EVALUATION OF CEMENT RAW MATERIALS IN WAYOU (NEW MUGHER) AREA

A Thesis
Presented to
The School of Graduate Studies
Addis Ababa University

In Partial Fulfillment
of the Requirements f~r the Degree
Master of Science in Geology

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ABSTRACT

The raw materials used in the manufacture of Portland cement were studied in the Wayu locality (New Mugher). The study showed that there is limestone of a good quality in large amount which justifies exploitation. The clay material studied was found out to be deficient in silica and needs a silica modulus corrector. Consequently, a sandstone body which is found beneath the basalt was investigated and the investigation showed that there is enough sandstone that can be used as a corrector. The study of the gypsum deposit also revealed that sufficient amount of gypsum exists. A conclusion was reached to the effect that the installation of a cement plant is justified.

INTRODUCTION

For a developing country like Ethiopia, the necessity for the establishment of a number of heavy industries is quite obvious. Among these industries the cement industry plays a major role and is vital for a development of a country. Almost all construction works require large quantities of cement and cement products. The demand for cement increases continuously as a country is undergoing development and this growing demand has to be satisfied. Ethiopia is blessed with lots of raw materials that may be used for cement manufacturing. The only thing is that the raw materials should be in close proximity so that the manufacuting could be economical. In Ethiopia, cement production is underway in three cement plants situated in Dire Dawa, Addis Ababa and Massewa. The Addis Ababa cement plant gets its raw materials from the Mugher valley which is about 150 km north-west of Addis Ababa. In Dire Dawa and Massewa, the raw materials are found nearby the plants.

Projects are being undertaken by the Building Materials Corporation to establish new cement plants in Wayu (New Mugher) (Fig. 1), and in Dire Dawa. This work is part of the on-going project and its purpose was to study and evaluate the raw materials used for cement manufacturing in the Wayu locality, putting more attention to the geologic aspects. That is,

(a) to study the limestone deposits and to prove their suitability for cement manufacturing, to re-evaluate the reserves given by De Leuw Cather International (1967) and investigate the possibility to prove additional reserves of limestone.

(b) to study the clay material at Wayu Mekoda and ascertain its suitability and to determine the reserves.

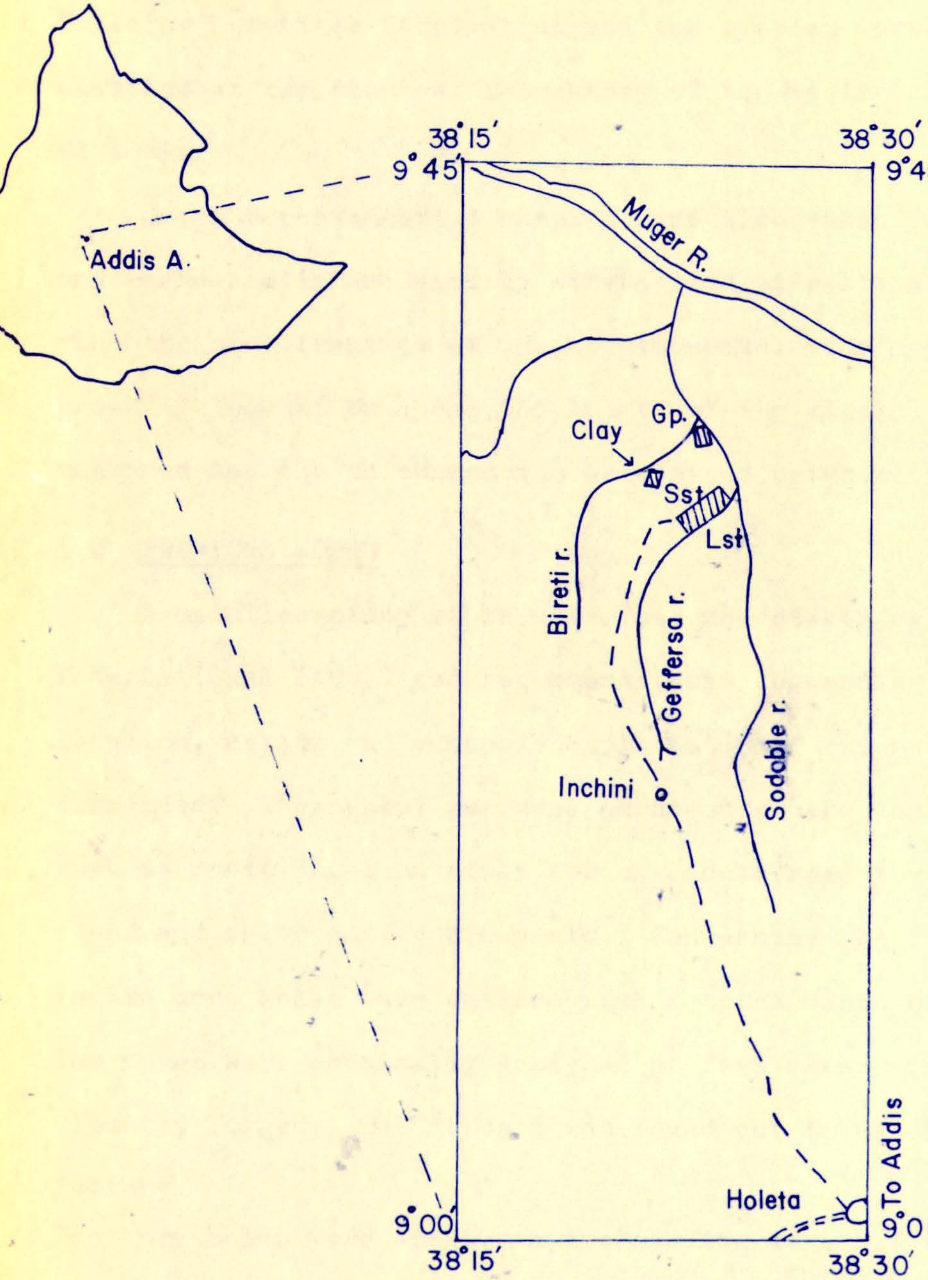
(c) to search for a deposit that may be used as a silica modulus corrector as was suggested by previous workers, De Leuw Cather International (1967) and Goumorov and Aklilu (1979), and determine its amount.

(d) to study the gypsum deposit near the sodoble river and determine its quality and estimate its reserve.

1.1 METHODS

A geological map of the area was made on a 12500 scale using aerial photographs as a base. Eight bore holes of 730 meters total depth were drilled by the National Boring Agency on the limestone deposit. Core samples from all the bore holes were logged and cores from four of the bore holes were chemically analysed at the chemical laboratory of the Geological Survey of Ethiopia. Petrographic study of the core samples from one of the bore holes (bore hole 1) which represents all the units, was undertaken using microscopes to determine vertical variations in the petrographic characteristics. This was suplemented by a petrographic study from a measured section along the limestone cliff. Moreover, seventeen bore holes of 490 meters total depth were also drilled in the area to determine the sandstone reserve in the vicinity of the sandstone outcrops.

LOCATION MAP



Scale 1:500000

To study the clay material deposit in the Wayu Mekoda area and to establish its reserve seventeen pits were dug by a team from the Building Materials Corporation and the samples were chemically analysed at the chemical laboratory of the Geological Survey of Ethiopia.

Seven representative samples were also taken from the test pits and mechanically analysed by sieving and pippette analysis to determine the size fraction of the constituents. The gypsum deposit was properly located on a map, the length of its lateral exposure was measured and the thickness was determined using altimeter.

1.2 PREVIOUS WORKS

A detailed study of the area was undertaken by De Leuw Cather International (1967) and recommendations concerning plant site location, method and economic exploitationof raw materials were forwarded. The report put more emphasis on the engineering aspects such as route location study for an access road to the area, electric power and water supply study etc. Concerning the raw materials, twelve bore holes were drilled with a total depth of 409.2 meters. The cores were chemically analysed at five meters interval and were visually logged. The deposit was found out to be chemically satisfactory.

The bore holes were drilled all along the edges of the limestone cliff and reached a maximum depth of only 45.5 meters . When the limestone could have been sampled and studied along the cliff with less amount of expense, there wasn't much sense in drilling all those bore holes. The area was also studied by a chinese team in 1977 but the report is not available.

Leron Gumorov and Aklilu Assefa (1979) of the E.I.G.S. studied the area in detail and suggested additional drilling sites inorder to prove additional limestone reserves. They also recommended that a silica modulus corrector should be searched for in the area.

2. GEOLOGICAL AND GEOGRAPHICAL SETTINGS OF THE STUDY AREA.

The area is in a locality called Wayu, 64 km. NNW. of Holeta town which itself is about 44 k.m. west of Addis Ababa (Fig. 1). It is bounded by the Gefersa and the Bireti rivers, both of which join the Sodoble river which is one of the main tributaries of the Mugher river. The rivers have cut through the Trap basalt and have exposed the Mesozoic Sedimentary rocks found below. The Mesozoic Sedimentary rocks which are exposed are the Shaly Sandstone Unit which includes interbeds of limestone, shale and sandstone followed by a Limestone Unit which is massive and fossiliferous. The lower sandstone is not exposed in the area but, in the northern part of the study area gypsum deposits are found beneath the limestone beds (fig. 31).

3. STRATIGRAPHY

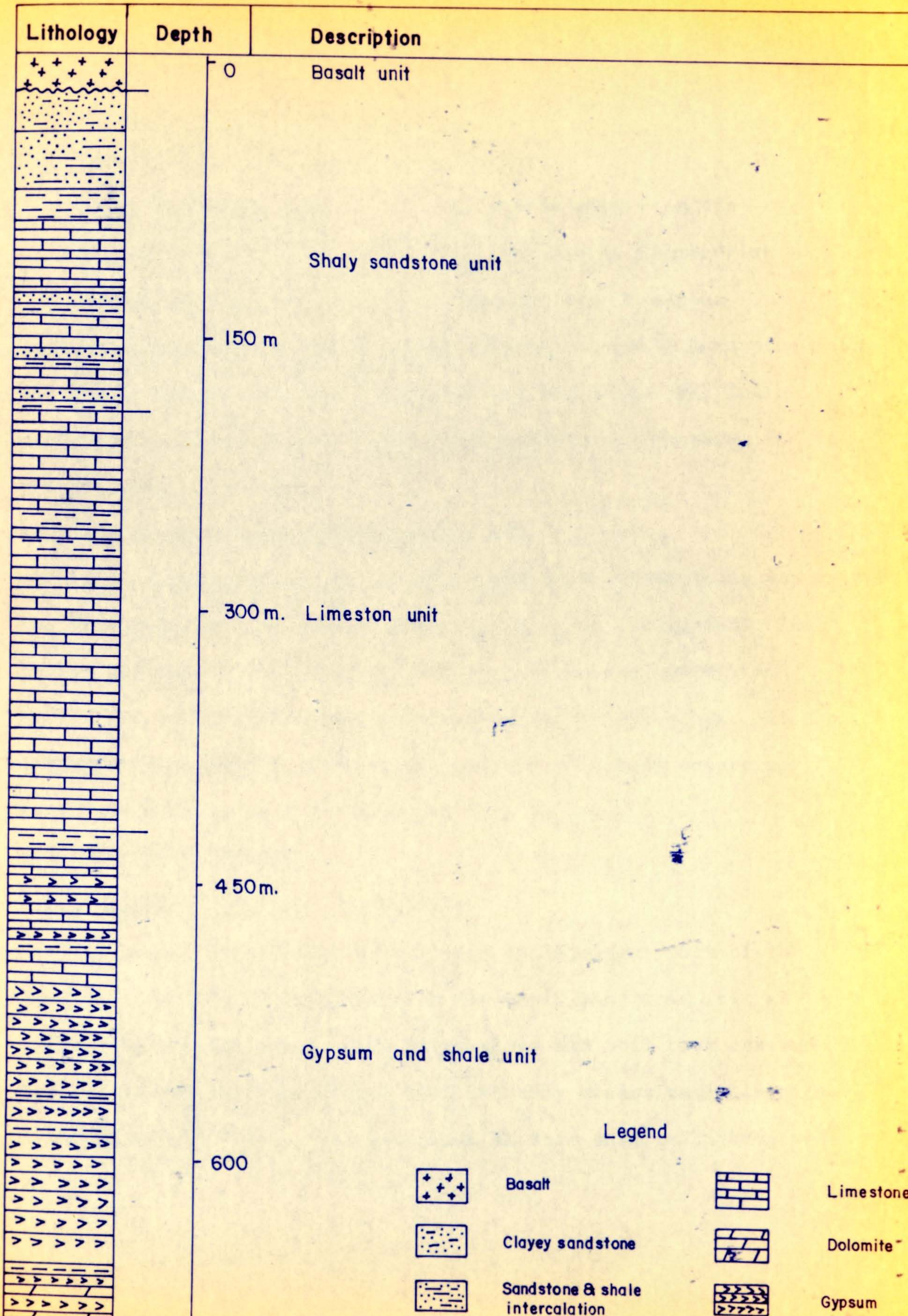
The lower most unit of the area is represented by Gypsum and Shale unit. The Gypsum and Shale unit is composed of well-bedded gypsum with thin interbeds of dolomite in its lower parts and intercalations of shale and limestone towards its upper parts. This unit is topped by Limestone unit which includes massive limestone followed by shale interbedded with relatively thin limestone beds and a cliff forming, massive, well-bedded limestone. This is overlain by Shaly Sandstone Unit which constitutes interbeds of limestone, shale and sandstone. This unit shows gradation from calcareous to arenaceous lithofacies. The top most unit in the area is the Tertiary basalt (Fig. 2).

Previous works on the succession of the Mesozoic units in the central parts of the Ethiopian plateau, particularly in the Blue Nile Basin include studies by Ferret, Galinies (1847), Jespen, Ahtearn (1961), Mohr (1962), Mehadi Shumburo (1968), Getaneh Assefa (1975), and Beauchamp (1977).

Based on the above works, particularly Jespen's work, the regional lithostratigraphy consist of the following units.

