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THE ROLE OF THERMAL ANALYSIS IN MINERALOGICAL STUDIES

PART I

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A b s t r a c t. Thermal analysis reinforces X-ray, chemical and other methods of arriving at mineralogical analyses of /i/ a white bentonite containing disordered α -tridymite, /ii/ the fuller's earth from Baulking, Berkshire, England, and /iii/ a black shale from the copper mines of Tharsis, Spain. The two montmorillonites /i/ and /ii/ have very low tetrahedral substitution, $\text{Si}_{7.98}^{\text{Al}}0.02$ and $\text{Si}_{7.99}^{\text{Al}}0.01$, respectively.

INTRODUCTION

Since 1961, when I met Dr. Anna Langier-Kuźniarowa at the First Clay Conference in Czechoslovakia, I have from time to time sent samples of clays and other minerals which I thought might be of interest in her thermal analysis work. Seven of these were illustrated in her book "Termogramy Mineratów Ilastych" /1967/. Of historical interest were the rediscovery of the purplish, pharmaceutical Kimolian earth of the Ancient Greeks - $\xi\mu\pi\acute{o}\sigma\phi\upsilon\rho\omicron\varsigma$ - and evidence that the *terra fullonica* found in Pompeii probably came from the island of Ponza. Of scientific interest were thermal studies of a Moroccan pyrophyllite, the greenish fuller's earth /Ca-montmorillonite/ of Woburn, England, and Sasumua yellow clay, highly halloysitic, from near Nairobi, Kenya.

This further selection of mineralogical studies, in which thermal analysis played a leading role, was presented to a meeting of the Mineralogical Society of Poland in Warsaw on 24th April 1978.

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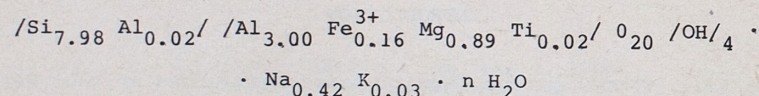
WHITE BENTONITE

In a survey of white bentonites, a sodium montmorillonite produced by treatment of a raw material from the Cyclades, Greece, was examined. A chemical analysis was supplied by the manufacturers /Table 1/. This

Table 1

Chemical analysis of purified white bentonite from the Cyclades, Greece

Component	Wt. %
SiO ₂	59.96
Al ₂ O ₃	18.55
Fe ₂ O ₃	1.56
MgO	4.51
CaO	1.13
TiO ₂	0.15
P ₂ O ₅	0.86
K ₂ O	0.18
Na ₂ O	4.34
H ₂ O ⁺	8.76
	100.00



A sample received for industrial appraisal /S4273/ was however very much less pure. A crude wet separation disclosed at least 15 per cent of non-clay particles. Microscopic examination of these showed that they were all smaller than 30-35 μm , suggesting that the clay slurry had been wet-sieved through a 400 mesh /38 μm / sieve.

XRD on this sample indicated that there was 17.5 ± 7.5 per cent free silica of a kind which was formerly called α -cristobalite but which Wilson, Russell and Tait /1974/ concluded should be called disordered α -tridymite.

Thermal analysis /Table 2, Fig. 1/ gave evidence of three phases, montmorillonite, a little calcite and a mineral dehydroxylating slowly over the range 462-654°C, before the montmorillonite was dehydroxylated in the range 654-704°C. The unknown mineral might be poorly crystallised illite, which is not always clearly shown on X-ray diffractograms. Indeed, a typical dioctahedral smectite from Dunning, Perthshire,

had endothermic peaks at 585, 675 and 860°C, even though illite had not been detected by X-ray examination /Coles & Hosking, 1957/.

