-work should start with <u>resampling at and around previous sampling points</u> with gradual extension over the adjoining areas.

It is to be noted, that when sampling for materials testing purposes the phenomenon of <u>extra-leaching</u> should by no means be overlooked. Due to extraim-good leaching conditions the rate of removal of bases and silica may be increased namely to an extent which results in the ananomalous upgrading of surface samples, but with no grade-improvement beneath. Surface samples are therefore be handled always with precaution, and in order to avoid misleading results, grade-estimations - even if only approximate - should be based on samples taken at depths of at least 3 metres below ground level. In order to get some genetic information, at least one of the pits has to reach the underlying clay and also the fresh parent rock, already at this early stage of prospecting.

Preparation of Exploration Projects

A succesful reconnaissance survey is generally followed by planning of the exploration of the most perspectivic areas. Depending mainly on geographic and economic conditions, projects regarding different areas may differ considerably. Principal factors to be considered when preparing such projects are as follows:

1) accessibility of the project area
2) existing road conditions; road-making and maintenance required
3) availability of suitable camp-sites
4) organization of the expedition (personnel (=trained and untrained); equipments for camping and exploration (drilling machines /=Empire or some other high-capacity mobile drills/)
5) drink-water and food supply; transport facilites (including labourer's transport)
6) organization of maintenance work-shops
7) planning and scheduling the drilling-campaign
    7.1) proposed site of base-lines, with the volume of bush-cutting required; siting of scout-drillings at every 250 to 500 feet on the base-line along the long axis of the plateau or of the occurrence
    7.2) siting of cross-cuts (at least two) perpendicular to the base-line, and joining it at productive holes sunken during the first stage
    7.3) planning of the drilling grid of the detailed phase (for areas expected to be productive) with a grid interval of 250 to 50 m. Planning of the footage necessary to complete the drilling campaign (based on the expectable thickness of the ore)

7.4) Calculation of inferred reserves and the estimated costs of exploration (on the basis of the number of boreholes necessary to prove the reserves required and the expenditure expected)

7.5) documentation of the project:
general layout of drilling points (scale 1:5000 or 1:2000)
generalized stratigraphic column
expected reserves (in million tons)

7.6) numbering system of boreholes; sampling standards (samples are to be taken usually at every 0.5 to 1.0 metres); core-handling; laboratory work; total footage to be drilled; schedule and estimated duration of the campaign.

Large occurrences are adviseable to be drilled in several subsequent stages and if so, separate part-projects are to be prepared for each stage. Exploration of large plateaux like the Ngaoundal in the Cameroons or those in Orissa/India; Trombetas/Brasilia, Weipa/Australia, Bokê/Guinea or Kibi and Nyinahin in Ghana took for instance as much as several tens of years to complete.

As for illustration see the exploration map of a medium--size plateau (Mt Ejuanema, Ghana) the reserves of which were proved by a drilling campaign that used hand-operated Empire--machines for drilling.

Planning and execution of the proving drilling stage

Preparatory works

Although detailed topographic survey and completion of map-base sheets are the most important of all preparatory works, they should be started after completion of the first scout-drillings only.

Siting of a base-line across the area to be prospected is therefore the first thing to do when beginning a campaign. Justified by positiv results of the first scout-drillings, systematic geodetic survey can be launched and based on the new/or revised large-scale topo-sheets subsequently also systematic borehole siting can be started. Under the pressure of certain circumstances it may be inescapable to start the drilling work simultaneously with the geodetic survey. Since this kind of compromise has always its risks it should be avoided, however, as far as possible. As to the technical details of geodetic work see Chapter 4.4.(Topography).

Since relief is one of the most important factors of lateritisation and bauxitization; morphological features such as inclination of slopes, stagnant pools, depressions; etc. are essential to be surveyed precisely and carefully. Beneath temporary pools the laterite or the bauxite may namely be substituted by fireclay or even by refractory-grade kaolinite.

Inclination measurements can be given up above 20°, since the intensity of erosion processes precludes the accumulation of bauxites here. Because of the possibility of secondary accumulations piedmont surfaces, in turn, may deserve some attention. Encouraged by positiv results of some preliminary pitting and sampling, geodetic survey can be extended over the piedmont areas, too.

Borehole siting is the last important step of the preparations. All proposed boreholes and pits are to be sited in the field instrumentally; sites are to be staked and numbered according to the respecting supplements of the Exploration Project. All intended exploration facilities (i.e. boreholes pits, shafts, cuttings, etc.) are to be indicated on the so called exploration map. Detailed topo-sheets should be comp[illegible] with 1 to 2 m contour-intervals.

Execution

Drilling

The principles of prospecting for various near-surface mineral resources are basically the same. Whether an occurrence is to be explored by drilling or pitting should be decided on the basis of economic and geological considerations. Since experience proved that in the case of lateritic bauxites satisfactory results may be achieved even by simple, hand-operated percussion drills, this kind of drilling became a popular method of prospecting especially in areas with abundant and cheap labour available Besides, percussion drills have the advantage of being light-weiht, portable and easy to repair.

As to personnel, one of the most important elements of the organization of drilling campaigns is to seek for suitable campsites not very far from the area to be drilled, because labourers generally do not like to have too long distances to walk. An alternative solution is to provide for some daily motor-transport for them, but for economic reasons this is unviable in most cases.

Drilling rigs are operated by "drill-gangs" consisting of the following crew:

a "sample boy", able to read and write
(for core-handling and sample-management)

a "water-boy" (responsible for water-supply for the crew)

2 to 4 labourers (doing the drilling work)

Drill-gangs are supervised and controlled by "headmen". (A headman has generally two or three gangs to supervise).

The requireable gang per shift advance is around 8 to 10 feet when drilling in medium-hard bauxitic laterite, while in hard cuirasse-type laterites productivites as low as 2 feet per gang per shift are quite acceptable. In soft laterites the advance may reach the 20 feet per day and even this highly efficient rate cannot be taken for unusual.

Samples are to be taken from every different kind of material penetrated, or - in the case of homogenous-looking laterites - at 2-feet intervals regularly.

After thorough panning and homogenizing, samples are first dried and then divided by coning and quartering on to two halves, one of which is sent for chemical analysis into the laboratories, while the other is to be kept for documentation.

When pressed for time, instead of percussion drills; various types of power-driven mobile drill-rigs may be put into action, to complete the campaign as quickly and economically as possible. (An example of the many different mobile drilling units is the Permanco-Drill used by BRGM in 1952/54 (when drilling the bauxite occurrence of the Kaw Mt-laterites), but there is a wide variety of such power-driven portable units made by Longyear, Atlas Copco, Ingersoll-Rand, Wirth and others, too.)

Of course drilling with power-driven equipments necessitates the adjustment of the personnel of the expedition: in addition to un-trained labourers, also appropriate number of skilled workers are to be employed.

In addition to labour problems also maintenance-requirements are considerably higher in the case of such "sophisticated" equipments than in the case of simple hand-operated drills.

The most suitable methods and equipments as well as the alternatives concerning campsite and personnel of the expedition are to be selected always according to local conditions and already at the early stage of the planning of the exploration.

Exploration methods other than drilling

When due to any (economic, technical or geological) reason drilling work is hindered or is to be complemented, exploration may go on also by

- pitting
- trenching, or
- by driving exploratory-drifts

Pitting

Pitting is carried out generally for checking bore-hole data to get full information on the geology of the laterite complex or to perform bulk-density tests for the reserve calculation.

Depending on purpose, both size and cross-section of the pits may be rather different. When pitting for a full profile down to the fresh rock, the pit should be of square cross-section of about 2x2 m (or 7x7 feet). (With a cross-section as large as that, excavation may go on safely even down to 10 or 15 metres if necessary).

The geology of the strata penetrated, should be carefully recorded and full documentation is to be prepared on each pit. As for the details of sampling and documentation see Chapter 3.7. on Sampling).

Shallow pits

Tracing of surface or near-surface deposits of bauxitic laterites may considerably be enlightened when excavating shallow exploratory pits for sampling purposes. Chemical assay of samples taken from these shallow pits is, however, to be handled as preliminary information only, and should by no means used for reserve calculation purposes.

Information provided by natural exposures such as termitaries or animal-holes are of the same value, and can be used just like artificial ones.

Trenching

Exploration of particularly narrow and elongated occurrences may be performed by excavating trenches arranged parallel to each other and perpendicular to the strike of the occurrence. Since the geometry of laterites is generally of three-dimensional character, trenching is by far not the commonest method of laterite-exploration, however.

Some peculiar details of prospecting for plateau-type tropical bauxites

Due to differences in geology the strategics of prospecting for lateritic bauxites is - in some respects - basically different from what is considered to be a proper strategy of prospecting in karstic areas.

The most important peculiarities of lateritic occurrences and the consequences of these peculiarities can be summarized in the terms of exploration as follows:

1) Extension and boundaries of the actual plateau-surface are reflected rather well by the topo-morphological parameters (slope conditions, contours, etc.) of each particular plateau. In the case of plateaux, the inclination of the marginal escarpment of which reaches or exceeds 30 degrees, the flat, essentially plain hilltop is marked very characteristically by the climax of the density of the contour-lines along the boundary between the escarpment and the plateau s.str.

Since drilling and/or pitting should always be confined on to the flat top-zone, the area of exploration is marked out essentially by the above mentioned contour-climax. Similarly, orientation, pattern and spacing of the drilling grid, is determined practically by the size and geometry of this uppermost lat zone.

2) Since the hilltops are by far not completely flat but exhibit slight undulations; areas less favourable or unfavourable for further exploration can always be delineated within the perspectivic top-zones. Temporary or permanent swamps filling the depressions of the undulating low-relief hilltop are for instance the first to be ruled out of the exploration, when seeking for bauxite. (They may be the signs of refractory--grade fire-clay reserves, however.)

3) Since the most important local control of bauxitization is drainage, and drainage is a factor determined essentially by relief water-balance and the pattern of surface water--courses, the most perspectivic domains of the plateau may effectively be outlined by means of aero-photo interpretations or of topo-sheet based detailed geomorphological analysis. The results may serve as a guiding principle of planning and scheduling the drilling operations.

4) The role of vegetation as an indicator of the nature of the underlying laterite can not be neglected either. Swamp--vegetation for instance can easily be recognized on aero-photographs, and thus the delineation of areas of probable degradation of the bauxite - if any - may be enlightened. Similarly, grassy patches covering hard iron-rich cuirasses are also rather obvious and may therefore be of considerable help in preparing the project of the exploration.

5) When planning the costs of transport, bush-cutting and other auxiliary operations depending closely on vegetation, the followings should be considered carefully:

whether the area of exploration is

a) forested,

b) of the savannah-woodland type, or

c) practically open grassland.

Some additional pecularities closely depending on vegetation are as follows:

a) Forested areas

1) Deforestation by burning up the vegetation is to be strictly avoided, because increasing the organic carbon content by washed-in ash and soot may lead to deterioration of even the highest commercial-grade ore beneath. Bauxites of forested plateaux have an anomalous $C_{org.}$-content anyway, thus even the slightest increase may cause severe problems in the digestion phase of the alumina technology.

2) Since gaseous carbondioxyde, carbonmonoxyde and methane formed on plant decay may concentrate in near-surface pores fissures and other hollows, great care is required when excavating pits shafts or trenches. Before sampling old, re-opened pits it is adviseable to make absolutely sure that no toxic gases are present. A traditional - and fairly satisfactory - way of checking the quality of the air at the pit-bottom is the so-called "candle-light test". If the candle-light reached down to the bottom becomes extinguished, descent is to be allowed after some effective ventillation procedure only. (Inhalation of toxic gases may lead namely to fatalities, like for instance in Ghana Mt Ejuaneme [illegible]

3) Bush-cutting forest-clearing and stripping of the top-soil should be undertaken immediately before the beginning of the mining operations only. (In the case of a too early clearing, vegetation would soon spread over the flat hilltop again

while on the slopes, soil-erosion and gullying would commence with the gullies reaching even the bauxite itself.)

4) If the marginal escarpment is particularly steep and pronounced, pitting or trenching is to be avoided along the edge of the plateau. Providing for a free water-influx, pits may lead namely to the acceleration of erosion here. By undermining the hard laterite-cap, erosion results in caving and or local collapse of the plateau-rim and may cause accidents.

b) In areas of scarce vegetation

Similarly to what was said in connection with the forested areas, clearing by burning up the bush or the grass is to be avoided here, too. (Danger of increasing the organic carbon content of the ore beneath!)

Sliding down of disjointed blocks along the marginal escarpment being a real danger here, too, pitting and/or drilling on the edge of the plateau is to be avoided.

4.3. BAUXITE GEOLOGICAL MAPPING AND MAP PLOTTING

The bauxite geological maps contain more details and data affecting (directly or indirectly) the amount and grade of bauxite, than general geological maps of the same scale do. The bauxite geological map complemented with the results of exploration by drilling, presents the subsurface extension of bauxite (and eventually also of its immediate hanging wall) as well as the structural elements detected by drilling or assumed. On the other hand, it is admissible that the representation of other geological features not affecting directly the problem of bauxite should be less detailed than the given scale would require it (e.g. the stratigraphic zonation of the deep underlyer should be entered into only as far as it is needed for the interpretation of the tectonical setting of the area).

Purpose and Conditions of the Bauxite Geological Map

It is obvious, that if the geological setting is very favourable, bauxite exploration can be done even without a geological map. Several examples of this kind are known. However, increasing demand in raw material and decreasing reserves mean ever more difficult exploration tasks. To cut down exploration risk, the cheapest and handiest solution is to prepare exploration operations more carefully, by means of (bauxite) geological mapping.

The objectives are essentially determined by the following.

1. The immediate target of mapping and plotting, i.e.
   1.1. reconnaissance
   1.2. preparation of a detailed exploration.

2. The level of geological knowledge available on the given area: available topographic maps, aerial photographs, geological (eventually also geomorphologic) maps and their scale as well as their reliability.

What is Needed to Prepare a Reconnaissance Survey

The results of applied geological mapping depends, along with the geological, topographic and human factors, upon the scale of the available geological and topographic maps, the niveau of geological knowledge of the area to be explored. As a minimum the following maps are needed:

Are to be mapped, sq.km	topographic maps	geological maps
1.000	1:100-200.000	1:100.000
300-1.000	1: 50-100.000	1:50-100.000
less than 300	1: 10- 25.000	1:25- 50.000

For a general geological mapping, in the Soviet practice normatives are used prescribing itinerary lengths and observation network density. Such prescriptions would be rather irreal in the case of bauxite geological mapping, because sampling and observation density etc. depend much more upon the terrain and structural conditions than on the map scale itself. Aerial photograps are nowadays practically indispensable, particularly in laterite areas, in case of highly dissected karst areas, or shallow-depth bauxite deposits.

Mapping and Map Plotting in the Service of Karst Bauxite Reconnaissance

The first thing to do is to collect all available literature data and maps concerning the given area, and to evaluate them from the point of view of bauxite geology. If one finds a convenient starting point (e.g., the maps indicate the presence of terrigenous formations which usually accompany bauxites and bauxite deposits), the stratigraphic situation is to be cleared up. It should be mentioned here that bauxite geological mapping needs a very careful stratigraphic revision. Bauxite accumulations having been preceded by continental periods of more or less intense erosion, it may happen that bauxite accumulated during the same sedimentary cycle overlies bedrocks of various age. Bauxite deposits being usually covered by oscillatory sedimentation, the age of their immediate cover may also be different without implying different age for the bauxites.

It may happen - especially in case of Palaeozic karst bauxite deposits - that on the general geological map the footwall and the hanging wall formations are not distinguished. This is usually due to the circumstance that the period of bauxite formation was of short duration, so as palaeontologically it is difficult to differentiate between the underlying and overlying limestonse. As a rule, in such cases they are also lithologically hardly discernible. A possible way out of such an impasse is to take a series of samples of the ascertained hangingwall and footwall rocks for paleontological and/or lithological microfaces studies. It is highly recommended that an expert in paleontology should attend immediately the mapping or reconnaissance operations.

Precising the stratigraphic position, the sedimentary gaps should be investigated and represented with utmost care, because they may be of particular importance for bauxite geology. In the Mediterranean karst bauxite province these gaps may range from the Middle Triassic to the Middle Eocene.

No mention is made here of the remnants of bauxite deposits in secondary or tertiary (reworked) position which may occur in the surroundings of the primarily sealed deposits.

3. Faciological investigations and the representation on maps of their results should also be performed. As indicated above (page 55.) the less rough the surface of bedrock, the greater is the role played by the overlying formations of different facies in the preservation of bauxite. Moreover, facies

differences may be indicative of the paleorelief of the bedrock. In the Mediterranean karst bauxite province the lagoonal sediments deposited in relatively sheltered bays, and in particular those of swamp (marh) facies turned out to be the most propice from the point of view of bauxite geology. Accordingly, it is recommended to symbolize on the map the facies of the immediate hangig wall, or to plot a facies map variety, independently of whether the hopeful sedimentary gap does contain bauxite or not.

4. The type of the deposit should also be established, including the structural elements of the bedrock, the bauxite and the cover. These affect very much the choice of the most appropriate method of exploration (type and capacity of the drills, pattern and density of the drilling grid, etc.).

5. The graphic representation on map sheet(s) is the final phase of the preparatory work. The scale may vary from 1:25.000 to 1:500.000, depending on the extension of the region explored and on the scale of the available topographic maps. In faulted and covered areas larger scale maps, in folded and well exposed areas 1:50,000 or smaller scale maps will do.

On the bauxite geological map lithostratigraphic units should be represented. A very important point is to observe and reflect the outcrop conditions. In situ rock and detritus should be clearly distinguished. Taking into account the geomorphologic situation, not transported, transported and "uncertain" detritus should also be discerned. This is of peculiar bearing in poorly disclosed areas, where the problem can be settled by exploration pits and trenches.

It may happen that bauxite geological mapping has to be started without any previous indication of bauxite or its country rocks in the given area.

Attention should be focussed on the sedimentary gaps which theorically may contain bauxite. Accordingly, unconformity surfaces are sought for If the possible bedrock cover contact is covered (e.g. by slope detritus) the cover should be removed at intervals of 2 to 5 km. Exploration trenching eventually may be successful. It is a high responsibility to declare an area unproductive (barren), and to discard it from further exploration. Nevertheless, if the contact turns out to be barren at several aptly spaced sites, exploration should not be unduly forced. A contact can be regarded as unproductive, if the bedrock is not karstified, and the sedimentation of the younger sequence starts with a more or less coarse-grained clastic series of brackish--water or marine facies. On the contrary, all types of clastic sediments (whether of reductive or oxidative environment) devoid of coarser detritus suggest possible bauxite formation and accumulation, thus being in favour of further exploration.

Detailed Bauxite Geological Mapping

Base maps required:

1:100.000 scale topographic and geological map
1: 25.000 scale topographic and geological map
1: 20-40.000 scale aerial photographs
1:5.000-10.000 scale topographic maps

Bauxite geological maps have to be constructed on two scales:

- A 1:25.000 scale map for starting the project,
- A 5: 5.000 scale map for the representation of the exploration results and for the calculation of reserves.

The 1:25.000 Scale Bauxite Geological Mapping and Map Plotting

If a less detailed bauxite geological map has been plotted for the reconnaissance survey, it should be revised and corrected in a way that it should comply with requirements of the 1:25.000 scale. If no previous bauxite geological map is available, mapping is to be done on 1:25.000 scale sheets. In both cases the following recommendations can be given.

1. If the 1:25.000 scale topographic and geological maps have been produced without the use of aerial photographs, they should be complemented by using the air photos. These are especially handy in contouring the outcrops. The relationships between the morphological features and the geological formations have to be established and checked by field work. It is desirable to have the aerial photographs transformed by magnification to the scale of the base map. In order to avoid parallaxis errors, control points have to be measured geodetically on the terrain.

2. Field work starts with checking the outcrops of bauxite and of the in situ bedrock. Bauxite outcrops should be measured with a precision meeting the demands of the 1:5.000 scale mapping. Eventually earlier ignored outcrops should be contured. Of each outcrop a 1:50 or 1:100 scale geological cross section has to be constructed, indicating the real thickness of bauxite, and the structural elements observable in the bedrock, in the bauxite, and in the cover as well.

The stratigraphic zonation of the deeper bedrock is in the majority of cases neglectable in this phase of work; but the exact knowledge of the higher formations of the cover may be important.

3. If in situ rocks and detritus have not been distinguished yet, this should be done, if necessary, by excavating a suitable number of exploration pits and trenches.

If it is possible - e.g., if there was done open-pit mining in the neighbourhood - it is worthwhile to study the degree of undulation (roughness) of the karsted bedrock. This comprises measurements as to the average interval between sinkholes, their largest amplitude, orientation, etc. These data may be useful both during the projecting and the evaluation.

The 1:5.000 Scale Bauxite Geological or Detailed Exploration Map

Detailed explorations should be represented on, and directed by using an at least 1:5.000 scale map. For plotting its bauxite geological variety, the following should be taken into consideration.

1. If no more detailed topographic map is available, a 1:25.000 scale topographic map has to be magnified to the scale 1: 5.000. In the immediate surroundings of the bauxite and bedrock outcrops a topographic revision is indispensable, making use of the correspondingly magnified aerial photographs.

2. Topographic revision is followed by a geological reambulation. If the bauxite outcrop contours have been measured during the 1:25.000 scale bauxite geological mapping, these data can be used, but they should be revised (checked) on the spot.

3. In this phase the geomorphological evaluation may be of great utility, Shallow-lying (down to 50 m) bauxite bodies may be fairly well indicated, due to the circumstance that the relief gently follows the karstic depressions of the bedrock. These surficial depressions usually can be detected on aerial photographs and checked on the terrain. Even the smallest not--drained spots should be represented on the map, because they may point to the presence of bauxite or clay fillings.

4. During the exploration, not only the sites of boreholes and pits etc., but also the thickness, grade and depth of the bauxite bodies should be marked on the map.

5. The newly detected structural elements should be added to those already figured on the map.

6. On the basis of this map, several map sheet varieties can be plotted, at different scales; such as the bedrock surface etc. maps, as required by the mining project.

Exceptionally it may occur that bauxite bodies or deposits occur uncovered on the surface of karstic rocks. It is evident, that in this case no reconnaissance and detailed bauxite geological mapping is needed. However, such favourable conditions are usually encountered in those regions of the world, where no suitable geological map and possibly even no aerial photographs are available. In this case, one schould proceed immediately to the direct geodetical measurement of the bauxite bodies, in lack of a national (country-wide) control point system by using local co-ordinates (see in more detail in Chapter 4.4.
Topographic surveying can be done on a scale of 1:10.000 to be magnified later to 1:5.000. This work can be done on the terrain during the prospecting-disclosing activities, the important point is that the map should be ready when reserve calculation is to be started. If no topographic surveyors are at the disposal of the geologist, as a last compromise the contours can be measured by using a measure tape and a compass.

