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Ethiopia.

TECHNOLOGICAL TESTS OF NON-METALLIC RAW MATERIALS

Prepared for the Government of Socialist Ethiopia by the United Nations Industrial Development Organization, the executing Agency of the United Nations Development Programme

Performed by: Research Institute for Ceramics, Refractories and Raw Materials, Pilsen, Czechoslovakia

In co-operation with: UNIDO-Czechoslovakia Joint Programme for International Co-operation in the Field of Ceramics, Budilding Materiels and Non-metallic Minerals Based Industries, Pilsen, Czechoslovakia

UNITED NATIONS INDUSTRIAL DEVELOPMENT ORGANIZATION
VIENNA

1. [illegible]

[illegible] of [illegible]ical, [illegible]tric, [illegible]l and [illegible]ical analyses of five Ethiopian raw material samples are given: those of acidic and basic tuff, pumice, bentonite and dolomite. Possibility of practical application of these raw materials in agriculture with respect to fertilization was evaluated. The achieved issues indicate the use of above mentioned raw materials not only in agriculture, but also for industrial purposes.

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3. INTRODUCTION

The evaluation of 5 small samples of [illegible] rocks, which were carried out by the [illegible] Ceramics, Refractories and Raw Materials [illegible] contract to the UNIDO project UC/ETH/84/013 - [illegible] Application of Non-metallic Sorbents in Agriculture (UNIDO Contract No 85/23) is presented.

The samples were dispatched by the Office for Exploitation of Mineral Resources, Addis Ababa, Ethiopia and their evaluation with respect to practical use in the agriculture and industry was requested.

4. [illegible]

a) [illegible] of the samples [illegible] is of very good quality, both tuffs and [illegible] quality [illegible] inferior.

b) Acidic tuff is a vitreous rock, whose chemical composition corresponds to effusive rhyolite. Vitreous phase is predominent in the sample, consequently it has low adsorption and ion exchange capacity. The raw material represented by the sample may have following applications:
   1) as fluxing agent for the manufacture of floor tiles or stoneware
   2) for adjustment of physical properties and structure of heavy argillaceous soils.

   This raw material is not suitable for the manufacture of expanded materials. For the use mentioned above it must be crushed and ground. Subsequent screening is also needed to achieve particle size distribution with maximum particles smaller than 0,1 mm.

c) Basic tuff is vitreous rock as well, akin to basalt. It shows also low adsorption capacity and ion exchange capacity. It can be similarly used as fluxing agent and for improvement of properties of clayey soils. This tuff is not expandable. Disintegration of it by means of crushing and grinding together with screening is necessary before this raw material is used for industrial purposes.

d) Pumice is a porous, vitreous rock chemically similar to rhyolite. It has low adsorption capacity for H_2O and basic dye stuffs, but considerably high ion exchange capacity.

   ..lowing applications of this material can be hand:

   1) manufacture of filtration baffle plates for water treatment or foodstuff industry
   2) production of porous building materials with hydraulic or clay bond

3) substatial improvement of physical properties of clayey soils, releasing of nutrient stuffs for plants as the result of ion exchange reactions. Both crushing and grinding of this pumice is needed prior to its practical application.

e) Bentonite sample represents diagenetic clayey rock with high montmorillonite content. This bentonite has outstanding adsorption properties and high ion exchange capacity. It is high quality raw material which may have several applications:

1) as a binding agent in foundry industry
2) in drilling muds
3) in manufacture of thermal insulations
4) in reclaiming of sand soils and increasing their yields
5) as carrier of herbicides and other chemical agents

Its industrial applications require appropriate disintegration and subsequent chemical activation.

f) Dolomite is a crystalline sediment containing predominantly dolomitic component. It shows high portion of contaminations. Consequently it would find application mainly in agriculture for the reduction of acidity and for introduction of Ca^{+2} into the soil. This dolomite is not suitable for more sophisticated industrial applications. Crushing and grinding of dolomite rock would be necessary (maximum particle size below 0,25 mm).

