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Chemistry of beneficiation products from
Altermark, northern Norway

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REPORT

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Chemistry of beneficiation products from Altermark, northern Norway

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Summary:

The chemistry of products from beneficiation tests of Altermark talc made by Pluss-Staufer AG is described. The earlier conclusions that the ore is very pure when it comes to elements with potential risks to health have been confirmed, although minor amounts of Cr and Ni are present. Of major importance is the composition of talc-products from the Nakkan deposits, which is currently being investigated, and the current mine as well as their relationship to chemical composition of the crude ore. Pluss Stauffer has succeeded in making pure talc-products of high quality from the Altermark talc. Some slightly different results were obtained from the Nakkan ore, with respect to recovery and whiteness, which were also reflected in results from the ore from the current mine. Chemical analyses show some rather similar trace element characteristics of products, but with some small variations in the content of Ni and Cr. The content of Ni and Cr are lowest in the Nakkan product. Estimation of mineralogy from the chemical data, indicate that the amount of talc in the best products reaches around 95%, the remainder being carbonates and chlorite.

In the present report a model is presented which explains the variations in the Ni and Cr contents in relation to the grade of talc-carbonate alteration. With progressive alteration of serpentinite to talc-carbonate the magnetite and Ni-bearing sulphides disappear. The Fe from magnetite moves into carbonate, talc and chlorite, while Ni from the sulphides moves into talc, and to a limited extent, into carbonate. Chromium, which is abundant in magnetite, moves primarily into chlorite, but to a much more limited extent also into talc.

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 beneficiation tests of material from the Altermark talc mine made by Tavakkoli (1999). There is a clear need to compare this with the test material taken from the Nakkan deposit and beneficiated by Tavakkoli (1999). Concerning the beneficiation test material, it is not the intention to go into detail, simply because the author knows too little about the processes involved, and because this is taken care of by Mr.Tavakkoli. However, since some additional information has been generated which complements the existing knowledge of the characteristics of the material, some comments are made.

Previous studies have shown that the talc-carbonate ore from Altermark is extremely low in harmful elements, except for minor amounts of nickel and chromium. Elements which pose potential risks to health, such as Cd, As, and U/Th are all either absent or at extremely low concentrations below the respective detection limits (Karlsen 1997).

GEOLOGICAL REVIEW

Most of the talc-deposits in Altermark occur as rims around serpentinitic bodies, and the talc-ores have been formed by the alteration of serpentinite. The talc ores consist of talc and carbonate in addition to minor amounts of chlorite and magnetite. Previous studies have shown that the ore varies slightly in mineralogical composition when moving from its inner parts, close to the serpentinite body, outwards to the surrounding country rocks. The major change is that the content of magnetite decreases from the inner parts towards the outer parts (Karlsen 1995, 1996). From previous studies, a general difference between samples from Nakkan and samples from the Altermark talc mine have been indicated, with more magnetite in the Nakkan samples. Most of the earlier estimations of magnetite content have been based on magnetic separation techniques in connection to whiteness measurements. The results have indicated a rather high content of magnetite in the ore of Nakkan especially. New tests by microscopy and image analyses (Karlsen in prep.) show that the content of magnetite is much lower than earlier anticipated. Most of the samples analysed from the Nakkan deposit have magnetite contents of less than 1%; the difference between Nakkan and the current mine is much lower than previously anticipated. This is important information because it impacts upon the recovery of talc from the ore during processing. Nevertheless, there is a significant chance that the parts of the Nakkan ore investigated to date do not have similar liberation characteristics when milled in the same manner as the average ore from the current talc mine. More fine-grinding might be found to increase the recovery.

In most talc derived from ultramafic rocks, concentrations of Ni and Cr are generally present. Nickel is sometimes present in sulphides, in other cases within talc, and, to a lesser degree, in carbonates. In the talc deposits of Altermark, Ni is primarily present within talc and, to a lesser degree, within carbonates. Sulphides are only present in very small amounts. Originally, the Cr in ultramafic rocks is present as chromite. During serpentinisation, however, the chromite is capped by magnetite, which in turn is broken down during formation of talc-carbonate as described above. When Cr-bearing magnetite breaks down, the Cr moves primarily into chlorite; very small amounts are present in talc.