Reconnaissance Mapping in Laterite Areas

The starting point is to study the geomorphology of the area. It has already been emphasized in Chapter 2.3. that laterization (and, in particular, bauxitization) beside the obvious climatic factors depends essentially upon the drainage situation of the area. The water balance of the rocks is determined by their physical properties and the given geomorphologic situation.

The most favourable conditions prevail on plateaux, flat or gently rolling hilltops, of slopes up to 10-12° only. On a surface of this type, chemical weathering predominates erosional effects being subordinate. In accordance with this fact, the biggest bauxite deposits of the World are situated on peneplains of polycyclic evolution. In Chapter 2.3. has been dealt with that e.g. in West Africa or India bauxite formation is bound to different height levels (altitudes). This is a reliable phenomenon consequently traceable over areas of several hundreds of square kilometers. Accordingly, a well-done topographic map provides a possibility to correlate corresponding planation surfaces. (This has to be accomplished on 1:50.000 or 1:62.500 scale topographic maps). Plateaux or hilltops larger than 1 ha should be contoured by isolines. Diagrams may be plotted demonstrating their elevation frequencies.
Slopes more abrupt than 12° should also be delimited.

This preliminary work should be followed by field trips involving sampling. Thus one can point out the most hopeful levels. Attention should be paid to take a representative number of samples from each of the successive levels. Within one unit, in function of the roughness of the terrain, one sample or profile for each 2 or 3 square kilometers are needed. Samples may be taken from cleaned scarps, from smaller pits, in some cases even immediately from the surface; the point is that is should be taken from below the iron crust (cuirasse). A hand-drill may be very useful. In this phase, it is not indispensable to intersect the entire laterite profile down to the fresh bedrock.

A few words should be said about the mapping of secondary or alluvial, detrital laterite accumulations. In the vicinity of ancient, strongly or completely denudated plateau-type bauxite deposits bauxite accumulations may occur even on abrupt slopes. A geomorphologic analysis is indispensable in such cases, too. The recovery factor depends, among others, upon the angle of the slope (intensity of erosion). Only pitting can clear up which is the most favourable slope angle providing the richest and purest accumulations of bauxite detritus. In this case also the ring contour method can be used to pick out the most hopeful areas of further exploration.

The Role of Aerial Photographs in the Reconnaissance

Aerial photographs have long been used in laterite exploration. Not only the morphologic featurees of the terrain, but also structural (tectonic) elements, the hydrographic network, and differences in vegetation are well obeservable. In an indirect way, by comparing the photos with personal observations made during the field work, conclusions can be drawn as to the local featurees of laterization.

The guidelines of laterite exploration have been summed up by Persons (1970). Slumping terrains indicate instable subsoil so they can be ruled out. Hilltops of vague contours of light grey colour indicate a laterite blanket. A slightly rolling terrain, indicating, as a rule, a mature morphology, may be lateritic. On the contrary, no laterite should be searched for in the recent alluvium of flat valley bottoms. Light-grey patches on elevated flat surface may be the erosion remnants of ancient laterite blankets. Plain surfaces, bare, or covered merely by grass, in forest areas suggest the presence of a hard iron crust at the very surface. It is a very important observation, that on surfaces capped by laterite there are no regular waterflows.

in recently cut-in valleys, along abrupt slopes good exposures of the laterite profile are common.

Liang (1964) has established that the various types of laterite are well discernible on aerial photographs, as given in Table No.7.

The Detailed Geological Mapping of Lateritic Bauxite Areas

This is the most neglected branch of laterite bauxite exploration. This is due to the fact that even without any kind of geological map successful prospecting has been done in the laterite bauxite zone of Africa and Asia, thanks to the circumstance that bauxite, as a rule, occurs at the very surface, thus being easily traceable in the field.

Nevertheless we consider it necessary to perform the following work, because mining has in numerous cases been badly surprised and has suffered heavy economic losses.

1. At least for the productive areas and their immediate vicinity a topographic base map of at least a scale of 1:10.000 is needed. Eventually an aerial photograph magnified to this scale will do, if the area is not very much covered by vegetation.
2. Pits, boreholes, plateau margins should be located and measured geodetically. In lack of a countrywide system, a local control point and co-ordinate system may be used.
3. The distinction of bauxite from laterite s.s. should be done on the basis of an appropriate number of chemical analyses. It should always be indicated in the legend of the map, which were the conditions of delimiting bauxite (geological "cut off"). The same is valid for laterite, ferruginous laterite, ferruginous clay, lithomargic clay etc. These terms vary widely even within the same country and under

the direction of the same mining authority, sometimes even on two neighbouring map sheets (plans), too.

4. It plays a very important role to know exactly the drainage conditions and the geomorphology of the area. These should be indicated on a map. Not-drained patches within the bauxitic plateau should be delimited, because they mean certainly unproductive (barren) "window" in the bauxite blanket.

Documentation to Para 4.3.(maps and explanatory texts) should be delivered to the participants on the spot.

Table No.7.

SUMMARY OF THE AIRPHOTO IDENTIFICATION OF LATERITE SOILS

(after LIANG, 1964)

Materials	Topography	Drainage	Erosion	Grey tone	Vegetation	Remarks
Laterite (crust)	Cap rock, flat hill-tops, ledges on slopes	Slight	Little rock-falls on edge of cap	Light	Grass or low shrubs	Caracteristic thin light grey line within darker tone
Laterite (garvel)	Flat hilltops, slight to rolling terrain	Slight	Little (gul-lying on slopes bel-low gravel)	Light	Grass or low shrubs	Light grey mass above slightly darker grey eroded area within darker tone
Laterite (hard-ened on exposure)	Rolling terrain with flat valley at high to inter-mediate slopes	Slight	Little	Light	Plantation ag-riculture stunted trees, light-grey foliage	Shows borrow pits abandoned farms, air-fields without vege-tation, denuded golf courses, parades, etc.
Lateritic soil	Rolling terrain at high to inter-mediate slopes	Varies from moderate to slight de-pending on degree of lateritisa-tion	Varies little in more advan-ced stage of lateritization	Light to medium	Plantations, swidden ag-riculture	Termite hills
Red and brown clays	Variable; all forms except in basins	Considerable surface drain-age develop-ment	Gullying ero-sion; depth of gullying indi-cation of depth of soil to rock slides	Medium to dark	Variable; intensive ag-riculture common	

4.4. GEODETICAL AND TOPOGRAPHIC OPERATIONS

Even for the simple orientation in an unknown terrain a topographic map is indispensable. Its importance becomes even more imperative, if one wants to depict or to trace out the location of the geological observation points and/or the exploration sites.

The accuracy of location can be very different depending upon the objective and scope of exploration ranging from the identification of corresponding points on the terrain and on the map (or photograph) by means of simple visual comparison to the high-precision geodetic measurements.

As the geologists can not avoid to claim the help of topographers, it seems to be justified to give here a short review of the surveying activities connected with geological exploration, with special regard to its working tools and methods.

In the practice, the following elements have to be measured:

- the horizontal angle closed by the directions pointing from the station point of the instrument towards other points,
- the vertical angle /the angle closed by the direction from the station point of the instrument towards another point with its vertical or horizontal projection),
- the distance between the points (eventually, directly the horizontal distance),
- the height difference between the points (the vertical projection distance).

The high-accuracy measurement of the horizontal and vertical angles is done by means of the <u>theodolite.</u> This is an instrument mountable on a tripod, on the static part of which (fixable to the tripod) there is a graduated circle (limbus). Above this is situated the turnable part (alidade), which can be rotated around a vertical axis perpendicular to the plane of the limbus and passing through the centre of the graduated circle. In the telescope standard of the turnable part (rotating around a horizontal axis) there is a telescope.

In case of a well adjusted instrument the horizontal axis is perpendicular to the vertical axis as well as to the sighting axis of the telescope (i.e. to the straight line connecting the optical centre of the objective with the centre of the reticule).

On the static part one finds the foot screws serving to setting vertical the vertical axis and the clamping screw destined to fix the instrument to the tripod, provided with a hook for the plummet needed for the exact centering above the measurement point.The most types of theodolite are provided with an optical plummet, too. On the alidade, there are several screws: one to fix the vertical axis, another to fix the horizontal one, and a micrometer screw o slow motion screw used for fine sighting. Important additional elements of the alidade are the bubble levels to assure the vertical orientation of the vertical axis,

- the vertical graduated circle (mounted concentrically and perpendicularly to the horizontal axis, moveable together with the telescope), the reading index and its bubble level,
- the reading apparatus of the horizontal and vertical circles.

After having centered the instrument to the measurement point sign and having set vertical the vertical axis, the horizontal angle closed by two measurement directions is performed as follows. The telescope is aimed at the left point and the corresponding angle value is read on the horizontal circle (with the alidade being fixed). The same procedure is accomplished as to the right point as well. The difference between the two circle readings is the horizontal angle needed. In order to rule out some errors due to the instrument, the measurement has to be repeated in a telescope position rotated by 180°, in inverse succession. The medium value of the two measured angles is accepted.

The vertical angle is read on the vertical circle, after having carefully adjusted the bubble levels of the reading index, in both telescope positions. In up-to-date instruments automatic altitude indices are often used.

The accuracy of the measurement performed with theodolites used for the surveying measurements in the service of geological exploration, is - depending upon the particular task - somewhere in the range between 1 angular second and 1 angular minute.

Tachymeters: these instruments serve to determine the location "en masse" of terrain points. These are theodolites capable to measure optically distances, with the help of a graduated rod set at the point to be measured. The reducing tachymeters have the advantage that immediately horizontal distances and altitude differences (elevations) can be determined. Several types of reducing tachymeters are known. The most widespread are the so-called diagram tachymeters: a moving diagram is projected in the field of view of the telescope (in correspondance with the changes of the vertical angle), and the rod readings have to be done at the crossing points of diagram lines with the vertical line of the reticule. The precision that can be attained by means of tachymeters is in the orders of magnitude of decimetre-metre as for the horizontal distance and centimetre-decimetre as for the altitude.

In the detailed survey the plane table and the phototheodolite are also used.

Distance measuring devices. Distances can be measured with an accuracy of centimetre usually by means of measuring tapes, a substense bar, or an electro-optical distance meter.

The substense bar is an invar base stadia set horizontally, and oriented perpendicularly to the distance in question at one of the target points. The horizontal angle marked by the terminal marks of the invar base stadia is to be measured. The distance may be calculated with trigonometrical method.

The electro-optical distance meters determine the distance by measuring the phase difference of a light beam, of modulated intensity, reflected by a reflecting surface (prisms) set at the other target pont of the distance to be measured. The light beam is continually emitted by an electrically excited luminescent di-d.

Levelling devices. These instruments serve to measure with a higher accuracy (of a millimetre order of magnitude) the elevation between different points. They are telescopes rotating around a vertical axis, mountable on a tripod. The horizontal position of the sighting axis of the telescope after a preliminary levelling by means of the footscrews and of the bubble level) is ascertained by means of a fine levelling screw and a high-sensitivity bubble level mounted on the telescope, in all directions. The device is located approximately at equal distance from the points to be measured (but not obligatorily on the connecting straight line) and readings are made at the horizontal line of the reticule of the telescope on the levelling rod put successively in vertical position onto the points. The difference of the readings gives the difference of altitude.

During the past twenty years, ever more and more automatic levelling instruments appeared on the marke. In this case, after the preliminary levelling a compensator assures the horizontal position of the sighting axis of the telescope in all directions.

Methods of measurement

In all countries, the base of surveying is a geodetical control point system. The horizontal projection location of the points is given by coordinates (X, Y) on the Earth's surface. The coordinate system is usually oriented astronomically N-S. In a given country, due to historical reasons or to the extremely large area more than one coordinate system may exist simultaneously. If this is the case, their mutual relationship must be known.

The third coordinate that determines the spatial position of a point is the altitude (Z) measured from a chosen reference surface, which is usually called "elevation above sea level". The control point system used for determining the altitudes is usually independent of the horizontal one. However, the altitude of the horizontal control points is usually determined starting from the altitude control points.

The first order control points are established firmly by bench marks fixed in the ground or on buildings. They are measured with high-precision devices, the mathematical contradictions due to errors of measurement are eliminated by some adjustment method that minimizes the effect of the errors. The coordinates are calculated from the adjusted values. Information on the location and coordinates of the control points can be obtained from the competent offices of the national geodetic surveys.

If in the given area there are no first order control points (not even in the immediate vicinity), an independent control point network should be developed for the geodetic surveying required by the geological exploration. In this case, the coordinates would be calculated in an independent coordinate system. The independent control point system can be developed by means of triangulation or by precise traversing. It can be connected to the first order control point system later, measuring several points if it is starting from the first order points. This way the data characterizing the relationship of the independent and the national coordinate system become known and the data of the other points can be converted, using formulae of transformation, to the national coordinate system.

When the control points are available (on the basis of a national survey or on that of an independent control point network) the network must be densificated by creating further points both for the measurement of exploration objects, and for the purposes of topographic mapping. The density of the points required is determined in part by the dispersion of the exploration objects, and in part by the features of the terrain. Densificating can be performed by means of theodolite only or combined with some other distance measuring device. The most common cases that occur in the practice are the following.

Intersection: in the known points the angles closed by the directions towards the neighbouring known points and towards the new point. (Measuring the third angle of the triangle (that is being at the new point between the directions pointing to the known points) a check and compensating possibility is also provided.)

Resection is performed when one can or will put the theodolite onto the new point only. In this case, however, three known ponts to aim at are needed for calculating the coordinates of the new point after having measured the two angles closed by the directions towards them.

Traversing is done by using along with the theodolite a distance measuring device, too. The essential point is to measure, starting from a known point, the angles and distances between successive (established, points and to calculate, step by step, the coordinates. If the terrain conditions allow only to measure slope distances, one has to determine the inclination angles respectively the elevations between the points as well, in order to comply with the requirements of the horizontal projection (calculation).

Traversing is a commonly used procedure to determine the points. It has several fundamental varieties which provide further combination possibilities.

Geodetic tasks in the service of geological exploration

An indispensable prerequisite for starting the exploration activity is to possess maps or aerial photographs showing the most important topographic elements, possibly also the relief, of the terrain to be explored. The scale of the topographic map which would serve as a basis for geological mapping is determined by the geological purpose: 1:100.000 to 1:10,000, or even more detailed (see Chapter 4.3.)

Such maps are available, as a rule, at the offices of the national geodetical survey. If no suitable maps exist, a particular firm specializing in similar tasks should be charged with producing them. The demands can be fulfilled most quickly by aerial photogrammetry, i.e. by maps plotted on the basis of the evaluation of aerial photographs.

In the cases of detailed geological mapping and exploration, the requirements of future mining are also to be considered. Consequently, more detailed maps are needed. For reserve calculation, maps of 1:2000 scale are indispensable. It is by no means indifferent, whether these are original 1:2000 scale surveying maps, or have been produced by magnification from smaller scale maps. In the latter case, the fact of being magnified and the original scale must be indicated on the map. Some field check is to be done, first of all at places where it is indispensable from the point of view of geological exploration and mining (e.g. the surroundings of bauxite outcrops, contour line of bedrock outcrops etc.). Such detailed maps must cover only a much more restricted area than those used during the reconnaissance geological surveying: they should refer only to the productive area and its immediate vicinity, where the mining establishments will be located. Even these maps can be produced by using the methods of aerial photogrammetry; however, in some cases a particular topographic surveying performed by the surveyors of the exploration company may be preferred. All the devices, instruments and methods desribed above can be used. If only an earlier-made map is available, it is indispensable to carry out corrections deriving from changes that have occurred after the construction of the map (e.g. new roads etc.).

The most important and indispensable geodetic work is to trace out, to mark the objects of exploration and to measure their coordinates. The tracing out may be eventually less accurate. Sometimes compromises have tobe made: the object of the exploration should be set to the projected site within a few metres, and it should be possible to establish (construct) it, involving as little ground removal etc. as possible. When a deviation from the projected site can not be avoided, the responsible geologist should decide.

The tracing out itself, during the reconnaissance, can be performed (with regard to the reduced requirements as to the precision) can be accomplished rather simply, by using a compass, or even more simply by counting steps.

During the detailed survey, however, the common procedure is to trace out the points by angle measuring and distance measuring devices operated by a topographer-surveyor.

By no means can geodetic work be avoided at the measuring of accomplished exploration establishments, no matter whether the result of the exploration has been positive or negative. This operation requires a much higher precision than the tracing out. In this case, too, the geologist should fix the requirements of precision. Attention is called here to avoid exaggerated demands. A precision within 1 m in the horizontal projection and within 1 dm in altitude complies with the requirements of mining. It is very important to emphasize that while tracing out setting-out is possible, evidently, only in the horizontal sense, for the location of the accomplished establishments is indispensable to measure the altitude as well, otherwise the data would be useless for the mining.

The X, Y and Z coordinates of the geological establishments provide a basis for graphic representation and for numerical evaluation as well. In the past few years calculations became much simpler aided by the common use of electronic pocket calculators.

If the mineral resources occur right at the surface, or there are outcrops of it, the contours of the outcrop(s) should be measured. This may be performed by means of a tachymetric survey, or (if a map representing the topography is available) by a measuring line and a compass, starting from the control points and ending with the target points. Using the compass, one should take into account the fact that the magnetic N-S direction does not coincide with the reference direction of the coordinate system. The difference (deviation) can be established by comparing the geodetically measured direction with the magnetic N-S direction.

4.5. GEOPHYSICS

The efficiency of geophysical methods in bauxite exploration depends on two main conditions:

- modern exploration aspect: the geophysicist carrying out the planning and interpretation of observations must have an appropriate knowledge in geology while the geologist who is concerned with the geological survey, must have geophysical knowledge and outlook;
- always the appropriate technical facilities and processing methods fitting the given geological model must be used.

If the above conditions are satisfied, before starting the survey, it must be considered, when, how and to what extent the geophysical methods are to be introduced in the procedures beginning with the location of the area assumed to be promising, up to the drafting of the final report meaning the conslusion of the exploration (eventually up to the exploitation of the ore).

In the following a brief outline is given of the geophysical methods used in bauxite exploration.

4.5.1. Ground-survey

As it is known, karstic bauxites have no specific physical parameters that would permit to separate them on the basis of measurements from the sediments surrounding them. Thus, the aim of the ground-survey is always to reveal geological structures that, under favourable conditions, may, contain bauxite deposits; to locate them; and to determine their depth.

It is also known that such structures are represented by depressions in the tectonized karstic dolomitic bedrock, thus the aim of the geophysical exploration is, in the first step, to trace the relief of the bedrock.

The parameters of the dolomitic bedrock are as follows:

- high specific electric resistivity (2000-5000 ohmm)
- high seismic boundary velocity (about 4000 m/s)
- density exceeding that of the covering sedimets (2.65 ...2.7 g/cm^3).

The same parameters of the bauxite and the overlying sediments differ from the above values. The resistivity of the clayey marl complex is low (10...80 ohmm), while that of the sandstones and limestones is high (500...2000 ohmm). The velocity of seismic waves is, as a rule, lower in the overburden than in the bedrock.

The inequalities within the bauxites and the overlying sediments themselves as well as the variability of the individual physical parameters require simultaneous use of several methods. The results of these methods completing each other are needed for the unambiguous geological interpretation of the observed anomalies.

In Hungary the geophysical survey connected with bauxite exploration, is carried out in several successive stages.

1) A complex geophysical reconnaissance, the results of which are summarized on small-scale (1:100000 or 1:50000) geophysical maps covering the marginal parts of the central range and its larger basins.

The aim of the measurements of this stage is to reveal the position of the buried basement in the depth and to locate its larger structural units.

The measurements of this stage are carried out by using the gravimetric, seismic and geoelectric methods.

Since this survey serves not only for bauxite exploration purposes, the work is financed from the Central Geological Survey fund.

2) At the second stage the scale of geophysical survey in areas promising for bauxite and having a bedrock surface not deeper than 500 m is, 1:25000, 1:10000 or 1:5000 depending on

the given depth and the complexity of the geological structure. In accordance with the geological model used and with the specific features of the depositional characteristics of the bauxite, it is advisable to apply several methods simultaneously.

At this stage drilling activity and geophysical survey have to be closely interconnected both in planning further prospecting and in the interpretation of the results.

3) Due to the successful methodological development carried out in recent years, in areas of bauxite deposits at small depths, even a 1:2000 scale geophysical mapping can be economic today.

Surface geophysical prospecting is a monopoly of the R.Eötvös Geophysical Institute (ELGI) which maintains close connections with the organizations that conduct the geological and bauxite exploration, respectively. Methods used at the afore-mentioned two stages and some examples of the interpretation of the results are reviewed in the followings.

a) VLF resistivity mapping

According to this method remote radiostations operating in a VLF (very low frequency) band of 15 to 25 kc are used as energy sources similar to the magnetotelluric method. The electromagnetic waves observed are represented here by plane waves. In the course of the observations their electric or magnetic compounds (eventually their combination) are measured and on the basis of the observed values conclusions can be drawn on the underground geoelectric structure.

The advantages of the method: it is rapid, inexpensive, easy to learn; there is no need to provide for energy source and a single person can carry out the measurements. Disadvantages: due to the given (single) frequency value, only an average information concerning the penetration depth can be obtained. The penetration depth is limited in the case of a homogenous (clayey, 10 Ohmm) overburden it is hardly more than 10 m, and even in sediments of 100 Ohmm resistivity is not more than about 30 m.

Fields of application:

- Following geological mapping it can be efficiently used in areas of shallow bauxite deposits. Based on the VLF resistivity map areas to be excluded from further exploration can be delineated (where the depth of the bedrock-surface is less than or equal to about 5 m). According to our experience, the area of unproductive districs detected by geophysical methods is generally 5-10 times larger than those indicated by the traditional geological mapping (s.str. outcrops).
- Under favourable conditions the method facilitates the establishment of the exact line of pinching out of the ore.
- VLF mapping helps to reveal the anomalies where boreholes should be sited or further geophysical observations are to be proposed.

b) Potential mapping

This method is a specific version of the geolectric resistivity mapping. The current electrodes are located far outside the investigated area. The two measuring electrodes measure the potential gradient values from one point to the other in a network. The final results of the observations are represented in the total conductivity map of the covering formations. This map reflects the variations of the resistivity and thickness of the formations overlying the high resistivity basement.

The anomalies obtained in the investigated area vary with the variations of the current lines and with the direction of the main structural features, thus they contain information on tectonics and fine structure, too.

. disadvantage of the method is that in the case of more complicated bauxite geological models (e.g. presence of high resistivity limestones in the overburden) it has to be supplemented with other measurements.

c) Shallow seismic refraction method

By this method generally the surface of the basement is traced, and it is completed, as a rule, with classical vertical electric soundings. The divergence of the high velocity seismic horizon and the ρ_∞ electric horizon corresponds generally to the presence of an electrically screening layer in the overlying sediments.