g) For further complex economic exploitation of Ethiopian minerals and rocks is recommended:

1) to work out outlines of preparation of bentonite and dolomite for agricultural purposes
2) to evaluate possibilities for economic exploitation of non-metallic minerals within Ethiopian industries
3) to enhance geological prospection for non-metallic raw materials

h) UNIDO-Czechoslovakia Joint Programme for International Co-operation in the Field of Ceramics, Building Materials and Non-metallic Minerals Based Industries and the Research Institute for Ceramics, Refractories and Raw Materials in Pilsen are ready to provide Ethiopia with technical assistance to exploit non-metallic mineral reserves.

5. EVALUATION OF SAMPLES OF ETHIOPIAN RAW MATERIALS

Five samples were delivered and following numbers were alloted to them in our laboratory:

No	Raw material	weight
430.85	tuff	50 kg
431.85	basic tuff	50 kg
432.85	pumice	50 kg
433.85	bentonite	50 kg
434.85	dolomite	30 kg

5.1. Methods

The samples of raw materials were before all thoroughly homogenized. The samples of bentonite and dolomite were preliminary granulated on the jaw crusher and then pulverized by attrition mill so that the greatest particle size was below 2 mm.

The average samples were prepered and analyzed by means of classical chemical methods and also by atomic absorption meassurements on the Perkin - Elmer (USA) equipment.

Grain size distribution of tuffs and pumice was estimated by screen analysis (sieves 0,063 mm, 0,125 mm, 0,250 mm, ... 16 mm).
The bentonite suspension was passed through the sieve 0,063 mm and the undersize was analyzed by means of the sedimentation procedures on Sedigraph 5000 (USA) equipment.

X - ray analysis of all samples was carried out on the X - ray goniometer (HZG 4 B, Zeiss, GDR).

Oriented preparations have also been made for roentgenographic estimation of smektites.

On the basis of gathered experimantal date the approximative mineralogical compositions of all samples have been calculated.

Water absorption values have been determined as the difference in weight of dried samples placed in the environment with the relative humidity of 75%. Absorption of basic [illegible] has been estimated by means of methylene blue. Method of [illegible] addition of methylene blue solution was used and the absorption balance was determined by drop test on the filtration paper. Cation exchange capacity has been determined by ammonium acetate method. The individual exchange cations have been estimated by means of atomic absorption spectrophotometry.

In addition, the samples of tuffs and pumice have been investigated by means of microscope and electron scanning microscope (JSMT - 20, Japan).

5.2. Results of investigations

Macroscopic description

430.85 Tuff

The sample contains mainly cemented fragments of light grey colour. Most of sample is formed by volcanic rock comprising especially volcanic glass. Inclusions, contained in it, have apparent grooved features.
Small quantities of hydroxidic iron, effusive rocks and crystalline quartz are also present. The content of clastic material does not exceed 10%. Therefore the sample is tuff from the petrological point of view.

431.85 Basic tuff

The sample is of a dark colour and formed nearly exclusively by volcanic glass. Most of glassy particles have scorious texture with numerous pores. Some particles show splinter type shape with arched fracture surfaces. The fragments of effusive rocks are present only scarcely.

432.85 Pumice

The sample is mainly composed of porous particles of white to grey colour the dimension of which are in the range from several milimeters to several centimeters. Some 10% of the sample are formed by the fragments of dark grey effusive rocks.

433.85 Bentonite

It is an argillaceous diagenetically consolidated material with very fine grains, the colour of which is from grey to green. It also contains rusty stains and cords. Greater fragments show certain degree of lamination and their surfaces conchoidal fracture. From the texture and structure it might be inferred that the rock has arisen through the transformation of intermediate tuffs.

434.85 Dolomite

This dolomite is white to grey rock with local greenish shades. It is compact, medium grained, crystalline material. It contains also local cords of hydroxydic iron. Some fragments of the sample are grey or dark grey.