Table 2

Thermal analysis of white bentonite S-4273

T °C	DTG °C	DTA °C	TG		TG LOSS			ALLOCATION TO MINERALS
			Breaks °C	Midpoints °C	Cumulative mg	Episode mg	%	
0								
100	150	163		137		95	9.07	0.66→0.66 moisture
200			180		95			
300						12	1.15	
400			462		107			9.56 montmorillonite 8H ₂ O, see below
500				558		18	1.72	
600	665	680	654		125			1.72→22.05 illite
700				679	150	25	2.39	
800			704					
900		870				7	0.67	0.67→1.52 calcite
1000					157			Δ 17.62 free silica 100.00

If we assume that illite is present in the impure sample and contains 7.8 per cent H₂O⁺, we arrive at 22.05 per cent of illite. The montmorillonite content of 58.15 per cent was based on the assumption that the 2.39 per cent lost between 654 and 704°C represented its dehydroxylation /4.11 per cent in the theoretically pure clay mineral/. Four times this amount gives 9.56 per cent of low temperature water equivalent to 8 H₂O. The remaining low temperature water, 0.66 per cent, may be assumed to be moisture. The high temperature loss is equivalent to 1.52 per cent calcite. The unaccounted for minerals, by difference, amount to 17.62 per cent; these are mostly free silica, and are in close agreement with the XRD analysis.

On being heated at a temperature rise of 10°C/min, equilibrium in dehydroxylation is of course not attained. In the range 462-654°C, however, there is enough time for a very finegrained illite to be dehydroxylated before the montmorillonite is affected by the heat. It is perhaps unusual that the montmorillonite in this clay loses its hydro-

xyls over such a narrow temperature range. Nevertheless it appears that thermal analysis has been of value in the quantitative analysis of this white bentonite.

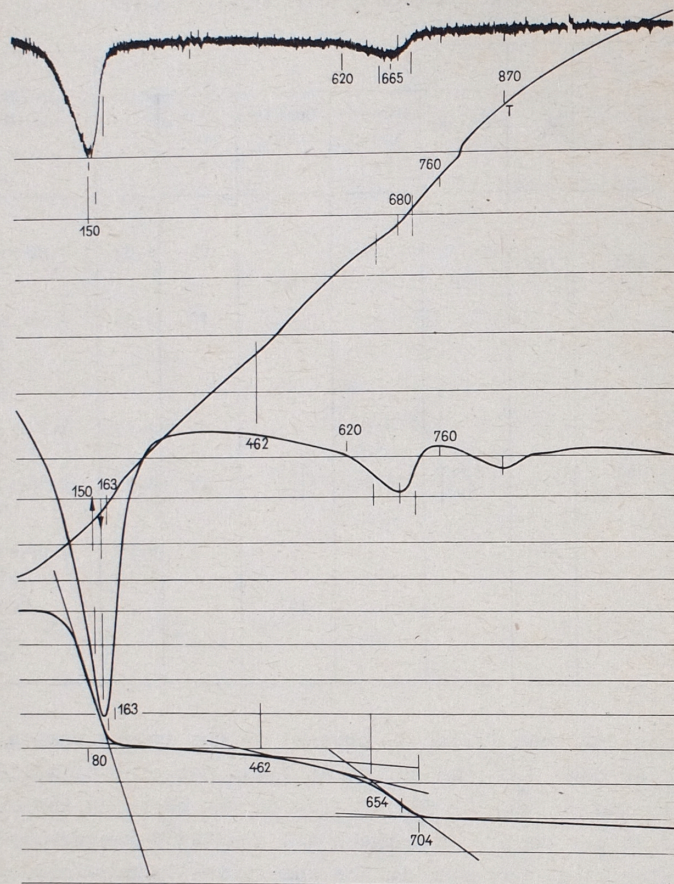


Fig. 1. Thermal curves of white bentonite /Ca-montmorillonite/ from Greece

BAULKING FULLER'S EARTH

In 1969 the Institute of Geological Sciences discovered deposits of fuller's earth near Baulking and Fernham in Berkshire and reported on them in their Reports No. 71/4 and 71/12, two years later. It was soon found that, with the optimal /4 per cent/ addition of sodium carbonate, the Ca-montmorillonite of Baulking and Fernham fuller's earths attained a swelling index of 127 and 103 ml per 10 g of clay, respectively,

compared with about 70 ml for Redhill fuller's earth similarly treated. As it was thought then that high swelling potential was due to substantial tetrahedral substitution, as in Wyoming bentonite, a careful mineralogical analysis was attempted.

