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Chemistry of products from the second beneficiation test of talc from Nakkan, Altermark, northern Norway

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REPORT

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Title:
Chemistry of products from the second beneficiation test of talc from Nakkan, Altermark, northern Norway

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Summary:
XRF-analyses of products from beneficiation tests of Nakkan talc, made by OMYA GMBH, is described. The results are compared with earlier test-results from Nakkan and from the mine. The mineralogical compositions have been estimated from the chemical data. The purest talc products contain around 96-97% talc and, in addition, minor amounts of chlorite and carbonate. The carbonate-product "Mag 2" contains around 80% carbonate, 15% talc and 5% chlorite.
Based on XRF analyses, the Ni content in the talc products is around 0.16%, which is comparable to earlier studies of Nakkan products, but lower than in products from the mine which contain around 0.24 %. If similar procedures have been followed in the beneficiation process, a general lower content of Ni in the talc lattice from the Nakkan deposit compared to the mine is indicated. Instead, more Ni is bound in sulphides and spinels. Although not encountered earlier in the Altermark talc by the present author, possible trace amounts of As are weakly indicated.
Since important trace elements occur in very small amounts or below the detection level by XRF, it is recommended to apply other analytical methods (ICP-AES, AAS, LECO) with lower detection levels to achieve more correct numbers.

Keywords: Talk	Karbonat	Røntgenfluorescens
Produktutvikling	Ultramafisk bergart	
		Fagrapport

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INTRODUCTION

The primary objective of this report is to present chemical data from the second beneficiation test of material from Nakkan, carried out by Tavakkoli (in press).
The report is written without detailed knowledge of the results and steps of the beneficiaton test, and is therefore just a simple description of the chemistry. The relationship between the chemistry, mineralogy, recovery and beneficiation processes need, however, a more detailed study, and should be carried out later.

METHODS

The following methods have been applied:
1. XRF – major and trace element analyses
2. Wet chemical method to find the amount of acid soluble FeO, MgO and CaO
3. Wet chemical method to find the amount of Fe^{2+}
4. Wet chemical determination of H_2O^+, H_2O^- (Penfield method)

From the XRF chemical data the general mineralogical content is estimated by a method developed by Karlsen (1998). A short description of the method is given in Appendix 1. Another method to estimate the mineralogical content is the acid solubility test. From the acid soluble content the amounts of carbonate/non-carbonate are estimated. Compared with the first method this is less precise, but additional information of the composition of the carbonates is gained. The determination of Fe^{2+}, H_2O^+ and H_2O^- has been applied to achieve information of the valence state within talc.

INVESTIGATED SAMPLES

The investigated samples (Table 1) are from the second beneficiation test of Nakkan material. In some of the tables shown in this report, products from earlier tests are incorporated for comparison.

Table 1: Overview of studied samples and their classification.

Product (from Tavakkoli in press)	**Product-type**
Ferro mag. 1	Magnetite-concentrate
Aufgabe	Talc-carbonate ore
Produkt 1	Talc-concentrate
Sichtprodukt	Talc-concentrate
Reject 1 + non.mag 2	Talc-carbonate-concentrate
Produkt 2	Talc-carbonate-concentrate
Mag 2	Carbonate-concentrate
Non.mag.1	Talc-carbonate-concentrate

COMPOSITION OF THE BENEFICIATION TEST MATERIAL

Complete XRF chemical analyses of the test material from the Nakkan deposit are given in Table 2. In Table 3, the mineralogical contents have been estimated. In Table 4, some components of great importance are shown for the studied samples and for previously studied material.

Talc-carbonate ore

The starting material ("Aufgabe", Tables 1, 2 & 3) has a chemistry and mineralogical composition very similar to the former test material from Nakkan ("Pin Mill Produkt" Tavakkoli 1998, Karlsen 1998, 1999) and contains around 55 wt% talc and 40 wt% carbonate (Table 3). For the first time for the present author, As has been indicated in the raw material (11 ppm). Since the indicated content is very close to the detection limit, this content might be insignificant, and more precise methods have to be applied.