Grain size distribution

The results of the particle size investigations in case of tuff and pumice samples are given in table 1.

1. The tuff sample 430.85 is relatively fine grained. It contains nearly 80% of particles with the diameter below 0,5 mm. There is no oversize on the sieve 8,0 mm.
Basic tuff 431.85 has coarser grains, showing slightly over 10% particles with the size below 0,5 mm, but nearly 60% particles having the size over 8,0 mm. Grain size distributions of these three samples are well characterized by following statistical parameters.

		430.85	431.85	432.85
d_{50}	(mm)	0,13	1,25	9,10
d_{75}	(mm)	0,42	2,75	12,05
d_{25}	(mm)	0,04	0,68	4,50
d_{75}/d_{25}	-	10,5	4,0	2,7

The size of medium grain shows considerable coarseness of grains in case of pumice 432.85 and basic tuff 431.85. On the other hand it informs us about the presence of considerable portion of fine particles in the tuff sample 430.85. The ratio d_{75}/d_{25} again shows the irregular participation of coarse and fine portions in the tuff sample 430.85 and pumice sample 432.85.

Fine particles are predominant in tuff, coarse particles in pumice.

The grain size distribution is more uniform in basic tuff 431.85.

Grain size distribution of bentonite 433.85 is given in table 2. This sample contains only 2,5% of particles with the size above 63 μm. It is a very fine powder, containing 62,5% of particles the size of which is below 2 μm.
The dolomite sample 434.85 comprised very coarse fragments, consequently no grain size investigations have been performed.

CHEMICAL COMPOSITION

The results of chemical analyses of volcanic glasses and bentonite are given in table 3.

Tuff 430.85 contains high portion of SiO_2, low quantity of Al_2O_3, only 2% of alkali earth oxides, high content of alkali oxides (nearly 9%) and high content of Fe_2O_3 (nearly 7%). This tuff resembles the acidic effusive rocks of rhyolite or dacite type.

Tuff 431.85 contains less then 47% of SiO_2, approximately 15% of Al_2O_3, high concentration of Fe_2O_3 (slightly over 11%) and alkali earth oxides (nearly 22%) and lower portion of alkali oxides (about 3,5%). This sample is therefore akin to basic effusive rocks of basalt type.

Pumice 432.85 has chemical composition resembling that of acidic tuff 430.85, high SiO_2 content, low content of alkali earth oxides (especially K_2O represents important component). It can be said that the composition of this sample resembles that of volcanic glass of rhyolite type.

The samples 430.85 and 432.85 show slightly increased L.O.I. value, which does not correspond to the H_2O + content in the volcanic glasses. It may be explained by the presence of alteration product in these samples.

[illegible] composition of [illegible] 433,85 [illegible] of [illegible]: it has [illegible] of SiO_2, lower content of Al_2O_3, very high [illegible] of Fe_2O_3 [illegible] higher content of [illegible]. The chemical composition [illegible] parent rock and free SiO_2.

The results of chemical analysis of bentonite 434.85 are shown in table 4. The sample contains high portion of MgO and CaO, increased content of the residue, insoluble in HCl (about 7%) and slight quantities of other oxides (approximately 0,6%).

X-RAY ANALYSIS

X-ray diffraction pattern of tuff 430.85 shows intensive feldspar diffractions (d_{001}=0,641 nm, $d_{20\bar{1}}$=0,404 nm, d_{002}=0,321) nm; other diffractions are less intensive or even diffusive, corresponding to plagioclase (andesine type). Quartz diffractions d_{100}=0,426 nm and d_{101}=0,334 nm may also be discerned. In [illegible]nge of lower angles 2 θ X-ray diffraction pattern is cambered, which indicates the presence of small quantity of alteration products resembling the illit-montmorillonite structures. From the roentgenogram it is also obvious that hyalineous phase is present as well as alterated feldspar and quartz.
Roentgenograms show abundance of hyalineous phase and presence of crystalline phases - alterated feldspar and quartz.