Magnetite, chlorite, Ni and Cr are all components that should be kept as low as possible in a talc-product made from ultramafic rocks and their distribution is of concern. Their effects are detrimental because magnetite and chlorite reduce the whiteness, while Ni and Cr are known to be potentially dangerous to health.

In the present report, the contents of the above-mentioned components are described, and a simple working model is given.

CHEMISTRY OF BENEFICIATION TEST MATERIAL

Complete chemical analyses of the test material from the Altermark talc mine are given in Table 1. Complete chemical analyses from the first test of the Nakkan material, tested by Tavakkoli (1998), were given by Karlsen (1998), but are also shown in Table 2 in this report. The contents of Ni and Cr from the test material will be given some special attention and are given separately in Table 3.
Table 3 shows that there are differences in Cr- and Ni-content between the Nakkan-products and those from the mine, with the lowest values for the Nakkan-products. Since Ni is located within the lattice of talc, it indicates that talc-crystals from the Nakkan sample carry lower amounts of Ni.
There is a strong positive correlation between Cr and Al_2O_3 (Fig. 1). Since Al_2O_3 is localised to the lattice of chlorite and to some extent within Fe-chromite it means that the more chlorite and Fe-chromite is removed by the process, the lower content of Cr is achieved.

MINERALOGICAL CONTENTS ESTIMATED FROM CHEMICAL DATA

Estimation of the mineralogical content of products, calculated on the basis of XRF-chemical data (Table 4) has been carried out using the following procedure; details are given by Karlsen (1998):

1. Chlorite is estimated based on the Al_2O_3 content
2. Talc is estimated based on the remaining content of SiO_2
3. Carbonate is estimated based on the remaining Loss On Ignition

According to the present method the following indications are given:
1. The best products have talc-content up to around 95 %.
2. The vast majority of chlorite is removed during processing
3. Products from Nakkan have a slightly lower chlorite content when compared to those from the current mine.
4. Talc occurs in significant amounts in the "waste" products.

The different methods of calculation will give somewhat different results as indicated in Table 5.

MODEL THAT ACCOUNTS FOR THE COMPOSITIONAL DIFFERENCES AND IMPLICATIONS FOR FUTURE INVESTIGATIONS

If internal variations within each of the deposits are taken into account, it is naturally difficult to know whether the samples are sufficiently representative. From earlier work and work currently in progress (Karlsen 1995, 1997, 1998, in prep.), the following trends appear in the Altermark talc ores:

1. The content of magnetite decreases outwards from the serpentine core.
2. As magnetite disappears, the Fe enters carbonate and talc instead, while Cr enters chlorite.
3. The content of chlorite is highest close to the surrounding country rocks.
4. The content of Fe in the lattice of talc increases outwards towards the surrounding country rocks.
5. The content of Ni in the talc lattice seems to be highest in the outermost parts towards the country rocks.

All these trends are related to the maturity of talc-carbonate alteration; the extent and duration of that alteration, the less magnetite remains, and the greater the proportion of Fe and Ni (?) present in the talc lattice (Fig. 1). The grade of alteration seems, at first sight, to be a function of distance from the serpentinite.

So, how do the different talc-deposits fit into this model?
Analyses done so far indicate that large parts of the Store Esjeklumpen deposit (the outer parts) represent a mature stage, with low magnetite content, high Fe and Ni in the lattice of talc and with some chlorite. In the current talc mine, all types are represented. At the Nakkan deposits both mature and immature types occur, but with a greater proportion of the immature type detected so far.