X-ray diffraction measurements showed, besides the montmorillonite, quartz - 'possibly well below 7 per cent', illite - 'not more than but not much less than 5 per cent', feldspars - possibly about 2 per cent, though very uncertain, calcite - probably in the range 1 - 2 per cent, and clinoptilolite - in the range 2 - 5 per cent, - vague, because there were no standards to work with. A rounded peak $d = 11.4 \text{ \AA}$ and small peaks 4.385 and 3.49 \AA were not identified.

From a detailed chemical analysis it was decided to calculate the carbonaceous matter first. Exchangeable cations were estimated separately, and these were allocated to montmorillonite, though a small proportion would have been associated with the illite and the clinoptilolite. The remaining alkalis and CaO had to be allocated to illite, clinoptilolite and feldspars, leaving enough /OH/ for the montmorillonite. Feldspars are more plentiful in the Aptian fuller's earths to the east, but are not thought to be less than 3 per cent in Baulking fuller's earth. If any concession has to be made, I should say that there might be less illite in the Baulking fuller's earth than I have calculated or that the illite might be less hydrated than I have assumed.

With these assumptions the mineralogical composition was calculated and thereafter the ionic composition of the montmorillonite /Table 3/.

The cation exchange capacity by the ammonium acetate method was found to be 88 meq/100 g. When the individual cations were estimated separately, their sum substantially exceeded the c.e.c. It was then discovered that 24 meq of Mg^{2+} and less than 2 meq of Ca^{2+} ions were soluble in deionised water of pH 6.2. By allowing for the soluble cations, apparently derived from the octahedral layer, the exchangeable cations were found to be:

Ca^{2+}	78.6 meq/100 g
Mg^{2+}	2.9
Na^{+}	3.5
K^{+}	2.4
	<u>87.4</u>

From these figures we can say that the c.e.c. of the pure montmorillonite itself is about 100 meq/100 g.

Mineralogical calculation of the composition
estimates of minerals including clino

Component	wt.-%	Carbon- aceous matter	Exchange- able cations	Illite Δ %	Clino- ptilolite	Feldspars
SiO ₂	52.43			2.04 ₅	2.04 ₇	1.94 ₆
Al ₂ O ₃	14.71			1.39 ₂	0.17 ₄	0.70 ₂
TiO ₂	0.81					
Fe ₂ O ₃	4.58					
FeO	1.25					
MnO	0.02					
MgO	2.48					
			0.05			
CaO	2.57		1.90 ₄			0.12 ₃
Na ₂ O	0.37		0.10 ₈		0.10 ₆	0.15 ₆
K ₂ O	0.70		0.09 ₈	0.24 ₀	0.16	0.20 ₂
H ₂ O ⁺	3.86	0.16		0.32 ₂		
H ₂ O ⁻	16.09				0.36 ₉	
CO ₂	0.6					
C	0.24	0.24				
Total	100.71	0.40		3.99 ₉	2.85 ₆	3.12 ₉

The cationic charges are

Mg	0.026
Ca	0.704
Na	0.036
K	0.022
	0.788

Substitutions are

Mg	0.594
Mn	0.003
Fe	0.180
Al	0.011
	0.788

Quartz is $0.044/7.999 \times 46.39_2 = 0.25_6\%$

Moisture may be $18.070 - 15.932 = 2.138$ or $2.138/18.070 \times 15.721 = 1.86\%$.

