The Chemical and X-Ray Analysis of Some Saudi Arabian Minerals

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Seven minerals from different provinces of Saudi Arabia were subjected to different methods of analysis. All the results were considered as a whole to see how far they complement or support each other.

Four samples were composed of kaolinite with free silica and hematite. Calcite and dolomite were identified in two samples.

An interesting feature of this study is magnetite which widespread in a big area and it is an important source of iron bearing minerals.

The resutls were discussed and explained in terms of the ideal formula of each compound.

A limestone is a sedimentary rock consisting essentially of calcium carbonate with minor amounts of magnesium carbonate, silica, clay, iron oxide or carbonaceous material. With an increase in the content of magnesium carbonate, limestone gradually passes over to a dolomitic limestone, which is a mixture of dolomite and calcite and finally to normal dolomite.

The structure of calcite was one of the earliest to be analyzed by x-rays[(1)]. Dolomite has a structure similar to that of calcite, but the atoms along any three-fold axis are alternately Ca and Mg.

The structure of kaolinite was suggested by Pauling[(2)]. It was worked out in some details by Gruner[(3)], Hendricks[(4)]. Brindley and Robinson(5) had an occasion to examine many kaolinite specimens.

Magnetite is an important ore of iron. Magnetite crystals are well formed in many rocks and give square or hexagonal outlines because of the octahedral form.

The chief products of iron-ore are the United States, with its great output from the lake superior mines. They are produced in U.S.S.R., France, China, Canada, Sweden, West Germany. Iron-Ore also occurs in several other countries.

Material and Methods

The samples under test were obtained from different provinces of Saudi Arabia. They are: El-Qasim Province, Wasia Province, Umm El-Radhumah Province, Marrat Province, Tabuk Province, Dammam Province and Gizan Province.

Samples were collected from different localities of each province. They were finely ground to grain sizes suitable for chemical analysis, differential thermal analysis and x-ray diffraction studies. The raw materials are not pure crystalline substances and for this reason oriented aggregates were prepared(6). This method gives a stronger, cohesive aggregates and was adopted to obtain a purer type of clay.

For x-ray studies, a small amount of material 0.2-0.4 mm in linear dimensions were packed as tightly as possible in a thin glass capillary. The glass capillary was mounted and rotated in the powder camera. The diffraction patterns were recorded using a Philips powder camera (114.6 mm diameter), generator and diffractometer with filtered copper radiation.

The following methods were carried out for analysis of Saudi Arabian ores an clay minerals:

1. *Differential thermal Analysis (D.T.A.)*

When thermal reaction takes place in material, the temperature of the material is greater or less than that of the inert material, depending on whether the reaction is exo-thermic or endo-thermic. The e.m.f. sets up in the differential thermocouple circuit was recorded as a function of temperature (Fig. 1).

2. *Chemical Analysis*

The samples under test were subjected to different methods of chemical analysis. The average value was taken for the samples obtained from each province.