Basalt Unit	Tertiary
Upper Sandstone Unit	Aptian ? - Cennomanian
Shaly Sandstone Unit	L. Kimmerdgian - Aptian
Limestone Unit	Callovian - L. Kimmerdgian
Gypsum and Shale Unit	Toarcian ? - Bathonian
Lower Sandstone Unit	Permo-Triassic ? - Liassic

Accordingly, the stratigraphic sequence of the studied area was


Lithology
Depth
Description
0
Basalt unit
Shaly sandstone unit
150 m
300 m.
Limeston unit
450 m.
Gypsum and shale unit
600
Legend
Basalt
Clayey sandstone
Sandstone & shale intercalation
Limestone
Dolomite
Gypsum

determined to be the following.

Basalt Unit	Tertiary
Shaly Sandstone Unit	L. Kimmerdgian - Aptain
Limestone Unit	Callovian - L. Kimmerdgian
Gypsum and Shale Unit	Toarcian ? - Bathonian

Gypsum beds which mark the boundary between the Shaly Sandstone Unit and the Limestone unit are not present in the area. The Lower sandstone is not exposed and the Upper Sandstone is missing due to pre-Trappian denudation.

4. RAW MATERIALS FOR CEMENT MANUFACTURE

Cement raw materials may be divided into those essentially supplying the lime component and those supplying aluminum silicates. The source of lime is naturally available as limestone, marble and marl. The sources of aluminum silicates are mainly clays. If the clays are deficient in silica, silica-rich naturally occurring materials such as sand and silt may also be used.

4.1 LIMESTONE DEPOSIT.

4.1.1. GENERAL NATURE OF THE DEPOSIT.

The calcareous lithofacies which forms an important part of the limestone deposit is found both in the Shaly Sandstone Unit as well as in the Limestone unit. Slope scree and soil have covered the top of the Shaly Sandstone Unit and only occassional limestone outcrops are observed. The limestone in this unit is interbedded with sandstone and shale. This is underlain by a massive, fossiliferous and cliff forming limestone followed by a terrace below which limestone which is interbedded with shale is found. The rivers haven't cut all through the deposit, except in the northern part of the area where gypsum is found exposed beneath limestone beds.

4.1.2. DISTRIBUTION AND THICKNESS

The limestone outcrops are limited within the valleys of the Geffersa, the Bireti and the Sodoble rivers. The deposit gets thicker towards the north. The cliff forming limestone is nearly horizontally bedded and has a uniform thickness. The calcareous lithofacies in the Shaly Sandstone Unit is interbedded with sand and shale which have different thicknesses ranging from 7.48 meters (bore hole 2) to 30.71 meters (bore hole 5). The clastic interbeds show a significant increase in thickness in the south-east direction. Within a distance of only about 200 meters, there is a difference of 10.55 meters in thickness- (Average thickness of the clastic interbeds in bore holes 1,2,3 and 4 is 13.185 meters while it is 23.74 meters in bore holes 5,6,7, and 8.)

From the bore hole data the average thickness of the deposit was calculated to be 110 meters. However, the lowest elevation reached by the bore holes is 1994.72 meters above sea level (bore hole 4, Fig. 6), and was still within the Limestone unit. It was apparent that the deposit continues beyond that depth, since the bed of the

Gefferse river, which is found at an elevation of 1838.3 meters, is also a limestone.

4.1.3. LITHOLOGY

4.1.3.1. MACROSCOPIC CHARACTERISTICS

The lower part of the studied deposit is composed of light-grey, fine-grained, massive limestone with some intercalations of carbonaceous material towards the upper parts. Stylolitic structures which are a record of extensive intrastratal solution are abundant and occassional limonite stains are present. This is overlain by fossiliferous and oolitic limestones. The fossils are mainly bivalves. Rhynchonelids and Belemenites, which are characteristic of the Jurassic limestones of Ethiopia, have been identified. Some crinoids, gastropodes and honey-comb corals were also observed. As is seen on the stratigraphic section prepared from the study of the cores of the drill holes, (Fig. 6), the limestone gets interbedded with friable, clayey sandstones and grey to dark-grey shales towards the top. The interbedded sandstonesare occassionaly ferrugenous and thinly bedded.

4.1.3.2. MICROSCOPIC CHARACTERISTICS

Petrographic study was made on a total of 25 samples from a section measured in the area (Fig. 11) and from one of the bore holes (bore hole 1), totally representing a thickness of about 130 meters.

The study revealed that the deposit consists of:

52.15 per cent microcrystalline allochemical limestones

34.8 per cent sparry allochemical limestones

13.05 per cent microcrystalline limestones.

The allochems consist of intraclasts, fossils and oolites. The intraclasts are mainly composed of micrites. Some intraclasts have feldspar and quartz grains, oolite bearing intraclasts are also present. The fossils are dominantly fragements of moilluscs and brachiopodes and are mostly replaced by sparite. Identified fossils include Crinoid stem sections, gastropodes, ostracodes and foraminiferas like circularies and Kurnubia palastiniensis which are characteristic of Callovian-Kimmeridgain and Kimmeridgian respectively.

The oolites are both circular and oval shaped and their cores are made up of feldspar, quartz grains and fossils. Other constituents in the limestones are quartz and feldspar grains whose amount reach as high as 25 per cent (sample no. 15, table 1.)

The petrographic study results for bore hole 1 and section 1 are given on tables 1 and 2 respectively.

PETROGRAPHIC STUDY RESULTS OF BORE HOLE 1

Table 1

(Data shown are in volume per cent)

Sample No	depth in metres	Allochems: Fossils * 1	2	3	4	Allochems: Intraclasts	Allochems: Oolites & pellets	Other constituents: Quartz	Other constituents: Feldspar	Orthochemical Constituents: Sparite	Orthochemical Constituents: Micrite	Rock Clan.
1	3.70	7		1	2		40			10	40	Fossiliferous Oomicrite
2	10.40	2	8	2	3			2	1	7	75	Biomicrite
3	15.40	1	1						1	5	93	Fossil bearing micrite
4	23.50	2		1	2	10	35		1	6	44	Intraclast bearing oomicrite
5	29.75	35			5				2	50	8	Biosparite
6	32.80	26			4		35			30	5	Fossiliferous oosparite
7	39.50	1			2			7	10	15	65	Fossil bearing sandy micrite
8	43.80	22			3	5				15	55	Intraclast bearing biomicrite
9	49.25	15		2	8	10	5			60		Intraclast bearing biosparite
10	65.00	5			40			7	10	8	30	Sandy biomicrudite
11	72.00		10					1			90	Fossil bearing micrite
12	80.00				1				1		99	Micrite
13	91.50				1				1	5	95	Micrite
14	92.60									2	98	Micrite
15	98.00	2		1	2			10	15	3	67	Fossil bearing sandy micrite

* 1 Molluscs and Brachiopod fragments
2 Foraminifera
3 Crinoids
4 Others

Table 2

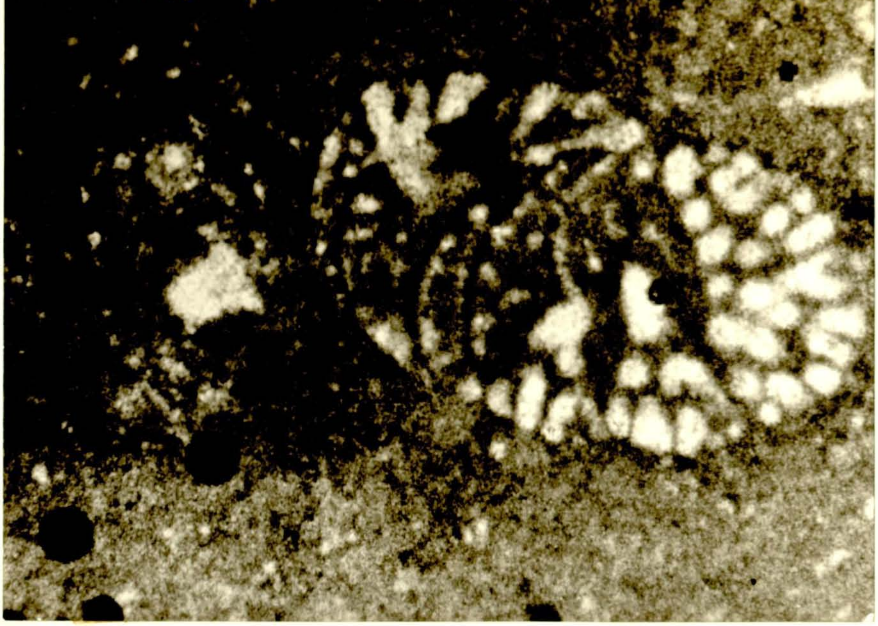
PETROGRAPHIC STUDY RESULTS OF MEASURED SECTION 1

(Date shown are in volume per cent)

Sample	Allochems						Other constituents		Orthochemical constituents		Rock Clan.
	FOSSILS *				Intraclasts	Oolites & pellets	Quartz	Feldspars	Sparite	Micrite	
No.	1	2	3	4							
53	2			3	20		8	12	5	50	Sandy Intramicrite
54		2		3		20	10	5	5	55	Sandy oomicrite
55	9	10	1	15	10	8		2	35	10	Intraclast bearing biosparite
56	4		1	10	35			5	45		Fossiliferous intrasparite
57				2		50		3	35	10	Fossil bearing oosparite
59	5			35	5	5		1	50		Intraclast bearing biosparudite
60	2			2	15	40		1	40		Intraclast bearing oosparite
62	20			10	5			1	4	60	Intraclast bearing biomicrudite
68				1			7	3		90	Slightly sandy micrite
76		1					2	5		92	Slightly sandy micrite

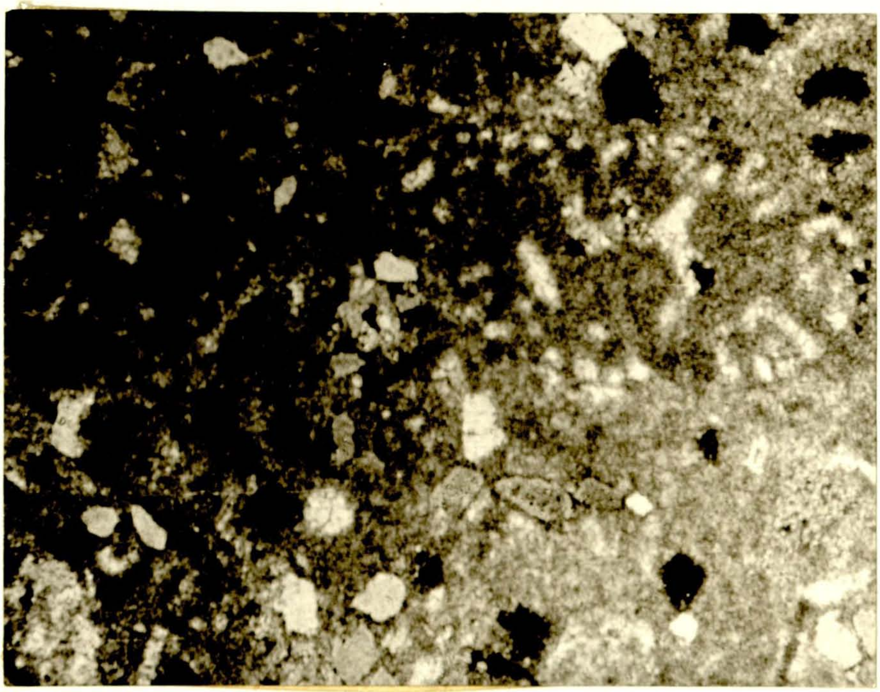
* 1 Molluscs and brachiopod fragments
2 Foraminifera
3 Crinoids
4 Others