Roentgenogram of tuff 431.85 contains within the range from 20° to 40° 2 θ the whole diffraction spectrum of plagioclase (labradorite type: $d_{20\bar{1}}$=0,404 nm, $d_{\bar{1}\bar{1}1}$=0,390 nm, d_{111}=0,375 nm, $d_{1\bar{3}\bar{1}}$=0,300 nm, $d_{0\bar{4}1}$=0,294 nm and $d_{1\bar{1}2}$=0,252 nm). In the range of low 2 θ angle values weak intensity diffraction of micaceous mineral is discernible.
Prevalent labradorite and accessory micaceous mineral are the only crystalline phases of the sample.

X-ray diffraction pattern of [illegible]mice 432.85 shows again prevalent amorphous hyalineous phase. Quartz, plagioclase (oligoclase type), small portions of alteration feldspar product, illite-montmorillonite with predominant illite component (asymetric diffraction at d = 1,2 nm) and calcite (d=0,303 nm) have also been identified as the representant of crystalline phase.

X-ray date of both tuffs and pumice are given in table 5.

Roentgenogram of bentonite 433.85 shows very [illegible] smektite diffractions (d_{001}=1,473 nm, d_{002}=0,[illegible]01 nm, d_{003}=0,[illegible]00 nm, d_{004}=0,353 nm, d_{005}=0,[illegible]03 nm and [illegible] diffraction d_{006}=0,250 nm).

X-ray diffraction patterns of ethylene glycol preparations show the shift of diffraction d_{001}=1,473 nm into the range of lower angles 2 θ Kd=1,70 nm and value d=1,053 nm is fixed. This value together with the diffraction d=0,50 nm corresponds to the small content of micaceous mineral (illite type). The only smektite in the sample is represented by montmorillonite. Complete diffraction spectrum shows quartz. Beside that also small quantities of cristobalite (d_{101}=0,402 nm) and calcite (d_{104}=0,303 nm) are present. X-ray date of bentonite 433.85 are given in table 6.

Carbonate diffractions predominates in the x-ray diffraction pattern of dolomite mineral . Many diffractions must be attributed to calcite. Diffractions d=0,843 nm and d=0,312 nm are those of some amfibole type mineral. Diffusive diffraction of smektite at d=1,5 nm is not too distinct. Presence of quartz has also been identified (d_{100}=0,426 nm and d_{101}=0,334 nm). Presence of feldspar (d=0,323 nm) is questionable. In the sample predominates dolomite and calcite. Amfibole, quartz and alteration silicate stuffs (chlorite type) are contained in only small quantities. X-ray date are given in table 7.

APPROXIMATIVE CHEMICAL COMPOSITION

On the basis of chemical and mineralogical analyses the approximative mineralogical composition of the samples was determined.

Glassy phase predominates over crystalline ones in both tuff samples and in pumice, but there are different types of feldspares in them and also quartz is not contained in all cases.

Oligoclase Ab_{85} An_{15}, free quartz and amorphous soda potash vitreous phase containing increased Fe_2O_3 content form the sample of tuff 430.85. Microphotograph of fraction with the particle size in the range 0,5 - 1,0 mm is given in Fig. 3.

Tuff 431.C5 is formed by [illegible] type of [illegible] (Ab_{30} An_{70}), accessory dark [illegible] mineral and [illegible] O_3 vitreous phase.
Microphotograph of fraction having particle size from 1,0 to 2,0 mm is given in Fig. 4.

Pumice contains small portion of plagioclase (oligoclase -andesin Ab_{80} An_{20}), quartz and high content of soda potash glass.

Scanning electron microscope photographs (Fig.1-3) show foamy microstructure of pumice particles. Microphotograph of the fraction with particle size from 1,0 to 2,0 mm is given in Fig 6.