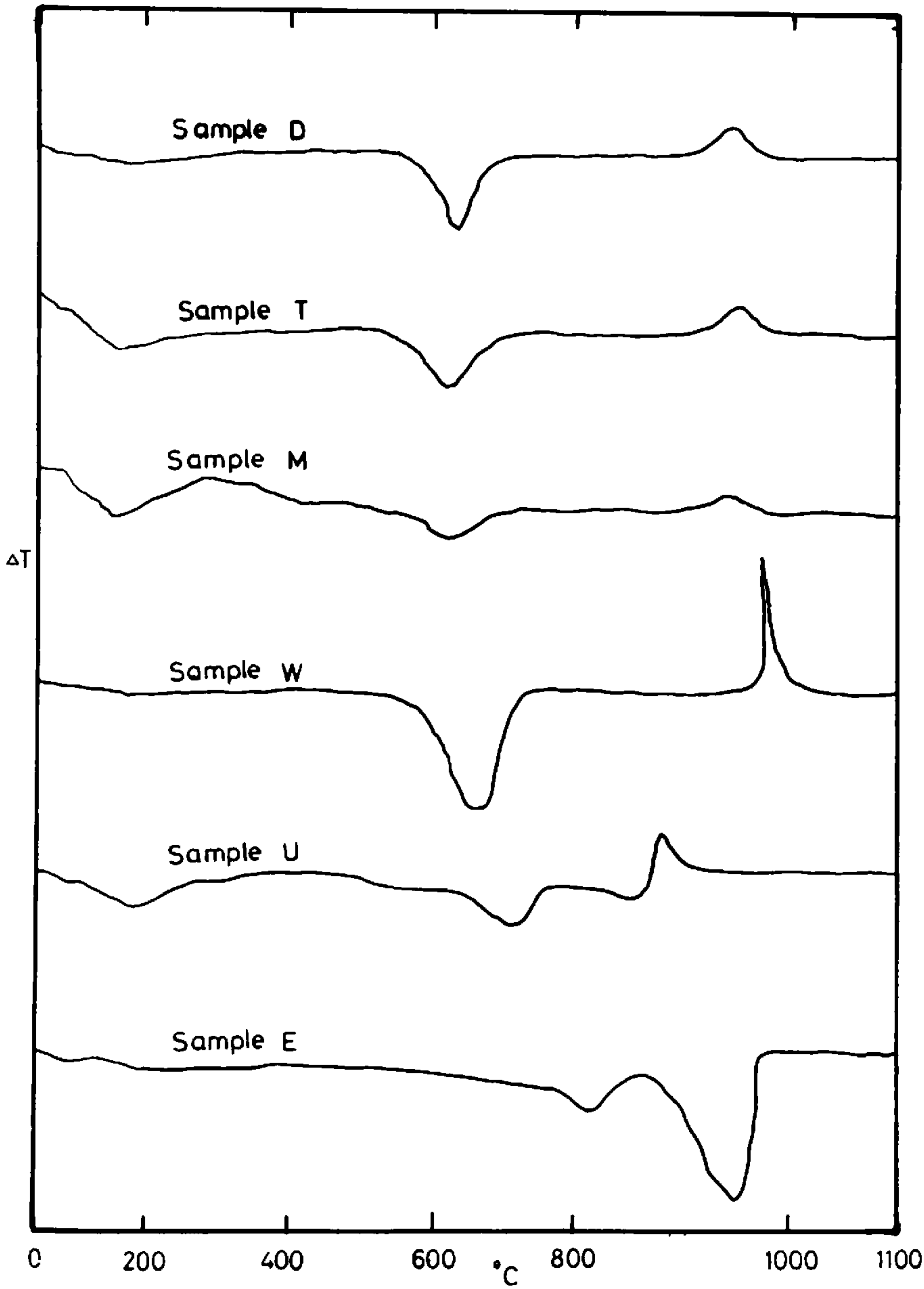

Fig. (1)

Differential thermal analysis curves of the six samples

The results of those methods are shown in Table 1.

3. *X-Ray Qualitative Analysis*

This method was carried out for the test pieces. From information given by the chemical analysis and D.T.A., a body of knowledge has been built enables the different clay and related minerals groups to be recognized. The photographs or th recording charts by diffractometer showed the diffraction patterns of calcite with free silica for the specimens of El-Qasim, dolomite with free silica for the samples of Umm El Radhumah, kaolinite with free silica and iron oxide for the minerals of Wasia, Marrat, Tabuk, Dammam and finally magnetite for the specimens of Gizan. The technique for the identification of the components present in each was done by comparison of the intensities and the spacings of x-ray diffraction lines given by the A.S.T.M. (American Society for Testing Materials) card (Tables 2, 3, 4).

The intensities were measured qualitatively by designating each line as strong (S), medium (M), weak (W), faint (F) and very faint ($\bar{F}$).

Discussion of Results

Seven minerals from different provinces of Saudi Arabia were subjected to different methods of analysis. One method of analysis is usually not enough to give complete picture of the constitution of most minerals. For this reason chemical analysis, differential thermal analysis and x-ray diffraction methods were used for the analysis of the present samples.

Now all the results will be considered as whole to see how far they complement or support each other.

The samples from Wasia, Marrat, Tabuk and Dammam provinces gave identical x-ray diffraction patterns and thermal behaviour and for these reasons they are taken together.

X-ray diffraction patterns showed that the four samples were composed of a mixture of kaolinite mineral, free silica and iron oxide. The free silica exists as α-quartz and the iron oxide exists as hematite. No other constituents could be identified from these patterns. Reverting to chemical analysis, let us consider only the Al_2O_3, SiO_2 components and loss on ignition.