Talc concentrates

The products "Produkt 1" and "Sichtprodukt", are very talc-rich, containing around 95-96 wt% talc, 3-4wt% carbonate, and trace amounts of chlorite (Table 3). The chemical composition is rather similar to previous products from Nakkan and from the mine, but with the following differences:

- The SiO_2 content is slightly higher (60.6-61.2 wt% vs. ~58-60wt% in previous products), but the total sum of the analyses are higher. When normalised to 100 % they are more similar.
- The content of minor elements such as Cr, Ni and Fe_2O_3 is rather similar to the previous test of the Nakkan material, but lower than in the material from the mine (Table 4).
- A possible presence of As (10 ppm in the "Sicthprodukt") has not been encountered in the previous test material.

Talc-carbonate concentrates

The material termed "Produkt 2", "Reject 1 + non.mag 2" and "Non.mag 1" are dominated by talc as they carry around ~70-90 wt% talc (Table 3). In the calculation shown in Table 3 the minerals in the products "Reject 1 + non.mag. 2" and "Produkt 2" do not add to 100% as seen by the last coloumn. Of this reason the numbers must be treated with care. There are several ways to explain the "error", for example by additional contents of magnetite, deviation from normal mineral-chemical formulas etc..

All talc-carbonate products carry higher amounts of chlorite than the pure talc products. They also have higher Cr (Table 4).

The numbers of the talc content given in the text are for pure talc, while the chlorite content comes in addition (Table 3). Since the properties of chlorite are very similar to those of talc, its presence is not considered as negative. Hence, it might be considered as talc in a final product.

The estimation of the content of minerals from XRF data as in Table 3 is based on the content of Al_2O_3, SiO_2, LOI and average mineral chemical formulas. In addition to this method, the amount of carbonate/non-carbonates has been estimated by analyses of the Acid Soluble content (Table 5). For most of the talc-rich products the results are comparable to the XRF-method in Table 3. For other products there are som major deviations, especially for the products "Prod. 2" and "Non.mag.1" where the carbonate content is considered to be too low.

Carbonate concentrate

Based on the XRF-analyses, the carbonate product "Mag. 2" contains around 80% carbonate, 15% talc and 5% chlorite (Table 3). These numbers are quite reasonable and in agreement with its content of LOI. The results from the acid soluble test indicate a considerably lower content of carbonate (Table 5), but are probably not correct, primarily because they do not fit the contents of LOI.

The product contains rather high amounts of Fe, underlining that the carbonate species present is breunnerite (Fe-rich magnesite). This is supported by the acid soluble content (Table 5).

Magnetite concentrate

The main waste material "Ferro mag. 1", obviously is a magnetite/chromite material, but it also carries carbonate as well as low amounts of talc, chlorite and minor sulphides. The carbonates in this product have relatively high FeO/MgO-ratio compared to the other products, due to the higher magnetic properties of Fe-carbonates.

Element variations

Fe_2O_3

The content of Fe_2O_3 in the best talc products is around 2.7-29 wt%. This is comparable with some of the products from the first beneficiation test of Nakkan material, but lower than in the products from the mine (Table 4). It is likely that most of this is sited within the talc lattice. The reason for the possible difference is probably that slightly more of the iron in the Nakkan deposit is bound in magnetite instead of the talc-lattice.

In addition to the magnetite-rich concentrate "Ferro.mag1", Fe_2O_3 is also concentrated in the carbonate product "Mag.2". Although we know that the carbonates are dominated by breunnerite, some additional small amount of the iron is probably present within fine grained inclusions of magnetite.

