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## The Ytterby mine - A historical review and an evaluation of its suggested spatial coupling to multiple sclerosis (MS)

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## **ABSTRACT**

The Ytterby mine is located on Island in the Stockholm archipelago. Mainly feldspars but also quartz were historically quarried in the mine, which is also the place of discovery of seven rare earth elements (REE). During the cold war era, the mine shaft was used as a diesel and jet fuel deposit for the Swedish Armed Forces. Recently, a spatial coupling between multiple sclerosis (MS), a chronic neurodegenerative disease in the central nervous system, prevalence and the quarry has been suggested. Previous studies show that adverse neurological health effects are associated with oral intake of REEs and there is support for a coupling between ionizing radiation and MS. The extent and character of health effects as a result of exposure to petroleum products are still debated. However, a substantial number of scientific reports support a coupling between neurodegenerative health effects and toxic constituents of jet fuels such as benzene, toluene, and n-hexane.

My data show that a possible overrepresentation of MS patients within the Ytterby postal code area could be an indication of a spatial coupling between the mine and MS. Such a possible coupling could be associated with the REEs present in the local rocks, with the previous storage of diesel or jet fuel MC-77 in the mine and/or with zones of high natural radioactivity in the area. Water samples collected in 15 wells in the Ytterby village show traces of five REEs, i.e. scandium (Sc), yttrium (Y), lanthanum (La), neodymium (Nd) and samarium (Sm) and the majority of sample locations at low ground elevation show contamination of diesel which is the most recent fuel stored in the mine. Moreover, results from an analysis of a black substance leaking out of cracks in the mine corridors confirm that REEs are present in substantial concentrations in the local rocks and also appear to be mobile. This should be taken into account when considering a potential contamination of the local water supply. Measurements of natural radioactivity have also been made around the contours of the quarry and zones of high ionizing radiation have been identified. By using these zones of high ionizing radiation as a proxy for rare minerals containing rare earth elements, I further suggest that the REE occurrences are highly localized around the quarry and could be associated with, or remobilized by, younger faults. My data show that a full investigation is warranted of a possible spatial coupling between neurological health issues, MS being one of them, and the mine.

## SAMMANFATTNING

Ytterby gruva är belägen på Resarö i Stockholms skärgård. Genom historien har framförallt fältspat men också kvarts brutits i Ytterby. Kvartsen användes i glas- och järnbruk och fältspaten försåg den expanderande porslinsindustrin med material. Malmformationen utgörs av en pegmatit vilket är en grovkornig bergart som till största delen består av just kvarts och fältspat. Gruvan är också världsberömd som fyndort för sju sällsynta jordartsmetaller: yttrium (Y), ytterbium (Yb), erbium (Er) and terbium (Tb), holmium (Ho), skandium (Sc) och tulium (Tm). Dessutom har gruvan bidragit till upptäckten av tantal (Ta) och niob (Nb), grundämnen som visade sig vara beståndsdelar av ett mineral som kom att bli kallat yttrantalit (Nordenskjöld, 1904). På senare tid, under det kalla kriget, användes gruvschaktet av den Svenska Försvarsmakten för lagring av diesel och jetbränslet MC-77.

Nyligen kontaktade invånare i gruvans närområde Karolinska Institutet och gjorde förfrågningar om ett eventuellt samband mellan multipel skleros (MS), en kronisk neurodegenerativ sjukdom i det centrala nervsystemet, och gruvan. Tidigare studier visar att förtäring av sällsynta jordartsmetaller (den engelska förkortningen är REE som står för Rare Earth Elements) är förknippat med skadliga neurologiska hälsoeffekter. Däremot saknas ännu kunskap om vid vilka koncentrationer de skadliga effekterna inträder för människor. Många studier debatterar också utbredningen och karaktären på de hälsoeffekter som exponering mot petroleumprodukter kan resultera i. Klart är dock att en väsentlig mängd fakta stöder ett samband mellan neurodegenerativa hälsoeffekter och giftiga beståndsdelar i jetbränsle såsom bensen, toluen och n-hexan.

Min studie visar att en möjlig överrepresentation av MS-patienter inom Ytterby postnummerområde kan vara en indikation på ett samband mellan Ytterby gruva och MS. Detta möjliga samband kan vara kopplat till de sällsynta jordartsmetaller som finns i de lokala bergarterna, till områden av hög radioaktiv strålning och/eller till Försvarsmaktens tidigare lagring av diesel och jetbränsle i gruvan. Analyser av vattenprover tagna i 15 privata brunnar i Ytterby visar spår av de fem sällsynta jordartsmetallerna: skandium (Sc), yttrium (Y), lantan (La), neodym (Nd) och samarium (Sm) och majoriteten av provtagningsplatserna belägna på låg höjd visar också kontaminering av diesel vilket är det senast lagrade bränslet i gruvan. Därutöver bekräftar analysresultat av en svart substans som läcker ut ur bergsprickor i gruvkorridorerna att REE är närvarande i väsentliga koncentrationer i de lokala bergarterna och att de också tycks vara rörliga. Hänsyn bör tas till detta i betraktande av en potentiell kontaminering av den lokala vattenförsörjningen. Trots att denna studie visar att det förekommer kontaminering av grundvattnet i olika former och i varierande grad så finns det inga fakta, förutom kunskapen om ett utbrett användande av privata brunnar i det förflutna, som bekräftar att människor med MS har förtärt kontaminerat grundvatten. Omfattande kartläggning och ingående studier krävs för att bekräfta ett sådant samband. Naturlig radioaktivitet har mätts runt konturerna på dagbrottet och områden med hög radioaktivitet har identifierats. Genom att använda dessa områden av hög radioaktiv strålning som ställföreträdare för sällsynta mineral och sällsynta jordartsmetaller, föreslår jag också att förekomsten av REE är mycket lokal och kan associeras med, eller återigen ha mobiliserats, i samband med uppkomsten av yngre observerade förkastningar. Målet med denna uppsats har varit att utvärdera om det finns grund för en mer omfattande studie kring ett eventuellt samband mellan Ytterby gruva och förekomsten av MS. Slutsatsen är att en fullständig undersökning av en eventuell koppling mellan neurologiska hälsoproblem, varav MS är ett, och gruvan är befogad.

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## 1. INTRODUCTION

This is a study of the geology, geochemistry, hydrochemistry and potentially associated multiple sclerosis (MS) around Ytterby mine which is located on Resarö Island in the Stockholm archipelago. Mainly feldspars but also quartz were historically quarried in Ytterby. The quartz is thought to have been used in glass and iron works while the feldspar provided the rising porcelain industry with material (Nordenskjöld, 1904; Lööf, 1981). The mine is also well known for the discovery of seven rare earth elements in the periodic table: yttrium (Y), ytterbium (Yb), erbium (Er) and terbium (Tb), holmium (Ho), scandium (Sc) and thulium (Tm) (Enghag, 1999). As the type locality of these rare earth elements, the Ytterby village gave its name to yttrium, ytterbium, erbium and terbium. Furthermore, the mine has also contributed to the discovery of tantalum (Ta) and niobium (Nb), elements found in a mineral that has become known as yttrotantalite (Nordenskjöld, 1904). Examples of minerals containing rare earth elements are Gadolinite, Yttrotantalite, Fergusonite, Anderbergite and Xenotime. Many of these rare minerals contain the radioactive elements uranium and thorium (Nordenskjöld, 1910).

In 1933 the mine was closed down (Lööf, 1981) but in the beginning of the 1950s it was back in use. This was the cold war era and the Ytterby mine, just like many other mines in Sweden, was used as a fuel deposit for the Swedish Armed Forces. Three different petroleum products have been stored in the mine-shaft over a period that totals about 35-40 years. During the 1950s and for approximately 25 years afterwards, jet fuel was stored in the mine shaft and more recently 2 types of diesel (Lindgren & Lundmark, 2012); ( J&W Energi och Miljö, Kemakta Konsult AB, 2001). In 1995 the storage of petroleum products in the Ytterby mine was brought to an end and it was emptied from diesel and closed down. Since 1999, the mine has been managed by The Swedish Fortifications Agency (Fortifikationsverket) and the work involved with the decommissioning is still in progress (Lindgren & Lundmark, 2012).

Recently, coupling between the prevalence of MS, a chronic inflammatory neurodegenerative disease of the central nervous system, and the quarry has been suggested. Residents in the Ytterby village contacted Karolinska Institutet and asked whether Karolinska Institutet knew of any coupling between the Ytterby mine and MS. They did not. No such study has previously been made in the area but initial data pointed towards a slight overrepresentation of MS among people living close to the mine. Thus, the objective of this study is to evaluate if suggested coupling between MS prevalence and any activity and/or characteristic of the mine warrants further investigation. The mine area is situated close to the Ytterby village where many houses have private wells. Historically many of these wells were used for drinking water which raises the question whether groundwater in the area could be a potential source of contamination. However, most of the wells are currently only used for irrigation which implies that no future potential health hazards originating from contaminated groundwater exist.

Moreover, natural radioactivity has been measured around the contours of the quarry and zones of high ionizing radiation have been identified. By using these zones of high ionizing radiation as a proxy for rare minerals containing rare earth elements, I further suggest that the REE occurrences are highly localized around the quarry and could be associated with or remobilized by younger faults.

## 1.1 PURPOSE

The purpose of this study is to elucidate the geological history of the Ytterby mine and to conduct a pilot study to evaluate if suggested spatial coupling between MS prevalence and the mine warrants further investigation.

## 2. GEOLOGICAL SETTING

The Ytterby mine is located in the south-eastern part of Resarö Island in the Stockholm archipelago. Put into a larger regional-geological context, the rocks in this area belong to the Proterozoic Svecofennian domain which covers most of the northern and central part of Sweden, the western part of Finland and part of the Kola Peninsula in Russia. The rocks belonging to the Svecofennian domain are grouped as synorogenic, late orogenic, post orogenic or anorogenic according to their respective time relation to the main folding stage of the Svecocarelian orogeny which occurred approximately 1850 m.y.ago. (Lindström et al., 2000). Isotopic age determination has dated the Ytterby pegmatite, i.e the mined rock type, to be approximately 1795 m.y.old (Welin, 1992) which suggests that it is late to post orogenic (Lindström et al., 2000).

The geological map of Resarö made by Nils Sundius (1948) gives a good overview of the area. The Ytterby pegmatite is situated in the south-eastern corner of the map and is marked with an upside down triangle. The green band which extends across the whole island, WNW-ESE, is described by Sundius (1948), as gabbroic greenstone. Greenstone is a generic term and in this case my interpretation (see section 6.1, geological field observations) is that it refers to mafic rocks with varying chemical composition and metamorphic grade, which are given a greenish colour by their mineral content. The surrounding rocks are all described as various types of gneiss-granite.

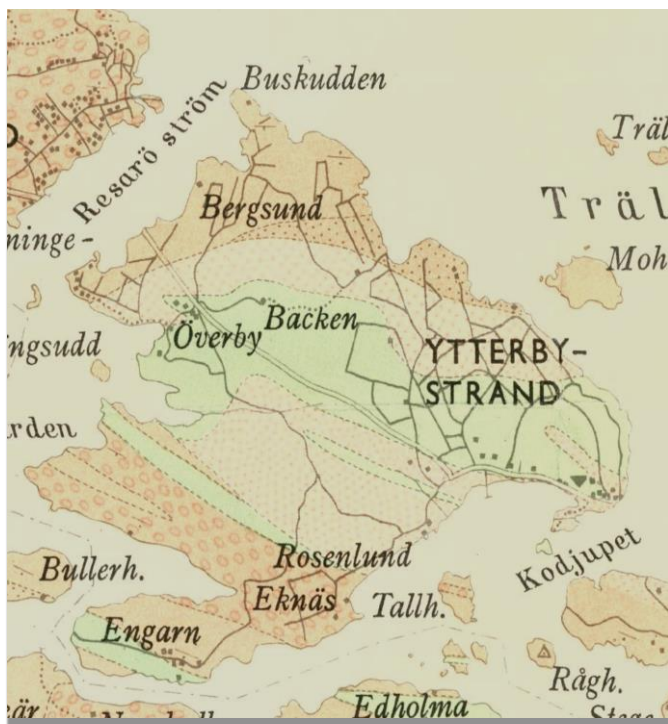


Figure 1: Geological map of the Resarö area. The Ytterby mine is marked by an upside down triangle. The green band is described as gabbroic greenstone and the surrounding rocks as various types of gneiss-granite. From Sundius (1948).

The pegmatite, i.e the mined rock, is a planar structure trending NNE-SSW and according to Nordenskjöld (1904), the length and width is approximately 15 respectively 12 m at the surface and declines with depth. Furthermore, the pegmatite is a 60° westerly inclined ore body, (Nordenskjöld, 1904), bordering two different rock types; amphibolites, i.e part of the greenstone mentioned above, in the NW hanging wall and gneiss in the SE (see section 6.1, geological field observations).

The most widely used classification system of pegmatites today is that of Černý (1991); (revised by Černý & Ercit, 2005). This system classifies pegmatites primarily by their emplacement depth. They are then divided into families, subclasses, types and subtypes based on geochemical features, mineral assemblages and structural features that reflect the pressure and temperature conditions during solidification. The rare element class which reflects low temperature and pressure is subdivided into two main pegmatite families: the LCT-family which is enriched in lithium (Li), cesium (Ce) and tantalum (Ta) and the NYF-family which is enriched in niobium (Nb), yttrium (Y) and fluorine (F) (Černý & Ercit, 2005; Simmons & Webber, 2008). The Ytterby pegmatite belongs to the NYF-family (Lindström et al., 2000). Another characteristic of the NYF-pegmatites is that they are enriched in heavy rare earth elements (HREE), Be, Ti, Sc and Zr (London, 2008). There is also a predominance of niobium (Nb) over tantalum (Ta) and they are depleted in phosphorus (P) (London, 2008). The NYF-family is then subdivided into subclasses distinguished by their specific rare-element association and further into types and subtypes by rare-element mineralogy (Černý & Ercit, 2005; London, 2008). According to Černý (1992), based on the work of Nordenskjöld (1910), the Ytterby pegmatite is associated with the rare earth element type and the gadolinite subtype.

The pegmatite body mainly consists of quartz, red microcline (k-feldspar), grey-white oligoclase (sodium feldspar) and biotite (dark mica) but there is also a considerable amount of other minerals (Lindqvist, 1989). The Swedish Museum of Natural History, Stockholm has made an account of them all. See appendix 1.

### **3. HYDROLOGICAL DATA**

The mean hydraulic conductivity in the rocks around the mine is calculated in a previous study (J&W Energi och Miljö, Kemakta Konsult AB, 2001) and is estimated to be  $3 \cdot 10^{-8}$  m/s. The same study has measured the mean daily inflow of water to the mine to be 9m<sup>3</sup>/day. This inflow is due to groundwater formation from infiltrating precipitation in the proximity of the mine. Since the mine is situated on a hillside this area of infiltration mainly extends upstream. The groundwater divide in the area is situated on the high ground north of the mine shaft and thus limits the area of infiltration upstream. The influence area is calculated by the same study to be 100 000 m<sup>2</sup> (J&W Energi och Miljö, Kemakta Konsult AB, 2001).

According to Sundius (1948) the inflow of groundwater to the mine was very sparse and during the last years of quarrying it only took a barrel to keep the mine dry and no pumping arrangement was needed. This implies that the mined rock was compact.

### **4. MULTIPLE SCLEROSIS (MS)**

Multiple Sclerosis (MS) is a chronic inflammatory neurodegenerative disease in the central nervous system. The course of the disease may vary among different individuals giving rise to various degrees of disability (KI-website, 2012).

MS is characterized by inflammatory lesions in the CNS accompanied by an autoimmune reaction against the body's own tissues (Fulgenzi, 2012). White blood cells attack the protective coating on the axons of nerve cells, myelin, which is vital for the rapid conduction in myelinated nerves (Murray, 2004). The loss of myelin results in scar tissues called sclerosis, also called plaques or lesions. As a result of these scar tissues, the communication along the axons, and consequently along the nerve, is slowed down or disrupted. A regenerating process which makes the axons remyelinate to some extent explains how remissions may occur after a relapse (Murray, 2004).

The disease often begins with episodic attacks of neurological symptoms which refer to the relapsing-remitting type of MS (RRMS), i.e. attacks and remissions of symptoms. This type of MS affects approximately 85% of individuals suffering from the disease. Individuals belonging to this group often enter a secondary-progressive (SPMS) course at a later stage. Others may begin with a primary-progressive course (PPMS) which is a continuous progression of the disease without attacks and is found in 10-15% of the patients (Wehman-Tubbs, 2005)

Early symptoms of MS might be diffuse and of short duration which makes it hard to identify the disease. Common early symptoms include *numbness in extremities* or *impaired vision* and the relapses are often short and well delimited from one another. As the disease progresses symptoms might become more dramatic and often include *walking and balance disturbances*. Entering a secondary progressive stage, the patient may be suffering from *paralysis* and *pronounced fatigue* (Fredrikson, 2003). Other common symptoms in MS include *tremor*, *optic neuritis*, i.e. inflammation of the optic nerve, *dysarthria* which is characterized by impaired speech and poor control of muscles in the face and neck and *dizziness from brainstem dysfunctions*. The above described symptoms might appear alone or in combinations (Wehman-Tubbs, 2005).

The disease is very unevenly distributed over the world. It is most common in Europe, North America and Australia while it is rare in African and Asian countries. Furthermore, some isolated groups within populations, for example the Sami, appear to have some sort of protection against the disease (Fredrikson, 2003). Among individuals with European ancestry living in temperate climates approximately 1 in 500 of the population is affected by MS and the first symptoms usually appear at ages 15 to 50 (Murray, 2004). Incidence peaks peaking at ages around 30 and then gradually declines. It is also more common among women than men (Wingerchuk, 2011).

The number of registered MS patients in Sweden in 2008 was 17 485 out of a total Swedish population of 9 256 347. This gives a MS prevalence of 189 in 100 000, i.e. 1 in 529, which is among the highest nationwide prevalence estimates in the world. It is also concluded that the risk for having MS in Sweden increased with each latitude north (Ahlgren et al., 2011).

The causes of MS are not fully understood but there seems to be a complex interaction between a genetic predisposition and environmental triggers that initiates the disease (Murray, 2004). In addition to the most discussed environmental factors, i.e. viral infections, vitamin D and smoking, occupational factors such as exposure to organic solvents, mineral oils and heavy metals have been proposed as risk factors of MS (Riise et al., 2011).

MS probably has a long latent time period between exposure and symptom onset which makes it difficult to establish if exposure to a particular environmental agent preceded the disease

(Marrie, 2004). Furthermore, due to the complexity of the disease it is difficult to distinguish one single environmental factor as the trigger in a susceptible individual. Another aggravating circumstance is that the interaction between the components of cause might vary from study to study and thereby give inconsistent results (Marrie, 2004).

## **5. METHODS**

*In this section I will first go through methods used for acquiring field data from the rocks in the quarry. Then I will describe how information from reports and informal interviews were obtained and finally I will show how water samples were collected and analysed.*

### **5.1 GEOLOGICAL OBSERVATIONS**

Determination of rock types were primarily made by using a hand lens to look for minerals present in the rock and by looking for textures in the rocks at the quarry. A compass was used to determine the orientation of structures.

### **5.2 CHEMICAL ANALYSES OF ROCKS & RADIATION MEASUREMENTS**

*This section presents the mode of procedure for making a chemical map of the quarry pegmatite and adjacent rocks. It will be divided into three parts; i) construction of the quarry sketch; ii) nuclear radiation and iii) XRF-measurements.*

#### **5.2.1 CONSTRUCTION OF THE QUARRY SKETCH**

First a grid-like map of the quarry was constructed (Fig. 2). This grid made it possible to determine how far from the pegmatite-amphibolite contact each sample was taken. Then two measuring tapes were attached to the northern wall of the quarry (orange lines on the sketch). These tapes were rolled out following the length of the quarry, i.e. north to south. Then a laser measuring device was used to determine the distance from the western tape to the western rock wall at 1 m intervals, beginning at W1 and ending at W34. The same procedure was made for the eastern tape to the eastern rock wall. In order to have the numbering of the western and the eastern wall at the same horizontal line, i.e. W1 at the same distance as E1 from the northern wall, the western tape was decided to be the governing one. Consequently the E1 spot is only 80 cm from the northern wall instead of 1 m but this is compensated for by subtraction of 20 cm in further measurements. All measurements when constructing the grid were made at waist height using a laser measuring device. At the same time as this sketch was constructed, XRF and radiation measurements were also made (see more information further on in this section). When all field data were collected, fault planes of the amphibolite were marked on the sketch and then a ruler was used to measure the distance from the fault planes to each sample spot all around the contours of the quarry, i.e. W1, W2, W3 and so forth. However, these distances (marked with an X in my working sketch, upper left corner) needed to be adjusted since they did not represent the shortest distance from the a/p-contact to the sample spot. The dip direction/ dip angle of the amphibolite is 318°NW/60°. Thus, the shortest distance from the contact to the measured spot is Y. Therefore all measured lengths (X) were corrected for as follows:  $Y = X \cdot \cos 30^\circ$ . Furthermore, a minor source of error is that the ground in the quarry dips to the south so the height above sea level for all measurements varies somewhat.