Approximative mineralogical composition of tuffs and pumice is as follows:

	430.81 tuff (%)	431,85 tuff (%)	432.85 pumice (%)
glass	87,5	96,2	91,5
feldspar	7,1	3,2	4,7
quartz	5,4	-	3,8
micaceous mineral	-	0,6	-

Montmorillonite prevails in bentonite 433.85. Dioctaedric micaceous mineral (illite type) is also present there. Nonclay portion of this sample is formed by both amorphous (intermediate tuff) and crystalline phase. Beside this it contains two SiO_2 modifications (quartz and cristobalite) and residual portions of parent rock (dacite). Approximative mineralogical composition of bentonite is as follows:

	433.85 bentonite (%)
montmorillonite	75
illite	5
vitreous phase	5
quartz	10
cristobalite	5

Dolomite is the most important mineral in the sample 434.85, second comes calcite. Small quantities of amfibole type mineral, quartz, chlorite and iron contaminations are also present. Following table shows the approximative mineralogical composition of dolomite.

	434.85 dolomite (%)
dolomite	77,9
calcite	14,6
amfibole	3,9
quartz	3,3
Fe contaminations	0,3

PHYSICO-CHEMICAL PROPERTIES

WATER ADSORPTION

The samples were disintegrated (particle size below 0,09 mm) and placed in the atmosphere with relative humidity of 75%. Water adsorption values were determined by weighing and refer to dry sample weight:

	H_2O adsorption at 75% rel. humidity (%)
430.85	1,16
431.85	0,86
432.85	1,05
433.85	18,21
434.85	0,36

It is obvious that both volcanic glasses and dolomit have very low water adsorption capacity. In case of acidic volcanic glasses (tuff and pumice) the values are slightly higher because of alteration products. [illegible] high water [illegible] city [illegible] bentonite, having high active [illegible].

[illegible]

[illegible] of samples have been [illegible] to [illegible]-form and adsorption value for methylene blue were estimated by means of titration.

	methylene blue adsorption (mol/kg $^{-1}$)
430.85	0,025
431.85	0,013
432.85	0,001
433.85	0,780
434.85	0,006

It is very low in case of volcanic glasses and dolomite and corresponds to the content of alteration products, which does adsorb this dye stuff where_as the hyalinous phase is inert in this respect.
Bentonite shows high methylene blue adsorption, depending on the montmorillonite content, which is considerable with this material.

ION EXCHANGE CAPACITY

The samples have been crushed to the maximum particle size below 0,2 mm and mixed with the ammonium chloride solution (0,15 mol/l). Ion exchange reaction between naturally adsorbed cations and ammonium ions from the solution has taken place. Ion exchange capacity has been estimated in the solutions by means of alkalimetric titration. Contents of individual cations were determined with the aid of atomic absorption spectrophotometry. The obtained results are shown in following table:

		430.85 tuff	431.85 tuff	432.85 pumice	433.85 bentonite
Ion exchange capacity	(mol.kg^{-1})	0,076	0,133	0,902	0,536
Mg^{2+}	(mol.kg^{-1})	0,004	0,042	0,311	0,118
Ca^{2+}	(mol.kg^{-1})	0,047	0,064	0,554	0,331
Na^{1+}	(mol.kg^{-1})	0,012	0,010	0,023	0,058
K^{1+}	(mol.kg^{-1})	0,008	0,005	0,016	0,030

Both tuff samples have low ion exchange capacity which correlates with their hyalineous structure. Basic tuff 431.85 contains higher quantities of echchangeable Na^{+} and K^{+} ions than acidic ones. Ion exchange capacity of pumice is enormously high due to exchangable Ca^{+2} content. This fact is also caused by great specific surfece of the sample and its foamy structure. Ion exchange capacity of bentonite is considerably high due to the predominant content of montmorillonite. This bentonite contains great portions of exchangeable earth alkali cations (Mg^{+2} and especially Ca^{+2}) and relatively high content of exchangeable alkali cations (K^{+} and mainly Na^{+}). The bentonite sample has not been investigated by the method mentioned above because carbonates are partially soluble in the ammonium chloride solution.