The amount of Fe^{2+} has been measured (Table 6). By comparing Fe^{2+} with the total Fe content measured by XRF (Table 2), some conclusions can be drawn with respect to the valence state of Fe; 1) in all talc-rich products as well as in the carbonate-product "Mag.2", the Fe^{2+} content is rather similar to the total Fe measured by XRF, implying that most Fe is present as

Fe^{2+} in the talc lattice and in the carbonate lattice. 2) In the "Ferro.mag 1"-product more than half of the amount of Fe is present as Fe_2O_3.

CaO

Some elevated contents of CaO are registered in "Produkt 2" and "Mag 2". These are most likely caused by minor amounts of dolomite.

Ni

The pure talc products contain around 1500-1600 ppm Ni. Ni is most likely sited within the crystal lattice of talc as Ni^{2+}. The content is similar to that of the former test material from Nakkan (Table 4). It is also quite similar to the content of the starting material ("Aufgabe", Table 4). However, it is obvious that Ni has been partly removed as a sulphide phase during magnetic separation as it is concentrated together with S (as well as Cu) in "Ferro.mag 1" (Table 2). The carbonate product "Mag 2" carries lower amounts of Ni than the talc products. The reason for this is that Ni occurs in smaller amounts in the carbonate crystal lattice than in the talc crystal lattice.

Cr

Although most of the Cr is sited within magnetite/chromite and therefore has been removed by magnetic separation, some small amounts remain in the non-magnetic fraction. The content of Cr in the two pure talc-products is measured to be 285 and 154 ppm by XRF (Tables 2 & 4). In the carbonate-rich material "Mag 2" the Cr content is somewhat higher, probably reflecting minor amounts of chromite/magnetite. Previous investigations (Karlsen 1995) have shown that fine grained inclusions of spinels are quite common within the core of carbonates. The general trend for the beneficiation-products is that Cr has a negative correlation with the amount of talc (Fig. 1): the more talc in the product, the less Cr. Between Cr and Fe (Fig. 2) there is another more distinct, but positive correlation. Since both Cr and Fe are enriched in magnetite, removal of this mineral leads to lower Cr and Fe.

As

Some very small amounts of *As* (10 ppm) are indicated in one of the two pure talc products ("Sichtprodukt", Tables 2 & 4). Since the given numbers for As are very close to the detection limit on the XRF, they have to be treated with care. It is recommended to apply a more precise method (ICP-AES) to investigate the products for As.

