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YEMEN ARAB REPUBLIC

THE SILICA SAND DEPOSIT AT THAGBAN GEOLOGICAL SURVEY AND LABORATORY ANALYSIS OF SAMPLES*

WORLD BANK/UNIDO
CO-OPERATIVE PROGRAMME

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GEOLOGICAL SURVEY
AND LABORATORY ANALYSIS OF SAMPLES

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PREFACE

A feasibility study for hollow glass manufacture in the Yemen Arab Republic was completed in April 1981 1/. It contained a preliminary survey of a silica sand deposit in Thagban 2/ (14 km NNW of Sana'a). The deposit's potential significance was also noted in a subsequent survey of the local construction industry, 3/ which covered the availability of building materials in the Yemen Arab Republic. The present report provides much more detailed information on the glass sand deposit and completes the project preparation work undertaken by the World Bank/UNIDO Co-operative Programme.

Consultants F. Schüssler and G. Hirner of the University for Mining and Metallurgy, Leoben, Austria conducted a geological survey of the deposit in May 1981, and this survey is incorporated as Part I of the present report. The chemical and physical properties of the samples extracted from the deposit were analyzed by A. Mayer and W. Pistora, also at Leoben, in July - August 1981. The laboratory analysis is included as Part II of the report. The photographs submitted with the original manuscript were in colour, and unfortunately some detail has been lost in their reproduction in black and white.

The reader should note that this report is to be used in conjunction with the "Feasibility Study for a Hollow Glass Manufacturing Project" referred to in footnote 1.

The consultants were assisted in the field by the Ministry of Economy of the Yemen Arab Republic and the United Nations Development Programme Office in Sana'a.

The observations and opinions expressed in this report are those of the authors and do not necessarily reflect those of either UNIDO or the World Bank Group.

1/ "Yemen Arab Republic: Feasibility Study for a Hollow Glass Manufacturing Project", World Bank/UNIDO Co-operative Programme, Report No. 15, April 1981.

2/ Referred to as Al Jiraf in the preliminary analysis.

3/ "Yemen Arab Republic: Construction Industry Survey", World Bank/UNIDO Co-operative Programme, Report No. 17, February 1981 (1st draft).

CURRENCY EQUIVALENTS

Currency Unit:	Yemeni Rial (YR)
	1 YR = 100 Fils
Currency Equivalent 1/:	1 YR = US$ 0.22
	US$ 1 = YR 4.5

ABBREVIATIONS

CP	-	World Bank/UNIDO Co-operative Programme
IBY	-	Industrial Bank of Yemen
LTL	-	Long Term Loan
Tons	-	Tonnes (metric)
YAR	-	Yemen Arab Republic

1/ Official rate of exchange since February 1973.

SUMMARY

The survey of construction materials in the Yemen Arab Republic (YAR) undertaken by the World Bank/UNIDO Co-operative Programme in 1979 noted in the course of field investigations the existence of a promising deposit of silica sand north of Sana'a. Samples were taken, and a preliminary analysis was included in the "Feasibility Study for a Hollow Glass Manufacturing Project" 1/. The present report was commissioned by the World Bank/UNIDO Co-operative Programme to determine the characteristics of the sand and the size and reserves of the deposit.

The sand occurrences near Sana'a are part of the Tawilah Group of continental sediments. One of these, the deposit near Thagban 2/, 14 km NNW of Sana'a, contains silica sand of the necessary quality and quantity for glass manufacture.

The first part of the report indicates proven reserves of 420,000 tons, which would sustain the hollow glass project for 35 years at its proposed rated capacity. More than 70 per cent of the material appears to be suitable for direct input to the glass plant.

The second part of the report contains the results of the chemical analysis and physical testing of the sand samples as well as the final evaluation of the deposit.

1/ "Yemen Arab Republic: Feasibility Study for a Hollow Glass Manufacturing Project", World Bank/UNIDO Co-operative Programme, Report No. 15, April 1981.

2/ Referred to as Al Jiraf in the preliminary analysis.

The deposit is penetrated by numerous dykes. Highly skilled technical personnel will therefore be needed for selective mining during the quarry operation. Field observations indicate proven reserves in four blocks covering over half of the 120,000 square metre area of the deposit. The remaining material is of lower quality. Given these limitations, it is likely that other suitable sand deposits would have to be found if the hollow glass project were to be expanded or the manufacture of sheet glass contemplated.

The chemical analysis and physical testing of the sand samples demonstrate its suitability for large scale glass production.

The colour of the glass to be produced will determine the standards of the mining and dressing methods. For green and amber glass, a low degree of dressing and non-selective mining will suffice. Sand qualities meeting the requirements of colourless glass (white glass) can be attained by increasing the degree of dressing combined with selective mining. White glass quality may also be obtained by utilizing the lower grade parts of the deposit combined with a substantially higher level of dressing.

The deposit's yield (in relation to the sand that is quarried) will depend essentially on the dressing methods applied (shattering the sand conglomerates, crushing the coarse grains, etc.), on the kind of glass to be produced (green, amber or colourless) and on the type of glass melting furnace used. The yield will range from 70 per cent for white glass to 90 per cent for coloured glass.

PART I

GEOLOGICAL SURVEY

by Dr. F. Schüssler and G. Hirner

Introduction

1. The silica sand deposit at Thagban, hereinafter referred to as the "deposit", covers an area of approximately 120,000 square metres. The area is intersected by basalt dykes, thus requiring the preparation of a topographic map (at a scale of 1:1000) (Annex 1). Simple methods (measuring tape and compass) were employed, supplemented by an aerial photograph (scale 1:8000) and a topographic map (scale 1:50,000) which were already available.

2. A total of 83 samples were extracted from the deposit. A further 4 samples were extracted from other locations. Most of the samples were gathered from profiles and a small channel; the remainder were taken from points on the surface of the deposit. In addition to the sampling profiles, three cross sections were drawn to show the general dip and strike of the sand layers. These data were used to calculate the reserves of silica sand.

Location

3. The deposit, forming small hills rising from a plain, is situated about 14 km NNW of Sana'a on the western side of the main road to Amran, which is asphalt paved. A 2 km length of unpaved gravel road leads from the main road to the deposit. Access to the deposit is also given by the road to Wadi Dahr which forms the northern borderline of the deposit, as shown in Fig. 1. Among all sand occurrences in this region only the one at Thagban (see Fig. 2) was chosen for detailed investigation. The others lacked silica sand of suitable quality.

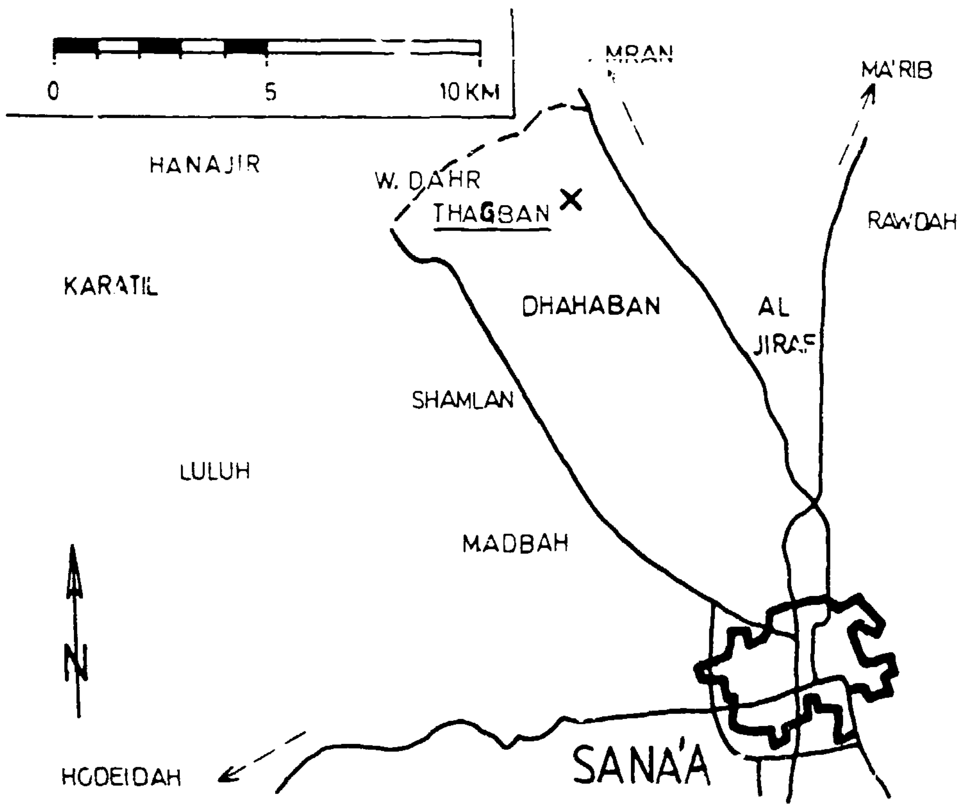

Fig. 1: Geographical location of the deposit.

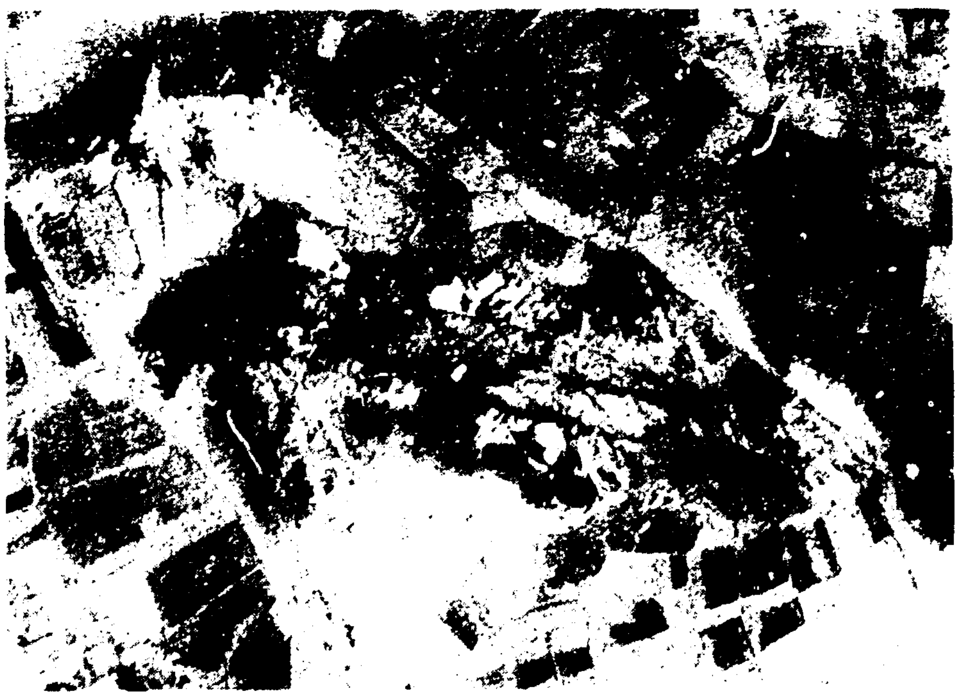

Fig. 2: Aerial view of the deposit.

General Geology

4. The silica sand deposit described in the present report is part of the Tawilah Group and Medj-Zir Series. According to the geologic map prepared by the US Geological Survey, these series are composed of continental sediments, mainly coarse, cross-bedded sandstone with lense-type intercalations of conglomerate and gravel. Some interbedded shale and sandstone occur in the lower part. The whole complex overlies unconformably partly upper Jurassic carbonatic rocks of the Amran series and partly, especially in the south of the YAR, the crystalline basement. The age of these sediments is assumed to be Upper Cretaceous and/or Lower Tertiary. Other occurrences of the same type are found south and west of Wadi Al Jawf, at the eastern side of the Sana'a basin, south of Rida, and along the border with the People's Democratic Republic of Yemen. No information was available on the lithology of these regions.

5. The sandstone massifs west of the deposit at Thagban show an intensive reddish colour deriving from a higher content of iron oxide. Only in the upper part of the strata, a white interlayer which is some ten metres thick interrupts the uniform sequence of the sandstone layers. This white sandstone is used for building purposes, although it has not found wide acceptance because corrosion of small iron-rich particles in the sandstone makes the white colour turn dirty brown after a while.

6. The approximately 300 metre thick red sandstone complex overlies the sand deposit at Thagban. No unconformity could be observed, even though the sudden change in the colour of the sand and sandstone indicates that the sediments derive from different regions. Stratigraphically, the overlying complex of the Tawilah sandstone is influenced by Quaternary basalt flows and dykes which the report subdivides into four units according to type of occurrence and colour of basalt. It was observed that there was

increased penetration of the sand by the volcanic dykes towards the north and northwest. However, no systematic distribution of volcanic influence was apparent.

7. Seen from the main road to Amran, the deposit is lighter in colour than the thick sandstone complexes in the background. The whole deposit is covered by a thin crust created by weathering processes. This crust is only some 5 mm thick and is strongly consolidated. Partly vertical and even overhanging walls have been formed, protected by the hardness of the weathered cover in combination with consolidated sand. Below this coating the mostly white sand appears which is consolidated at some places, but only to a small extent. In most cases the crushing of the material should be easily carried out without extreme abrasion of the equipment. Principally two different lithologic units can be observed:

- sand in different colours and with different grain size distribution
- basalt dykes

Silica Sand

8. The following description of the sequence of the sand layers is typical of the deposit. Fine-grained white sand at the bottom with about 80 per cent usable material is followed by an approximately 1.5 m thick intercalation of a dense, clayish sandstone which is splintery and shows a typical red flower-like pattern (fig. 3). The base of this layer is rich in iron oxide with some centimetre-thick reddish or violet streaks. Due to the high degree of hardness of this interlayer, the morphologic structure is similar to an excavation. The hanging wall is composed of a several-centimetre thick coarse-grained sand with a miximum grain size of 1 cm, and a 2 - 4 m thick layer of medium-grained sand (maximum grain size about 1 - 2 mm). The higher parts of this layer graduate to fine-grained materials. The same sequence of bedding is then repeated. At least four such strata complexes could be identified in the deposit. The correlation between these complexes cannot

be done easily because they vary according to their thickness and sometimes the dense clayish sandstone thins out.

Fig. 3: Two intercalations of dense, clayish sandstone

9. As already mentioned, there are some reddish streaks in the fine-grained sand layers. Contamination of the silica sand by other minerals apart from hematite and magnetite, e.g. rutile, chromite, garnet, etc., is also present causing a different discoloration of the sand. Yellowish and brownish streaks or lenses were observed and an intensively red coloured interlayer of several mm thickness appears west of the beginning of the cross-section A-A' (see Annex 1).

10. The results of the chemical testing and investigation of the sand samples are given in Part II. The grain size distribution shows that about 73 per cent of the sand is suitable as raw material for the hollow glass manufacturing plant. The average composition of the material is:

- 4% grains larger than 0.5 mm
- 63% grains between 0.5 and 0.09 mm

- 6% grains smaller than 0.09 mm
- The remaining 27% comprises the screening portions larger than 0.5 and smaller than 0.09 mm. The grain size can be reduced with adequate grinding machinery.

The output of the deposit will actually be higher than 73 per cent, according to several samples which were taken from the coarse-grained material to check the chemical composition of this type of sediment. This would confirm the larger degree of utilization of the whole deposit indicated by the screen analysis of the 1979 sample.

Basalt Dykes

11. The strike of the sand strata changes from 100° in the north to 70° in the south and to 40° - 60° in the east. Local data on the strike may differ significantly from the above-mentioned figures because of cross-bedding and tectonic dislocations of complexes. The general dipping is approximately 8 - 10° to the south. Locally, a dipping to the north was observed.

12. Numerous volcanic cones penetrate the deposit. One main dyke striking W-E reaches a maximum thickness of 11 m. The geological map (Annex 1) reflects the distribution of the dykes. Fig. 4 shows the confluence of some small dykes. The black colour on the rock surface is indicative of the origin of the dykes and of their influence on the composition of the silica sand. In the contact zone between dykes and sand, the sand changes to a type of quartzite which is similar to molten glass. On average, 30 cm of silica sand on either side of a dyke cannot be used.

13. Many dykes have an average thickness of 0.75 m and only a few exceed 2 m. In general most dykes dip very steeply, about 70° to 85°. The directions of dipping cannot be distributed statistically; however, it seems that the majority of N-S striking dykes dip to the east. The chemical composition of the basalts is quite uniform, with only the main dyke tending to be more acidic.

Fig. 4: Confluence of dykes

14. It is probable that the dykes merge in depth to a central source. This is taken into account in the calculation of reserves, and a quarrying activity which goes far beneath the surface level of the plain is not recommended.

15. Four blocks were chosen in the deposit area, shown different patterns on the geological map, all obviously containing good quality silica sand. Additional blocks suitable for glass production were tentatively identified.

Calculation of Reserves

16. The following is an explanation of the geological map (Annex 1) and the cross-sections (Annexes 2, 3, and 4):

- The boundary of the deposit was drawn from registrations which considered only the border with the plain. However, it must be noted that the deposit continues in depth.

- The altitude of the plain is about 2,210 m above sea level, with the highest point of the deposit some 40 m above the plain. Contour lines from the topographic map were not at close intervals, but the drawing of contour lines was not of immediate interest for calculating the reserves, as the thickness of the layers was registered during field work.
- The patterned areas on the map are those parts of the whole deposit which are considered by the consultants to be of primary economic value.
- The scale of the geological cross-sections had to be adapted to the length of the profiles and changes from 1:500 to 1:2,000. Thin intercalations were combined to a thicker layer.

17. On the basis of the Feasibility Study for a Hollow Glass Manufacturing Project prepared by the World Bank/UNIDO Co-operative Programme, the required amount of silica sand is about 12,100 tons per year at rated capacity. This figure includes only the demand for silica sand for hollow glass production. Sources in the Ministry of Economy pointed out that there is also a high demand for sheet glass in the YAR. However the amount of silica sand needed to produce the market requirements for sheet glass (estimated at about 30,000 tons per year) would be excessive for this comparatively small deposit.

18. The calculation of the surface area of each block was done by means of planimeter. Three registrations were undertaken to minimize errors. The mean value was multiplied by the average thickness of the geological cross-sections and notes were made during the field mission. This value was reduced to 75 - 85 per cent according to the number of dykes, their thickness and other factors diminishing total usable reserves, such as degree of consolidation, layers of contaminated silica sand, etc.

19. The total value of each block was multiplied by the

specific weight of unconsolidated or slightly consolidated silica sand.[1/] Resulting from this calculation, the tonnage of silica sand in each block includes all grain sizes represented in the deposit.

20. As samples were taken from each block, the mean value of the usable grain size fractions was calculated and multiplied by the tonnage. The final data giving the actual reserves can be directly compared with the yearly demand for silica sand. The calculation of the percentage of output from each block derives from the samples shown in Table 1 below.

Table 1: Output calculation for the four blocks

	AREA 1		AREA 2		AREA 3		AREA 4	
	No.of sample	usable grain size portion %	No.of sample	usable grain size portion %	No.of sample	usable grain size portion %	No.of sample	usable grain size portion %
Samples	III/1	51.24	P 11	96.03	II/1	66.10	V/1	90.30
	III/2	81.44	P 12	75.69	II/2	28.42	V/2	49.14
	III/3	94.67	P 13	72.73	II/3	56.03	V/3	83.68
	III/4	91.34	P 16	64.75	II/4	78.89	V/4	56.90
	III/5	48.91	P 05	93.90	II/5	74.40	V/5	82.73
	III/6	91.24			II/6	94.49	V/6	92.30
	III/7	72.16			II/7	55.20	V/7	47.20
	III/8	56.29			II/8	60.13	V/8	91.53
	III/9	70.93			II/9	56.84	V/9	23.30
	P 1	71.20			II/10	100.00	V/10	85.69
					S1/1	57.01		
					S1/2	82.53		
					S1/3	98.31		
					S1/4	78.68		
					S1/5	74.00		
arithmetic average	72.94%		77.30% 93.90%		70.74%		70.38%	

21. The total actual reserves of silica sand amounting to 420,000 tons are calculated in Table 2 overleaf.

1/ Specific weight for unconsolidated sand: 1.63 g/cm^3
" " for consolidated sand: 1.98 g/cm^3
" " for pure silica sand: 2.65 g/cm^3

Table 2: Calculation of reserves

	Surface Area (m^2) Registration 1	2	3	mean value (m^2)	thickness (m)	waste (%)	total volume (m^3)	bulk weight (g/cm^3)	tonnage (tons)	output (%)	actual reserves (tons)
AREA 1	26,940	26,740	27,000	26,893	4	15	91,436	1.63	149,000	72.94	109,000
AREA 2	16,180	16,030	16,110	16,107	8	20	103,085	1.63	168,000	77.30	130,000
	2,720	2,700	2,700	2,707	5	25	10,051	1.63	17,000	93.90	16,000
AREA 3	13,000	13,080	13,100	13,060	10	20	104,480	1.63	170,000	70.74	120,000
AREA 4	9,220	9,200	9,240	9,220	5	15	89,185	1.63	64,000	70.38	45,000
				67,987		TOTAL ACTUAL RESERVES					420,000

22. The total actual reserves only take into account material above the level of the plain and could be larger if the continuation of the quarry operation in depth were considered. This must be proved by some drill holes, otherwise the probable increase of the dykes cannot be determined.

23. As the samples were taken from different layer levels, the whole deposit is adequately represented. Based on 16,760 tons per year of rated capacity of finished bottles and other products, requiring 12,092 tons per year of silica sand, the above sand reserves can supply the proposed project for approximately 35 years.

24. The appearance of two of the blocks is shown in:

- Fig. 5, covering a large sector of the deposit including the proposed quarry area 1. Two intercalations of dense clayish sandstone forming excavations can be seen in the centre of the photograph.
- Fig. 6, pointing to the major part of area 2. At the right side of the photo, the channel can be seen as a thin, white line where samples were extracted.

Fig. 5: Area 1 of the proposed quarry operation

Fig. 6: Area 2 of the proposed quarry operation

Other Sand Deposits

25. At the western side of the basin, underlying strata of the Tawilah Group occur as slightly consolidated sandstone. Both the chemical composition and the grain size distribution seem to be completely different from the Thagban deposit. However, the whole flank of the mountain range as far as Wadi Dahr was investigated. Two samples were taken at Wadi Dahr. Another sample was taken north of Thagban at a water drill hole.