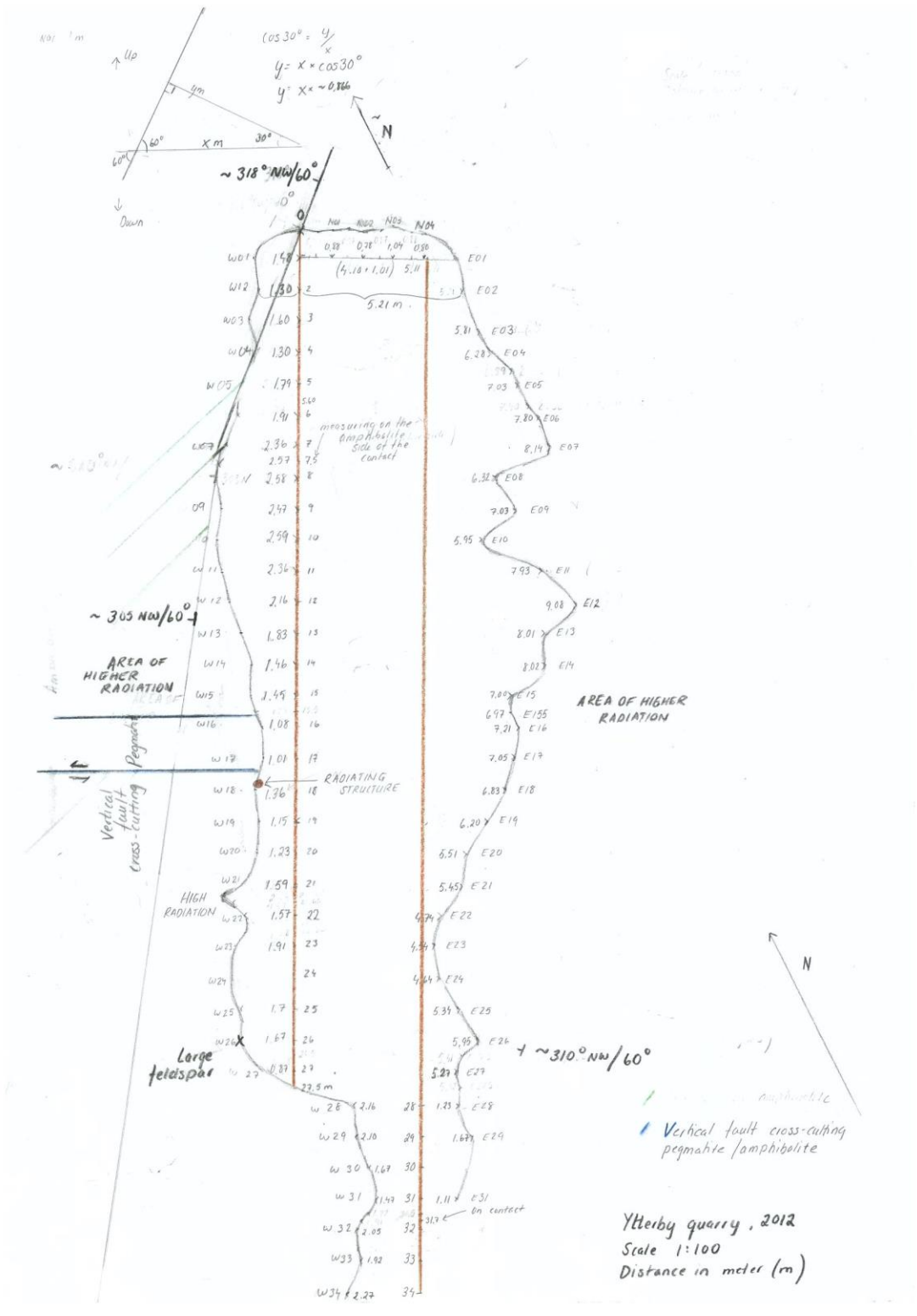


Figure 2: Working sketch of the Ytterby quarry.

## 5.2.2 NUCLEAR RADIATION

Nuclear radiation in the Ytterby quarry was measured with a Radalert 50. This device measures the rate of alpha, beta, gamma and x-radiation. It measures the amount of radiation in CPM (Counts Per Minute) or  $\mu\text{Sv/hr}$ . 100 CPM equals 1  $\mu\text{Sv/hr}$ .

Before the nuclear radiation measurements were made, the normal background count, i.e. the normal level of nuclear radiation which occurs at a given time and place, was determined. Thirty consecutive minute readings were recorded, added together and then divided by 30. The resultant number was then regarded as the average background count and used as a reference to determine abnormal nuclear radiation levels.

## 5.2.3 X-RAY FLUORESCENCE

A portable X-ray fluorescence spectrometer (XRF) has been used to map the chemical composition of the Ytterby pegmatite and the rocks in its immediate proximity. This instrument determines the elemental content of a material, i.e. it both identifies and quantifies the elements present. An element is defined by its characteristic X-ray emission wavelength and the quantity of that particular element is measured by the intensity of its characteristic line. The Beam mining mode has been used (XRF-user manual, 2010).

Measurements are made in situ, made by pointing the analyser at the rock. The instrument measures the element content of the sample area over a surface area which is about  $1\text{ cm}^3$  to a depth of about 2 mm, displaying element concentrations in weight %. When doing this type of measurements it is important to be aware of what is actually measured. The analysis of the target element(s) might be influenced by other elements in the rock matrix (XRF-user manual, 2010).

The elements analysed are: Mg, Al, Si, P, S, Cl, K, Ca, Ti, V, Cr, Mn, Fe, Co, Ni, Cu, Zn, W, As, Pb, Bi, Zr, Mo, Ag, Cd, Sn, Sb (XRF-user manual, 2010).

## 5.3 INTERVIEWS & REPORTS

Historical data from the time when Ytterby mine was used for mining feldspar and quartz were taken from historical documents mainly found at the library in Vaxholm and in the georegister at the Swedish Geological Survey (SGU).

Information about the Ytterby mine as a fuel deposit was retrieved from the archives of The Swedish Fortifications Agency (Fortifikationsverket) and through informal interviews. The Swedish land registry informed me that the present owner of the mine is The Swedish Fortifications Agency. Thus, I contacted the owner of the mine to get in touch with people, both within The Swedish Fortifications Agency and the Swedish Defence, who worked in the mine during and after the period it was used as a fuel deposit. No formal interviews were conducted with these persons but rather informal meetings held during maintenance inside the mine. In these meetings I had the opportunity to study the mine from the inside, to take samples, to learn about the history of the mine and ask questions. Each visit gave rise to more questions, questions kept for the next meeting. During this iterative process time was not a limiting factor and consequently there was no need for ranking questions in order of importance.

Reports regarding potential health effects of the stored fuels are mainly found at The Military Archives of Sweden (Krigsarkivet) and in scientific literature. Statistical data on MS were provided by the MS-group at Karolinska Institutet (KI).

## 5.4 CHEMICAL ANALYSES OF GROUNDWATER

### 5.4.1 INORGANIC ANALYSES

My intention was to collect as many samples as possible in a 1 km radius around the mine. The Södra Roslagen environmental and health office (The Södra Roslagens Miljö- och Hälsoskyddskontor) provided me with information about wells in the area and the well register kept by the Swedish Geological Survey (SGU) was also consulted. These data were not completely updated and many of the marked wells were no longer in use or simply not there. Instead I asked as many people as I could get in touch with in this area if they had a well. All people who were asked and who had a well allowed me to collect water samples. In total 19 samples were collected in a period of 4 days (except for samples 1 and 2 taken 3 weeks earlier in the quarry). Fifteen samples were taken from wells; three of these were still used for drinking water, nine for irrigation and three were not in use at all. Two of these samples were taken further away from the mine in order to get reference values for my analyses. Two samples were taken from ditches and two samples from the quarry. Yet another sample was taken from a water-tank inside the mine. For all sample locations there were two sets of data collected on two different occasions. Unfortunately not all 55 elements shown in fig. 4 were screened for in the first run. This is the reason why some elements only show results from run number two. Sample locations are shown in fig. 3.



Figure 3: Water sample locations.

### Sampling procedure

Sampling procedure was adjusted to the circumstances of each sample location. At some locations, samples were collected directly from running water and at other locations the water was collected in a small bottle before it was poured into the sample bottles. To minimize the risk for contamination the samples designated for inorganic analyses were collected in acid washed plastic bottles which were pre-rinsed with sample water before they were filled. Samples were also filtered and pre-rinsed with a 3 M nitric acid solution, distilled water and sample water.

A pH/EC/TDS/Temperature meter (HI 991301) was used for measuring temperature, conductivity and pH. All these measurements were performed at the sample locations by stirring the instrument in a plastic bottle filled with sample water.

### Inductively Coupled Plasma Optical Emission Spectrometry (ICP-OES)

ICP-OES is a technique that allows for almost all elements in the periodic table to be analysed at the same time and for concentrations at trace levels. Thus, it is used for determining what elements are present in a sample and at what concentrations. Elements screened for in this analysis are marked blue in the periodic table shown in fig. 4.

The figure shows a periodic table where elements are color-coded. Elements screened for ICP-OES are marked in blue. These include: H, Li, Be, B, C, N, O, F, Ne, Na, Mg, Al, Si, P, S, Cl, Ar, K, Ca, Sc, Ti, V, Cr, Mn, Fe, Co, Ni, Cu, Zn, Ga, Ge, As, Se, Br, Kr, Rb, Sr, Y, Zr, Nb, Mo, Tc, Ru, Rh, Pd, Ag, Cd, In, Sn, Sb, Te, I, Xe, Cs, Ba, La, Hf, Ta, W, Re, Os, Ir, Pt, Au, Hg, Tl, Pb, Bi, Po, At, Rn, Fr, Ra, Ac, Ce, Pr, Nd, Pm, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, Lu, Th, Pa, U, Np, Pu, Am, Cm, Bk, Cf, Es, Fm, Md, No, Lr.

Figure 4: Elements screened for in the ICP-OES are marked blue in the periodic table.

The samples were prepared for ICP-OES analysis by filtration into 10 ml test tubes and added 100  $\mu$ l nitric acid. Test tubes, syringes and filters were pre-rinsed with distilled water. Then the instrument was calibrated using standard solutions and a blank was also added. The sample was injected into the instrument as a stream of liquid sample. In the instrument the sample was converted into an aerosol, i.e. particles suspended in gas. This aerosol was transported to the plasma where the solvent was removed from the sample and the resultant dry sample particles were broken down into a gas of sample molecules. This sample gas was dissociated into free atoms and excited and/or ionized by the plasma. The excited atoms and ions emitted their characteristic radiation which was turned into electronic signals that were converted into concentration information (Boss & Fredeen, 1997).

## 5.4.1 ORGANIC ANALYSES

Another set of water samples was collected from each of the locations described in section 5.4.1. Samples were taken directly from running water or collected in a glass bottle before they were poured into the sample bottles. These bottles were pre-rinsed with sample water.

The samples were first collected in 10 ml glass bottles but the water volume turned out to be too small for detecting small volumes of oil. In order to decrease the limit of detection, the water was re-sampled in 1 l glass bottles filled to 90%. These samples were sent away to an external laboratory, ALS Scandinavia AB, where an Oil-TPH analysis, OV-20C was performed. TPH stands for Total Petroleum Hydrocarbon being the sum of aliphatic and aromatic compounds in a sample. This is a Gas Chromatography - Flame Ionizing Detector (GC-FID) method that gives results both as a total C10-C40 and in fractions which helps to identify what type of oil is present, if any.

## 6. RESULTS

*Results consist partly of existing material, both published and non-published, and partly of my own results, i.e. geological field observations, organic and inorganic water analyses and chemical map of the quarry. When no source is stated, it is my own results.*

### 6.1 GEOLOGICAL FIELD OBSERVATIONS

Geological field observations are mainly focused on the quarry area and to a minor extent on the mine and mine tunnels. Fig. 5 shows a photograph of the quarry and fig. 6 shows the quarry sketch which is the result of the work described in section 5.2.1. Sample locations marked on this sketch, i.e. N01 and so forth, will be referred to in the text.



Figure 5: The Ytterby quarry looking north.

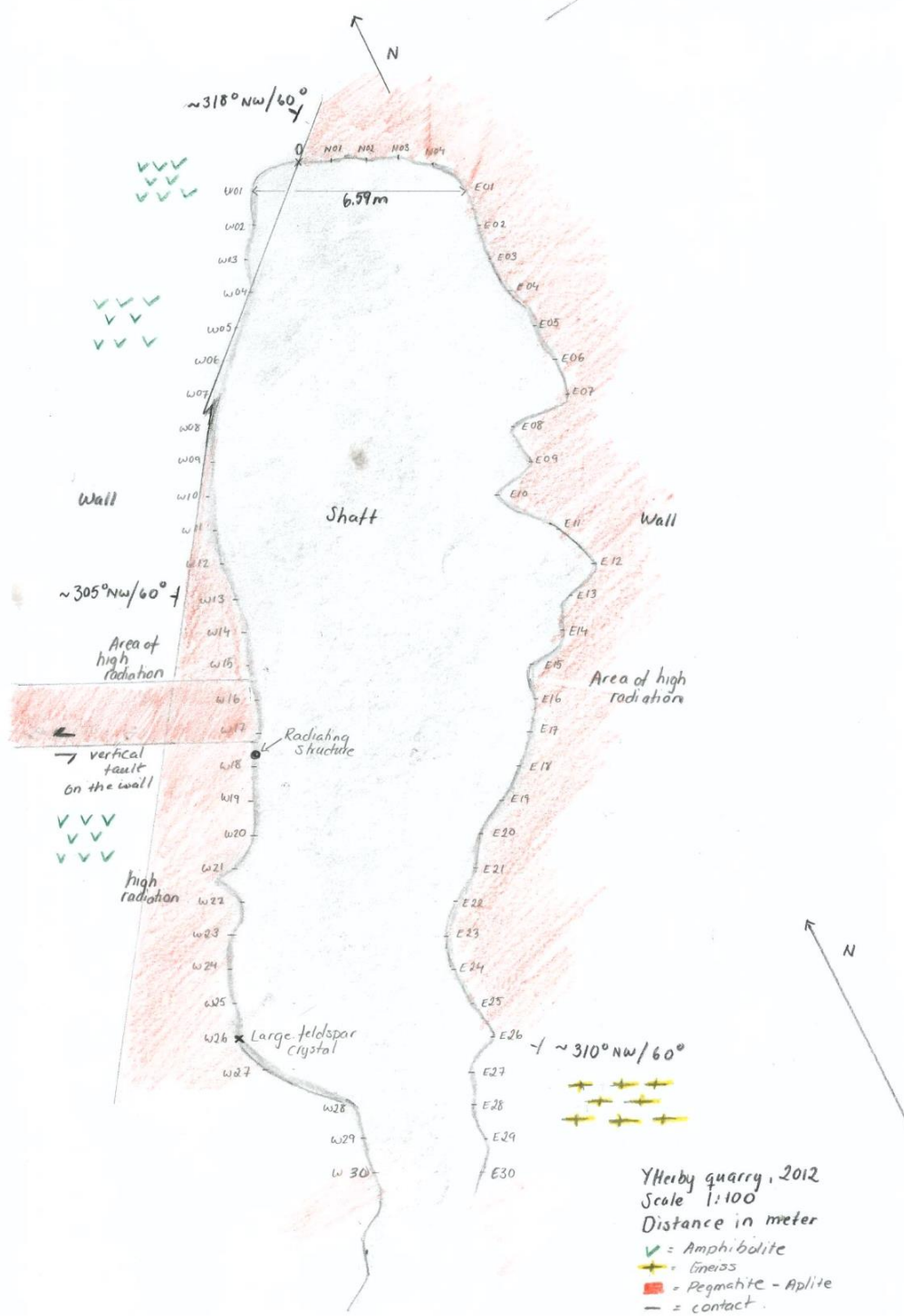


Figure 6: Sketch of the Ytterby quarry.

### 6.1.1. OBSERVED STRUCTURES

In the quarry area two different deformation stages have been observed:

1) The upper boundary of the pegmatite is a planar contact with the overlying amphibolite. The amphibolite dips at 60 degrees towards 318 degrees NW. The planar contact indicates that this structure is a fault resulting from tectonic movements. Adjacent to this surface there is an altered layer approximately 10-20 cm wide. Its proximity to the contact implies that this zone might have been altered by the amphibolite. Moreover, foliation is not well developed in the amphibolite. The lower boundary, visible in the SE corner of the quarry, is a contact with a gneiss which dips at 60 degrees towards 310 degrees NW.

2) There are two or three vertical structures roughly trending W-E, displacing the contact between the amphibolite and the pegmatite. These fractures seem to have channelled the fluids that heavily altered both the amphibolite and the pegmatite in the proximity to this fracture zone and which caused unusual mineralizations in the amphibolite (Fig. 7). The presence of these W-E trending faults is also evidence that the faults themselves and thereby also the fluids that ran through them are younger than both the amphibolite and the pegmatite.



Figure 7: Mineralization in altered amphibolite.

The chronology of the gneiss, amphibolite and pegmatite is more difficult to determine since I have only found one place where a cross-cutting relationship can be seen in the quarry. This is at the south-western corner of the quarry where the foliation in the amphibolite is cross-cut by pegmatite. This would imply that the pegmatite is younger than the amphibolite. Since this feature is not seen at any other place there is also a possibility that the amphibolite, having a higher melting temperature than the pegmatite, could have caused partial melting of the pegmatite and if this is the case, then the chronology would be reversed from that suggested above. As described above the mined pegmatite in Ytterby shows no signs of ductile deformation but rather brittle deformation. However, in the mine tunnels NE of the quarry I have observed numerous pegmatite veins of varying size and most of these veins are folded by at least one deformational period. This means that there are multiple generations of pegmatites in the area, the quarry pegmatite probably being the youngest.

The quarry is part of a hill, Isterberget, where exposure of bedrock is fairly sparse. The terrain southwest of the W-E trending fault appears to be cracked apart into loose rock fragments which results in a blocky terrain.

### 6.1.2. NUCLEAR RADIATION DATA

Natural radioactivity has been measured around the contours of the quarry and zones of high radiation were identified. Fig. 8 shows how nuclear radiation varied along the contours of the quarry, i.e. clockwise from N01 to W01 (Fig. 6) and fig. 9 shows how nuclear radiation varied with distance from the a/p-contact. The top at E155 in the first chart corresponds to the top at 9 m distance from the contact. The cluster of high radiation peaks between W22 and W15 corresponds to 1.6-2.4 m distances from the contact (for a complete list of ionizing radiation data see appendix 3).

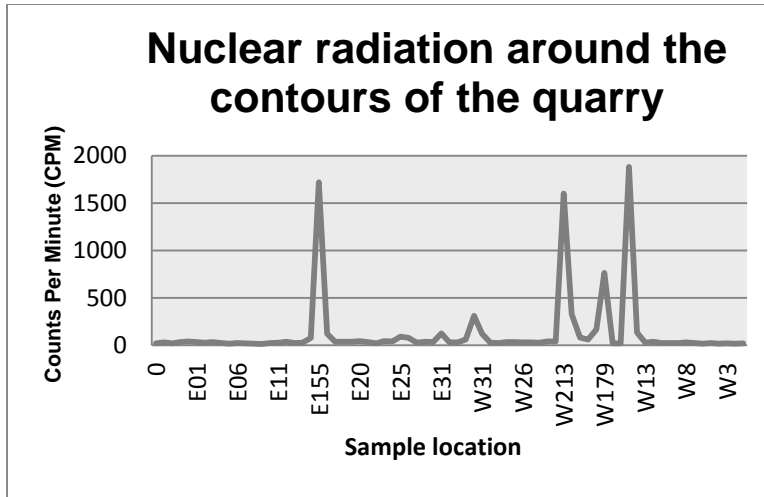


Figure 8: Nuclear radiation around the contours of the quarry.

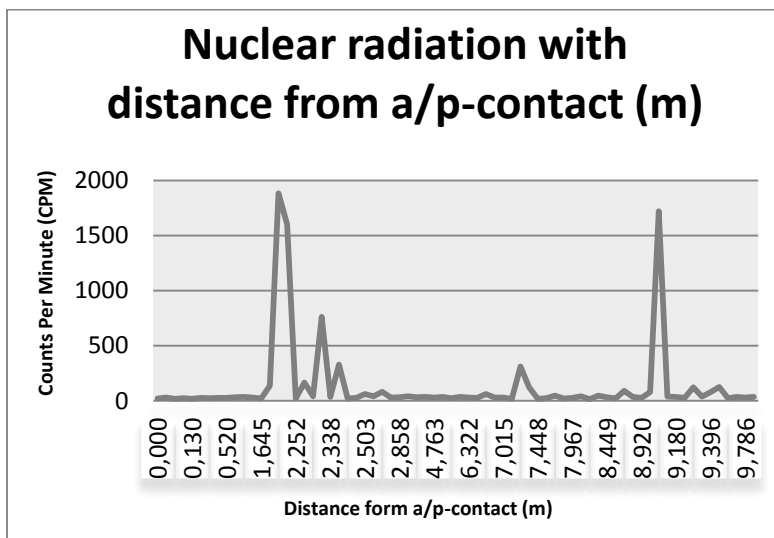


Figure 9: Nuclear radiation with distance from the amphibolite/pegmatite contact (m).

Data show that the pegmatite is highly radiating in certain limited areas. It appears as if there is an E-W trending streak of high radiation across the pegmatite ( see sample locations W13-W23 and E15-E16). The highest values measured were between 1500-1800 CPM (Counts Per Minute) or 15-18  $\mu\text{Sv/hr}$ . In most other areas the radiation was low, corresponding to normal background levels of approximately 20-40 CPM, and in yet another few places it was more moderately increased to about 100-700 CPM. Fig. 10 shows a geometrically and nuclear radiating structure situated on the western wall in the quarry (W18).



Figure 10: Geometrically and nuclear radiating structure situated on the western wall in the Ytterby quarry, scale 1:13.

### 6.1.3. CHEMICAL DATA

*In this section results from XRF-measurements are presented. For a complete list of data, see appendix 3.*

X-ray fluorescence (XRF) was used for an elemental analysis of the Ytterby pegmatite and the rocks in its immediate surroundings. Elemental concentrations are plotted against distance from the amphibolite/pegmatite contact to see how these concentrations evolve. However, this elemental analysis does not contain any of the REE since they were not included among the elements screened for by the hand-held XRF. The analysis is rather focused on how the feldspar changes along the profile and identified zones of elevated radioactivity are used as a proxy of rare earth minerals.

Elemental concentrations measured on the north-eastern side of the quarry do not appear to vary along the profile in the same manner as the concentrations on the western side. I have therefore chosen to show the two sets of data separately. Fig. 11 to 46 present data for: i) sample locations N01-E26, ii) sample locations W01- W30 (note the difference in scale in figures). Moreover, in the south-western part of the quarry, i.e. south of W27, there are involvements of other rock-types within the pegmatite samples which explain why data at 7 m distance in the western profile stand out from the rest of the data.