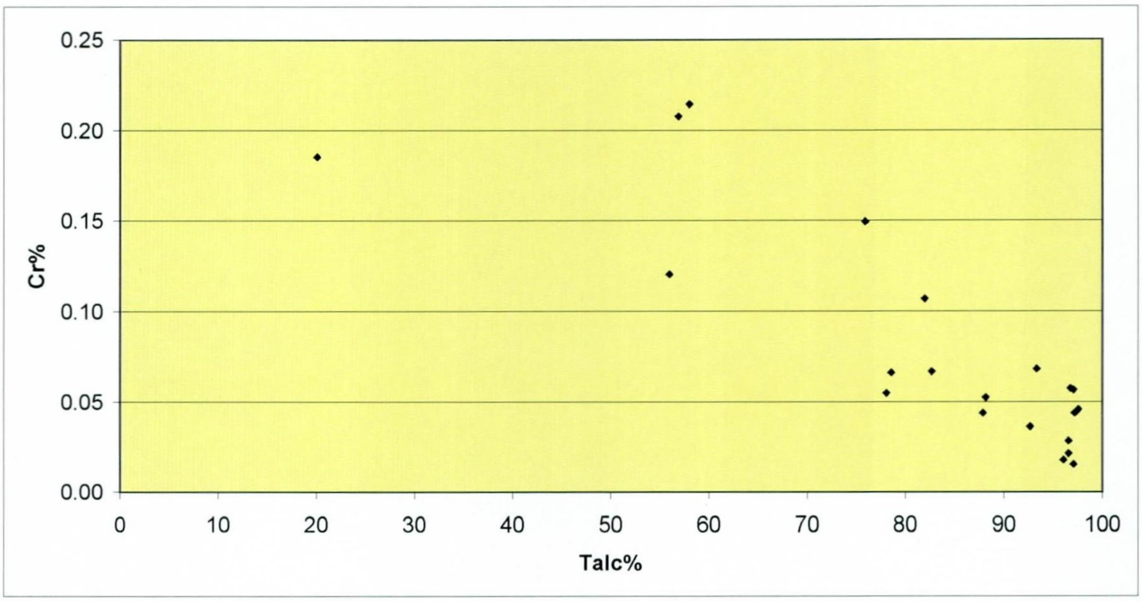

Figure 1: Cr vs. talc plot which shows a general negative correlation between the contents of talc and Cr in the products.

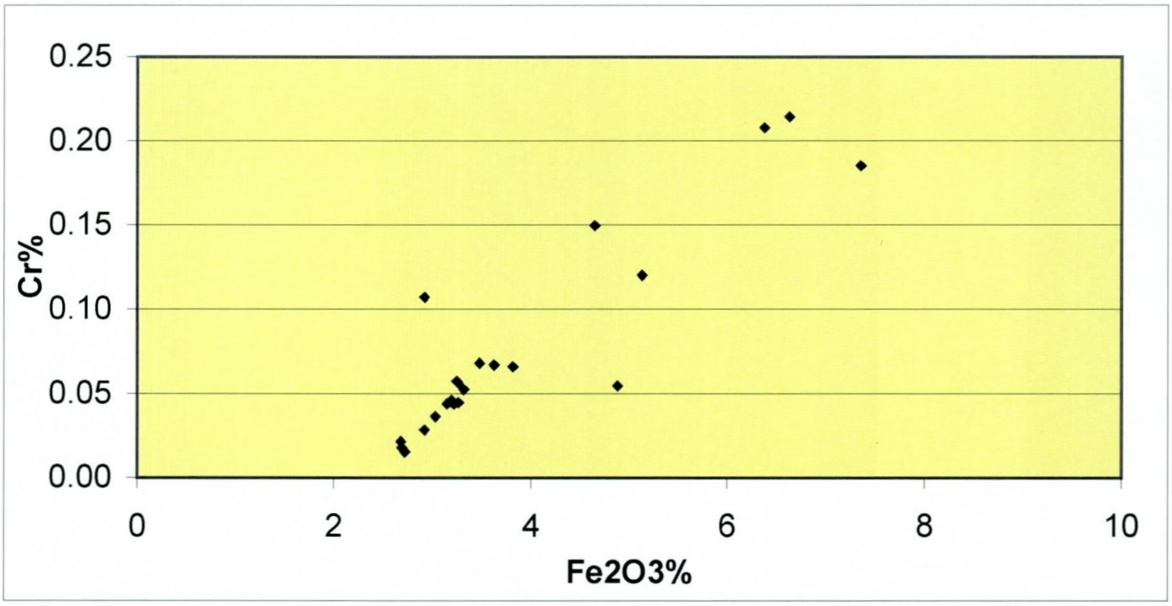

Figure 2: Cr vs. Fe_2O_3 (total) which shows a positive correlation due to the content of Cr in magnetite.

SUMMARY

- The best products from the beneficiation tests of Nakkan material made by Tavakkoli (1999) contain around 95-96 wt% talc, while the rest is breunnerite (3-4wt%) and chlorite.
- With respect to minor elements, the best products are rather similar to the best products made from Nakkan earlier, but different from the best products from the test of material of the present talc-mine as both the Cr, Ni, and Fe_2O_3 contents are lower.
- Possible traces of As have been encountered. Since the indicated content is very close to the detection limit (10 ppm) the results are questionable.
- Due to low concentrations, more accurate analytical methods of important elements (e.g. As) are recommended (ICP-AES, AAS, LECO).