Practical experience shows that the method proves to be effective in the case of structures, the horizontal extension of which exceedes their two-fold depth from the surface.

d) Underground potential mapping (UPM)

The UPM is a DC mapping method permitting to trace the structure and the morphology of the high resistivity bedrock (Triassic limestone or dolomite) in the environment of a borehole. It is used in boreholes near structures proved or assumed by previous drilling activity. In the course of the measurements one of the current electrodes is located in the borehole, within the bauxite layer itself, while the other is planted on the earth's surface in a theoretically infinite distance. Due to this configuration - the current electrode's being under the electrically screening layer - the anomalies show first of all the conductivity variations of the horizon near to the surface of the basement.

The observation scheme is shown by Fig. No.46.

At the observation point P the ΔV potential difference is measured by the pairs of electrodes M_1N_1 and M_2N_2, respectively. The anomaly reflecting the structure is obtained by eliminating the effect of the theoretical model from the observed values of field intensity.

Efficient utilization of the method requires computerized data processing immediately following the field work.

e) Gravity survey

The gravity method is used generally when bauxite deposits connected with deeper (100-500 m) geological structures are to be explored. When smaller depths are investigated, sometimes also the so called "microgravity" version can be of effective use.

In the normal order of succession of geophysical methods gravity-mapping has his place at the very beginnings.

In any given area the gravity map is considered to be the geophysical base-map; e.g. seismic profiles to be measured later on are located on it, etc.

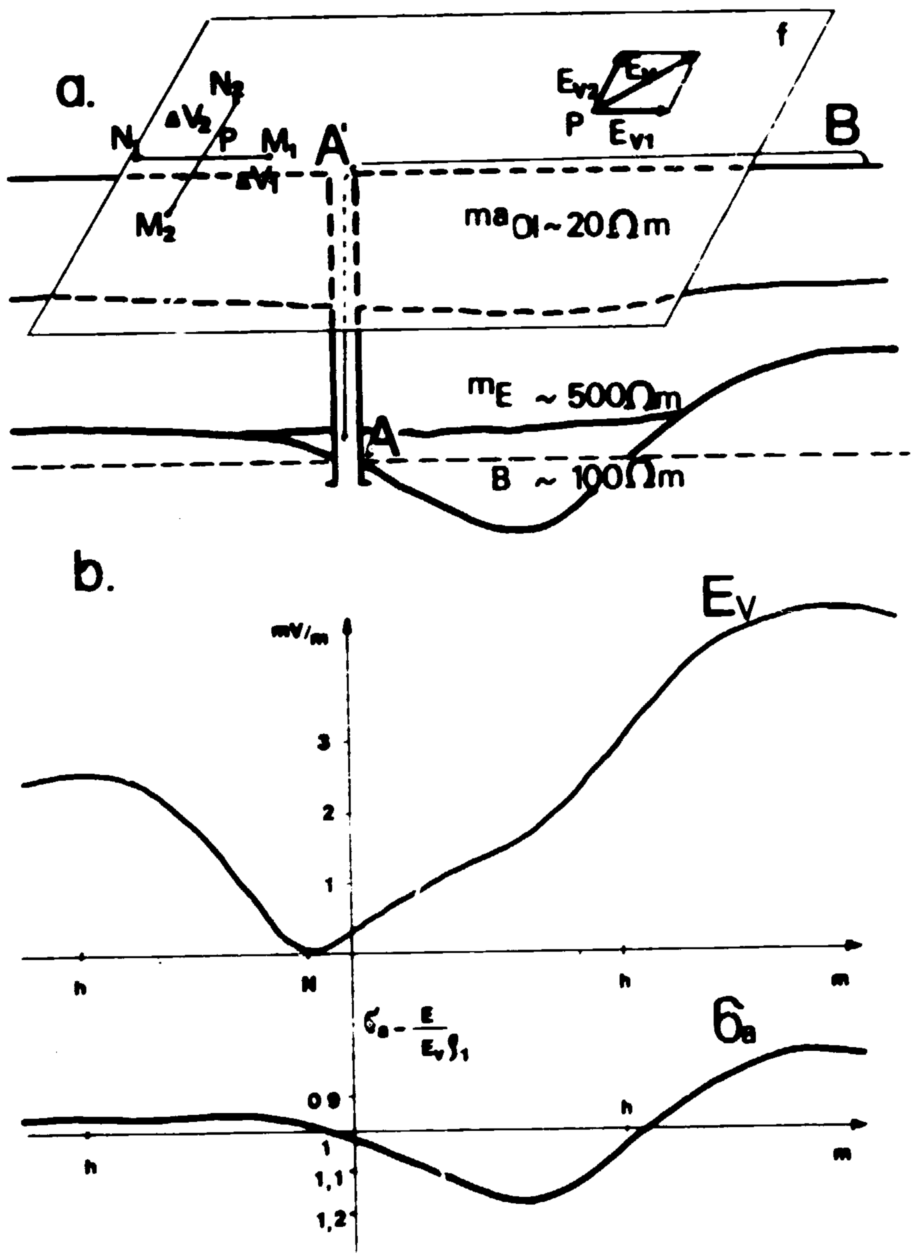
The Bouguer anomalies obtained from the gravity measurements, are brought about mainly by the elevations and depressions of the high density (Triassic) basement.

The secondary, digital processing of gravity data permit the construction of new maps. Using a two dimensional filtering, the Bouguer anomaly compounds of different spatial frequencies can be selected, the anomaly maps of which reflect bodies situated at different depths.

f) Interpretation problems of the surface geophysical measurements

The scheme of observations carried out in the vicinity of basement outcrops is given in Fig.No.47. together with the results of interpretation (as a concrete example). It can be seen that the basement overlain by a thin soil cover or being exposed in an outcrop, is clearly indicated by the VLF anomaly alone, while the proper interpretation of an anomaly caused by a thin clay sheet of 10 ohmm resitivity requires a supplementary geoelectric sounding (SE) already. To locate a bauxite body having a more complicated model - like in the right hand side of the figure, - beside VLF, also vertical electric soundings and shallow seismic refraction are needed.

Principles of the UPM method
(as used by the ELGI)



a) The real geolectric model and the arrangement of the UPM observation points.

b) Curves of the absolute value of the real field intensity (E_v) and of the apparent specific conductivity (σ_a), respectively, along the profile A-B

Fig. N° 46.

Investigation in an area of Triassic dolomite (limestone) outcrops

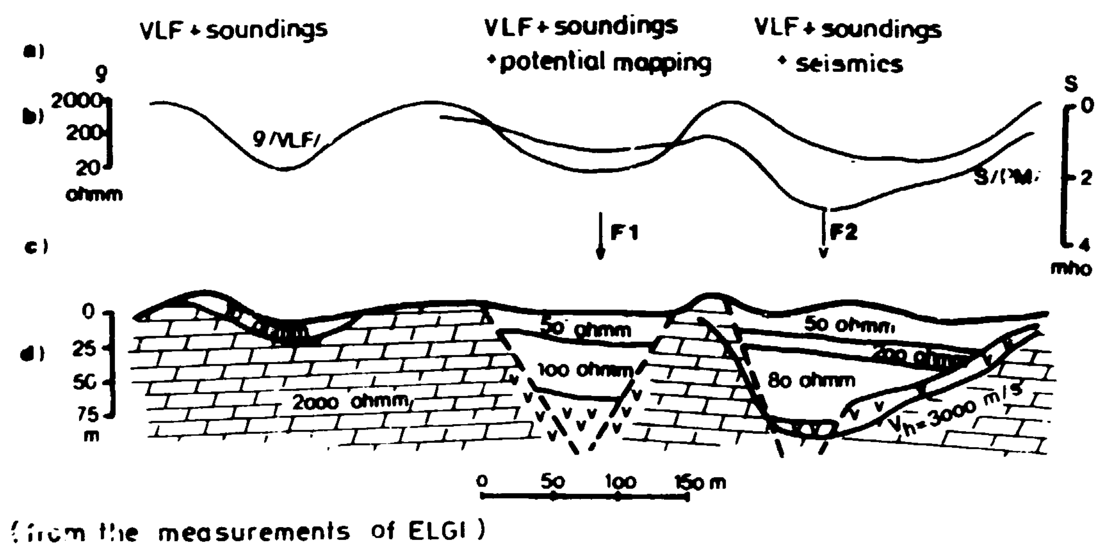


Fig. N°47.

a) measurements required

b) results

c) location of proposed boreholes

g) geological section

The anomaly map of the VLF measurements and their interpretation are illustrated by Fig.48.

Interpretation of a VLF anomaly map
(from ELGI measurements)

VLF anomaly   Bauxite geological interpretation

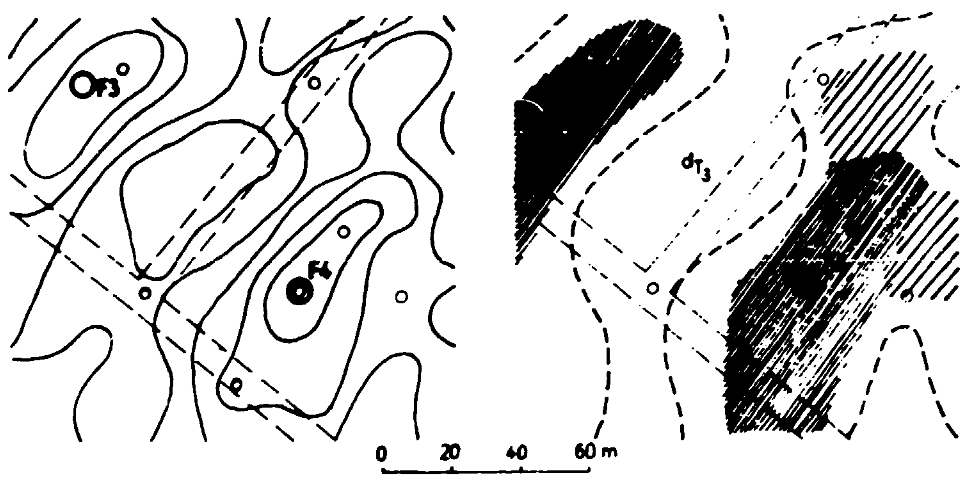


Fig.N°48.

Legends:

recommended boreholes
geoelectric soundings
outcrops of dolomite
assumed bauxite deposit

The anomaly map of the VLF measurements and their interpretation are illustrated by Fig. 4ᶜ.

Geological interpretation of geophysical measurements carried out in areas of, shallow bauxite deposits covered by younger sediments is shown by Fig. 49. Both the geophysical and the geological profiles are based on real data originating from a concrete bauxite deposit.

On profile (a) the depth of the basement ranges from 50 to 150 m. The boundaries of this were established by the microgravity method toward the deep basin and by VLF measurements toward the basement outcrops. The reconnaissance mapping was carried out by seismic refraction and potential mapping methods and indicated the presence of some horst and graben structures in the bedrock.

When tracing the surface the errors of both methods must be taken into account. The seismic horizon gives an "average" picture, i.e. on the horsts it goes deeper and in the grabens higher as compared to the true situation. The results of the potential mapping, in turn, are effected by the varying resistivity of the overlying formations and this can be corrected only to some extent by taking also the sounding data into consideration. (At the bottom of the figure the geological section is shown as constructed on the basis of drill cores.)

For further, more adequate exploration of bauxite-bearing geological structures - following the sinking of the first boreholes - the UPM and shallow seismic methods may be used. An example for this case is given on section (b) Similarly to the first example, the structures were indicated by complex VLF, PM and seismic measurements. The UPM results received from the first boreholes as well as the seismic horizon obtained by using an appropriate observation system fitting the revealed structure, reflect already the real situation of the bauxite bearing geological structure.

Geophysical exploration of bauxites at 30-100 m depths, and geological interpretation of the results.
(From ELGI measurements)

ρ(VLF) = VLF resistivity profile
Δg = micro gravity profile
S(PM) = conductivity profile of potential mapping

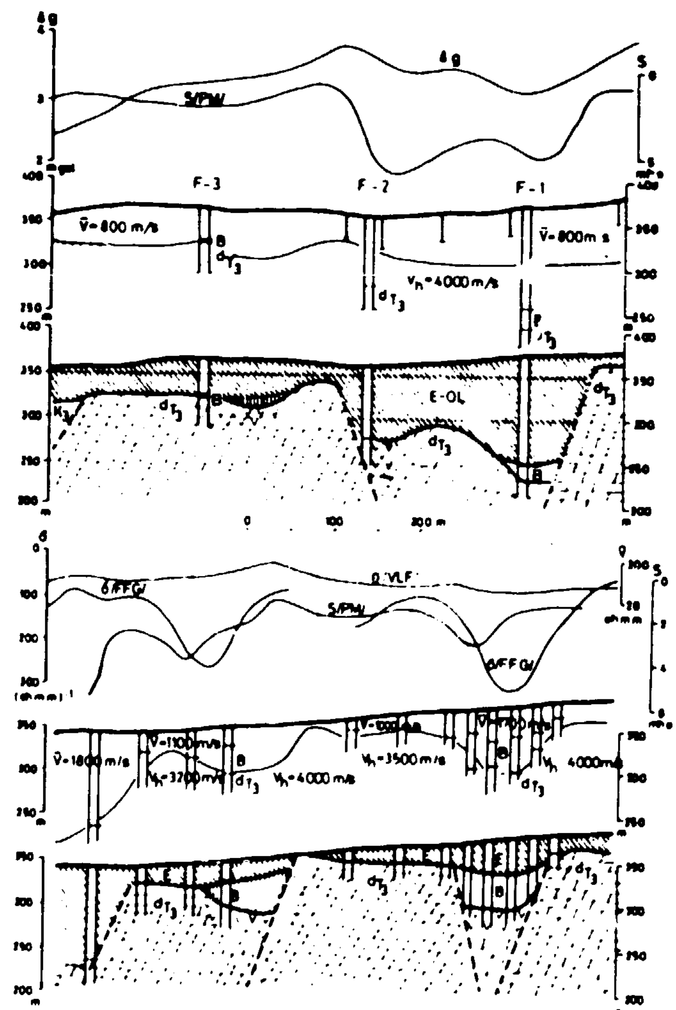


Fig N° 9

σ (FFG) = specific conductivity profile of the undergroung potential mapping (UPM) method

(curve) = seismic horizon

⊥ = ρ_{∞} horizon

4.5.2. Well-logging

The tasks of well-logging in bauxite prospecting holes are manyfolded. The logs have to furnish information e.g. in order to help the stratigraphical-lithological analysis of the overburden, to outline and divide the bauxite body and to establish its approximate grade, to furnish rock-mechanical and hydrogeological data on both the roof and the footwall. In this paper only the aspects of bauxite exploration s.str., i.e. well logging with bauxite exploration purposes, are discussed. In boreholes of that kind, generally the following traditional logs are run (depth scale: 1:200).

Spontaneous potential (SP)-log

On the sensitive SP logs the clayey, low-grade portions of the bauxite deposit can be marked off.

Conventional resistivity logs

The specific resistivity (R_a) log run by the traditional 0,1 and 4 m electrode potential probes permit, as a rule, to distinctly delimit the bauxite deposit from the underlying bedrocks (there being a 10-100 fold resistivity contrast). Toward the overlying sediments the delimitation is not so sharp, but nevertheless, unambiguous.

The inner subdivision of the deposit from the point of view of the clay-(Si)-content can be done qualitatively (the specific resistivity of clay being 10 ohmm and that of the high-grade bauxite: about 100 ohmm).

Gamma-ray log

In the natural gamma-ray log of sedimentary layers the radiation intensity of the bauxite deposit is strikingly high.

The intensity of natural gamma radiatior is due in this case - contrary to the case of clay and marl - not to the K^{40} isotopes but to the U, Ra, The accumulation. As it is known, the Th content of karstic bauxites amounts to as much as 45 g/l; its U content is about 13 g/t; for other bauxite types similar values are characteristic.

The distribution of gamma radiation intensity in a bauxite deposit of another investigated area is illustrated by Fig. No. 50.

Distribution of gamma radiation intensity in a shallow bauxite exploration area (730 measurements)

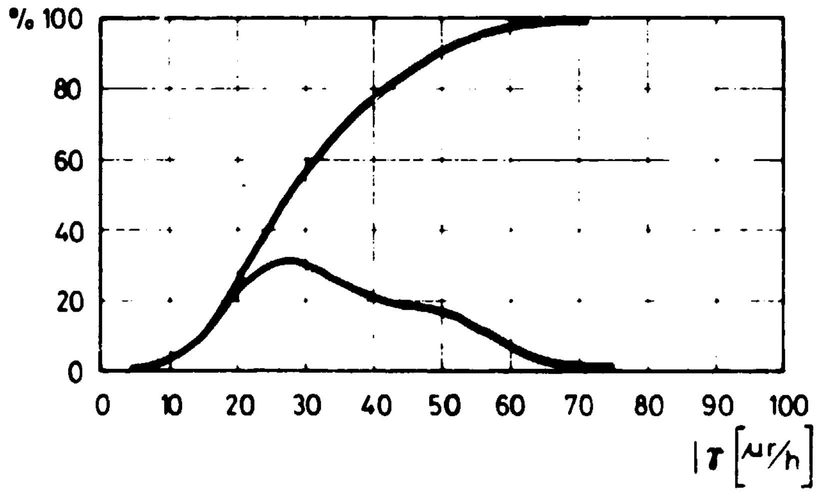


Fig N°50.

The intensity of natural gamma radiation - when the deposit is in a geologically undisturbed state - is, as a rule, proportional to the Al content of the ore.

Gamma-gamma or density log

As it is known, when the Co^{60} isotope, giving hard gamma radiation, is used, the intensity of the detected rays dispersing on the electron shell of rocks depends on the density of the surrounding formations. Run is bauxites, the gamma-gamma log varies essentially as a function of the Fe content.

Hydrogen (neutron) log

The neutron-gamma logging that has been applied since the early periods of bauxite prospecting practice, and the neutron-neutron logging as well, give readings proportional to the H-content of the space around the detector. Thus, their role is similar to that of the specific resistivity log.

The measurement of the borehole diameter (cavernometry) belongs also to this set of logs.

When bauxite indications appear, 1:100 scale detailed logging is carried out using the resistivity log with a 0,1 m potential probe or neutron-neutron log and neutron activation log, the latter being the basic log in the set of logging methods used in bauxite exploration.

Neutron activation gamma ray log

Some of the elements, when bombarded by neutrons transform into radiating isotopes.

The energy level (spectrum) of the gamma radiation and the half-life are characteristic for the isotope and the parent element, respectively. The intensity of gamma radiation reflects the quantity of the parent element. Thus, the method gives the possibility to determine the concentration of different elements.

To determine the aluminium content, the neutron activation method is used. The characteristic data of the main nuclear reactions taking place in the bauxite formation as a result of neutron irradiation are contained in the following table.

Element	Abundance %	Neutron-energy MeV	Cross section m barn	Reaction	Active product	Half-life	Gamma energy MeV
1. Al^{27}_{13}	100	therm.	210	n, γ	Al^{28}_{13}	2.3 min.	1.78
2. Si^{28}_{14}	92.3	3.9	3.0	n,p	Al^{28}_{13}	2.3 min.	1.78
3. Al^{27}_{13}	100	2.1	2.8	n,p	Mg^{27}_{12}	9.45 min.	0.83 1.01

Two records are made for the interpretation of the neutron activation log:
a gamma ray curve and then the activation curve which, of course, contains - beside the activated (and disintegrating) gamma isotopes, - the natural gamma activity of the bauxite. Superposing one record on the other, Fig.No.51 has been drawn, which shows the activation log of the bauxite body. The magnitude of the activation gamma "piling up" on the natural gamma level depends, in a given (favourable) case, only on the Al content of the bauxite. That is, practically only the gamma rays provided by nuclear reaction shown in the chart are detected.

The analysis of the bauxite deposit carried out on the basis of the 1:100 scale logs in a bauxite exploring well is shown by the following figure.

Complex log of the bauxite body

a = resistivity log
b = natural radioactivity log
c = neutron acitvation gamma ray log

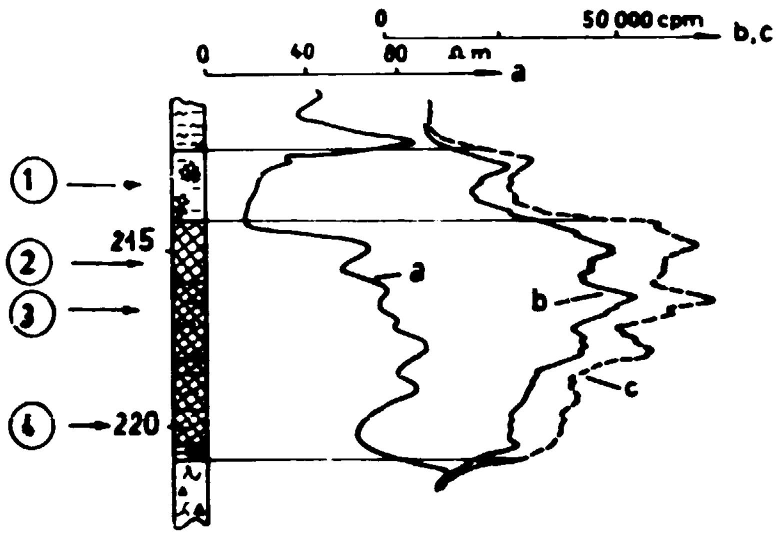


Fig. N° 51

Quality	Al_2O_3 %	SiO_2 %
1	30	27
2	67	2
3	50	3
4	40	10

Changes of the silicon content (within the bauxite formation), on the basis of the experiments carried out so far, are reflected well by the electric logs.
Generally with increasing Si content of clay minerals - clayeyness - the electric resistivity of the layer decreases simultaneously. This is possibly in connection with the conducting electrolite linked with clay minerals in larger quantities.

At present, by logging the prospecting boreholes, the Al content of the bauxite or the bauxite formation can be determined with an accuracy of ± 6 %. The change of Si content cannot be detected by the activation method but it can be followed on the basis of the resistivity log.

The works of development relating this theme are, of course, under way at present too.

Well logging instruments

For logging shallow bauxite prospecting holes simple well logging devices are suitable. In Hungary the K-300, K-500, K-600 type Hungarian (ELGI) made devices are used.

The neutron activation logging being of basic importance is carried out by using the relatively high yield Cf-252 neutron source, and integrated and selective detection procedures.

4.6. HYDROGEOLOGICAL RESEARCH AS AN INTEGRAL PART OF THE EXPLORATION OF NEAR-SURFACE BAUXITE DEPOSITS

Karstic occurrences

Careful general geological, lithologic l, hydrogeological and structural geological investigations are indispensable during the early stage of exploration already. As to hydrogeology it should go on on the following lines:

- estimation of bedrock-permeability (identification of the most important aquifers and aquicludes)
- recognition and study of the underground drainage system (concerning both confined and unconfined waters); lithological study of the water-bearing strata, piezometric surfaces, determination of the groundwater-table, the flow-rates and the recharge of both the groundwater and the karstic water.)
- it is necessary to obtain all hydrological and meterorological data (e.g. annual rainfall) related to the area in question.