26. The eastern side of the Sana'a basin is built up of layers similar to those in the western part of the basin. There seem to be fewer dykes, but the quality of the sand is not good enough for economic use.

27. Apart from the sand occurrences in the vicinity of Sana'a, the consultants were informed about sand deposits north of Sadah which were reported to be of good quality and only slightly penetrated by basalt dykes.

Conclusions and Recommendations

28. The only deposit in the vicinity of Sana'a which can be used for glass production is the one described in this report. The existing reserves of 420,000 tons are sufficient for 35 years' production by the proposed glass plant. Additional silica sand deposits must be investigated for other glass manufacturing projects

29. The consultants do not recommend working the quarry at Thagban below the level of the Sana'a basin because the thickness of the dykes seems to increase in depth. If a quarry operation below the surface of the basin is considered, an additional drilling programme will be necessary.

PART II

LABORATORY ANALYSIS OF SAMPLES

by Dr. A. Mayer and Dr. W. Pistora

General Characteristics of the Samples

30. Sand samples were extracted from the following locations, indicated in Annex 1.

P	-	(P_1 to P_{20})
I	-	(I/1 to I/23)
II	-	(II/1 to II/13)
III	-	(III/1 to III/9)
IV	-	(IV/1 to IV/3)
V	-	(V/1 to V/10)
SI	-	(SI/1 to SI/5)
B	-	(1 sample from a water drill hole)

Series P: The samples of series P occur as lightly consolidated nodules. Only samples P_{11}, P_{12}, P_{13} and P_{19} are unconsolidated sand. P_{18} shows a higher degree of consolidation. However, during mechanical dressing, extensive disintegration into original grading can be expected. Sample P_4 is consolidated mainly by silicate cementing agents and therefore cannot be used as raw material for glass.

The colour of samples from series P vary from white grey to reddish, indicating a relatively low content of Fe_2O_3.

P_1 to P_{11} samples (excluding P_4) show a low percentage of fine grains (appr. 1% less than 63 µm 1/) and a high

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1/ 500 µm = 0.5 mm

percentage of coarse grains (appr. 24% over 500 μm).
P_{12} to P_{20} samples (excluding P_{18}) consist, on average, of 7% fine grain and 16% coarse grain. After relatively simple dressing the yield of sand from series P samples will be about 75% 1/.

Series I: The samples from series I (with the exception of I/20) consist of pebble-like, overcrusted quartz sand which will, in most cases, shatter to its original grading during a relatively simple mechanical or hydromechanical milling operation. Only samples I/8, I/15 and especially I/21 are extremely consolidated, so that total disintegration cannot be achieved without sophisticated dressing techniques.

Sand from this series is characterized by its whitish-grey colour (low Fe-content) as well as its reddish-brown colour (rich in Fe), as in samples I/4, I/8, I/12, I/14 and I/19.

Samples I/1 to I/23 (excepting I/20 and I/21) are partly coarse grained, with 3% of the grain smaller than 63 μm and around 28% larger then 500 μm. This means that a minimum of appr. 70% 2/ of usable sand can be recovered from the raw material.

Series II: Series II comprises nodule-like or consolidated crusts. Besides the very high content of Fe_2O_3 in samples II/3, II/5, II/7, II/9, and II/12, the material is consolidated to such a high degree that the compound will not shatter during dressing. Only sand samples II/1, II/2, II/4, II/6, II/8, II/10, and II/13 are in accordance with the

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1/ percentages in weight

2/ The weathered crust forming the surface of the deposit - about one cm deep - is particularly rich in coarse grains.

average sand quality of series P. Therefore selective mining in this area seems to be necessary 1/. Nevertheless a yield of over 70% may be obtained with a coarse grain proportion of approximately 28%.

<u>Series III:</u> The mostly crusty and nodule-like sample materials includes well-dressable, low Fe content (samples No. III/2 III/3 and III/6). Sand samples III/1, III/4, III/5, III/8 and III/9 can also be treated but their usage as glass raw material is restricted due to strongly adhered iron-bearing silicates. Sample III/7 cannot be used at all because of the high degree of consolidation.

The colour of the sand varies between light (good quality) to brown, violet and black (poor quality).

<u>Series IV:</u> Sample IV/3 is similar to samples III/8 and III/9, which have medium quality but which are still of economic value. The samples IV/1 and IV/2 are highly consolidated; therefore the proper grain size for glass production cannot be obtained by applying simple dressing methods.

<u>Series V:</u> The sample material is partly nodular and partly unconsolidated sand of grey to violet colour. Samples V/1, V/3 and V/7 show Fe-rich contaminations. All 10 samples of this series can be dressed quite easily and are of medium to low quality. The practical yield by non-selective mining is estimated to be over 70%.

<u>Series SI:</u> Sample SI/1 is strongly consolidated in part and usable with some restrictions because of the high kaolin and iron-bearing silicate content (mostly alumo-silicates with Fe hydroxides). Samples SI/2, SI/3 and SI/4 can be dressed easily, although contamination with iron-bearing silicates is relatively high. Sample SI/5 shows a very good sand quality with a remarkably high proportion of kaolin.

1/ The surface of the sand deposit was very even in this area and it was not possible to collect unweathered samples.

Due to the favourable grain size distribution of the raw material, a yield of 75% is realistic.

Sample B: Partly consolidated sand of good quality.

Grain Size Distribution

31. Quartz grains larger than appr. 1 mm will dissolve very slowly in the glass melt. Grains smaller than appr. 0.1 mm can create dust problems during handling as well as in the furnace. Therefore, the following granulometric values are required for the production of hollow and sheet glass (Tab. 3):

Table 3

Composition of the granulation of sands for glass making:

less than	0.06 mm		max. 0.1%
0.06	-	0.1 mm	max. 6 %
0.1	-	0.4 mm	max. 88 %
0.4	-	0.5 mm	max. 4 %
0.5	-	1.0 mm	max. 2%

(percentages in weight)

32. Some European producers of glass prefer coarser glass sands similar to the granulation of the sand from Thagban, in accordance **with the classification of sands in Table 4.**

Table 4

Characteristic values of granulation and size range of coarse, medium, fine and very fine glass-melting sands:

size category (in mm) test sieves acc. to DIN 4188	share in weight - %			
	quartz sand			
	coarse	medium	fine	very fine
> 1.0	max. 1			
1.0 - 0.5	5 - 10	max.1		
0.5 - 0.355	15 - 35	5 - 15	max.1	
0.355 - 0.25	25 - 35	30 - 50	15 - 30	max 1
0.25 - 0.125	20 - 30	40 - 60	60 - 80	80 - 90
0.125 - 0.063	0 - 1	0 - 2	2 - 5	10 - 20
< 0.063			max. 1	max. 3

33. A screen analysis was carried out of the loose, untreated sand samples of the deposit at Thagban (see Annex 5). The result of this analysis shows yields of the granulometrically usable sand of between 20% and 95%. These values refer to a glass project without significant sand dressing - only with crushing and air separation of dust.

34. Therefore, it is recommended that the raw sand be dressed. A sand washer running in several steps should set up in addition to the normal combination of sieves. Hydrocyclons, Archimedes screws, and/or high-intensity magnetic separators could be used to increase the output and decrease the Fe content of the usable raw material from the deposit to an average of up to 80%. In this case, the share of coarse grains would come to 10 - 15% and the fine granulation which may be dusted to 1 - 5%.

Tables 5 and 6 indicate the average grain distribution of all 80 samples and the estimated usable 50. According to

Table 4 the theoretical usable portions of coarse type sand are approximately 85% for all the 80 samples and 90% for the 50.

Table 5

Average values of all 80 samples from Thagban crushed by a simple impact crusher and washed:

grain size	weight-%
> 1 mm	9
0.5 - 1 mm	12
0.2 - 0.5 mm	55
0.09 - 0.2 mm	18
< 0.09 mm	6

Table 6

Average grain size distribution from dressable samples (50 samples) after running through a 2-step washer (70% solids, 30% water):

grain size	percentage in weight
1 mm	5
0.5 - 1 mm	15
0.2 - 0.5 mm	60
0.09 - 0.2 mm	1[illegible]
0.09 mm	4

Mineral Components

35. All samples - with the exception of I/20 (basalt) - consist of quartz sand (β-quartz, SiO_2) consolidated in crusts

or nodules of white, grey, yellow, red, violet or nearly black color. This pure quartz sand is contaminated by calcium carbonate ($CaCO_3$), kaoline minerals ($Al_2O_3.2\ SiO_2.2\ H_2O$) and Fe-hydroxides (in low quantities).

36. These three mineral components are evident either in pure or mixed grains, for instance in the form of a mixture of calcium carbonate and the clay mineral "kaolinite" which forms hard, barely dressable crusts. The consolidation of the crusts is also partly caused by a silica cement. Even though in principle these contaminations are bad for glass producing sands, they do not greatly affect the quality of the raw material, because the harmful impurities are imbedded between or around the quartz grains (see photos of electromicroscope and microscanner in Annex 6). Therefore the dressing of the crusts (washing etc.) of all Thagban sands remains within economic limits.

37. Apart from the accompanying minerals mentioned above, the following trace minerals are represented, especially in the fine granulations (they could be separated e.g. by high intensity magnetic separation and/or Archimedes screws):

rutile, brookite	(TiO_2)
hematite	(Fe_2O_3)
ilmenite	($FeTiO_3$)
magnetite	(Fe_3O_4)
chromite	($FeOCr_2O_3$)
"disthene"	($Al_2O_3.SiO_2$) 1/
augite	
garnet	
hornblende	
mica	
tourmaline	
zirconium	
sulfides etc.	

1/ Similar to Andalusite

38. Pages 1 and 2 of Annex 6 show the enriched accompanying minerals concentrated through high intensity magnetic separation of samples P1 to P11. Besides the large quartz grains (Si) one can see (Al) fixed to (Si) as kaolinite, (Al) fixed to (Si) and (Ca) as garnet, (Ti) combined with (Fe) as ilmenite and isolated (Ti) as TiO_2 (rutile).

39. Pages 4 and 5 of Annex 6 show the coating and cementation of quartz grains by $CaCO_3$, ferro-hydroxides, marl, etc.

40. Annex 6 summarizes the distribution of the most essential accompanying elements. It must be noted that the samples were separated magnetically and on average represent appr. 0.7% of total raw material of the sand samples. In areas with higher concentrations of Fe and Ti, the portion of accompanying minerals may rise to 3%.

41. The low content of disthene ($Al_2O_3.SiO_2$) and zirconium silicate ($ZrSiO_4$) - which are difficult to fuse - (see page 10 of Annex 6) is advantageous for the dressing of the raw material.

42. As a result of X-ray analysis, additional interesting substances could be recognized as trace elements in the sand samples. An investigation of waste material (dressing by magnetic separation or flotation) is necessary in order to ascertain the contents of trace elements, namely, rare earths.

43. Annexes 6 and 7 show the following typical trace elements and compounds of different samples of the Thagban sand. The quantitative analysis therein shown was plotted from the electronic microscope pictures and electronic micro-analysis back-scattered images indicated in the righthand side of Annex 6.

Page 1:	Fe-carbonate with high content of **manganese**
Page 2:	Scapolite (Na, Ca, Cl-Si compound)
Page 3:	Zirconium silicate ($ZrSiO_4$)
Page 4:	Argentiferous "Yttrocerite" (Yttrium, Silver, Cerium, Fluor-compounds)
Page 5:	Cu-Sulfide
Page 6:	Chrome spinel - "Picotite" $(Mg,Fe)(Al,Cr)_2O_4$
Page 7:	Scheelite - ($CaWo_4$)
Page 8:	Yttrium mineral - Yttrofluorite YF_3

44. Figures 7 to 10 are microphotographs of thin sections of four samples.

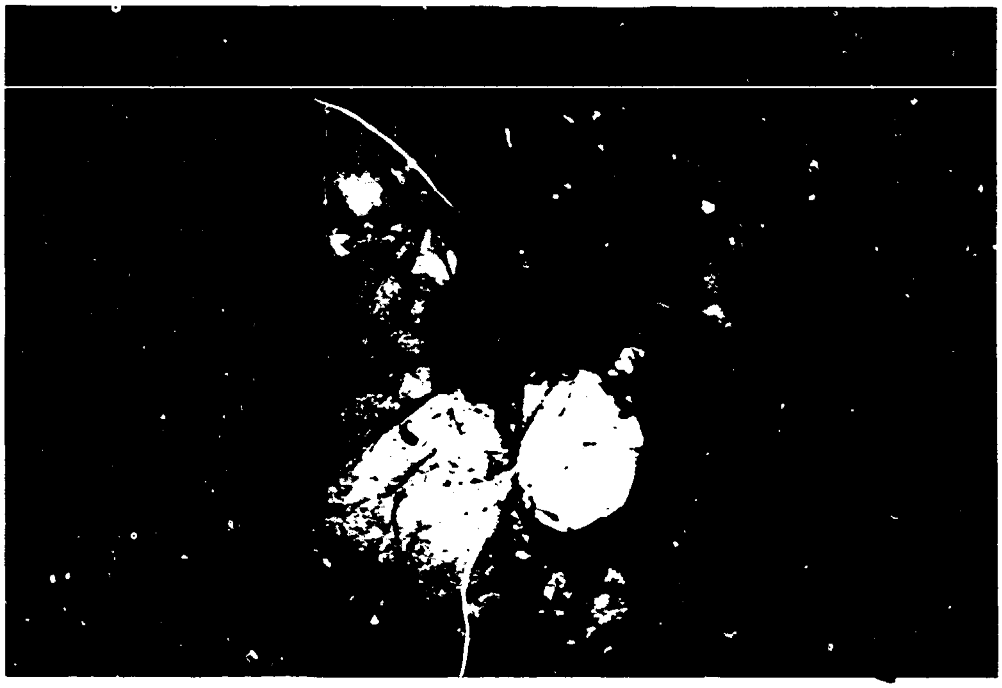


Fig. 7: Microphotography of sample I/17

70 x; the grey, brownish, white, blue etc. coloured quartz grains of the coarse grain are cemented by kaoline, calcite and some hydroxides. The quartz sand particles of this type are intensively squashed (good melt-down behaviour)

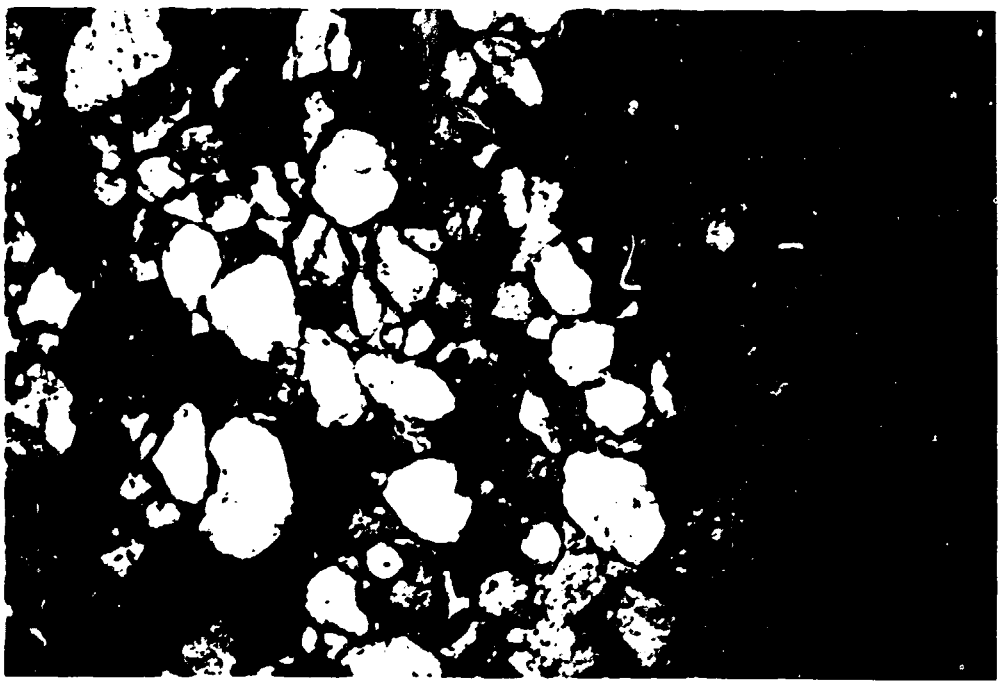


Fig. 8: Microphotography of sample III/2

Typical fine grained, pure quartz sand with clean grain outlines

Fig. 9: **Microphotography showing typical crossview of** consolidated sand. The cementing agent between the grains consists mainly of $CaCO_3 + Al_2O_3.SiO_2$. Due to the fact that the fine granulation was removed (possibly by the wind), the outer zones are richer of coarse grains than the inner zones. This fact together with the partly strong cementation of the grains can cause a falsification of the screen analysis.

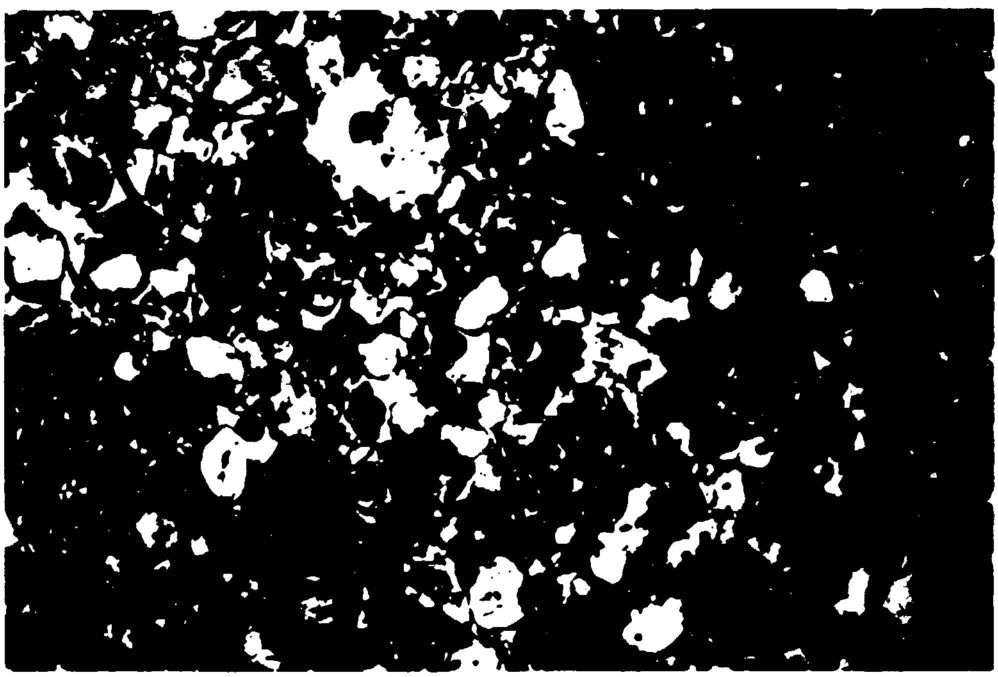


Fig. 10: Typical microphotography of portions which can be separated magnetically. Quartz = grey, blue. TiO_2, $FeTiO_2$, Fe_3O_4 etc. = opaque. Fe-Al hydroxides = yellow

Ferrous Content as a Quality Criterion

45. Iron content in sand causes the glass to colour and thus represents an obstacle to the production of colourless glass.

46. Specifications for glass sand are closely associated with the type of glass to be produced from them. In order to facilitate melting, it is desirable that the sand contains only grains which pass through a 20 mesh screen. The level of permissible iron content is lowest for optical glass, where Fe_2O_3 should not exceed 0.015%. For fine tableware, good colour cannot be maintained with Fe_2O_3 over 0.04%. For colourless plate glass, and to a larger extent for amber or green glass bottles and colourless ware, larger amounts of iron are permissible.

Table 7

Maximum Fe_2O_3 content in sands
(Values used in industry throughout the World 1980)

green-glass	0.5%
profile glass	0.1%
tableware	0.03%
flacons	0.025%
crystal, lead-crystal	0.015%

47. Although the sand used for nearly colourless container glass contains only 0.05% Fe_2O_3, bleaches should be added in order that the Fe_2O_3 content does not exceed 0.03%, as per table 7. This is because other components of the sand such as limestone, dolomite, feldspar, sodium, etc. also contain Fe_2O_3.

48. For green container glass, European glass producers use sand with a Fe_2O_3 content up to 0.6 - 0.7% and with an Al_2O_3 content not exceeding 6%. The typical shade of the green container derives from the combination of Fe_2O_3 with approximately 0.2% Cr_2O_3.

For amber container glass, sands with a content of Fe_2O_3 between 0.1 - 0.4% can be used.

Table 8

Typical batches used in industry

	amber bottles 1	green bottles 2	"colourless"glasses 3	4
Sand	a) 62.03 0.16% Fe_2O_3	b) 63.75 0,60% Fe_2O_3	c) 55.81	d) 56.38
Feldspar	-	-	e) 6.91	f) 5.36
Soda ash	18.49	17.-	18.12	16.31
Limestone	10.02	18.49	8.69	10.50
Dolomite	8.68	-	9.21	10.81
Na_2SO_4 (Salt cake)	0.50	0.28	0.86	0.62
Sodiumnitrate	-	-	0.40	-
Coal	0.08	-	-	0.02
Chromite	-	0.48	-	-
Iron oxide-red	0.20	-	-	-
	100.-	100.-	100.-	100.-

Other Contaminants

49. Although the Al_2O_3 in the sand samples frequently

exceeds 3%, the presence of this substance, as well as of $CaCO_3$ is not detrimental in glassmaking. However the Al_2O_3 and $CaCO_3$ are contaminated by a large amount of Fe_2O_3. Furthermore, clay is not a common and useful carrier of Al_2O_3 because of technical problems which may arise during the melting process. Therefore the necessary Al_2O_3 is brought into the batch by feldspar.

50. Titanium combined with iron causes a light yellowish shade in colourless glass production. Titanium compounds occur in Thagban sands as TiO_2, ilmenite ($FeTiO_3$) or Fe-containing Ilmenorutil. These, as well as Fe-hydroxides, hematite, magnetite and pyrite, must be removed for colourless glass production. Other harmful impurities only appear as negligible trace substances in the sand samples.