Sample positions are shown on Fig. 11



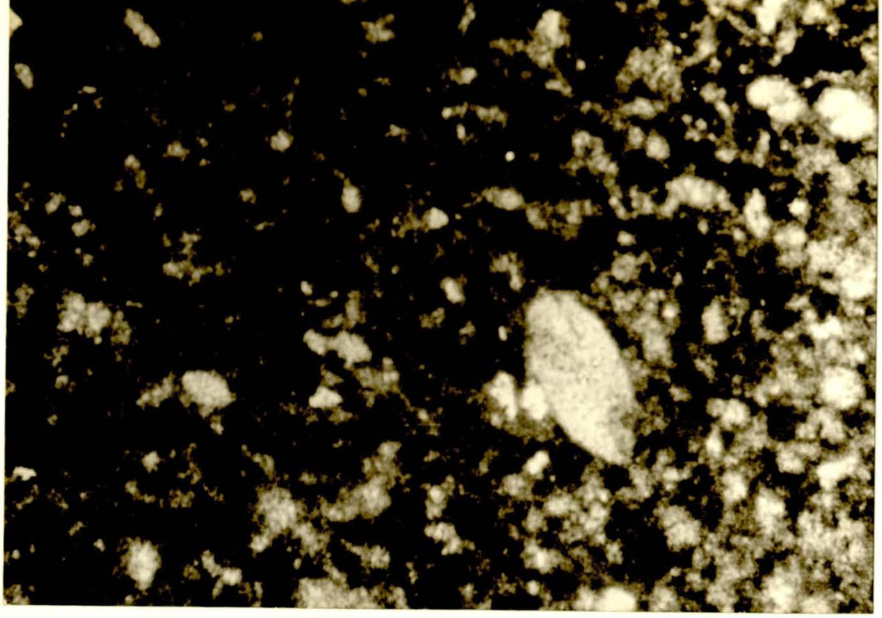
Plate

1. Fossil bearing micrite with Kurnubia palastinesis.
   X 64



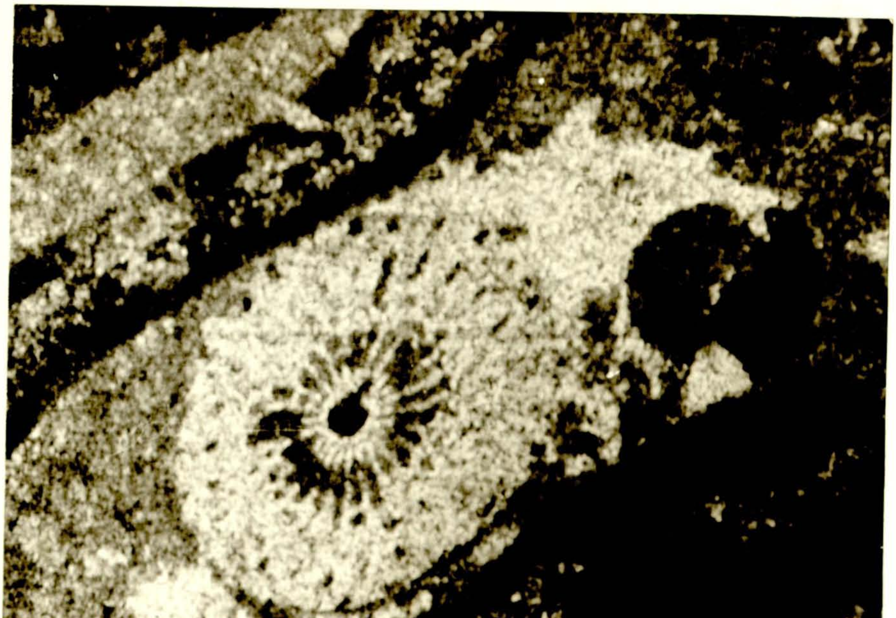
PLATE

2. Fossil bearing sandy micrite with Kurnubia palastinesis .
   X 64



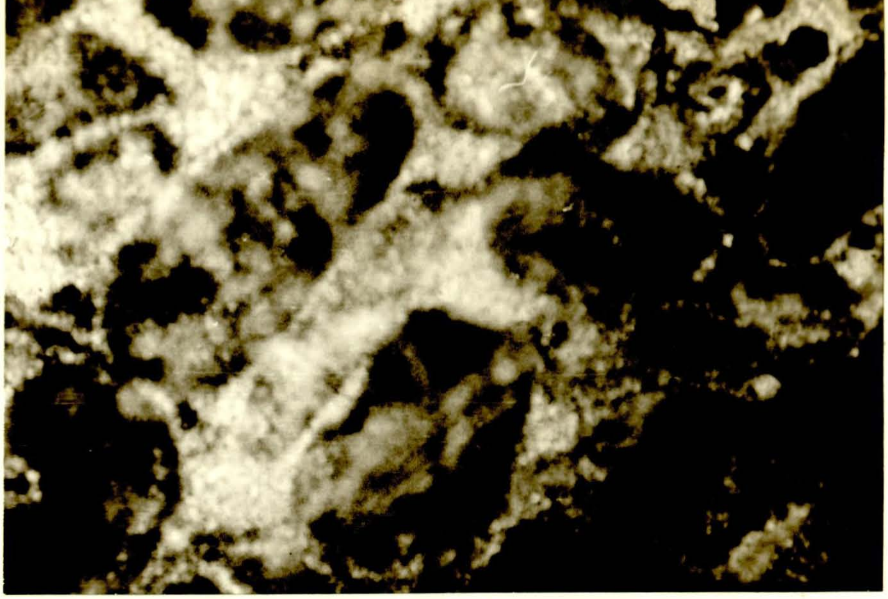
Plate

3. Fossil bearing sandy micrite with ostracoda.
X 64



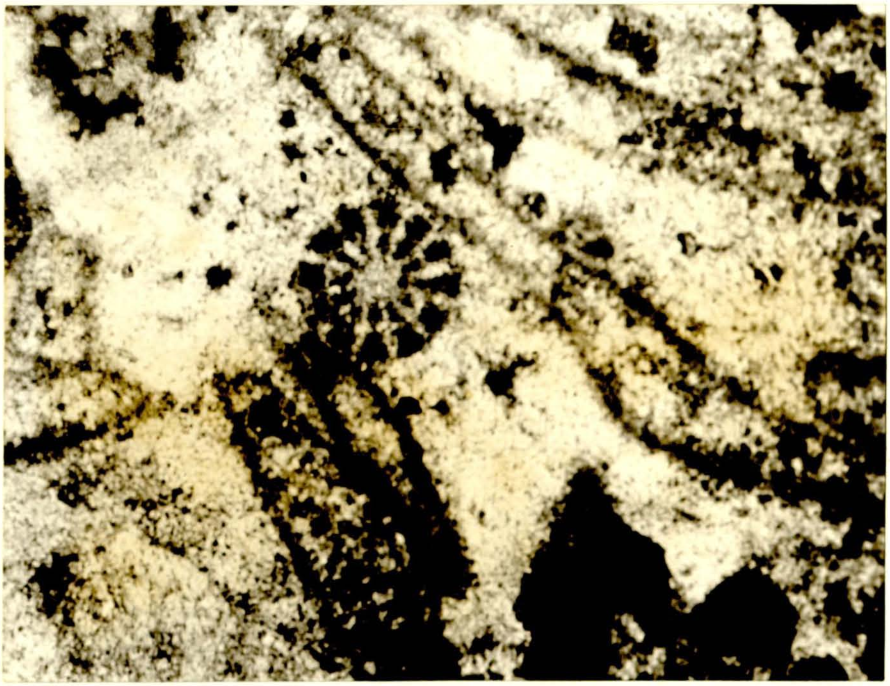
PLATE

4. Intraclast bearing biosparudite with recrystallized solitary
corals. X 64



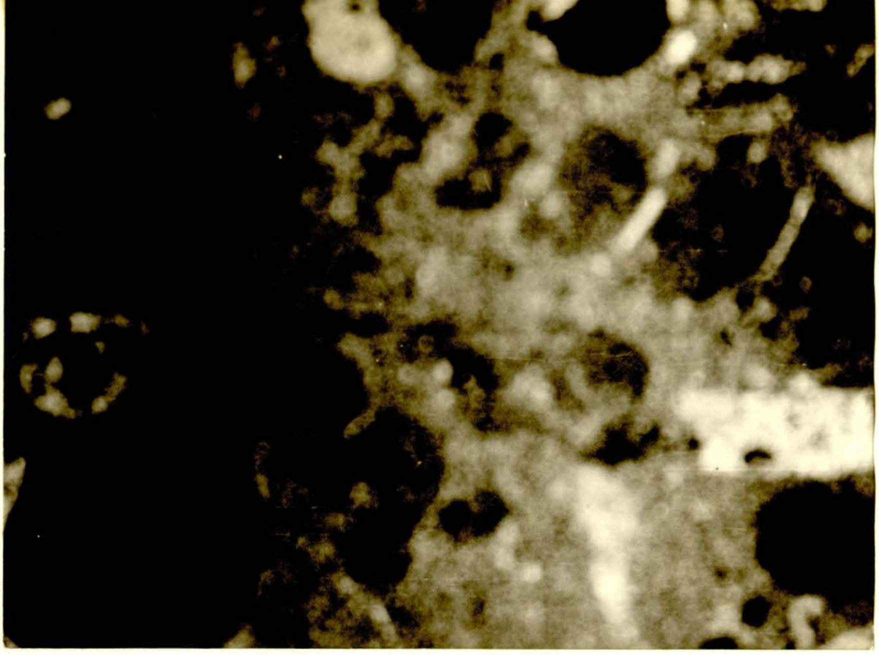
Plate

5. Intraclast bearing biosparite. X 64



PLATE

6. Fossiliferous intrasparite with a section of crinoid stem. X 64



Plate

7. Intraclast bearing biomicrite with sections of gastropodes.
X 25

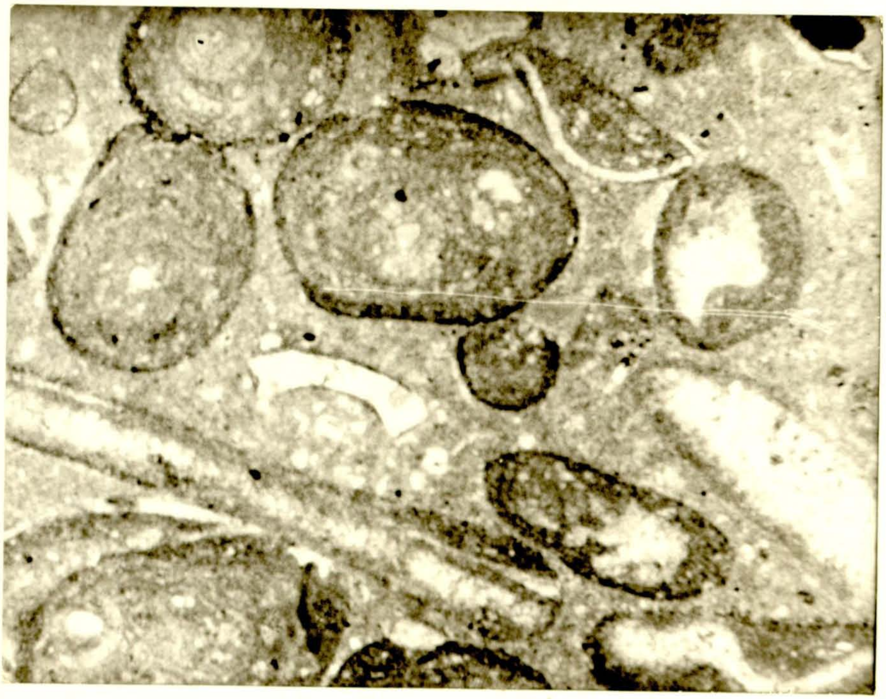
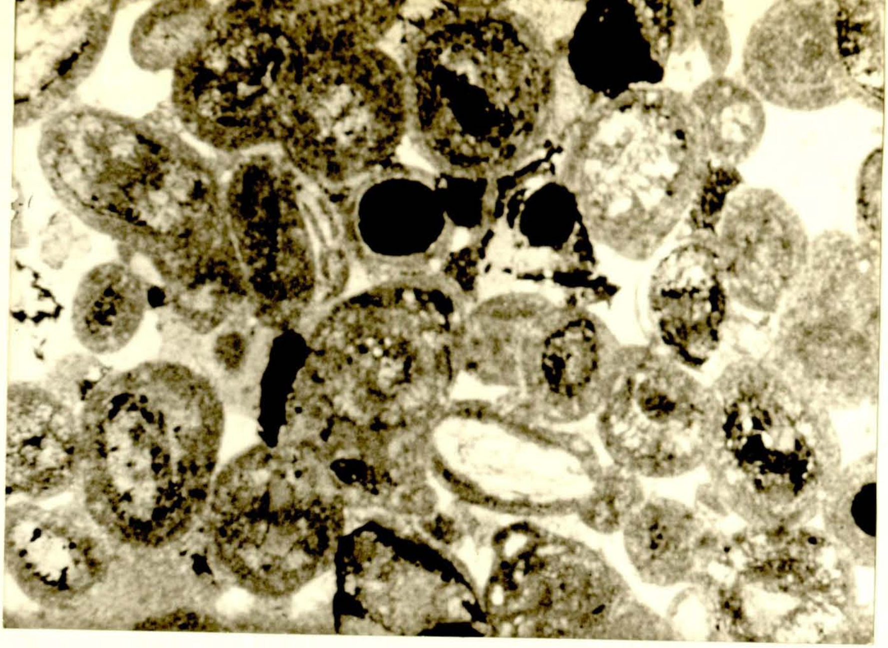
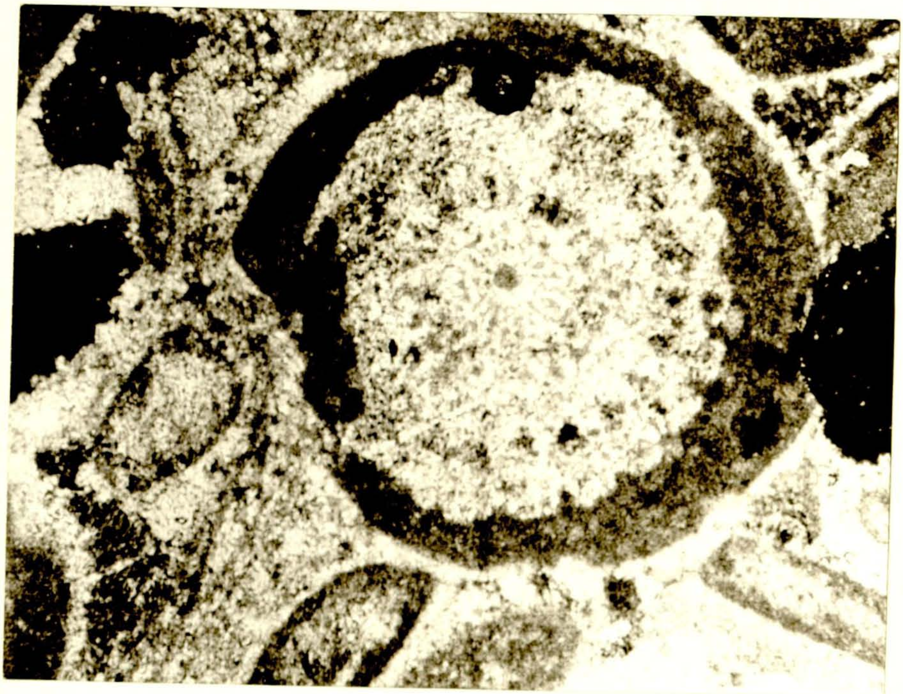


PLATE
8. Intraclast bearing oomicrite with fossil fragments. X 64



Plate

9. Fossil bearing oosparite. X 25



PLATE

10. Fossil bearing oosparite with solenpora sp. X 64

4.1.4 CHEMICAL PROPERTIES

Samples from four of the drill holes were chemically analysed for SiO_2, Al_2O_3, Fe_2O_3, CaO, MgO, Na_2O, K_2O, and for loss on ignition. Sample intervals were not uniform throughout but, for most parts it was approximately five meters. Core samples from bore holes 1, 2 and 3 were analysed from top to bottom and bore hole 4 core samples were chemically analysed from about 70 meters depth downwards only.