CONCLUSION

- Chemical analyses of material from beneficiation tests made on material from the Nakkan deposit and the mine amplify the impression that the talc-carbonate ores in Altermark have high quality with very low contents trace elements which pose a potential health risk, with the exception of small amounts of Ni and Cr.
- Ni and Cr occur in smaller amounts in the products from Nakkan when compared to products from the present mine, if parallel test procedures are followed.
- Microscopy carried out in another report indicate that the general differences in magnetite content between the Nakkan deposit and the current mine are small, and that the magnetite content is much lower than earlier anticipated from magnetic separation carried out in connection with whiteness measurements. Clearly appreciable quantities of other minerals, including talc were reporting to the magnetic fraction. The implication of this is of some considerable importance, namely that the behaviour during grinding probably is different for average samples of the two deposits. The conclusion would be the average Nakkan sample requires finer grinding to liberate magnetite from associated minerals to achieve a more efficient separation.

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	SiO2	Al2O3	Fe2O3	TiO2	MgO	CaO	Na2O	K2O	MnO	P2O5	LOI	Sum
	%	%	%	%	%	%	%	%	%	%	%	%
Flot.prod., 47%< 2um	59.49	0.25	3.20	0.01	29.83	0.12	<0.10	<0.01	0.01	<0.01	5.47	98.40
Flot.prod, 25%<2um	59.27	0.32	3.26	0.02	30.05	0.13	<0.10	<0.01	0.01	<0.01	5.72	98.73
Flot. Prod, 17%<2um	58.80	0.34	3.25	0.01	30.17	0.10	<0.10	<0.01	0.01	0.01	5.59	98.29
Grinding & classifying, 33.0%<2um	56.74	0.37	3.48	0.01	30.21	0.23	<0.10	<0.01	0.02	0.01	7.39	98.49
Grinding & classifying 63%<2um	59.14	0.22	3.15	0.01	29.69	0.08	<0.10	<0.01	0.01	0.01	5.89	98.17
Non.mag2, grind. & class., 42%<2um	59.87	0.23	3.27	0.01	30.22	0.10	<0.10	<0.01	0.01	0.01	5.55	99.24
Flotation reject, 36%<2um	45.23	0.74	4.65	0.02	31.74	0.87	<0.10	<0.01	0.06	0.02	14.98	98.41

	Mo	Nb	Zr	Y	Sr	Rb	U	Th	Pb	Cr	V	As
	%	%	%	%	%	%	%	%	%	%	%	%
Flot.prod., 47%< 2um	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0010	<0.0010	<0.0010	0.0461	0.0010	<0.0010
Flot.prod, 25%<2um	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	0.0016	<0.0010	<0.0010	0.0569	0.0010	<0.0010
Flot. Prod, 17%<2um	<0.0005	<0.0005	0.0005	<0.0005	<0.0005	<0.0005	<0.0010	<0.0010	<0.0010	0.0576	0.0010	<0.0010
Grinding & classifying, 33.0%<2um	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0010	<0.0010	<0.0010	0.0684	0.0012	<0.0010
Grinding & classifying 63%<2um	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	0.0011	<0.0010	<0.0010	0.0440	0.0009	<0.0010
Non.mag2, grind. & class., 42%<2um	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0010	<0.0010	<0.0010	0.0450	0.0009	<0.0010
Flotation reject, 36%<2um	<0.0005	<0.0005	0.0005	<0.0005	<0.0005	<0.0005	<0.0010	<0.0010	<0.0010	0.1495	0.0017	<0.0010

	Sc	S	Cl	F	Ba	Sb	Sn	Cd	Ag	Ga	Zn	Cu
	%	%	%	%	%	%	%	%	%	%	%	%
Flot.prod., 47%< 2um	<0.0010	<0.10	<0.10	<0.10	<0.0010	<0.0010	<0.0010	<0.0010	<0.0010	<0.0010	0.0024	0.0007
Flot.prod, 25%<2um	<0.0010	<0.10	<0.10	<0.10	<0.0010	<0.0010	<0.0010	<0.0010	<0.0010	0.0014	0.0022	0.0006
Flot. Prod, 17%<2um	<0.0010	<0.10	<0.10	<0.10	<0.0010	<0.0010	<0.0010	<0.0010	<0.0010	<0.0010	0.0023	<0.0005
Grinding & classifying, 33.0%<2um	<0.0010	<0.10	<0.10	<0.10	<0.0010	<0.0010	<0.0010	<0.0010	<0.0010	0.0013	0.0024	0.0007
Grinding & classifying 63%<2um	<0.0010	<0.10	<0.10	<0.10	<0.0010	<0.0010	<0.0010	<0.0010	<0.0010	<0.0010	0.0024	<0.0005
Non.mag2, grind. & class., 42%<2um	<0.0010	<0.10	<0.10	<0.10	<0.0010	0.0010	<0.0010	<0.0010	<0.0010	0.0011	0.0033	0.0010
Flotation reject, 36%<2um	0.0013	<0.10	<0.10	<0.10	<0.0010	<0.0010	<0.0010	<0.0010	<0.0010	0.0014	0.0040	0.0019