The Quality of the Thagban Sands

51. The characteristics described in paragraph 30 are indicative of the quality of these sands. Various analyses were undertaken of the following samples:

a) single, typical raw sand samples (important for selective mining);
b) mixture of different raw sand samples simulating the result of mechanized mining methods;
c) washed and magnetically separated single raw sand samples and
d) sand mixtures as under b) but washed and magnetically separated.

The results of these analysis are indicated in paragraphs 52 to 55.

52. Light sands with low consolidation (no crusts, few nodules), of the type P3, contain 0.07 - 0.11% Fe_2O_3 and can be

improved by washing (70% solids, 30% H_2O which can be recycled) to approximately 0.02% Fe_2O_3, which is within the standard for colourless glass.

53. Light raw sands of the types P6, 7, 10, 11, 12, etc. also indicate Fe_2O_3 contents of 0.07% - appr. 0.11%. However, simple washing only raises the quality to 0.04 - 0.06% Fe_2O_3. Only pilot plant dressing tests can prove whether several (3 or 4) washings will remove the clay, lime and iron hydroxides, or whether other dressing techniques must be applied to produce high quality sands.

54. Highly contaminated sands:

a) The red sand of type I/4 is suitable for green glass (Fe_2O_3:0.22 - 0.38%). This type cannot be recommended for the production of colourless glass even after dressing.

b) The yellow sand of type V/7 can be used in the same way as under a). It has a Fe_2O_3 content of 0.38 - 0.52%.

c) The brown sand of type II/9 or similar ones such as type III/1 (violet) with high Fe_2O_3 contents (over 1%) should be separated before washing or sieving.

55. Dressed Sands:

a) M4: Mixture of all sand samples (except red, yellow, violet and brown coloured sands). Using a most simple dry dressing technique (sieving at 1000 microns), Fe_2O_3 can be brought down to 0.15%, which is suitable for green and amber glass.

Using an M4 mixture, crushing it, dedusting it by an air separator to remove the fine, light kaoline and carbonate portion, and sieving it at 1000 microns, Fe_2O_3 will drop to 0.09%, which is more suitable for green and amber glass production, the undesired dust portion having been removed.

b) M5 was obtained by washing the M4 mixture for 10 minutes (70% solids, 30% water), whereby Fe_2O_3 will be 0.058%. This percentage is still too high for colourless glass production.

c) M5/1 was obtained by extracting magnetizable portions from the washed M5 sand mixture by means of high intensity magnetic separation. 0.038% of Fe_2O_3 was achieved. It appears that this dressing method will achieve colourless glass sand quality.

d) M0 is a mixture of all sand samples (P, I,II,III,IV, V, SI) which were sieved at 0.5 mm and washed once (as for M5). The Fe_2O_3 content obtained was 0.08%, which is suitable for green and amber glass.

e) M1 is the M0 sand mixture separated magnetically after hydromechanical dressing (as under c). The Fe_2O_3 content obtained was 0.052%, which is still too high for colourless glass production.

f) M2 is a mixture of sand samples SI/1 to SI/5 washed once. Fe_2O_3 was 0.056%, which is not suitable for colourless glass without further dressing.

g) M3 consists of a mixture of all sands of series SI/1-SI/5, washed once and separated magnetically. The percentage of Fe_2O_3 was 0.045%.

h) M6 is a mixture of an average of all samples from Thagban, sieved at 500 and 90 microns and washed (70% sand, 30% water), The Fe_2O_3 content diminished from 0.38% to 0.068% by this dressing.

i) P3A is the P3 sand washed once. A very good percentage of 0.02% of Fe_2O_3 was obtained.

k) P3AM is the P3 sand washed once and separated magnetically whereby the excellent value of 0.015% of Fe_2O_3 was obtained.

56. The chemical composition of different European glass sands is summarized in **Tables** 9 - 13 and is compared with the raw and simply dressed Thagban sand in **Table 14.**

57. Table 15 lists the loss **on** ignition of the different Thagban sand samples, indicating thus the percentage of organic matter in the sand.

Table 9

Typical values of French glass sands

	Type Nemours	
Location of the deposit:	Nemours	
Type of the Sand:	NEO3	NE14
Chemical composition in %		
SiO_2	99.8	99.8
Fe_2O_3	0.010	0.015
Al_2O_3	0.03	0.04
TiO_2		
CaO + MgO	0.01	0.01
K_2O + Na_2O	0.01	0.01
Ignition loss	0.05	0.05

Table 10

Typical values of Austrian types of glass sand

Location of the deposit	Zelking		St.Georgen
Type of sand	ZE 23	ZE85	SG 83
Chemical composition in %			
SiO_2	93.0	97.0	96.5
Fe_2O_3	0.3	0.15	0.04
Al_2O_3	4.5	2.0	2.5
TiO_2	0.1	0.05	0.05
CaO + MgO	0.1	0.1	0.1
K_2O + Na_2O	2.3	0.5	0.8
Ignition loss	0.4	0.3	0.3

Table 11

Typical values of Belgian and Dutch types of glass sand

Location of the deposit	Heerlen			Maasmechelen		Mol
Type of the sand	S50	S55	S75	MaMI	MaMII	M 32
Chemical composition in %						
SiO_2	99.8	99.8	99.7	99.75	99.65	99.5
Fe_2O_3	0.022	0.025	0.03	0.012	0.016	0.028
Al_2O_3	0.07	0.08	0.15	0.1	0.15	0.25
TiO_2	0.03	0.04	0.05	0.01	0.02	0.04
CaO + MgO	0.01	0.01	0.01	0.01	0.01	0.01
K_2O + Na_2O	0.01	0.01	0.03	0.01	0.02	0.02
Ignition loss	0.1	0.1	0.15	0.1	0.1	0.18

<u>Table 12:</u> Typical values of kinds of glass sand **from Haltern (FRG)**

location of the deposit	Flaesheim	Haltern			Haltern		
type of sand	No 2	H11	H12	H14	Type 1	Type 2	Type 3
chemical composition in %							
SiO_2	99.5	99.7	99.65	99.5	99.7	99.65	99.63
Fe_2O_3	0.04	0.035	0.04	0.05	0.028	0.026	0.024
Al_2O_3	0.20	0.15	0.17	0.20	0.1	0.12	0.13
TiO_2	0.05	0.02	0.03	0.04	0.02	0.04	0.04
CaO + MgO	0.05	0.01	0.01	0.01	0.01	0.01	0.01
K_2O + Na_2O	0.03	0.02	0.03	0.03	0.01	0.01	0.02
Ignition loss	0.19	0.1	0.15	0.02	0.1	0.1	0.15

Table 13: Classification of quartz raw material according to the chemical and mineralogical composition

	crystal quartz (Brazil)	gangue quartz (Portugal)	very pure quartz sand (BRD, Belgium, France, the Netherlands)	quartz sand	quartz sand containing: Fe, clay and feldspar
	chemcal analysis in weight %				
SiO_2	99.99	99.8	99.5 – 99.8	99.0 – 99.6	99
Al_2O_3	0.01	0.05	0.05 – 0.3	0.1 – 0.5	1.0 – 6.0
Fe_2O_3	0.001	0.002	0.01 – 0.02	0.02 – 0.05	0.1 – 1.0
TiC_2	0.01	0.01	0.05	0.01	0.1 – 0.5
K_2O Na_2O	0.01	0.01	0.1	0.15	0.2 – 2.0
Ignition loss	0.1	0.1	0.1 – 0.2	0.3	0.5 – 2.0
	mineral analysis in weight %				
quartz	100	99.9	≈99	98	≈90
feldspar clay etc. others		0.1	} 1.0	} max.2	} 10

Table 14: Values of analyzed Thagban sands (%)

sample No	SiO_2 = Diff.	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	Ign. loss 1000°C	Insol. in HF
V 1	99.03	0.20	0.052	Trace	Trace	0.20	Trace	0.18	0.34
V 2	99.29	0.20	0.056	0.05	Trace	Trace	Trace	0.14	0.26
V 3	98.74	0.25	0.045	0.23	0.05	Trace	Trace	0.44	0.25
V 4	97.72	0.70	0.155	0.36	0.08	Trace	Trace	0.81	0.18
V 5	99.28	0.15	0.058	0.08	0.02	Trace	---	0.13	0.28
V 6	99.36	0.20	0.068	0.08	0.02	Trace	---	0.16	0.11

Table 15: **Ignition Loss of Analyzed Thagban Sands**

(at 1050° C)

Sample	No. 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
P	f.+)	f.	f.	f.	1.0	f.	f.	f.	f.	f.	f.	1.0	1.6	1.2	1.0	1.0	1.2	f.	1.8	1.2			
I	f.	1.6	f.	0.4	1.0	–	f.	0.8	1.0	1.0	f.	0.6	1.6	f.	1.8	0.8	f.	f.	f.	5.7	1.6	0.6	0.6
II	f.	2.4	2.6	0.8	f.	f.	0.6	1.0	2.0	f.	4.0	0.6	f.										
III	1.8	0.4	0.6	2.4	0.8	0.6	2.6	f.	0.4														
IV	1.4	3.0	1.0																				
V	0.4	f.	0.4 1.0	1.0	0.6	f.	1.6	1.6	1.2	0.8													
SI	0.6	0.6	0.6	f.	f.																		

+) f. free = without loss on ignition

Conclusions and Recommendations

58. The results of the investigations of the Thagban sands indicate that they are suitable for the production of green and amber, as well as colourless glass.

59. Due to the contamination of the sand by Fe-bearing and clayish-fine granulation, and due to the partial consolidation which is, on the one hand, limited to several strata in the whole deposit and, on the other hand, causes high investment cost for sophisticated dressing techniques, the following alternatives for the utilization of the sand can be recommended:

- Exclusive production of green and amber glass at low investment levels for dressing the raw material

  Mining should be done by wheel loaders. Sieves should be installed for separating grain sizes larger than 0.5 mm (alternatively 0.7 or 1.0 mm according to the layout of the plant). The fine portion, totalling 90% of the raw material, is suitable for glass production.

  In addition to the sieving system, a crusher should be installed for utilizing the crusts and the consolidated sand portions. By this additonal dressing, probably more than 95% of total reserves could be used.

- The very fine particles (Kaoline clay, $CaCO_3$, etc.) cause technological problems due to dusting in the glass making process. An air separator and wet screening for grain sizes smaller than 0.1 mm should therefore be installed in addition.

- Production of colourless and green glass

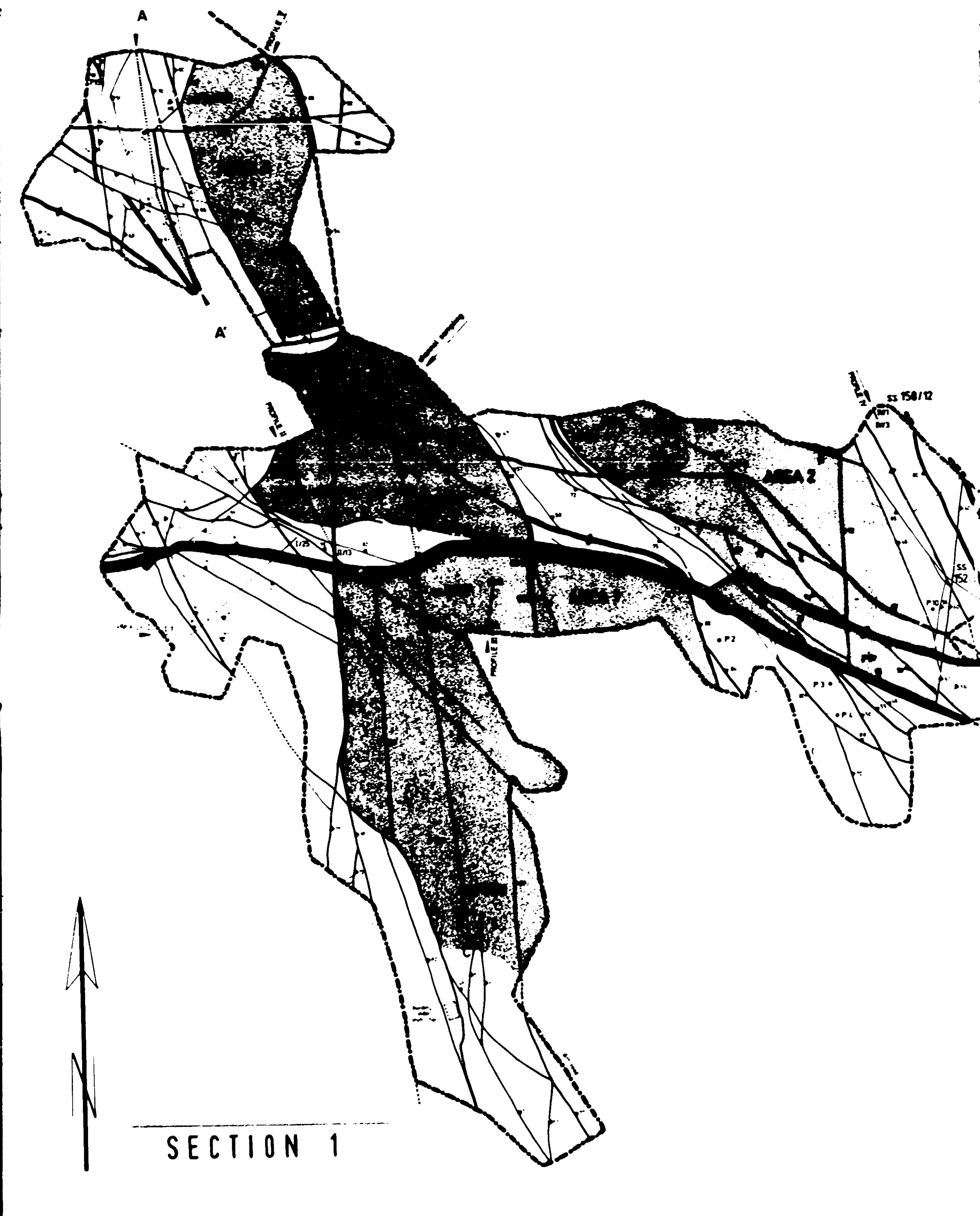
  From the many alternative dressing techniques, the following two are recommended:

a) A common wet process dressing gives the best sand qualities for the production of green glass after unselective mining (discontinous washing).

b) Selectively mined sands (light sands) for the production of colourless glass will have to be washed and brought to the desired purity by applying Archimedes screws and by magnetic separation. The discontinuous washing process calls for a large stock of the sand raw material.

The installation of two separate dressing lines for green and amber glass and for colourless glass would result in unacceptably high investment costs, unless the production capacity of the glass plant is so high that a large quantity of separately dressed raw sand could be used.

- Installation of a flotation plant
  Since the sand from Thagban is nearly free of feldspar, mica, pyrite etc., the installation of a cost-intensive (investment as well as operating cost) flotation plant does not seem to be needed for the production of colourless glass.



SECTION 1

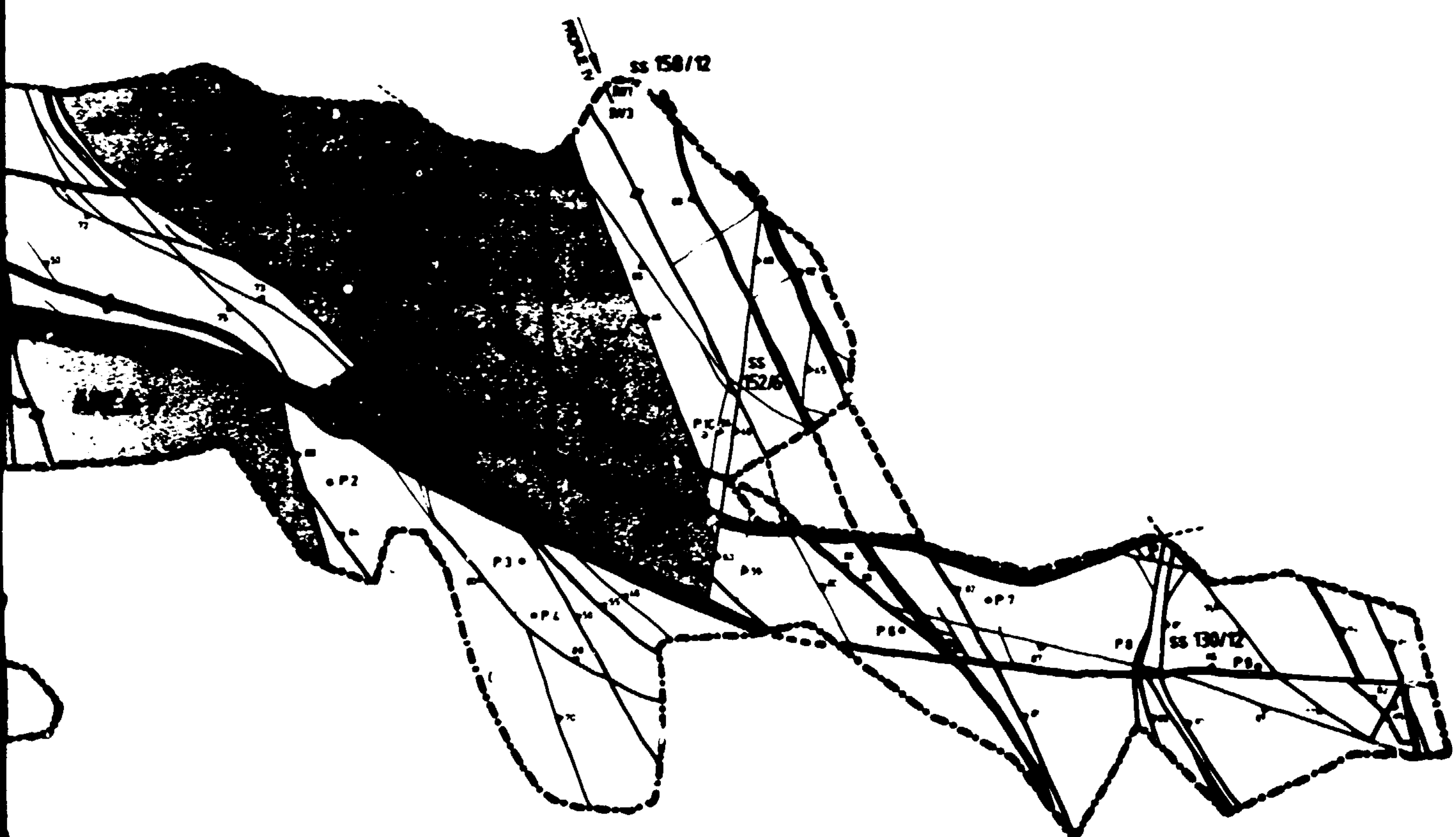
Annex 1	YEMEN ARAB REPUBLIC	JUNE 1981

GEOLOGICAL MAP
of the
SILICA SAND DEPOSIT AT THAGBAN

SCALE 1:2000

0 50 100m

prepared by F SCHUSSLER & G HIRNER — field work in May 1981



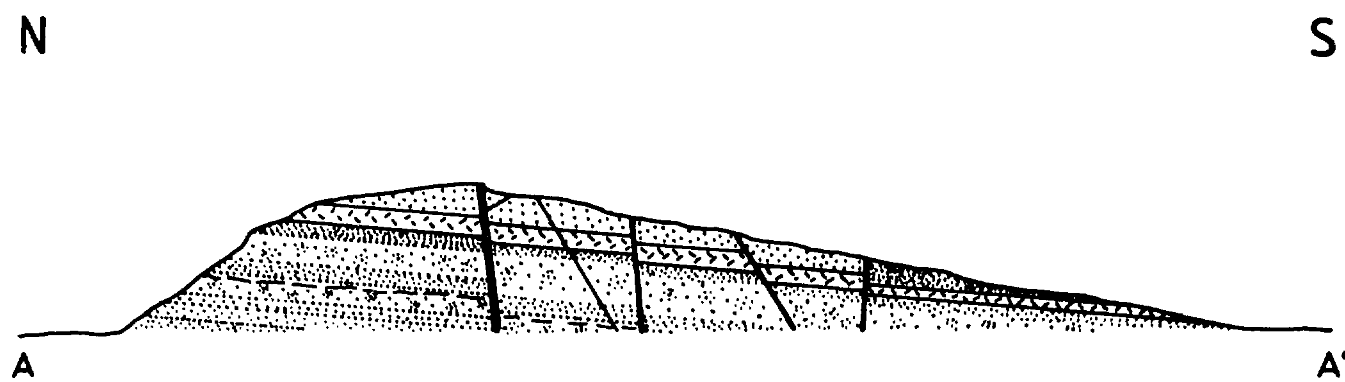
LEGEND

	boundary of the deposit
	basalt dykes (thickness of dykes drawn to scale)
	direction and degree of dipping
	vertical dipping
PROFILES I-V	sampling profiles apart from channel sampling
AA', BB', CC'	geological cross-sections
P1-P15	additional samples
S1-S15	channel samples
ss 000/00	strike and dip of sand layers
	boundaries of the areas 1-4