DISCUSSIONS OF PRACTICAL APPLICATIONS

The evaluated Ethiopian raw materials have the properties enabling them for many industrial and agricultural applications.

Both tuffs (430.85 and 431.85) could be used as effective flux agent in some technologies (e.g. manufacture of stoneware) of ceramic industry. Both tuffs have low adsorption ability, consequently they are not suitable for the improvement of the soil quality in general. But they could be utilized for the treatment of heavy clayey soils with so called merged structure.

[illegible] (4[illegible]) [illegible] (especially for [illegible]). After [illegible] (crushing and [illegible]) [illegible] perlite is.
It may be also used as a fluxing agent in ceramics. With respect to agriculture it can be applied in a similar way like both tuff samples. At the same time soil reaction could be substantially influenced.

Bentonite 433.85 contains extraordinary high portion of montmorillonite component, which is responsible for its excellent physico-chemical properties. This bentonite could be used in many industrial and agricultural applications. After mechanical and chemical activation it could find the use as binding agent in foundry industry, in peletising processes, as drilling liquid etc. After crushing and grinding it can be utilized for treating sandy soils. Bentonite would have a strong influence on their physical and chemical properties. Acidic activation of this raw material cannot be applied due to presence of mineral nontronite, consequently it cannot be used as bleaching clay. Further special tests would be needed, if the ability of bentonite to be a carrier of fertilizers or component of nutrient mixtures should be proved.

Dolomite (434.85) is not suitable for more sophisticated industrial applications (e.g. in ceramic or synthetic resin industry). Due to higher calcareous content, it would be suitable for liming the soils practically of all kinds.

From the information mentioned above, preparation of all evaluated raw materials would be necessary, if these materials are used in practice.
Dry crushing and grinding would have to be carried out in all cases. Eventual screening on sieves would also be often advisable. Optimum production parameters would have to be determined by further tests with greater samples (minimum weight = 100 kg).

6. [illegible]

This report contains [illegible] of the evaluation of five [illegible] from Ethiopia: acidic and basic tuff, pumice, bentonite and dolomite. Both tuffs are formed [illegible] by vitreous phase. They are inert with respect to their physico-chemical properties. Comprising only low portions of volatile components, they are not capable of baing expanded. Due to high content of Fe_2O_3, alkali earth oxides and alkali oxides they show properties of effective fluxing agents, consequently they can be used in some ceramic technologies. In agriculture they will certainly find the application in treatment of physical proper'ies of heavy clayey soils.

Pumice is highly foamed volcanic glass with the microstructure resembling that of expanded perlites. For this reason its application is also akin to that of expanded materials mentioned above (filtration porous baffles, porous materials). Its application in agriculture is similar to that of both tuffs mentioned above (treatment of heavy soils).

Bentonite contains high portion of effective montmorillonite component, which endows this raw material with outstanding properties like high adsorption capacity and ion exchange capacity. These properties enable bentonite to be used in many practical applications.

In agriculture this raw material finds the use in the treatment of sandy soils, when considerable changes in their structure are required and reclaiming is followed.

High remainder insoluble in acids and a considerable content of Fe_2O_3 cause the dolomite not to be suitable e.g. for the manufacture of glazes and synthetic resin fillers. It can be used for liming the soils and promoting their yield not to speak of enhancement various useful soil reactions.

All evaluated samples were delivered in lumps and must be disintegrated by crushing and grinding if their practical application is intended.

Nevertheless the concrete working out the technology and choice of appropriate protection equipment would require the consultation with the Ethiopian experts. The results of investigations contained in this report indicate various application possibilities. For this reason, further research aimed at practical utilization of different raw materials and consultations with Ethiopian experts are recommendable.