	Ni	Yb	Co	Ce	La	Nd	W
	%	%	%	%	%	%	%
Flot.prod., 47%< 2um	0.2383	<0.0010	0.0066	<0.0010	<0.0010	<0.0010	<0.0030
Flot.prod, 25%<2um	0.2398	<0.0010	0.0070	<0.0010	<0.0010	<0.0010	<0.0030
Flot. Prod, 17%<2um	0.2367	<0.0010	0.0068	<0.0010	<0.0010	<0.0010	<0.0030
Grinding & classifying, 33.0%<2um	0.2327	<0.0010	0.0071	<0.0010	<0.0010	<0.0010	<0.0030
Grinding & classifying 63%<2um	0.2381	<0.0010	0.0066	<0.0010	<0.0010	<0.0010	<0.0030
Non.mag2, grind. & class., 42%<2um	0.2375	<0.0010	0.0067	<0.0010	<0.0010	<0.0010	<0.0030
Flotation reject, 36%<2um	0.2217	<0.0010	0.0087	<0.0010	<0.0010	<0.0010	<0.0030

Table 1 : Chemical analyses (XRF) of beneficiation test material from the Altermark talc mine.

	SiO2	Al2O3	Fe2O3	TiO2	MgO	CaO	Na2O	K2O	MnO	P2O5	LOI	Sum
	%	%	%	%	%	%	%	%	%	%	%	%
Talc-conc 1	56.83	0.20	3.03	<0.01	31.02	0.25	<0.10	<0.01	0.020	<0.01	7.50	98.87
Talc-conc 2	59.63	0.11	2.68	0.010	31.08	0.14	<0.10	<0.01	0.010	<0.01	5.56	99.22
Talc-conc 2, prod 2	59.21	0.08	2.69	<0.01	30.73	0.20	<0.10	<0.01	0.010	<0.01	6.01	98.97
Pin mill product	34.32	0.41	6.38	0.010	34.18	0.78	<0.10	<0.01	0.110	<0.01	22.57	98.75
Non-magnetic	47.87	0.41	3.82	<0.01	32.35	0.76	<0.10	<0.01	0.050	<0.01	13.82	99.09
Rest 1	33.27	0.76	5.13	<0.01	34.31	1.68	<0.10	<0.01	0.110	0.01	23.89	99.23
Rest 2	50.36	0.40	3.63	<0.01	31.88	0.83	<0.10	<0.01	0.040	<0.01	11.87	99.09
Rest 2, prod 2	54.32	0.24	3.22	<0.01	32.13	0.45	<0.10	<0.01	0.030	<0.01	9.45	99.84