SECTION 2

CROSS SECTION

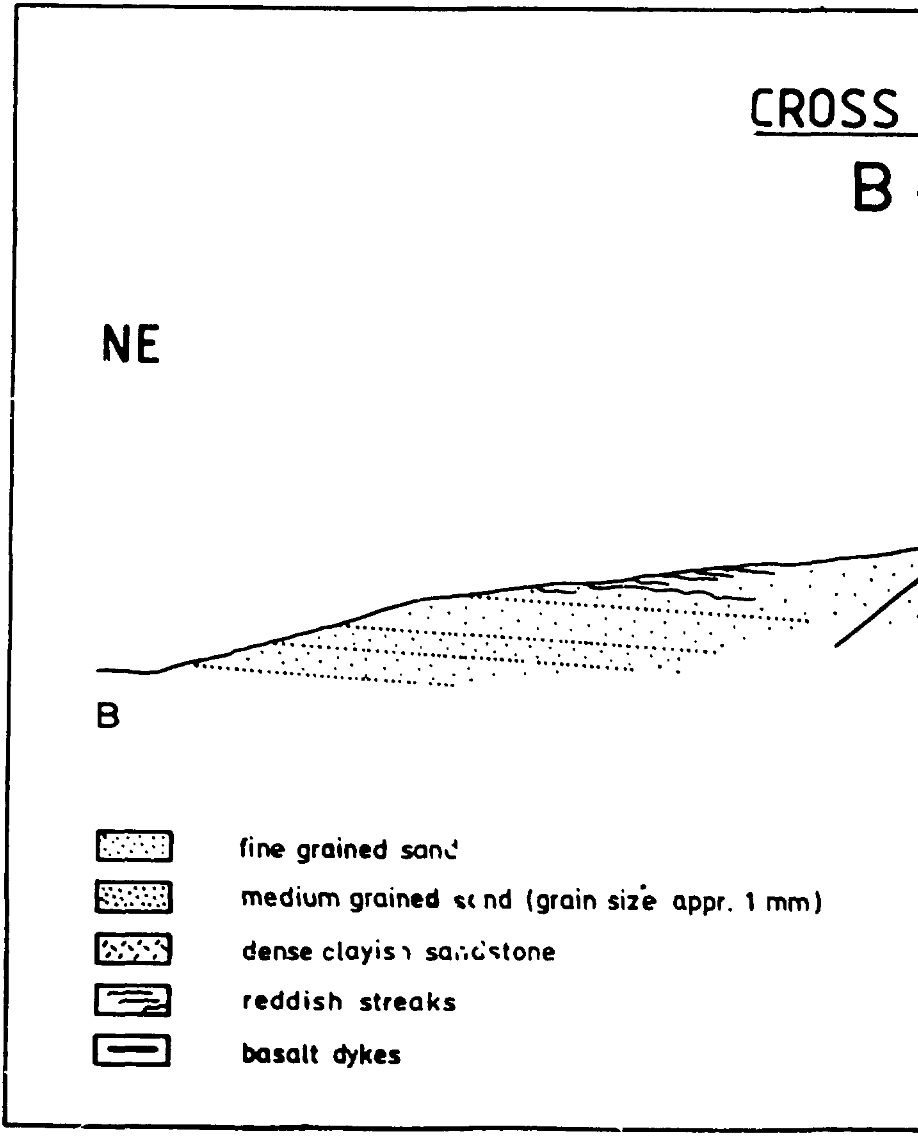
A - A'



- fine grained sand
- medium grained sand (grain size appr. 1 mm)
- fine grained sand with coarse intercalations
- dense clayish sandstone
- basalt dykes
- reddish streaks

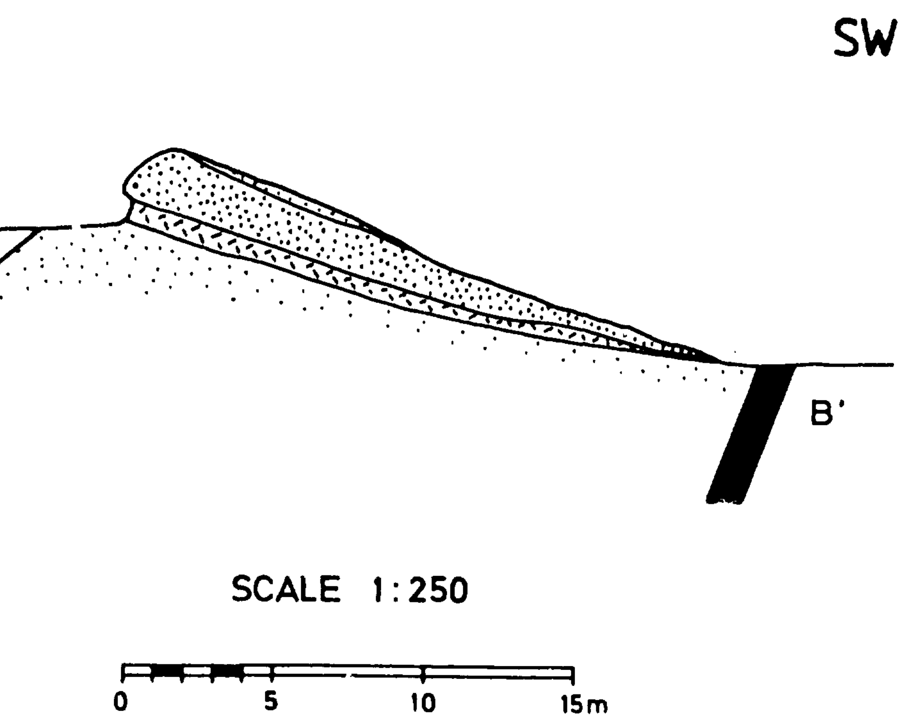
SCALE 1 : 1000

0 50m


CROSS
B
NE
B
fine grained sand
medium grained sand (grain size appr. 1 mm)
dense clayish sandstone
reddish streaks
basalt dykes

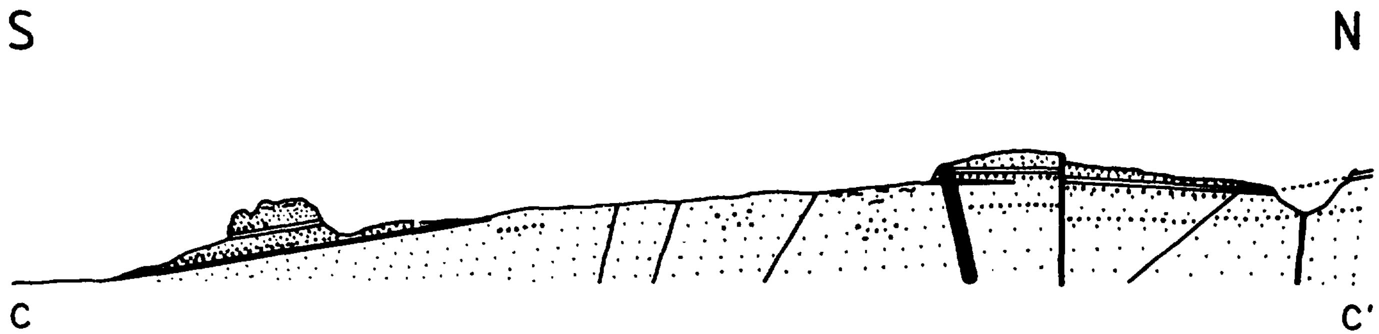
SECTION

- B'



Annex 3

CROSS SECTION
C - C'



- fine grained sand
- medium to coarse grained sand (appr. 1-10 mm)
- reddish, violet or brownish streaks
- dense clayish sandstone
- basalt dykes

SCALE 1:2000

Annex 4

ANNEX 5

GRAIN SIZE DISTRIBUTION

(SCREEN ANALYSIS)

	grain size (mm)	class residuals (g)	class residuals (%)	cumulative residuals (g)	cumulative residuals (%)
P_1	> 1,00	0,85	4,32	0,85	4,32
	1,00 - 0,5	5,60	28,47	6,45	32,79
	0,5 - 0,2	12,30	62,53	18,75	95,32
	0,2 - 0,125	0,80	4,07	19,55	99,39
	0,125- 0,09	0,10	0,51	19,66	99,90
	< 0,09	0,02	0,10	19,67	100
	Total	19,67	100	-	-

	grain size (mm)	class residuals (g)	class residuals (%)	cumulative residuals (g)	cumulative residuals (%)
P_2	> 1,00	0,65	3,33	0,65	3,33
	1,00 - 0,5	2,85	14,61	3,50	17,95
	0,5 - 0,2	12,25	62,82	15,75	80,77
	0,2 - 0,125	3,50	17,95	19,25	98,72
	0,125- 0,09	0,20	1,03	19,45	99,74
	< 0,09	0,05	0,26	19,50	100
	Total	19,50	100	-	-

	grain size (mm)	class residuals (g)	class residuals (%)	cumulative residuals (g)	cumulative residuals (%)
P_3	> 1,00	0,25	1,26	0,25	1,26
	1,00 - 0,5	2,40	12,09	2,65	13,35
	0,5 - 0,2	13,70	69,02	16,35	82,37
	0,2 - 0,125	3,20	16,12	19,55	98,49
	0,125- 0,09	0,10	0,50	19,65	98,99
	< 0,09	0,20	1,01	19,85	100
	Total	19,85	100	-	-

	grain size (mm)	class residuals (g)	class residuals (%)	cumulative residuals (g)	cumulative residuals (%)
P_4	> 1,00				
	1,00 - 0,5	**Quartzite (no adhesion)**			
	0,5 - 0,2				
	0,2 - 0,125	**No sieve analysis**			
	0,125- 0,09				
	< 0,09				

	grain size (mm)	class residuals (g)	class residuals (%)	cumulative residuals (g)	cumulative residuals (%)
P_5 (14 g)	> 1,00	0,40	2,88	0,40	2,88
	1,00 - 0,5	1,00	7,22	1,40	10,09
	0,5 - 0,2	9,50	68,49	10,90	78,59
	0,2 - 0,125	2,70	19,47	13,60	97,14
	0,125- 0,09	0,20	1,44	13,80	98,05
	< 0,09	0,07	0,50	13,87	100
	Total	13,87	100	-	-

	grain size (mm)	class residuals (g)	class residuals (%)	cumulative residuals (g)	cumulative residuals (%)
P_6	> 1,00	0,10	0,52	0,10	0,52
	1,00 - 0,5	1,70	8,83	1,80	9,35
	0,5 - 0,2	13,03	67,69	14,83	77,04
	0,2 - 0,125	4,12	21,40	18,95	98,44
	0,125- 0,09	0,27	1,40	19,22	99,84
	< 0,09	0,03	0,16	19,25	100
	Total	19,25	100	-	-

	grain size (mm)	class residuals (g)	class residuals (%)	cumulative residuals (g)	cumulative residuals (%)
P_7	> 1,00	0,26	1,33	0,26	1,33
	1,00 - 0,5	2,80	14,31	3,06	15,64
	0,5 - 0,2	15,00	76,69	18,06	92,33
	0,2 - 0,125	1,40	7,16	19,46	99,49
	0,125- 0,09	0,10	0,51	19,56	100
	< 0,09	-	-	-	-
	Total	19,56	100		

	grain size (mm)	class residuals (g)	class residuals (%)	cumulative residuals (g)	cumulative residuals (%)
P_8	> 1,00	1,54	7,93	1,54	7,93
	1,00 - 0,5	7	36,06	8,54	43
	0,5 - 0,2	10,60	54,61	19,14	98,61
	0,2 - 0,125	0,20	1,03	19,34	99,64
	0,125- 0,09	0,02	0,10	19,36	99,74
	< 0,09	0,05	0,26	19,41	100
	Total	19,45	100	-	-

P_9 (14g)

grain size (mm)	class residuals (g)	class residuals (%)	cumulative residuals (g)	cumulative residuals (%)
> 1,00	0,70	5,05	0,70	5,05
1,00 - 0,5	3,80	27,44	4,50	32,49
0,5 - 0,2	7,35	53,07	11,85	85,56
0,2 - 0,125	0,80	5,78	12,65	91,34
0,125- 0,09	0,50	3,61	13,15	94,95
< 0,09	0,70	5,05	13,85	100
Total	13,85	100	-	-

P_{10}

grain size (mm)	class residuals (g)	class residuals (%)	cumulative residuals (g)	cumulative residuals (%)
> 1,00	0,60	3,09	0,60	3,09
1,00 - 0,5	4,85	24,96	5,45	28,05
0,5 - 0,2	12,75	65,62	13,20	93
0,2 - 0,125	1,	5,15	19,20	98,82
0,125- 0,09	0,18	0,92	19,38	99,74
< 0,09	0,05	0,26	19,43	100
Total	19,43	100	-	-

P_{11}

grain size (mm)	class residuals (g)	class residuals (%)	cumulative residuals (g)	cumulative residuals (%)
> 1,00	0,05	0,26	0,05	0,26
1,00 - 0,5	1,5	7,71	1,55	7,97
0,5 - 0,2	13,	66,84	14,55	74,81
0,2 - 0,125	4,25	21,85	18,80	96,66
0,125- 0,09	0,35	1,80	19,15	98,46
< 0,09	0,3	1,54	19,45	100
Total	19,45	100	-	-

P_{12}

grain size (mm)	class residuals (g)	class residuals (%)	cumulative residuals (g)	cumulative residuals (%)
> 1,00	0,15	0,78	0,15	0,78
1,00 - 0,5	5,90	30,49	6,05	31,27
0,5 - 0,2	11,70	60,47	17,75	91,73
0,2 - 0,125	1,30	6,72	19,05	98,45
0,125- 0,09	0,10	0,52	19,15	98,97
< 0,09	0,20	1,02	19,35	100
Total	19,35	100	-	-

P 13

grain size (mm)	class residuals (g)	class residuals (%)	cumulative residuals (g)	cumulative residuals (%)
> 1,00	0,20	1,04	0,20	1,04
1,00 - 0,5	5,25	27,27	5,45	28,31
0,5 - 0,2	9,00	46,75	14,45	75,06
0,2 - 0,125	3,60	18,70	18,05	93,77
0,125- 0,09	0,55	2,86	18,60	96,62
< 0,09	0,65	3,38	19,25	100
Total	19,25	100	-	-

P 14

grain size (mm)	class residuals (g)	class residuals (%)	cumulative residuals (g)	cumulative residuals (%)
> 1,00	0,67	3,42	0,67	3,42
1,00 - 0,5	4,60	23,51	5,27	26,93
0,5 - 0,2	12,20	62,34	17,47	89,27
0,2 - 0,125	1,70	8,69	19,17	97,96
0,125- 0.09	0,19	0,97	19,36	98,93
< 0,09	0,21	1,07	19,57	100
Total	19,57	100	-	-

P 15

grain size (mm)	class residuals (g)	class residuals (%)	cumulative residuals (g)	cumulative residuals (%)
> 1,00	8,30	42,87	8,30	42,87
1,00 - 0,5	9,64	49,79	17,94	92,67
0,5 - 0,2	1,10	5,68	19,04	98,35
0,2 - 0,125	0,25	1,29	19,29	99,64
0,125- 0,09	0,03	0,16	19,32	99,79
< 0,09	0,04	0,21	19,36	100
Total	19,36	100	-	-

P 16

grain size (mm)	class residuals (g)	class residuals (%)	cumulative residuals (g)	cumulative residuals (%)
> 1,00	0,67	8,88	1,74	8,88
1,00 - 0,5	4,60	30,37	7,69	39,25
0,5 - 0,2	12,20	56,66	18,79	95,92
0,2 - 0,125	1,70	2,81	19,34	98,72
0,125- 0,09	0,19	0,51	19,44	99,23
< 0,09	0,21	0,77	19,59	100
Total	19,15	100	-	-

P17

grain size (mm)	class residuals (g)	class residuals (%)	cumulative residuals (g)	cumulative residuals (%)
> 1,00	4,40	22,98	4,40	22,98
1,00 - 0,5	8,68	45,32	13,08	68,30
0,5 - 0,2	5,63	29,40	18,71	97,70
0,2 - 0,125	0,36	1,88	19,07	99,59
0,125- 0,09	0,03	0,16	19,10	99,74
< 0,09	0,05	0,26	19,15	100
Total	19,15	100	-	-

P18

grain size (mm)	class residuals (g)	class residuals (%)	cumulative residuals (g)	cumulative residuals (%)
> 1,00	0,1	0,51	0,1	0,51
1,00 - 0,5	2	10,30	2,1	10,81
0,5 - 0,2	3,80	19,57	5,90	30,38
0,2 - 0,125	10	51,50	15,90	81,87
0,125- 0,09	2,42	12,46	18,30	94,23
< 0,09	1,1	5,66	19,42	100
Total	19,42	100	-	-

P19

grain size (mm)	class residuals (g)	class residuals (%)	cumulative residuals (g)	cumulative residuals (%)
> 1,00	0,25	1,29	0,25	1,29
1,00 - 0,5	7,65	39,23	7,90	40,62
0,5 - 0,2	10,0	51,42	17,90	92,03
0,2 - 0,125	0,95	4,88	18,85	96,92
0,125- 0,09	0,15	0,77	19	97,69
< 0,09	0,45	2,31	19,45	100
Total	19,45	100	-	-

P20

grain size (mm)	class residuals (g)	class residuals (%)	cumulative residuals (g)	cumulative residuals (%)
> 1,00	0,20	1,01	0,20	1,01
1,00 - 0,5	1,65	8,29	1,85	9,30
0,5 - 0,2	12,65	63,57	14,50	72,86
0,2 - 0,125	4,80	24,11	19,30	96,98
0,125- 0,09	0,30	1,51	19,60	98,49
< 0,09	0,30	1,51	19,90	100
Total	19,90	100	-	-

I1

grain size (mm)	class residuals (g)	class residuals (%)	cumulative residuals (g)	cumulative residuals (%)
> 1,00	0,20	1,04	0,20	1,04
1,00 - 0,5	4,65	24,13	4,85	25,17
0,5 - 0,2	13,73	71,25	18,58	96,42
0,2 - 0,125	0,50	2,59	19,08	99,01
0,125- 0,09	0,05	0,26	19,13	99,27
< 0,09	0,14	0,73	19,27	100
Total	19,27	100	-	-

I2

grain size (mm)	class residuals (g)	class residuals (%)	cumulative residuals (g)	cumulative residuals (%)
> 1,00	3,10	15,74	3,10	15,74
1,00 - 0,5	8,75	44,42	11,85	60,15
0,5 - 0,2	6,10	30,96	17,95	91,12
0,2 - 0,125	1,05	5,33	19	96,45
0,125- 0,09	0,25	1,27	19,25	97,72
< 0,09	0,45	2,27	19,70	100
Total	19,60	100	-	-

I3

grain size (mm)	class residuals (g)	class residuals (%)	cumulative residuals (g)	cumulative residuals (%)
> 1,00	0,20	1,03	0,20	1,02
1,00 - 0,5	1,45	7,42	1,65	8,45
0,5 - 0,2	12,65	64,77	14,30	73,22
0,2 - 0,125	4,50	23,04	18,80	96,26
0,125- 0,09	0,40	2,05	19,20	98,31
< 0,09	0,33	1,69	19,53	100
Total	19,53	100	-	-

I4

grain size (mm)	class residuals (g)	class residuals (%)	cumulative residuals (g)	cumulative residuals (%)
> 1,00	0,70	3,70	0,70	3,70
1,00 - 0,5	3,20	16,93	3,90	20,63
0,5 - 0,2	13,85	73,28	17,75	93,92
0,2 - 0,125	0,65	3,44	18,40	97,35
0,125- 0,09	0,20	1,06	18,60	98,41
< 0,09	0,30	1,59	18,90	100
Total	18,90	100	-	-

I5

grain size (mm)	class residuals (g)	class residuals (%)	cumulative residuals (g)	cumulative residuals (%)
> 1,00	1,00	5,18	1,00	5,18
1,00 - 0,5	3,20	16,58	4,20	21,76
0,5 - 0,2	12,75	66,06	16,95	87,82
0,2 - 0,125	1,70	8,81	18,65	96,63
0,125- 0,09	0,35	1,81	19,00	98,45
< 0,09	0,30	1,56	19,30	100
Total	19,30	100	-	-

I6

grain size (mm)	class residuals (g)	class residuals (%)	cumulative residuals (g)	cumulative residuals (%)
> 1,00				
1,00 - 0,5				
0,5 - 0,2	(missing)			
0,2 - 0,125				
0,125- 0,09				
< 0,09				
Total				

I7

grain size (mm)	class residuals (g)	class residuals (%)	cumulative residuals (g)	cumulative residuals (%)
> 1,00	1,30	6,65	1,30	6,65
1,00 - 0,5	3,10	15,85	4,40	22.51
0,5 - 0,2	11,45	58,57	15,85	81,07
0,2 - 0,125	3,00	13,35	18,95	96,42
0,125- 0,09	0,35	1,79	19,20	98,21
< 0,09	0,35	1,79	19,55	100
Total	19,55	100	-	-

I8

grain size (mm)	class residuals (g)	class residuals (%)	cumulative residuals (g)	cumulative residuals (%)
> 1,00	2,60	13,10	2,60	13,10
1,00 - 0,5	8,30	41,81	10,90	54,91
0,5 - 0,2	7,25	36,53	18,15	91,44
0,2 - 0,125	0,90	4,53	19,05	95,97
0,125- 0,09	0,35	1,76	19,40	97,73
< 0,09	0,45	2,27	19,85	100
Total	19,85	100	-	-

I9

grain size (mm)	class residuals (g)	class residuals (%)	cumulative residuals (g)	cumulative residuals (%)
> 1,00	1,50	7,51	1,50	7,51
1,00 - 0,5	1,30	6,51	2,80	14,02
0,5 - 0,2	14,35	71,86	17,15	85,88
0,2 - 0,125	2,50	12,52	19,65	98,40
0,125- 0,09	0,25	1,25	19,90	99,65
< 0,09	0,07	0,35	19,97	100
Total	19,97	100	-	-

I10

grain size (mm)	class residuals (g)	class residuals (%)	cumulative residuals (g)	cumulative residuals (%)
> 1,00	0,90	4,59	0,90	4,59
1,00 - 0,5	1,20	6,12	2,10	10,71
0,5 - 0,2	5,35	27.30	7,45	38,01
0,2 - 0,125	9,80	50,00	17,25	88,01
0,125- 0,09	1,65	8,42	18,90	96,43
< 0,09	0,70	3,57	19,60	100
Total	19,60	100	-	-

I11

grain size (mm)	class residuals (g)	class residuals (%)	cumulative residuals (g)	cumulative residuals (%)
> 1,00	0,30	1,52	0,30	1,52
1,00 - 0,5	0,75	3,80	1,05	5,32
0,5 - 0,2	2,80	14,18	3,85	19,48
0,2 - 0,125	12,70	64,30	16,55	83,80
0,125- 0,09	2,50	12,66	19,05	96,46
< 0,09	0,70	3,54	19,75	100
Total	19,75	100	-	-

I12

grain size (mm)	class residuals (g)	class residuals (%)	cumulative residuals (g)	cumulative residuals (%)
> 1,00	2,08	10,63	2,08	10,63
1,00 - 0,5	6,00	30,67	8,08	41,31
0,5 - 0,2	10,00	51,13	18,08	92,43
0,2 - 0,125	1,10	5,62	19,18	98,06
0,125- 0,09	0,13	0,66	19,31	98,72
< 0,09	0,25	1,29	19,56	100
Total	19,56	100	-	-