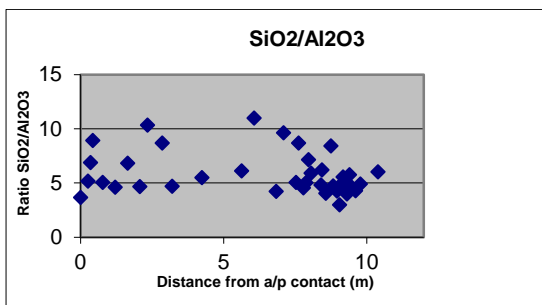


Figure 11:  $\text{SiO}_2/\text{Al}_2\text{O}_3$ , North-eastern wall.

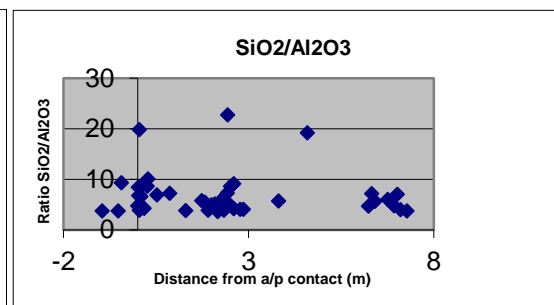


Figure 12:  $\text{SiO}_2/\text{Al}_2\text{O}_3$ , Western wall.

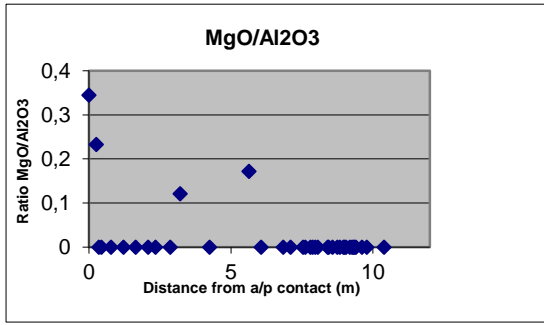


Figure 13: MgO/Al<sub>2</sub>O<sub>3</sub>, North-eastern wall.

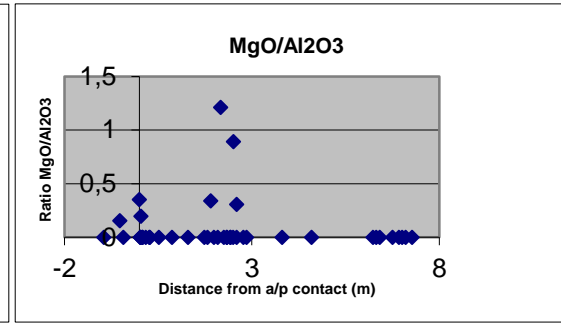


Figure 14: MgO/Al<sub>2</sub>O<sub>3</sub>, Western wall.

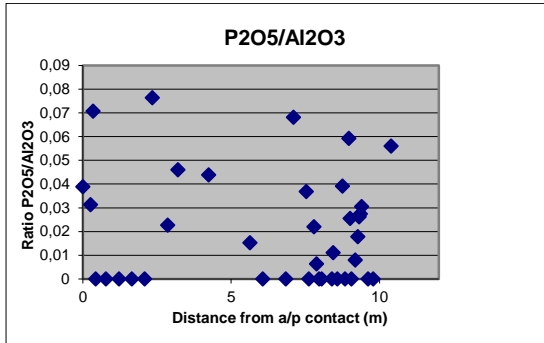


Figure 15: P<sub>2</sub>O<sub>5</sub>/Al<sub>2</sub>O<sub>3</sub>, North-eastern wall.

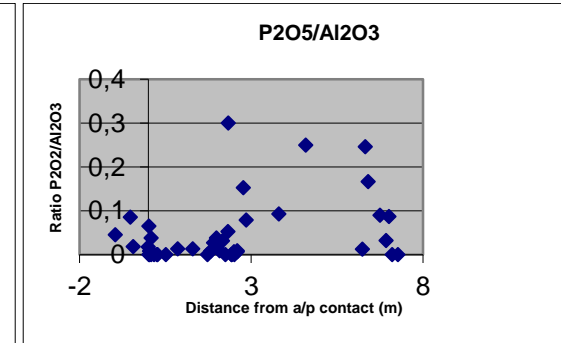


Figure 16: P<sub>2</sub>O<sub>5</sub>/Al<sub>2</sub>O<sub>3</sub>, Western wall.

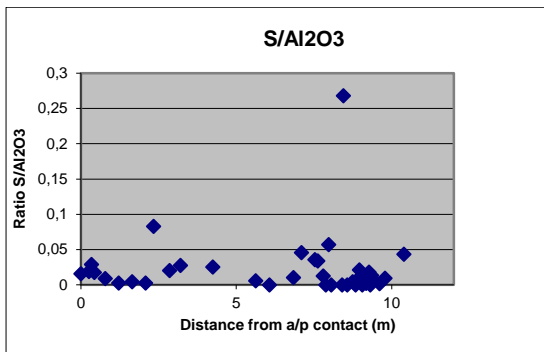


Figure 17: S/Al<sub>2</sub>O<sub>3</sub>, North-eastern wall.

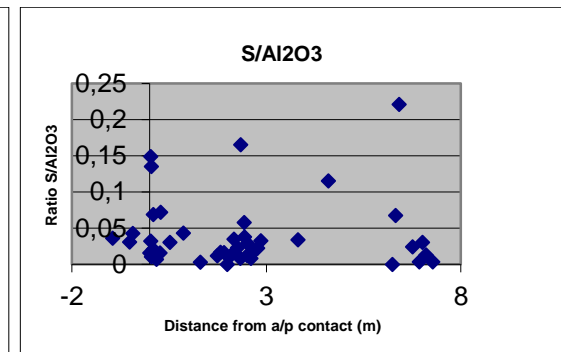


Figure 18: S/Al<sub>2</sub>O<sub>3</sub>, Western wall.

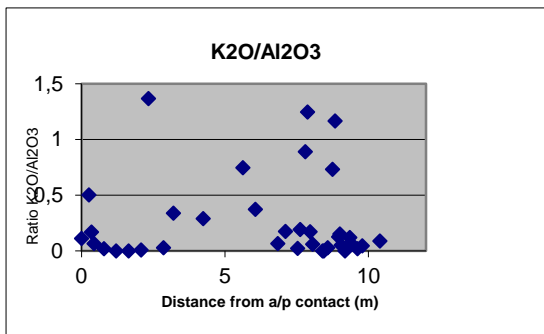


Figure 19: K<sub>2</sub>O/Al<sub>2</sub>O<sub>3</sub>, North-eastern wall.

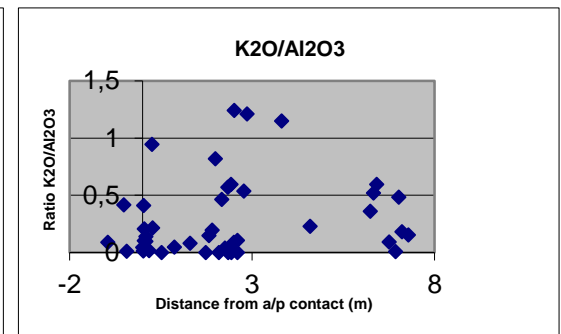


Figure 20: K<sub>2</sub>O/Al<sub>2</sub>O<sub>3</sub>, Western wall.

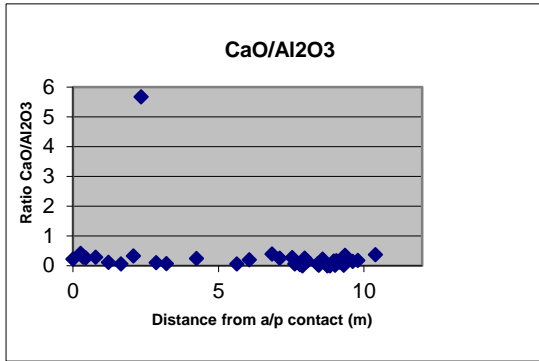


Figure 21: CaO/Al<sub>2</sub>O<sub>3</sub>, North-eastern wall.

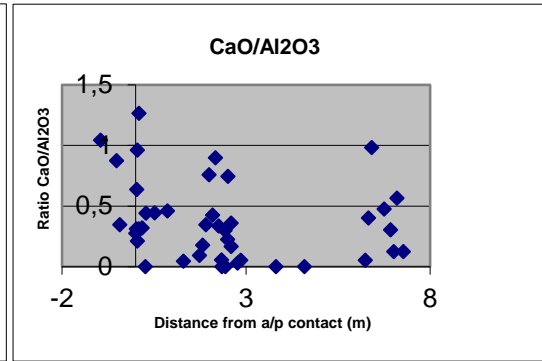


Figure 22: CaO/Al<sub>2</sub>O<sub>3</sub>, Western wall.

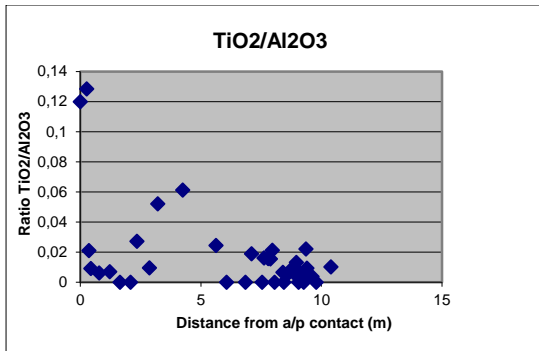


Figure 23: TiO/Al<sub>2</sub>O<sub>3</sub>, North-eastern wall.

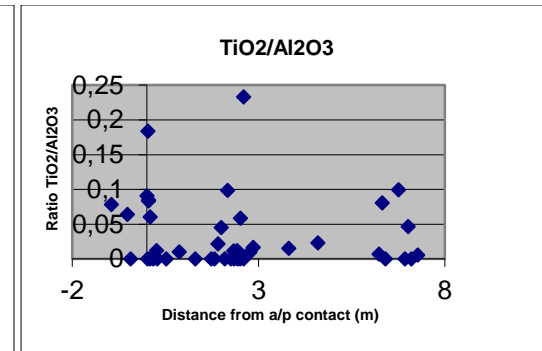


Figure 24: TiO/Al<sub>2</sub>O<sub>3</sub>, Western wall.

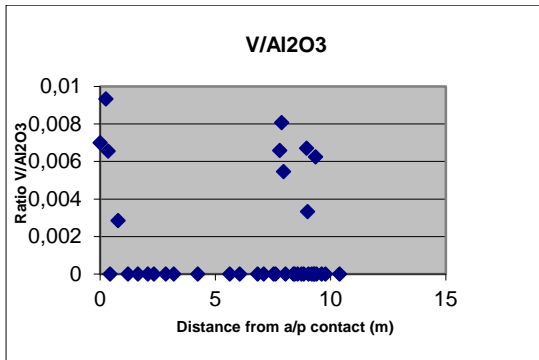


Figure 25: V/Al<sub>2</sub>O<sub>3</sub>, North-eastern wall.

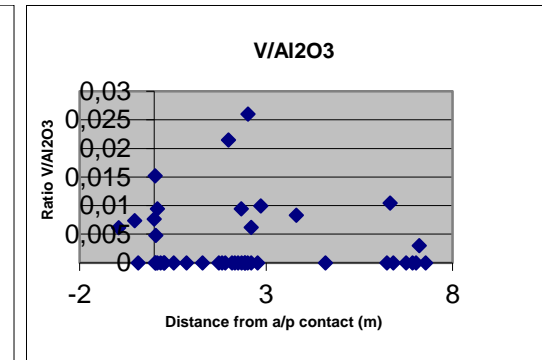


Figure 26: V/Al<sub>2</sub>O<sub>3</sub>, Western wall.

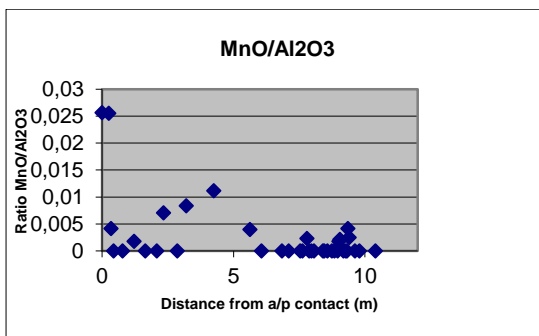


Figure 27: MnO/Al<sub>2</sub>O<sub>3</sub>, North-eastern wall.

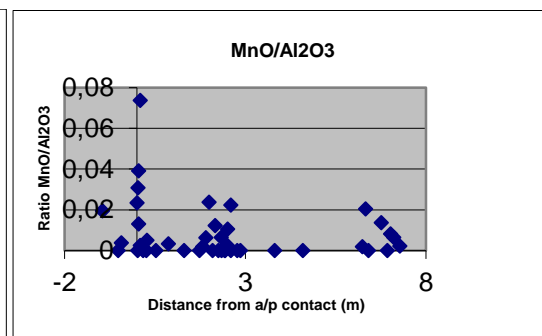


Figure 28: MnO/Al<sub>2</sub>O<sub>3</sub>, Western wall.

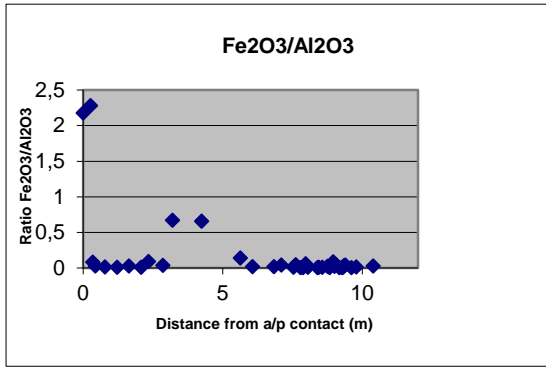


Figure 29:  $\text{Fe}_2\text{O}_3/\text{Al}_2\text{O}_3$ , North-eastern wall.

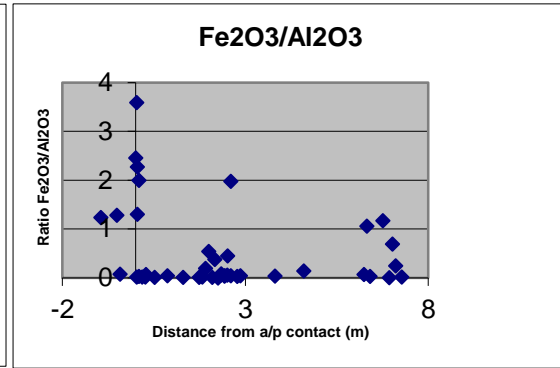


Figure 30:  $\text{Fe}_2\text{O}_3/\text{Al}_2\text{O}_3$ , Western wall.

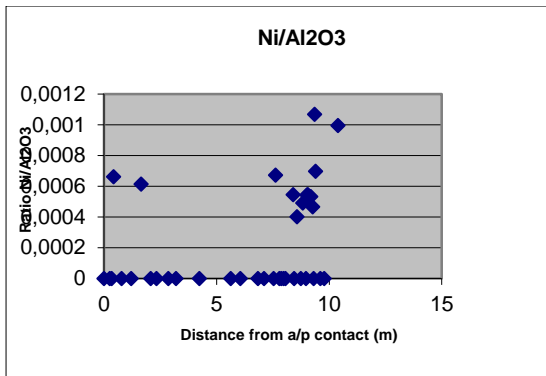


Figure 31:  $\text{Ni}/\text{Al}_2\text{O}_3$ , North-eastern wall.

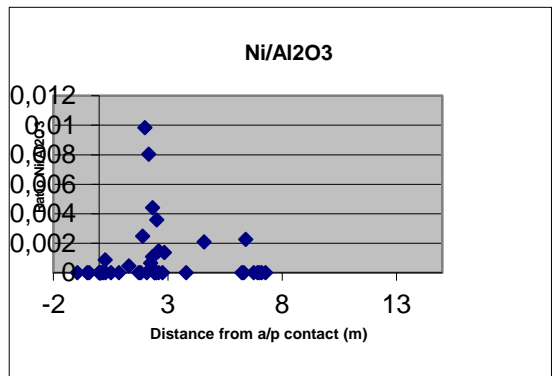


Figure 32:  $\text{Ni}/\text{Al}_2\text{O}_3$  Western wall.

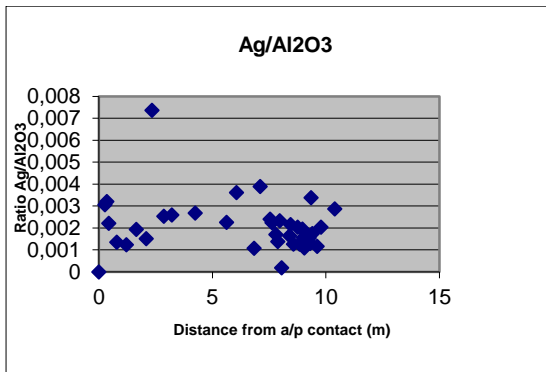


Figure 33:  $\text{Ag}/\text{Al}_2\text{O}_3$ , North-eastern wall.

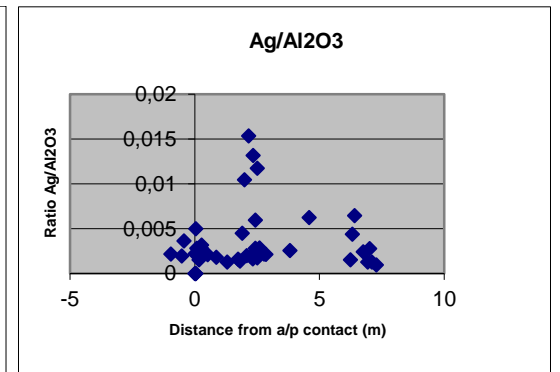


Figure 34:  $\text{Ag}/\text{Al}_2\text{O}_3$ , Western wall.

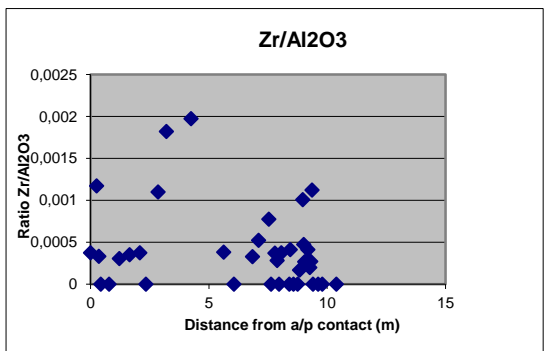


Figure 35:  $\text{Zr}/\text{Al}_2\text{O}_3$ , North-eastern wall.

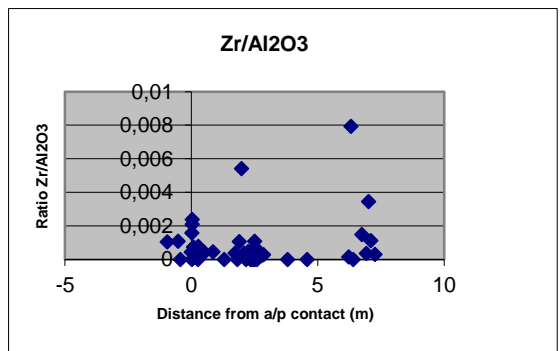


Figure 36:  $\text{Zr}/\text{Al}_2\text{O}_3$ , Western wall.

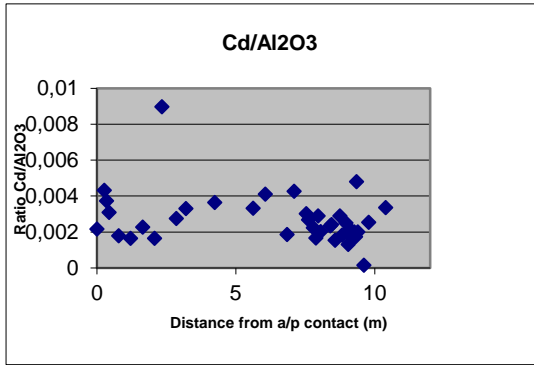


Figure 37: Cd/Al<sub>2</sub>O<sub>3</sub>, North-eastern wall.

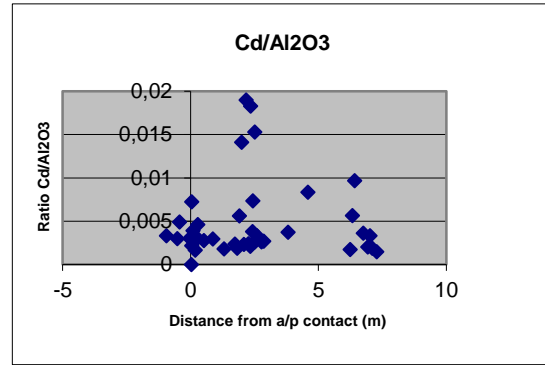


Figure 38: Cd/Al<sub>2</sub>O<sub>3</sub>, Western wall.

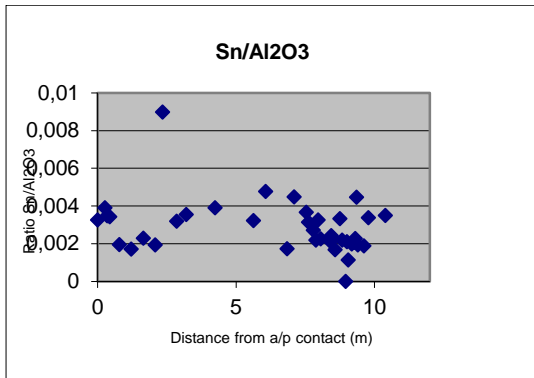


Figure 39: Sn/Al<sub>2</sub>O<sub>3</sub>, North-eastern wall.

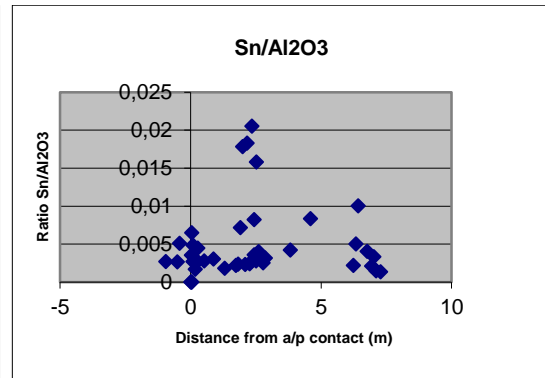


Figure 40: Sn/Al<sub>2</sub>O<sub>3</sub>, Western wall.