Error in total /0.71%/ may be moisture, so true moisture may be 1.15%

Table 3

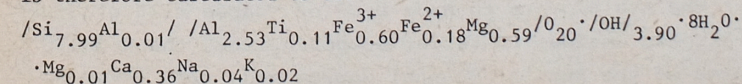
of Baulking fuller's earth based on XRD
ptilolite and on exchangeable cations

Carbonates	Δ	g-equiv. of cationic constituents	g-equiv. per total of 44	Atoms per unit cell	
	46.39 ₂	3.0897	31.998	7.999	{0.044 7.955}, 7.96 ₆ {0.011 2.518}
	12.44 ₂	0.7323	7.588	2.529	
	0.81	0.0304	0.315	0.105	
	4.58	0.1721	1.782	0.594	
	1.25	0.0348	0.360	0.180	3.98 ₃
	0.02	0.0006	0.006	0.003	
0.15g	2.27 ₁	0.1126	1.166	0.583	3.88 ₃ [15.93 ₂]
	0.05	0.0025	0.026	0.013	
0.54 ₃	1.90 ₄	0.0680	0.704	0.352	
	0.10 ₈	0.0035	0.036	0.036	
	0.09 ₈	0.0021	0.022	0.022	
	3.37 ₈	0.3749		3.883	
	15.72 ₁	1.7448		18.070	
{0.17 ₄ 0.42 ₆ }					
	89.02 ₁	4.2486			

Mineralogical composition could be

montmorillonite	86.9 \pm 2
illite	4 \pm 1
clinoptilolite	2.9 \pm 1
feldspars	3.1 \pm 1
quartz	0.3 \pm 0.5
carbonates	1.3 \pm 0.5
carbonaceous matter	0.4 \pm 0.1
moisture	1.1 \pm 0.5

The ionic composition of the montmorillonite, scaled up to allow for the free silica, is therefore calculated to be:



If these soluble cations had not been taken into account they would have led one to believe that Baulking fuller's earth has a higher degree of tetrahedral substitution than the other Aptian fuller's earths of England. However the calculation presented here shows the least tetrahedral substitution of any of the 10 ionic compositions hitherto published /Robertson, 1961/.

	Si	Al ³⁺	Al ²⁺	Ti	Fe ³⁺	Fe ²⁺	Mg	M ⁺
Aptian mean	7.93	0.07	2.51		0.73	0.16	0.64	0.94
Baulking	7.99	0.01	2.53	0.11	0.60	0.18	0.59	0.78
cf Bathonian	7.67	0.33	3.04		0.49	0.06	0.42	0.80

Grim and Kulbicki /1961/ in their well-known classification of montmorillonites had found that in Cheto-type /Mg-rich/ montmorillonites the calculated c.e.c. was greater than the measured by a comparable difference. They had prepared the clay for chemical analysis by treatment with less than 0.1 M HCl and had thought that the acid treatment had "removed some cations from within the lattice thereby increasing the computed value".

I believe that the good potential swelling power of Baulking fuller's earth is not due to tetrahedral substitution but to its higher degree of purity compared with the other fuller's earths; possibly to particle shape and size; to the reaction of some released Mg²⁺ ions with the added sodium carbonate; and to lower earth pressure in its geological history.

I regard the very close similarity of the ionic compositions of all Aptian fuller's earths of England as indicating a single volcanic source /Cowperthwaite *et al.*, 1972/. It seems to be extremely improbable that the montmorillonite occurring in Kent, Surrey, Bedfordshire /Woburn/ and Berkshire would show so little variation in ionic composition if it had been formed from riverborne raw materials derived from very different tracts of land /Poole *et al.*, 1971/, where different rocks were exposed.

Jeans *et al.*, /1977/, while showing beyond doubt that the Aptian fuller's earths of England are of volcanic origin, found two ages for these clays, 118-125 Ma and 142-148 Ma and suggested their origin in a volcano beneath the Waddenzee in the Netherlands, and provided some rare-earth ratios in support of this hypothesis.