	Mo	Nb	Zr	Y	Sr	Rb	U	Th	Pb	Cr	V	As
	%	%	%	%	%	%	%	%	%	%	%	%
Talc-conc 1	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0010	<0.0010	<0.0010	0.0364	0.0005	<0.0010
Talc-conc 2	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0010	<0.0010	<0.0010	0.0216	<0.0005	<0.0010
Talc-conc 2, prod 2	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0010	<0.0010	<0.0010	0.0178	<0.0005	<0.0010
Pin mill product	<0.0005	<0.0005	<0.0005	<0.0005	0.0007	<0.0005	<0.0010	<0.0010	<0.0010	0.2078	0.0014	<0.0010
Non-magnetic	<0.0005	<0.0005	<0.0005	<0.0005	0.0009	<0.0005	0.0010	<0.0010	<0.0010	0.0663	0.0006	<0.0010
Rest 1	<0.0005	<0.0005	<0.0005	<0.0005	0.0023	<0.0005	<0.0010	<0.0010	<0.0010	0.1205	0.0007	<0.0010
Rest 2	<0.0005	<0.0005	<0.0005	<0.0005	0.0007	<0.0005	<0.0010	<0.0010	<0.0010	0.0671	0.0008	<0.0010
Rest 2, prod 2	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0010	<0.0010	<0.0010	0.0440	<0.0005	<0.0010

	Sc	S	Cl	F	Ba	Sb	Sn	Cd	Ag	Ga	Zn	Cu
	%	%	%	%	%	%	%	%	%	%	%	%
Talc-conc 1	<0.0010	<0.10	<0.10	<0.10	<0.0010	<0.0010	<0.0010	<0.0010	<0.0010	<0.0010	0.0028	0.0013
Talc-conc 2	<0.0010	<0.10	<0.10	<0.10	<0.0010	<0.0010	<0.0010	<0.0010	<0.0010	<0.0010	0.0030	0.0009
Talc-conc 2, prod 2	<0.0010	<0.10	<0.10	<0.10	<0.0010	<0.0010	<0.0010	<0.0010	<0.0010	<0.0010	0.0031	0.0009
Pin mill product	<0.0010	<0.10	<0.10	<0.10	<0.0010	<0.0010	<0.0010	<0.0010	<0.0010	<0.0010	0.0029	0.0021
Non-magnetic	<0.0010	<0.10	<0.10	<0.10	<0.0010	<0.0010	<0.0010	<0.0010	<0.0010	<0.0010	0.0027	0.0024
Rest 1	0.0011	<0.10	<0.10	<0.10	<0.0010	<0.0010	<0.0010	<0.0010	<0.0010	<0.0010	0.0032	0.0040
Rest 2	<0.0010	<0.10	<0.10	<0.10	<0.0010	<0.0010	<0.0010	<0.0010	<0.0010	<0.0010	0.0036	0.0022
Rest 2, prod 2	<0.0010	<0.10	<0.10	<0.10	<0.0010	<0.0010	<0.0010	<0.0010	<0.0010	<0.0010	0.0045	0.0019

	Ni	Yb	Co	Ce	La	Nd	W
	%	%	%	%	%	%	%
Talc-conc 1	0.1465	<0.0010	0.0064	<0.0010	<0.0010	<0.0010	<0.0030
Talc-conc 2	0.1415	<0.0010	0.0060	<0.0010	<0.0010	<0.0010	<0.0030
Talc-conc 2, prod 2	0.1393	<0.0010	0.0060	<0.0010	<0.0010	<0.0010	<0.0030
Pin mill product	0.1456	<0.0010	0.0085	<0.0010	<0.0010	<0.0010	<0.0030
Non-magnetic	0.1555	<0.0010	0.0073	<0.0010	<0.0010	<0.0010	<0.0030
Rest 1	0.1713	<0.0010	0.0091	<0.0010	<0.0010	<0.0010	<0.0030
Rest 2	0.1561	<0.0010	0.0074	<0.0010	<0.0010	<0.0010	<0.0030
Rest 2, prod 2	0.1463	0.0013	0.0068	<0.0010	<0.0010	<0.0010	<0.0030

Table 2 : Chemical analyses (XRF) of beneficiation test material from the Nakkan deposit. (From Karlsen 1998).

Table 3: Cr- and Ni-content of the test material. For comparison, Loss On Ignition (LOI) is included. Low LOI means high talc-content.