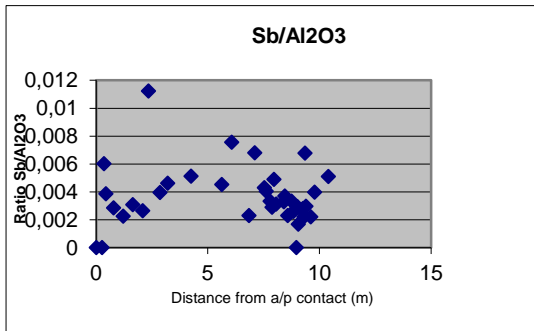


Figure 41: Sb/Al<sub>2</sub>O<sub>3</sub>, North-eastern wall.

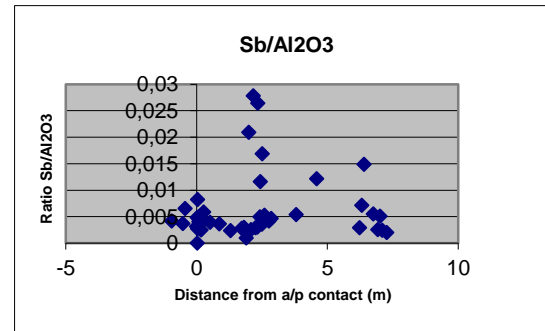


Figure 42: Sb/Al<sub>2</sub>O<sub>3</sub>, Western wall.

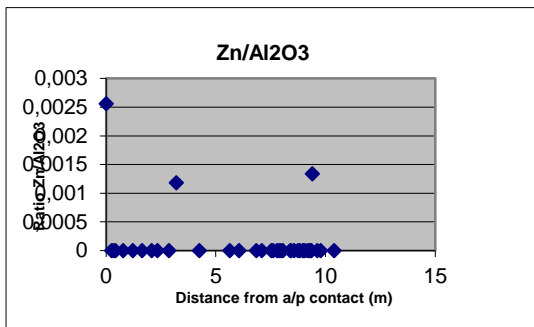


Figure 43: Zn/Al<sub>2</sub>O<sub>3</sub>, North-eastern wall.

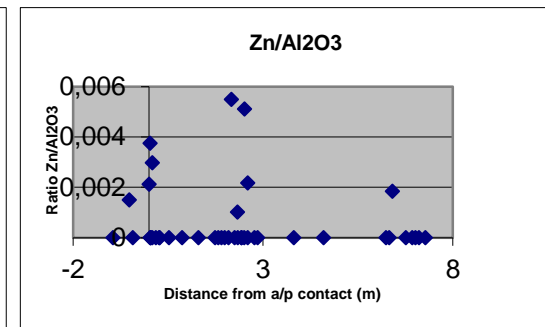


Figure 44: Zn/Al<sub>2</sub>O<sub>3</sub>, Western wall.

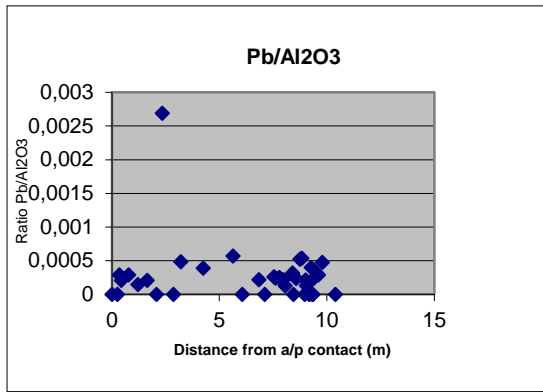


Figure 45: Pb/Al<sub>2</sub>O<sub>3</sub>, North-eastern wall.

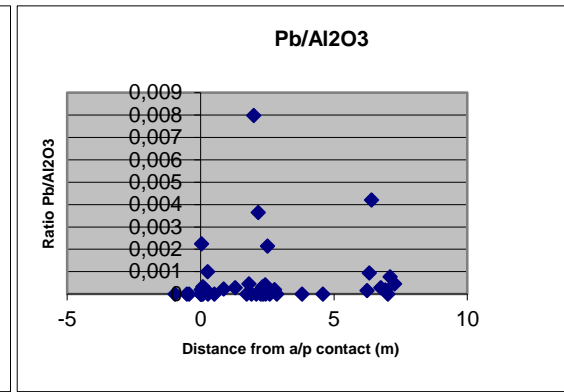


Figure 46: Pb/Al<sub>2</sub>O<sub>3</sub>, Western wall.

Figures above show that silica (Si) and aluminium (Al) remain fairly stable through the profile while most of the other elements show occasional zones of elemental enrichment. However, even if no gradual changes in the chemistry are observed with distance from the amphibolite/pegmatite contact, there is a recurrent feature in many of the plots. At a distance of approximately 2-3 m in the north-eastern profile and at 8-9 m distance in the western profile, many elements such as potassium (K), phosphorous (P), zircon (Zr), nickel (Ni), vanadin (V) appear in both low and high concentrations. This suggests that the chemical variation in the pegmatite is zonal and depends on factors other than the distance from the a/p-contact. These zones of elemental enrichment coincide with the observed areas of high nuclear radiation and the vertical faults. I have chosen to use these zones of high elemental enrichment and high nuclear radiation as proxies for rare minerals and thus the REEs.

Cadmium (Cd), tin (Sn) and antimony (Sb) follow the same undulatory path through the north-eastern profile and show the same peak at 2 m distance at the western profile.

Although there does not appear to be a gradual change of chemistry in the profile, there clearly is a textural one. When I move away from the amphibolite-pegmatite-contact towards the north-eastern corner of the quarry, the rock becomes fine grained and the biotite disappears. Graphic granite, i.e. an intergrowth of quartz and feldspar, is found in this zone (2-3 m distance) which also appears to be enriched in many elements. Moving even further East there seem to be a transition from this fine grained rock to granite.

The boundary is enriched in elements such as iron (Fe), magnesium (Mg), manganese (Mn), titanium (Ti), potassium (K), calcium (Ca) and zircon (Zr). The Grant isochron diagram presented below clearly shows that the pegmatite has a metasomatic connection with the amphibolite (also seen as the biotite-rich margin in fig. 48 and 49). The diagram compares samples at 0.259808 m (which is assumed to be altered) and at 0.34641 m (which is assumed to be unaltered). I have chosen these samples because the amount of Al<sub>2</sub>O<sub>3</sub> is almost exactly the same and this oxide is likely to be immobile (see appendix 3 for complete list of data). The concentration of each element is multiplied by an arbitrary factor, here 1000, 500, 10, 1 or 0.1. This is done to make the elements fit on the same plot and the values represent relative magnitudes of the components not their absolute magnitude. All elements or oxides plotting below the line of unity are added by metasomatism, e.g. Fe<sub>2</sub>O<sub>3</sub>. All elements or oxides plotting above the line are removed by metasomatism, e.g. S. I am assuming constant volume when using this diagram.

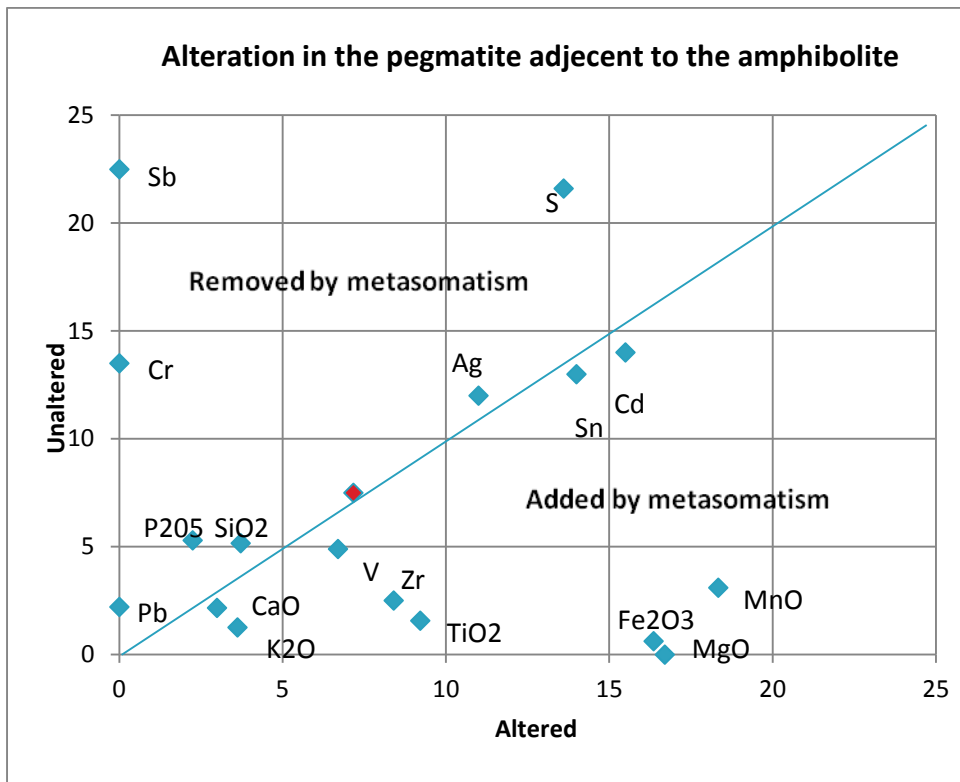


Figure 47: Grant isochron diagram showing metasomatic alteration in the pegmatite adjacent to the amphibolite.



Figure 48: Biotite rich margin between amphibolite and pegmatite. Figure 49: Biotite rich margin, Close-up.

### *Chemical analysis of black substance in mine corridors*

Occurrences of a black substance inside the mine corridors have been observed (Fig. 50 and 51). Results from an externally made analysis (ALS Scandinavia) of this substance are presented in the table 1. These results show that the water content of the substance is 85%. The loss on ignition (LOI), which is expressed as a weight percent of the dry substance, is 12.6%. This means that 12.6% of the dry substance is organic material. The main elements included are manganese (Mn 65.6%) and calcium (CaO 10.2%). Results also show that barium (Ba), copper (Cu), yttrium (Y), lanthanum (La), cerium (Ce) and neodymium (Nd) are present in substantial concentrations. Moreover, a Raman analysis using a LabRAM HR 800 instrument with an argon-ion laser at the Department of Geological Sciences, Stockholm University, was employed to identify a manganese oxide,  $Mn_3O_4$  ( $Mn^{II}Mn_2^{III}$ ), present in this substance. This oxide is known as the mineral Hausmannite. Although, it is not within the scope of this thesis to determine the propagation of this black substance in the local rock fractures, but given the amount of leakage it should be taken into account when considering the potential leakage of hazardous elements to the local water supply.



Figure 50 & 51: Black substance leaching from cracks in the mine corridor.

ELEMENT		SAMPLE
TS*	%	15.6
GF**	% av TS	12.6
SiO <sub>2</sub>	% TS	1.14
Al <sub>2</sub> O <sub>3</sub>	% TS	0.185
CaO	% TS	10.2
Fe <sub>2</sub> O <sub>3</sub>	% TS	<0.1
K <sub>2</sub> O	% TS	<0.1
MgO	% TS	0.656
MnO	% TS	65.6
Na <sub>2</sub> O	% TS	0.144
P <sub>2</sub> O <sub>5</sub>	% TS	0.0296
TiO <sub>2</sub>	% TS	0.0033
As	mg/kg TS	5.72
Ba	mg/kg TS	1710
Be	mg/kg TS	0.934
Cd	mg/kg TS	13.4
Co	mg/kg TS	200

<b>Cr</b>	mg/kg TS	<10
<b>Cu</b>	mg/kg TS	1890
<b>Hg</b>	mg/kg TS	0.35
<b>Mo</b>	mg/kg TS	162
<b>Nb</b>	mg/kg TS	29.4
<b>Ni</b>	mg/kg TS	33.8
<b>Pb</b>	mg/kg TS	40
<b>S</b>	mg/kg TS	395
<b>Sn</b>	mg/kg TS	<0.1
<b>Sr</b>	mg/kg TS	690
<b>Th</b>	mg/kg TS	5.79
<b>U</b>	mg/kg TS	12.1
<b>V</b>	mg/kg TS	772
<b>W</b>	mg/kg TS	428
<b>Zn</b>	mg/kg TS	286
<b>Zr</b>	mg/kg TS	89
<b>Sc</b>	mg/kg TS	2.25
<b>Y</b>	mg/kg TS	1480
<b>La</b>	mg/kg TS	1810
<b>Ce</b>	mg/kg TS	3320
<b>Pr</b>	mg/kg TS	417
<b>Nd</b>	mg/kg TS	1670
<b>Sm</b>	mg/kg TS	386
<b>Eu</b>	mg/kg TS	32.6
<b>Gd</b>	mg/kg TS	457
<b>Tb</b>	mg/kg TS	63.8
<b>Dy</b>	mg/kg TS	336
<b>Ho</b>	mg/kg TS	70.5
<b>Er</b>	mg/kg TS	177
<b>Tm</b>	mg/kg TS	21.7
<b>Yb</b>	mg/kg TS	116
<b>Lu</b>	mg/kg TS	17.4

*\*TS=Dry substance*

*\*\*GF=Loss on ignition (LOI)*

Table 1: Results from an externally made analysis (ALS Scandinavia) of the black substance leaching from cracks in the mine corridors.

## **6.2 HISTORY OF THE YTTERBY MINE**

*This part of the results is based on informal interviews and literature review and it will be divided into three sections:*

- i) Ytterby – a quartz and feldspar mine*
- ii) Ytterby – REEs*
- iii) Ytterby – a fuel deposit during the cold war era.*

*Each section starts with a historical overview and ends with information regarding health issues that potentially could be associated with that part of the mine's history.*

### **6.2.1 A QUARTZ AND FELDSPAR MINE**

The Ytterby mine is located on Resarö Island in the Stockholm archipelago. The mine appears to date back to the 1750s when it was first used for mining quartz. This quartz is thought to have been used in the ironworks in the northern part of Uppland and by glassworks in the Stockholm area (Löf, 1981). Some documents even suggest that the mining of quartz began in the 17<sup>th</sup> century. As time went by and the knowledge of how to manufacture both flint and feldspar porcelain became more widespread in Europe, the demand for feldspar increased and one of the porcelain factories near the mine, Gustafsbergs, took over the running. The mining of feldspar is then thought to have started somewhere around the 1790s and then became the major mineral to be quarried there (Nordenskjöld, 1904). In the 1850s another porcelain manufacturer, Rörstrand, took over the ownership and kept it until 1926. In 1933 the mine was closed down (Löf, 1981).

At the end of the 1890s the depth of the mine was brought down to approximately 171 m (Nordenskjöld, 1904). Since the elevation of the quarry is approximately 31 m, a depth of 171 m corresponds to an elevation of -140 m.

The pegmatite in Ytterby is an inclined ore body and the mine follows the ore (Fig. 52) (Nordenskjöld, 1904).

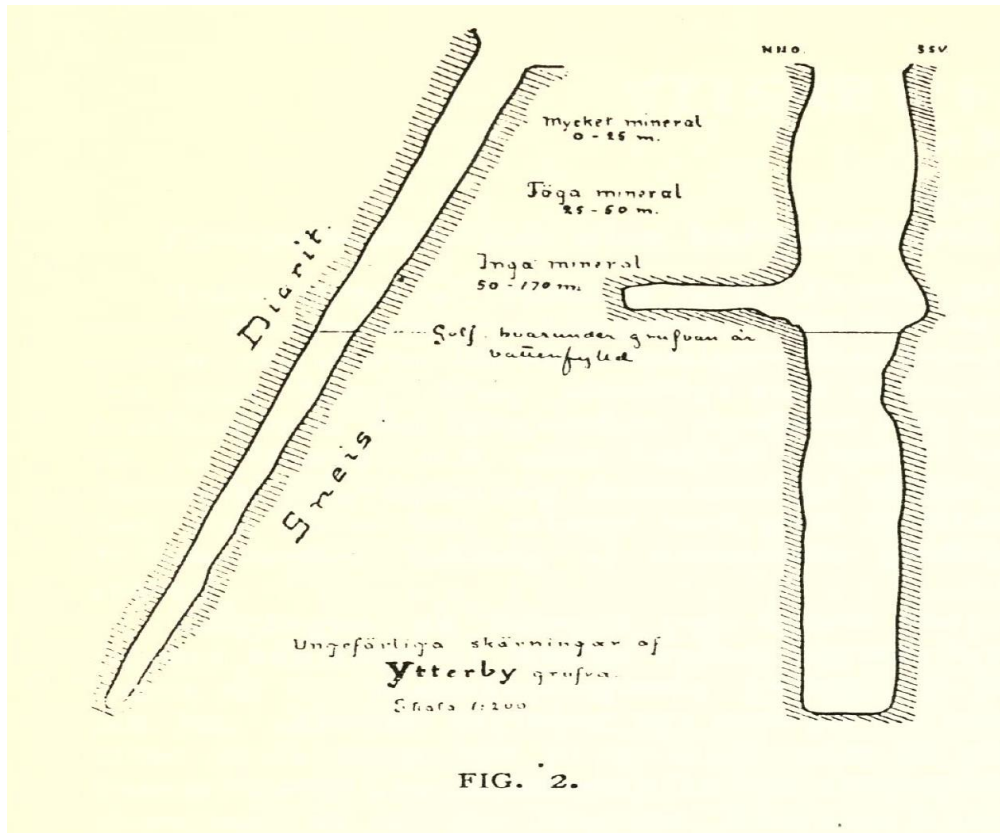


Figure 52: The pegmatite in Ytterby is an inclined ore body and the mine follows the ore. From Nordenskjöld (1904).

The mine is 10 m wide at the ground surface but narrows continuously with depth (Nordenskjöld, 1904). The N-S propagation is approximately 20 m at the ground surface, 50-70 m in the middle and reduces down to approximately 18 m at an elevation of -80. At elevation around -30 m there is a drift system extending about 25 m north relative to the main shaft, height app, 15 m. Below elevation -35, there are indications of another drift system, but this is not confirmed (J&W Energi och Miljö, Kemakta Konsult AB, 2001).

### 6.2.1.1 POTENTIAL LINKS TO HEALTH

A review of the literature regarding health issues associated with quartz and feldspar mining shows that the primary concern is silicosis. Silicosis which is a fibrotic lung disease caused by inhalation of free crystalline silicon dioxide or silica is a problem all over the world (Leung et al., 2012). In Ytterby, silicosis might well have been a health issue at the time for quarrying quartz and feldspar, both silica-rich minerals, but as of today the quarry is abandoned and this risk should not exist anymore. Therefore I will not go any further into this subject in this study.

## 6.2.2 RARE EARTH ELEMENT LOCALITY

Historical records tell that Carl Arrenhius, captain in the Swedish Armed Forces and an amateur geologist, in 1788 discovered an unusually heavy black stone in the quarry. He sent a sample for analysis to Johan Gadolin, a chemist from Åbo, Finland. In 1794 Gadolin concluded that the rock contained a completely new element which was later named yttrium (Y). The black mineral was named gadolinite after its discoverer. In this new mineral another six rare earth elements were found: ytterbium (Yb), erbium (Er) and terbium (Tb), holmium (Ho), scandium (Sc), thulium (Tm) (Enghag, 1999). Also, the mine has contributed to the discovery of tantalum (Ta) and niobium (Nb), elements found as part of a mineral that has become known as yttrotantalite (Nordenskjöld, 1904).

According to U.S. Geological Survey (USGS), REEs are a set of 17 chemical elements in the periodic table; the 15 lanthanides with atomic number 57 through 71 plus scandium with atomic number 21 and yttrium with atomic number 39. Scandium and yttrium are considered REEs since they tend to occur in the same ore deposits as the lanthanides and exhibit similar chemical properties (USGS web-site, 2012). The lanthanides include the following 15 elements in order of atomic number; lanthanum (La), cerium (Ce), praseodymium (Pr), neodymium (Nd), promethium (Pm), samarium (Sm), europium (Eu), gadolinium (Gd), terbium (Tb), dysprosium (Dy), holmium (Ho), erbium (Er), thulium (Tm), ytterbium (Yb) and lutetium (Lu).

The lanthanides are usually divided into two sub-groups; light rare earth elements (LREEs) which comprise lanthanum to europium and heavy rare earth elements (HREEs) which comprise gadolinium to lutetium. Both yttrium and scandium are considered HREEs. As described in section 1.1, the Ytterby pegmatite belongs to the NYF-family which means that it is enriched in HREEs.

As separate metals the REEs are steel-grey to silvery in colour and they are soft and formable. Their electron structure results in unusual magnetic and optical characteristics. However, REEs do not occur in nature as metallic elements but are rather incorporated into various mineral groups (SGU, 2011). Chemical similarities of the REEs such as ionic radius and oxidation number make it possible for these elements to substitute for each other in crystal structures. This is the reason why there often are many different REEs in one separate mineral (SGU, 2011). Examples of minerals containing rare earth elements in Ytterby are anderbergite, arrhenite, fergusonite, gadolinite, ortite, yttrotantalite and xenotime (Nordenskjöld, 1910). The following rare earth elements occur in various concentrations in these and possibly other minerals in Ytterby: scandium (Sc), yttrium (Y), lanthanum (La), ytterbium (Yb), erbium (Er) and terbium (Tb), holmium (Ho), thulium (Tm), Samarium (Sm), and gadolinium (Gd), (Nordenskjöld, 1904; Nordenskjöld, 1910).

Sundius (1948) suggests that the rare earth minerals in Ytterby formed in association with the crystallization of the pegmatite magma, i.e. during the partitioning of water solutions from the pegmatite magma at the time for crystallization. According to Almström (1925), the majority of the minerals containing rare earth elements were found close to the ground surface in the ESE-ern corner of the quarry, i.e. close to the gneiss in the pegmatite footwall.