It is possible that the ash here was also of sand size-grading as predicted by me in Cowperthwaite *et al.*, /*op. cit.*, p. 323/, whereas at Redhill and Woburn the ash appears to have been of coarse silt grading. There are other reasons, besides this, for supposing that the volcano was in the rift area of the English Channel approaches; the decrea-

sing purity as the deposits are traced towards the east and northeast; the thinning in those directions; and the prevailing wind direction. Moreover it is about 600 km from the Waddenzee volcanic area to Baulking, - too far, I believe, to have produced such a thick deposit of ash. It is also unlikely that the Wolf Rock, 360 km from Baulking and formerly suggested as a possible source, was the only volcano in an actively rifting area.

I also think that clinoptilolite, so often found in altered volcanic ashes, is another indication of the volcanic origin of these rocks; and that it may be concentrated in sands when montmorillonite is washed out of the weathered ash.

As we had so much detailed information about the composition of Baulking fuller's earth, we eagerly accepted Dr. Kuźniarowa's offer to carry out a thermal analysis of the same sample. The main effects of the Derivatograph of Baulking fuller's earth are given in Table 4. Beside them are given the weight losses derived from the mineralogical composition.

Table 4

Comparison between thermogravimetric loss and calculated mineralogical composition of Baulking fuller's earth

T °C	DTA large endo- medium endoexo- therms °C	DTG °C	Episodes °C	Cumulative loss %	Episode losses %	Losses due to minerals
0						
100	<u>153</u>	<u>172</u>			14.55	1.18 moisture 13.51 mont, 8H ₂ O 14.51
200			230	14.55		
300						0.27 clinoptil: 0.18 carb matter
400	388 ?430				1.22	
500	460 <u>540</u>	515	490	15.77	2.04	0.32 illite
600	<u>655</u>	<u>650</u>	620	17.81	1.02	2.38 mont./OH/4 0.84 carb matter
700			708	18.83	0.51	0.17 MgCO ₃
800	<u>830</u> 885		815	19.34	0.51	0.43 CaCO ₃
900						
1000				19.85	<u>19.85</u>	<u>19.68</u>

The total losses in the thermally and chemically analysed samples differ by only 0.17 per cent. The loss in weight up to 230°C is only 0.05 per cent lower than the calculated moisture and 8 H₂O in the montmorillonite. Organic matter carbonises at a low temperature and the carbon burns away at a high temperature. The carbonates lose their CO₂ below 830°C. The peak at 540°C is probably partly due to illite.

It is probable that much of the zeolitic water of clinoptilolite is lost at a low temperature. Montmorillonite, calcium-saturated, loses its water in two temperature ranges; between 350°C and ~550°C the hydroxyl loss, as was shown by Mering /1946/, appears to be proportional to the c.e.c. In the present thermal study this loss, about 2.5 per cent H₂O, neatly fills the so far unaccounted weight loss below 620°C, - the end of a weight loss episode. The remaining 0.88 per cent weight loss occurs above this temperature. The weight loss episodes 20-230-620-1000°C can be satisfactorily explained by known mineralogy. In reverse, the TG curve would allow one to arrive at a fair estimate of the montmorillonite content since the clay had been equilibrated at ~56 R.H. beforehand. The loss up to 230°C would give a useful approximation to the 8H₂O of the montmorillonite and a quarter of this would give its /OH/ content. The carbonates can be reasonably well estimated, but XRD is really needed for identifying and roughly measuring the illite and clinoptilolite. Nevertheless the Derivatograph has proved to be a good confirmation of the analytical work previously carried out.