Sample	Cr %	Ni %	LOI %
MINE *(Tavakkoli 1999)*			
Flot.prod., 47%< 2um	0.0461	0.2383	5.47
Flot.prod., 25%<2um	0.0569	0.2398	5.72
Flot. Prod., 17%<2um	0.0576	0.2367	5.59
Grinding & classifying, 33.0%<2um	0.0684	0.2327	7.39
Grinding & classifying 63%<2um	0.0440	0.2381	5.89
Non.mag2, grinding & classifying, 42%<2um	0.0450	0.2375	5.55
Flotation reject, 36%<2um	0.1495	0.2217	14.98
NAKKAN *(Tavakkoli 1998)*			
Talc-conc. 1	0.0364	0.1465	7.50
Talc-conc. 2	0.0216	0.1415	5.56
Talc-conc. 2, prod. 2	0.0178	0.1393	6.01
Pin mill product	0.2078	0.1456	22.57
Non-magnetic	0.0663	0.1555	13.82
Rest 1	0.1205	0.1713	23.89
Rest 2	0.0671	0.1561	11.87
Rest 2, prod. 2	0.0440	0.1463	9.45

Table 4: Simplified estimates of mineralogical contents from XRF-chemical analyses of processing test material. Estimation-method is described by Karlsen (1998).

Sample	Chlorite Wt-%	Talc Wt-%	Carbonate Wt-%	Rest Wt-%
TALC MINE *(Tavakkoli 1999)*				
Flot.prod., 47%< 2um	1.5	94.6	2.9	1.0
Flot.prod, 25%<2um	1.9	94.0	3.4	0.7
Flot. Prod, 17%<2um	2.0	93.2	3.2	1.6
Grinding & classifying, 33.0%<2um	2.2	89.8	7.1	0.9
Grinding & classifying 63%<2um	1.3	94.1	3.9	0.7
Non.mag2, grinding & classifying, 47%<2um	1.3	95.2	3.1	0.4
Flotation reject, 36%<2um	4.3	70.3	23.8	1.5
NAKKAN *(Tavakkoli 1998)*				
Talc-conc 1	1.2	90.5	7.5	0.9
Talc-conc 2	0.6	95.2	3.3	0.9
Talc-conc 2, prod 2	0.5	94.6	4.3	0.6
Pin mill product	2.4	53.8	41.3	2.5
Non-magnetic	2.4	75.5	21.5	0.6
Rest 1	4.4	51.1	43.8	0.7
Rest 2	2.3	79.5	17.1	1.0
Rest 2, prod 2	1.4	86.3	11.8	0.5

Table 5: Estimatiton of carbonate content based on Acid Insoluble MgO and Loss On Ignition of the beneficiation test material from the mine. If future tests on Acid Soluble Rest are carried out, FeO must be included.

TALC MINE *(Tavakkoli 1999)*	Acid Soluble (ASR)			Loss On Ignition (LOI)	
	CaO %	MgO %	Carb % based on ASR	LOI	Carb % based on LOI
Flot.prod., 47%< 2um	0.16	2.29	5.8	5.47	2.8
Flot.prod, 25%<2um	0.16	1.89	4.8	5.72	3.3
Flot. Prod, 17%<2um	0.11	1.47	3.7	5.59	3.1
Grinding & classifying, 33.0%<2um	0.25	3.79	9.6	7.39	6.8
Grinding & classifying 63%<2um	0.11	3.46	8.8	5.89	3.7
Non.mag2, grinding & classifying, 42%<2um	0.11	2.07	5.3	5.55	3.0
Flotation reject, 36%<2um	0.84	10.23	26.0	14.98	22.4