Mining operations when carried out by open-pit methods are invariably threatened by surface-waters. To minimize this kind of hydrogeological hazard belongs to the main objectives of the mining geologist.
As related to the open-pit mine, surface-waters may be divided into the following two groups: waters of external and internal origin. The term external refers to all surface waters - fluvial or lacustrine, permanent or temporary - being in a position higher than the actual groundlevel of the pit, and thus able to flow in by gravitation.
Internal waters are essentially meteoric waters (i.e. rain or thaw-water) falling or seeping into the pit and being stored in the form of puddles generally at the lowermost level. Planning of an efficient dewatering system necessitates comprehensive knowledge of the annual figures of

precipitation, discharge and the high-water levels of all streams and creeks of the area concerned. When having sufficiently long and complete series of meteorological observations the determination of high-water level and discharge may be carried out by the analytical method. When no adequate precipitation data are available, satisfactory results may be achieved by the semiempiric method of continual approach, too.

Probable high-water discharge

Depending primarily on the inclination of the terrain, rain-water running off the slopes flows generally towards the deepest point of the surroundings. It may form either shallow interconnected rills or a more or less distributed thin sheet of water flowing over the soaked surface of the slope. Further downslopes it may be collected first by narrow gullies and later on by ordinary creeks and streams. The region which drains all the rainwater that falls on it into a stream is called the drainage area or -basin and is contoured by outstanding ridges called the watersheds or divides.

Part of the rainwater falling on to a given area is lost by evapotranspiration and by runoff, part of it, however, penetrates the soil-cover by infiltration. The total rainfall to runoff ratio of a given area is demonstrated by the runoff-index (α) which can be calculated according to the following formula:

$$\alpha = \frac{h_L}{h_o}$$

where h_L is the amount of rainwater lost by runoff, and
h_o is the total amount of rainfall.

The figures of rainfall are determined by measuring the height of the water-column in the standard rain-gauge and may be expressed in terms of time-units either in the form of water-column heights pro time-unit or in cumulative water--column heights attained from the beginning up to the end of the observation period. The average figures of runoff pro unit time can be calculated as follows:

$$Q = \alpha \cdot f \cdot \frac{h_L}{\Delta T}$$

where Q = amount of runoff pro unit time

α = runoff-index

f = drainage-basin area

h_L = rainwater, lost on runoff

ΔT = time period

Analytical method

Long series of observations prove that there is a close negative correlation between the amount and the intensity of rainfall. Heavy torrential rains do not last for a long time while settled rains are generally less intense. By plotting the figures of runoff against the duration of rainfall, at a logarithmic scale, Montanavit (1918) obtained a diagram demonstrating the characteristics of local rainfall of the investigated area (climatic probability-curve) (Fig.No. 52.).

According to the length of the observation series used in plotting the diagram the curve may be called the one-, ten-, or hundred-years probability-curve of rainfall. The position and number of maxima pro hundred years gives directly the probability of the maximum figure.

Probable high-water discharge can be calculated from the runnoff-time (T_L) by using the above function. Runoff--time is the period during which rainwater falling at the furthermost points of the catchment area reaches the bed--section of the river concerned. Calculated from the stream-gradient and the flow-rates see Fig. No. 53.

$$T_L = \sum_{1}^{n} \frac{L_i}{V_i}$$

where L_i = is the length of elementary reaches (sections of uniform gradient) and

V_i = is the flow-rate measured at the valley-bottom.

Probable discharge can be calculated then by using the following formula:

$$Q = F \frac{h_r}{T} \qquad \text{(cf.Fig. No.52.)}$$

The maximum yield of undrained areas is calculated by multiplying the extent of the catchment area with the figure of rainfall (h_r) pro unit time.

Analogical methods

When no continued series of rainfall observations are available the most probable rainfall-data of unknown or inadequately known territories should be estimated by using the analogy of some well-known territories nearby. These analogical methods are mostly sophisticated semiempiric approaches the esposition of the particulars of which do not belong to the subject of the present booklet.

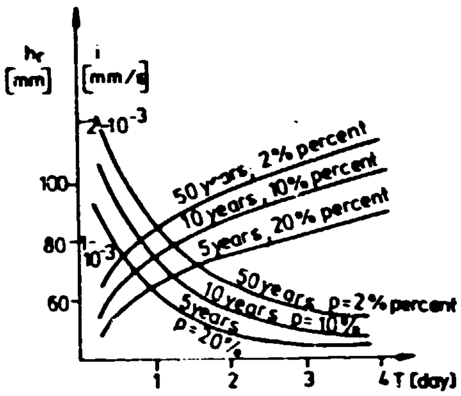


Fig. 52

CLIMATIC PROBABILITY CURVES

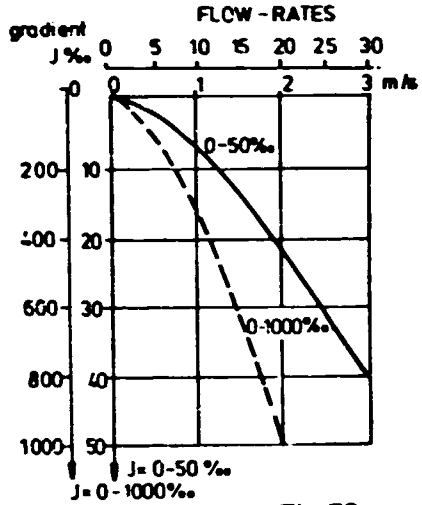


Fig. 53

FLOW-RATES (MEASURED AT THE VALLEY BOTTOM) vs. GRADIENT (AFTER E. NÉMETH)

RELATIVE FREQUENCY DISTRIBUTION OF FIGURES OF FRACTURE POROSITY (I^{x}) AND EFFECTIVE (WATER CONDUCTIVE) FRACTURE POROSITY (r^{x}) OF THE KARSTIC BEDROCK

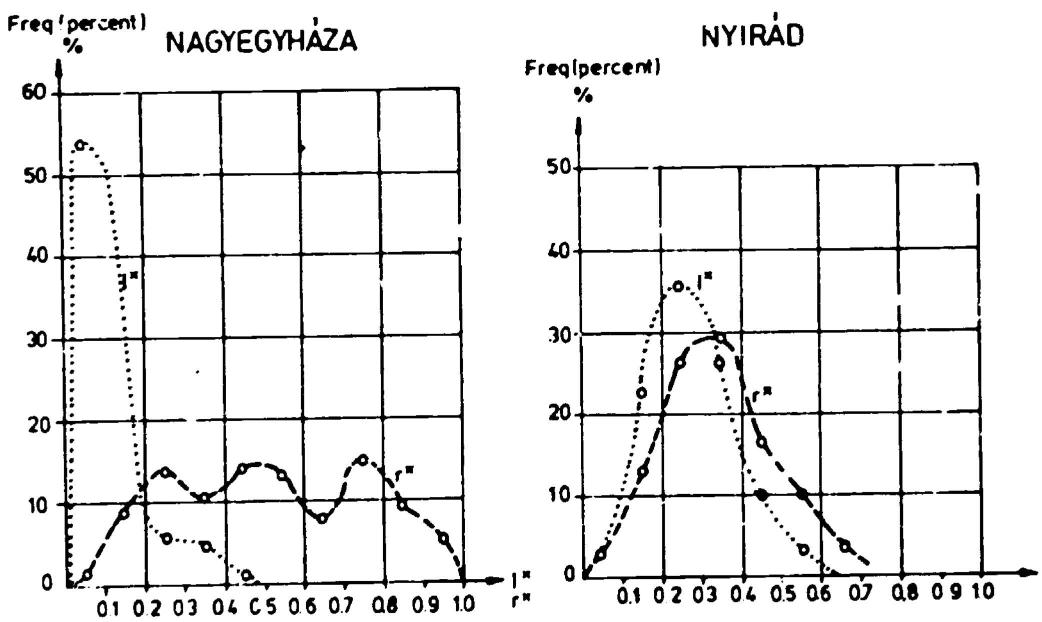


Fig. 54

HORVÁTH - NYERGES 1976

Water-protection of mines

Water-protection of strip-mines

Protection of strip-mines against surface-waters of
- external, and
- internal origin

is carried out as follows:

1) Protection against external waters

Water inflow from external sources can succesfully be handled by various networks of water-conducting trenches and channels which provide a free, gravitation-controlled discharge or diversion for any surface water coming from higher elevations.

The elements of such a water protection system are

a) simple surface channel-ways for gravitational water-conduction and diversion,

b) ring-like surface channel system surrounding the pit in order to provide for a free discharge of rainfall and thaw water,

c) impermeable lining of the surface channelways to eliminate direct inte connection between external surface waters and ground-water,

c) artificial holding ponds. As maximum inflow from external sources is generally an apisodic phenomenon, the construction of high-capacity temporary storage pools may be much more economic in must of the cases than the building out and maintenance of a whole channel-system of the same capacity throughout.

2) Protection against internal waters

Rains falling directly into the working pit together with groundwater seepage are responsible for continuous recharge of internal waters at the bottom of most pits. The removal of internal waters is carried out by pumping. Optimum pumping rates are established on the basis of recharge rates of the internal water-system. This can be calculated from the figures of rainfall, infiltration runoff and the rate of underflow. Theoretically the maximum pumping rate (Q_{max}) should be at least equal to or higher than the probable recharge maximum. In areas of high-intensity episodic rains, however, where recharge rates are high but of a clear episodic character, optimum pumping rates may be considerably lower than the probable maximum recharge. When planning a pumping rate (Q) less than Q_{max} the following equation should be kept in mind:

$$\Delta h = (Q_{max} - Q) \frac{t}{F_1} \cdot 10^3 \text{ mm}$$

where Δh is the amount of "internal" water measured in millimeters, covering the F_1 area of the deepest part of the working pit when the probable maximum recharge is realized. The limit of decreasing Q as related to Q_{max} is determined by economic considerations. As far as mining operations may go on freely and safely, and the cohesive strength of the soaked wall-rock and the ore is not decreased beyond a reasonable limit, pumping rates can also be decreased.

Hydrogeology of underground bauxite mines

Most of the Hungarian Central Mountains are built up of karstic limestones and dolomites of Mesozoic age. This Mesozoic rock complex is essentially a cracked aquifer forming an extensive karstic reservoir system. Since mos

CHARACTERISTIC HYDROGEOLOGICAL PROFILES

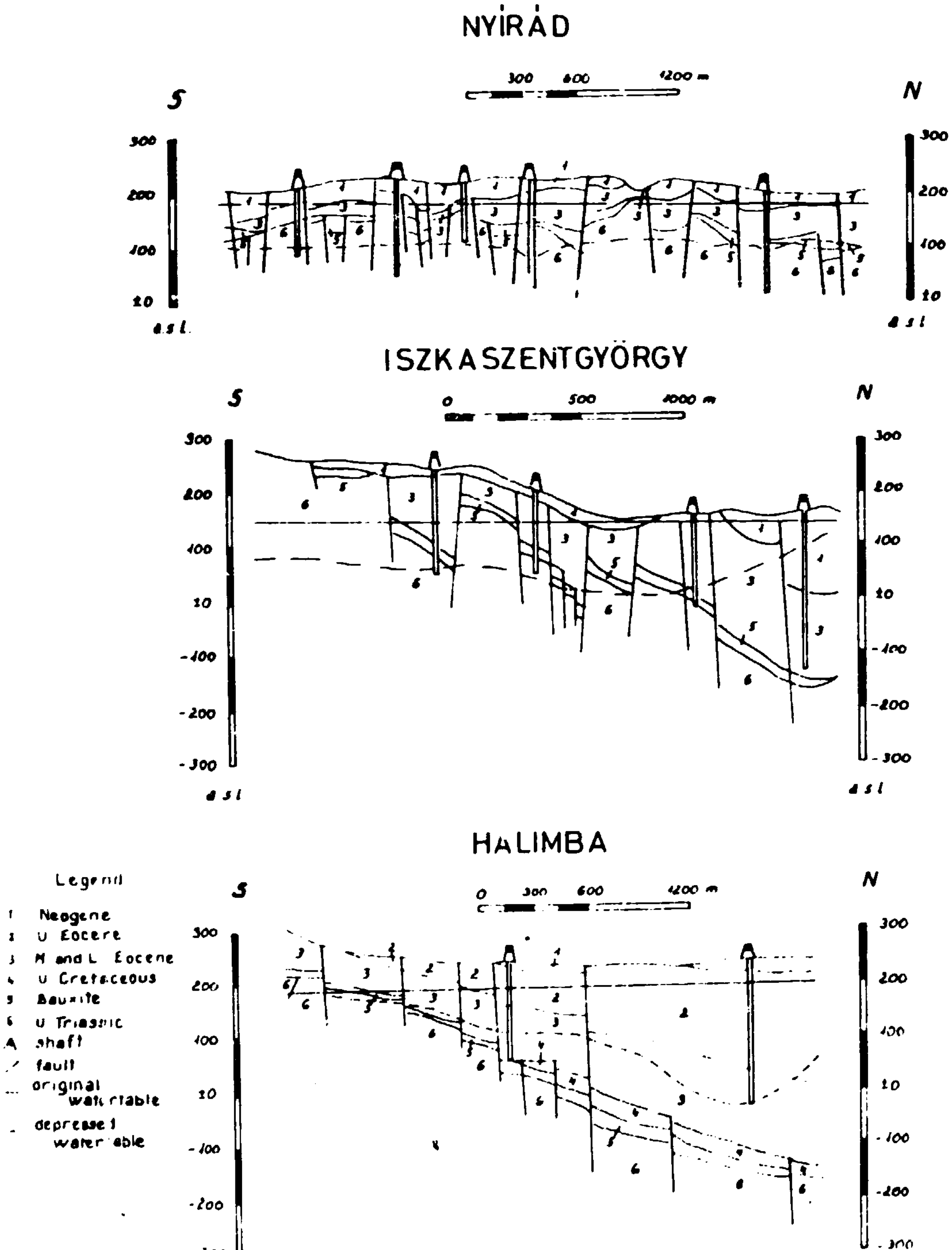


Fig. 55

workable bauxite deposits of the country are in a position well below the karstic water-table and there is generally no protective impervious layer between the ore and the water--bearing host rock, mining is threatened seriously by karstic water-inrushes. (see Fig.No. 55.)

Water-hazard and the possible means and methods of prevention of water-inrushes are of considerable influence upon both the in-situ value and the economy of the exploitation of a deposit. Thorough knowledge of recharge, discharge, and ground-water movement characteristics is therefore essential when drawing up the outlines of any safe and economic exploitation system.
Although most occurrences are threatened by footwall-waters only, occasional inrushes originating in the roof limestone complex may also occur. (e.g. Eocene limestone at the Halimba deposit)
The magnitude of the water-hazard is demonstrated very well by water-abstraction figures of the last 20 years. Production of every ton of bauxite necessitated the production of 50 to 200 cubic metres of water from below, (a surplus expenditure of 40 to 100 Fts pro ton). For geological, economical and engineering reasons hydrogeological research should go on aeways contemporaneously and in close connection with all the non-hydrological investigations carried out during the exploration of the given deposit.
Hydrogeological research may provide information by

1) new data collection, and
2) by processing the available data by special methods.

The disclosure of principal hydrogeological characteristics of the area in question is the task of the first stage of exploration. It consists of recognition of the main aquifers, aquicludes and the impervious protective layers, establishment of permeability, transmissivity, etc. of both bedrock and overburden; estimation of groundwater flow-rates and investigation of the main characteritics of groundwater movements.

In the next stage of exploration hydrogeological research is directed already towards the problems of planing and execution of a reliable water-protection system.
There are two principle methods of dewatering developed during the last 20 years:

the preventive (active), and the

passive (or subsequent) methods.

Passive dewatering is effectuated by water-galleries (sumps) combined with underground pump-stations. Water is conducted from the workings to the pump-stations gravitationally, and is pumped out at a rate adequate to natural recharge, thus providing a more or less dry environment for the mining operations.
The target of active water protection is the prevention of water insrushes either by blocking the waterways of the reservoir in the immediate surroundings of the mining operations (e.g. cementation) or by regional depression of the karstic water-table (active dewatering).
The depression of the water-table at the Nyirád-Nagyárkány area is attained by submersible pumps operated in large-diameter boreholes (water-shafts). 28 water-shafts were drilled during the first stage of the dewatering program, 19 of which are in continuous operation. The minimum capacity of the individual boreholes is 6 cubic metres promin but yields as much as 21 cubic metres pro unit may also be attained when necessary.
Large-diameter wells are sited close to the deepest-situated yet workable deposits. Each well is 200 to 250 m deep and has a final dimater of 2000 mms. (screen: 1400 mm) They are installed with automatically controlled 7 cubic metres pro min capacity submersible pumps the actual-lift of which is 120 to 160 metres. The number of pumps installed in a given well depends on depth to water-table and the intended depression.
As a result of active dewatering going on since 1965 the

depressed water table in the central part of the Nyirád area is now a hundred meter below the original one.
An excellent example of passive dewatering is the one applied at the Kincsesbánya deposits of the Fejér County Bauxite Mines, where tapping of the karstic reservoir is carried out by water-galleries driven into the karstic bedrock. Water is pumped on to the surface after a proper cleansing procedure only.
Planning and execution of either of the above described water-protection systems requires the following hydrogeological information to be available:

transmissivity and porosity of the aquifer; frequency of joints, cracks, fissures and faults; the percentage of infiltration; rate of recharge; figures of water-table fluctuation; places of free water-inflow, etc.

All these data can be obtained by ordinary field-survey and/or by drilling which may or may not be related to bauxite prospecting.

Hydrogeological field-survey

All data referring to areal distribution of aquifers and aquicludes should be collected. Faults, slumps and other signs of any recent or fossil mass-movements should carefully be recorded. Results of airborne geophysics and any kind of geophysical.
Results of airborne geophysics and any kind of groundsurvey (remote-sensing, etc.) together with all meteorological and hydrological data (rainfall, evapotranspiration, runoff, infiltration, etc.) should also be carefully collected. Records of regular water-table fluctuations affecting both the surface and the underground drainage systems are to be obtained; interrelations between surface and subsurface waters should possibly be disclosed; careful geomorphological mapping of all areas of exposed aquifers should be carried out including the record of all karstic and other hydrological

phenomena (creeks, springs, lakes, etc.) and all places of artificial tapping (wells, mines, open-pits, quarries) of surface and/or subsurface reservoirs.
The boundaries of the catchment area can be established on the basis of processing and evaluation of the above hydrological and geomorphological data. Based on the same data also the planning of any further hydrological groundsurvey (measurements, etc.) may be undertaken if necessary.

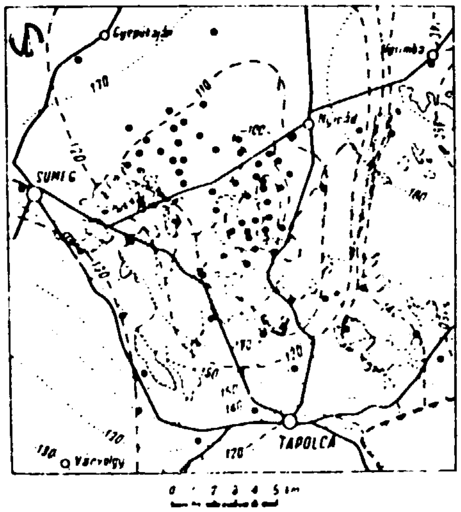
Based partly on previous documentation and literary information partly on personal field observations the outlines of geology of the surroundings can be drawn up rather easily, and when all geologic factors, controlling the physical properties and geometry of aquifers and aquicludes are disclosed, the principal hydrogeological characteristics of any unknown area can be predicted by extrapolation of the characteristics of well-known analogous areas. All this may serve as a firm basis for planning of the necessary hydrogeological drilling. The results of the field-survey are summarized by hydrogeological maps, which in addition to hydrogeological data contain also considerable geological, lithological, hydrographic and hydrochemical information.

Hydrogeological observations in bore holes

Hydrogeological information can be obtained either by measuring hydrogeological characteristics in bauxite-prospecting holes or in special holes drilled directly for the sake of hydrogeological observations.

As to hydrogeology, the information obtained from bauxite-prospecting holes is indirect, thus it may be taken for the preliminary stage of hydrogeolcgical exploration only. Hydrogeological evaluation is possible only when all phenomena, indicative of hydrological properties (e.g. volume-weight, porosity, voids, vughs, cementation, etc.) are carefully recorded right from the first to the last core recovered.

HYDROGEOLOGICAL SKETCH MAP OF THE NYIRÁD AREA



OUTCROPS OF DOLOMITE

BOUNDARY OF THE BALATON HIGHLANDS

MONITOR WELL

CONTOUR LINES OF THE KARSTIC WATER TABLE IN 1.1.1958

CONTOURS OF THE KARSTIC WATER TABLE IN 1.1. 1975

Fig. 56

HÓRISZT 1975.

Sudden falls of the bit should be recorded carefully with exact figures of depth. Variations of the degree of compaction and the frequency of cracks of the cores should be described in detail and the documentation should cover also the degree of fragmentation or powderization of the penetrated rocks and the nature of fissure fillings if any.

Hydrogeological boreholes are sited always with some special hydrogeological consideration in mind.(e.g. to reveal numerical particulars of storage-capacity, and transmissibility data of singular aquifers by means of hydrogeological and geophysical measurements.)

Most hydrogeological boreholes are developed into monitor wells used for continuous water-table observations. There are about 100 such monitor wells comprising a hydrogeological observation-network in the Hungarian Central Mts. The effects of active dewatering such as the rate of increase of the radius of the depressions within the range of the mining operations, are all carefully tracked by regularly recording the water-table data in every well of the network. Systematic obsèrvations and data-processing enable the hydrogeologist to assist in preparing the schedules of the mining operations and to predict reliably most rural water supply damages expectable as a consequence of water protection of the mines.

In remote areas not yet drawn into production the purpose of water-table measurements is the investigation of the ground-water movements and water-table fluctuations of the undisturbed karstic water-system.
The results of regional analysis of ground-water levels are summarized in regional hydrogeological contour maps. An example of these contour maps is shown by Fig.No. 56. It is the hydrogeological sketch-map of the area of the Nyirád bauxite mines, demonstrating both the initial and the drawdown karstic water-table, the latter being caused by active water-protection of the mines.

As to geophysics it is the conventional well-logging method which provides most hydrogeological information. Physical properties of rocks, such as porosity, fragmentation, etc. can be read off directly from the logs and also the depth to the various aquifers and the levels of free water-inflow can be established when necessary. As an example let us recall an experimental calculation carried out in order to investigate the possibilities of obtaining representative fracture porosity data from the conventional well-logs. In the mining routine the degree of rock fragmentation representing fracture-porosity is generally expressed in terms of cumulative lengths of fissures per unit rock-surface area. In bore-hole geology the same figure is referred to the unit running meter of the borehole. As the length of fissures can not be read off from the well-logs, the fissure-length per running meter figure is to be substituted here by a fracture porosity figure which can be calculated by analogy from the complex well-logs (cavernometry resistivity-, n-γ-, and therm γ-curves) of the investigated rock-complex on the one hand and the hydrogeological parameters of another, already well--known rock-complex on the other.
Fracture porosity figures obtained by the above analogical method are succesfully used in planning of the water-protection of bauxite mines. The same method can be applied to calculate the figures of effective (water-conducive) fracture porosity, too. (See Fig.No. 54.)