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Table 2: **XRF - chemistry of beneficiation products (Tavakkoli in press) from the Nakkan - talc ore. All numbers given as %. The following elements have concentrations below detection limits for all samples: Na_2O, K_2O and P_2O_5 (<0.01%); Cl , F (<0.1%); U, Th, Pb, Sc, Sn, Cd, Ag, Ga, Yb, La (<0.0010%); Mo, Y, Rb (<0.0005%); W (<0.0030%).**

	SiO_2	Al_2O_3	Fe_2O_3	TiO_2	MgO	CaO	MnO	LOI	SUM
Ferro.mag. 1	2.69	0.41	47.36	0.15	14.48	0.41	0.15	11.09	76.51
Aufgabe	34.59	0.58	6.63	0.01	33.71	1.04	0.11	21.95	98.46
Produkt 1	61.20	0.22	2.92	<0.01	31.63	0.21	0.02	6.16	102.18
Sichtprodukt	60.67	0.10	2.72	0.01	30.84	0.12	0.01	5.97	100.42
Reject 1 + non.mag. 2	49.76	0.38	2.92	<0.01	27.60	0.43	0.02	17.74	98.68
Produkt 2	46.61	0.91	4.88	0.01	36.27	2.15	0.09	8.39	99.13
Mag. 2	10.91	0.81	7.35	0.01	38.57	1.41	0.21	39.73	98.89
Non.mag 1	53.89	0.40	3.32	0.01	31.22	0.78	0.04	9.76	99.24

	Nb	Zr	Sr	Cr	V	As	S	Ba	Sb	Zn	Cu	Ni	Co	Ce
Ferro.mag. 1	0.0006	0.0005	<0.0005	3.3653	<0.0005	<0.0010	1.02	<0.0010	0.0013	0.0314	0.0131	0.2652	0.0149	0.0169
Aufgabe	<0.0005	<0.0005	0.0007	0.2144	0.0014	0.0011	<0.10	0.0010	<0.0010	0.0030	0.0018	0.1528	0.0088	<0.0010
Produkt 1	<0.0005	0.0006	<0.0005	0.0285	0.0005	<0.0010	<0.10	<0.0010	<0.0010	0.0026	0.0006	0.1593	0.0064	<0.0010
Sichtprodukt	<0.0005	0.0007	<0.0005	0.0154	0.0006	0.0010	<0.10	<0.0010	<0.0010	0.0027	<0.0005	0.1549	0.0065	0.0011
Reject 1 + non.mag. 2	<0.0005	0.0006	0.0023	0.1072	0.0011	0.0023	<0.10	0.0012	<0.0010	0.0030	0.0032	0.1826	0.0086	<0.0010
Produkt 2	<0.0005	0.0006	<0.0005	0.0550	0.0007	0.0012	<0.10	0.0011	<0.0010	0.0034	0.0012	0.1651	0.0069	0.0011
Mag. 2	<0.0005	0.0010	0.0017	0.1853	0.0013	0.0012	<0.10	<0.0010	<0.0010	0.0030	0.0018	0.0994	0.0107	<0.0010
Non.mag 1	<0.0005	0.0005	<0.0005	0.0526	0.0007	0.0013	<0.10	<0.0010	<0.0010	0.0026	0.0017	0.1683	0.0072	0.0013

Table 3: Estimates of mineralogical compositions from XRF-chemical analyses of processing test material. Estimation-method is described by Karlsen (1998, 1999), Appendix. NB! The XRF-data has been normalised to give 100%.