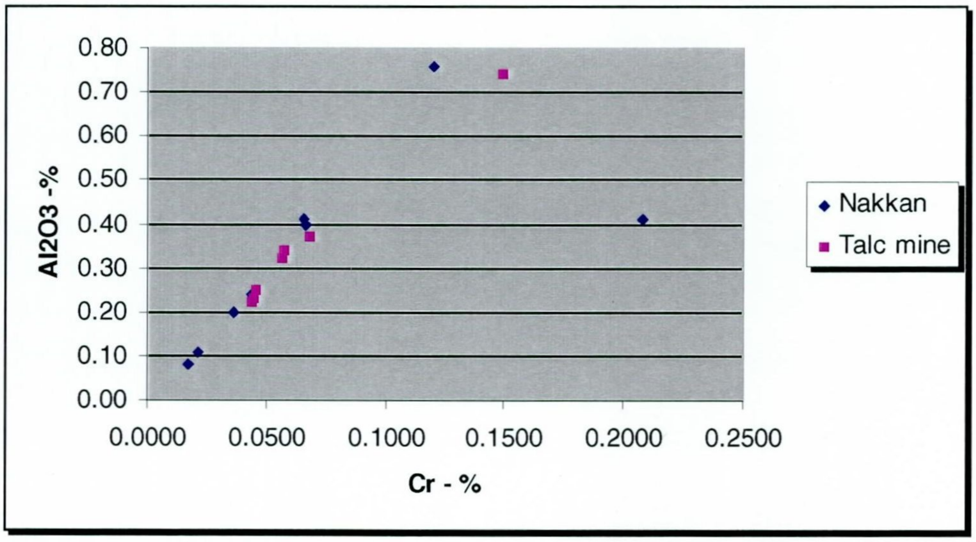

Figure 1: There is a positive correlation between contents of Cr and Al_2O_3 in the samples, primarily caused by the successive removement of chlorite and Fe-chromite during beneficiation.

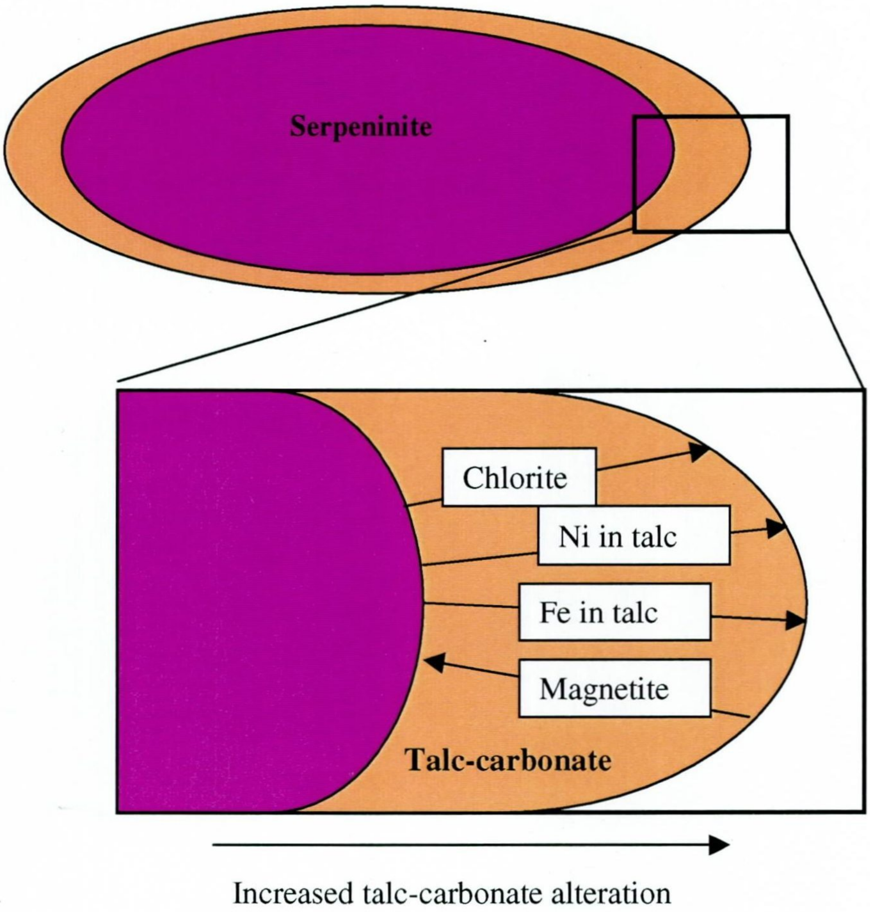

Figure 2: Model that shows compositional trends in the talc-ore. The arrows point in the direction of increasing contents.