Hydrogeologocal observations in underground mines

Regular observations carried out simultaneously with the mining operations in underground bauxite mines provide useful data on the basis of which checking and adjustment and/or development of the actual dewatering method can be undertaken if necessary.

Underground cavings are excellent places of direct lithological and structural geological observation. In areas where the hydrological characteristics of the wall rocks are known from drill-cores or from outcrops only,observations carried out in underground mines of analogous areas nearby, may be of utmost importance especially when planning and executing the dewatering of a new mine.

The most common hydrogeological features to be observed in underground mines are as follows:

1) General hydrogeological characteristics (location of faults, stratigraphic contacts, bedding planes, protective layers; laboratory assay of characteristic rock samples; degree of fragmentation (cumulative length of fissures per unit area)

2) All parametres of spontaneous water-inflows (location, denomination of the aquifer; specific yield, time; chemical compositions; the working action by the impact of which the water inflow was generated, etc.)

3) Hydraulic gradient; pressure distrubution (on the basis of measurements carried out in underground monitor stations, or in monitor wells.) The results are to be summarized in water-table contour maps.

4) Hydrogeological parameter of the tapping system and of the individual tapping units as follows:

- temporal changes (construction and abandonment of water-galleries)
- yield of the tapping units as a funciton of time
- exact location of the tapping units
- chemical composition of the water
- constructional data of the dewatering units
- technical details of lowering retrieval and maintenance of the dewatering installations (pumps)

(in large-diameter wells)
- costs of construction and operation.

Hydrogeological observation in lateritic region

Since the formation of plateau-type laterites and lateritic bauxites is controlled primarily by hydrogeological factors systematic hydrogeological research can not be spared when prospecting for bauxitic laterites. It consists of regular hydrogeological observations, data collection and proper interpretation of the data obtained.

Hydrogeological investigation of large plateaux with temporary or permanent swamps should go on along the following lines:

1) Measurements of rainfall at regular intervals, and calculation of the daily, monthly and annual averages.

2) Regular monitoring of water-table fluctuations of temporary and permanent swamps during both the dry- and the rainy-season

- registration of water-temperature (morning- and midday-figures), calculation of monthly and annual averages for the dry- and the rainy season,
- water-sampling for pH-determination (separately from every swamp) 1 or 2 samples pro week. Calculation of mean pH values for the dry-season and for the rainy season,
- hydrogeological measurements in order to establish the rate of groundwater-flow within the lateritic complex (laterite+bauxite)
- investigation of groundwater movement from the thickness of the rock-complex penetrated by tracer--containing water during the unit-time period (empirical method)

- determination of the porosity of bauxitic specimens, in order to provide transmissivity data necessary for the calculation of theoretical flow-rates,
- construction of hydrological maps (including the establisment of the main directions of runoff and groundwater discharge)
- delineation of flat, water-logged parts of the plateau (by field-experience and measurements)
- chemical analysis of water-samples collected in temporary swamps during the dry season and rainy season; solvent capacity measurements at various temperatures in order to establish the conditions of dissolution of silica,
- determination of dissolved silica in headwaters of the gullies along the edge of the plateau (during the rainy season and - in the case of permanent water-courses also during the dry season)
- measuring the depth to groundwater-table in boreholes (when drilled by power-driven equipments, boreholes should be used for hydrogeological purposes after casing only!) and in exploration pits or in shafts sunk down to the water-table directly for hydrogeological purposes at the bottom of driedup temporary swamps. (Observations should go on during both the rainy season and the dry season and both upper and lower extremes of the fluctuating water--table should be established.)

When carried out carefully and regularly throughout the years of reconnaissance, prospecting and proving drilling, the above described investigations may provide also valuable hydrogeological information on the origins of plateau-type bauxitic laterites. It is to be noted, that the combination of the hydrogeological map and the areal distribution of high-grade ores may be of particular interest!

Exercises

Hydrogeological practice at the Hungarian bauxite mines

1) Introduction to the active dewatering system of the Nyirád Bauxite Mines

Bauxite mining has long traditions at Nyirád and so does water-protection. As a result of more than 20 years of systematic and careful observations, quite an amount of hydrogeological data had been accumulated which can be used now for planning further hydrogeological operations. Based on the analysis of long series of figures of yield and water-table-changes for instance the expectable future drawdown caused by the present active dewatering system can reliably by predicted, and what is more, also preliminary planning of the active water-protection of areas of similar hydrogeological setting may be carried out using the results hitherto achieved at Nyirád for an analogy. Mechanization of the underground mining operations called for a safe, dry waterless environment. This could be achieved by an active waterprotection of both the underground working places and the haulage ways. When planning an active dewatering system like this, the following questions are to be answered at first.

- what are the expectable amounts of water-inflow,
  the rate of recharge and
  the approximate size of the catchment area?
- what kind of factors affect the water-table?
- what are the physical properties of the aquifers and aquicludes controlling groundwater movements?
- what is the probable - or in the case of planning a pumpstation - the possible max. and min. rate discharge at the time of expectable water-inrushes.

Answers are possible only when all factors are being known and quantitatively recorded.

To facilitate systematic monitoring of the karstic water-table a hydrogeological observation-network was built out in the areas surrounding the mines threatened most seriously by the water-hazard. This observation-network provides all ground-water data demanded for the calculation of the temporal progress of and the boundaries the drawdown cone (depression) within the range of the operating mines. When siting the monitor wells the followings had been considered:

- all members of the multile vel water-system should be monitored,
- boreholes should be located so that the grid-interval of the monitoring network be closer in the vicinity of the future dewatering-wells or underground pump stations than elsewhere.

Monitoring of the progress of dewatering and checking of the state of the dried-up levels is carried out by systematic water-table measurements in the monitor-wells. The record serves as a firm basis for scheduling the mining operations.

Areal progress of the depression can be traced by regularly measuring the depth to water-table in wells located along the margins of the drawdown cone.

By processing and evaluation of these data it is possible to forecast water supply shortages and other environmental damages. At the moment the hydrogeological observation network of the Hungarian Central Mts. consists of about a 100 monitor well. Depth to water-table and specific yield are recorded in each well, either by continuous registration or by means of the so called "point"-measurements. (ie. Periodic observations, regularly repested at the same section of the day)

Point-measurements are carried out by simple hand-operated mechanical acoustic-, or electric devices, while continuous registration is accomplished by automatic water-table recorders, called "Replin"-5.

All records are documented on special hydrogeological cards. Each well has its separate card ahich in addition to the absolute figures contains also the monthly and annual variations of both water-table and specific yield.
Hydrogeological data coming from the areas of the operating mines are summarized monthly in large-scale and small-scale hydrogeological charts (contour-maps) and a general hydrogeological map is issued annually comprising all data related to the hydrogeology of the Central Mountains. In addition to data obtained from monitor wells of the observation network, monthly charts constain also underground information (down-the-mine measurements, etc.).
For trying to solve local hydrogeological problems, complitation of hydrogeological or hydraulic profiles may be also of use. Development of computerized datea-processing of hydrogeological data is in progress now.

4.7. DRILLING METHODS AND TECHNIQUES

One of the most important working tools of the field geologist is the drilling machine. A convenient knowledge of the mechanism of drilling, of the main types and most important technical parameters of the drilling equipment is very useful for the geologist. Being familiar with the geological setting of the given area, with its rock types, he is capable of conceiving an idea about the possibilities of the drilling machine and its operators. This is the main reason for giving some fundamental data and technical details concerning the mechanism and tools of drilling.

The mechanism of drilling

Core drilling is essentially a small-capacity mechanical rotary flush drilling. The rock is being disintegrated on an annular section by the rotating motion of a small-diameter, small-surface and small-moment drilling bit pressing the bottom of the borehole. The flushing medium pumped into the drilling rod and passing though the waterways of the bit carries the rock fragments between the rod and the hole wall to the surface. The core broken and caught by the corelifter is brought to the surface during the run-out, thus interrupting the process of drilling.

Drilling conditions in nature are never identical. Accordingly, no universal drilling technology may exist. The most convenient drilling technology is to be chosen taking into account the geological and topographic conditions in orded to achieve undisturbed rock sampling and high core recovery at an economical cost.

Diamond drilling has some serious advantages as compared to other methods.

Bit:	Diamond	Corundum Al_2O_3	Tungsten Carbide WC, W_2C	Steel
Relative abrasion hardness	90 000	1 000	900	10
Compression strength TN/mm^2	8 800	2 500	5 600	1 000
Melting point °C	3 100		2 680	1 530

Diamond drilling, moreover, allows the choice of the most suitable kind of bit for the particular rock to be drilled. Its very high core recovery rendered diamond drilling the most widely used technology of exploratory drilling.

The desintegration mechanism is, essentially, fracturing by shearing. During the rotation of the stones, due to the elasticity of the rock, the rock fragment is split off and carried away by the flow of the drilling fluid.

The pressure surpassing the resistance of the rock, acting on the stones, is assured by the bit weight, consisting essentially of the weight of the rods. At the beginning of drilling, the weight of the rods can be increased by means of a mechanical and hydraulical lowering unit. Inversely, drilling in great depths, a decrease of rod weight can be achieved by the same means.

For the penetration rate and for the life duration of the stones bit weight is the most important drilling parameter. Overweight or oscillating weight may damage the bit and/or the core.

Time is needed for carrying away the cuttings and for piercing the rock by the stones. Consequently, increase of bit speed results in increased advance only up to a certain limit. Enpirical prescriptions indicate maximum peripheral speeds as follows: 1-2 m/sec for surface set wholestone bits and 2,5 m/sec for impregnated bits. (Fig.No.57.)

During drilling, speed must be changed only gradually. In general the above mentioned technological statements are valid - by certain restriction - are valid for the hard metal crowns, too.

Flushing

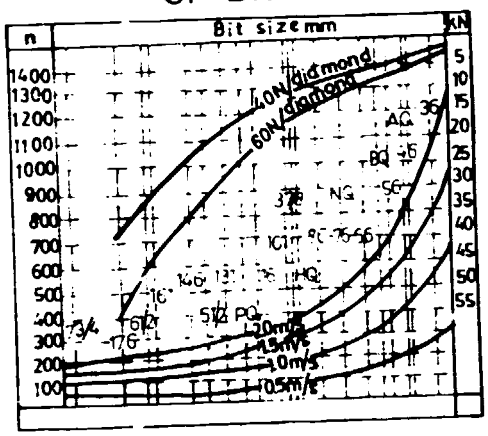
The rock fragments liberated at the borehole bottom are carried away by the circulating medium injected through the drilling rods, up to the surface in the annulus. Other functions of drilling fluids are to lubricate and to cool the bit, to protect the hole wall by compensating the rock pressure.

In early times the circulating medium for core drilling was simply water. Water could compensate rock pressure only in a very restricted range. Therefore nowadays polymer muds are used, of low density (1.02 g/cm^3) and of low viscosity (10 centipoise).

In regions of poor water supply as well as in the case of drilling highly permeable strata, causing circulating fluid loss, air flushing has been introduced. Air as a drilling medium perfectly meets the requirements of flushing as to the transportation of rock fragments and to the cooling of the bit, but it can not comply with the requirements concerning hole wall protection. Accordingly, air flushing may be used only to intersect hard, permeable, but solid, standing rocks. Air is the best drilling medium aiming at high core recovery and uncontaminated core samples.

Small amounts of fluid entering the borehole from the layers may result in seizure of the core barrels, due to the agglutnation of rock grains. Using surface-active substances, this subsurface water may be used to produce a fog-like flushing. If water rush-in is more intensive, foam-flushing is appli-

DIAGRAM OF OPTIMUM OF ROTARY SPEED OF BIT



^{x}1kp ≃ 10N

Fig Nº 57

QUANTITY OF CIRCULATION VS ANNULUS DIAGRAM

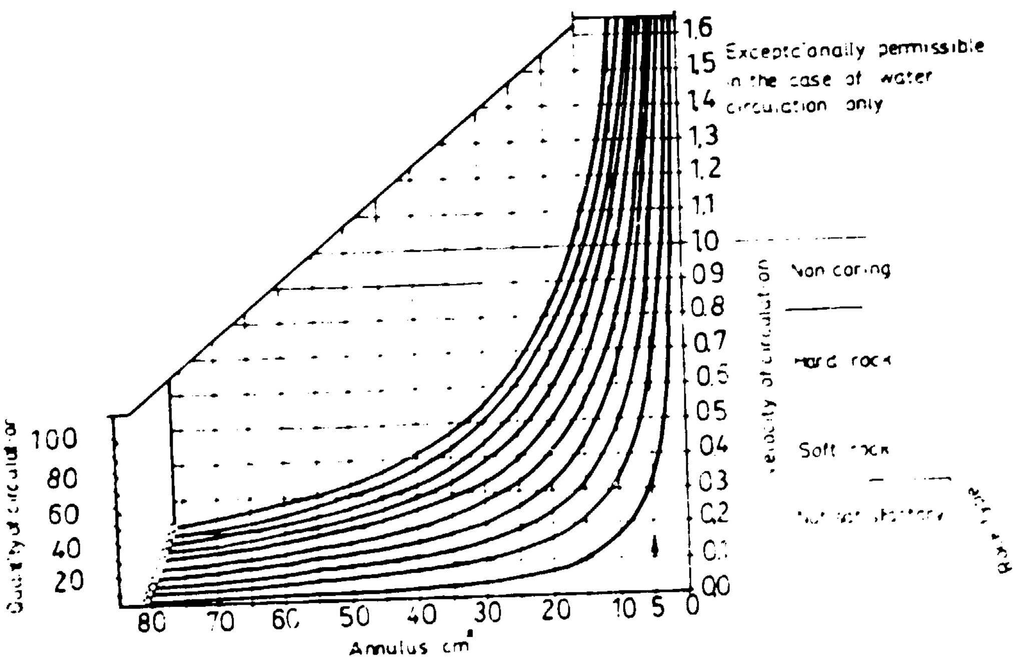


Fig. Nº 58.

cable, which is very favourable from the point of view of hole wall stability. High water supply and high water table combined with air injected into the drilling rods results in air-lift flushing.

High flow speed is needed for keeping clean the borehole bottom and for carrying out all the cuttings. This, however produces a high dynamic pressure in the core barrel itself as well as between the core barrel and the hole wall. High flow speed and high dynamic pressure may damage both the core and the wall of the hole, particularly so in soft and friable sediments. The graph of Fig.No.58.may be useful for finding an optimum.

If there is a considerable decrease of pressure in the core barrel, the inner tube will rotate together with the outer one, thus loosing its protecting effect, and the core may be damaged. It is desirable that pressure loss in the core barrel should not surpass 10 bars.

The amount of drilling fluid can be aptly varied according to bit size and rock type only by using piston or plunger pumps of infinitely variable stroke frequency.

The air requirement of the air drilling is determined by the upward air speed in the annulus, which must be by all means higher than the falling speed of the cuttings. Heavier and bigger rock grains require higher speed. In the practice, an efficient bottom cleaning can be obtained at a flushing speed of 15-18 m/sec. However, some experts indicate 40 m/sec upwards speed as the prerequisite of perfect bottom cleaning.

Drilling speed

A clean hole bottom supposed, it is the bottom pressure of drilling fluid that determines the speed of drilling. The best drilling performance may be obtained by underbalanced drilling, when the dynamic drilling fluid pressure equals the rock pressure (pore pressure). Overbalancing results in bad cutting transport and increase of drilling resistance of the rock. Non-balanced drilling results, on the other hand, in pore pressure surpassing the drilling fluid pressure and in increase of rock tension, thus cutting down the drilling speed. From the point of view of advance and security, the density of the flushing medium should be chosen in a way that the drilling fluid gradient should scarcely surpass the rock pressure gradient, without reaching the breaking load.

Drilling methods - core sampling

For exploratory core drilling, the counter-flush methods are used. The essential point is that during drilling the upwards flowing drilling fluid carries the core to the surface inside the smooth rods. There are no core-round rips. This is realized by the drilling medium being injected into the annulus, or by double tubes. However, cores may become damaged and/or overturned during hydraulic transportation, this method does not meet up-to-date geological demands.

A better core recovery can be obtained by the wire-line method which equires special rods and a special cable drum. It is considered to be an economical technology only for drilling greater depths.

In fairly well-known areas of structurally undisturbed geological setting, less important country rocks may be intersected by non-core drilling.

The best performance can be achieved at small-diametre non-core drilling by using diamant bits aptly chosen for the given rocks. Udeful data can be obtained by examining thoroughly the cuttings and by comparing the technical parameters determined during drilling with the log graphs of the geophysical logging performed at the end of the drilling. Drilling speed or its reciprocal value are used to correlate formation boundaries. However, the ralationship existing between drilling speed and rock resistance is disturbed by several factors such as the wearing of the bit, the filling up (blocking) of the bit, changes of the density of the drilling medium, etc. In order to avoid this iconvenience, the quotient of the specific drilling speed and of the logarithm of the specific bit weight (coefficient "d") is plotted along the profile. In this the coefficient "d" may be used to forecast pore pressure. Even for the geological evaluation several data became widely used such as the changes in momentum of the power-swivel, the drilling fluid output, pressure, specific weight, colour of the fluid-out, as well as profiles showing the changes if the cuttings as to size, shape, specific weight, clay ratio etc. In order to facilitate geological forecast and to avoid technical problems (bit failure, core seizure, sloughing, tightenless of rods, etc.) it is highly recommended to record these parameters even during core drilling. This is done by the instrumentation of the drilling equipment.

Extraordinary conditions require the application of extraordinary methods. Perhaps the greatest problem in drilling derives from the loss of drilling fluid. The most elegant method of avoiding it is to use air drilling. In the case if the permeable layers are unconsilated, or if no air flushing equipment is available, other procedures may also be successful. There are various substances which mixed up with the circulating fluid stuff or seal up the pores and fissures of the rock. The layer in question may be cemented or seled up by a two-component tamponing substance. The critical section can be intersected by blind drill and eventually cased a method assuring definitive closing.

Difficulties may arise if the rock is loose, liable to fall in. If the stability of the borehole wall is endangered be unconsolidated rock filled with water, the most probable way to settle the problem is to recur to the method of underbalanced drilling. It is even more problamatic if the loose layer is dry. In such cases, special muds, cementation, tamponation and casing may be purposeful.

Marls may absorb water from the flushing fluid, eventually swell and became triable. A convenient protection can be found in using special muds (adding KCl+polyacrilate-amide).

In loose or very fracturated rocks it is difficult to get a convenient core recovery. Even the "commerical" and special core barrels (to be dealt with below) do not solve the problem in some cases.

Vibration drilling and hydrodynamic drilling (similar to those used in rock mechanical sampling) have also been applied to exploratory drilling.

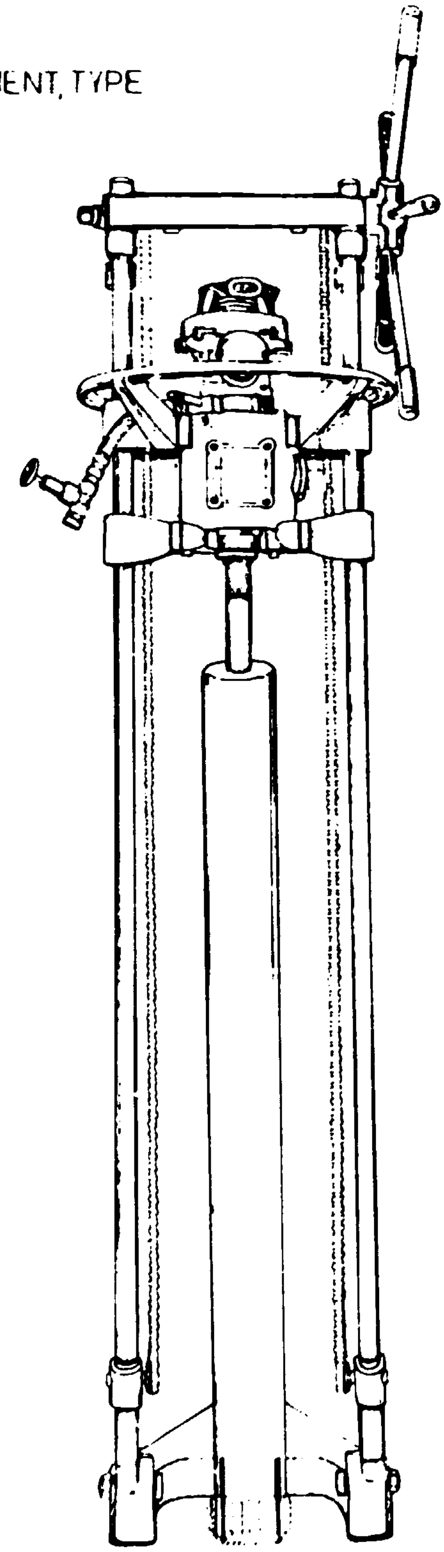
If the rock to be drilled is homogeneous in the entire profile, easy to drill, furnishing good cores, and if no particular core recovery is to be achieved, an economical drilling may be done using carbid invest bits, too.

DRILLING EQUIPMENTS

Machine types

An up-to-data drilling equipment meets the requirements of the afore-sketched moder technology if:

DRILLING EQUIPMENT, TYPE
WINKIE GW-15



- it is easily transportable and quickly moontable
- the bit speed is variable continuously within the wide range required by diamond bit drilling. Revolution number and turning moment are indicated and/or recorded by instruments
- the lowering unit is automatic and finely controllable. Bit weight should be measurable and/or recordable
- directional drilling is possible (in the range of 0 to 90 ^{o})
- pump performance can be varied continuously within the fluid speeds required for complete bottom cleaning. Pump pressure should be measurable and/or recordable
- hydraulic catch and handling of the rods assures the protection of the bit and the cores against undue mechanical stresses.

The unconditional fulfilment of all these requirements involves the considerable increase in weight of the equipment.

Drilling equipment type WINKIE GW-15 (of the firm J.K. SMIT & SONS), Fig.No.59. It may be used for rock mechanical purposes and for exploratory drilling as well. Round-trips are facilitated by the circumstance that the equipment can be mounted on a rod puller. This is the lightest equipment (without rod puller and unipress 36 kgs). It is possible to drill using its own weight, taking it by the hand. It is functionated by a Wankel motor 7.5 kW. Using 50 mm diameter steel rods, depths up to 45-60 m can be reached.

The hydraulic NGW-15 type core drill Fig.No.60. is an advanced version of the well-known and popular type GW-15. The very sensitive lowering unit and the power-swivel (of hydraulic, infinitely variable gear) allows to realize the most convenient drilling parameters and their fine control.