Sample	Chlorite Wt-%	Talc Wt-%	Carbonate Wt-%	Sum
NAKKAN (Tavakkoli in press) (Present study)				
Ferro mag. 1	3.1	4.1	28.7	35.9 *
Aufgabe	3.4	54.6	40.4	98.4
Produkt 1	1.3	95.3	4.1	100.7
Sichtprodukt	0.6	96.5	4.0	101.1
Reject 1 + non.mag 2	2.3	79.7	29.7	111.7 *
Produkt 2	5.4	72.7	10.0	88.1 *
Mag 2	4.8	15.3	80.2	100.3
Non.mag.1	2.4	85.8	12.4	100.6
TALC MINE *(Tavakkoli 1999)*				
Flot.prod., 47%< 2um	1.5	96.1	3.0	100.6
Flot.prod, 25%<2um	1.9	95.2	3.4	100.6
Flot. Prod, 17%<2um	2.0	94.8	3.2	100.0
Grinding & classifying, 33.0%<2um	2.2	91.2	7.2	100.6
Grinding & classifying 63%<2um	1.3	95.9	3.9	101.1
Non.mag2, grinding & classifying, 47%<2um	1.4	96.0	3.1	100.5
Flotation reject, 36%<2um	4.4	71.5	24.2	100.1
NAKKAN *(Tavakkoli 1998)*				
Pin mill product	2.4	54.5	41.8	98.7
Non-magnetic	2.4	76.2	21.7	100.3
Talc-conc 1	1.2	91.5	7.6	100.3
Talc-conc 2, prod 2	0.5	95.6	4.3	100.4
Rest 1	4.5	51.5	44.1	100.1
Rest 2	2.4	80.3	17.3	100.0
Rest 2, prod 2	1.4	86.5	11.8	99.7
Talc-conc 2	0.6	96.0	3.3	99.9

* *The numbers deviate significantly from 100%. For "Reject1 + non.mag 2" it means that the talc-content is overestimated, while for "Product 2" the talc-content is underestimated. For Ferro-Mag 1 the low number is caused by the content of magnetite, which is not included in this calculation.*

Table 4: **A summary of XRF-analyses of some trace elements of importance in addition to Fe_2O_3. For comparison, the talc/chlorite-content from Table 3 is included.**

Sample	Talc- (+chlor.)	Fe_2O_3 %	Cr %	Ni %	As %	LOI %
NAKKAN (Tavakkoli in prep.)						
Aufgabe	58.0	6.63	0.2144	0.1528	0.0011	21.95
Ferro mag. 1	7.2	47.36	3.3653	0.2652	<0.0010	11.09
Mag 2	20.1	7.35	0.1853	0.0994	0.0012	39.73
Reject 1 + non.mag 2	82.0	2.92	0.1072	0.1826	0.0023	17.74
Non.mag.1	88.2	3.32	0.0526	0.1683	0.0013	9.76
Sichtprodukt	97.1	2.72	0.0154	0.1549	0.0010	5.97
Produkt 1	96.6	2.92	0.0285	0.1593	<0.0010	6.16
Produkt 2	78.1	4.88	0.0550	0.1651	0.0012	8.39
MINE (Tavakkoli 1999)						
Grinding & classifying, 33.0% <2um	93.4	3.48	0.0684	0.2327	<0.0010	7.39
Grinding & classifying 63% <2um	97.2	3.15	0.0440	0.2381	<0.0010	5.89
Non.mag2, grind. & classif., 47% <2um	97.4	3.27	0.0450	0.2375	<0.0010	5.55
Flotation reject, 36% <2um	75.9	4.65	0.1495	0.2217	<0.0010	14.98
Flot.prod., 47% <2um	97.6	3.20	0.0461	0.2383	<0.0010	5.47
Flot.prod., 25% <2um	97.1	3.26	0.0569	0.2398	<0.0010	5.72
Flot. Prod., 17% <2um	96.8	3.25	0.0576	0.2367	<0.0010	5.59
NAKKAN (Tavakkoli 1998)						
Pin mill product	56.9	6.38	0.2078	0.1456	<0.0010	22.57
Non-magnetic	78.6	3.82	0.0663	0.1555	<0.0010	13.82
Rest 1	56.0	5.13	0.1205	0.1713	<0.0010	23.89
Rest 2	82.7	3.63	0.0671	0.1561	<0.0010	11.87
Rest 2, prod. 2	87.9	3.22	0.0440	0.1463	<0.0010	9.45
Talc-conc. 1	92.7	3.03	0.0364	0.1465	<0.0010	7.50
Talc-conc. 2	96.6	2.68	0.0216	0.1415	<0.0010	5.56
Talc-conc. 2, prod. 2	96.1	2.69	0.0178	0.1393	<0.0010	6.01