I13 (15g)

grain size (mm)	class residuals (g)	class residuals (%)	cumulative residuals (g)	cumulative residuals (%)
> 1,00	2,90	19,86	2,90	19,86
1,00 - 0,5	4,70	32,19	7,60	52,05
0,5 - 0,2	5,20	35,62	12,80	87,67
0,2 - 0,125	1,10	7,54	13,90	95,21
0,125- 0,09	0,20	1,37	14,10	96,58
< 0,09	0,50	3,42	14,60	100
Total	14,60	100	–	–

I14

grain size (mm)	class residuals (g)	class residuals (%)	cumulative residuals (g)	cumulative residuals (%)
> 1,00	0,60	3,07	0,60	3,07
1,00 - 0,5	8,15	41,73	8,75	44,80
0,5 - 0,2	9,90	50,69	18,65	95,49
0,2 - 0,125	0,80	4,10	19,45	99,59
0,125- 0,09	0,05	0,26	19,50	99,85
< 0,09	0,03	0,15	19,53	100
Total	19,53	100	-	-

I15

grain size (mm)	class residuals (g)	class residuals (%)	cumulative residuals (g)	cumulative residuals (%)
> 1,00	0,25	1,27	0,25	1,27
1,00 - 0,5	3,95	20	4,20	21,27
0,5 - 0,2	6,95	35,19	11,15	56,46
0,2 - 0,125	3,85	19,49	15	75,95
0,125- 0,09	1,60	8,10	16,60	84,05
< 0,09	3,15	15,95	19,75	100
Total	19,75	100	-	-

I16

grain size (mm)	class residuals (g)	class residuals (%)	cumulative residuals (g)	cumulative residuals (%)
> 1,00	1,10	5,74	1,10	5,74
1,00 - 0,5	4,90	25,59	6,00	31,33
0,5 - 0,2	8,30	43,34	14,30	74,67
0,2 - 0,125	2,85	14,88	17,15	89,56
0,125- 0,09	0,85	4,44	18	93,99
< 0,09	1,15	6,01	19,15	100
Total	19,15	100	-	-

I 17

grain size (mm)	class residuals (g)	class residuals (%)	cumulative residuals (g)	cumulative residuals (%)
> 1,00	1,40	7,22	1,40	7,22
1,00 - 0,5	8,70	44,85	10,10	52,06
0,5 - 0,2	7,75	39,94	17,85	92,01
0,2 - 0,125	1,00	5,15	18,85	97,16
0,125- 0,09	0,30	1,55	19,15	98,71
< 0,09	0,25	1,29	19,40	100
Total	19,40	100	-	-

I 18

grain size (mm)	class residuals (g)	class residuals (%)	cumulative residuals (g)	cumulative residuals (%)
> 1,00	0,55	2,82	0,55	2,82
1,00 - 0,5	2,80	14,30	3,35	17,11
0,5 - 0,2	8,80	44,94	12,15	62,05
0,2 - 0,125	5,40	27,58	17,55	89,63
0,125- 0,09	1,25	6,38	18,80	96,02
< 0,09	0,78	3,98	19,58	100
Total	19,58	100	-	-

I 19

grain size (mm)	class residuals (g)	class residuals (%)	cumulative residuals (g)	cumulative residuals (%)
> 1,00	0,45	2,26	0,45	2,26
1,00 - 0,5	8,05	40,45	8,50	42,71
0,5 - 0,2	6,25	31,41	14,75	74,12
0,2 - 0,125	2,45	12,31	17,20	86,43
0,125- 0,09	0,95	4,77	18,15	91,21
< 0,09	1,75	8,79	19,90	100
Total	19,90	100	-	-

I 20

grain size (mm)	class residuals (g)	class residuals (%)	cumulative residuals (g)	cumulative residuals (%)
> 1,00	0,05	0,25	0,05	0,25
1,00 - 0,5	6,55	33,11	6,60	33,37
0,5 - 0,2	6,40	32,36	13	65,72
0,2 - 0,125	2,55	12,89	15,55	78,61
0,125- 0,09	1,23	6,22	16,78	84,83
< 0,09	3,00	15,17	19,78	100
Total	19,78	100	-	-

grain size (mm)	class residuals (g)	class residuals (%)	cumulative residuals (g)	cumulative residuals (%)
> 1,00	0,05	0,26	0,05	0,26
1,00 - 0,5	5,90	30,89	5,95	31,15
0,5 - 0,2	7,15	37,43	13,10	68,59
0,2 - 0,125	2,60	13,62	15,70	82,20
0,125- 0,09	1,25	6,54	16,95	88,74
< 0,09	2,15	11,26	19,10	100
Total	19,10	100	-	-

I_{21}

grain size (mm)	**class residuals** (g)	(%)	**cumulative residuals** (g)	(%)
> 1,00	0,45	2,34	0,45	2,34
1,00 - 0,5	5,90	30,70	6,35	33,04
0,5 - 0,2	11,77	61,24	18,12	94,28
0,2 - 0,125	0,70	3,64	18,82	97,92
0,125- 0,09	0,15	0,78	18,97	98,70
< 0,09	0,25	1,30	19,22	100
Total	19,22	100	-	-

I_{22}

grain size (mm)	**class residuals** (g)	(%)	**cumulative residuals** (g)	(%)
> 1,00	0,32	1,64	0,32	1,64
1,00 - 0,5	2,00	10,26	2,32	11,86
0,5 - 0,2	14,00	71,79	16,32	83,69
0,2 - 0,125	2,90	14,87	19,22	98,56
0,125- 0,09	0,10	0,51	19,32	99,08
< 0,09	0,18	0,92	19,50	100
Total	19,50	100	-	-

I_{23}

II1

grain size (mm)	class residuals (g)	class residuals (%)	cumulative residuals (g)	cumulative residuals (%)
> 1,00	1,75	9,02	1,75	9,02
1,00 - 0,5	5,60	28,87	7,35	37,89
0,5 - 0,2	10,60	54,64	17,95	92,53
0,2 - 0,125	1,05	5,41	19	97,94
0,125- 0,09	0,15	0,77	19,15	98,71
< 0,09	0,25	1,29	19,40	100
Total	19,40	100	-	-

II2

grain size (mm)	class residuals (g)	class residuals (%)	cumulative residuals (g)	cumulative residuals (%)
> 1,00	5,35	27,23	5,35	27,23
1,00 - 0,5	9,50	48,35	14,85	75,57
0,5 - 0,2	3,35	17,04	18,20	17,05
0,2 - 0,125	0,70	3,56	18,90	96,18
0,125- 0,09	0,30	1,53	19,20	97,71
< 0,09	0,45	2,29	19,65	100
Total	19,65	100	-	-

II3

grain size (mm)	class residuals (g)	class residuals (%)	cumulative residuals (g)	cumulative residuals (%)
> 1,00	1,70	8,70	1,70	8,70
1,00 - 0,5	6,75	34,53	8,45	43,22
0,5 - 0,2	5,25	26,85	13,70	70,08
0,2 - 0,125	2,60	13,30	16,30	83,38
0,125- 0,09	1,15	5,88	17,45	89,26
< 0,09	2,10	10,74	19,55	100
Total	19,55	100	-	-

II4

grain size (mm)	class residuals (g)	class residuals (%)	cumulative residuals (g)	cumulative residuals (%)
> 1,00	0,02	0,11	0,02	0,11
1,00 - 0,5	2,00	10,60	2,02	10,70
0,5 - 0,2	4,20	22,26	6.22	32,96
0,2 - 0,125	4,30	22,78	10,52	55,75
0,125- 0,09	4,50	23,85	15,02	79,60
< 0,09	3,85	20,40	18,87	100
Total	18,87	100	-	-

II$_5$

grain size (mm)	class residuals (g)	class residuals (%)	cumulative residuals (g)	cumulative residuals (%)
> 1,00	1,35	6,94	1,35	6,94
1,00 - 0,5	4,40	22,63	5,75	29,58
0,5 - 0,2	12,30	63,27	18,05	92,85
0,2 - 0,125	1,15	5,92	19,20	98,77
0,125- 0,09	0,04	0,21	19,24	98,97
< 0,09	0,20	1,03	19,44	100
Total	19,44	100	-	-

II$_6$

grain size (mm)	class residuals (g)	class residuals (%)	cumulative residuals (g)	cumulative residuals (%)
> 1,00	0,30	1,54	0,30	1,54
1,00 - 0,5	1,55	7,97	1,85	9,51
0,5 - 0,2	9,85	50,65	11,70	60,15
0,2 - 0,125	6,45	33,16	18,15	93,32
0,125- 0,09	0,70	3,60	18,85	96,92
< 0,09	0,60	3,08	19,45	100
Total	19,45	100	-	-

II$_7$

grain size (mm)	class residuals (g)	class residuals (%)	cumulative residuals (g)	cumulative residuals (%)
> 1,00	0,02	0,11	0,02	0,11
1,00 - 0,5	5,70	29,97	5,72	30,07
0,5 - 0,2	4,60	24,18	10,32	54,26
0,2 - 0,125	2,25	11,83	12,57	66,09
0,125- 0,09	1,75	9,20	14,32	75,29
< 0,09	4,70	24,71	19,02	100
Total	19,02	100	-	-

II$_8$

grain size (mm)	class residuals (g)	class residuals (%)	cumulative residuals (g)	cumulative residuals (%)
> 1,00	1,50	7,78	1,50	7,78
1,00 - 0,5	6,95	36,09	8,45	43,87
0,5 - 0,2	10,55	54,78	19	98,65
0,2 - 0,125	0,15	0,78	19,15	99,43
0,125- 0,09	0,07	0,36	19,22	99,79
< 0,09	0,04	0,21	19,26	100
Total	19,26	100	-	-

II_9

grain size (mm)	class residuals (g)	class residuals (%)	cumulative residuals (g)	cumulative residuals (%)
> 1,00	2,55	13,14	2,55	13,14
1,00 - 0,5	6,60	34,02	9,15	47,16
0,5 - 0,2	9,20	47,42	18,35	94,59
0,2 - 0,125	0,70	3,61	19,05	98,20
0,125- 0,09	0,05	0,26	19,10	98,45
< 0,09	0,30	1,55	19,40	100
Total	19,40	100	-	-

II_{10}

grain size (mm)	class residuals (g)	class residuals (%)	cumulative residuals (g)	cumulative residuals (%)
> 1,00	-	-	-	-
1,00 - 0,5	0,15	0,77	0,15	0,77
0,5 - 0,2	13,55	69,42	13,70	70,18
0,2 - 0,125	5,65	28,94	19,35	99,13
0,125- 0,09	0,15	0,77	19,50	99,90
< 0,09	0,02	0,10	19,52	100
Total	19,52	100	-	-

II_{11}

grain size (mm)	class residuals (g)	class residuals (%)	cumulative residuals (g)	cumulative residuals (%)
> 1,00	-	-	-	-
1,00 - 0,5	4,25	21,57	4,25	21,57
0,5 - 0,2	9,65	48,98	13,90	70,56
0,2 - 0,125	3,15	15,99	17,05	86,55
0,125- 0,09	1,05	5,34	18,10	91,88
< 0,09	1,60	8,12	19,70	100
Total	19,70	100	-	-

II_{12} (15g)

grain size (mm)	class residuals (g)	class residuals (%)	cumulative residuals (g)	cumulative residuals (%)
> 1,00	0,50	3,34	0,50	3,34
1,00 - 0,5	3,00	20,00	3,50	23,35
0,5 - 0,2	10,20	68,05	13,70	91,39
0,2 - 0,125	1,10	7,34	14,80	98,39
0,125- 0,09	0,09	0,60	14,89	99,33
< 0,09	0,10	0,67	14,99	100
Total	14,99	100	-	-

II$_{13}$

grain size (mm)	class residuals (g)	class residuals (%)	cumulative residuals (g)	cumulative residuals (%)
> 1,00	4,20	21,37	4,20	21,37
1,00 - 0,5	9,50	48,35	13,70	69,72
0,5 - 0,2	4,30	21,88	18,00	91,60
0,2 - 0,125	0,90	4,58	18,90	96,18
0,125- 0,09	0,30	1,53	19,20	97,71
< 0,09	0,45	2,29	19,65	100
Total	19,65	98,25	-	-

III$_1$

grain size (mm)	class residuals (g)	class residuals (%)	cumulative residuals (g)	cumulative residuals (%)
> 1,00	2,40	12,60	2,40	12,60
1,00 - 0,5	7,65	40,16	10,05	52,76
0,5 - 0,2	7,55	39,63	17,60	92,39
0,2 - 0,125	1,20	6,30	18,80	98,69
0,125 - 0,09	0,05	0,26	18,85	98,95
< 0,09	0,20	1,05	19,05	100
Total	19,05	100	-	-

III$_2$

grain size (mm)	class residuals (g)	class residuals (%)	cumulative residuals (g)	cumulative residuals (%)
> 1,00	0,70	3,52	0,70	3,63
1,00 - 0,5	3,65	18,93	4,35	22,56
0,5 - 0,2	13,70	71,06	18,05	93,62
0,2 - 0,125	1,20	6,22	19,25	99,84
0,125 - 0,09	0,03	0,16	19,28	100
< 0,09	-	-	-	-
Total	19,28	100	-	-

III$_3$

grain size (mm)	class residuals (g)	class residuals (%)	cumulative residuals (g)	cumulative residuals (%)
> 1,00	0,10	0,52	0,10	0,52
1,00 - 0,5	1,70	8,81	1,80	3,32
0,5 - 0,2	14,30	74,05	16,10	83,38
0,2 - 0,125	3,05	15,79	19,15	99,17
0,125 - 0,09	0,[illegible]	0,52	19,25	99,69
< 0,09	0,06	0,31	19,31	100
Total	19,31	100	-	-

III$_4$

grain size (mm)	class residuals (g)	class residuals (%)	cumulative residuals (g)	cumulative residuals (%)
> 1,00	-	-	-	-
1,00 - 0,5	2,50	12,66	2,50	12,66
0,5 - 0,2	13,60	68,86	16,10	81,52
0,2 - 0,125	2,55	12,91	18,65	94,43
0,125 - 0,09	0,40	2,03	19,05	96,46
< 0,09	0,70	3,54	19,75	100
Total	19,75	100	-	-

III$_5$

grain size (mm)	class residuals (g)	class residuals (%)	cumulative residuals (g)	cumulative residuals (%)
> 1,00	0,95	4,91	0,95	4,91
1,00 - 0,5	9,70	50,18	10,65	55,10
0,5 - 0,2	8,25	42,68	18,90	97,78
0,2 - 0,125	0,35	1,81	19,25	98,59
0,125 - 0,09	0,05	0,26	19,30	99,84
< 0,09	0,03	0,16	19,33	100
Total	19,33	100	-	-

III$_6$

grain size (mm)	class residuals (g)	class residuals (%)	cumulative residuals (g)	cumulative residuals (%)
> 1,00	0,15	0,77	0,15	0,77
1,00 - 0,5	2,30	11,82	2,45	12,60
0,5 - 0,2	6,30	32,39	8,75	44,99
0,2 - 0,125	7,75	39,85	16,50	84,83
0,125 - 0,09	[illegible],75	9,00	18,25	93,83
< 0,09	1,20	6,17	19,45	100
Total	19,45	100	-	-

III$_7$

grain size (mm)	class residuals (g)	class residuals (%)	cumulative residuals (g)	cumulative residuals (%)
> 1,00	0,15	0,75	0,15	0,75
1,00 - 0,5	4,90	24,56	5,05	25,31
0,5 - 0,2	6,85	34,34	11,90	59,65
0,2 - 0,125	3,75	18,80	15,65	78,45
0,125 - 0,09	1,80	9,02	17,45	87,47
< 0,09	2,50	12,53	19,95	100
Total	19,95	100	-	-

III$_8$

grain size (mm)	class residuals (g)	class residuals (%)	cumulative residuals (g)	cumulative residuals (%)
> 1,00	1,05	5,36	1,05	5,36
1,00 - 0,5	8,30	42,35	9,35	47,70
0,5 - 0,2	9,30	47,45	18,65	95,15
0,2 - 0,125	0,65	3,32	19,30	98,47
0,125 - 0,09	0,15	0,76	19,45	99,23
< 0,09	0,15	0,76	19,60	100
Total	19,60	100	-	-

III_g

grain size	class residuals		cumulative residuals	
(mm)	(g)	(%)	(g)	(%)
> 1,00	0,85	4,35	0,85	4,35
1,00 - 0,5	5,60	28,72	6,45	33,08
0,5 - 0,2	12,00	61,54	18,45	94,62
0,2 - 0,125	0,95	4,87	19,40	99,49
0,125- 0,09	0,05	0,26	19,45	99,74
< 0,09	0,05	0,26	19,50	100
Total	19,50	100	-	-

IV$_1$

grain size (mm)	class residuals (g)	class residuals (%)	cumulative residuals (g)	cumulative residuals (%)
> 1,00	0,05	0,26	0,05	0,26
1,00 - 0,5	3,50	17,91	3,55	18,16
0,5 - 0,2	5,50	28,13	9,05	46,29
0,2 - 0,125	3,75	19,18	12,80	65,47
0,125 - 0,09	2,20	11,25	15,00	76,73
< 0,09	4,55	23,27	19,55	100
Total	19,55	100	-	-

IV$_2$

grain size (mm)	class residuals (g)	class residuals (%)	cumulative residuals (g)	cumulative residuals (%)
> 1,00	-	-	-	-
1,00 - 0,5	3,10	15,82	3,10	15,82
0,5 - 0,2	7,25	36,99	10,35	52,81
0,2 - 0,125	4,60	23,47	14,95	76,28
0,125 - 0,09	1,90	9,69	16,85	86,97
< 0,09	2,75	14,03	19,60	100
Total	19,60	100	-	-

IV$_3$

grain size (mm)	class residuals (g)	class residuals (%)	cumulative residuals (g)	cumulative residuals (%)
> 1,00	0,75	3,76	0,75	3,76
1,00 - 0,5	6,15	30,83	6,90	34,59
0,5 - 0,2	12,05	60,40	18,95	94,99
0,2 - 0,125	0,55	2,76	19,50	97,74
0,125 - 0,09	0,20	1	19,70	98,75
< 0,09	0,25	1,25	19,95	100
Total	19,95	100	-	-

V_1

grain size (mm)	class residuals (g)	class residuals (%)	cumulative residuals (g)	cumulative residuals (%)
> 1,00	0,05	0,26	0,05	0,26
1,00 - 0,5	2,60	13,47	2,65	13,73
0,5 - 0,2	12,85	66,58	15,50	80,31
0,2 - 0,125	3,30	17,10	18,80	97,41
0,125- 0,09	0,30	1,55	19,10	98,96
< 0,09	0,20	1,04	19,30	100
Total	19,30	100	-	-

V_2

grain size (mm)	class residuals (g)	class residuals (%)	cumulative residuels (g)	cumulative residuels (%)
> 1,00	2,35	12,34	2,35	12,34
1,00 - 0,5	8,10	42,52	10,45	54,86
0,5 - 0,2	5,80	30,45	16,25	85,30
0,2 - 0,125	2,55	13,39	18,80	98,69
0,125- 0,09	0,20	1,04	19	99,74
< 0,09	0,05	0,26	19,05	100
Total	19,05	100	-	

V_3

grain size (mm)	class residuals (g)	class residuals (%)	cumulative residuals (g)	cumulative residuals (%)
> 1,00	0,70	3,65	0,70	3,65
1,00 - 0,5	3,20	16,67	3,90	20,31
0,5 - 0,2	11,95	62,24	15,85	82,55
0,2 - 0,125	2,95	15,36	18,80	97,92
0,125- 0,09	0,30	1,56	19,10	99,48
< 0,09	0,10	0,52	19,20	100
Total	19,20	96,0	-	-

V_4

grain size (mm)	class residuals (g)	class residuals (%)	cumulative residuals (g)	cumulative residuals (%)
> 1,00	1,60	8,10	1,60	8,10
1,00 - 0,5	7,70	38,99	9,30	47,09
0,5 - 0,2	8,45	42,78	17,75	89,87
0,2 - 0,125	1,45	7,34	19,20	97,22
0,125- 0,09	0,25	1,27	19,45	98,48
< 0,09	0,30	1,52	19,75	100
Total	19,75	98,75	-	-

V5

grain size (mm)	class residuals (g)	class residuals (%)	cumulative residuals (g)	cumulative residuals (%)
> 1,00	0,30	1,52	0,30	1,52
1,00 - 0,5	3,90	19,75	4,20	21,27
0,5 - 0,2	14,35	72,66	18,55	93,92
0,2 - 0,125	0,70	3,54	19,25	97,47
0,125- 0,09	0,20	1,02	19,45	98,48
< 0,09	0,30	1,52	19,75	100
Total	19,75	100	-	-

V6

grain size (mm)	class residuals (g)	class residuals (%)	cumulative residuals (g)	cumulative residuals (%)
> 1,00	-	-	-	-
1,00 - 0,5	1,40	7,28	1,40	7,28
0,5 - 0,2	9,50	49,48	10,90	56,77
0,2 - 0,125	4,30	22,40	15,20	79,17
0,125- 0,09	2,00	10,42	17,20	89,58
< 0,09	2,00	10,42	19,20	100
Total	19,20	100	-	-

V7

grain size (mm)	class residuals (g)	class residuals (%)	cumulative residuals (g)	cumulative residuals (%)
> 1,00	0,40	2,09	0,40	2,09
1,00 - 0,5	10,45	54,71	10,85	56,81
0,5 - 0,2	8,05	42,16	18,90	98,95
0,2 - 0,125	0,10	0,52	19,00	99,48
0,125- 0,09	0,05	0,26	19,05	99,74
< 0,09	0,05	0,26	19,10	100
Total	19,10	100	-	-

V8

grain size (mm)	class residuals (g)	class residuals (%)	cumulative residuals (g)	cumulative residuals (%)
> 1,00	0,30	1,53	0,30	1,53
1,00 - 0,5	2,15	10,94	2,45	12,47
0,5 - 0,2	10,10	51,40	12,55	63,87
0,2 - 0,125	6,60	33,59	19,15	97,46
0,125- 0,09	0,35	1,78	19,50	99,23
< 0,09	0,15	0,76	19,65	100
Total	19,65	100	-	-