They are;

Ideal formula ratio of kaolin	Al_2O_3	:	$2SiO_2$	:	$2H_2O$
	101.96	:	120.17	:	36
Ratio of molecular weight relative to Al_2O_3	1	:	1.18	:	0.35
Chemical ratio of wasia clay	35.7	:	40.5	:	14
Ratio of mol. wt. relative to Al_2O_3	1	:	1.13	:	0.39
Chemical ratio of Marrat clay	18.1	:	50.9	:	10.2
Ratio of mol. wt. relative to Al_2O_3	1	:	2.81	:	0.95
Chemical ratio of Tabuk clay	23	:	47.6	:	11.6
Ratio of mol. wt. relative to Al_2O_3	1	:	2.07	:	0.50
Chemical ratio of Dammam clay	11.5	:	48.7	:	6.1
Ratio of mol. wt. relative to Al_2O_3	1	:	4.23	:	0.53

Comparing the chemical constitution of the four samples with that of the ideal formula of kaolin, certain discrepancies are obvious. The lowest percentage present is that corresponding to Al_2O_3. With Al_2O_3 as reference and completely combined in the lattice of kaolinite, there is an excess of SiO_2. The excess could be identified as free silica (α-quartz). Dammam clay has higher percentage of free silica while wasia clay has less percentage in comparison with the most typical kaolinite.

The excess of the loss on ignition may be due to the adsorbed water or due to the organic matters.

Kaolinite minerals from these provinces have higher percentage of iron oxide in comparison with the most typical koalin. Iron oxide exceeds 20% in Dammam clay while Wasia clay has less percentage of it. The iron oxide could be identified as hematite (Fe_2O_3),(Table 2). The presence of such oxide has an important effect on the physical behaviour of clays.

The absence of magnesite in the x-ray diffraction patterns are expected since it is less 5% of the total weight of the sample.

The raw materials from El-Qassim and Umm Radhumah provinces showed the diffraction patterns of calcium carbonate CaCO and dolomite Ca Mg (CO) respectively. The free silica was identified as α-quartz in the two minerals.

Comparing the chemical analysis, Table 1 with that of the ideal formula of calcite and dolomite and assuming that CaO is completely combined in the lattice of them, a reasonable explanation is possible.

Ideal formula ratio of $CaCO_3$	CaO	:	CO_2
	56.08		44.01
Ratio of mol. wt. relative to CaO	1	:	0.78
Chemical ratio, Table 1	44.3	:	39
Ratio of mol. wt. relative to CaO	1	:	0.88
Ideal formula ratio of $Ca\,Mg(CO_3)_2$	CaO	MgO	$2CO_2$
	56.08	40.31	88.02
Ratio of mol. wt. relative to CaO	1	0.72	1.57
Chemical ratio, Table 1	20.7	14.8	36.8
Ratio of mol. wt. relative to CaO	1	0.72	1.78

With CaO as reference, there is a small excess of CO_2 which may be due to organic matters. The determination of the clay minerals in limestone and dolomite is particularly difficult since it is frequently necessary to dissolve away the carbonate in order to concentrate the clay minerals to get adequate analytically data, and some of the clay mineral themselves are fairly soluble in acids.

X-ray diffraction patterns (Table 4), of the specimen from Gizan province showed that the raw material was composed of mainly magnetite (Fe_3O_4) with small amount of titanium oxide (TiO_2) and free silica (α -quartz). Magnetite occurs in large quantity in this province and is an important source of iron bearing minerals.

The chemical analysis of Saudi Arabian magnetite was compared with the typical domestic ores from United States, (Table 5). Saudi Arabian magnetite contains TiO_2 with 4.7% which is harmful with sulpher and phosphorus, if they present in the finished iron and steel products.

References

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Table 1.

Mineral From	L.O. I	SiO_2	Al_2O_3	Fe_2O_3	MgO	CaO	NaO	SO_3	U. D.
Wasia	14.0	40.5	35.7	5.0	2.5	0.7	0.85	0.2	0.55
Marrat	10.2	50.9	18.1	11.6	3.2	2.8	1.14	0.17	1.89
Tabuk	11.6	47.6	23.0	9.6	2.6	1.4	0.12	1.6	2.48
Dammam	6.1	48.7	11.5	23.1	2.6	4.1	0.12	1.5	2.28
El-Qasim	39.0	7.2	2.6	2.0	4.0	44.3	–	0.6	0.3
Umm El-Radhumah	36.8	20.2	4.6	1.8	14.8	20.7	–	0.5	0.6
					TiO_2				
Gizan	1.26	1.6	2.5	88.0	4.7	2.8	Tr	0.38	–