7. APPENDIX

Table 1. Grain Size Distribution of Volcanic Tuffs and Pumice

Table 2. Grain Size Distribution of Bentonite

Table 3. Chemical Composition of Volcanic Tuffs, Pumice and Bentonite

Table 4. Chemical Composition of Dolomite

Table 5. X - ray Data of Volcanic Tuffs

Table 6. X - ray Data of Bentonite

Table 7. X - ray Data of Dolomite

Figure 1. Scanning Electron Micrograph of Pumice (432.85), x 150

Figure 2. Scanning Electron Micrograph of Pumice (432.85), x 1000

Figure 3. Scanning Electron Micrograph of Pumice (432.85, x 2000

Figure 4. Microphotograph of Acid Tuff (430.85), x20

Figure 5. Microphotograph of Basic Tuff (431.85), x20

Figure 6. Microphotograph of Pumice (432.85), x20

Table 1. Grain Size Distribution of Acid Tuff, Basic Tuff and Pumice

/mm/	430.85 Tuff /%/	431.85 Tuff /%/	432.85 Pumice /%/
> 8.0	0.0	8.0	58.4
4.0 - 8.0	1.3	7.9	19.9
2.0 - 4.0	5.1	15.2	9.5
1.0 - 2.0	5.1	26.1	2.3
0.50 - 1.0	10.3	31.0	0.8
0.250 - 0.50	12.0	8.2	0.4
0.125 - 0.250	16.3	2.0	0.6
0.063 - 0.125	16.4	0.5	2.3
< 0.063	33.5	1.1	5.8

Table 2. Grain Size Distribution of Bentonite

/ µm /	433.85 Bentonite /%/
$\geq$ 63	2.5
32 - 63	3.5
16 - 32	4.0
8 - 16	6.5
4 - 8	9.0
2 - 4	12.0
1 - 2	13.0
$<$ 1	49.5
Total	100.0

Table 3. Chemical Composition of Volcanic Tuffs, Pumice and Bentonite

	430.85 Tuff /%/	431.85 Tuff /%/	432.85 Pumice /%/	433.85 Bentonite /%/
L.O.I.	3.48	0.54	4.58	9.43
SiO_2	65.50	46.38	68.77	58.45
TiO_2	0.52	1.44	0.31	1.43
Al_2O_3	12.69	14.97	9.93	11.31
Fe_2O_3	6.84	11.24	4.74	10.38
MgO	0.51	10.96	0.59	3.55
CaO	1.47	10.27	1.82	2.46
Na_2O	4.63	2.50	4.53	1.31
K_2O	4.19	1.06	4.64	1.53
Total	99.83	99.86	99.91	99.85

Table 4. Chemical Composition of Dolomite

	434.65 Dolomite /%/
L.O.I.	43.65
SiO_2	4.91
TiO_2	0.02
Al_2O_3	2.18
Fe_2O_3	0.25
MgO	17.04
CaO	31.93
Na_2O	0.03
K_2O	0.12
Total	100.14
$MgCO_3$	35.65
$CaCO_3$	56.99
Insoluble	6.91

Table 5. X - ray Data of Volcanic Tuffs and Pumice

430.65		431.65		432.65		
-	-	1.005	15	1.100	20	S
0.641	10	-	-	0.642	20	F
-	-	-	-	0.382	10	F
0.426	25	-	-	0.426	10	Q
0.404	15	0.404	25	-	-	F
-	-	0.390	40	-	-	F
-	-	0.375	25	0.375	30	F
-	-	0.365	10	-	-	F
0.334	[illegible]	-	-	0.334	100	Q
0.321	100	0.321	100	0.321	70	F
-	-	0.313	15	-	-	F
-	-	0.302	30	0.300	[illegible]	F
-	-	0.294	25	-	[illegible]	F
-	-	-	-	0.265	20	F
-	-	0.279	25	-	-	F
-	-	-	-	0.246	10	Q

S = micaceous mineral
F = feldspar
Q = quartz

Table 6. X - ray Data of Bentonite

d /nm/	I	
1.473	70	M
1.053	15	I
0.634	10	F
0.448	50	M
0.426	15	Q
0.402	10	C
0.353	10	M
0.334	100	Q
0.257	20	M