Average values of contituent elements in their oxide forms for the whole depth are given on table 4a and average values for samples below 70 meters depth are given on table 4b. This way it was possible to see to what extent the average values of the constituents were affected by the presence of the clastic interbeds in the upper parts of the deposit. The average chemical composition of the limestone according to De Leuw Cather International (1967), is given on table 3.

Table 3

Average chemical composition of the limestone according to De Leuw Cather International.

SiO_2	1.91 per cent
Al_2O_3	0.39 per cent
Fe_2O_3	0.80 per cent
CaO	54.04 per cent
Loss on ignition	42.7 per cent

Table 4a

Average values in per cent of weight in the dry samples at 110°C (for the whole depth)

	Bore hole 1	Bore hole 2	Bore hole 3	Average
SiO_2	15.85	15.06	13.14	14.68
Al_2O_3	2.46	3.20	2.03	2.56
Fe_2O_3	1.49	1.84	1.34	1.55
CaO	43.26	43.23	45.20	43.89
MgO	0.721	0.86	0.93	0.84
Na_2O	0.1	0.1	0.1	0.1
K_2O	0.63	0.60	0.43	0.55
L.o.I	34.98	34.60	36.48	35.33

Table 4b

Average values in per cent of weight in the dry samples at 110°C (for samples below 70 meters depth)

	Bore hole 1	Bore hole 2	Bore hole 3	Bore hole 4	Average
SiO_2	4.33	9.97	4.66	9.52	7.12
Al_2O_3	0.8	2.29	0.92	2.56	1.64
Fe_2O_3	0.54	1.33	0.67	1.01	0.89
CaO	51.97	48.52	51.65	47.06	49.8
MgO	0.61	0.79	0.65	0.76	0.7
Na_2O	0.1	0.1	0.1	0.1	0.1
K_2O	0.16	0.44	0.19	0.39	0.29
L.o.I.	41.1	37.49	40.8	37.77	39.29

From the chemical analysis data which is given on tables 6,7,8, and 9, it can be observed that these average values have been affected by certain high or low values from beds shallower than 70 meters depth.

To clarify this observation let us consider bore hole 1 as an example, SiO_2 content ranges from 1.3 to 67.4 per cent with an average value of 15.82 per cent. Values of Sio_2 which are rather high are from sample numbers 118476 (54.5 per cent), 118479 (23.5 per cent), 118480 (34.6 per cent), 118481 (67.4 per cent), and 118482 (30.2 per cent), These relatively high values that have raised the average values are seen to correspond to sandstone and shale in the magascopic description of the core samples (Fig.3). If these values which are due to the clastic interbeds are not taken into account, the average SiO_2 value would only be 5.23 per cent. Moreover, relatively higher amounts of quartz and feldspar grains in the limestone (25 per cent, Plate 2) have also raised the silica content.

Similarly, the values of CaO range from 1.5 to 54.5 per cent. The lowest values belong to samples 118476 and 118481 and are 14 per cent and 1.5 per cent respectively. These values are also seen to correspond to the clastic interbeds. Loss on ignition as low as 13.8 per cent, 26.2 per cent and 6.2 per cent which are from samples 118476, 118480 and 118481 respectively have also lowered the average value of loss on ignition.

The total alkali is usually calculated as the per cent age of Na_2O plus 0.658 times the percentage content of K_2O and cements with total alkali content below 0.6 per cent have been found as a rule to cause little expansion with reactive aggregates. (Lea and Desch, 1956). According to the American Society for Testing and Materials specification (A.S.T.M., C-150-70, as referred in Ames, 1975), the maximum accepted percentage of the alkalies is also 0.6. The total alkali content calculated from the average values was found out to be only 0.46 per cent, and thus satifies the requirement.

Moreover, an excess proportion of magnesia also gives rise to unsoundness in cements by crystallizing in the form of periclase (Mgo), which causes expansion cracking in concretes. In the A.S.T.M. specification (C-150-70), the maximum accepted amount of magnesium oxide is 5 per cent. The average content of magnesia in the studied limestone is only 0.84 per cent and thus, the limestone satisfies this requirement also. Small amounts of P_2O_5 in the raw materials can lead to unsoundness in the manufactured cement. If present in quantities up to 2.5 per cent in Portland cement clinker, sound cement can be obtained by correct burning and proportioning but, such cements will be slow hardening. This is because the P_2O_5 decomposes $3\ CaO \cdot SiO_2$ in favour of a $2\ CaO \cdot SiO_2$ solid solution containing the P_2O_5 and excess CaO. The limiting value of P_2O_5 in Portland cement clinker is thus fixed at about 2.5 - 2.75 per cent (Lea and Desch, 1956). The amount of P_2O_5 was not determined in the studied raw materials and the suitability of the raw materials in this respect could not be evaluated.

4.1.5. LATERAL AND VERTICAL VARIATIONS IN THE CHEMICAL AND PETROGRAPHIC CHARACTERISTICS.

The deposit showed significant vertical variations in chemical compositions (Fig. 3,4 and 5). An increase in the amounts of SiO_2, Al_2O_3 and Fe_2O_3 is accompanied by a decrease in the amounts of Cao and loss on ignition. Some rather high or low values of these constituent elements are due to the presence of the clastic interbeds.

The upper parts of the deposit up to an average depth of 70 meters showed relatively higher values in SiO_2 (14.68 per cent), and lower values in CaO (43.89 per cent), and loss on ignition (35.29 per cent).

The limestone below 70 meters depth whose chemical analysis was not affected by the clastic interbeds, showed lateral variations in chemical properties (Tabel 4b). The SiO_2 content increases from bore hole 1 to bore hole 2, decreases towards bore hole 3 and again increases in bore hole 4. This pattern applies also for Al_2O_3 and K_2O and to a lesser extent to Mgo. CaO behaves in the reverse manner.

Petrographic studies have also revealed that there is a significant vertical variation in the petrographic characteristics of the limestone (Tabel 1). The deposit is composed of mainly crites which are interbedded with bisoparites, oosparites, fossil aring intrasparites and intraclast bearing biosparudites. The ount of allochems in the micrites also shows significant variation. crocrystalline allochemical limestones as well as microcrystalline mestones are present. Some micrites have as high as 25 per cent ldspar and quartz grains.(Plate 2).

No lateral variation in the petrographic characteristics could realised from the studied two sections.

4.1.6. DEPOSITIONAL ENVIRONMENT

In the upper parts of the deposit carbonate and clastic sediments are found interbedded. The interbedding implies shallow-sea environment and could be explained using the interpretation of Talbot (1973) as a model. When sea level remained constant for a period, the accumulation of sediments would outstrip subsidence and would lead to lateral seaward migration of the clastic material. A sharp rise of sea level would cause a strong reduction in terrigenous sedimentation at the same site and carbonate sediments would be deposited instead. A fall in the sea level would again cause the deposition of the clastic material on the top of the carbonates.

The fossils identified are typical of shallow marine environment. Moreover, the presence of oolitic limestones is an indication of very shallow, high-energy shelf environment where effective wave base reaches the sea bed. On the otherhand , micrites are deposited in low-energy environments either in the deepest part of the shelf below effective wave base or in sheltered zones such as lagoons and tidal flats, which are found to the lee of the high energy zone. Thus, the varied facies in the studied limestone testify to different shallow water environments. Fluctuations in sea level gave rise to significant variations in depositional conditions which resulted in the interbedding of the various facies.

4.1.7 RESERVES

De Leuw Cather International (1967) calculated the reserves of the cliff forming limestone to be 24 million metric tons. In calculating the reserves they used an average thickness of 30 meters which they got from the drillings which were all situated at the edge of the cliff along a length of 3000 meters. They also used a width of 150 meters which was not proved by any drilling and the specific gravity of the limestone was taken to be only 1.8.

In this study attempt was made to calculate the limestone reserves both in the cliff forming Limestone Unit and Shaly Sandstone Unit using information from the additional eight bore holes. Reserves in the cliff forming limestone calculated by De Leuw Cather were re-evaluated and additional limestone reserves in the Shaly Sandstone Unit were proved.

The average core recovery was 87.25 per cent. It was observed while logging that the unrecovered portion mostly belonged to the clastic interbeds, particularly to the shale interbeds. The average thickness of limestone excluding the clastic interbeds and after the core recovery percentage was taken into consideration, was calculated to be 77.47 meters.

Average thickness of the deposit =110 meters

" " " " clastic interbeds = 18.53 meters

" " " " unrecovered portion= 14.00 meters

Average thickness of the limestone would then be

$$110 - (18.53 + 14) = 77.47 \text{ meters.}$$

The average elevation of the upper four bore holes (Fig. 28) is 2127.63 meters and that of the edge of the cliff is 2050 meters. The average slope distance is 300 meters and therefore, the horizontal distance or the width of the limestone ascertained by the bore holes was calculated to be 289.78 meters.

The distribution of the bore holes along a length of 3000 meters, was not uniform and consequently the reserves were classified into Catagory A (proved reserves), Catagory B (probable reserves) and Catagory C_1 (possible reserves) (Fig.28).

Table 5

CLASSIFICATION OF THE LIMESTONE RESERVE

Catagory	Thickness in meters	Surface area in sq. meters	Volume	Specific G.	Tonnage
A	75	140000	10500000	2.6	27300000
B	75	280000	21000000	2.6	54600000
C_1	75	420000	31500000	2.6	81900000

If the annual production of the cement plant is 500,000 tons, which is the common production capacity of a cement plant in a developing country, the raw materials required annualy will be 800,000 tons. The reserves calculated under catagories A and B (81.9 metric tons) would then be sufficient for 102 years.

CHEMICAL ANALYSIS OF LIMESTONE, EXPRESSED AS PER CENT BY WEIGHT - (BORE HOLE -1)

Sample No.	Depth interv in meters	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	H_2O -110^oC	L.O.I $>110^oC$	TiO_2
118472	0.50 - 10.40	7.8	1.5	1.4	48.9	0.6	<0.1	0.3	0.7	39.0	
118473	10.40-15.25	4.0	0.9	0.9	51.6	0.6	"	0.1	0.3	41.7	
118474	15.25-20 .00	7.7	2.0	1.1	49.0	0.7	"	0.3	0.9	39.0	
118475	20.00-28.00	14.7	1.4	0.9	45.5	0.6	"	0.4	0.5	35.8	
118476	28.00-29.75	54.5	7.5	3.7	14.5	1.3	"	1.7	3.3	13.8	0.6
118477	29.75-34.45	8.6	0.8	1.5	49.6	0.5	"	0.2	0.2	39.6	
118478	34.45-40.00	12.8	1.9	1.4	45.0	0.7	"	0.5	0.6	36.4	
118479	40.00-46.05	23.5	2.9	1.9	38.4	0.7	"	0.7	1.0	31.4	0.3
118480	46.05-56.20	34.6	3.5	2.1.	31.8	0.7	"	0.9	0.9	26.2	0.4
118481	56.20-61.85	67.4	12.0	6.0	1.5	1.2	"	2.4	2.7	6.2	1.0
118482	61.85-67.00	30.3	6.0	3.1	30.3	1.2	"	1.1	1.1	26.7	0.5
118058	67.00-72.00	3.0	0.4	0.5	53.1	0.6	<0.1	0.1	0.1	42.0	
118059	72.00-77.00	3.1	0.7	0.4	52.6	0.6	"	0.1	0.1	41.8	
118060	77.00-82.00	1.7	0.6	0.3	53.8	0.6	"	<0.1	0.1	42.4	
118061	82.00-87.00	1.7	0.6	0.4	53.2	0.6	"	"	0.1	42.3	
118062	87.00-92.00	2.1	0.9	0.5	53.5	0.6	"	"	0.2	41.9	
118063	92.00-95.60	1.3	0.5	0.5	54.5	0.6	"	"	0.2	42.8	
118064	95.60-99.00	10.4	1.1	0.8	48.3	0.6	"	0.3	0.2	38.2	
118065	99.00-105.00	11.4	1.6	0.9	46.8	0.7	"	0.4	0.1	37.4	

TABLE 7

CHEMICAL ANALYSIS OF LIMESTONE, EXPRESSED AS PER CENT BY WEIGHT
(BORE HOLE L-2)

Sample No.	Depth interval in meters	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	H_2O -110°C	L.O.I. > 110°C	TiO_2	MnO_2
118483	0.00-6.00	35.6	11.7	6.8	17.7	1.7	0.1	1.7	5.0	18.5	1.0	0.1
118484	6.00-10.65	15.3	5.2	2.3	40.7	0.8	<0.1	0.9	1.5	33.5		<0.1
118236	10.66-18.00	9.4	2.1	1.4	46.6	0.8	"	0.4	0.8	37.8	"	"
118237	18.00-25.85	2.8	0.7	0.7	53.1	0.6	"	0.1	0.3	42.1	"	"
118238	25.85-30.55	11.2	3.0	2.1	43.9	0.9	"	0.4	1.4	36.2	"	"
118239	30.55-36.00	17.1	2.2	1.4	41.1	1.4	"	0.5	0.8	34.7	"	"
118240	38.25-44.7	6.7	1.0	1.1	48.9	0.6	"	0.2	0.4	39.8	"	"
118241	44.7-55.60	22.6	3.3	2.4	38.0	0.9	"	0.8	1.2	31.2	"	"
118242	55.6-70.70	65.8	8.8	3.6	6.9	0.8	"	2.1	1.6	8.8	0.7	"
118066	71.00-72.00	37.6	13.0	6.3	16.9	1.6	<0.1	2.3	3.3	18.0		
118067	73.47-74.30	18.3	2.3	2.1	40.9	1.0	"	0.5	0.3	33.6		
118068	75.70-80.00	4.0	0.5	0.5	52.7	0.6	"	0.1	0.2	41.5		
118069	80.00-85.00	7.1	0.8	0.6	50.3	0.6	"	0.2	0.1	39.6		
118070	85.00-90.00	3.5	1.0	0.6	52.4	0.7	"	0.2	0.2	41.3		
118071	90.00-95.00	1.9	0.6	0.4	53.5	0.7	"	0.1	0.2	42.3		
118072	95.00-99.50	2.7	0.8	0.5	53.6	0.7	"	0.1	0.1	42.0		
118073	101.67-106.0	1.6	0.4	0.4	54.2	0.5	"	0.1	0.1	42.8		
118074	106.00-111.00	10.4	1.5	0.7	48.2	0.7	0.1	0.4	0.3	37.8		
118075	111.00-115.00	12.6	2.0	1.2	45.6	0.8	<0.1	0.4	0.2	36.0		