V_9

grain size (mm)	class residuals (g)	class residuals (%)	cumulative residuals (g)	cumulative residuals (%)
> 1,00	4,55	22,81	4,55	22,81
1,00 - 0,5	11,55	57,89	16,10	80,70
0,5 - 0,2	3,00	15,04	19,10	95,74
0,2 - 0,125	0,40	2,01	19,50	97,74
0,125- 0,09	0.20	1.00	19.70	98.75
< 0,09	0.25	1.25	19.95	100
Total	19.95	99.75	-	-

V_{10}

grain size (mm)	class residuals (g)	class residuals (%)	cumulative residuals (g)	cumulative residuals (%)
> 1,00	0.65	3.36	0.65	3.36
1,00 - 0,5	2.70	13.95	3.35	17.31
0,5 - 0,2	13,30	68,73	16,65	86,05
0,2 - 0,125	2,50	12,92	19,15	98,96
0,125- 0,09	0,10	0,52	19,25	99,48
< 0,09	0,10	0,52	19,35	100
Total	19,35	100	-	-

	grain size (mm)	class residuals (g)	class residuals (%)	cumulative residuals (g)	cumulative residuals (%)
SI_1	> 1,00	0,90	4,60	0,30	4,60
	1,00 - 0,5	8,30	42,39	9,20	46,99
	0,5 - 0,2	9,60	49,03	18,80	96,02
	0,2 - 0,125	0,60	3,06	19,40	99,08
	0,125- 0,09	0,15	0,77	19,55	99,85
	< 0,09	0,03	0,15	19,58	100
	Total	19,58	100	-	-

	grain size (mm)	class residuals (g)	class residuals (%)	cumulative residuals (g)	cumulative residuals (%)
SI_2	> 1,00	0,86	4,46	0,86	4,46
	1,00 - 0,5	3,28	17,01	4,14	21,47
	0,5 - 0,2	7,85	40,72	11,99	62,19
	0,2 - 0,125	5,87	30,45	17,86	92,63
	0,125- 0,09	0,82	4,25	18,68	96,89
	< 0,09	0,60	3,11	19,28	100
	Total	19,28	100	-	-

	grain size (mm)	class residuals (g)	class residuals (%)	cumulative residuals (g)	cumulative residuals (%)
SI_3	> 1,00	0,25	1,28	0,25	1,28
	1,00 - 0,5	0,86	4,40	1,11	5,57
	0,5 - 0,2	5,60	28,62	6,71	34,30
	0,2 - 0,125	12,15	62,12	18,86	96,42
	0,125- 0,09	0,60	3,07	19,46	99,49
	< 0,09	0,10	0,51	19,56	100
	Total	19,56	100	-	-

	grain size (mm)	class residuals (g)	class residuals (%)	cumulative residuals (g)	cumulative residuals (%)
SI_4	> 1,00	1,30	6,65	1,3	6,65
	1,00 - 0,5	3,65	18,67	4,96	25,32
	0,5 - 0,2	11,70	59,85	16,65	85,17
	0,2 - 0,125	2,40	12,28	19,05	97,44
	0,125- 0,09	0,25	1,29	19,30	98,72
	< 0,09	0,25	1,29	19,55	100
	Total	19,55	100	-	-

SI5

grain size (mm)	class residuals (g)	class residuals (%)	cumulative residuals (g)	cumulative residuals (%)
> 1,00	0,95	4,85	0,95	4,85
1,00 - 0,5	4,93	25,18	5,88	30,03
0,5 - 0,2	10,70	54,65	16,58	84,68
0,2 - 0,125	2,35	12,00	18,93	96,68
0,125- 0,09	0,35	1,79	19,28	98,47
< 0,09	0,30	1,53	19,58	100
Total	19,58	100	-	-

water drill hole

grain size (mm)	class residuals (g)	class residuals (%)	cumulative residuals (g)	cumulative residuals (%)
> 1,00	0,05	0.26	0,05	0,26
1,00 - 0,5	2,75	14,18	2,80	14,43
0,5 - 0,2	11,40	58,76	14,20	73,20
0,2 - 0,125	3,95	20,36	18,15	93,56
0,125- 0,09	0,55	2,84	18,70	96,39
< 0,09	0,70	3,61	19,40	100
Total	19,40	100	-	-

ANNEX 6

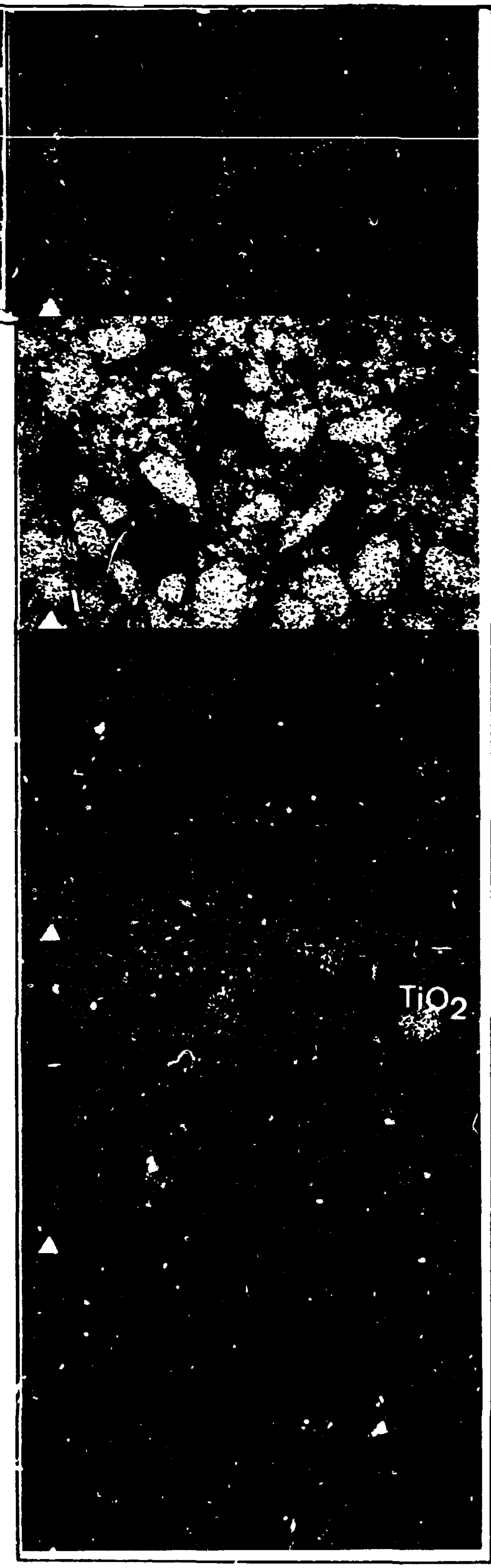
ELECTRONIC MICROSCOPE PHOTOGRAPHS

OF SAND SAMPLES

(ENLARGEMENT 35 X AND 70 X)

Note: Pictures on the right are backscattered pictures while those on the left are secondary images.

elements



Al

Si

Ca

Ti

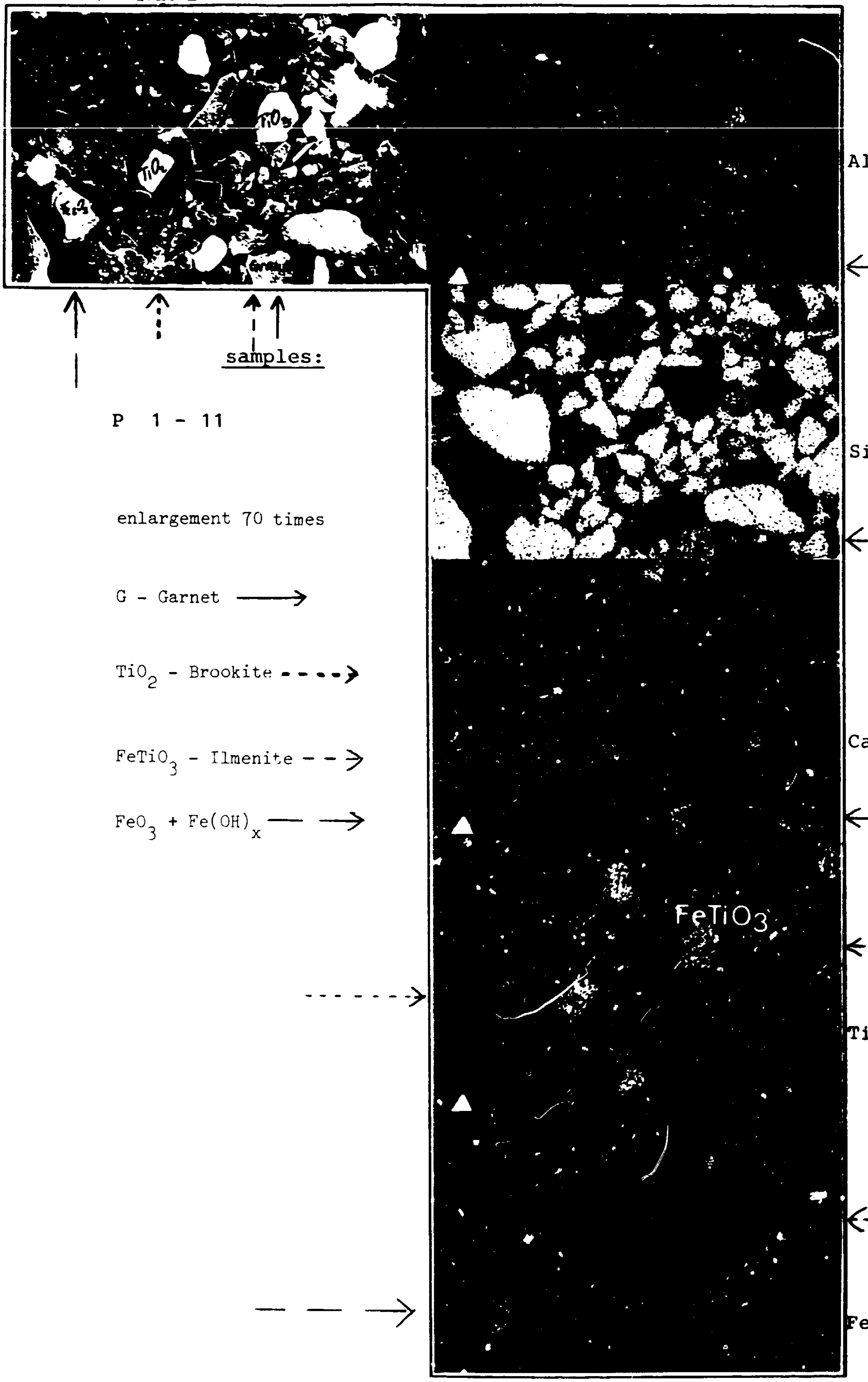
Fe

samples:

P 1 - 11

enlargement 35 times

elements



samples:

P 1 - 11

enlargement 70 times

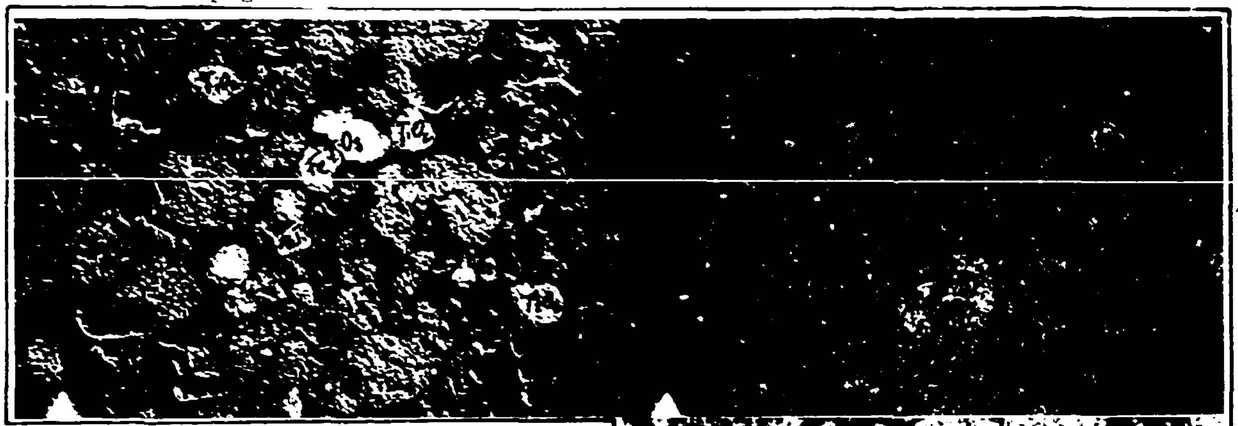
G - Garnet ⟶

TiO_2 - Brookite - - - - ⟶

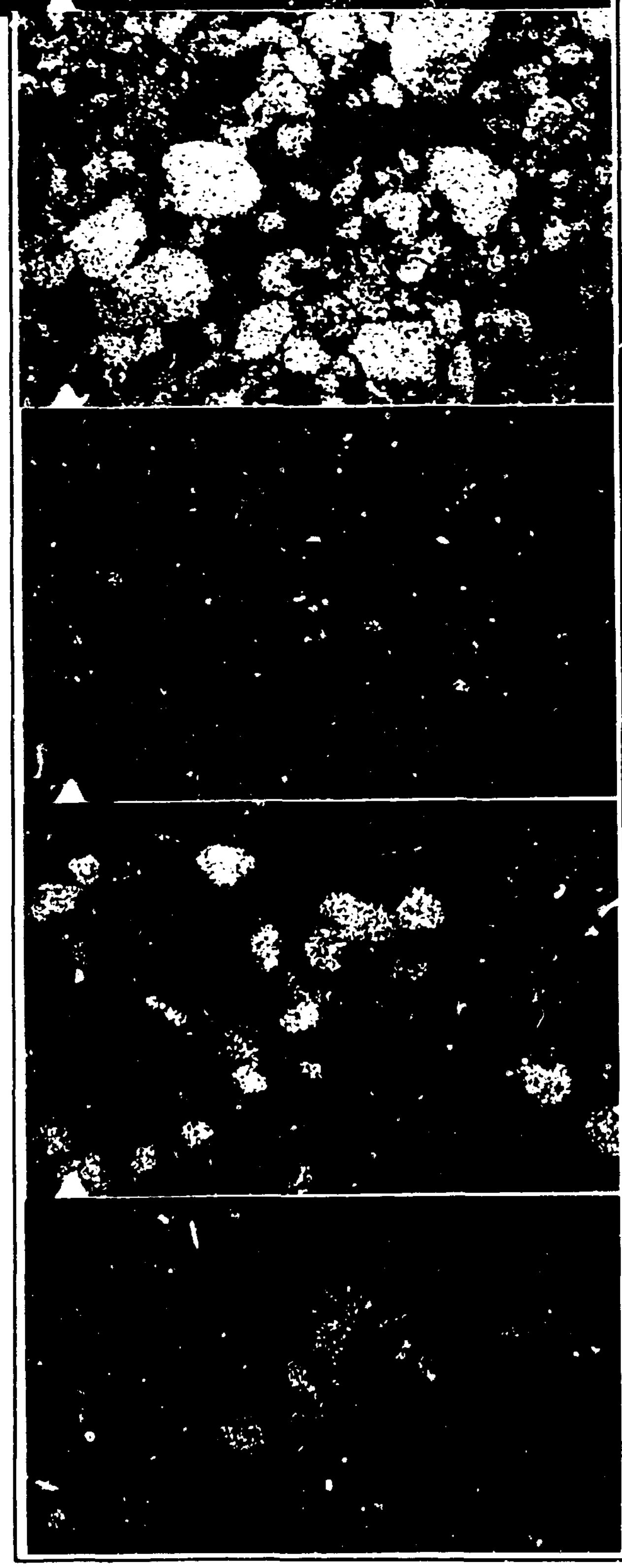
$FeTiO_3$ - Ilmenite - - ⟶

FeO_3 + $Fe(OH)_x$ — ⟶

elements



Al



Si

Ca

Ti

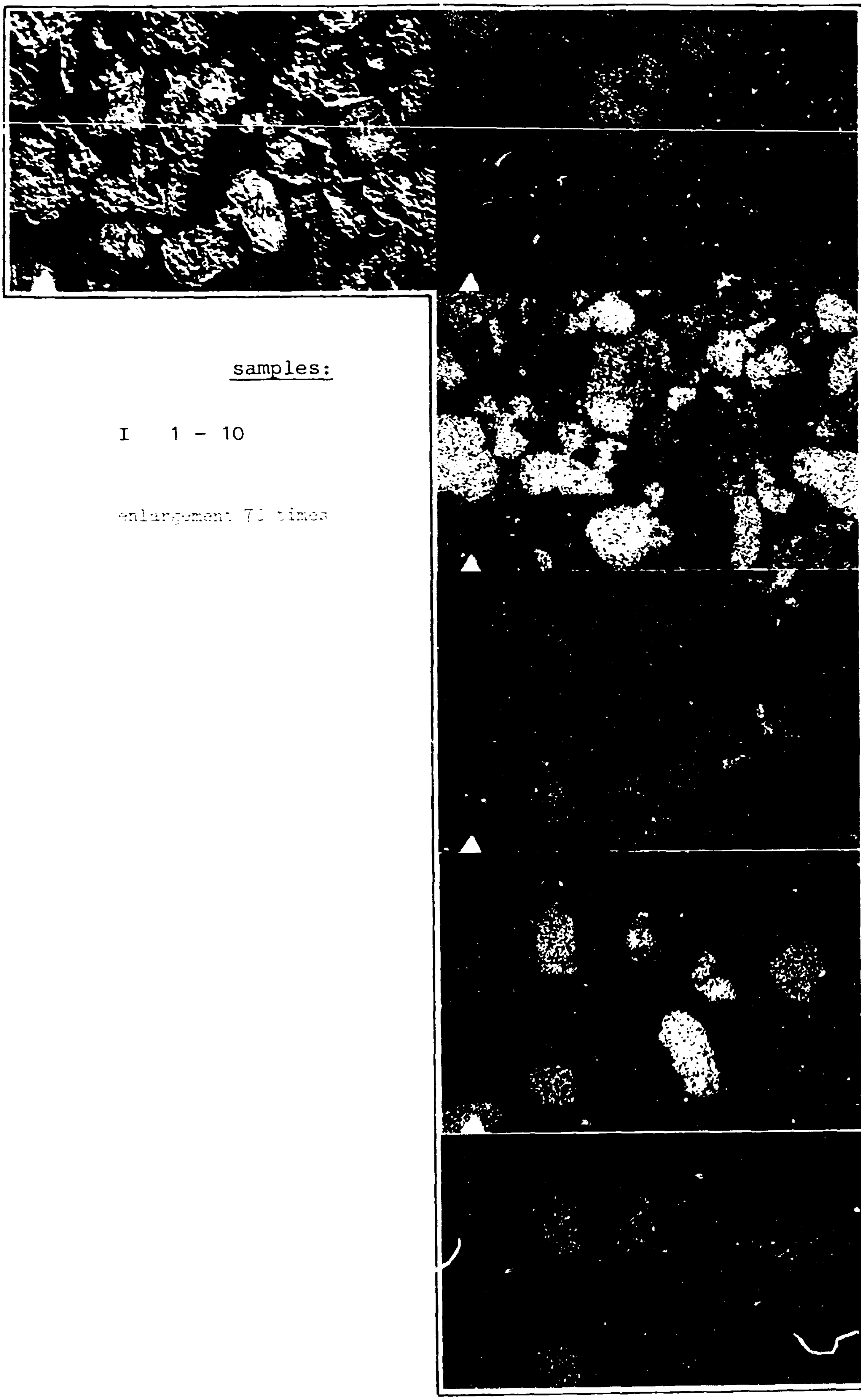
Fe

samples:

I 1 - 10

enlargement 35 times

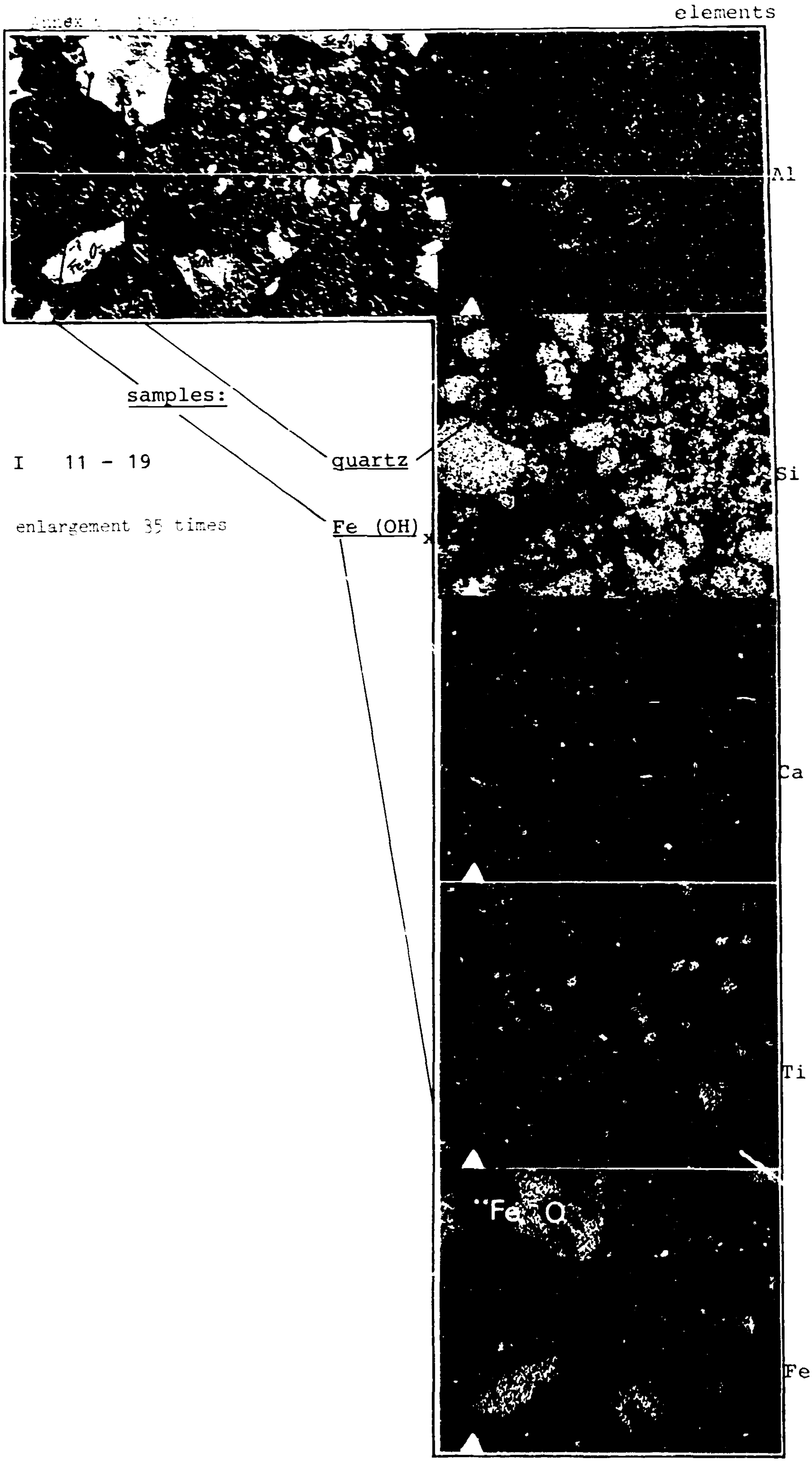
elements



samples:

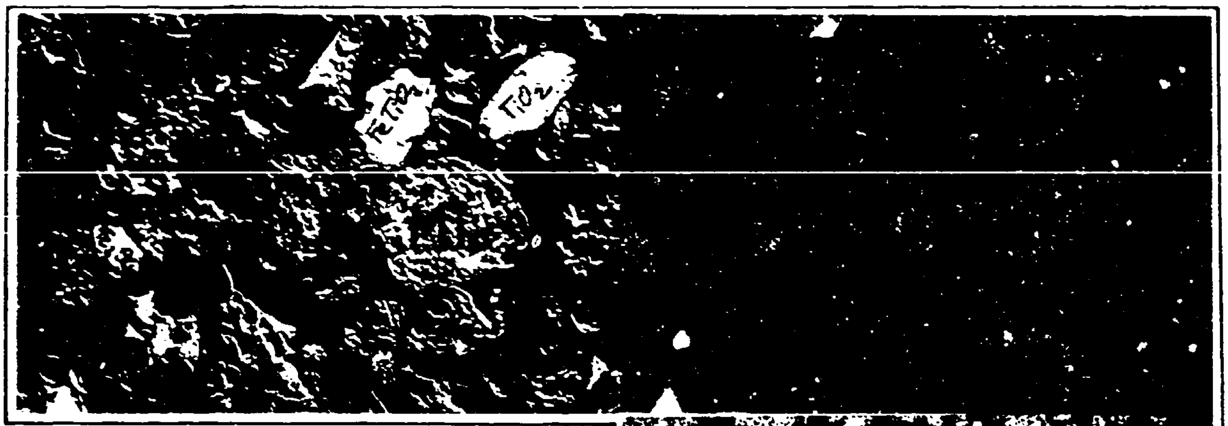
I 1 - 10

enlargement 70 times



I 11 - 19

enlargement 35 times



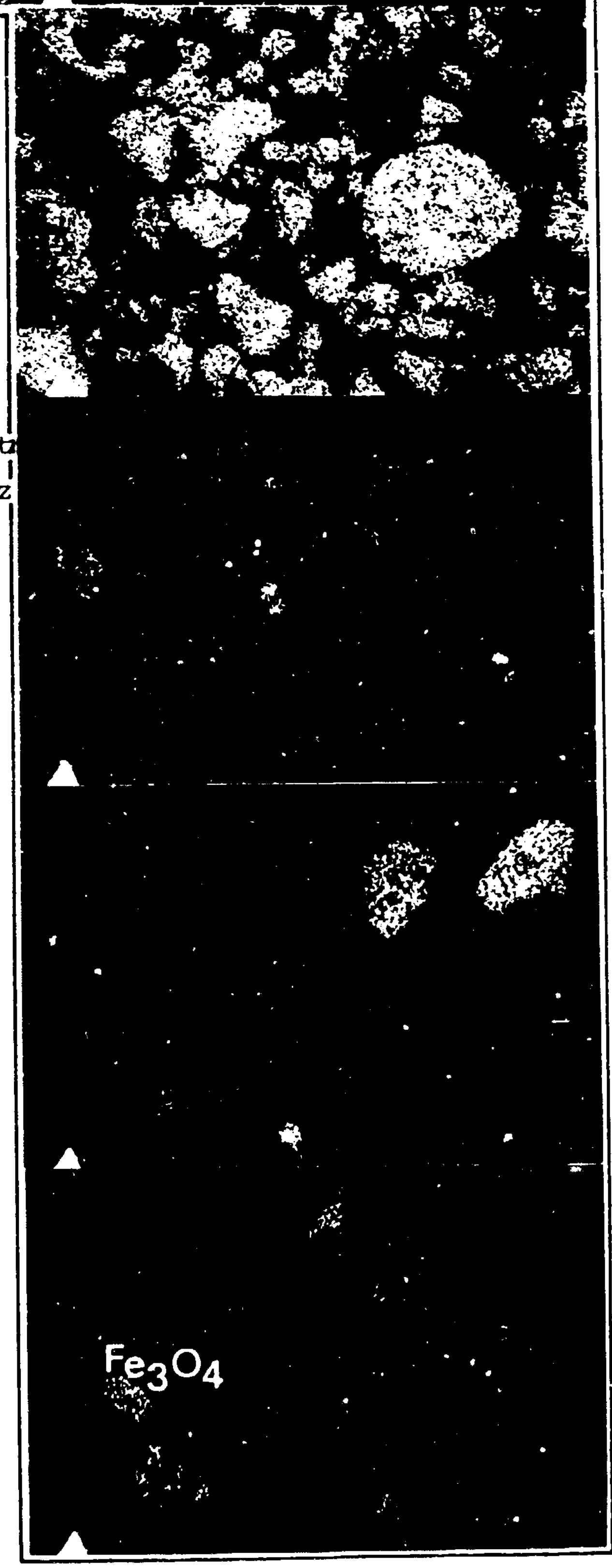
samples:

I 11 - 19

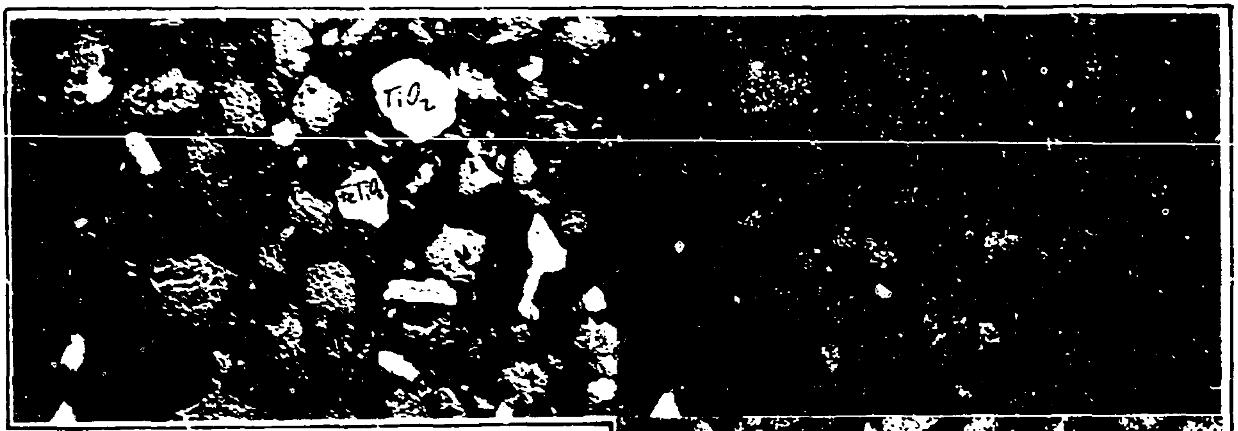
enlargement 70 times

Mi=microcrystalline quartz

Mo=monocrystalline quartz



elements



Al

samples:

II 1 - 10

enlargement 35 times

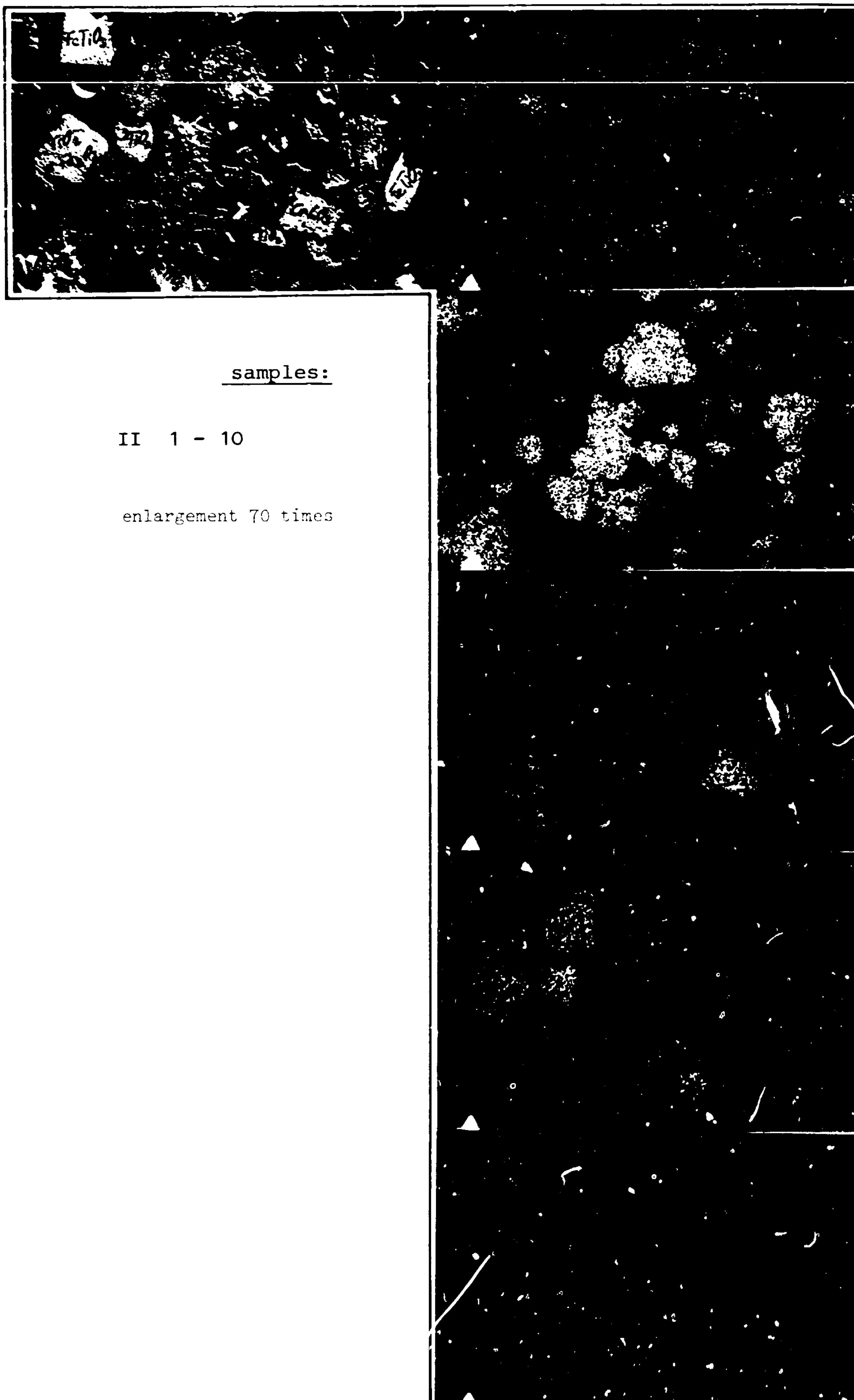
Si

Ca

Ti

Fe

elements



Al

samples:

II 1 - 10

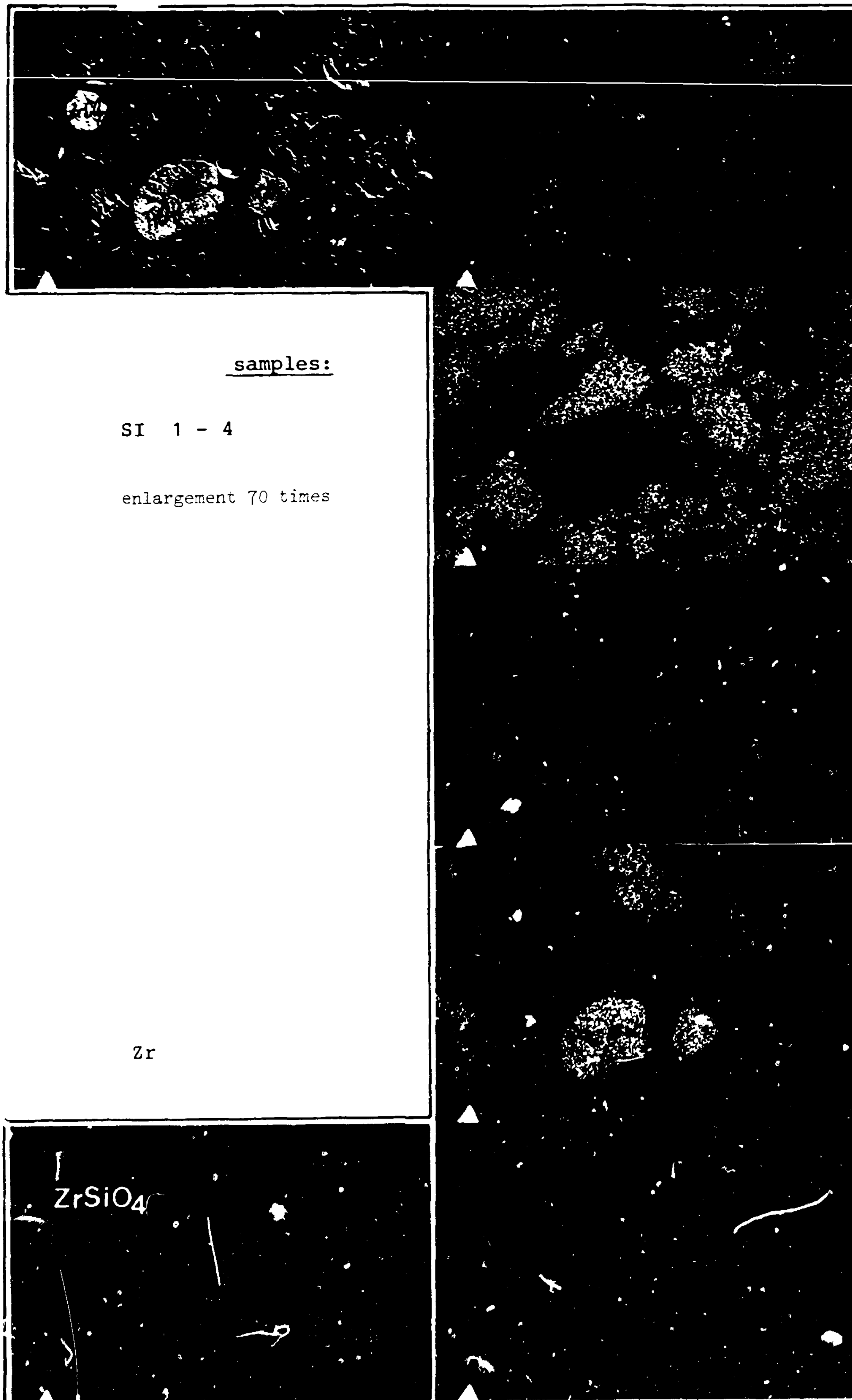
enlargement 70 times

Si

Ca

Ti

Fe


elements
Al
samples:
SI 1 - 4
enlargement 70 times
Si
Ca
Ti
Zr
ZrSiO4
Fe

ANNEX 7

TRACE ELEMENTS AND COMPOUNDS

THAGBAN SANDS

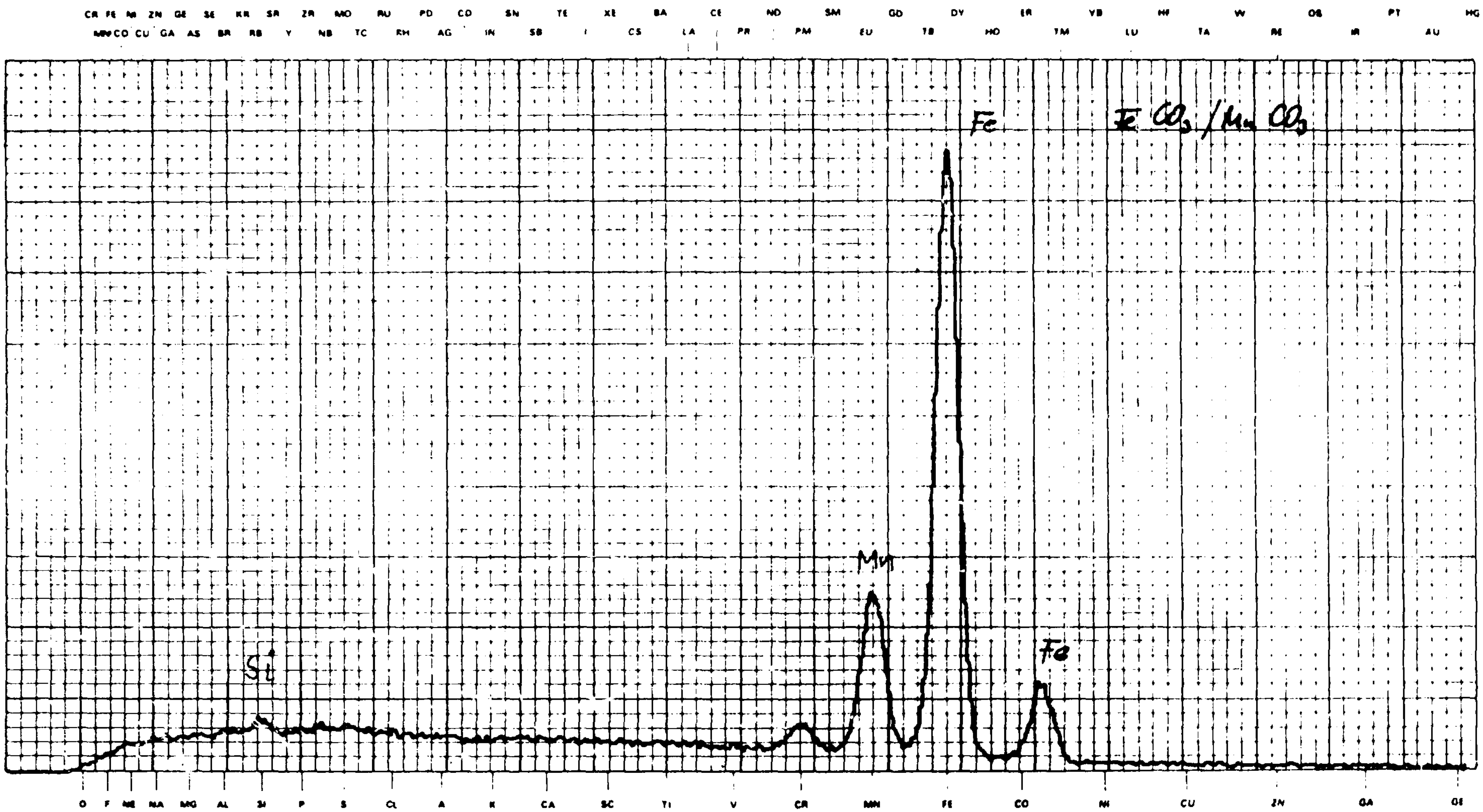
(Quantitative analysis)

Laboratory..................................... Researcher.. Ms/Ro .... Date. 28 07 1981

Sample. I/1 - 10

KeV................................. Seconds................................. Take off Angle.................................

L alpha lines



K alpha lines

Link Systems Ltd X Ray Analysis

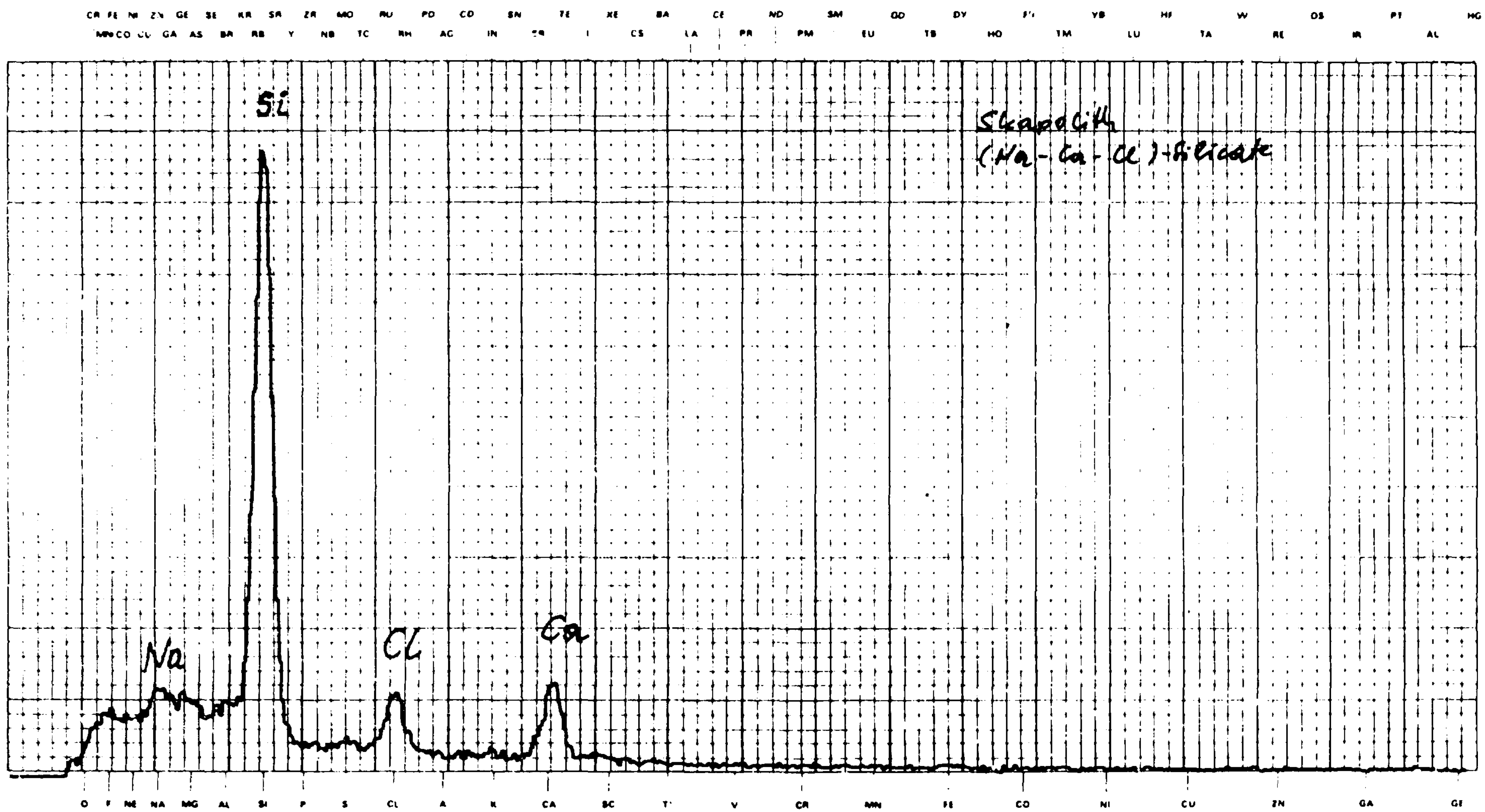
Annex 7
Page 1

Laboratory. .... Researcher.. Ka/Ro .... Date.. 28 07 1981 ....