There are at least four industrially important hydration states in the moisture content range of Ca-montmorillonite, /1/ a high moisture content of about 14 per cent in Baulking fuller's or about 16 per cent in the pure clay mineral, below which the swelling power on the addition of sodium carbonate declines, /2/ a low moisture content - about 6 per cent in Surrey fuller's earth - at which the earth has the highest decolorising power when it is used for purifying light-coloured vegetable oils; /3/ "peak greenstrength" and /4/ the limit of moisture content used in foundry moulding sand, equivalent to about 8 + 16 and 8 + 24 H₂O respectively, are described in my address to the First Clay Conference in Poland, at Bolesławiec, 25 April 1978, /Robertson, 1979/.

Ad. 1. In a theoretically pure Ca-montmorillonite the Ca²⁺ ions are thought to be surrounded by water of hydration, first 6H₂O in octahedral arrangement, and at higher humidities a further 2H₂O /Mering, 1946/. Mg²⁺ has only 6H₂O around it and Na⁺ and K⁺ are not hydrated cations, any more than they are in NaCl or KCl.

The degree of hydration of the cations in Baulking fuller's earth montmorillonite can therefore be calculated:

			At R.H.16	At R.H.56
Mg ²⁺	ions	0.013	x 6 0.078	x 6 0.078
Ca ²⁺	ions	0.352	x 6 2.112	x 8 2.816
Na ⁺	ions	0.036	x 0 -	x 0 -
K ⁺	ions	0.022	x 0 -	x 0 -
			<u>2.190</u>	<u>2.894</u>

Mering showed that whereas Na-montmorillonite has basal spacings on the uptake of water $d = 9.5, 12.4, 15.4$ and 19.0 \AA , Ca-montmorillonite on hydration does not have a 12.4 \AA hydrate, but first shows a spacing at about 14 \AA which corresponds with the octahedral groups of Ca/H₂O/6. In the later stage of hydration, at a 15.4 \AA spacing, another 2H₂O may be associated with the Ca²⁺ ions, and the interlayer space is filled with two complete sheets of water molecules, the so-called Hendricks double layer.

If any part of the 8H₂O of the Ca-montmorillonite is removed, an artefact is produced and swelling power is impaired.

Ad. 2. On the other hand when the Ca-montmorillonite is dried partially, so that only the 6H₂O surrounding the Ca²⁺ and Mg²⁺ ions remains, the earth has its optimal bleaching power. In Baulking fuller's earth this state would be reached when the moisture content is 5.74 per cent. A fuller's earth dried to this state of hydration has a high porosity and surface activity. It is better to reach this moisture by fairly rapid thermal treatment than by slow drying at a low R.H. because the adsorbent surface tends to be larger when the clay is dried fairly rapidly.

BLACK SHALE FROM RIO TINTO MINE, SPAIN

This black shale /S4511/, described as Pizarra negras de filon norte, from the copper mines of Tharsis, near Huelva, Spain, has been affected hydrothermally. Unaltered Palaeozoic shale would be expected to contain mainly quartz, mica, chlorite and kaolinite, carbonates and carbonaceous matter. The question arose as to the mineralogical composition of the altered rock.

Electronmicrographs showed rods or needles of rutile, quartz fragments and a large amount of smectite foils. One observer thought there might be some amorphous oxides among the finer particles. An X-ray diffractogram was interpreted as indicating quartz 15 per cent, pyrite 2 per cent, and rutile 1.5 per cent. The smectite peak $d = 15.5 \text{ \AA}$ was small, but the trace was not clear at high spacings. No other clay mineral appeared to be present.

The DTA curve /Fig. 2/ shows a large endotherm at 140°C with a small endothermic effect at 240°C and a small endotherm at 555°C. These can be ascribed to a significant amount of smectite. Carbonaceous matter seems to be burnt off at three temperature ranges, 260-300°C, around 450 perhaps, and from 580-790°C. The 450°C peak however is sharp and probably mostly due to pyrite. The DTG curve is useful here