These minerals also contain radioactive elements such as uranium and thorium in varying concentrations (Nordenskjöld, 1910) and as seen in fig. 6, zones of high radioactivity are identified in the pegmatite and at some places in the piles of waste rock.

In 1989, ASM, American Society of Metals, appointed the Ytterby mine a Historical Landmark. This is an appointment for sites and events that have played an important role in the discovery, development and growth of metals and metalworking. Ytterby was the sixth site in Europe to receive this appointment (Enghag, 1999).

### 6.2.2.1 POTENTIAL LINKS TO HEALTH

I interpret the identified zones of high ionizing radiation as zones that also contain rare minerals and consequently rare earth elements. This interpretation is based on the fact that rare earth elements occur in minerals that often also contain elements such as uranium and thorium. Thus, in this section I will look at health issues associated with not only REEs but also with ionizing radiation.

Very few studies of REEs and health have been found, particularly research concerning the long-term effects of exposure through ingestion. Existing studies are mainly provided by Chinese scientists. This makes sense since China is the world leading producer of rare earth elements (SGU, 2011). Some of these studies are available in English but many of these interesting papers are written in Chinese and are therefore not accessible to me. In this section I will give a brief summary of what I have found.

According to Boer (1996), who conducted experiments on rats, the REEs are assumed to be equivalent in toxicological behaviour due to their physical and chemical similarity. Hirano and Suzuki (1996) and Haley (1991) stated on the other hand that the toxicity of lanthanides decreases as the atomic number increases. They further concluded that this was probably due to an increased solubility and ionic stability of the heavier lanthanides. Moreover, Hirano and Suzuki (1996) showed that intake of ionic REEs through drinking water were absorbed by the intestines of the rats and deposited in the skeleton, teeth and soft tissues such as the lung, liver and kidney. Two studies reported that administration of yttrium to rats was associated with significantly retarded growth (Schroeder and Mitchener, 1971; Boer et al., 1996). The same studies also reported that feeding of scandium to rats was associated with growth suppression, but less so relative to yttrium. Schroeder and Mitchener (1996) also suggested that yttrium has carcinogenic properties.

A study conducted among villagers in a REE-enriched area in Jiangxi, China, reported that REEs do not easily accumulate in the brain stem but rather in the cerebral cortex, i.e. the outer layer of the brain (Zhu et al., 1997). Thus, the cerebral cortex is more susceptible than the brain stem to damage caused by REEs. This study further suggested that ingestion of small doses of REEs might not be unimportant and that the long-term effect should be investigated (Zhu et al., 1997). Zhu et al. (1997) also refer to another study (Zhou et al., 1992) that reported that an increase in intake of REEs (6.67 mg/day compared to a control group intake of 3.3 mg/day) was associated with a decrease in intelligence quotient and a reduction of sensory conduction of the central nervous system. According to Zhu et al. (1997) an “increase in REE intake could make the activity of cholinesterase in the hippocampus remarkably decreased, and the brain cell apparently dissociated”. Zhu et al. also report that long-term intake of REE in low doses may be comparable to the doses found in the REE area.

Another Chinese study (Feng et al., 2006) on rats reported that chronic exposure to lanthanum could result in adverse effects on the learning ability. This adverse effect on the learning

ability could in turn be due to perturbations of trace elemental distributions, enzymes and neurotransmitter systems in the brain.

#### *Ionizing radiation*

Chemical analyses of minerals found in Ytterby show that many of them contain long-lived radioactive elements such as uranium, thorium and cesium (Nordenskjöld, 1908). Axelsson et al. (2001) suggest that ionizing radiation could be a contributing factor to MS in certain cases and according to a study conducted by the Geological Survey in Norway (Bölviken, 2001), statistical analyses show that high rates of MS are associated with high levels of radon (Rn) in indoor air. Based on these observations they further suggest that high concentrations of radioactive elements in soil or air could be a risk factor for MS.

Due to the high ionizing radiation adjacent to the mine, health authorities in Vaxholm district turned to The National Institute of Environmental Medicine (Statens Miljömedicinska Laboratorium) to take part in an investigation to see if there was any radioactivity in the groundwater close to the mine. Water samples were taken from three deep drilled private wells, between 80 and 110 m deep, located close to the mine. The samples were analysed by the Swedish Radiation Protection Institute and they concluded that the radioactivity content in all three samples was normal (Hälsöförskottet, 1980).

### **6.2.3 A FUEL DEPOSIT FOR THE SWEDISH ARMED FORCES DURING THE COLD WAR ERA**

During the cold war era the Ytterby mine, just like many other mines in Sweden, was used as a fuel deposit for the Swedish Armed Forces. Three different petroleum products have been stored in the mine-shaft over a period that totals about 35-40 years (Lindgren & Lundmark, 2012; J&W Energi och Miljö, Kemakta Konsult AB, 2001).

1950: s -1978	<b>MC-77, aircraft fuel</b>	Swedish Armed Forces
1980-1983	Diesel fuel (unknown type)	Swedish Petroleum AB rented the mine
1985-1995	<b>Diesel fuel 50</b>	Swedish Armed Forces (vehicles)
	<b>Diesel fuel 60</b>	Swedish Armed Forces (ships)

The reconstruction of the mine into a fuel deposit involved blasting away rock to give room for 500-600 m tunnels linking the old mine with a newly constructed quay to the NE of the quarry. The mine opening was sealed with a concrete vault which was covered with ca. 15 m boulders left from the blasting. These boulders were then covered with a blast protective mantle (J&W Energi och Miljö, Kemakta Konsult AB, 2001).

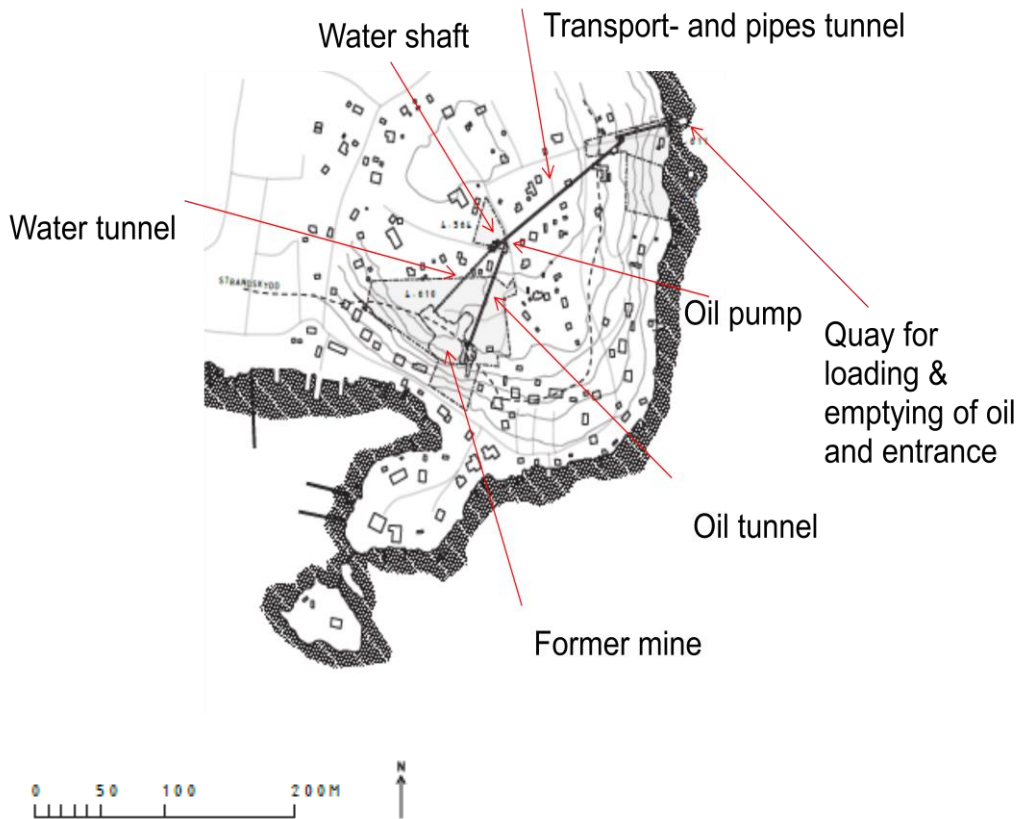


Figure 53: Base map of integrated underground structures. As the mine is inclined towards the NW, the bold continuous line (former mine) describes the propagation of the mine projected on ground level. Modified after Fortifikationsverket (2012).

- 4:610 – Quarry
- 4:564 – Former emergency exit
- 4:611 – Quay & entrance to the underground space
- 4:9 – Part of the quay & a minor quarry

The petroleum products have been stored directly against the rock wall in the mine shaft. The shaft is situated below the natural groundwater level, meaning that groundwater is continuously running into the shaft and by that prevents the oil from spreading into the rock. The oil which is less dense than water floats on top of the water surface, i.e. the inflow of groundwater. In case of flexible waterbed, as in Ytterby, the height of the water surface is adjusted with pumps at loading and emptying. This is to make sure that the oil surface is always kept at a constant distance from the rock roof to minimize the risk of departing volatile hydrocarbons. This gas could otherwise constitute a risk for explosion. All water, except for that needed for this waterbed, is pumped out of the shaft where it passes by an oil- divider and out to the Baltic Sea (Lindgren & Lundmark, 2012).

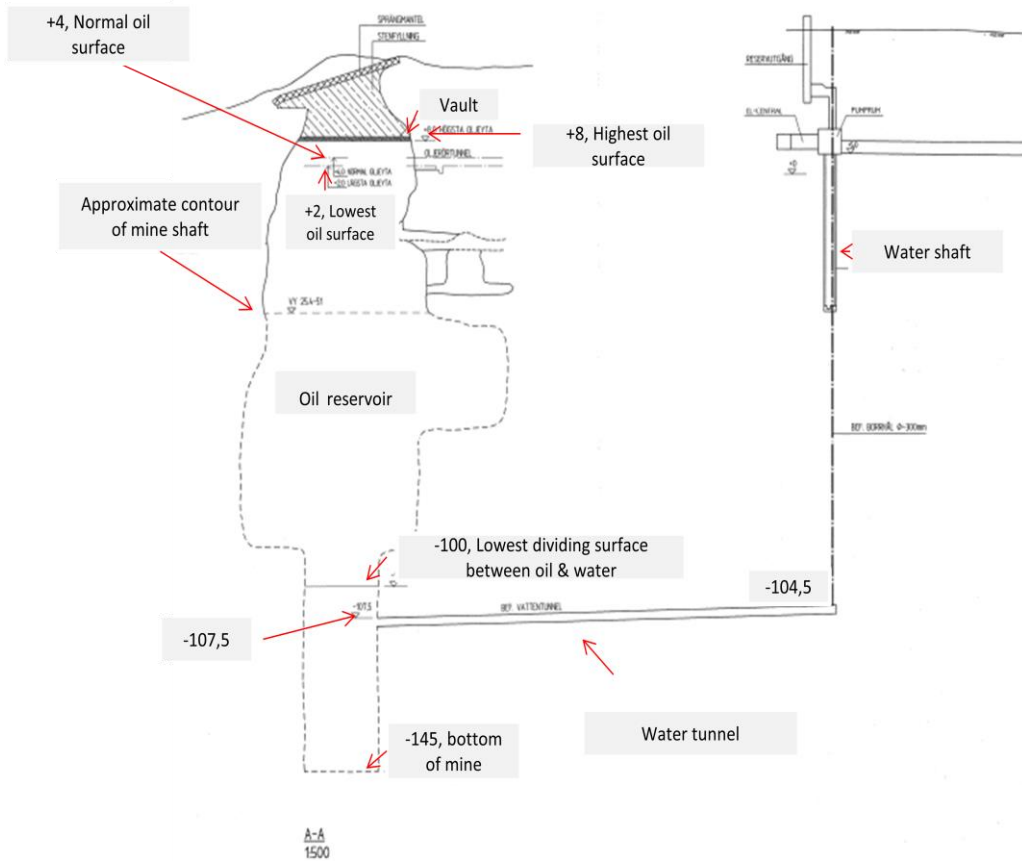


Figure 54: Oil reservoir & water shaft at the Ytterby mine. Modified after Fortifikationsverket (1958).

The lowest dividing surface between oil and water was at -100 m, i.e. 100 m below the sea level, and the highest +8m (Fig.54). Thus the petroleum products have been in contact with approximately the top 100m of the mine.

The storage capacity of the mine was 50, 000 m<sup>3</sup> fuel, i.e. 50, 000, 000 l (Lindgren & Lundmark, 2012). To visualize the enormous quantity of oil stored, this can be translated to approximately 1, 250 tankers including trailers.



Figure 55: Tanker in Ytterby. Lundmark

It was known that this type of fuel storage, i.e. directly against the rock wall, affects the local environment in various ways. Nevertheless, the supply of petroleum products was considered more important for the national society than the potential environmental consequences it could result in. Environmental awareness was not well developed in the beginning of the 1950s and storage areas were chosen in order to minimize oil leakage to the environment, probably mainly for economic purposes. (Lundmark, 2001).

### 6.2.3.1 POTENTIAL LINKS TO HEALTH

*As mentioned above, three different petroleum products have been stored in the mine-shaft over a period of 35-40 years. In the next section I will go through them one at a time, looking at contents and specific qualities. At the end I will briefly present data from previous investigations regarding groundwater contamination in the mine area.*

#### *MC-77*

MC-77 is an aircraft fuel for jet-planes and helicopters. It is also called REA-77 and is the same product as Jet B (international name). This fuel was introduced in the Swedish Armed Forces in 1956 (Försvarets Sjukvårdsstyrelse, 1977).

*MC-77 (also called REA-77 and Jet-B)*

<b>Product specification - MC-77 (REA-77)</b>
Försvarets Sjukvårdsstyrelse (1977), FMV (1988)
In the product specification below is only included information relevant to this study.
Flammable liquid class 1 – Dangerous goods, Health hazardous
<i>Content aromatic hydrocarbons (benzene hydrocarbons): max 25 vol% (usually 15-20 vol%)</i>
Out of which Benzene: max 1 vol% (usually 0.2 vol%)
Out of which Toluene: usually 0.2 vol%
Out of which Xylene: usually 1.0 vol%
<i>Content other hydrocarbons (alkanes, alkenes and cycloalkanes): min 75 vol%*</i>
Alkanes: max 5 vol%
Sulphur content: max 0.40 vol%
<i>Additives:</i>
Oxidation protection: (2,4-dimethyl-6-tertiary-butylfenol): app. 13 mg/l
Corrosion inhibitors (lubricant): (Santolene C) (Linoleic acid and phosphoric acid ester – Hitec E-515): app. 12 ppm
<i>Health risks</i>
The product emits fumes hazardous to health. Exposure to the fumes can result in headaches, fatigue and nausea. If exposed to high volumes of fumes memory functions and reaction times can deteriorate and may result in unconsciousness. Long term repeated contact may result in permanent damages to the nervous system. The product irritates eyes and mucous membranes. Splashes in the eyes are very painful. Exposure to the skin results in degreasing which may result in chaps and eczema. Contains substances that can be absorbed through the skin giving similar effects as when fumes are inhaled.

\* n-hexane, i.e. the unbranched isomer of hexane, constitutes approximately 1 vol % (Ritchie, 2010).

Table 2: Product specification MC-77. Modified after Försvarets Materielverk (1988).

This unleaded aircraft fuel is a mixture of aliphatic and aromatic hydrocarbons. The relative amount of these might differ in different batches of fuel depending on the petroleum source, holding a maximum content of aromatic hydrocarbons of 25 vol%. The uptake of aliphatic

hydrocarbons in humans is generally less than for aromatics (Ritchie et al., 2001). In the next section the contents of MC-77 and their possible implication in health issues will be reviewed.

This petroleum product belongs to the light nonaqueous-phase liquids (LNAPLs) meaning hydrocarbons with low solubility in water and less density than water. These characteristics make the compounds float on the groundwater table which in turn means that they can spread quickly over a wide area and cause significant environmental problems (Nelson Eby, 2004). However, within this group of hydrocarbons there are a few monoaromatic compounds called BTEX (benzene, toluene, ethyl-benzene and xylene). These compounds have enhanced water solubility in freshwater and are therefore very mobile in groundwater. Benzene and toluene have the highest relative solubility in freshwater within the BTEX group and can therefore contaminate the groundwater and pose significant health hazards (Nelson Eby, 2004).

There are many studies reporting the acute and long-term neurobehavioural, i.e. relationship between the nervous system and behaviour, effects of occupational exposure to neurotoxic constituents of jet fuels, i.e. benzene, toluene, xylenes, n-hexane etc. (Ritchie, 2010 and references therein). It is also shown that neurobehavioural and neurohistopathological effects identified in people exposed acutely or chronically to jet fuels could be related to exposure to hydrocarbon constituents (generally C6 to C10 and particularly aromatic hydrocarbons) (Ritchie et al., 2001, 2003; Ritchie, 2010).

#### *Benzene*

Benzene is a known carcinogenic and hematotoxic agent (Kirkeleit et al., 2006). Benzene administered to animals by ingestion or inhalation is reported to be carcinogenic (WHO, 2011). The WHO's guidelines for drinking water (2011) states that acute exposure to benzene in high concentrations affects the central nervous system. The guideline value, i.e. maximum recommended concentration, for benzene in drinking water is 10µg/l (WHO, 2011).

#### *Toluene*

It has been observed that frequent and continuous inhalation of toluene has caused impairment of the central nervous system and irritation of mucous membranes (WHO, 2011). The guideline value for toluene in drinking water, i.e. of health significance is 700µg/l (WHO, 2011).

#### *Xylene*

Xylene vapour is quickly absorbed by the lungs and xylene vapour and liquid is slowly absorbed through the skin (Langman, 1994). It is shown that this type of exposure to xylene effect many organ systems, the central nervous system being one of them (Langman, 1994). Data on the effects of xylene through oral intake appear to be less frequent, but according to WHO's guidelines for drinking water, the acute oral toxicity of xylene is low. The guideline value in drinking water is 500µg/l (WHO, 2011).

#### *n-hexane*

According to the US Agency for Toxic Substances and Disease Registry (ATSDR) (1999) the most likely exposure to n-hexane is by breathing in contaminated air. A less likely means of exposure is through contaminated drinking water in private wells. Damages to the nervous system are observed both in experiments with rats and in studies of humans occupationally exposed to n-hexane in the air. Studies on rats have further shown that it is a breakdown product of n-hexane, i.e. 2,5 hexanedione, which causes nerve damage, not n-hexane itself. Studies on rats also showed that nerve damage such as a decrease in motor nerve conduction

velocities is caused by large doses of ingested n-hexane (ATSD, 1999). Ritchie et al. (2001) report that chronic exposure to n-hexane and/or to its major metabolites may lead to significant perturbations in the sensory system, the central integrative processes and the motor components of the nervous systems (Ritchie et al. 2001 for complete list of references).

The product description for MC-77 states that the content of benzene is max 1% (usually 0.2%), toluene usually 0.2% and xylene usually 1%. Even though these figures might seem negligible, it is worth remembering that the storage capacity of the Ytterby mine was about 50,000 m<sup>3</sup>, i.e. 50,000,000 l. Calculating the amount of benzene and toluene together at their usual quantities, 0.2% + 0.2%, it gives a total volume of 200,000 l of these toxic compounds that are relatively soluble in fresh water. Translating this to tankers with trailers 200,000 l would correspond to 5 tankers with trailers. In a less conservative estimate, for instance including xylene, n-hexane and a max volume of % of benzene, figures would increase eightfold.

In 1977, an investigation (Försvarets sjukvårdsstyrelse, 1977) made by The Medical Board of the Swedish Armed Forces was made to evaluate possible correlations between health issues and exposure to MC-77, i.e. the aircraft fuel formerly stored in the Ytterby mine. This investigation involved 4000 employees in the Swedish Armed Forces who had handled the aircraft fuel MC-77. The aim of the medical examinations was to elucidate whether MC-77 had any effect on brain functions, the central and peripheral nervous system, blood-forming organs as well as liver and kidney functions. The examined employees were divided into two groups; high exposure to MC-77 and low exposure to MC-77. They were further sub-divided into two age dependent groups, younger than 50 years and older than 50 years. The neurological examination showed an overrepresentation of subjective problems from functional areas of cranial nerves among the individuals in the high exposure group. The problems consisted primarily of headache and dizziness. This group also had a higher frequency of disabling in the peripheral nervous system (PNS) in the form of reduced vibration sense and reduced perception of touch in their feet. The investigation characterized these symptoms as mild and concluded that they did not give rise to disabilities of practical importance. It was further reported that this type of mild disability is common among older people and was therefore handled as normal ageing rather than a negative change in health status. However, age does not explain the reported reduced vibration sense. The conclusion of this investigation was that exposition for MC-77 alone could not evoke severe health conditions among the employees in the Swedish Armed Forces but it also stated that it could not be excluded that the course of other diseases in the nervous system could deteriorate as a consequence of exposure to MC-77 (Försvarets Sjukvårdsstyrelse, 1977).

In 1977-78 it was discovered that hydrogen sulphide producing microorganisms had developed at the contact surface between the jet fuel and the water surface (Lundmark, 2001). This hydrogen sulphide affected silver-plated surfaces in the aircraft fuel pumps resulting in airplane crashes (Lundmark, 2001). Therefore MC-77 was removed in 1978 and the mine was from thereon used for storage of diesel (Lundmark, 2001).

## Diesel

<b>Product specification - Diesel 50 (vehicles)</b>
FMV (1980)
Flammable liquid class 2b or 3
Fuels composed of petroleum fractions with distillation limits of app. 170-360 °C
Flash point 40-60°C
Sulphur content: max 0.30 vol%

Table 3: Product specification – Diesel 50. Modified after Försvarets Materielverk (1980).

<b>Product specification - Diesel 60 (ships)</b>
FMV (1995)
Fuels composed of petroleum fractions with distillation limits of app. 170-370 °C
Compliance with demands for diesel quality class D (summer quality – possible to filter in -10°C) or class 2 (winter quality, possible to filter in -32°C)

Table 4: Product specification – Diesel 50. Modified after Försvarets Materielverk (1995).