Table 8

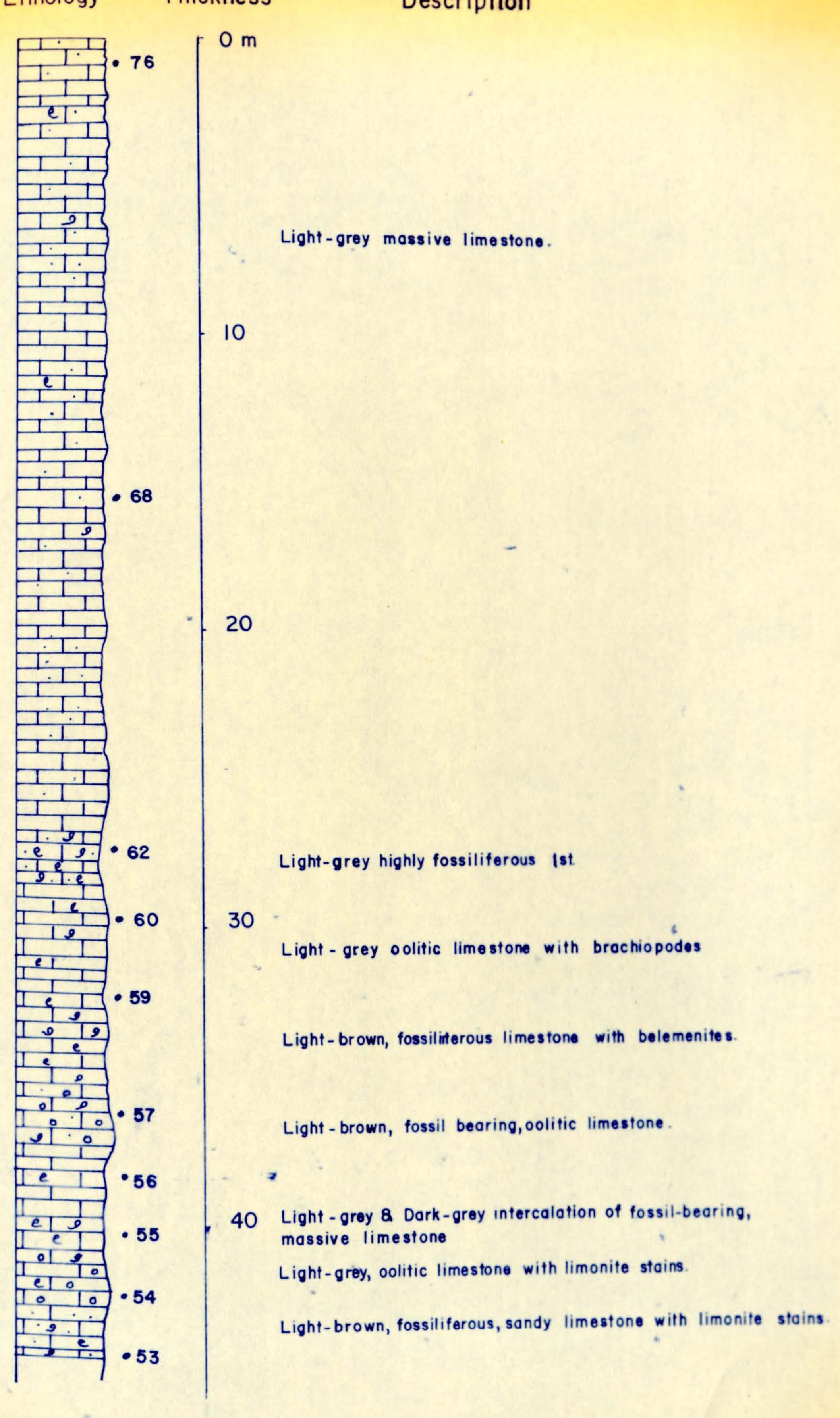
CHEMICAL ANALYSIS OF LIMESTONE, EXPRESSED AS PER CENT BY WEIGHT (BORE HOLE L-3)

Sample No.	Depth intervals in meter	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	H_2O -110°C	L.O.I. > 110°C	TiO	MnO
118243	0.00-4.00	20.1	5.1	2.4	37.6	1.1	<0.1	0.8	2.5	31.4	N.D	<0.1
118244	4.00-14.65	5.7	1.3	1.1	51.3	0.6	"	0.2	0.3	40.7	"	"
118245	14.65-27.00	5.1	1.4	0.9	51.2	0.9	"	0.2	0.5	40.7	"	"
118246	27.00-44.00	18.2	1.8	1.4	43.0	1.0	"	0.5	0.6	34.5	"	"
118247	44.00-50.25	18.4	2.7	2.4	.4	1.2	"	0.6	1.0	33.1	"	"
118248	50.25-67.00	50.2	8.7	3.9	16.3	1.2	"	1.9	1.5	16.6	0.7	"
118470	67.27-69.00	59.1	4.4	4.0	12.3	3.3	"	1.3	0.4	15.2	0.4	
118461	69.75-75.15	6.7	0.8	0.7	50.6	0.6	"	0.2	0.3	39.7		
118462	75.15-79.00	1.6	0.4	0.4	53.7	0.6	"	0.1	0.1			
118463	79.00-85.00	2.5	0.7	0.5	52.8	0.6	"	0.1	0.1	41.8		
118464	85.79-89.28	1.2	0.4	0.4	53.9	0.6	"	0.1	0.1	42.8		
118465	90.00-94.33	1.7	0.6	0.5	54.0	0.6	"	0.1	0.1	42.3		
118466	95.00-99.00	2.1	0.8	0.5	53.9	0.6	"	0.1	0.2	42.1		
118467	100.00-104.25	2.1	0.5	0.5	54.1	0.6	"	0.1	0.2	42.4		
118468	104.25-110.00	8.8	1.6	0.9	48.4	0.7	"	0.4	0.3	38.4		
118469	110.00-113.50	5.2	1.1	1.1	50.7	0.8	"	0.2	0.2	40.5		
118471	113.50-119.00	14.7	2.3	1.2	44.4	0.8	"	0.5	0.4	35.5		

Table 9

CHEMICAL ANALYSIS OF LIMESTONE, EXPRESSED AS PER CENT BY WEIGHT (BORE HOLEL-4)

Sample No	Depth interval in meters	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	H_2O -110°C	L.O.I. > 110°C	TiO_2
118451	70.00-71.10	57.0	17.9	5.4	2.4	1.5	0.1	2.6	4.8	8.4	
118452	71.10-76.00	7.8	0.9	0.7	49.8	0.6	<0.1	0.2	0.4	39.3	
118453	76.00-81.00	2.5	0.6	0.4	53.2	0.6	<0.1	0.1	0.2	42.2	
118454	81.00-86.00	2.4	0.9	0.6	53.1	0.7	"	0.1	0.1	41.5	
118455	86.00-91.00	1.6	0.6	0.4	53.7	0.7	"	0.1	0.1	42.4	
118456	91.00-96.00	2.4	0.6	0.4	53.3	0.7	"	0.1	0.1	42.0	
118457	96.00-101.70	2.9	0.9	0.6	53.3	0.7	"	0.1	0.2	41.6	
118458	102.70-108.00	2.5	0.9	0.5	52.8	0.7	"	0.1	0.1	41.9	
118459	108.00-113.00	3.1	0.6	0.4	52.9	0.7	""	0.1	0.1	41.8	
118460	113.00-115.50	13.0	1.7	0.7	46.1	0.7	"	0.4	0.1	36.6	


Description
0 m
10
20
30
40
76
68
62
60
59
57
56
55
54
53
Light-grey massive limestone.
Light-grey highly fossiliferous lst.
Light-grey oolitic limestone with brachiopodes
Light-brown, fossiliferous limestone with belemenites.
Light-brown, fossil bearing, oolitic limestone.
Light-grey & Dark-grey intercalation of fossil-bearing, massive limestone
Light-grey, oolitic limestone with limonite stains.
Light-brown, fossiliferous, sandy limestone with limonite stains.
• Sample positions.

4.2 CLAY MATERIAL

4.2.1. GENERAL NATURE OF THE DEPOSIT

The deposit is a residual soil which is a product of weathering of the Trap basalts. It occurs on either side of the Kotcha creek where the basalt bedrock is exposed. The deposit is widely distributed over the area. The investigated area which comprises about 0.4 sq.km. represents only a minor portion of the deposit. It was chosen because the material has to be close enough to the proposed plant site. The average thickness of the deposit is about 4.14 meters below which weathered rock fragments are encountered.

4.2.2. MEGASCOPIC CHARACTERISTICS

The colour of the soil varies from redish-brown to darkgrey which is characteristics of imperfectly drained soils. Managanese mottles and concretions are abundant and the soil shows well developed, angular-blocky structure.

4.2.3. TEXTURAL STUDIES

Samples from seven test pits were mechanically analysed by sieving and pippette analysis to determine size fractions of the constituents. The result obtained is given in table 10.

Table 10

Size Analysis Data in Per Cent by Weight (Pit Locations Fig. 30)

	SAND	SILT	CLAY
Pit 1	3.67	23.66	72.67
Pit 2	3.54	16.48	79.98
Pit 3	3.43	19.28	77.29
Pit 4	3.80	22.47	73.73
Pit 5	4.23	20.73	75.04
Pit 6	4.12	29.40	66.47
Pit 7	5.05	25.92	69.03
Average	3.98	22.56	73.46

According to Folk (1968) classification, the above result showed that in terms of grain size, the soil studied is silty clay.

4.2.4. CHEMICAL PROPERTIES

Samples from seventeen pits were chemically analysed for SiO_2, Al_2O_3, Cao, MgO, Na_2O, K_2O, $H_2O_{-110^\circ C}$, loss on ignition and for minor elements such as TiO_2 and MnO. Results are given on tables 11, 12, 13 and 14. For every pit sample intervals depended on the physical characteristics of the soil such as variations in colour, texture or structure, and as a result were different.

The average values for the different elements expressed in their oxide form was found out to be as follows:

Table 11

Average Values of Chemical Analysis of the Clay Material

SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	L.O.I.	TiO_2	MnO
42.01	20.13	16.02	1.56	1.25	0.33	0.73	8.86	2.6	0.26

The relations between the silica, alumina, and ferric oxide contents of a cement are expressed in the form of the following moduli in which the percentage weight ratios are used.

Silica modulus $SiO_2/(Al_2O_3 + Fe_2O_3)$

Iron modulus Al_2O_3/Fe_2O_3

The silica modulus has an average value of 2.4 - 2.7, but drops to 1.7 in Portland cements with a high content of aluminum oxide and iron oxide. The iron modulus varies from about 1 to 4 in grey cements and may even exceed 10 in white cements but, must not fall below 0.66 (Lea and Desch, 1956).

Accordingly, it can be summarized that the studied samples have:

(a) Low values of the silica modulus with an average value of 1.2 per cent.

(b) Average iron modulus value of 1.18 per cent

(c) A loss on ignition of 4.1 to 11.3 per cent.

According to the A.S.T.M. specification (C-150-70), the maximum percentage of the alkalies in cements should be 0.6. The total alkali content in the clay material was found out to be 0.81 per cent. The alkalies tend to be volatilized in the high temperature portions of the klin and significant amount of alkalies from the raw mix are lost during burning. (Lea and Desch, 1956). Thus, the A.S.T.M. specification for the finished product could be met with raw materials having some what higher values of alkalies.

The deposit shows no significant lateral and vertical variations in chemical composition (Tables 11, 12, 13, and 14)

Hence, the material studied are chemically suitable for the manufacture of Portland cement, provided the silica modulus is raised using silica-rich materials.

4.2.5. RESERVES

Seventeen pits with 200 meters interval were dug along three profiles of 1000 meters length (fig. 30). From these pits it was found out that the average thickness of the soil is 4.14 meters. With a surface area of 400,000 sq. meters, this would give a proved reserve of 1,656,000 m^3 or the equivalent of 1656000 x 2 = 3,312,000 metric tons.

For one ton of cement 0.35 ton of clay is required. Considering an annual production of 500,000 tons of cement, the clay reserve would be enough only for about 9 years. This means that the proved reserve would not be sufficient. However, the deposit is laterally extensive and more reserves could be proved easily.