M = montmorillonite
I = illite
C = cristobalite
Q = quartz
F = feldspar

Table 7. X - ray Data of Dolomite

d /nm/	I	
1.403	1	S
0.843	15	A
0.451	1	S
0.426	3	Q
0.404	3	D
0.369	5	D
0.334	10	Q
0.327	5	C
0.323	5	F
0.312	20	A
0.302	55	C
0.289	100	D
0.281	5	C
0.257	10	D
0.254	10	D
0.249	5	C
0.240	10	D
0.227	5	C
0.220	25	D

S = smectite

A = amphibole

F = feldspar

Q = quartz

C = calcite

D = dolomite


Fig. 1.

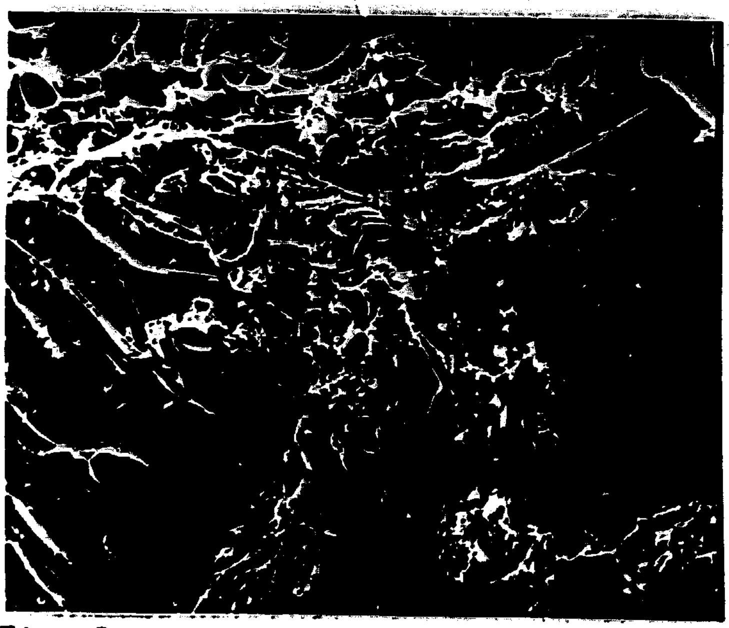
Fig. 2.

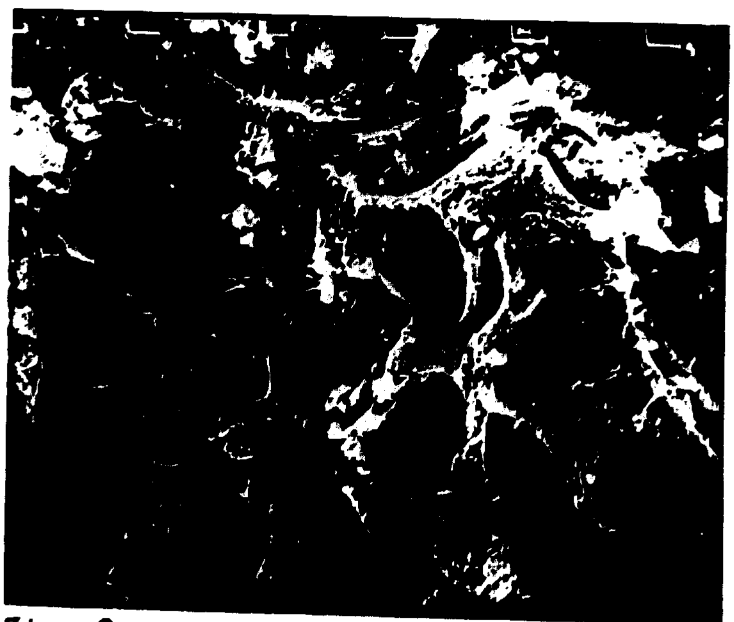
Fig. 3.

Fig. 4.

Fig. 5.

Fig. 6.