Diesel fuel 50 was used in vehicles and diesel fuel 60 in ships. Diesel fuel 60 has a higher flashpoint than diesel fuel 50 (Lindgren, 2012). A study made on rats by Gerlofs-Nijland et al. (2010), concludes that there is a link between diesel engine exhaust (DEE) and neuroinflammation and that different parts of the brain appear to be uniquely responsive to changes induced by exposure to DEE. However, as this study refers to diesel fuel which has undergone combustion in vehicle engines it is not comparable to the effects it might have when ingested.

The findings of a recent study (Riise, 2011) of offshore workers in the Norwegian petroleum industry, i.e. workers exposed to hydrocarbons and a number of associated chemicals, concluded that there was no increased risk of MS among the workers compared to the general working population in Norway. However, the same study refers to other scientific reports that support an association between MS and organic solvents (Riise, 2011 and references therein).

In 1995 the storage of petroleum products in the Ytterby mine was brought to an end and the diesel was removed. From 1999, the mine is managed by The Swedish Fortifications Agency (Fortifikationsverket). In the year 2000 the remaining 500 m<sup>3</sup> of petroleum product was pumped out (Lindgren & Lundmark, 2012; J&W Energi och Miljö, Kemakta Konsult AB, 2001).

In 2001, an Environmental Impact Assessment (EIA) was made (J&W Energi och Miljö, Kemakta Konsult AB, 2001). This study described the current status in and around the mine and made an assessment of potential environmental consequences in connection with decommissioning of the fuel deposit. The investigation evaluated two different alternatives for after-treatment: base case and hydraulic drainage. Base case meant that the pumping of leak-water from the mine-shaft would stop, all drifts would be sealed and the water level in the mine left to reach normal groundwater levels. Hydraulic drainage meant that the water level inside the mine would be kept below the normal groundwater level. This would be done to prevent the shaft from being gradually filled with water and thereby, when water-level equaled the groundwater level, the water would stop coming into the shaft and instead start running through it. If this were to happen it could lead to contamination of the groundwater which runs through the shaft. The latter alternative would imply a permanent solution where the incoming groundwater would be drained off through a pipe to the Baltic Sea. The final

recommendation of the investigation was hydraulic drainage (J&W Energi och Miljö, Kemakta Konsult AB, 2001).

However, a third alternative was chosen for clearing the mine from oil. This alternative is a manual variant of hydraulic drainage and is still in progress. The daily inflow of groundwater is estimated to be  $10\text{m}^3$  and the corresponding volume is drained off through an existing pipe to the recipient, i.e. Trälhavet (Lindgren & Lundmark, 2012).

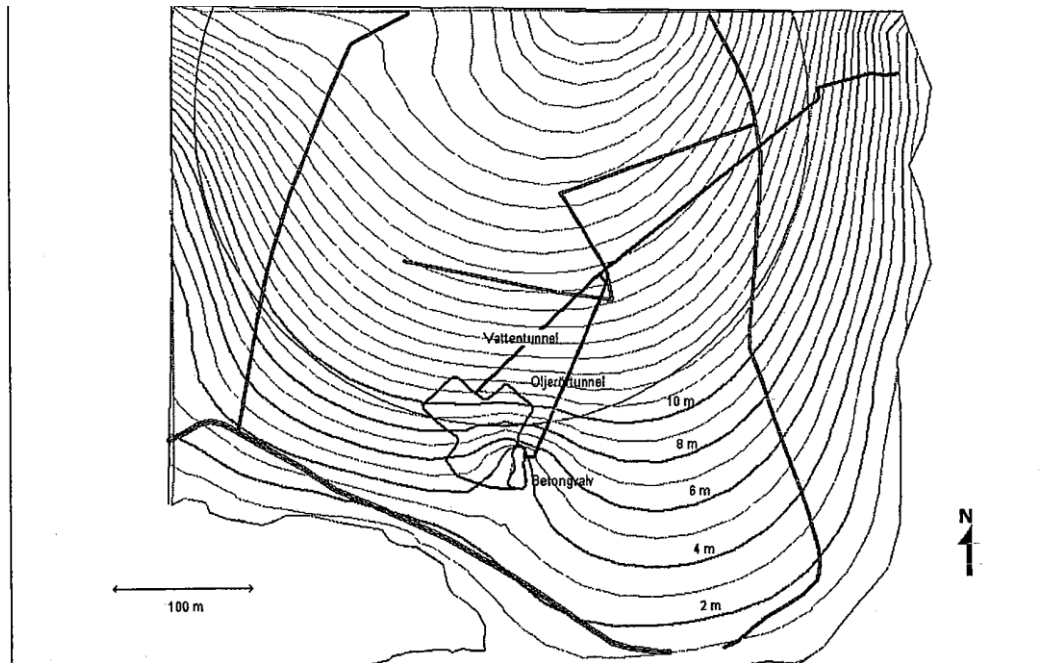


Figure 56: Groundwater levels in 2001. Ekvidistance 1 m. As the mine is inclined towards the NW, the bold continuous line (former mine) describes the propagation of the mine projected on ground level. From J&W Energi och Miljö, Kemakta Konsult AB (2001).

This model is made by J&W Energi och Miljö and Kemakta Konsult AB (2001) and the following assumptions regarding groundwater in the Ytterby area as of year 2001 are made:

- groundwater level in the mine is +3 m
- groundwater level at the coast line is  $\pm 0$
- groundwater level follows topography to the north and west
- groundwater level is located a few meters below ground surface.

The groundwater levels in and around the mine shaft (Fig. 56) correspond to artificial levels. In this area the groundwater level is lowered below its natural level and these artificial levels have been kept constant since the mine became a fuel deposit up to the present. The influence on the groundwater levels is seen as curved lines around the mine shaft.

The risk of oil spreading from the mine increases when the surrounding water pressure, i.e. the groundwater level, is equal to or below the water pressure in the shaft. The pressure level around the Ytterby mine is increasing in all directions except to the south (Fig. 56). This implies that the risk of groundwater contamination is higher to the south of the mine relative to the other directions.

During this investigation, four drill holes for groundwater observations were made around the deposit and one into the actual mine-shaft where the petroleum products were stored. Locations for each of these drill holes are marked on the map below. GV 0105 is the hole that was drilled into the mine shaft. The groundwater levels were as follows:

Observation hole	GW0101	GW0102	GW0103	GW0104
Ground water level (m)	15	26.4	6.4	2.4

Table 5: Groundwater level (m) in observation holes.

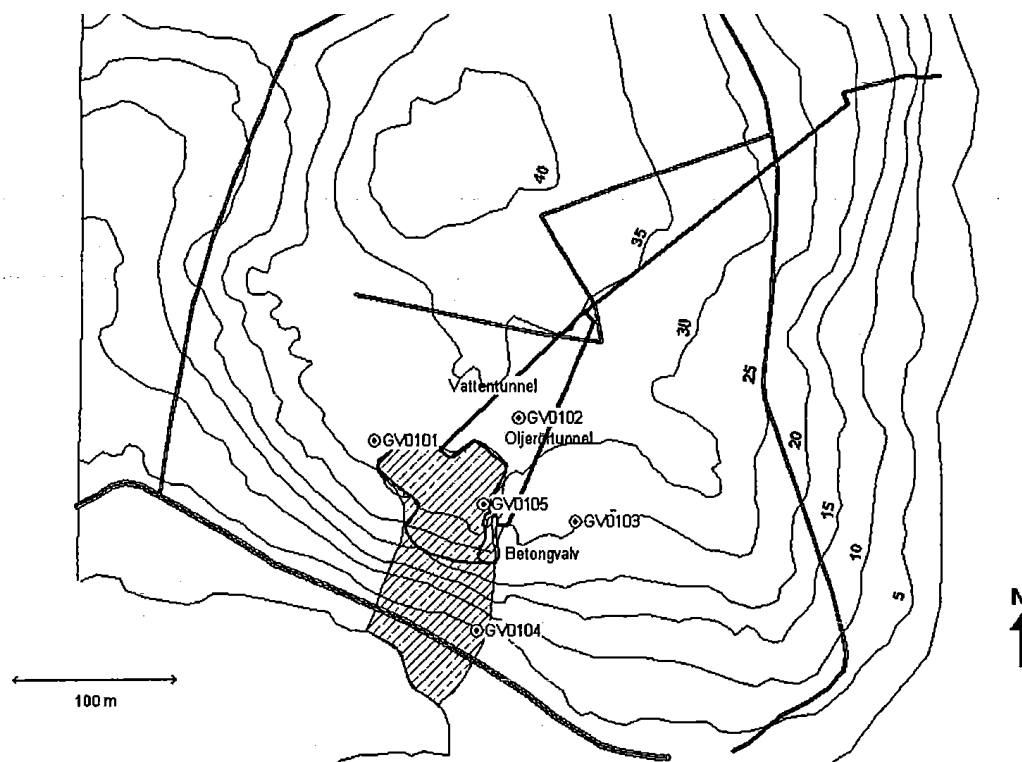


Figure 57: Base map showing bored groundwater observation holes, topography and spreading of groundwater contamination in 2001, Environmental impact Assessment (EIA). From J&W Energi och Miljö, Kemakta Konsult AB (2001)

During these observations it was concluded that there was 200 m<sup>3</sup> of petroleum products left on the water surface in the mine-shaft and that the groundwater south of the shaft, i.e. GW0104, was contaminated by the stored petroleum products. The groundwater level in this drill hole is lower than normal surface level of the petroleum products during storage (+3) (J&W Energi och Miljö, Kemakta Konsult AB, 2001). These are the results for GW0104:

- *aliphatic fractions >C12-C16*: 130 µg (occurs in diesel and recommended limits for drinking water is 100 µg/l and for irrigation 1000 µg/l) (ALS web-site, 2012).
- *aromatic fractions >C10-C35*: 52 µg, (occurs in heavier petroleum products and recommended limits for drinking water is 2-10 µg/l and for irrigation 70-100 µg/l).
- *PAH (Polynuclear Aromatic Hydrocarbons) others*: 2.9 µg
- *lead inorganic*: 2.4 µg.

## 6.3 INORGANIC & ORGANIC HYDROCHEMICAL DATA

*In this section I will present the results from analyses made on water samples collected in the Ytterby village. Only data that appear to be relevant from a health perspective are presented. For more extended data the reader should consult the sample data in appendix 2.*

### 6.3.1 INORGANIC HYDROCHEMICAL DATA

Our natural environment can affect human health in many ways and one of them is through the influence of rocks and soils on drinking water. Rocks are made up of naturally occurring chemical elements that can be transferred into the groundwater and an excess or lack of certain elements can have adverse effects on human health.

As part of the European Union (EU), Sweden has stipulated limits for drinking water quality. These limits are incorporated in the National Food Administration's Directions (Livsmedelsverkets Föreskrifter) (SLVFS 2001:30, reprint LIVSFS 2011:3). These directions are however not applicable to private wells which instead are covered by The Board of Health and Welfare's general guidelines (Socialstyrelsens allmänna råd) (SOSFS 2003:17, Försiktighetsmått för dricksvatten). Consequently it is these recommended limits that I have used as guidance for analysing the Ytterby water samples from a health perspective. Where no limits have been stated by The National Board of Health and Welfare nor by the National Food Administration, I have consulted the guidelines for drinking-water quality issued by the World Health Organization (WHO, 2008).

Few studies are made regarding the effects of long-term exposure through ingestion of REEs (Section 6.2.2.1). Thus, for these elements there are no standard recommended limits. However, I have found some literature suggesting indicative admissible concentrations for rare earth elements which are used here (See Boer et al. 1996 for complete list of references).

Water samples in this study are taken from 15 private wells and 2 ditches (sample 15 & 22). The majority of the wells are currently used for irrigation only and two of them are not in use at all. Three of these wells are still used for drinking water and at least another 5 of them have been used as a drinking water source for more than 30 out of the last 50 years. All samples are screened for 55 elements in the periodic table (Section 5.4.1). There will be a brief overview of those elements where at least one of the well samples, i.e. not samples from ditches, the quarry or inside the mine, shows concentrations above recommended limits for drinking water or any other observed anomaly. For all sample locations there are as previously described two sets of data (the second set of data is designated by a B after the sample name). These sets of data do not entirely show the same results. Whether this is due to normal groundwater variations or to difficulties in measuring these types of elements is hard to interpret. There are also a few elements out of the 55 that I didn't screen for in the first run.

All samples in this study have near neutral or slightly alkaline pH (6.97-8.24). Electrical conductivity in the range of 0.19 – 1.75 mS/cm varies somewhat between the samples. The highest value was observed in a well located very close to the sea.

### Lead

1 out of 15 samples show concentrations just above the recommended limits of 10 µg/l for drinking water.

Sample	Sample concentration
12- YB-07	10.49 µg/l

Table 6: Result of analysis, lead.



Figure 58: Blue markings represent locations where lead (Pb) concentrations were above 10 µg.

According to WHO (2011), exposure to lead is associated with a wide range of health effects including neurodevelopmental effects. Infants and children are considered the most sensitive group. It is also concluded that most lead in drinking water comes from plumbing and other fittings that contain lead (WHO, 2011).

### Sodium

The taste threshold for sodium is 200 000 µg/l (SOSFS 2003:17). According to WHO (2011), there is no health-based recommendation limit since the contribution of sodium through drinking water is low. Only one of the samples shows a sodium concentration above 200 000 µg/l. However, the concentrations ingested from water are very small compared to other intake with food (SOSFS 2003:17).

Sample	Sample concentration
12-YB-18	244 300 µg/l

Table 7: Result of analysis, sodium.



Figure 59: Blue markings represent locations where sodium (Na) concentrations were above 200 000 µg.

### Sulphur

Samples show very high concentrations of sulphur. The ICP measures the total amount of sulphur in the samples so it is not possible to say in which form it occurs in the water. However, the stable form of sulphur is sulphate which is the most likely form to be in the samples. High levels of sulphate are commonly due to a sulphide rich geologic environment or an indication that low pH surface water could have affected the well (SOSFS 2003:17) The well samples range in concentrations from 151 300 to 2 333000 µg/l. According to WHO, there is no identified level of sulphate in drinking water that could cause health issues. However, since sulphate concentrations above 500 000 µg/l could have a laxative effect health authorities should be notified (the same figure is 200 000 µg/l according to SOSFS 2003:17). Infants and children are also believed to be more affected by high concentrations of sulphate and thus be more susceptible for getting diarrhoea (Calderon, 2000). If sulphur is present in the water as hydrogen sulphide the most obvious effect is a rotten-egg-smell.

Sample	µg/l S conc.	Sample	µg/l S conc.
12-YB-03B	408800	12-YB-12B	445500
12-YB-04B	1142000	12-YB-13B	362400
12-YB-05B	573900	12-YB-14B	1213000
12-YB-06B	909000	12-YB-15B	1178000
12-YB-07B	636300	12-YB-16B	1966000
12-YB-08B	997100	12-YB-17B	151300
12-YB-09B	650800	12-YB-18B	2333000
12-YB-10B	1023000	12-YB-22B	853900
12-YB11B	1124000		

Table 8: Results of analyses, sulphur.



Figure 60: Blue markings represent locations where sulphur (S) concentrations were above 200 000 µg.

### Uranium

Only chemical aspects of uranium are addressed in this section. The recommended limit for drinking water by the National Board of Health (SOSFS 2003:17, Försiktighetsmått för dricksvatten) is 15µg/l. WHO's recommendation is 15-30 µg/l. The uranium concentrations varied somewhat in my two runs of water samples. In the first run 7 out of 15 samples show concentrations above 15 µg/l and 3 of these above 30 µg/l (marked orange in the table below). In the second run none of the samples were above 15 µg/l, but it is still the same samples that show concentrations above DL. Due to the very small concentrations dealt with here, this variance is probably due to groundwater fluctuations.

Sample	U conc.	Sample	U conc.
12-YB-03	6.606	12-YB-12	6.381
12-YB-03B	<DL	12-YB-12B	<DL
12-YB-04	17.95	12-YB-13	<DL
12-YB-04B	5.768	12-YB-13B	<DL
12-YB-05	31.65	12-YB-14	5.276
12-YB-05B	8.166	12-YB-14B	<DL
12-YB-06	22.99	12-YB-15	<DL
12-YB-06B	<DL	12-YB-15B	<DL
12-YB-07	18.75	12-YB-16	<DL
12-YB-07B	<DL	12-YB-16B	<DL
12-YB-08	26.8	12-YB-17	<DL
12-YB-08B	1.081	12-YB-17B	<DL
12-YB-09	<DL	12-YB-18	40.58
12-YB-09B	<DL	12-YB-18B	12.69
12-YB-10	37.35	12-YB-22B	<DL
12-YB-10B	<DL		

12-YB-11	7.928
12-YB-11B	<DL

Table 9: Results of analyses, uranium.



Figure 61: Blue markings represent locations where uranium (U) concentrations were above 15 µg.

Intake of uranium through food is normally between 1-4 µg/day and in drinking-water less than 1µg/l (WHO, 2011). However, naturally occurring uranium is common in rock-types like granites and pegmatites. Wells drilled into the rock in these areas could therefore contain higher concentrations of uranium (SOSFS 2003:17). There is still uncertainty regarding chronic health effects of exposure to environmental uranium in humans and there is “no clear evidence of effects below an exposure concentration of 30µg/l”<sup>1</sup> (WHO, 2011).

### REE

Furthermore, five rare earth elements are present in the sampled groundwater in small concentrations; lanthanum (La), scandium (Sc), samarium (Sm), neodymium (Nd) and yttrium (Y). These are of particular interest in this study since REEs in drinking water could possibly be related to health issues (Boer, 1996). As mentioned above I have found relatively few articles concerning recommended levels of REEs in drinking water.

Boer et al (1996) refer to older studies (see Boer et al. 1996 for complete list of references) for the following indicative admissible drinking water concentrations for REEs. These studies are carried out on rats and are then recalculated to indicative admissible drinking water concentrations (iAC) to humans. Below I have listed the iAC for the rare earth elements found in the Ytterby samples.

*neodymium and samarium:* at 1050 µg/l no adverse effects observed (based on a study carried out during 90 days)

*scandium and yttrium*: 2 µg/l, lowest observed adverse effect in the form of retarded growth and diminished body weight (based on a chronic study )

*lanthanum*: 2 µg/l, no studies found (principle of prudence)

Concentrations found in the samples are summed up in the table below. Then there are maps showing at which sample locations concentrations above DL were found (marked in blue). There is one map for each rare earth element.

Sample	µg/l La conc.	Sc conc.	Sm conc.	Nd conc.	Y conc.
12-YB-03	<DL	28.33	<DL	<DL	0.4447
12-YB-03B	<DL	<DL	<DL	<DL	<DL
12-YB-04	<DL	19.67	<DL	<DL	1.19
12-YB-04B	1.42	<DL	<DL	<DL	5.527
12-YB-05	<DL	25.71	0.6907	<DL	8.279
12-YB-05B	1.673	<DL	<DL	<DL	5.386
12-YB-06	<DL	17.16	<DL	<DL	4.054
12-YB-06B	<DL	<DL	<DL	<DL	2.863
12-YB-07	<DL	26.46	<DL	<DL	2.522
12-YB-07B	<DL	<DL	<DL	<DL	1.738
12-YB-08	0.1075	0.2084	<DL	<DL	0.3223
12-YB-08B	<DL	<DL	<DL	<DL	<DL
12-YB-09	0.4989	31.75	<DL	<DL	3.542
12-YB-09B	7.608	<DL	<DL	1.605	4.369
12-YB-10	<DL	12.62	<DL	<DL	0.4347
12-YB-10B	<DL	<DL	<DL	<DL	<DL
12-YB-11	<DL	18.92	<DL	<DL	0.3492
12-YB-11B	<DL	<DL	<DL	<DL	<DL
12-YB-12	<DL	15.44	<DL	<DL	0.5412
12-YB-12B	1.043	<DL	<DL	<DL	<DL
12-YB-13	<DL	22.92	1.151	<DL	0.1178
12-YB-13B	<DL	<DL	<DL	<DL	<DL
12-YB-14	<DL	14.46	<DL	<DL	1.438
12-YB-14B	1.112	<DL	<DL	<DL	1.238
12-YB-15	<DL	25.56	1.325	<DL	4.962
12-YB-15B	7.204	<DL	<DL	1.341	3.434
12-YB-16	<DL	33.89	<DL	<DL	1.416
12-YB-16B	2.902	<DL	<DL	<DL	1.256
12-YB-17	<DL	14.5	<DL	<DL	1.067
12-YB-17B	1.408	<DL	<DL	<DL	NA
12-YB-18	<DL	22.23	<DL	<DL	0.4354
12-YB-18B	<DL	<DL	<DL	<DL	NA
12-YB-22B	5.526	<DL	<DL	<DL	2.61

Table 10: Results or analyses, REE.



Figure 62: Blue markings represent locations where *lanthanum* (La) was detected in the water samples.



Figure 63: Blue markings represent locations where *scandium* (Sc) was detected in the water samples.



Figure 64: Blue markings represent locations where *samarium* (*Sm*) was detected in the water samples.



Figure 65: Blue markings represent locations where *neodymium* (*Nd*) was detected in the water samples.



Figure 66: Blue markings represent locations where *yttrium* (*Y*) was detected in the water samples.

For more data regarding rare earth elements and associated health effects I refer to section 6.2.2.1

### 6.3.2 ORGANIC HYDROCHEMICAL DATA

The results from Oil-TPH analyses, OV-20C are presented in figure 29 and table 49. Several samples have concentrations of C10-C12 and/or C12-C16 exceeding detection limits and these samples are marked blue in the map and orange in the table.



Figure 67: Blue markings represent locations where diesel was detected in the water samples.