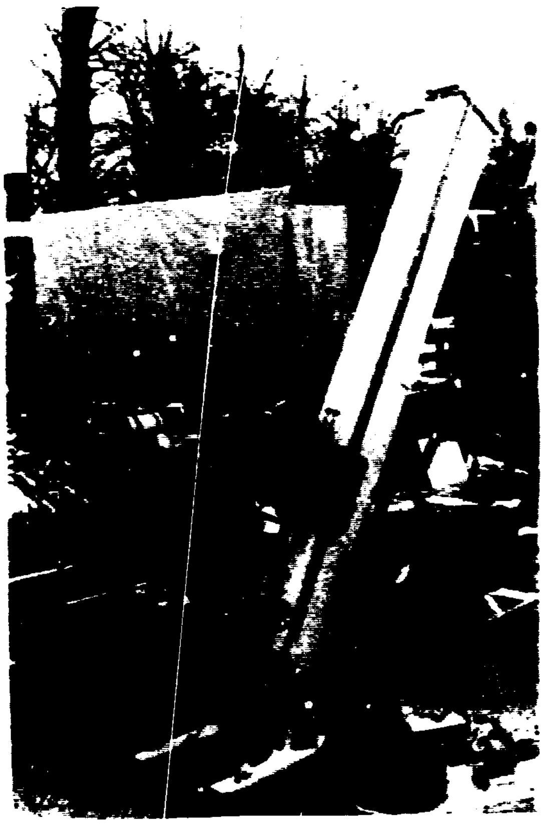
Its technical data are the following:

Gear: Fichte-Sach Wankel motor, 12 kW
Bit speed and turning moment
1 speed 150- 850 n/min., 105 Nm
2 speed 850-2000 n/min., 45 Nm
Unipress, power 7 kN
Feed lengths depending on the length of the mast 750, 1250, 1750, 2250 mm
Total weight 300 kg
Maximum depth, steel rods 200 m

The firm WIRTH has produced more than 10 years ago the multupurpose, completely hydraulic drills of the series "BO" which can be used for core drilling, water drilling, foundation drilling etc. This is perhaps the most up-to-date type of equipment; of this array the type "BO" should be presented (Fig.No.61.) which is the smallest one, convenient for the average depth of bauxite exploration. The variable construction of the drilling equipment, the exchangeability of the units permits ideal application for numerous purposes. It can be readily dismounted to small units which can be transported on horse back or by light helicopters.

Technical data:

Mast: 7 sizes (in the range from 2010 to 7850), exchangeable.
It can be rotated (in order to assure directional drilling) round-the-clock. Dismounted, together with the power-swivel, put in a pit further from the gear aggregate, drilling can be performed in whatever direction wanted.
Due to the hydraulic power-swivel and the hydraulic lowering, a section corresponding to the useful length of the mast can be drilled without interruption.



WIRTH BO TYPE EQUIPMENT.

DEPTH CAPACITY

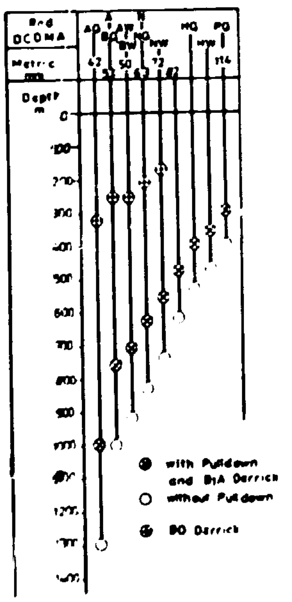


Fig N° 62

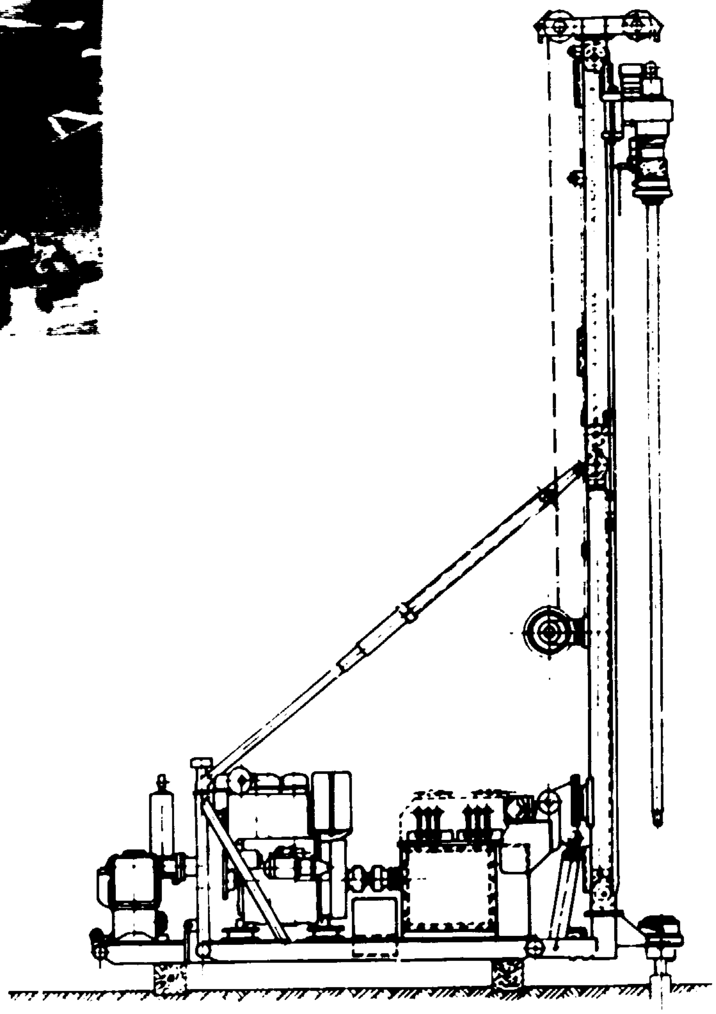


Fig N° 61

The hydraulic rod-setting and dismounting equipment simplifies the manual work of the round-trips, protecting the bit and the cores.

- The hydraulic tubing equipment facilitates the casing operation and moreover can be used for tube-drawing and tube-pressing.
- The instrumentation of the equipment corresponds to that of the similar types.

Depth capacity is illustrated in the table on Fig.No.62.

Technical data:

Gear 24 kW or 37 kW

Useful length of the mast 1150-6400 m (7 sizes to choice)

Lowering unit

	small mast	big mast
max. thrust	30 kN	36 kN
max. pull	22 kN	60 kN

The mast and the lowering unit are turnable.

Hydraulic power swivel

type	B[illegible]	BOK	B1A
number of rotation	80-870	150-1500	40-700
moment	1250 Nm	90 Nm	3800 Nm

Both drums of the double-drummed lifting gear are exchangeable.

Max.pull power of the drill cable drum		13,6 Nm
Max.cable speed		0,65 m/sec
Wire-line cable drum		
1 variant	max.pull strength	4,0 kN
	max.cable speed	1,8 m/s
2 variant	max.pull strength	8,0 kN
	max.cable speed	0,9 m/s

Maximum pressure of the piston pump	15 bar
Maximum fluid capacity	120 l/min.
Total weight of the equipment	730 kg

In case of the type B1A the possibilities of variation are even greater. The equipment can be completed with a rod receiver, the power swivel can be hydraulically turned onto the receiver and thus the round trip becomes completely automatic (one-man drill).

Depth capacity is, with a 50 mm rod, (steel), 630 m.

Outstanding, completely hydraulic core drills are the types JKS 400 and JKS 500 produced by J.K.SMIT & SONS (Canada) (Fig.No.63.)

Technical data

	JKS 400	JKS 500
Diesel or electro gear	30 kW	37 kW
Depth capacity, 54 mm rod	340 m	460 m
Total weight	612 kgs	1610 kgs

Of similar construction but of greater capacity is the TORAN 2x20 type core drilling equipment produced by Bergman Borr AB Solna, Sweden. The gear is of 52 kW.

A completely hydraulic core drilling equipment is produced by the firm ZMUW Sosnowiec (Poland), too.

The Craelius type core drilling machines, still produced in great number, can not be considered as up-to-data. At this type, the rods are fixed into a spindle and rotated. Depending upon the size of the equipment, the continually feeding lenght varies from 30 to 70 cm. The new types produced by the companies Atlas-Copco (Craelius), Joy, Longyear and Salzgitter are characterized by long feed.

HYDRAULIC CORE DRILL. SMIT AND SONS

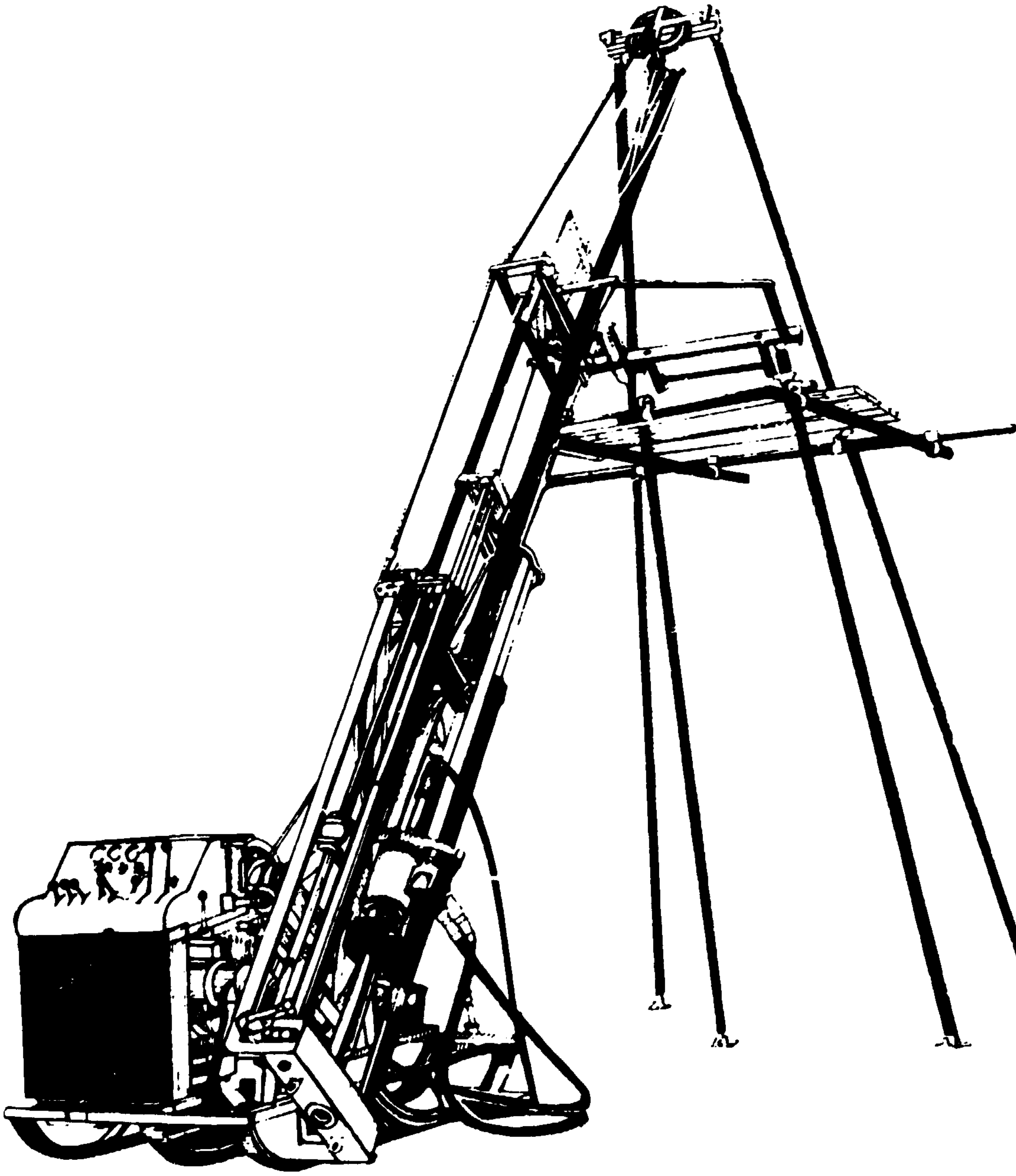


Fig Nº 63

Most companies are ready to supply the equipments mounted on a sledge, a trailer etc., too.

The drilling rods transit the energy (the moment of the power swivel) to the bit, load it and through the waterways conduct the bottom-cleaning energy to the bit. The rods are loaded by a combined charge.

The threads should be quickly and easily manageable and they should not leak. In order to achieve an optimum performance, the rods should be chosen always in accordance with the bit size. The corresponding sizes of the Craelius Metric Standard system (CMS) are:

Bit diameter	56 mm	66 mm	76 mm	86 mm
Core barrel diameter	55 mm	65 mm	75 mm	85 mm
Rod size	50 mm	60 mm	72 mm	82 mm

There are smaller and bigger sizes as well. However, diametres smaller than 56 mm involve bad core recovery, while those bigger than 86 mm are no more economically applicable. On the global scale, the overwhelming majority of exploratory drilling is done within that range. If, for some or other reason, a bigger-diametre borehole is needed, the use of a grief stem (drill collar) is recommended.

If the rock formation is liable to swelling, the rod--size should be by one degree smaller.

The wire-line core drilling requires special rods. Even in case of usual core drilling, jointing without narrowing is preferred. A new type is represented by the welded-joint rods of the firm WIRTH.

If one wants to increase the depth capacity of a given drilling equipment the normal steel rods should be substituted by aluminium alloy or magnesium-zirconium rods.

CORE BARRELS

All over the world the modernization of core barrels is in progress. There are numerous types.

The core barrel is a tube (or device) serving to catch and to protect the core sample. Its main dimensions are fixed in several standards. In the range of 36-146 mm, the core barrel sizes are given most advantageously by the CMS. The Craelius core barrels have been designed to serve for the diamond bits of the exploratory boreholes; accordingly the diamonds are well exploited.

The core barrel type "B" Craelius is a simple one. Its core recovery being unsatisfactory, it can be considered as obsolete. Even those double core barrels are no more in use, the tubes of which are rotating together. These protect the core sample from the washing effect of the flush flux only. In the "T" Double Tube Core Swivel Type Barrel (Fig.No.64.) inner tube is suspended on a ball-bearing, and it is standing together with the core. It protects the core against mechanical impacts, too. The bit kerf of the corresponding bit is only 7 mm. It is produced in the CMS system in the range from 36 to 101 mm.

The conveinent core barrel of bigger diameter bits is the type "D". The bit kerf is thicker. The thin wall results in a higher drilling performance acccompanied by low diamond wearing at low expenses.

The "T" type 86 mm core barrel bit contains only 22 car-

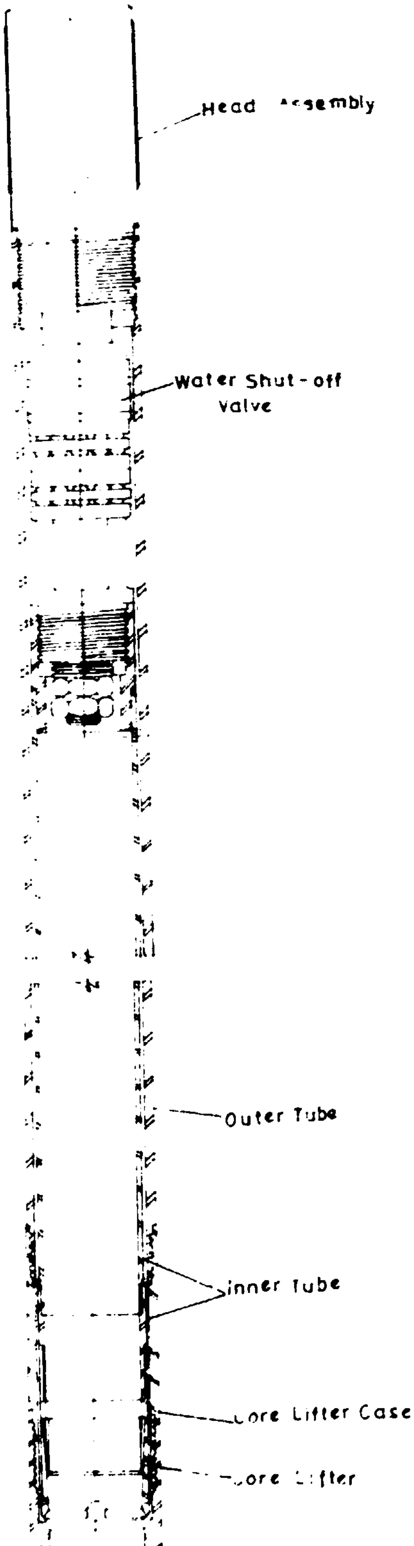


Fig N° 64

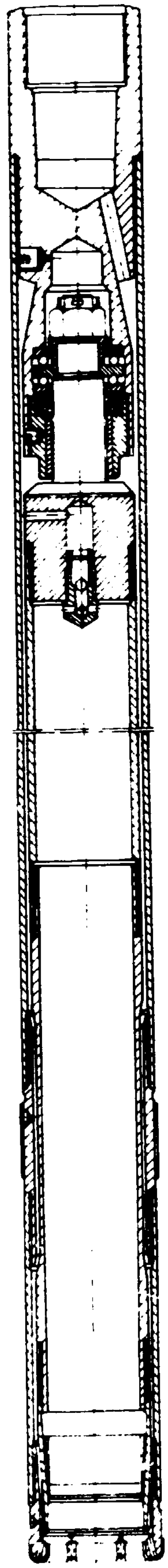


Fig N° 65

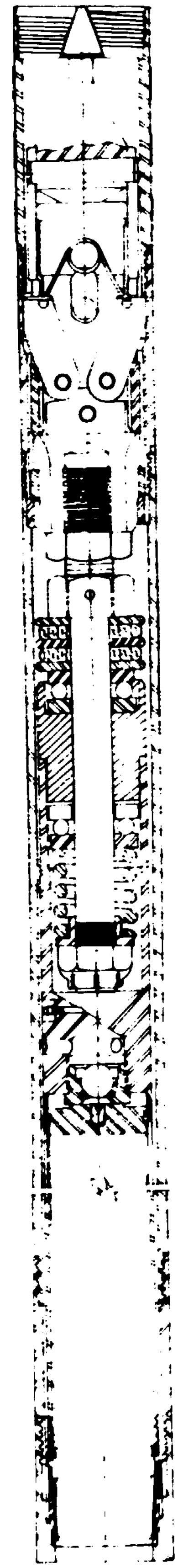


Fig N° 66

ats/bit. The 1 mm difference between the core barrel and the hole wall allows only water flushing. The K-3 type double swivel core barrel is more robust and it is fit for more viscose water flushing as well. Used with a particular bit, the same may serve for air flushing, too.

The Longyear "L" Double Tube Swivel Type (Fig.No.65.) gives a signal when the core sample is jammed in the barrel. In this case, the inner tube is pulled upwards and a rubber ring closes the waterway. The increasing pressure in the pump alarms the operator, who can stop drilling in order to avoid the core being grained.

The significance of the Longyear triple core barrel resides in the innermost tube being split. Discarding the upper segment of the tube, the unhurt core can be examined directly. The inner tube is of a polished crome surface.

The rubber-socket inner-shell core drill protects the core by clothing it in a rubber socket.

Other core barrels known from the literature are the ejectro core barrel, which inverts the direction of flushing near the hole bottom by means of an ejector built in the core barrel. In the Moser-Spann core barrel the sliding out of the core is made impossible by opening a valve of compressed air, thus filling with air a rubber boot. There are also procedures operating with freezing the rock.

The great variety of core barrels manufactured for different types of friable and consolidated rocks suggest that the problem has not yet been solved. Oriented core can be obtained by using the Core-orienting Craelius or Christensen--Hügel core drilling equipments.

The main disadvantage of core drilling, i.e. the round trips, can be avoided by applying the continuous wire-line core drilling (Fig.No.66.).The inner tube of the core barrel is thrust through the rods and lifted after the core being drilled by a particular instrument.

In case of horizontal or upwards drilling (up to 45 ^{o}) the inner core tube is transported by the pressure of the mud to the bit.

DIAMOND BITS

For choosing the appropriate bit (depending upon the rock type to be drilled)the following should be considered: bit profile, bit kerf, waterways, stone quality, stone grain size, quality of the matrix, depth of embedding of the diamonds.

It is obvious that from the combinations of these parameters a very big number of diamond bit types result. This is exactly the main reason why diamond drilling has become the most efficient and economical method of exploratory drilling.

The size of the diamond (stone/carat) depends upon the rock and upon the capacity of the drilling equipment. In a compact, soft rock the size of the diamonds is about 10-15 stone/carat. In very disturbed, fractured rock smaller-size diamonds are recommended, while in hard and very hard rocks the appropriate size ranges 20-40 to 40-80 stone/carat.

The waterways of diamond bits should be designed taking into account the size of the rock fragments of the cutting. Three typical patterns of waterway arrangement are illustrated in Fig.No.67. for the Craelius-type bits. At the traditional waterway pattern of the diamond bits (Figs No.68., 69.) the drilling fluid flow arrives at the cutting surface of the bit at the bottom of the hole, at the formation of the core, washing the core.

In case of the type called Face Discharge Ports (Fig.No. 70.) the drilling fluid flow gets out at the surface of the bit kerf, avoiding the core. This type is used for air circulating, too. Double bit (Fig.No.71.) is also appropriate for avoiding the core and the drilling fluid to meet. The waterways determine, at least to a certain extent, the profile of the bit. In hard rocks thin-wall bits are used. The firm J.K.SMIT designed multi-step and was tooth bits for soft rocks. These enhance the performance and increase the duration of the diamonds (Fig.No.72.). The bits pertaining to wireline core barrels are usually stepped along a cilinder shape. The Step Bits stabilize the drilling rod and minimize deviation from the vertical.

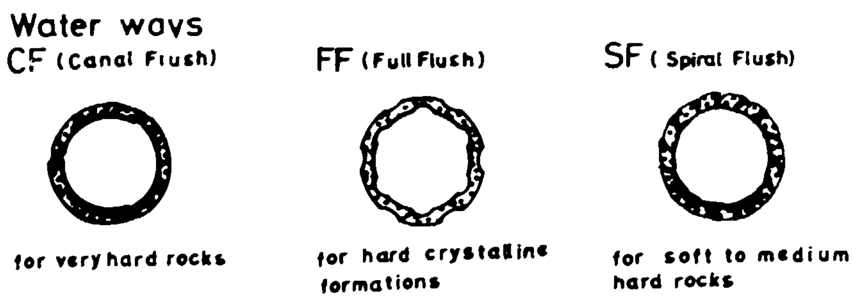


Fig. N° 67.