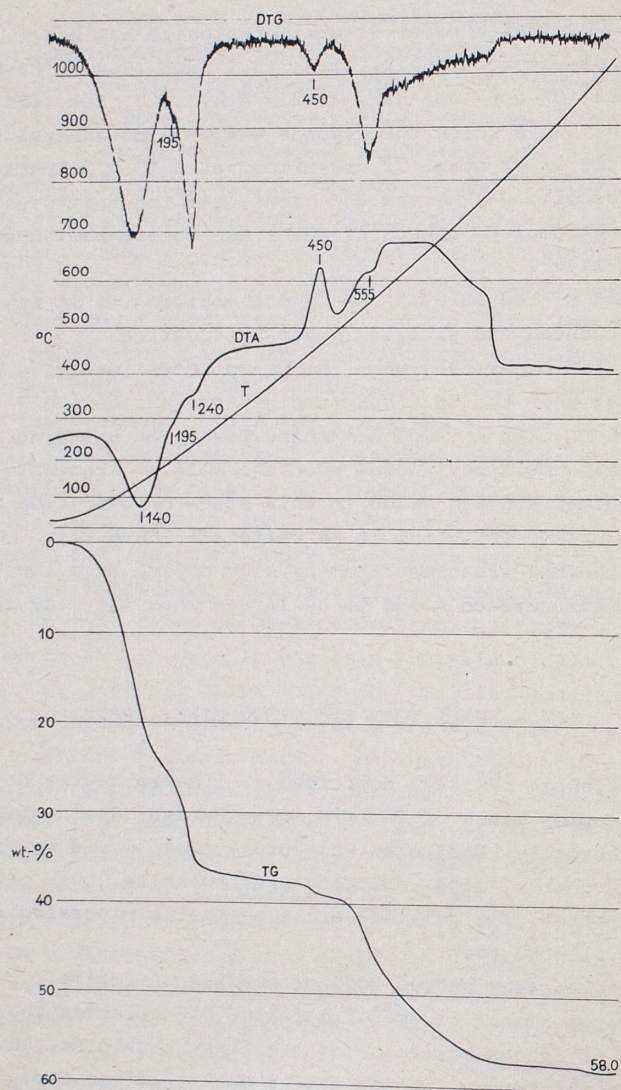


Fig. 2. Thermal curves of black shale from Tharsis copper mine, Spain

because it shows the double weight loss at 140 and 240°C and a substantial weight loss about 555°C, all due to the smectite. The thermogravimetric curve has seven inflections /Table 5/.

Table 5
Thermal analysis of black shale from Tharsis copper mine, Spain

Step no.	TG loss		T °C	Loss %	Comments
	mg	%			
1	40	25	20 - 180	25	moisture, adsorbed water montmorillonite 8H ₂ O
2	58	36.25	180 - 380	11.25	H ₂ O ex carb. matter and ? amorphous matter
3	60.5	37.8	380 - 440	1.55	
4	62.5	39.06	440 - 480	1.25	pyrite mainly
5	64	40	480 - 520	0.98	mont. /OH/ ₄
6	91.5	57.19	520 - 770	17.19	carbon
7	93	58	770 - 1000	0.81	

This sample had not been equilibrated at a standard relative humidity and was very moist; it also contained a lot of carbonaceous matter. The 0.98 per cent loss, if due to montmorillonite, would mean that there was 23.84 per cent of montmorillonite. 8H₂O present. The losses 2 and 6 in the Table give an upper limit for the carbonaceous matter of about 28 per cent.