Oil concentrations exceeding detection limits							
Results in µg/l							
Sample	12-YB-01	12-YB-03	12-YB-04	12-YB-05	12-YB-06	12-YB-07	12-YB-08
Oil index	<50	<50	<50	<50	<50	<50	<50
fraction >C10-C12	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0
fraction >C12-C16	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0
fraction >C16-C35	<30	<30	<30	<30	<30	<30	<30
fraction >C35-<C40	<10	<10	<10	<10	<10	<10	<10
Sample	12-YB-09	12-YB-10	12-YB-11	12-YB-12	12-YB-13	12-YB-14	12-YB-15
Oil index	<50	<50	<50	<50	<50	<50	<50
fraction >C10-C12	7.6	<5.0	<5.0	<5.0	<5.0	5.6	9.9
fraction >C12-C16	<5.0	<5.0	<5.0	<5.0	<5.0	6	15.2
fraction >C16-C35	<30	<30	<30	<30	<30	<30	<30
fraction >C35-<C40	<10	<10	<10	<10	<10	<10	<10
Sample	12-YB-16	12-YB-17	12-YB-18	12-YB-19	12-YB-22	12-YB-23	
Oil index	<50	<50	<50	<100	<50	1300	
fraction >C10-C12	19.2	14.6	11.1	<100	20.5	<100	
fraction >C12-C16	9.2	7.6	25.2	<100	28.2	600	
fraction >C16-C35	<30	<30	<30	<100	<30	600	
fraction >C35-<C40	<10	<10	<10	<100	<10	<100	

Table 11: Orange markings represent oil concentrations exceeding detection limits.

In the table and diagrams below, the oil contamination is plotted against ground surface elevation. Samples from inside the mine or the quarry, i.e. 12-YB-01, 12-YB-19 and 12-YB-23 are removed from in-data. Studying these plots, the majority of the contaminated samples are collected in areas located at lower ground surface elevation than 20 m. The samples which do not show any traces of oil are on high ground in the centre of Resarö and appear to be located upstream the diesel contamination in the mine. Important to note is that two of the contaminated samples, 12-YB-15 and 12-YB-22, are taken in ditches why they might be affected by other contamination sources.

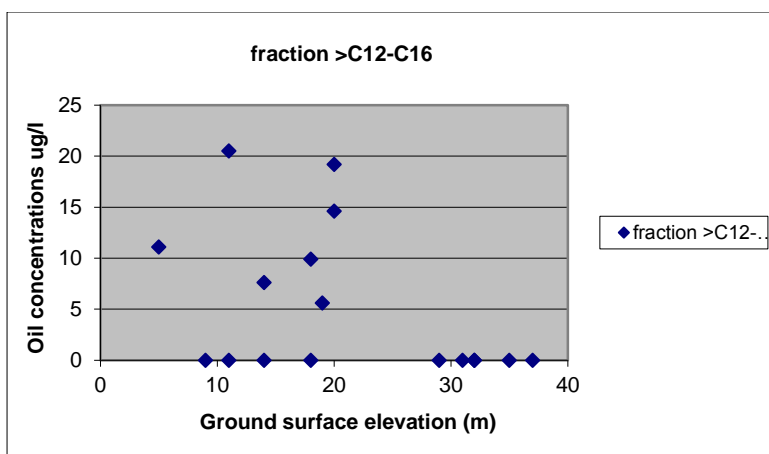


Figure 68: Oil concentrations, fractions >C12-C16, plotted against ground surface elevation.

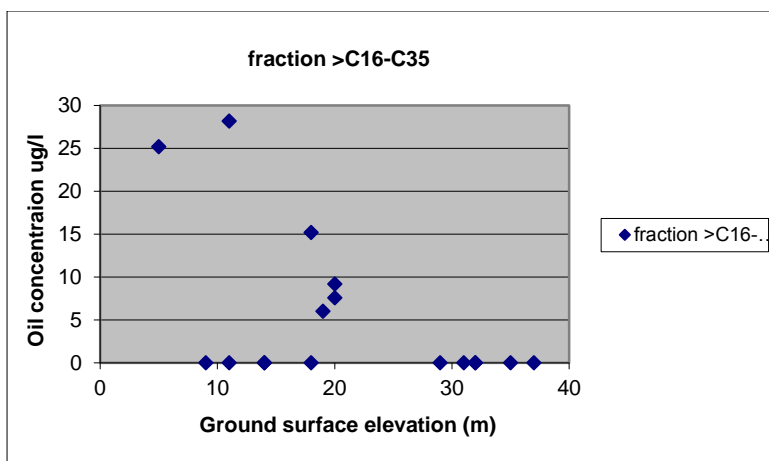


Figure 69: Oil concentrations, fractions >C16-C35, plotted against ground surface elevation.

Reference data for analyses of oil samples are primarily taken from ALS Scandinavia AB, laboratory who made the oil analyses (ALS web-site, 2012). Since my analyses do not show if the fractions are aliphatic or aromatic I have listed all reference data regarding *recommended limits* for both drinking water and irrigation that might be of interest (Table 12).

µg/l	Drinking water	Irrigation
Alifatic hydrocarbons >C12-C16	100	1000
Alifatic hydrocarbons >C16-C35	100	1000
Aromatic hydrocarbons >C10-C16	10	100
Aromatic hydrocarbons >C16-C35	2	70

Table 12: Reference data for analyses of oil samples. From ALS Scandinavia AB (2012).

Identification of oil from inside the mine, i.e. oil skimmed off the water surface in the mine shaft, showed that the remains in the shaft today probably are Diesel.

The water samples taken in the mine shows that there is no oil in the water tank. There is still oil on the water surface in the mine shaft and in the water on the ground in the mine corridors.

## 6.4 MULTIPLE SCLEROSIS SPATIALLY ASSOCIATED WITH THE MINE

In an area defined by the postal code for Ytterby, i.e. 185 94, there is a population of 1558 individuals according to Statistics Sweden (SCB). Together with collaborators at the Clinical Neuroscience Department, at the Karolinska Institute, I have searched the Swedish MS register for patients who have this postal code in the year 2012 and added a few patients who we know used to live in this area for a time period of approximately 30-40 years. This demonstrates a total number of 4-8 MS patients in the Ytterby village and might suggest an increased number compared to the expected 3 MS patients based on the national prevalence of 189/100 000. Moreover, the registered MS patients are known to live within a distance of 1 km from the mine while the postal code for Ytterby covers a slightly larger area. This implies that the population used is oversized and that a reduction of 300 people would give a more accurate population number, even further increasing the MS prevalence ratio. In addition to the ethical permission to search the Swedish MS register for patients currently living in this area my collaborators at the Karolinska Institute have also applied for ethical permission to search for more MS patients who previously lived in the area. This search is currently in progress.

## 7 DISCUSSION

The aim of this study was to evaluate if a suggested coupling between MS prevalence and the mine warrants further investigation. Clearly, the quarrying of quartz and feldspar can be excluded in this discussion. As a REE locality, however, the Ytterby mine is highly interesting. Previous studies show that adverse neurological health effects are associated with oral intake of REEs but solid knowledge of acceptable concentrations of these elements in drinking water is still scarce and is yet to be determined. The water samples collected in the Ytterby village show traces of five REEs, i.e. scandium (Sc), yttrium (Y), lanthanum (La), neodymium (Nd) and samarium (Sm). These do not appear in large amounts and my two sets of samples show different results for all the above elements except for yttrium (Y). Whether this is due to normal groundwater variations or to difficulties in measuring these types of elements is hard to interpret. In order to draw any further conclusions from this, a larger and more controlled study is needed. My results also show that the REE occurrences are highly localized in the quarry. Moreover, results from the analysis of the black substance leaking out of cracks in the mine corridors confirm that yttrium (Y), lanthanum (La), cerium (Cs) and neodymium (Nd) are present in substantial concentrations in the local rocks and also appear to be mobile. This should be taken into account when considering the potential leakage to the local water supply. Moreover, it is crucial to obtain a thorough understanding of acceptable concentrations of these elements in drinking water and to investigate whether there is a cumulative adverse effect of REEs due to possibly similar toxicological effects. Do they sum up to relatively high concentrations?

In addition to the adverse neurological health effects associated with REEs, many of the minerals that hold the REEs also contain radioactive elements such as uranium and thorium. Natural radioactivity has been measured around the contours of the quarry and zones of high ionizing radiation were identified. There is support for a coupling of ionizing radiation and MS (Section 6.1.2). Previous sampling for radon in three private wells close to the mine did not show any abnormal values but there is need for further sampling to get a better understanding of this area. In this study I have mainly thought of drinking water as the most likely pathway of the discussed contaminants, but in this context it appears as if there might be

another option. There are indications that rocks from the quarry were used as building material in some of the houses in the Ytterby village which might have led to an increase in radiation exposure to its population.

The third type of activity that has taken place in the mine is the storage of jet fuel MC-77 and diesel for the Swedish Armed Forces. Seven out of seventeen water samples (15 private wells and 2 ditches) show contamination of diesel which is the most recent fuel stored in the mine. Since it is very likely that MC-77 has spread in a similar manner, diesel could probably also be used as an analogue for the stored jet fuel. The majority of the contaminated water samples are collected in areas located at lower ground surface elevation than 20 m. No consideration has been made to the depth of the wells or other hydrological data which implies that these figures should be interpreted with care. The pattern is there and it raises the question whether geographical location could be a link between water used and MS patients. If future studies will be conducted they should investigate the source of the patients' water thoroughly. A major complication in mapping the patients' water source is that it historically appears to have been common to collect water in public wells.

Previous studies debate the extent and character of health effects as a result of exposure to petroleum products and its chemical constituents. However, a substantial number of scientific reports support a coupling between neurodegenerative health effects and toxic constituents of jet fuels such as benzene, toluene, and n-hexane. All these constituents are present in MC-77 which makes it a potential risk factor for MS. An interesting option in this context is using the spread of diesel as an indication of the past spread of MC-77. Another question that arises is whether the storage of aircraft fuel and diesel in the mine shaft could have affected the solubility of the minerals found there, i.e. minerals containing REEs and radioactive elements and thereby made them appear in greater concentrations in the water.

Finally I would like to address the fact that the possible overrepresentation of MS patients in the Ytterby village is based on a very small population. Figures like these ones could simply be a statistical coincidence. Even though groundwater contamination does exist in various forms and in varying degrees, there are no data, except for knowledge about an extensive usage of private wells in the past, confirming that MS-patients in the area have ingested contaminated groundwater. Extensive mapping and in-depth studies will be required to confirm any suggested correlation between the Ytterby mine and MS prevalence in the area. One option would be to continue investigating these findings with a more detailed study where the disease history for each affected individual is recorded and to combine this information with suggested environmental triggers, timing of influence and source of drinking water. Another option to test these hypotheses is to conduct the same type of study in other locations where i) the same type of fuel has been stored but where no REEs are present in the local rocks and ii) REEs are present in the local rocks but no fuel has been stored. It would also be informative to know whether there are other health issues overrepresented in the Ytterby area. The aim was to evaluate if there are grounds for a thorough investigation of MS associated with the mine. The conclusion is that a full investigation of coupling between neurological health issues, MS being one of them, and the mine is warranted. This topic is also of current interest in connection with the planned REE mining in Norra Kärr, Gränna (300 km SW of Stockholm, the capital in Sweden). The ore is thought to be the fourth largest in the world and is located in the catchment area of the Swedish large lake Vättern. Lake Vättern is the fifth largest source of water supply in Europe and provides 300 000 people with drinking water

(Ödling et al., 2012). The scale of potential environmental and health consequences as a result of mining REEs in this area could be very large.

Furthermore, I have found that local W-E trending vertical faults, displacing the contact between the amphibolite and the pegmatite, appear to have locally controlled the distribution of REEs. These faults appear to have provided the main control on distribution of rare minerals and thus the REEs and nuclear radiation. Results from nuclear radiation measurements show areas of high radiation on both sides of the quarry at the height of the vertical fault. It appears as if it has been a W-E trending streak of high radiation across the pegmatite here. XRF measurements also show an enrichment of elements following the trend of these vertical structures across the mined pegmatite and into the amphibolite. The distance from the a/p-contact appears to be of subordinate importance relative to the proximity to the vertical faults for the concentration of rare minerals and thus REEs and nuclear radiation. These findings go well with the description in Almström (1925) of how these rare minerals were clustered close to the ground surface in the ESE corner of the quarry. Thus, the rare earth elements appear to be localized in the proximity of the fractures.

## **8 CONCLUSION**

According to my data it cannot be excluded that a possible overrepresentation of MS patients within the Ytterby postal code area could be an indication of a spatial coupling between the mine and MS. Such a possible coupling could be associated with the REEs present in the local rocks, with the previous storage of diesel or jet fuel MC-77 in the mine and/or with zones of high natural radioactivity in the area. Previous studies show that adverse neurological health effects are associated with oral intake of REEs and there is support for a coupling between ionizing radiation and MS. A substantial number of scientific reports support a coupling between neurodegenerative health effects and toxic constituents of jet fuels such as benzene, toluene, and n-hexane. The aim was to evaluate if there are grounds for a thorough investigation of MS associated with the mine. The conclusion is that a full investigation is warranted of a possible coupling between neurological health issues, MS being one of them, and the mine.

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## Appendix 1

### MINERALS FOUND AT YTTERBY

The Ytterby pegmatite which is situated in the south-eastern corner of Resarö island mainly consists of large crystals of quartz and feldspar but there is also a considerable amount of other minerals. The Swedish Museum of Natural History, Stockholm has made an account for them all. Chemical formulas are taken from mindat.org (2012), Blatt, H et al, (2006). To note is that radioactive trace elements are not included in the chemical formulas.

albite – $\text{NaAlSi}_3\text{O}_8$
allanite - $(\text{CaY})(\text{Al}_2\text{Fe}^{2+})(\text{Si}_2\text{O}_7)(\text{SiO}_4)\text{O}(\text{OH})$
anderbergite - (Zr, Ca, Si, O, H, REE) (also contains $\text{Th}_2\text{O}_5$ , see Nordenskjöld, 1908 for a complete analysis)
apatite – $\text{Ca}_5(\text{PO}_4)_3(\text{F},\text{OH},\text{Cl})$
arrhenite - (Y, Er, Ca, Zr, Ta, Si, O),
bastnäsit(Ce) – $(\text{Ce},\text{La})(\text{CO}_3)\text{F}$
bertrandite – $\text{Be}_4(\text{Si}_2\text{O}_7)(\text{OH})_2$
beryl – $\text{Be}_3\text{Al}_2(\text{Si}_6\text{O}_{18})$
Biotite – $\text{K}(\text{Fe},\text{Mg})_3\text{AlSi}_3\text{O}_{10}(\text{OH})_4$
bismuth – Bi
calcite – $(\text{CaCO}_3)$
Chlorite – $(\text{Mg},\text{Fe})_5\text{Al}_2\text{Si}_3\text{O}_{10}(\text{OH})_8$
chrysoberyl- $(\text{BeAl}_2\text{O}_4)$
cordierite – $(\text{Fe},\text{Mg})_2\text{Al}_4\text{Si}_5\text{O}_{18}$ , At low P in peraluminous rocks
cyrtolite – $\text{Zr}((\text{SiO}_4),(\text{OH})_4)$
epidote – $\text{Ca}_2\text{Al}_2\text{Fe}^{3+}\text{SiO}_4\text{Si}_2\text{O}_7(\text{O},\text{OH})$
Fergusonite – $(\text{Y},\text{Ce},\text{La},\text{Nd},\text{Y})\text{NbO}_4$ (also contains $\text{UO}_3$ , see Nordenskjöld, 1908 for a complete analysis)
fluorite – $\text{CaF}_2$
Gadolinite – $\text{Y}_2\text{Fe}^{2+}\text{Be}_2\text{Si}_2\text{O}_{10}$ (also contains $\text{ThO}_2$ and $\text{Ce}_2\text{O}_3$ , see Nordenskjöld, 1908 for a complete analysis)
Galena – $\text{PbS}$
Garnet -
Hisingerite- $\text{Fe}^{3+}_2(\text{Si}_2\text{O}_5)(\text{OH})_4 \cdot 2\text{H}_2\text{O}$
keiviite-(Y) – $(\text{Y},\text{Yb})_2(\text{Si}_2\text{O}_7)$
Kimuraite-(Y) – $\text{Ca}(\text{Y},\text{Nd})_2(\text{CO}_3)_4 \cdot 6\text{H}_2\text{O}$
Lanthanite – $(\text{La},\text{Ce})_2(\text{CO}_3)_3 \cdot 8\text{H}_2\text{O}$
Lokkai-(Y) – $\text{Ca}(\text{Y},\text{Gd},\text{Nd},\text{Dy})_4(\text{CO}_3)_7 \cdot 9\text{H}_2\text{O}$
Magnetite – $\text{Fe}^{2+}\text{Fe}^{3+}_2\text{O}_4$
Microcline – $\text{KAlSi}_3\text{O}_8$
Microclinperthite – Mixture of Albite-Anorthite series, K-feldspar
Milarite – $\text{K}_2\text{Ca}_4\text{Al}_2\text{Be}_4\text{Si}_{24}\text{O}_{60} \cdot \text{H}_2\text{O}$
Molybdenite – $\text{MoS}_2$
Monazite – $\text{CePO}_4$ – Typical high content of LREEs Th and U
Muscovite – $\text{KAl}_3\text{Si}_3\text{O}_{10}(\text{OH})_2$
Oligoclas – $(\text{Na},\text{Ca})(\text{Al}(\text{Si},\text{Al})\text{Si}_2\text{O}_8)$
Orthoclase – $\text{KAlSi}_3\text{O}_8$
Plagioclase – $\text{NaAlSi}_3\text{O}_8$ - $\text{CaAl}_2\text{Si}_2\text{O}_8$
Polycrase – $(\text{Y},\text{U})(\text{Ti},\text{Nb})_2\text{O}_6$
Prehnite – $\text{Ca}_2\text{Al}_2\text{Si}_3\text{O}_{12}(\text{OH})$
Pyrite – $\text{FeS}_2$
Pyrrhotite – $\text{Fe}_{1-x}\text{S}$ ( $x=0$ to $0.17$ )
Quartz – $\text{SiO}_2$

Tengerite – $Y_2(CO_3)_3 \cdot 2-3H_2O$
Thortvelite – $(Sc, Y)_2Si_2O_7$
Titanomagnetite – titanium rich magnetite
Wasit – a variety of allanite
Xenotime – $(Yb, Y, HREE)(PO_4)$
Yftsite-(Y) – $(Y, Dy, Er)_4(Ti, Sn)(SiO_4)_2O(F, OH)_6$
Yttrotantalite – $(Y, Ca, U^{4+}, F^{2+})_2(Ta, Nb)_2O_8$ (also contains other REE, see Nordenskjöld, 1908 for a complete analysis)
Zircon – $ZrSiO_4$

First set of samples

Appendix 2

Sample	pH	T. C°	Cond. (mS/cm)	ugr/L										
				Al	Ba	Be	Ca	Cd	Ce	Co	Cr	Cu	Fe	K
12-YB-03	7.3	14.5	0.58	12.3	63.32	<DL	65080	<DL	<DL	<DL	<DL	9.432	22.96	2265
12-YB-04	7.63	15	0.55	1.346	11.66	<DL	47820	<DL	<DL	<DL	<DL	13.89	5.295	1370
12-YB-05	8.08	16.7	0.76	6.482	29.66	<DL	65590	<DL	<DL	<DL	<DL	0.4674	137.3	1500
12-YB-06	8.16	11.8	0.66	5.616	11.85	<DL	43860	<DL	<DL	<DL	<DL	0.6998	43.89	865.7
12-YB-07	7.6	14.7	0.58	3.328	15.01	<DL	63420	<DL	<DL	<DL	<DL	40.4	0.7858	1396
12-YB-08	7.84	14.8	0.82	1.893	0.2672	<DL	370.3	<DL	<DL	<DL	<DL	13.39	2.134	1811
12-YB-09	6.97	18.8	0.55	29.56	32.51	<DL	73830	<DL	<DL	<DL	<DL	48.52	230.9	3231
12-YB-10	8.24	17.1	0.58	3.56	16.34	<DL	31790	<DL	<DL	<DL	<DL	3.836	22.87	523
12-YB-11	7.66	14.9	0.47	2.659	1.931	<DL	44300	<DL	<DL	<DL	<DL	72.82	<DL	678.1
12-YB-12	7.1	15.4	0.25	8.051	10.01	<DL	32830	<DL	<DL	<DL	<DL	119.6	9.903	1005
12-YB-13	7.2	14.5	0.33	1.149	30.41	<DL	49360	<DL	<DL	<DL	<DL	76.51	1.966	1475
12-YB-14	7.97	19.5	0.72	4.192	14.76	<DL	36950	<DL	<DL	<DL	<DL	15.05	9.03	772.8
12-YB-15	7.08	18	0.82	182.8	250	<DL	61270	<DL	<DL	5.6	0.8128	20.67	839.7	53630
12-YB-16	7.09	12.7	0.7	141.8	197.5	<DL	81010	<DL	<DL	1.537	0.7817	17.96	226.6	38160
12-YB-17	7.24	19.6	0.19	79.43	24.11	<DL	30220	<DL	<DL	<DL	<DL	20.68	91.52	1807
12-YB-18	7.94	16	1.75	1.009	46.55	<DL	64430	<DL	<DL	<DL	<DL	1.464	-0.1856	7192
SOS				500			100000					200	500	12000
WHO					700			3			50	2000		