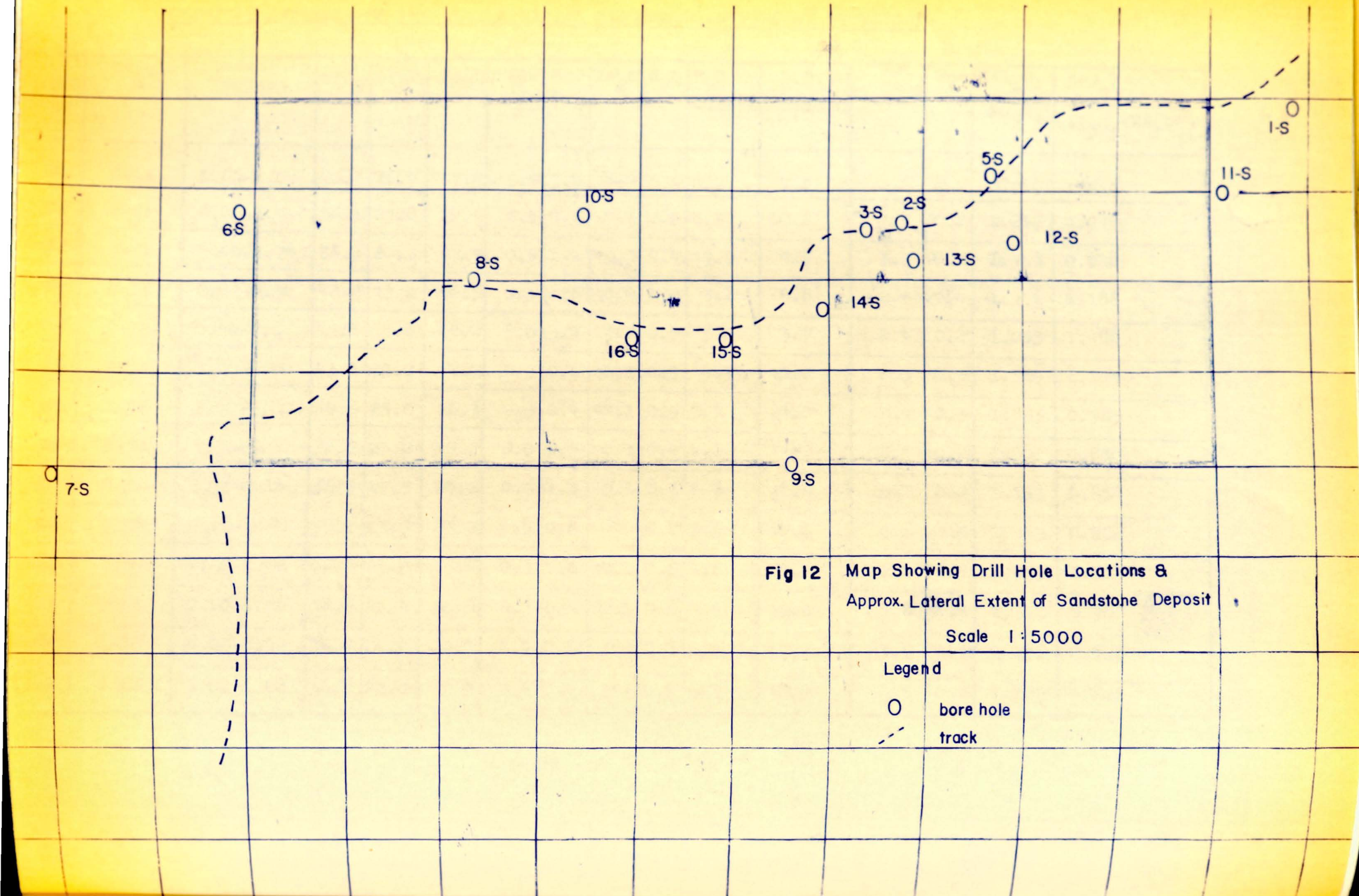


Fig 12 Map Showing Drill Hole Locations & Approx. Lateral Extent of Sandstone Deposit

Scale 1 : 5000

12 CHEMICAL ANALYSIS OF THE CLAY MATERIAL EXPRESSED IN PERCENT BY WEIGHT

S.No.	Sample No.	Interval in meters	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	H_2O -110° C	L.O.I. >110° C	TiO_2	MnO	$\frac{Al_2O_3}{Fe_2O_3}$	$\frac{SiO_2}{(Al_2O_3+Fe_2O_3)}$
[illegible]	C-1A	0.00-1.0	42.3	16.9	17.8	5.5	3.0	1.8	0.9	3.2	4.7	2.8	0.2	0.949	1.219
[illegible]	C-2A	0.00-3.0	36.4	21.8	17.4	0.5	0.6	<0.1	0.5	8.5	10.6	2.7	0.2	1.252	0.919
[illegible]	C-2B	3.00-6.70	36.3	20.5	17.7	0.9	1.1	0.3	0.4	10.9	9.4	3.7	0.2	1.158	0.950
[illegible]	C-3A	0.00-0.40	42.2	19.0	16.5	3.1	1.8	0.9	1.0	3.8	8.8	2.6	0.4	1.151	1.188
[illegible]	C-3B	0.40-2.6	45.6	15.8	15.0	8.0	3.7	2.3	0.9	3.0	3.7	2.4	0.2	1.053	1.480
[illegible]	C-5A	0.00-2.00	43.1	23.0	14.7	0.3	0.6	<0.1	0.9	4.5	10.0	2.3	0.3	1.564	1.143
[illegible]	C-5B	2.00-4.00	40.6	25.0	16.3	0.3	0.4	<0.1	0.5	3.7	11.0	2.4	0.3	1.533	0.983
[illegible]	C-5C	4.00-5.00	36.7	25.0	19.2	0.5	0.5	0.1	0.4	4.1	11.2	2.9	0.2	1.302	0.830
[illegible]	C-5D	5.00-7.00	36.5	22.5	20.2	0.6	1.3	<0.1	0.3	6.3	10.0	3.2	0.2	1.113	0.854
[illegible]	C-5E	7.00-7.80	35.1	23.3	20.2	0.5	0.8	"	0.2	5.6	10.6	3.6	0.3	1.153	0.806
[illegible]	C-6A	0.00-2.00	42.8	23.0	15.4	0.3	0.6	<0.1	0.8	4.6	9.9	2.4	0.3	1.493	1.114
[illegible]	C-6B	2.00-4.00	38.8	24.4	18.4	0.3	0.6	<0.1	0.5	4.4	10.6	2.8	0.3	1.326	0.906
[illegible]	C-6C	4.00-5.00	36.4	24.0	20.2	0.4	0.6	"	0.3	5.0	10.7	3.5	0.3	1.188	0.823
[illegible]	C-6D	5.00-6.60	36.2	22.0	19.9	0.6	0.9	"	0.1	6.2	10.5	3.5	0.3	1.105	0.826

Table 13 CHEMICAL ANALYSIS OF THE CLAY MATERIAL EXPRESSED IN PERCENT BY WEIGHT

Pit No.	Sample No	Interval in meters	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	H_2O -110°C	L.O.I. >110°C	TiO_2	MnO	$\frac{Al_2O_3}{Fe_2O_3}$	$\frac{SiO_2}{(Al_2O_3+Fe_2O_3)}$
C-7	C-7A	0.00-1.00	46.0	19.3	13.9	0.4	0.8	0.1	1.4	5.5	10.1	2.0	0.4	1.388	1.385
C-7	C-7B	1.00-2.70	44.9	20.5	14.9	0.5	0.8	<0.1	1.1	5.9	9.6	2.3	0.3	1.375	1.268
C-7	C-7C	2.70-5.15	39.6	19.5	16.7	0.9	1.6	"	0.4	9.1	9.3	2.9	0.2	1.167	1.093
C-7	C-7D	5.15-6.00	40.5	18.7	15.6	1.3	1.5	0.5	1.0	9.2	8.2	2.7	0.2	1.198	1.180
C-7	C-7E	6.00-6.50	42.8	16.3	14.7	1.7	2.9	0.5	0.8	10.3	8.1	2.8	<0.1	1.108	1.380
C-7	C-7F	6.50-7.20	44.5	15.6	12.4	1.6	3.1	0.2	0.5	13.2	8.0	2.0	0.1	1.258	1.589
C-8	C-8A	0.00-0.80	41.7	21.2	15.7	0.4	0.7	<0.1	0.9	5.5	10.6	2.5	0.3	1.350	1.130
C-8	C-8B	0.80-5.00	38.5	22.8	19.0	0.4	0.5	"	0.5	5.3	10.5	2.7	0.4	1.2	0.921
C-8	C-8C	5.00-5.15	42.0	21.3	15.0	0.7	0.7	"	0.4	6.9	9.9	3.0	0.2	1.42	1.157
C-8	C-8D	5.15-5.70	36.0	20.7	20.9	0.8	0.9	"	0.2	8.0	10.0	3.6	0.2	0.99	0.865
C-9	C-9A	0.00-1.00	38.3	20.4	17.5	1.0	1.2	0.4	0.6	8.6	9.1	3.1	0.2	1.165	1.010
C-9	C-9B	1.00-3.00	41.2	21.0	16.4	0.9	0.9	0.2	0.8	6.8	9.8	2.5	0.3	1.280	1.101
C-11	C-11A	0.00-2.00	42.8	22.8	15.2	0.3	0.6	0.1	0.9	4.7	9.8	2.3	0.3	1.5	1.126
C-11	C-11B	2.00-6.00	37.7	24.0	18.6	0.4	0.5	0.1	0.5	5.3	10.7	2.6	0.4	1.29	0.884

ble 14 CHEMICAL ANALYSIS OF THE CLAY MATERIAL EXPRESSED IN PERCENT BY WEIGHT

it No.	Sample No	Intervals in meters	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	H_2O -110° C	L.O.I. >110°C	TiO_2	Mno	$\frac{Al_2O_3}{Fe_2O_3}$	$\frac{SiO_2}{(Al_2O_3 + Fe_2O_3)}$
C-11	C-11C	6.00-7.00	34.2	22.3	20.7	0.7	0.7	<0.1	<0.1	8.0	9.8	3.7	0.2	1.077	0.795
C-12	C-12A	0.00-1.00	41.4	21.0	15.7	0.6	0.8	0.2	1.0	6.5	10.6	2.2	0.3	1.337	1.128
C-12	C-12B	1.00-2.00	37.4	22.3	17.3	0.6	0.6	<0.1	0.6	8.8	10.1	2.3	0.2	1.289	0.944
C-12	C-12C	2.00-2.80	37.4	20.5	18.3	0.8	1.0	<0.1	0.8	9.0	10.2	1.3	0.2	1.12	0.963
C-12	C-12D	2.80-3.50	37.2	22.0	18.3	0.7	0.8	<0.1	0.4	7.4	10.6	2.6	0.3	1.202	0.923
C-12	C-12E	3.50-4.50	41.5	18.7	16.5	3.3	1.7	1.1	0.9	5.3	7.3	3.0	0.2	1.133	1.178
C-13	C-13A	0.00-0.70	48.1	17.2	13.0	0.5	0.7	0.2	1.2	4.7	11.3	2.3	0.2	1.323	1.59
C-13	C-13B	0.70-1.80	53.3	17.0	11.4	0.7	0.8	0.3	1.3	4.8	8.8	2.3	0.1	1.491	1.876
C-13	C-13C	1.80-3.85	47.1	20.0	13.6	0.6	0.9	0.2	1.2	6.5	8.4	2.2	0.3	1.47	1.401
C-14	C-14A	0.00-1.00	48.7	16.6	11.6	1.2	1.1	0.3	1.1	7.6	9.3	1.9	0.3	1.431	1.726
C-14	C-14B	1.00-2.30	46.0	15.9	14.3	8.0	3.6	2.3	0.8	2.9	3.7	2.6	0.3	1.111	1.523
C-15	C-15A	0.00-1.10	50.6	15.4	10.9	2.7	1.6	0.6	0.9	7.3	8.0	1.6	0.3	1.412	1.93
C-15	C-15B	1.10-2.20	44.2	15.2	14.8	8.7	3.4	0.3	0.8	2.9	4.1	2.5	0.3	1.027	1.47
C-16	C-16A	0.00-1.00	48.5	18.4	12.2	0.8	1.1	0.2	1.3	6.5	8.9	2.1	0.3	1.508	1.584

ble 15

CHEMICAL ANALYSIS OF THE CLAY MATERIAL EXPRESSED IN PERCENT BY WEIGHT

Pit No.	Sample No.	Intervals in meters	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	H_2O -110°C	L.O.I. >110°C	TiO	MnO	Al_2O_3 / Fe_2O_3	SiO_2 / $(Al_2O_3 + Fe_2O_3)$
C-16	C-16B	1.00-2.00	46.2	20.2	13.4	0.7	1.1	0.1	1.2	5.9	9.0	2.1	0.3	1.507	1.375
C-16	C-16C	2.00-4.00	44.9	21.0	15.4	0.5	0.7	0.1	0.9	5.0	9.3	2.5	0.3	1.363	1.233
C-16	C-16D	4.00-6.40	41.5	20.1	16.8	0.6	0.8	0.1	0.7	6.5	9.4	2.8	0.4	1.196	1.124
C-17	C-17A	0.00-1.00	51.3	16.2	10.7	1.0	1.1	0.2	0.9	7.3	9.2	1.7	0.2	1.514	1.907
C-17	C-17B	1.00-4.00	44.9	20.5	14.9	0.7	0.9	0.1	0.9	6.1	9.0	2.3	0.5	1.375	1.268
C-17	C-17C	4.00-500	41.7	19.7	16.4	2.2	1.6	0.6	0.7	6.7	8.0	2.9	0.2	1.201	1.155
C-17	C-17D	5.00-6.00	47.1	15.8	13.6	8.1	2.5	2.6	1.1	2.4	2.9	2.7	0.2	1.161	1.602

4.3 SANDSTONE DEPOSIT

4.3.1. GENERAL NATURE OF THE DEPOSIT

The Sandstone deposit which comprises 38.7 per cent of the Shaly Sandstone Unit is underlain by interbeds of limestone, shale and sandstone which constitute the lower parts of the Shaly Sandstone Unit. It is overlain by soil cover and basalts and is located along the north-western edge of the studied limestone deposit. The sandstone outcrops are not mappable with a scale of 12500. There are very few outcrops and some more have been exposed by a road cut. So, drilling was necessary to determine lateral and vertical extent of the deposit. From the drilling results it was observed that there is a lateral as well as a vertical variation in the distribution of the sandstone. i.e., in thickness and in the depth at which the sandstone is found. In some places the sandstone outcrops on the surface while in others it is found underneath a considerable thickness of overburden. The thickness of the overburden varies from about 1 meter to 11 meters, with an average thickness of 5.60 meters. Clay and shale intercalations are rather common within the sandstone. The sandstone deposit is a left-over from differential erosion that has been buried by basalt flow. Some of the basalts have been removed during the formation of the valley and as a result some outcrops of sandstone are seen. The rest have been covered by soil and slope screes of different thicknesses.

4.3.2. THICKNESS

The thickness shows considerable variation. From the drilling information it was seen that the thinnestbed is 2.5 meters thick and the thickest reached 40 meters, including the clay intercalations (about 10 meters thick). However, the average thickness was calculated to be 18.4 meters.

4.3.3. LITHOLOGY

4.3.3.1. MACROSCOPIC CHARACTERISTICS

The sandstone is clayey, very fine-grained and poorly sorted. The grains are highly friable, except for some highly ferrugenous thinnly bedded and relatively compact sandstones. Clay intercalations are common and show gradation with the sandstone. The colour varies from light-grey to redish-yellow and some are variegated.