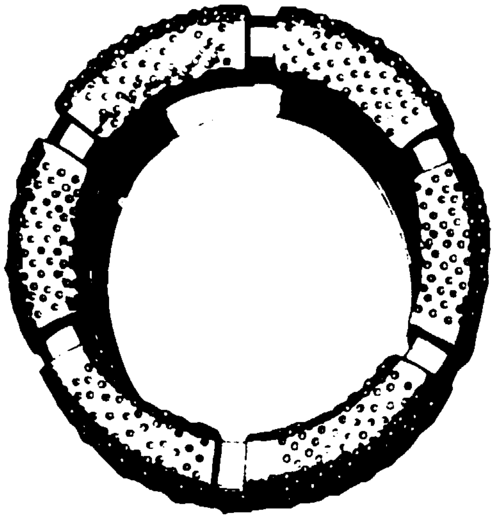


Fig N° 68 a

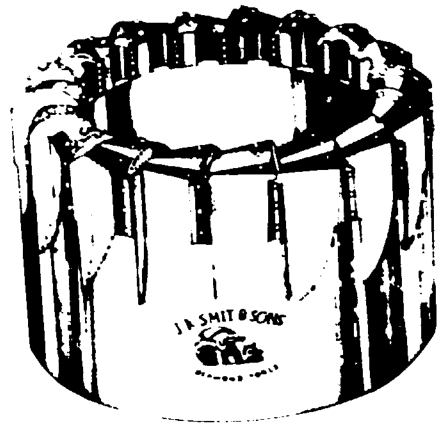


Fig N° 69 a

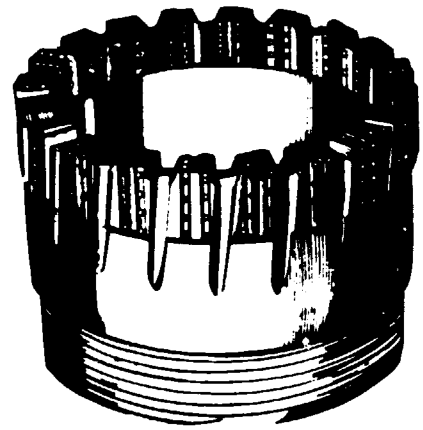


Fig N° 69 b

Fig N° 68 b

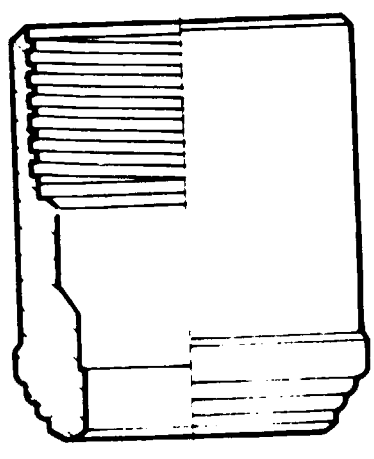


Fig N° 69 c

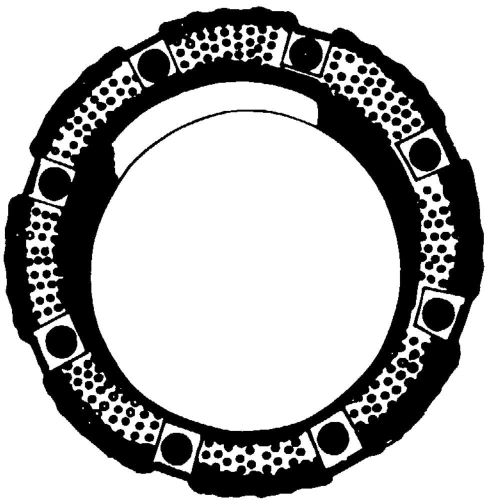


Fig N° 70.

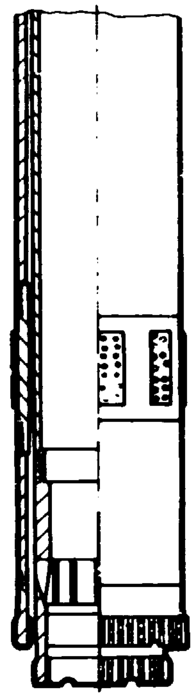


Fig. N° 71

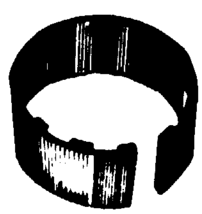


Fig N° 72/a

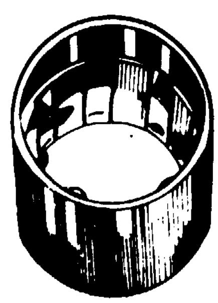


Fig N° 72/b

TABLE FOR CHOOSING THE DRILLING TOOLS AND DRILLING PARAMETERS FOR DRILLING BAUXITE

	Rock type				
	Very hard abrasive	Fractured hard	Clay-structured compact	Clay-structured soft	Nodular porous
Core Bit type	Surface set	Inner cone	Saw or step bit	FDP	GBK Inner-cone FDP
Min.Core Dia	42	58 (48)	42	58 (48)	58 (48)
Stone/ct Stone quality	40-80/W.Afr 15-20/Carb.	40-80/W-Afr. 15-20/Carb.	20-40/Congo 15-25/W.A.		10-15/Congo
Core Barrel	"T" (simple)	K-3 spec	K-3	K-3 Triple-tube	K-3 Triple-tube spec
Core Catcher	Spring	Basket spec	Spring	Spring	Basket spec
Reamer		+ upside		+ upside	+ upside
Drilling medium	air water	foam air mud	air foam mud	air foam mud	foam mud
Velocity of drilling fluid (upwards) m/s	0.8	0.4-0.8	0.4	0.4	0.6
Rotational speed of bit, m/s	1.5	1.o	1.0-1.5	1.0-1.5	1.0
Diamond load (N/Stone)	60-100	40-80	10-60	10-50	1-50

FDP = Face Discharge Ports

Reamer: + upside: this means that the reamer shoud be mounted on both the lower and the upper end of the core barrel.

The loading capacity has been taken into consideration according to C.Marx to be used only in exceptiona cases.

The table can by no means be of equal value with practical experience. Nevertheless it may turn out to be useful in an unknown area till the first experience is obtained.

EXERCISES at the Bausite Prospecting Co. of the Hungarian Aluminium Corporation (Balatonalmádi) related to Paragraphs 4.1., 4.2., 4.3., 4.5., 4.6. and 4.7.

5. PROCESSING OF THE RESULTS OF BAUXITE PROSPECTION; FINAL GEOLOGICAL REPORTS, RESERVE CALCULATION AND ECONOMIC ASSESSMENT

5.1. CONTENT AND PREPARATION OF FINAL GEOLOGICAL REPORTS

Even the best possible geological prospection will be useless to an other person without a well-compiled report. The general nature and content of the report depends on the aim of the geological project and prospection, the general geological setting (e.g. the type of the bauxite deposit; some reports have to be more detailed on account of previously unknown area or economic deposits). Last but not least the higher authorities, for example in Hungary the Central Geological Office controlling all of geological activities in the country in hand, should have special requirements concerning the report.

Each report depending upon its purpose will differ somewhat in organization, details, but the basic point of view of any communication is to describe what has been observed and to synthesize and explain the geological relationships and events. This is the only way to avoid the error of drawing conclusions from points of "evidence" that were originally introduced as ideas and not as facts R.R.Compton (1962).

It is obvious that the results of geological exploration are recorded most completely in the final geological report which is to be written after the detailed bauxite prospection of an economic unit. That is why in this chapter we don't deal with the content of any interim report but with the final report only.

The final report has to contain all data in such detail that on the basis of the report the economic evaluation can be elaborated and the preliminary mining projects can be designed.

The final report consists of three main parts:

A. Descriptive part
B. Tables
C. Illustrations

This order shows the construction of the report only. If it is possible the maps of reserve calculation should be prepared at first, preceded only by compilation of the fundamental data documented in tables, which provide a basis for these maps. While the reserve calculation is going on, the other maps, illustrations and tables are to be compiled resp. plotted. The descriptive part is based on this documentation and it is nothing more than the explication of the illustrations and tables and the summary of the conclusions that can be drawn.

A. Descriptive part

1. Introduction
   - Names and addresses of the companies which carried out the prospection and report. Brief content, aim, number and date of the agreement between the customer and contractor, if any. How far could the company carry out the exploration.
   - Starting and finishing date of the exploration.
   - Name of experts who took part in the exploration and in the preparation of the geological report.
   - Acknowledgements.
2. General aspects: details of this paragraph depend on the economic situation of the explored area and on that whether there have been made any geological or economic study on this region.

- Geographic setting: orography, hydrography, climate, roads and railways, population, employment, raw materials for construction.

- Localization of the explored area.

3. Geological prospection

   - Surveying tasks: topographical mapping, map drawing, verification, siting of the geological exploratory objects (bore holes, pits, trenches), ground control network and its precision, method of establishing of eventually applied local coordinate system, number-, location-, distribution of fixed points, precision of surveying measurements.

   - Scale and reliability of topo-sheets used for geological mapping, scale and reliability of the geological maps.

   - Geological prospection: quantitative data of drilling, pitting and trenching, technical data of the pits: plan and depth (given in 0.1 m), technical data of drillings: type of drilling machines and their productivity (shift/m) total drilled interval, diameter of cores, recovery of core, density and orientation of grids used for prospection, productivity of prospection, costs of prospection.

   - Geophysical methods used in the prospection, description of principles, reliability.

   - Mining: if in the region in hand there are any mining activities: used mining methods and costs of production.

   - Geological tests: method of sampling, number of routine analyses, applied analytical methods, reliability of analysis, check analyses, analysis of impurities, method and number of the qualitative and quantitative mineralogical investigations, petrographical tests, method, and number of the determination of bulk density, recovery factor, beneficiation tests if any, - stratigraphic, lithological palaeontological tests and soil mechanics.

4. Geological setting: we have to avoid the scientific speculations and to make an effort to deal with the geological problems directly related to industrial-economical interests. The description of the lateritic and karstic bauxite deposits fairly differs in content:

   Laterite bauxite deposits:

   - Regional geology and structural patterns.
   - Local geology: extension and distribution of lateritized besement(s), their petrographic properties, mega- and microscopic character, physical properties; porosity, permeability, texture and structure, chemical and mineralogical composition.
   - Structure of the complete lateritic horizon, description of the varieties of formations building up the laterite profile (sensu sricto laterite, sensu lato laterite, ferruginous laterite, aluminous laterite, lithomargic clay, ironcrust, etc.), thickness of overburden, if any.
   - Bauxite and bauxitic complex, terminology: exact definition for what we have regarded as industrial grade bauxite; nature of deposits, petrographical features, chemical- and mineralogical composition of bauxite, technological properties.

   Karst bauxite deposits:

   - Localization of bauxite deposits in the regional tectonical units.
   - General tectonical features and their role in the bauxite accumulation.
   - Petrography and stratigraphy (use of lithologic unit terms) group, formation, member, lentil, tongue, bed) and time-stratigraphic unit terms)

system, series, stage, zone) must be applied consistently according to the accepted rules. Usage of the names must be checked in the bibliographies and/or in the most recent publications.

- Bauxite and bauxitic complex, terminology, general geological character of the deposits (extension, thickness, distribution of lenses) relation to the footwall and cover, petrographic properties of bauxite, mineralogical and chemical composition of the bauxite, technological properties.

- Genetical questions.

- Hydrogeology.

5. Reserve calculation
   - Method of calculation, of reserves, volume, bulk density, and reserve categories.
   - Economic assessment: workability, cost limit, real cost.

6. Summary and conclusions: this chapter gives a brief information about the economic value of the prospected area, with the most important economic data. It contains the location of deposits, the geologic frame--work and the quantity and quality of the deposits. Recommendations are given for further prospection.

B. Tables

1. Coordinates of fix points and bore holes (pits) with duration of drilling and pitting.

2. Stratigraphical and lithological description of the formations explored by drilling and pitting. (No of the bore-hole or pit, interval, name of formation, brief petrograpical description, fossils, lithological unit and age. On a well known area the petrographic description is not needed in every case.

3. Standard five-component analysis (independently form grade of bauxite).

4. Analysis for all components (bauxite and associated formations: immediate footwall and cover).

5. Impurities and trace elements.

6. Mineralogical costituents.

7. Bulk density.

C. Illustrations

Basic illustrations of the Final Report summarizing the results of the "proving drilling" stage of exploration are as follows:

Simple contour maps and isopach maps

- small-scale maps demonstrating the location of the occurrence, and its surroundings Scale: 1 to 75 000 or 1 to 50 000
- large-scale detailed (exploration) maps Scale: 1 to 10 000 or 1 to 5 000
- topographic sheets with drainage, and contours of 1 to 2,5 m intervals Scale: 1 to 2 000
- geological map Scale: 1 to 2 000
- contour-map of the bedrock surface (with 2.5 m contours) Scale: 1 to 2 000 or 1 to 5 000
- isopach maps of the bauxite-complex (with 1 m intervals) with the lines of the cross-sections marked Scale: 1 to 2 000
- isopach maps of the industrial grade, workable sections of the deposit (with 1 m isopachs) Scale: 1 to 2 000
- contour map of the surface of the bauxite-complex (with 2.5 m contours) Scale: 1 to 2 000

- isopach map of the coverbeds (with 2.5 m isopachs)
  Scale: 1 to 2 000

- areal distribution of impurities (i.e. percentages of CaO, MgO, P_2O_5, S and S^{org}) within the industrial--grade, mineable portions of the deposit (concentration--intervals 0.2 to 5 per cent; base map: "isopach map of the industrial grade, workable parts of the deposit")
  Scale: 1 to 2 000

Base maps for the reserve calculation
Depending on the method used, they may be

- the map of geological blocks
- the map of the area-of-influence of the boreholes
- isopach map of the reserves
- vertical and parallel cross-sections of the ore body
  Scale: 1 to 2 000

- Hydrogeological maps Scale: 1 to 2 000

Geological cross-sections
- detailed profiles of the ore bodies Scale: 1 to 1 000
  1 to 500

- small-scale sections across the occurrence
  Scale: 1 to 5 000

Others
Illustrations enumerated below are composed in pencil by the geologist or by his assistant and are traced in black ink on transparent paper by draughtsmen. Coloured blue--prints of the original drawings are attached to the report in the form of supplements or inset plates

- "identity-sheets" of productive boreholes with the upper and lower boundary of the ore checked - and, if necessary, also revised - on the basis of geophysical information (especially when the difference between the boundary established from the data of core-drilling and of the carottage exceeds 1.0 metre)

- idealised stratigraphic columns
- hydrogeological profiles
- geophysical maps
- isometric tectonical-(-block)-diagrams

Insets (text-figures, diagrams, etc.) according to need: photographs of various field-scenes (landscapes, outcrops, surface exposures /open-pits/), cores, hand-specimens, fossils, drilling rigs, morphotectonic elements, photomicrographs of details of thin sections, etc.

Lately also the preparation of part of the illustrations is becoming the subject of computerization. Contour maps, isopach maps and part of the profiles may be plotted for instance by automatic plotters and thus, beside raising the accuracy of the work, both labour and time can be spared. In Hungary automation of the draughtsmen's work is being under development now, experiments are going on at several institutions (e.g. the R.Eötvös Geophysical Institute, the Hungarian Geological Institute, the Hungarian Aluminium Corporation, etc.). According to presentday estimates, however, there are no computer-made maps or profiles at the moment which may be used simply for substitutes of the invention of the geologist, and it will take rather a long time yet to produce all illustrations automatically.

5.2. RESERVE CALCULATION

The aim of the calculation is to determine:

- the geological reserves
- the mineable reserves
- economic (industrial) grade reserves

5.2.1. Terminology

The geologic reserve is that part of the ore body, which satisfies the requirements of the "reserve registration". Requirements have been installed by state regulation in Hungary as follows:

Module	2.6
Al_2O_3	40 %
S	0.6 %
Thickness	1.0 %

Geological reserves contain also the barren intercalations which cannot be mined out separetely from the bauxite.

Consequently the quality of the bauxite reserve - in this case - is determined by the chemical composition of bauxite and barren (improductive) layers proportionally, but the reserve doesn't contain the barren interlayers when it can stripped separately. See fig.No.73.

On the figure presented, the bauxitic clay of 20 cm, and dolomite debris belong to the geologic reserve. The debris of dolomite of 4 m - as it is mineable separetely - is not to be taken in account.

Mineable reserve is the geologic reserve reduced by the reserve to be left in pillars (underground mining!) and by the working loss. This latter in Hungary is 10 % in open cast mining and 25-35 % in underground mining.

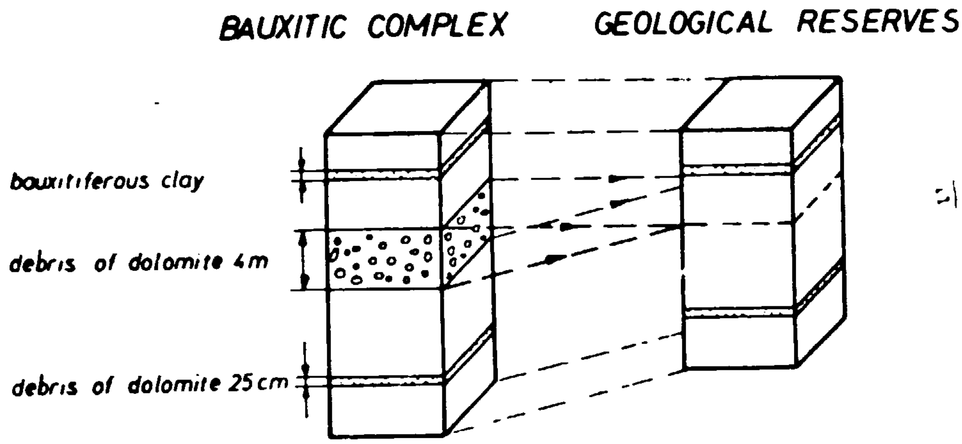


Fig N° 73

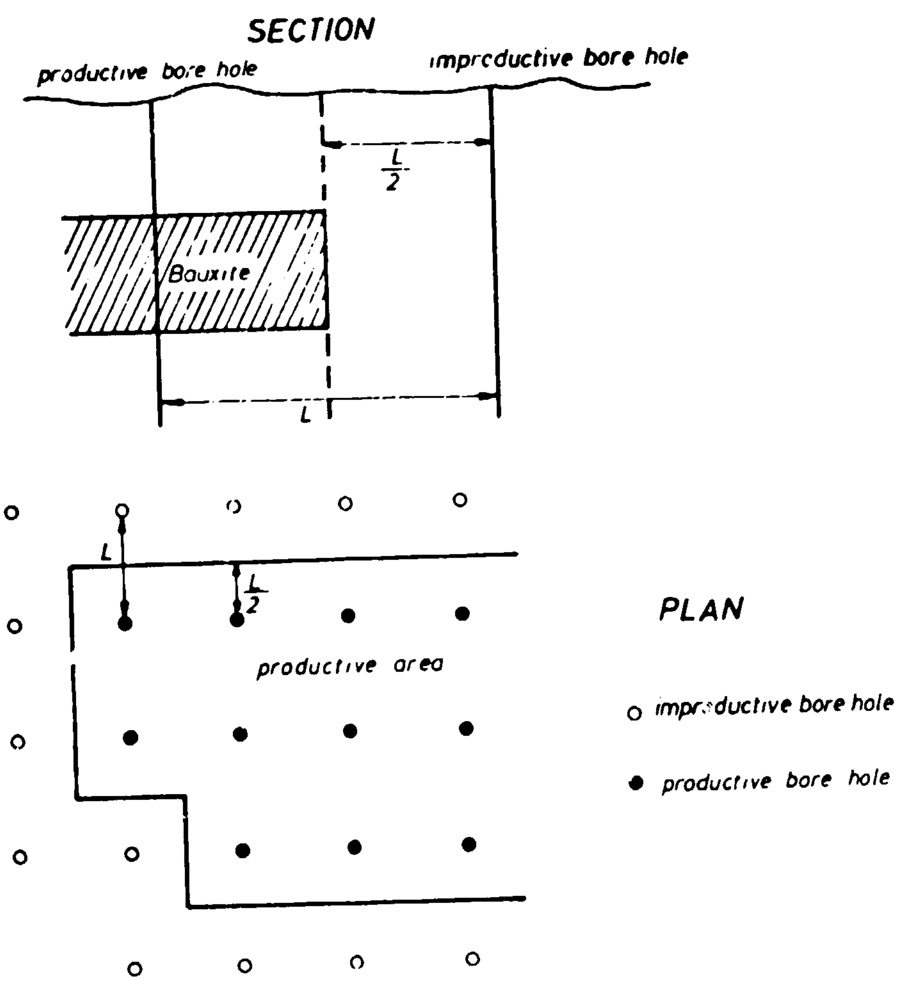


Fig N° 74

The dilution factor is that part of the unproductive associated rocks which is admixed with the product in the course of mining activities. or in order to decrase the mining cost, is deliberately stripped with bauxite in the highly mechanized mines. The volume of mineable bauxite is increased and the quality decreased on account of dilution. In Hungarian underground minings it is 1.5-3 % of the volume of mineable reserve. On the basis of chemical composition of associated rocks the decrease in quality can be estimated.

Economic grade reserves are that part of the mineable reserve, which can be mined out economically (see in detail in para No.5.4.

The working loss is that part of the geologic reserve which during the mining operation, is left behind.

5.2.2. Grouping of basic data for the reserve calculation

In the reserve calculation the first step is the grouping of the data of the bauxite body on the basis of the cores or pit samples and its analysis. We determine the bauxite thickness that is to be taken into consideration

Interval from m to m	Thickness m	Al_2O_3	SiO_2	Module
6.0 - 7.0	1.0	36.2	26.0	1.4
6.0 - 8.0	1.0	55.6	11.3	4.9
8.0 - 9.0	1.0	53.2	6.8	7.8
9.0 -10.0	1.0	41.0	17.1	2.4
10.0 -11.0	1.0	50.5	9.8	5.2
11.0 -12.0	1.0	52.0	5.6	9.3
12.0 -13.0	1.0	35.5	20.2	1.8

In our example the interval of the geologic reserve is between 7.0-12.0 (even thorugh the interval between 9-10 m has a module less than 2.6) because this interval cannot be stripped selectively.

According to the table the bauxite thickness in this case will be 5.0 m and the average

Al_2O_3 % = 50.34
SiO_2 % = 10.12
M = 4.97

Besides the Al_2O_3 and SiO_2, in Hungary, we consider the percentage of Fe_2O_3, L.O.I. and as contamination CaO, MgO, $\sum$ S % too, and in the inventory we compute the weighted average of these components as well.

5.2.3. Methods used for reserve calculation

The methods are as follows:

- arithmetic mean
- geologic blocks
- polygons
- profiles
- isopach lines

Applying any method we must determine:

- thickness of the bauxite
- bulk density (recovery factor)
- productive area

We have alredy dealt with the determination of the bauxite thickness taken into calculation (para 5.2.1.) and bulk density or recovery factor (para 3.6.1., 3.6.2.). The boundaries of the productive area is plotted on the reserve calculation map. The scale of map should be 1:2000-1:5000. The scale depends on the extension of deposits and the grid of exploration.

The aim is to have a map where the area can be measured easily and exactly. On the basis of co-ordinates we mark all the productive and unproductive bore holes/pits on the map. For the demarcation of the productive areas we apply different kind of methods:

- Demarcation considering the whole bauxite thickness; It is a mechanical method, an inaccurate proceeding in the case of karstic bauxites, but fairly good for lateritic bauxites. It is based on the bisection of the distance between the productive and the closest unproductive bore holes/pits (see Fig. No.74. on page 324.).
- This system is used in the reserve calculation methods of arithmetic mean and geologic blocks.
- Demarcation with extrapolation of the bauxite thickness on the basis of profiles; We construct the profiles through each bore hole taking into consideration the nature of the deposit and the trend of the uneven surface of bedrock. We establish the wedging of the deposit and we display on it the cutoff for thickness (e.g. at 1 m thickness), which is the limit of our consideration. Connecting these points on the map, we get the productive area.