Sample.... II/1 - 10 ....

KeV................................ Seconds.................................. Take off Angle...

L alpha lines



K alpha lines

Link Systems Ltd X Ray Analysis

Laboratory..............................

Researcher.. Ha/Qa..................

Date... 28 07 1981 ....

Sample......I/1 - 10 ....

KeV..............................

Seconds..............................

Take off Angle..............................

L alpha lines

K alpha lines

Link Systems Ltd X Ray Analysis

Annex 7
Page 3

Laboratory..................

Researcher...Ms/Or...

Date...28 07 1981...

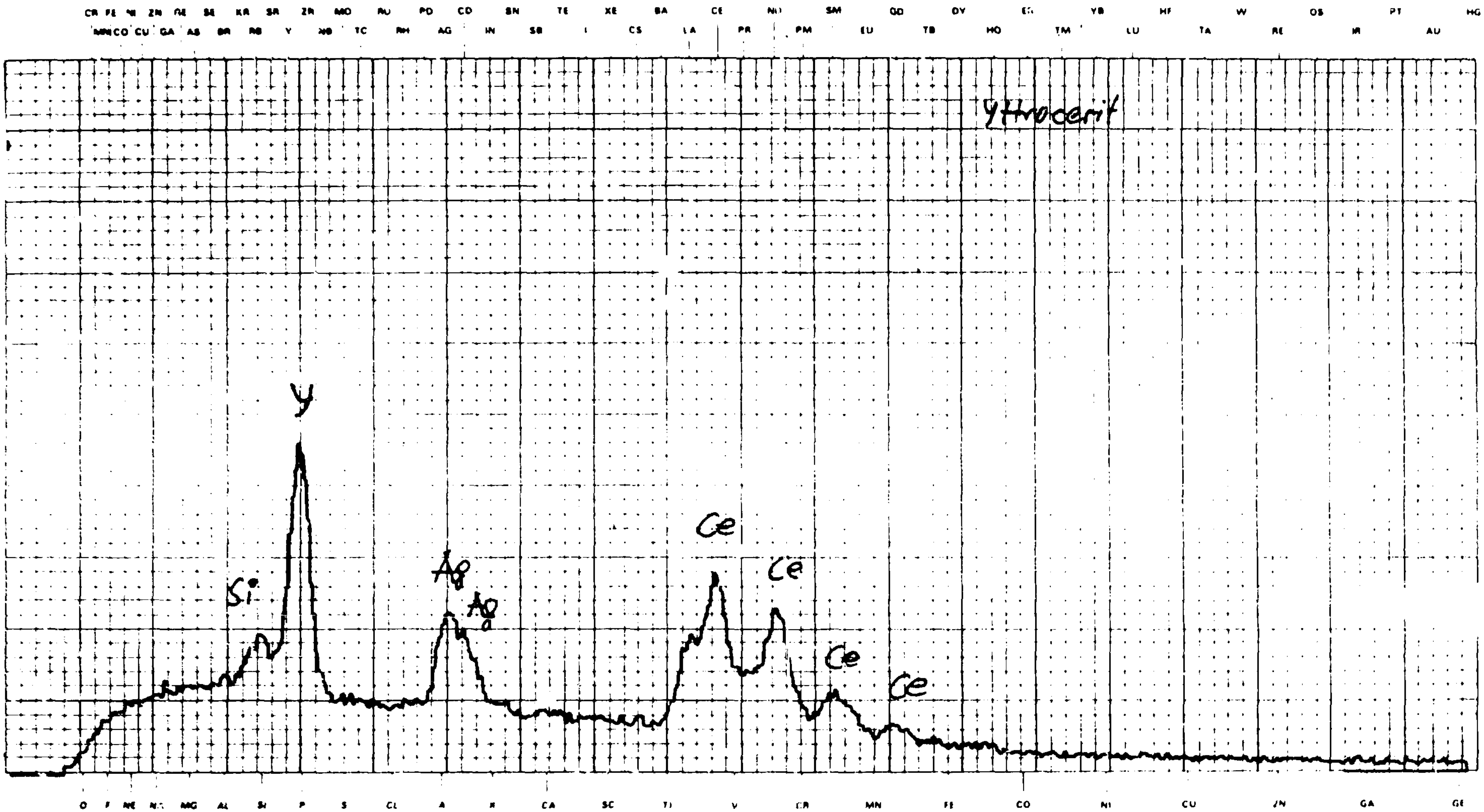
Sample...I/11 - 19...

KeV..................

Seconds..................

Take off Angle..................

L alpha lines



K alpha lines

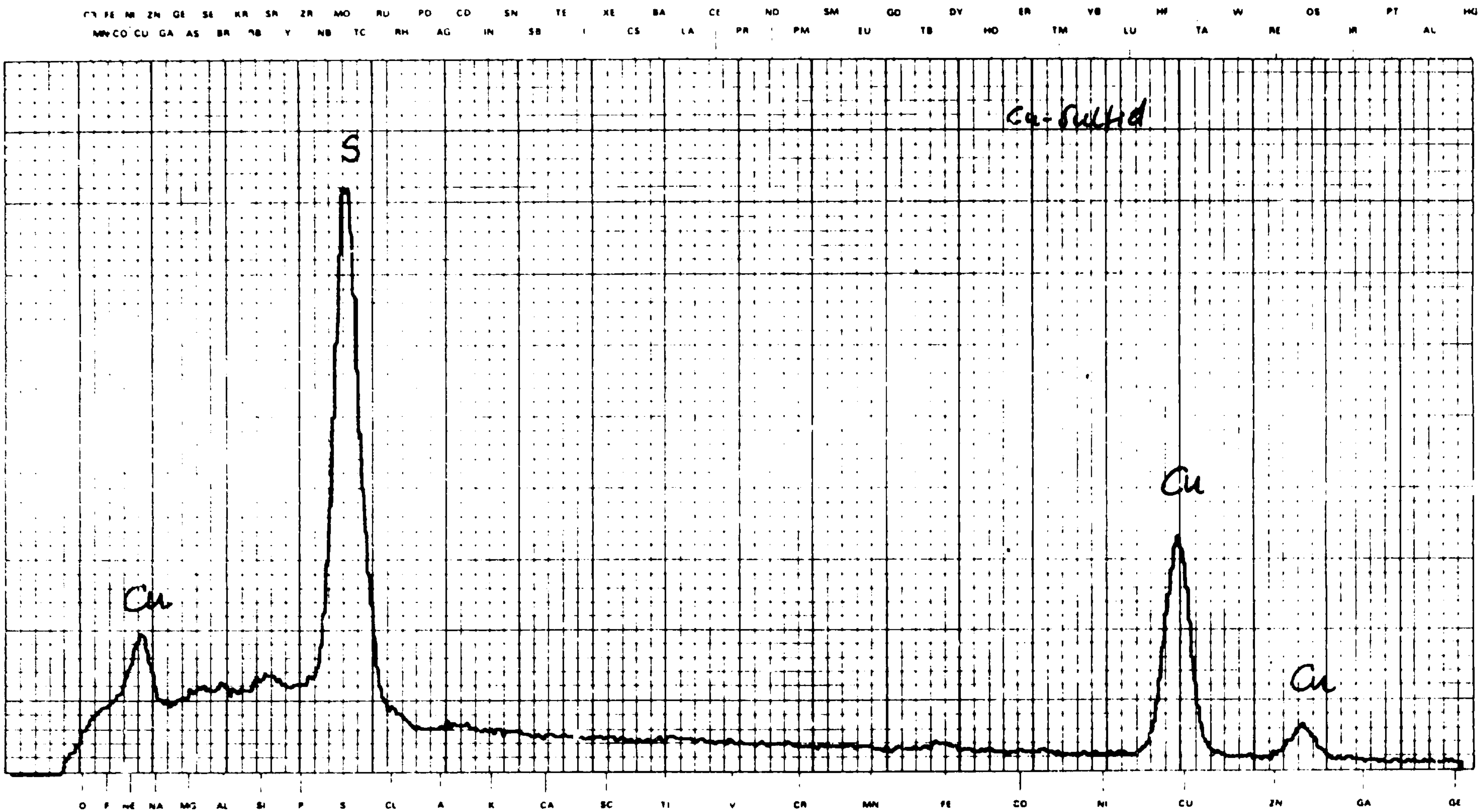
Link Systems Ltd X Ray Analysis

Laboratory.............. .. .. Researcher.. ....ma / Rr................ Date...... 28 07 1981 ....

Sample.......... I/11 - 19 ....

Kev................................. Seconds.................................. Take off Angle..................................

L alpha lines



K alpha lines

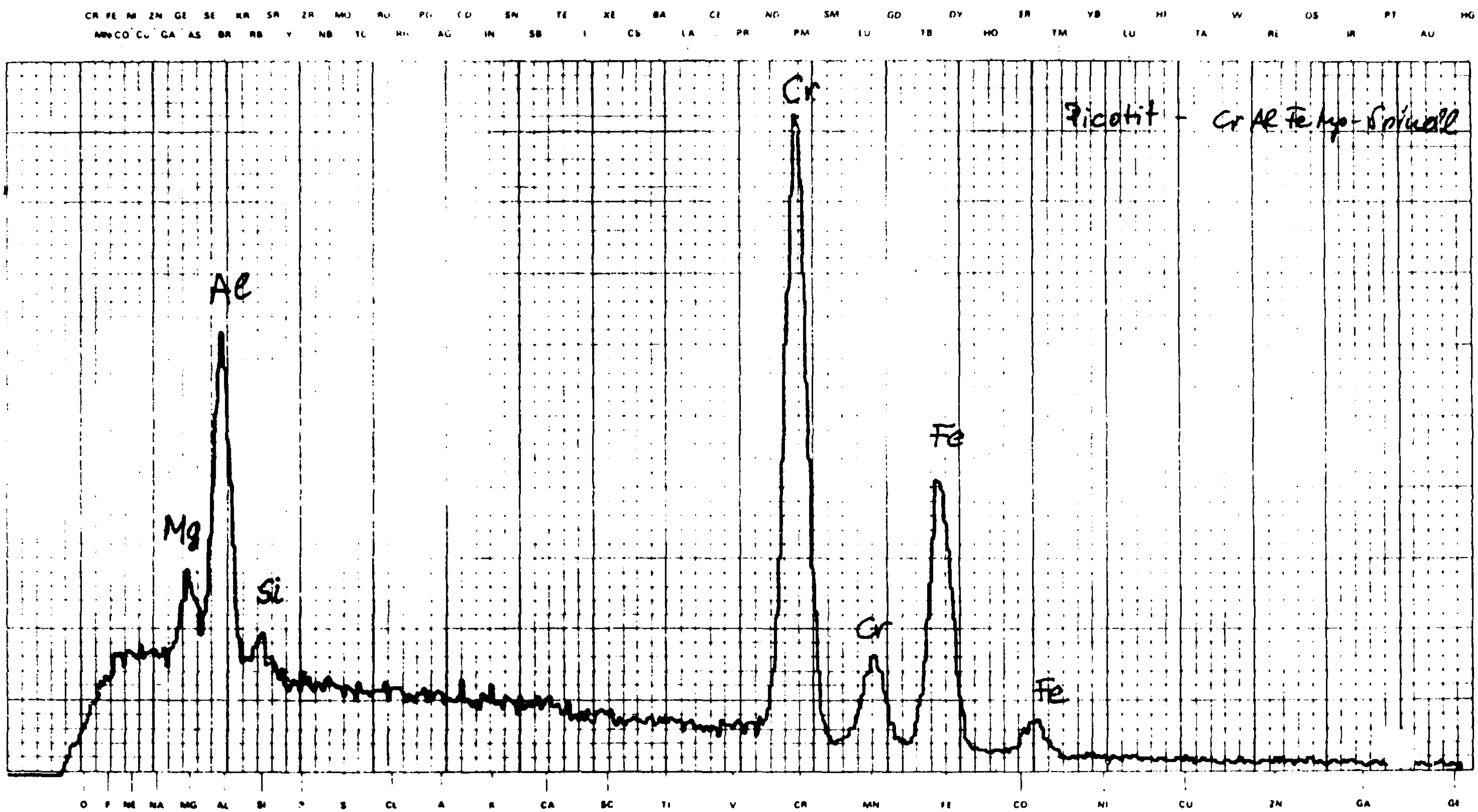
Link Systems Ltd X Ray Anslysis

Laboratory .... Researcher .... Date 28 07 1981

Sample II/1 - 10

KeV .... Seconds .... Take off Angle ....

L alpha lines



K alpha lines

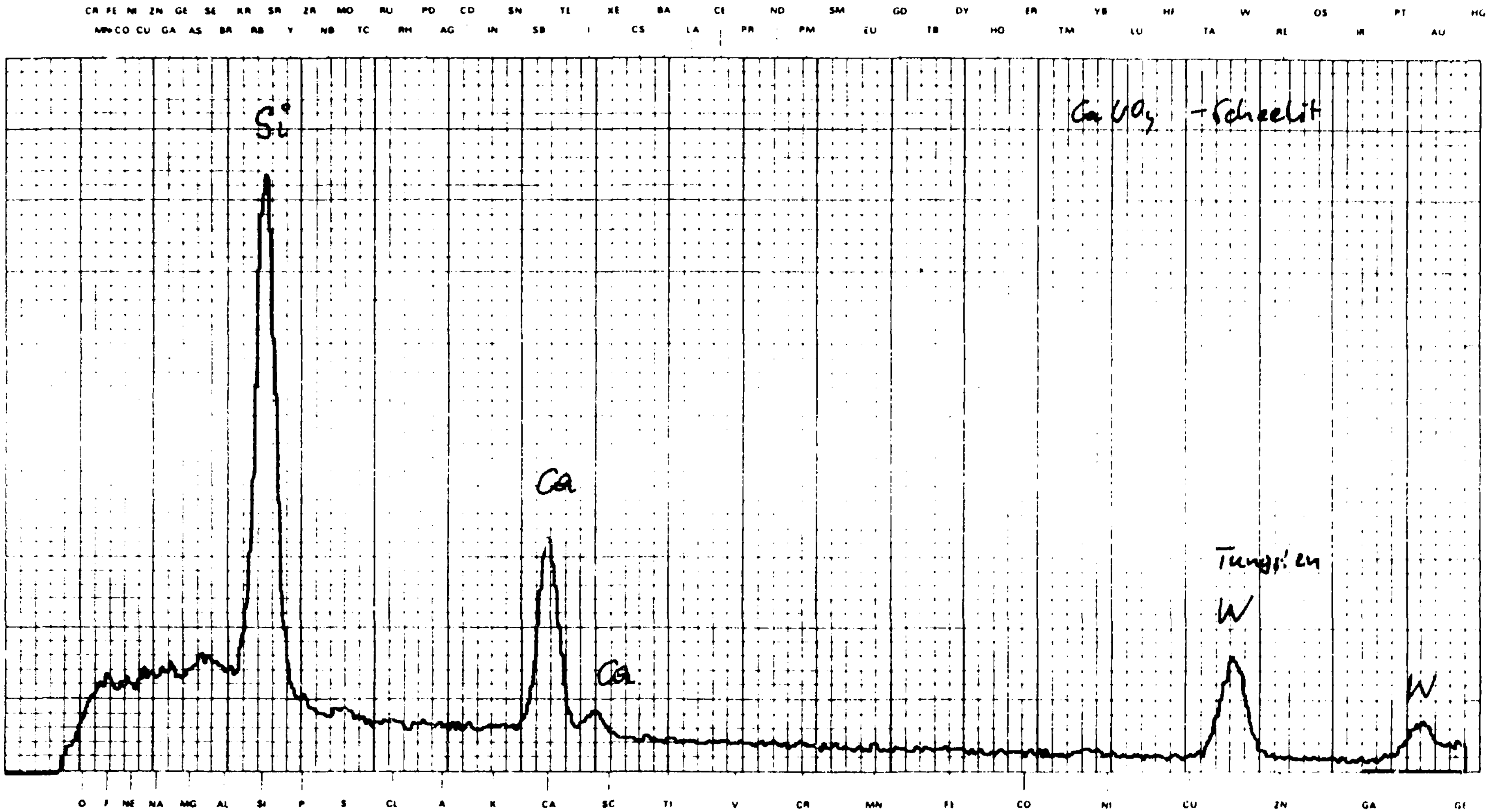
Link Systems Ltd X Ray Analysis

Laboratory.. Researcher.. na/Rr.......................... Date 28 07 1981

Sample III/2 - 9

KeV.................................... Seconds.................................. Take off Angle..............................

L alpha lines



K alpha lines

Link Systems Ltd X Ray Analysis

Annex 7
Page 7

Laboratory...

Researcher.. Ra/Rw

Date 28 07 1981

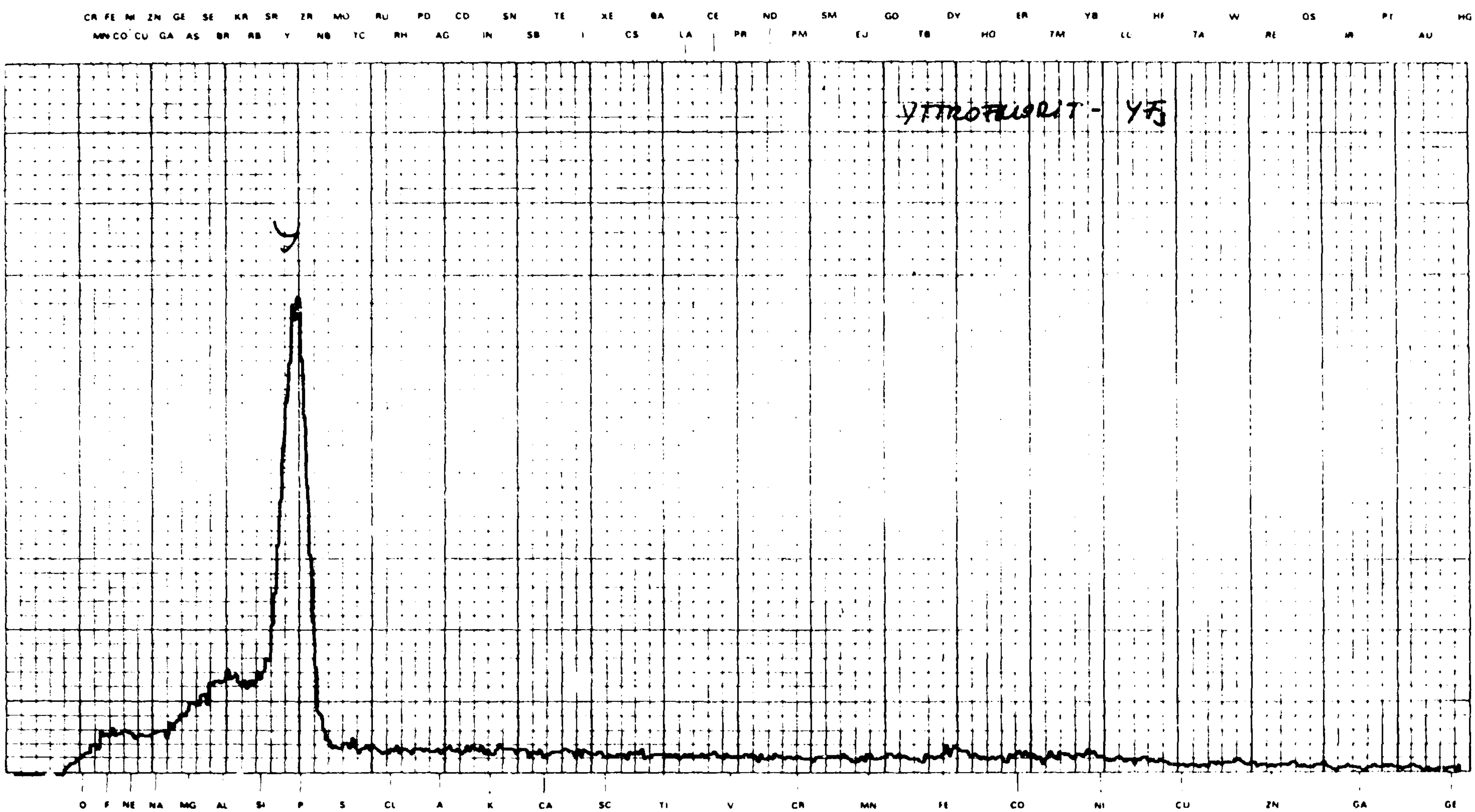
Sample III/2 - 9

KeV

Seconds

Take off Angle

L alpha lines



K alpha lines

Link Systems Ltd X Ray Analysis