Table 5: Acid Soluble determination, and estimates of carbonate contents. The mineral compositions used in the estimation are given in appendix.

	Acid Soluble (AS)			
	FeO %	CaO %	MgO %	Carb % based on AS
NAKKAN (Tavakkoli in press)				
Ferro mag. 1	5.46	0.20	10.33	31.2
Aufgabe	1.29	1.01	15.98	35.6
Produkt 1	0.26	0.17	1.61	4.0
Sichtprodukt	0.29	<0.10	2.40	5.2
Reject 1 + non.mag 2	1.21	1.37	10.40	25.3
Produkt 2	0.52	0.22	3.81	8.9 ***
Mag 2	2.40	0.39	15.85	36.3 ***
Non.mag.1	0.69	0.30	2.32	6.5***
TALC MINE *(Tavakkoli 1999)*				
Flot.prod., 47% < 2um	n.a.	0.16	2.29	5.8
Flot.prod, 25% <2um	n.a.	0.16	1.89	4.8
Flot. Prod, 17% <2um	n.a.	0.11	1.47	3.7
Grinding & classifying, 33.0% <2um	n.a.	0.25	3.79	9.6
Grinding & classifying 63% <2um	n.a.	0.11	3.46	8.8
Non.mag2, grinding & classifying, 42% <2um	n.a.	0.11	2.07	5.3
Flotation reject, 36% <2um	n.a.	0.84	10.23	26.0

*** Considered to be too low, especially the Mag.2 product.

Table 6: Determination of Fe^{2+}, given as FeO, and H_2O^+/H_2O^-.

	H_2O^-	H_2O^+	Fe^{2+} (FeO)
Ferro.mag. 1	0.05	2.61	19.41
Aufgabe	<0.02	4.29	4.35
Produkt 1	0.02	5.24	2.22
Sichtprodukt	0.21	5.47	2.1
Reject 1 + non.mag. 2	0.02	4.91	3.35
Produkt 2	0.03	5.32	2.79
Mag. 2	0.03	5.17	5.68
Non.mag 1	0.04	2.25	2.72

Method step by step:

1. Chlorite is estimated based on the Al_2O_3 content
   - SiO_2 and LOI are put into the chlorite in amounts that fit to the mineral-chemical formula (below)

2. Talc is estimated on the basis of remaining SiO_2 content after step 1.
   - LOI is put into the talc formula in amounts that fit to the mineral-chemical formula (below)

3. Carbonate is estimated based on the remaining LOI after steps 1 and 2.

Requirements:

Free from other silicates than talc and chlorite.

Simplifications:

All Al_2O_3 occurs within chlorite.

The minerals have the compositions given below.

More detailed information is given by Karlsen (1998).

Mineral compositions used as a basis for estimation of mineralogical content from XRF data:

	Alterm. talc	*Alterm.breunnerite*	*Alterm. chlorite*
SiO_2	62.43		30.40
TiO_2	0.32		0.00
Al_2O_3	0.04		17.11
FeO (total)	1.05	11.68	6.30
MnO	0.00	0.12	0.06
MgO	31.63	39.33	31.31
CaO	0.00	0.28	0.03
Na_2O	0.09		0.00
K_2O	0.03		0.01
Cr_2O_3	0.09		2.75
NiO	0.22		0.11
Sum	95.90	51.41	88.08
LOI	4.10	48.59	11.92