Table 2

Wasia		Marrat		Tabuk		Dammam		Card inded data	
dA°	I/I$_o$	dA°	I/I$_o$	dA°	I/I$_o$	dA°	I/I$_o$	dA°	I/I$_o$
7.14	M	7.15	M	7.14	M	7.14	M	7.14	50
4.45	M	4.46	M	4.45	M	4.45	M	4.46	75
4.35	S	4.36	M	4.34	M	4.34	M	4.34	85
4.25	F•	4.26	W•	4.26	F•	4.26	M•	4.26	35
4.16	M	4.18	M	4.16	M	4.17	M	4.16	65
4.10	W	4.12	W	4.10	W	4.11	W	4.11	40
3.84	W	3.81	W	3.83	W	3.84	W	3.83	50
3.75	W	3.77	F	3.75	F	3.77	F	3.72	20
3.69	$\bar{F}$,H	3.71	$\bar{F}$,H	3.72	$\bar{F}$,H	3.68	$\bar{F}$,H	3.686	29
3.58	M	3.59	M	3.56	W	3.59	W	3.56	50
3.39	F	3.41	F	–		–		3.37	12
3.36	W•	3.37	M•	3.34	M•	3.35	S•	3.343	100
3.16	F	–		–		–		3.148	5
2.68	W,H	2.67	M,H	2.67	W,H	2.69	M,H	2.703	100
2.55	M	2.57	M	2.55	M	2.53	W	2.553	85
2.53	F,H	2.52	W,H	2.53	W,H	2.54	M,H	2.519	73
2.51	M	2.50	M	2.51	W	2.52	W	2.521	50
2.46	S	2.47	M	2.47	M	2.46	W	2.484	85
–		–		2.43	F•	2.44	F•	2.458	12
2.38	F	2.39	F	2.39	F	2.37	$\bar{F}$	2.378	25
2.34	S	2.36	S	2.33	S	2.34	S	2.332	95
2.30	M	2.32	M	2.31	M	2.31	W	2.282	65
2.25	F	2.26	F	–		–		2.243	20
2.19	F	2.17	F	–		–		2.183	12
–		–		–		–		2.116	6
1.98	$\bar{F}$	1.96	F	–		–		1.984	12
1.93	$\bar{F}$	–		–		–		1.936	6
–		–		–		–		1.872	6
1.85	$\bar{F}$	1.85	F	–		–		1.835	6
1.80	F•	1.81	F•	1.83	W•	1.83	M•	1.817	17
–		–		–		–		1.783	4
1.72	$\bar{F}$	–		–		–		1.698	8
1.68	F,H	1.69	F,H	1.69	F,H	1.69	W,H	1.696	60
1.65	$\bar{F}$	1.65	F	1.67	F	1.66	F	1.662	25
1.61	M	1.60	F	1.61	$\bar{F}$	1.61	F	1.616	16
–		–		–		–		1.584	4
1.55	$\bar{F}$	–		–		–		1.537	8
1.50	$\bar{F}$•	1.52	F•	1.54	F•	1.52	W•	1.541	14
1.48	S	1.48	S	1.48	S	1.48	S	1.483	100
1.38	F•	1.38	$\bar{F}$•	1.36	F•	1.36	W•	1.375	11
1.35	$\bar{F}$•	1.36	$\bar{F}$•	1.34	$\bar{F}$•	1.34	$\bar{F}$•	1.372	9
1.27	$\bar{F}$•	1.27	$\bar{F}$•	1.26	$\bar{F}$•	1.27	$\bar{F}$•	1.288	3
1.25	$\bar{F}$•	1.23	$\bar{F}$•	1.23	F•	1.23	$\bar{F}$•	1.256	4
1.22	$\bar{F}$•	1.20	$\bar{F}$•	1.20	F•	1.20	$\bar{F}$•	1.228	2
1.18	$\bar{F}$•	1.17	$\bar{F}$•	1.18	$\bar{F}$•	1.18	$\bar{F}$•	1.1997	5
1.08	$\bar{F}$•	1.09	$\bar{F}$•	1.10	$\bar{F}$•	1.09	F	1.0816	4
1.06	F•	1.06	$\bar{F}$•	1.06	$\bar{F}$•	1.06	F	1.0636	1
1.04	$\bar{F}$•	1.05	$\bar{F}$•	1.04	$\bar{F}$•	1.04	F	1.0437	2
1.01	$\bar{F}$•	1.02	$\bar{F}$•	1.02	$\bar{F}$•	1.02	$\bar{F}$•	1.0149	2
0.98	$\bar{F}$•	0.99	$\bar{F}$•	0.98	$\bar{F}$•	0.98	$\bar{F}$•	0.9896	2
0.96	$\bar{F}$•	0.95	$\bar{F}$•	0.95	$\bar{F}$•	0.95	$\bar{F}$•	0.9607	2

• = α-quartz
H = hematite

Table 3.