4.3.3.2. MICROSCOPIC CHARACTERISTICS

Petrographic study could only be made on three thinsections of sandstone from the core samples. Since the sandstones are clayey and very friable, it was very difficult to prepare thin sections and loose grains were mounted to make thinsections. Consequently, the relationship between matrix, grains and cements was not studied appropriately.

However, the study showed that the sandstone is immature, poorly sorted with subangular to subrounded grains. It is composed of about 20 per cent clay matrix and 80 per cent grains.

The petrographic study results are given below.

Sample no. 1

70 per cent quartz	show undulose and straight extinctions. Most of the grains are coated by limonite and some are fractured.
23 per cent feldspar	The types in descending order of abundance are, orthoclase, microcline and plagioclase.

5 per cent rock fragments and chert.

1 per cent biotite and hornblend.

1 per cent zircon, rutile and magnetite.

Sample no.2

74 per cent quartz	Similar with the above but with less limonite stains.
20 per cent feldspar	"

3 per cent rock fragments and chert

1 per cent biotite

2 per cent magnetite and zircon.

Sample no. 3

70 per cent quartz Similar with the above one

20 per cent feldspar

9 per cent rock fragments and chert

1 per cent magnetite and zircon.

According to the classification of PettiJohn (1975), the studied sandstones are arkosic wackes.

4.3.4. CHEMICAL PROPERTIES

Sandstone samples representing a thickness of five meters from one of the bore holes (bore hole 3-s) were chemically analysed to get some idea about the composition of the sandstone. The chemical analysis result is given in table 16.

Table 16. Chemical Analysis of the Sandstone Expressed in Per cent of Weight.

B.H.No.	Interval in meters	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	H_2O -110°C	L.O.I.	TiO_2	MnO
	21-24	72.7	10.8	5.4	0.4	1.0	<0.1	2.8	2.1	4.1	N.D.	0.1
	24-26	71.9	10.0	5.2	0.4	1.2	0.1	2.7	2.3	4.2	0.7	"

It was seen from the chemical analysis result that the percentage of SiO_2 is relatively low and that of Fe_2O_3 somewhat high. This may be because the sandstone is ferrugenous and contains significant amount of clay. The average sandstone has 75-80 per cent SiO_2 and less than 3 per cent Fe_2O_3 (Milner, 1962)

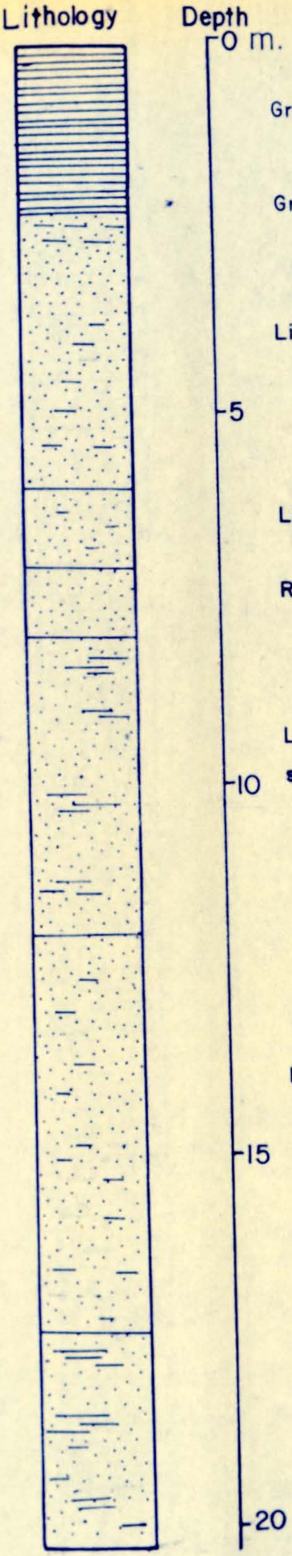
Since the samples were taken from what was considered to be with relatively less amount of clay, lower silica content should be expected from most of the rest of the sandstone.

4.3.5. DEPOSITIONAL ENVIRONMENT

The interbeds of limestone, shale and sandstone which overlie the Antalo limestone were taken to be the lower part of the Upper sandstone representing a gradational contact. (Mehadi, 1968 and Beauchamp, 1977). But, according to Jepsen (1961) and Getaneh (1975), the interbeds constitute a separate unit. The Upper sandstone, including the Shaly Sandstone Unit, was supposed to be a regressive facies by Blanford (1869) and Merla and Minucci (1938). Mehadi on the contrary believed that this unit was accumulated in a few separated basins which are shallow and therefore, doesn't indicate regression of the sea but, is more likely a result of gradual shallowing of the basin due to sedimentary infillings.

The clayey, very fine-grained sandstone within the Shaly Sandstone Unit coarsens upward giving way to the Upper Sandstone which is continental.

The Shaly Sandstone Unit also shows gradation from calcareous to arenaceous lithofacies. The upward coarsening and the gradation may be taken as an indication of transition from a marine to a continental environment. Based on the above observations and



Description

Grey soil

Grey soil with some weathered basalt pebbles.

Light-grey, friable, v. fine-grained clayey sst.

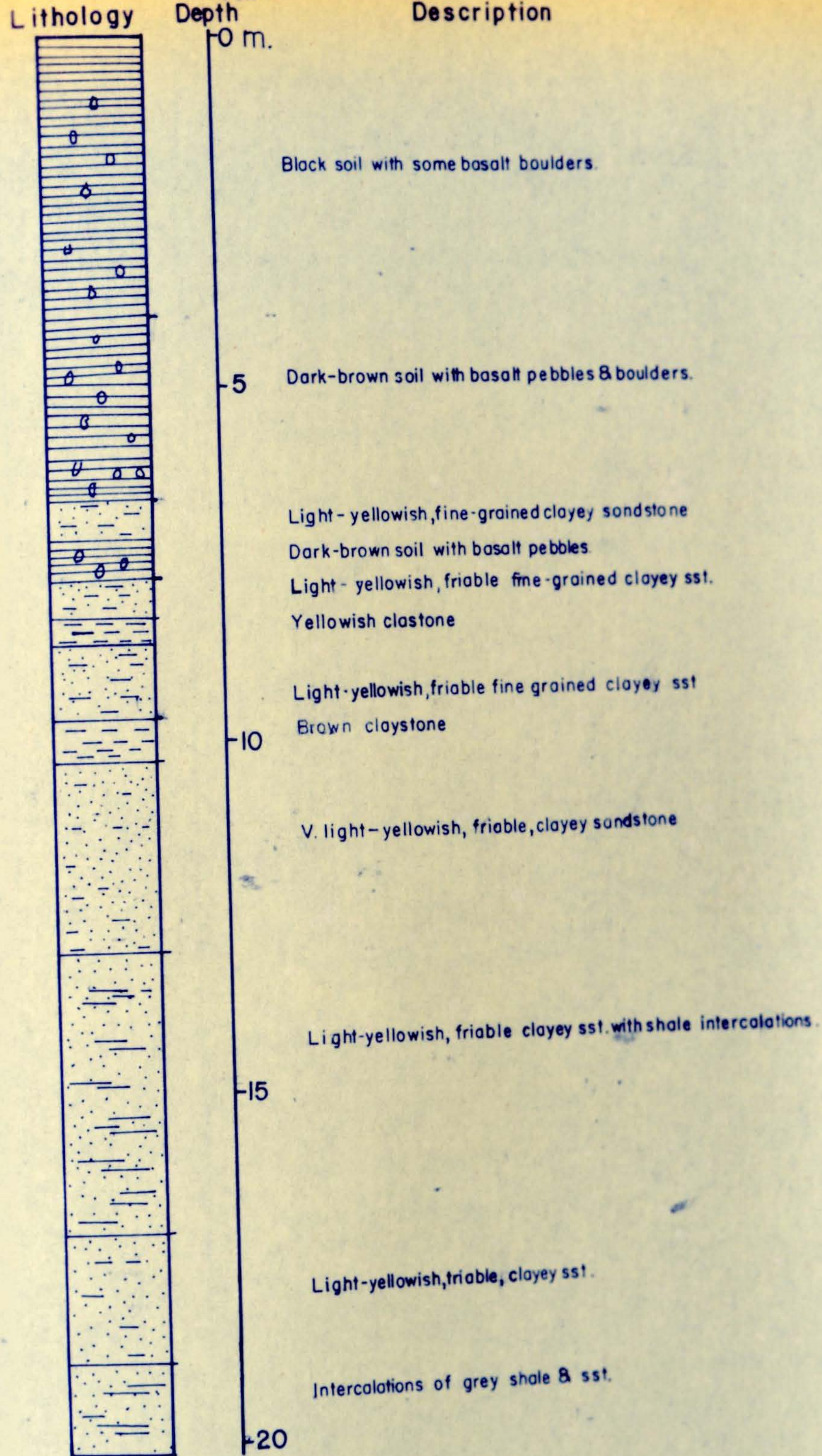
Light-yellowish, friable, v. fine-grained clayey sst.

Redish- brown, v. fine - grained clayey sst.

Light-yellowish, v. fine-grained, clayey sst. with grey shale intercalations.

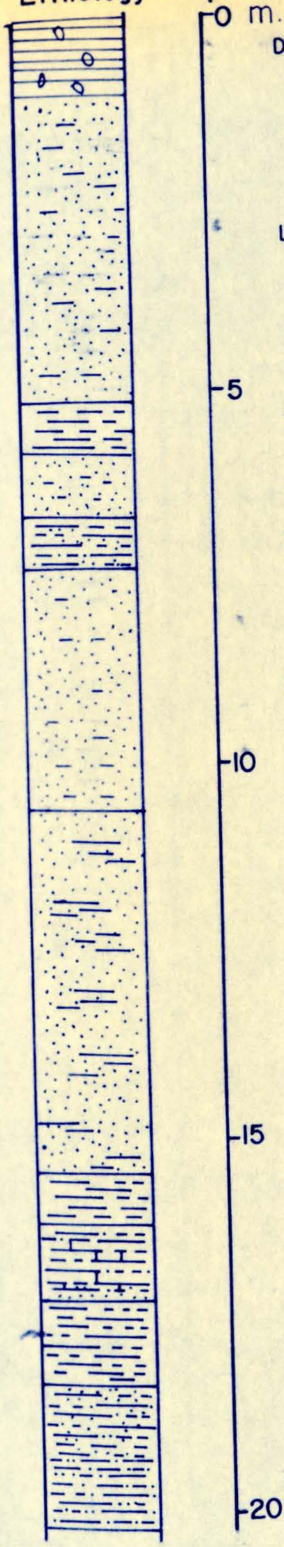
Light-yellowish, v. fine-grained, clayey sst.

Light-yellowish, clayey sst with shale intercalations.



Lithology
Depth
Description
0 m.
5
10
15
20
Black soil with some basalt boulders.
Dark-brown soil with basalt pebbles & boulders.
Light-yellowish, fine-grained clayey sondstone
Dark-brown soil with basalt pebbles
Light-yellowish, friable fine-grained clayey sst.
Yellowish clastone
Light-yellowish, friable fine grained clayey sst
Brown claystone
V. light-yellowish, friable, clayey sandstone
Light-yellowish, friable clayey sst. with shale intercalations.
Light-yellowish, triable, clayey sst.
Intercalations of grey shale & sst.

Lithology Depth Description



Dark-brown soil with weathered basalt fragments

Light yellowish, friable, fine-grained, clayey sst

Yellowish-green shale

Yellowish, friable, v.fine-grained, clayey sst.

Varigated shale with sand intercalations.

Light-grey, fine-grained, friable, clayey sst.

Light-grey, fine-grained, clayey sst. & shale intercalations.

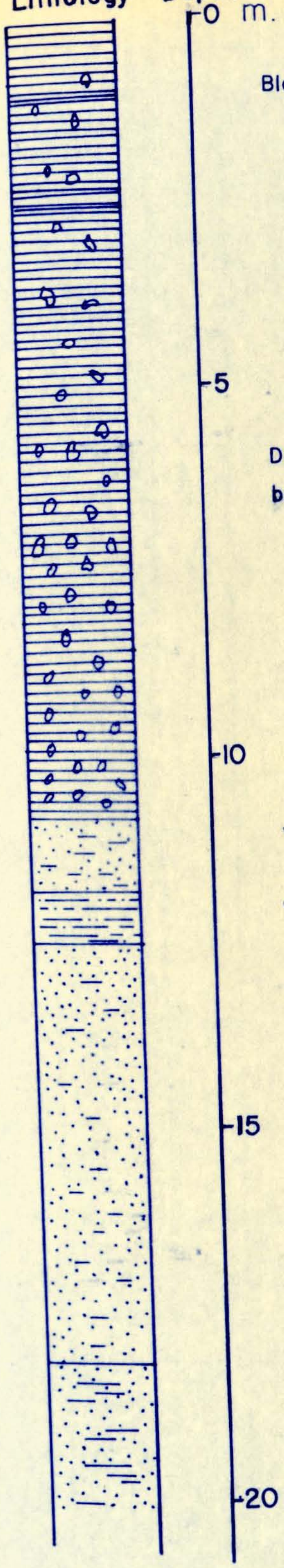
Yellowish-red shale

Light-grey calcareous shale with sand interc.

Greenish shale

Intercalation of yellowish-grey shale & fine-grained clayey sst.

Lithology | Depth | Description



Black soil with some basalt boulders & pebbles

Dark-brown soil with many weathered basalt boulders & pebbles

Yellowish, fine-grained, friable clayey sst.