By combining the information given by XRD with that from the thermal analysis, we arrive at a first approximation in a mineralogical analysis:

carbonaceous matter	27.8 per cent
smectite, not more than	23.8
rutile	1.5
pyrite	2.0
quartz, by difference	44.9

Chemical analysis of some of the constituents, shown in Table 6, allows us to make a further refinement. If we ascribe the Fe₂O₃ to montmorillonite and the Al₂O₃ to montmorillonite we arrive at figures of 9.73 and 7.97 per cent, respectively. The sum, 17.7 per cent, may be regarded as the upper limit for the smectite content. Carbonaceous matter estimated from the measured carbon determination can hardly be more than 9.47 per cent. It is possible that this constituent varies within the rock. We can now turn back to the TG calculation, bring in the 0.9 per cent of gypsum indicated in the chemical analysis and arrive

Table 6

Chemical analysis of black shale from Tharsis copper mine, Spain

Component	Wt. %
SiO ₂	77.11
Al ₂ O ₃	2.15
Fe ₂ O ₃	3.03
MgO	0.06
CaO	0.46
Other oxides	0.46
C	5.41
Water	10.86
	100.08

neral in this hydrothermally altered shale.

Acknowledgements. I am indebted to Professor Anna Langier-Kuźniarowa for carrying out thermal analyses of the white bentonite and of the Baulking fuller's earth; and to Dr. Radko A. Kühnel for the analytical work on the black shale. The chemical analysis of the Baulking fuller's earth was by Mr. Peter J. Rice of W. H. Herdsman Ltd., and its exchangeable ions and soluble magnesium were determined by Robertson Research International Ltd.

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ve at a "best fit" mineralogical analysis of the more carbonaceous sample:

carbonaceous matter	27.8 per cent
smectite	17.7
rutile	1.5
pyrite	2.0
gypsum	0.9
quartz, by difference	50.1.

We can take this as a warning: coarse quartz should be estimated separately if it is important to know its proportion. The amounts of sample required for XRD and EM are so small that quartz grains are by no means all detected. On the other hand it is interesting that smectite is the clay mi-

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ZNACZENIE ANALIZY TERMICZNEJ W BADANIACH MINERALOGICZNYCH

CZEŚĆ I

Streszczenie

Przedstawiono wyniki analizy termicznej: 1/ białego bentonitu, zawierającego nieuporządkowany α -trydymit z Cyklad /Grecja/, 2/ ziemi fullerskiej z Baulking, Berkshire /Anglia/ oraz 3/ czarnego łupku z kopalni miedzi Tharsis /Hiszpania/. W wyniku tych analiz oraz badań rentgenowskich i chemicznych stwierdzono m. in., że montmorillonity ze wspomnianego białego bentonitu i ziemi fullerskiej wykazują tylko znikomy stopień podstawienia Si przez Al w warstwach tetraedrycznych /odpowiednio: Si_{7.98}Al_{0.02} i Si_{7.99}Al_{0.01}/.

OBJAŚNIENIA DO FIGUR

Fig. 1. Krzywe termiczne białego bentonitu /Ca-montmorillonitu/ z Grecji

Fig. 2. Krzywe termiczne czarnego łupku z kopalni miedzi Tharsis, Hiszpania

Роберт Х. С. РОБЕРТСОН

ЗНАЧЕНИЕ ТЕРМИЧЕСКОГО АНАЛИЗА В МИНЕРАЛОГИЧЕСКИХ ИССЛЕДОВАНИЯХ

ЧАСТЬ 1

Резюме

Представлены результаты термического анализа: 1/ белого bentонита, содержащего неупорядоченный α - тридимит с Циклад /Греция/, 2/ фуллеровой земли Баулькинга, Беркшира /Англия/, а также 3/ чёрного сланца из медной шахты в Тарсисе /Испания/. В результате этих анализов, а также рентгеновских и химических исследований установлено, между прочим, что

в монтмориллонитах из описываемого белого бентонита и фуллеровой земли в минимальной степени проявляется замещение Si Al в тетраэдральных слоях /соответственно $\text{Si}_{7.98}\text{Al}_{0.02}$ и $\text{Si}_{7.99}\text{Al}_{0.01}$ /.

ОБЪЯСНЕНИЕ ФИГУР

Фиг. 1. Термические кривые белого бентонита /Са-монтмориллонита/ из Греции

Фиг. 2. Термические кривые чёрного сланца из шахты в Тарсисе, Испания