El-Qasim		Card index data	
dA°	I/I_o	dA°	I/I_o
4.28	F*	4.26	35
3.83	F	3.86	12
3.31	W*	3.343	100
3.04	S	3.035	100
–		2.845	3
2.46	F	2.495	14
2.43	$\bar{F}$*	2.458	12
2.27	$\bar{F}$	(2.285) (2.282)	18 12*
2.14	F*	2.128	9
2.11	F	2.095	18
1.94	$\bar{F}$	1.927	5
1.90	F	1.913	17
1.84	F	1.875	17
1.80	$\bar{F}$*	1.817	17
–		1.626	4
1.64	$\bar{F}$	1.604	8
–		1.587	2
1.56	$\bar{F}$*	1.541	15
1.53	F	1.525	5
–		1.518	4
–		1.510	3
–		1.473	2
1.46	F	1.440	5
–		1.422	3
1.35	$\bar{F}$*	1.375	11
1.34	$\bar{F}$*	1.372	9
–		1.356	1
1.30	F	1.339	2
–		1.297	2
–		1.281	1
–		1.247	1
–		1.235	2
1.18	$\bar{F}$*	1.1997	5
–		1.1538	3
–		(1.0473)	3
1.04	$\bar{F}$	(1.0447)	4*

Umm El-Radhumah		Card index data	
dA°	I/I_o	dA°	I/I_o
4.28	F*	4.26	35
4.06	$\bar{F}$	3.03	5
3.72	$\bar{F}$	3.69	50
3.32	W*	3.343	100
2.88	S	2.886	100
2.71	F	2.670	10
2.52	$\bar{F}$	2.540	10
2.44	F*	2.458	12
2.41	F	2.405	10
2.30	$\bar{F}$*	2.282	12
2.23	W	2.192	30
2.14	$\bar{F}$	2.128	12
–		2.066	5
2.06	F	2.015	15
–		1.848	5
1.84		1.804	20
1.80	F*	1.817	17
1.76	F	1.786 1.781	30
1.55	F	1.567	10
1.53	F	1.545	10
1.52	F*	1.541	15
–		1.496	1
1.45	$\bar{F}$	(1.465) (1.445)	5 5
1.41	$\bar{F}$	1.431	10
–		1.413	5
1.37	$\bar{F}$	1.389	15
1.35	$\bar{F}$*	(1.375) (1.372)	11 9
1.33	$\bar{F}$	1.335	10
1.28	$\bar{F}$	(1.297) (1.269)	5 5
–		1.238	5
1.19	$\bar{F}$*	1.1997	5
–		1.008	5
–			

* = α-quartz

Table 4.

Gizan		Card index data		Gizan		Card index data	
dA°	I/I_o	dA°	I/I_o	dA°	I/I_o	dA°	I/I_o
4.88	$\bar{F}$	4.85	8	–		1.123	4
3.53	W,T	3.50	80	1.11	$\bar{F}$	1.093	12
2.99	F	2.967	30	–		1.050	6
2.86	W,T	2.85	100	–		0.9896	2
2.55	S	2.532	100	–		.9695	6
–		2.424	8	–		.9632	4
2.18	F,T	2.17	40	–		.9388	4
2.14	F,T	2.12	60	–		.8952	2
2.11	F	2.099	20	0.89	$\bar{F}$	.8802	6
1.74	$\bar{F}$	1.715	10	0.86	$\bar{\bar{F}}$	.8569	8
1.68	F,T	1.695	60	0.81	$\bar{F}$	(.8233)	4
1.65	W,T	1.668	80			(.8117)	6
1.63	W,T	1.649	80	–		.8080	4
1.60	F	1.616	30				
1.85	W	1.485	40				
–		1.419	2				
1.38	F,T	1.401	50				
–		1.328	4				
1.30	$\bar{F}$	1.281	10				
–		1.266	4				
–		1.212	2				

T = Titanium oxide

Table 5.

Content	Magnetite								
	Non-titanifeous N.Y., N.J., Pa.			Titaniferous, N.Y., Colo., Minn., N.C.			Saudi Arabia Gizan (averaged)		
Fe	40	to	67.5	34	to	63	62		
P	0.02	to	0.42	0	to	0.06	Tr		
S	0.08	to	0.42		–		0.15		
SiO_2	1	to	20	0.8	to	18.0	1.6		
Al_2O_3	0.7	to	4.5	2.5	to	10	2.5		
CaO	0.3	to	5.6	0	to	3	2.8		
MgO	0.2	to	4.2	0	to	6	–		
MnO_2	0.04	to	1.4	0	to	0.3	–		
TiO_2	0	to	Tr	12	to	16	4.7		
Cr_2O_3		–		0	to	2.5	–		
V_2O_5		–		0.60	to		–		
H_2O	0	to	1.6	0	to	0.04	0	to	1.26

Tr = Traces