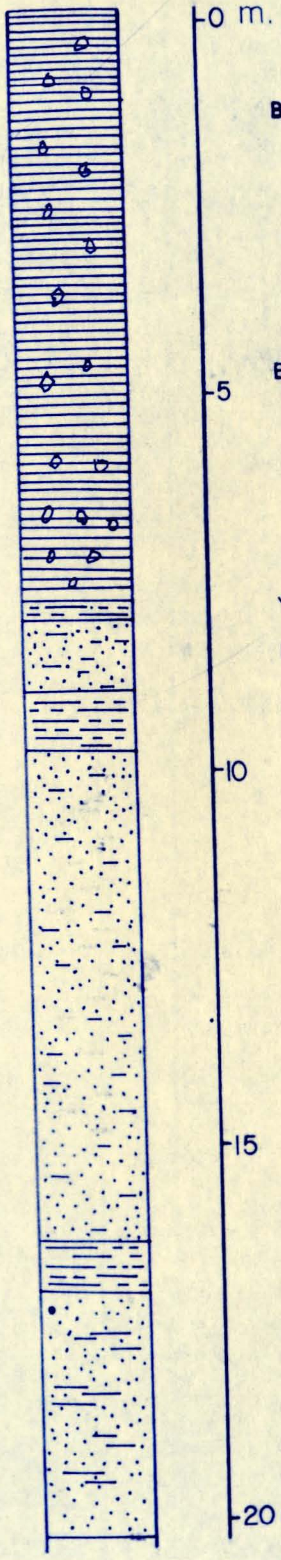
Varigated shale with some sst. intercalations

Light-yellowish & light-grey, friable, clayey sst.

Light=yellowish, clayey sst. with shale intercalaions

Borehole 15-S

Lithology | Depth | Description



Black soil with basalt pebbles & boulders

Brown soil with basalt pebbles & boulders

Yellowish & grey shale with some sand

Light-yellowish, v. fine-grained clayey sst.

Varigated shale

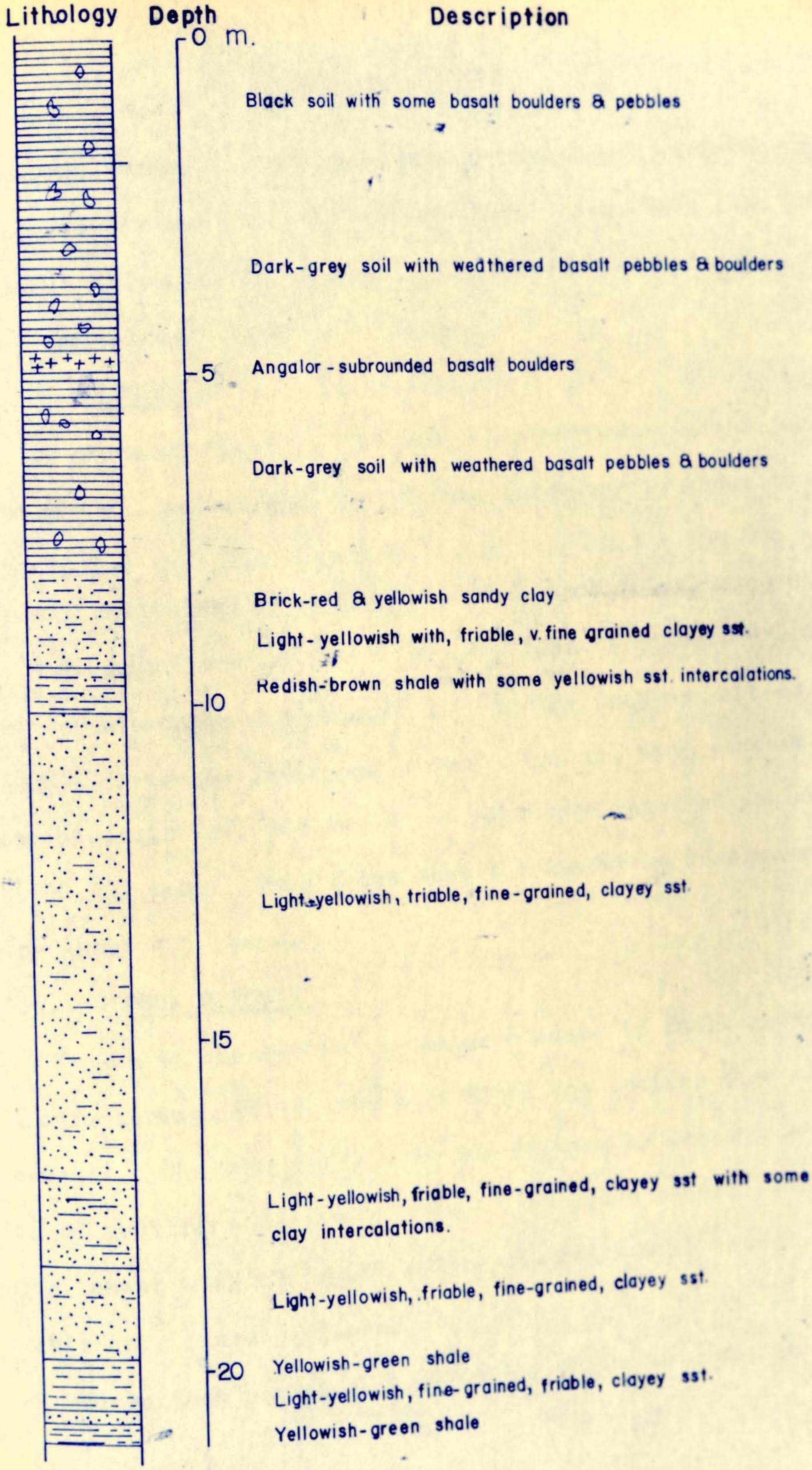
Light-yellowish, v. fine-grained friable, clayey sandstone

Yellowish-red shale

Light-yellowish, v. fine-grained, friable sst.
with grey shale intercalations

Borehole 16-S

Fig 27



previous works, the most probable depositional environment could be a low-energy environment such as tidal flats which pass transitionally inshore into alluvial coastal plains where the deposition of the continental sandstone took place.

4.3.6. RESERVES

As shown on Fig. 12, the sandstone body occupies an area of about 400,000 sq. meters and the average thickness is about 18.3 meters. This means that the sandstone deposit is 18.3 x 400,000 = 7,320,000m^3 or the equivalent of 7,320,000 x 2.35 = 17.10 million metric ton.

For annual production of 500,000 tons of cement, 975,000 tons of raw materials are required. Assuming that as high as 10 per cent silica corrector would be needed since the SiO_2 content of the sandstone is low, the amount of sandstone required per year would be 97,500 tons. This shows that the sandstone reserve would last for about 175 years.

4.4. GYPSUM DEPOSIT

Gypsum is one of the raw materials used in small amounts in cement manufacturing. It is used to control the setting time of Portland cements. The setting time as was defined by Lea and Desch (1956) is of arbitrary magnitude, being time which passes after mixing the cement with the water before the paste will resist a certain arbitrarly fixed pressure.

The maximum content of gypsum which may be added is limited according to the A.S.T.M. specification (C-150.70), to 3.0 per cent sulphur trioxide in the finished cement.

4.4.1. GENERAL NATURE OF THE DEPOSIT

The gypsum deposit is located at the northern corner of the studied area (Fig.31). It is bounded by $38^{\circ} 23' 10'' - 38^{\circ} 24' 30''$ East and $9^{\circ} 23' 50'' - 9^{\circ} 32' 19''$ North coordinates. The deposit is found beneath the limestone and occupies the lowest position in elevation. It is interbedded with dolomite which grades upward into limestone. The lower part is pure gypsum. It comprises three separate bodies, all along the southern bank of the Sodoble river and the average thickness of the gypsum deposit is about 150 meters.

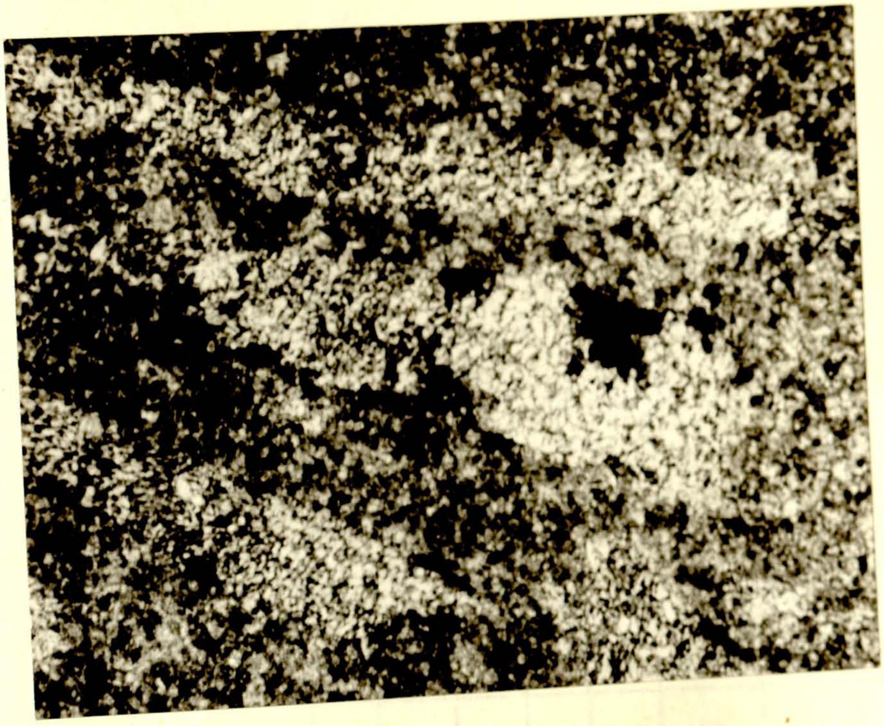
4.4.2. LITHOLOGY

4.4.2.1. MACROSCOPIC CHARACTERISTICS

The gypsum is finely crystalline, well-bedded, hard and massive. It shows secondary solution features on the surface and its colour varies from white to light - grey and pink.

4.4.2.2. MICROSCOPIC CHARACTERISTICS

Two thin sections, one from the gypsum and another from the interbedded dolomite were made to get some idea about their petrographic characteristics. The gypsum is fibrous and contains 1 per cent of very fine quartz grains. No fossils are present in the gypsum but, the dolomite which is interbedded with the gypsum is fossiliferous (20 per cent).Most of the fossils are replaced by



Plate

11. Fine-grained fossiliferous dolomite showing fossils replaced by gypsum. X 64

gpysum (Plate 11). The dolomite is composed of fine-grained dolosparites, and contain 1 per cent quartz and feldspar grains.

4.4.3. CHEMICAL PROPERTIES

Two random samples of gypsum were chemically analysed to determine the purity of the gypsum. The result obtained is given in table 17. Chemical analysis of the gypsum expressed in per cent of weight (After Gumorov and Aklilu, 1979).

Table 17

Sample No	SiO_2	Al_2O_3	TiO_2	Fe_2O_3	Mno	CaO	MgO	Na_2O	K_2O	H_2O -110°C	L.O.I.	SO_3
1	1.0	0.2	-	0.2	0.1	33.1	0.1	0.1	0.1	14.0	6.7	46.6
2	1.0	0.2	-	0.2	0.1	33.1	0.1	0.1	0.1	14.3	[illegible].2	45.8

A suplhur trioxide content of 36 per cent is usually specified for cement manufacturing. (Groves,, 1956). The value of SO_3 satisfies this specification and the result of the analysis for the various elements showed that the gypsum is pure and is suitable for cement manufacturing.

4.4.4. DEPOSITIONAL ENVIRONMENT

The gypsum is interbedded with thin dolomite beds and towards the top with limestone and shale. Most dolomites are of secondary or diagenetic origin rather t'an primary. Dolomites finer than .01 mm are believed to be of primary origin (Folk, 1968).

The fineness of the dolomite crystals and the thinness of the beds may be taken as an indication that the dolomite is likely to be primary which precipitated at the early stage of the gypsum formation. Association of gypsum and dolomite is presumed to be a product of a prograding shallow logoon-sabkha complex (Pettijohn, 1975).

4.4.5. RESERVES

The gypsum outcrops occupy a total length of about 1000 meters and the average thickness is about 150 meters. Considering a surface area of 1000 x 300 = 300,000 sq. meters, the reserve of the gypsum deposit is estimated to be 300,000 x 150 x 1.4 = 63 million metric tons. This would be enough for 4200 years with an annual production of 500,000 tons of cement.

5. CONCLUSION AND RECOMMENDATION

The study showed that the limestone is chemically of a good quality and is found in large amount (81.9 million tons) to justify utilization. In calculating reserves, only the limestone beds, leaving the interbedded sandstone and shale, were considered, and this would require selective quarrying. But, the average chemical analysis result, including the clastic interbeds, showed that the deposit is chemically suitable for cement manufacturing. The silica content was found out to be a bit high (14.68 per cent) and this could be of an advantage since the studied clay material is deficient in silica. This shows that there is a possibility to use the deposit as a whole and this ofcourse, would increase the reserve.

The clay material studied didn't turn out to be of a good quality but, as the value of this material is very low to allow distant transportation, the clay material in this area has to be used making the necessary corrections. The proved reserve is too low (3.3 million tons) to justify utilization but, the lateral distribution of the deposit is extensive and more reserves could be proved. So, more pits have to be dug inorder to prove additional reserves.

The sandstone deposit studied is a left-over from differential erosion that has been buried by basalt flows and as a result is of different thicknesses. Very few outcrops are found in the area and most of the sandstone is found beneath an overburden having different thicknesses. The thickness of the overburden which consists of basalt boulders and soil, varies from about 1 meter to 11 meters, with an average thickness of about 5.60 meters. This means, 2,240,000m^3 overburden has to be cleared off to get to the sandstone. Moreover, the sandstone contains many intercalations and about 20 per cent clay matrix and as a result the silica content is expected to be relatively low. All the sandstone core samples have to be chemically analysed to get the average content of silica for the whole deposit so that, the amount of sandstone which will be required will be exactly known.

The gypsum deposit studied is chemically pure and is therefore suitable for cement manufacturing. The gypsum is interbedded with dolomite, particularly where the interbedding starts. These interbeds should be avoided while quarrying. The deposit is quite big and is considered to be in excess of what may be required for the cement manufacturing.

In conclusion, the raw materials studied are suitable for the manufacture of Portland cement, and exist in sufficient quantity to warrant the installation of a cement plant in the Wayu locality.

6. ACKNOWLEDGEMENT

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