This system of demarcation is used for the reserve calculation methods of profiles or isopach lines.

Method of arithmetic mean

In this method the bauxite body is converted into a symplified geometrical plane bordered by paralell planes. The base of this body is the productive area, the height of it is the average thickness of the bauxite deposit.

Geological reserve:

$$Q = t \times \bar{v} \times bd$$

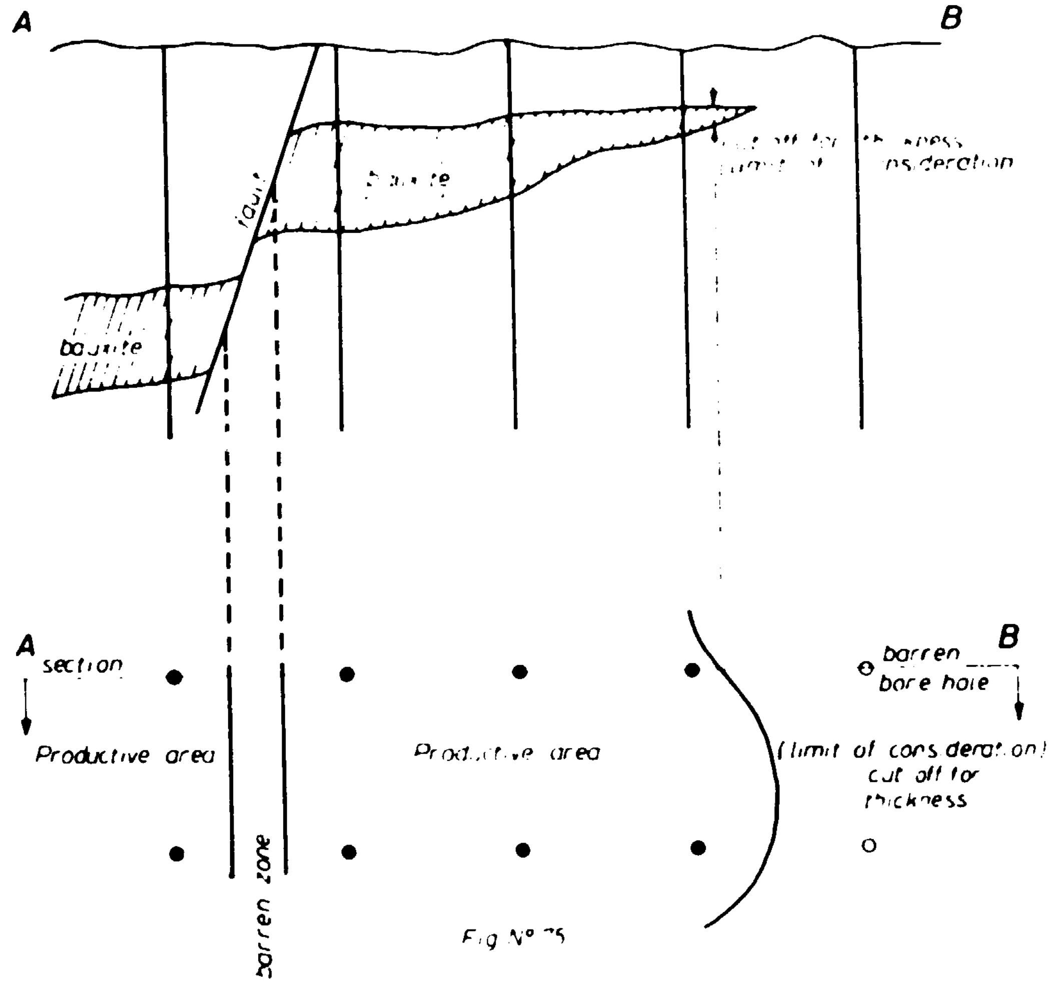


Fig N° 75

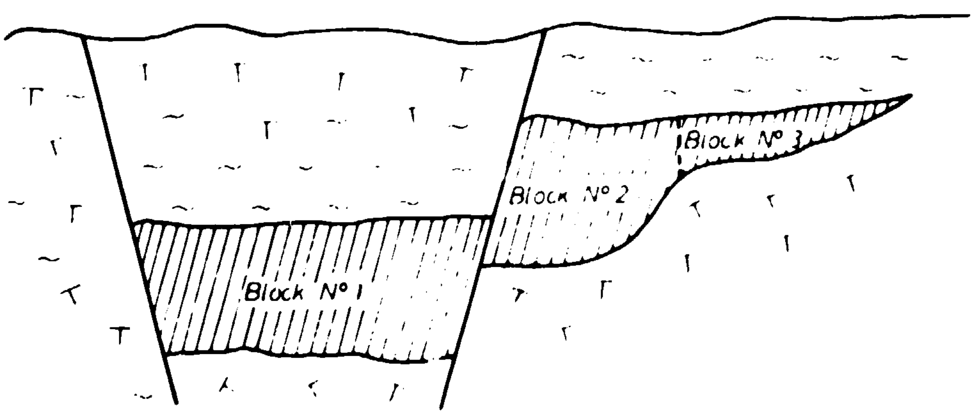


Fig N° 76

Where: Q = reserves in tons
T = productive area in m^2
$\bar{v}$ = arithmetic mean of thickness in m
bd = bulk density t/m^3

The average grade of bauxite is calculated with the grade of bauxite of each bore hole/pit, weighted with its thickness.

This method is reliable enough if the points of drilling/pit are in regular grid and there is no significant difference in thickness. Consequently in the case of lateritic bauxite deposits this method seems reliable.

Method of geological (mining) blocks

This method used to be called as the method of prism as well, because the deposit is divided into perpendicular prisms (or blocks). This division is achieved on the basis of geological (mining aspects: for example faults or significant change in thickness of ore) see Fig. Nos 75., 76.

Within one block the reserve is computed with the method of arithmetic mean and then we make the additions. The quality is given by the weighted average grade. The average grade of the deposit is given by the weighted quality of the blocks.

Method of polygons

Any polygon representing the area of influence of a productive bore hole/pit at the middle of the polygon, is a set of all points lying closer to the bore hole/pit at the middle, than any other bore hole/pit. The polygon in question, is constructed by drawing radii from the bore hole in question to the neighbouring bore hole, halving them and then erecting normals on the median points thus formed. The thickness and grade of the bauxite body explored by drilling/pitting at the middle, has been extended to cover the whole area of the polygon obtained in this way (see Fig. No.77.)

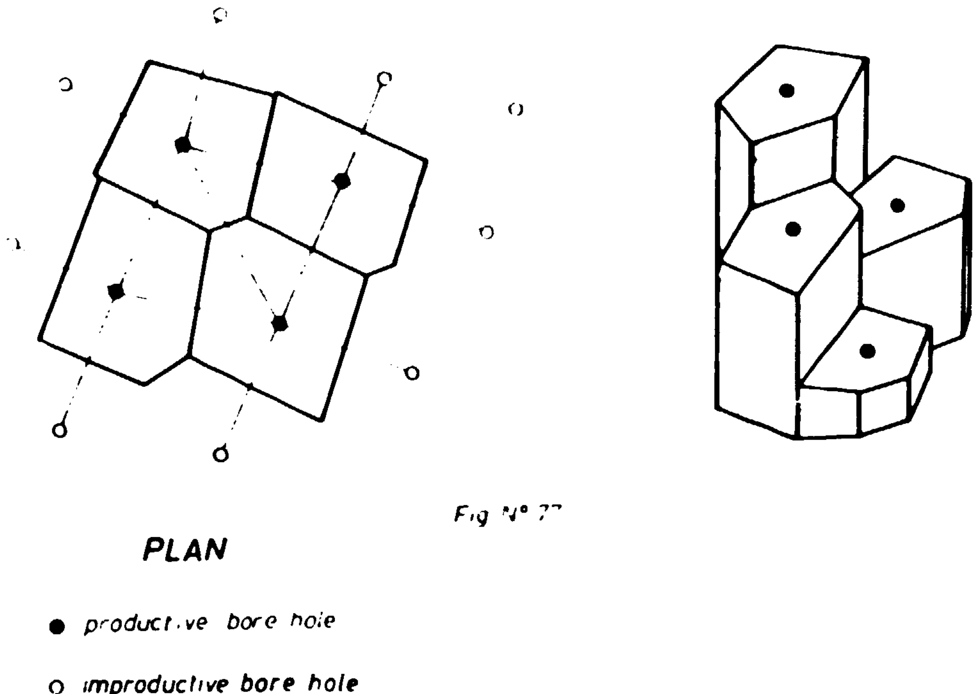


Fig N° 77

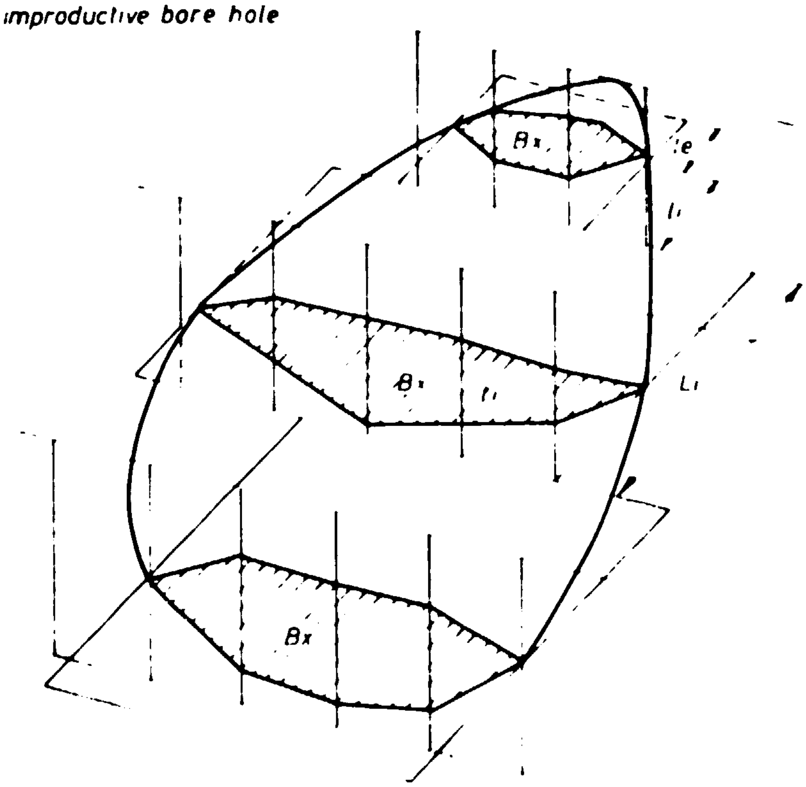


Fig N° 78

Method of profiles

This method is based on the sections drawn on the basis of bore holes/pits, determining the area of the deposit in each section. Measuring the distance on the map, between two section lines, we can calculate the volume of the ore body which is bordered by the area of influence of the two profiles. By addition of each proportioned part of the deposit, we get the volume and quality of the reserves. The base of this geometric body divided by the profiles, is t_i and its height is the area of influence of the profile L_i (see Fig. No.77.).

Reserve of the ore body is:

$$Q = t_i \times L_i \times \text{bulk density}$$

The area of influence can be recorded by halving the distance between two profile lines (see Fig. No.78.). Demarcation of the marginal parts of the deposit is carried out by inter- or extrapolation. By the external section the marginal part is cut into two parts. The lenght of the internal part will be l_i and that of external part will be l_e.

Reserve of the marginal body is:

$$Q_{ie} = (t_i \times l_i) + \frac{t_i \times l_e}{3} \times bd$$

The reserve of the whole body is:

$$Q = \sum(Q_i + Q_{ie})$$

This reserve calculation method is a simple process if the sections run in paralell direction, if not, an interpolation is needed. For example by plotting the isopach map of bauxite thickness and on the basis of the values of thickness we can construct the paralell profiles.

The quality of ore bodies are given on the basis of bore-holes/pits and the average grade can be derived from the grade of each bore hole/pit weighted with their thickness.

Method of isopach lines

After constructing the isopach lines of bauxite thickness we measure with planimeter the area lying between two isopach lines. The volume of the geometric body can be calculated on the basis of the formula of a truncated-cone:

$$V = \frac{h}{3}\sum(t_{n-1} + t_n) + \sqrt{t_{n-1} \times t_n} \pm \frac{\sum t_n \times h}{3}$$

or the formula of a trapezoid:

$$V = n\left(\frac{t_o}{2} + t_1 + t_2 \ldots . t_{n-1} + \frac{t_n}{2}\right) \pm \frac{\sum t_m \times h}{3}$$

In these formulae

h = space (interval for example 1.0 m)
t_o = area of isopach of .0 m
t_m = area determined a sigle line. In the case of protrusion of surface of bedrock it is "+ "and in the case of sinking it is a"-"value.

Although this method is very laborious it can be well applied for the karstic deposits because this process simulates the uneven karstic surface well.

5.3. COMPUTERIZATION OF BAUXITE RESERVES

Input data:

- chemical analysis of each bore hole/pit with the analysis intervals (given from m to m)
- bulk density (or recovery factor)
- area and No of block
- reserve categories (see the cards of reserve calculation on page 334.

Output data:

- thickness and average of components of bauxite by bore-holes/pits
- geologic reserves and average grade are grouped by blocks, deposits, occurrence,etc. and by categories
- volume of cover

Calculation of the average grade and bauxite thickness by bore-holes/pits is as follows: the concerned data are summarized and weighted with the thickness. The partial and total averages with the corresponding intervals are printed by the machine. The calculation runs according to the formerly given cutoff-s taking into consideration the possibility of selective mining as well.

When the bore hole crosses more than one strata the average can recalied by layers as well. In general the bauxite is not analysed for CaO %, MgO %, $\sum$ S %, P_2O_5 %, $C_{org.}$ % in each interval. The values of the intervals analysed for these contaminations too have to be accumulated seperately. The weighted averages of these data are given as well.

The average values of each bore hole/pit is stored in the memory of the computer. The values below different kinds of cutoff are not stored.

No of bore hole / pit	Interval m		Al_2O_3 %	SiO_2 %	Fe_2O_3 %	TiO_2 %	Loss on ignition %	CaO %	MgO %	Σ S %	P_2O_5 %	CO_2 %	Corg %	Card N° 1	Sign of card
	from	to													

No of bore hole / pit	Interval m		Bulk density		moisture %	Card N° 2	Sign of card
	from	to	wet	dry			

No of bore hole / pit	Mining unit	Mining block			Card N° 3	Sign of card
		Nr.		Area of block		

Averaging of grade by groups of bore holes (in the case of "block method")

The average grade of the geologic (mining block) is calculated on the basis ov averages of each bore hole. The mining blocks are regarded as groups of bore holes, when the reserve calculation is carried out with the block method. The results are printed by the computer data of meter percents, their sums and the averaging to the given bore hole. The average thickness is calculated on the basis of their arithmetic mean. The average grade of blocks is stored in the memory.

Reserve calculation

The reserve calculation on the basis of the polygon and the geologic (mining) method is done on the same system as given in para No. 5.2.3. The records of reserves are summarized according to bore holes, blocks, deposits occurrences, categories of according to any given criteria (for example different kinds of cut off for grades. Printing of units of any component (reserve component %) is also effective.

Calculation of cover recovering

The volume of the cover (barren) upon the basic area of the bauxite surface calculated in the reserve, can be determined using the input data of the cards No. 1 and 3. (see page 334.). The tonnage of the overburden belonging to the slope wall is determined in the traditional way. The thickness of the overburden is given by the first productive meter of the bore hole, thus the average thickness of overburden can be calculated, within one geologic (or mining) block.

The volume of overburden is given by multiplying the thickness by the area of the block.
This volume is printed by computer; likewise the summarized volume of the overburden of each block, as well.

5.4. ECONOMIC ASSESSMENT OF BAUXITE DEPOSITS

The task of bauxite resource management is the utmost exploitation of the potential national-economy asset represented by the in situ raw material, and the ensuring of a maximum recovery of value (in money terms) over the entire integrated aluminium industry.
The economic assessment of bauxite deposits is an important constituent of bauxite resource management.
In Hungary, the economic assessment of mineral resources is based essentially on the concept of differential mining rent. This assessment, which has the form of a forecast, is revised at regular intervals. Called the workability assessment, it has been installed by state regulation as an organic constituent of mineral reserve calculation and registration (bookkeeping) since 1970.

The workability assessment of a mineral includes the calculation of the extractible reserves and a forecasting of the value and cost of the mining product.

Fundaments of economic assessment

The cost limit

Mineral deposits characterized by favourable natural conditions occur in limited numbers. Among the deposits, arranged in decreasing order of desirability, there will be one least favourable one, the product of which is still needed to satisfy social demand. It is the expenditure required to work this poorest of deposits that must still be worked to satisfy needs (the marginal expenditure) that determines the cost limit (the m[illegible]al cost) of the mineral in question.

Starting from the fact that a mineral can be replaced at some stage of its processing by some homogeneous processing product, the cost limit of the mineral at the mine gate is:

$$w = \frac{a - b}{c} - s,$$

where w = is the cost limit of the mineral in Ft/ton[+],

a = is the cost of the processed product that can replace the product won from the mineral (its value or, in case of exports, its price), at the processing-plant gate, in Ft/ton,

b = is the cost of the processed product won from the mineral, minus the cost of the mineral used up in Ft/ton,

c = is the quantity of mineral needed to produce one ton of processed product, in ton/ton,

s = is the freight cost of the mineral from the mine gate to the processing-plant gate, in Ft/ton,

b = and c are functions of the mineral's grade.

In possession of b and c parameters for different grades of the mineral, a cost-limit function derived from a processed product can be written up for any mine. This is usually performed once per five years, in the form of a forecast for the next five-year period.

[+]Ft = forint is the Hungarian monetary unit; tons are metric, although this restriction does not affect most of the argument.

The cost limit of Hungarian bauxite has been derived from aluminium metal made out of imported alumina, as the most favourable marginal source of aluminium metal:

$$w = 29.3\ (Al_2O_3^* + 9.6) - s,$$

where $Al_2O_3^*$ is the reduced Al_2O_3 content of bauxite;
equals the actual (mechanical) Al_2O_3 content corrected by

minus 3 percentage points of Al_2O_3 per percent SiO_2 content,
minus 1 percentage points of Al_2O_3 per percent CaO content,
minus 2 percentage points of Al_2O_3 per percent MgO content,
plus 0.05 percentage points of Al_2O_3 per cu.metre per ton of saleable water pumped out of the bauxite mine.

Real cost

Real cost is either the expenditure avoided by not exploiting a deposit, or the long-term incremental cost at national-economy level required to develop and work a deposit (or part-deposit), using modern technology. Real cost does not include pro-rata owning costs due to previous investment aimed at developing (working other deposits) part-deposits, but it includes the repayment of principal and interest on any additional investment required.

If the bauxite deposit is on virginal area, the real cost includes the cost of infrastructure.

Real cost is made up by prospecting cost, mine development cost, block development cost, block extraction cost, and mine operating cost.

Real cost is obtained as a result of case-by-case calculation or, using a computer, by means of cost functions relating cost to natural parameters of the mine, deposit, mineral etc.

The basic unit of a workability assessment is the mining block, a part of the deposit to be regarded as quasi-homogeneous as to degree of exploration, specific value and mining costs.

Workability assessment furnishes two measures: a workability index, to be denoted Mm after the Hungarian abbreviation, and a so-called in-situ value, E: this latter expresses in money terms the profit at the national-economy level of winning the mineral:

$$Mm = \frac{w}{k} \quad \text{in Ft/Ft}$$

and

$$E = Q_k (w - k) \quad \text{in Ft,}$$

where w = is the cost limit in Ft/ton,
k = is the real cost is Ft/ton, and
Q = is the extractible workable reserve in tons.

In possession of the results of the computation implied by these formulae (usually done by computer), a block of a deposit is considered workable if $Mm \geqq 1$ or $E \geqq 0$. (It will be noted that these two conditions are equivalent).

That part of the non-workable reserve which is rendered workable first by any favourable change in the exogenous conditions (currently defined by $0.8 \leqq Mm < 1$) is being registered as a marginal reserve. The state protects the workable and marginal reserve by suitable laws. These reserves must not be left behind in a mine, without express authorization to do so.

The in situ value of a deposit approximately equals the differential mining rent that is represents, over and above, the poorest deposit whose winning is still necessary to satisfy social demand. Its magnitude depends at any one time on world market prices, processing cost and recovery, and mining cost and recovery. As exploration passes into prospection and prospection into development, the in situ value increases step by step until it attains - after extraction - the value of the extracted mineral.

EXERCISES at the Bauxite Prospecting Co. (Balatonalmádi) and at the Research Engineering and Prime Contracting Centre (Budapest) of the HUNGALU, related to paragraphs 5.1., 5.2., 5.3. and 5.4.

6. MINING GEOLOGY

Mining geology becomes all-important when the exploitation of the occurrence, referred to in the Final Report, begins. Although the objectives of mining geologist are rather diverse, there are some main tasks which are essential to cope with in every mine. Some of them are listed below:

1) Planning and supervision of all mine exploration works (i.e. foot-wall drillings, and horizontal blasthole-drillings at every sublevel of the open-pit mine by coring with one-meter sample-intervals. Coring can be carried out either by hand-operated portable drilling rigs or by light-weight, mobile, power-driven equipments). Channel-samples belong also to the mining geologist's duties to take. In underground workings in addition to footwall--drillings also roof- and side-wall drillings and chanelling of the side-walls and the face should be undertaken regularly in order to get sufficient information concerning the grade and exact thickness of the ore prepared for mining.

2) On-site bulk density tests.

3) Measuring and record of structural geological features. Processing and evaluation of structural geological data.

4) Continuous record of grade and tonnage of the worked-out ore. Supervision and co-ordination of all geological activities related to the preparation of new sections of the ore-body to be drawn into production.

5) Planning and scheduling of bauxite shipments from different working places according to grade and tonnage required.

6) Continuous control of the grade of the ore shipped out during each shift (by checking and recording the rapid chemical assay of each "partie").

7) Resource-management such as record and evaluation of production data (ton-pro-shift, -day, -month, -year figures), production losses; calculation of reserves; annual balance of reserves, etc.

8) Planning and execution (supervision) of exploration of areas immediately adjoining to the area under development. Preparation of proposals for further exploration or of Exploration Reports.

9) Documentation of all mining geological observations (compilation and continuous completion of maps and profiles by registration and plotting of newly incoming data). Preparation of Monthly Reports on mining geological activities.

10) Record and evaluation of hydrogeological observations; continuous monitoring of the effects of active dewatering (=this is generally the task of a special department called the Hydrogeological Service of the Mines). Documentation of all hydrogeological observations; preparation of Hydrogeological Reports.

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