Sample	pH	T. C°	Cond. (mS/cm)	REE										
				La	Mg	Mn	Mo	Na	Ni	P	Pb	Rb	Sc	Si
12-YB-03	7.3	14.5	0.58	<DL	6018	2.793	1.266	26970	<DL	63.08	0.2007	<DL	28.33	3208
12-YB-04	7.63	15	0.55	<DL	14760	14.28	1.683	49960	<DL	8.296	3.114	<DL	19.67	5115
12-YB-05	8.08	16.7	0.76	<DL	11260	50.82	0.537	93510	<DL	11.15	3.117	<DL	25.71	5675
12-YB-06	8.16	11.8	0.66	<DL	6296	18.32	0.5889	95720	<DL	8.674	2.072	<DL	17.16	4889
12-YB-07	7.6	14.7	0.58	<DL	11710	2.817	1.348	41560	<DL	6.988	10.49	<DL	26.46	4492
12-YB-08	7.84	14.8	0.82	0.1075	67.59	2.14	0.9365	160700	14.54	9.122	3.294	<DL	0.2084	3644
12-YB-09	6.97	18.8	0.55	0.4989	6675	3.343	0.4167	21450	<DL	7.521	3.634	<DL	31.75	3887
12-YB-10	8.24	17.1	0.58	<DL	5019	28.02	0.7445	88310	<DL	6.527	2.915	<DL	12.62	4887
12-YB-11	7.66	14.9	0.47	<DL	7820	0.9598	0.6784	36520	<DL	8.349	2.454	<DL	18.92	5471
12-YB-12	7.1	15.4	0.25	<DL	2014	0.2919	1.071	10960	0.9317	3.723	5.243	<DL	15.44	4268
12-YB-13	7.2	14.5	0.33	<DL	2350	8.074	0.1721	7061	<DL	4.13	2.037	<DL	22.92	4384
12-YB-14	7.97	19.5	0.72	<DL	3093	33.7	2.124	106200	2.653	6.373	9.252	<DL	14.46	9309
12-YB-15	7.08	18	0.82	<DL	13480	167.5	7.579	31520	35.07	251.2	5.655	10.08	25.56	4572
12-YB-16	7.09	12.7	0.7	<DL	15040	53.22	1.55	12550	5.036	72.53	3.083	8.906	33.89	4161
12-YB-17	7.24	19.6	0.19	<DL	1687	7.282	0.3461	2829	<DL	15.81	2.079	<DL	14.5	4012
12-YB-18	7.94	16	1.75	<DL	17420	44.41	4.273	244300	<DL	6.257	<DL	2.557	22.23	3151
SOS					30000	300		200000		600	10			
WHO							70		70		10			

Sample	pH	T. C°	Cond. (mS/cm)	REE							Zn		Zr
				Sm	Sn	Sr	Ti	U	V	Y	Zn	Zr	
12-YB-03	7.3	14.5	0.58	<DL	<DL	125.7	3.348	6.606	0.5977	0.4447	241.3	0.152	
12-YB-04	7.63	15	0.55	<DL	<DL	311.7	2.171	17.95	4.372	1.19	289.9	<DL	
12-YB-05	8.08	16.7	0.76	0.6907	4.736	695.4	3.744	31.65	5.85	8.279	6.841	7.425	
12-YB-06	8.16	11.8	0.66	<DL	<DL	542.7	2.676	22.99	3.126	4.054	17.55	2.564	
12-YB-07	7.6	14.7	0.58	<DL	<DL	355.1	2.408	18.75	1.752	2.522	100.3	<DL	
12-YB-08	7.84	14.8	0.82	<DL	1.458	1.002	0.1036	26.8	0.3952	0.3223	62.35	0.0353	
12-YB-09	6.97	18.8	0.55	<DL	1.286	217.3	2.854	<DL	0.747	3.542	145.8	1.048	
12-YB-10	8.24	17.1	0.58	<DL	<DL	346.2	1.918	37.35	0.8731	0.4347	10.89	0.5395	
12-YB-11	7.66	14.9	0.47	<DL	<DL	150.8	2.184	7.928	5.926	0.3492	30.64	<DL	
12-YB-12	7.1	15.4	0.25	<DL	<DL	120.3	2.051	6.381	1.041	0.5412	213.4	<DL	
12-YB-13	7.2	14.5	0.33	1.151	<DL	155.4	2.159	<DL	0.2992	0.1178	348.4	<DL	
12-YB-14	7.97	19.5	0.72	<DL	<DL	260.9	1.982	5.276	1.361	1.438	69.06	<DL	
12-YB-15	7.08	18	0.82	1.325	1.219	143.8	11.2	<DL	1.099	4.962	60.88	2.952	
12-YB-16	7.09	12.7	0.7	<DL	2.388	184.9	5.723	<DL	0.8036	1.416	425.3	0.9172	
12-YB-17	7.24	19.6	0.19	<DL	3.588	37.16	5.385	<DL	0.3401	1.067	131.2	0.5984	
12-YB-18	7.94	16	1.75	<DL	<DL	698.4	2.231	40.58	1.483	0.4354	266.2	<DL	
SOS								15					
WHO								15-30			3000		

Second set of samples

Appendix 2

Sample	pH	T. C°	Cond. (mS/cm)	ugr/L										REE
				Ag	Al	B	Ba	Cd	Co	Co	Cr	Cs	Cu	Dy
12-YB-03B	7.3	14.5	0.58	13.12	11.11	34.76	46.63	<DL	<DL	<DL	<DL	<DL	10.89	<DL
12-YB-04B	7.63	15	0.55	13.66	7.315	151.8	23.43	<DL	<DL	<DL	<DL	<DL	<DL	<DL
12-YB-05B	8.08	16.7	0.76	14.01	8.634	144.7	21.1	<DL	<DL	<DL	<DL	<DL	1.382	<DL
12-YB-06B	8.16	11.8	0.66	11.99	6.675	99.3	8.852	<DL	<DL	<DL	<DL	<DL	<DL	<DL
12-YB-07B	7.6	14.7	0.58	13.62	8.557	12.14	10.46	<DL	<DL	<DL	<DL	<DL	20.36	<DL
12-YB-08B	7.84	14.8	0.82	<DL	4.666	36.15	<DL	<DL	<DL	<DL	<DL	<DL	9.828	<DL
12-YB-09B	6.97	18.8	0.55	12.94	77.73	<DL	22.21	<DL	<DL	<DL	<DL	<DL	88.33	<DL
12-YB-10B	8.24	17.1	0.58	9.406	5.25	157.2	9.721	<DL	<DL	<DL	<DL	<DL	<DL	<DL
12-YB11B	7.66	14.9	0.47	12.69	4.769	11.96	<DL	<DL	<DL	<DL	<DL	<DL	81.12	<DL
12-YB-12B	7.1	15.4	0.25	11.37	8.415	<DL	2.503	<DL	<DL	<DL	<DL	<DL	59.4	<DL
12-YB-13B	7.2	14.5	0.33	12.73	3.812	<DL	23.01	<DL	<DL	<DL	<DL	<DL	62.87	<DL
12-YB-14B	7.97	19.5	0.72	11.12	6.322	181.5	11.03	<DL	<DL	<DL	<DL	<DL	10.79	<DL
12-YB-15B	7.08	18	0.82	14.08	129.4	5.862	189.4	<DL	<DL	<DL	<DL	<DL	15.21	<DL
12-YB-16B	7.09	12.7	0.7	14.33	99.82	3.938	160.5	<DL	<DL	<DL	<DL	<DL	13.08	<DL
12-YB-17B	7.24	19.6	0.19	10.39	21.03	<DL	16.07	<DL	<DL	<DL	<DL	<DL	15.98	<DL
12-YB-18B	7.94	16	1.75	13.13	3.852	199.3	36.42	<DL	<DL	<DL	<DL	<DL	<DL	<DL
12-YB-22B				12.25	486.8	<DL	45.56	<DL	<DL	<DL	<DL	<DL	4.558	<DL
SOS					500								200	
WHO						2400	700				50		2000	

Sample	pH	T. C°	Cond. (mS/cm)	REE		REE		REE		REE		REE		
				Er	Eu	Fe	Ga	Gd	Ge	Ho	K	La	Lu	Mg
12-YB-03B	7.3	14.5	0.58	i -.1856	<DL	26.92	i -15.14	<DL	i 2.605	<DL	2914	<DL	<DL	4773
12-YB-04B	7.63	15	0.55	i 1.241	<DL	75.72	i -15.77	<DL	i 2.111	<DL	1712	1.42	<DL	10100
12-YB-05B	8.08	16.7	0.76	i 1.165	<DL	6.77	i -15.43	<DL	i 2.664	<DL	1732	1.673	<DL	10220
12-YB-06B	8.16	11.8	0.66	i .5804	<DL	18.47	i -15.33	<DL	i 3.573	<DL	880.6	<DL	<DL	5700
12-YB-07B	7.6	14.7	0.58	i -.1461	<DL	4.109	i -15.15	<DL	i 2.806	<DL	1641	<DL	<DL	9771
12-YB-08B	7.84	14.8	0.82	i .1178	<DL	3.515	i -15.80	<DL	i 3.316	<DL	2161	<DL	<DL	68.21
12-YB-09B	6.97	18.8	0.55	i 1.110	<DL	291.1	i -14.49	<DL	i 2.163	<DL	3823	7.608	<DL	4460
12-YB-10B	8.24	17.1	0.58	i -.0513	<DL	9.446	i -16.23	<DL	i 3.213	<DL	380.4	<DL	<DL	3833
12-YB11B	7.66	14.9	0.47	i -.2687	<DL	1.359	i -14.36	<DL	i 4.122	<DL	524.1	<DL	<DL	7864
12-YB-12B	7.1	15.4	0.25	i -.1606	<DL	5.352	i -15.63	<DL	i 2.517	<DL	964.1	1.043	<DL	2142
12-YB-13B	7.2	14.5	0.33	i -.1979	<DL	<DL	i -15.06	<DL	i 3.510	<DL	1386	<DL	<DL	2221
12-YB-14B	7.97	19.5	0.72	i .1426	<DL	8.239	i -16.90	<DL	i 3.901	<DL	748.2	1.112	<DL	2802
12-YB-15B	7.08	18	0.82	i 8.475	<DL	754.7	i -14.43	<DL	i 1.523	<DL	51000	7.204	<DL	12200
12-YB-16B	7.09	12.7	0.7	i 2.937	<DL	195.7	i -15.10	<DL	i 2.331	<DL	36150	2.902	<DL	13280
12-YB-17B	7.24	19.6	0.19	i .3549	<DL	46.14	i -15.07	<DL	i 3.072	<DL	1578	1.408	<DL	1590
12-YB-18B	7.94	16	1.75	i -.2930	<DL	1.052	i -15.16	<DL	i 3.366	<DL	8601	<DL	<DL	14270
12-YB-22B				i 11.10	<DL	785.1	i -13.54	<DL	i 3.444	<DL	3502	5.526	<DL	4541
SOS						500					12000			30000
WHO														

Second set of samples

Appendix 2

Sample	pH	T. C°	Cond. (mS/cm)	REE					REE					REE	
				Mn	Mo	Na	Nd	P	Pb	Pr	Rb	S	Sb	Sc	Si
12-YB-03B	7.3	14.5	0.58	1.68	<DL	17720	<DL	<DL	2.513	<DL	<DL	408800	i 1.362	<DL	3723
12-YB-04B	7.63	15	0.55	35.53	<DL	62990	<DL	<DL	3.281	<DL	<DL	1142000	i .6573	<DL	5775
12-YB-05B	8.08	16.7	0.76	37.41	<DL	61340	<DL	<DL	3.848	<DL	<DL	573900	i .5453	<DL	5583
12-YB-06B	8.16	11.8	0.66	7.317	<DL	64760	<DL	<DL	2.867	<DL	<DL	909000	i -.3687	<DL	5052
12-YB-07B	7.6	14.7	0.58	<DL	<DL	20610	<DL	<DL	4.216	<DL	<DL	636300	i .8493	<DL	4167
12-YB-08B	7.84	14.8	0.82	1.577	<DL	110500	<DL	<DL	5.78	<DL	<DL	997100	i .3609	<DL	3832
12-YB-09B	6.97	18.8	0.55	3.785	<DL	10550	1.605	<DL	4.809	<DL	<DL	650800	i 1.392	<DL	4307
12-YB-10B	8.24	17.1	0.58	15.9	<DL	60840	<DL	<DL	3.981	<DL	<DL	1023000	i .3150	<DL	5999
12-YB11B	7.66	14.9	0.47	<DL	<DL	26670	<DL	<DL	3.913	<DL	<DL	1124000	i .1272	<DL	5492
12-YB-12B	7.1	15.4	0.25	<DL	<DL	6701	<DL	<DL	4.037	<DL	<DL	445500	i .4964	<DL	4511
12-YB-13B	7.2	14.5	0.33	6.601	<DL	5242	<DL	<DL	2.642	<DL	<DL	362400	i .8838	<DL	4359
12-YB-14B	7.97	19.5	0.72	27.55	1.452	70410	<DL	<DL	5.618	<DL	<DL	1213000	i .6050	<DL	9420
12-YB-15B	7.08	18	0.82	22.56	3.375	21740	1.341	52.37	4.164	<DL	6.465	1178000	i 1.701	<DL	4520
12-YB-16B	7.09	12.7	0.7	28.13	<DL	8576	<DL	15.13	2.339	<DL	8.505	1966000	i 1.871	<DL	4210
12-YB-17B	7.24	19.6	0.19	<DL	<DL	2075	<DL	2.806	<DL	<DL	151300	i 1.367	<DL	3797	
12-YB-18B	7.94	16	1.75	35.97	2.405	158000	<DL	<DL	2.474	<DL	<DL	2333000	i .8220	<DL	3203
12-YB-22B				10.38	<DL	7740	<DL	5.289	3.342	<DL	<DL	853900	i .7995	<DL	5388
SOS				300		200000		600	10			200000			
WHO					70				10			500000			
Sample	pH	T. C°	Cond. (mS/cm)	REE					REE					REE	
				Si	Sm	Sn	Sr	Tb	Ti	U	V	Y	Yb	Zn	Zr
12-YB-03B	7.3	14.5	0.58	3596	<DL	<DL	100	<DL	2.247	<DL	<DL	<DL	<DL	73.22	<DL
12-YB-04B	7.63	15	0.55	5483	<DL	<DL	595.5	<DL	2.954	5.768	2.607	5.527	<DL	4.765	5.135
12-YB-05B	8.08	16.7	0.76	5382	<DL	<DL	561.1	<DL	2.998	8.166	2.802	5.386	<DL	11	4.928
12-YB-06B	8.16	11.8	0.66	4804	<DL	<DL	465.1	<DL	2.096	<DL	<DL	2.863	<DL	8.009	2.094
12-YB-07B	7.6	14.7	0.58	4020	<DL	<DL	276.1	<DL	1.916	<DL	<DL	1.738	<DL	23.66	<DL
12-YB-08B	7.84	14.8	0.82	3635	<DL	<DL	1.738	<DL	<DL	1.081	<DL	<DL	<DL	38.05	<DL
12-YB-09B	6.97	18.8	0.55	4145	<DL	<DL	134.6	<DL	2.723	<DL	<DL	4.369	<DL	182.3	1.416
12-YB-10B	8.24	17.1	0.58	5704	<DL	<DL	261.3	<DL	1.415	<DL	<DL	<DL	<DL	2.228	<DL
12-YB11B	7.66	14.9	0.47	5265	<DL	<DL	156.9	<DL	1.743	<DL	3.116	<DL	<DL	16.81	<DL
12-YB-12B	7.1	15.4	0.25	4302	<DL	<DL	126.2	<DL	1.633	<DL	<DL	<DL	<DL	67.89	<DL
12-YB-13B	7.2	14.5	0.33	4181	<DL	<DL	145.1	<DL	1.748	<DL	<DL	<DL	<DL	213	<DL
12-YB-14B	7.97	19.5	0.72	8921	<DL	<DL	233.8	<DL	1.721	<DL	<DL	1.238	<DL	39.57	<DL
12-YB-15B	7.08	18	0.82	4321	<DL	<DL	134.5	<DL	9.282	<DL	<DL	3.434	<DL	25.21	2.182
12-YB-16B	7.09	12.7	0.7	4003	<DL	<DL	167	<DL	4.655	<DL	<DL	1.256	<DL	258.3	1.162
12-YB-17B	7.24	19.6	0.19	3639	<DL	<DL	35.34	<DL	2.029	<DL	<DL	<DL	<DL	64.77	<DL
12-YB-18B	7.94	16	1.75	3025	<DL	<DL	569	<DL	1.863	12.69	<DL	<DL	<DL	20.65	<DL
12-YB-22B				5142	<DL	<DL	88.73	<DL	11.63	<DL	<DL	2.61	<DL	11.83	1.485
SOS									15						
WHO									15-30					3000	

## XRF-DATA

## Appendix 3

Location on quarry sketch	0	0	0	N005	N01	N015	N02	N025	N03	N035	N04
Dist. from a/p-contact (m)	0,00	0,00	0,00	0,43	0,78	1,21	1,65	2,08	2,34	2,86	3,20
Elemental content. wt%											
Mg	2,114	1,007	0	0	0	0	0	0	0	0	0,616
Al	5,372	3,796	3,96	4,795	7,052	8,968	6,03	7,381	1,651	4,81	4,477
Si	17,51	17,394	24,097	37,831	31,516	36,544	36,416	30,431	15,094	36,958	18,652
P	0,172	0,098	0,231	0	0	0	0	0	0,104	0,09	0,17
S	0,163	0,136	0,216	0,161	0,119	0,042	0,052	0,035	0,259	0,187	0,233
Cl	0	0	0	0	0	0	0	0	0	0	0
K	0,945	3,002	1,049	0,486	0,213	0	0	0,094	3,543	0,202	2,376
Ca	1,676	2,14	1,548	1,773	2,764	1,423	0,501	3,294	12,673	0,677	0,432
Sc	0	0	0	0	0	0	0	0	0	0	0
Ti	0,73	0,552	0,094	0,049	0,049	0,071	0	0	0,051	0,052	0,264
V	0,071	0,067	0,049	0	0,038	0	0	0	0	0	0
Cr	0	0	0,027	0	0	0	0	0	0	0	0
Mn	0,202	0,142	0,024	0	0	0,023	0	0	0,017	0	0,055
Fe	15,449	11,438	0,43	0,177	0,125	0,099	0,22	0,099	0,197	0,238	3,972
Co	0	0	0	0	0	0	0	0	0	0	0
Ni	0	0	0	0,006	0	0	0,007	0	0	0	0
Cu	0	0	0	0	0	0	0	0	0	0	0
Zn	0,026	0	0	0	0	0	0	0	0	0	0,01
Y	0	0	0	0	0	0	0	0	0	0	0
Zr	0,0038	0,0084	0,0025	0	0	0,0052	0,004	0,0052	0	0,01	0,0154
Mo	0	0	0	0	0	0	0	0	0	0	0
Ag	0	0,022	0,024	0,02	0,018	0,021	0,022	0,021	0,023	0,023	0,022
Cd	0,022	0,031	0,028	0,028	0,024	0,028	0,026	0,023	0,028	0,025	0,028
Sn	0,033	0,028	0,026	0,031	0,026	0,029	0,026	0,027	0,028	0,029	0,03
Sb	0	0	0,045	0,035	0,038	0,038	0,035	0,037	0,035	0,036	0,039
W	0	0	0	0	0	0	0	0	0	0	0
Pb	0	0	0,0022	0,0019	0,0039	0,0025	0,0024	0	0,0084	0	0,0041
Bi	0	0	0	0	0	0	0	0	0	0	0
LE	55,509	60,138	68,146	54,604	58,014	52,705	56,658	58,553	66,288	56,663	68,607
Total	100	100	100	100	100	100	100	100	100	100	100
CPM	21			22	31	27	21	32		26	40

Location on quarry sketch	E01	E02 (A)	E02 (B)	E03	E04	E045	E05	E056	E06	E07	E08
Dist. from a/p-contact (m)	4,24	4,76	4,76	5,63	6,06	6,84	7,10	7,62	7,97	8,57	7,45
Elemental content. wt%											
Mg	0	0	0	0,872	0	0	0	0	0	0	0
Al	4,345	6,538	5,467	4,448	3,219	7,381	2,722	4,722	4,552	9,212	0,273
Si	21,118	30,606	28,945	24,066	31,318	27,574	23,195	36,325	28,818	33,04	45,285
P	0,157	0,116	0,097	0,056	0	0	0,153	0	0	0	0,128
S	0,209	0,096	0,147	0,049	0	0,144	0,235	0,304	0,491	0	0,059
Cl	0	0	0	0	0	0	0	0	0	0	0
K	1,98	9,895	5,673	5,216	1,887	0,75	0,751	1,426	1,226	0,41	0
Ca	1,445	0	0	0,405	0,907	4,019	0,954	0,397	1,564	2,886	0
Sc	0	0	0	0	0	0	0	0	0	0	0
Ti	0,301	0,06	0,185	0,123	0	0	0,058	0,086	0,109	0,052	0
V	0	0	0,046	0	0	0	0	0	0,047	0	0
Cr	0	0	0	0	0	0	0	0	0	0	0
Mn	0,071	0,027	0,02	0,026	0	0	0	0	0	0	0
Fe	3,768	0,233	1,459	0,827	0,078	0,172	0,15	0,275	0,347	0,1	0,029
Co	0	0	0	0	0	0	0	0	0	0	0
Ni	0	0	0	0	0	0	0	0,006	0	0,007	0
Cu	0	0	0	0	0	0	0	0	0	0	0
Zn	0	0	0	0	0	0	0	0	0	0	0
Y	0	0	0	0	0	0	0	0	0	0	0
Zr	0,0162	0	0,0046	0,0032	0	0,0046	0,0027	0	0	0	0
Mo	0	0	0	0	0	0	0	0	0	0	0
Ag	0,022	0,022	0,025	0,019	0,022	0,015	0,02	0,02	0,02	0,022	0,021
Cd	0,03	0,029	0,031	0,028	0,025	0,026	0,022	0,024	0,025	0,027	0,026
Sn	0,032	0,037	0,031	0,027	0,029	0,024	0,023	0,028	0,028	0,029	0,032
Sb	0,042	0,051	0,045	0,038	0,046	0,032	0,035	0,036	0,042	0,04	0,033
W	0	0	0	0	0	0	0	0	0	0	0
Pb	0,0032	0,008	0,0082	0,0048	0	0,0031	0	0,0022	0,0019	0,0042	0
Bi	0	0	0	0	0	0	0	0	0	0	0
LE	66,461	52,279	57,818	63,79	62,469	59,855	71,678	56,347	62,728	54,172	54,115
Total	100	100	100	100	100	100	100	100	100	100	100
CPM	34	28	28	35	24	38	18	22	25	20	17

Location on quarry sketch	E09	E10	E11	E12 (A)	E12 (B)	E13	E14	E15	E153	E155 (A)	E155 (C)
Dist. from a/p-contact (m)	8,31	7,53	9,27	10,39	10,39	9,61	9,79	9,01	9,01	9,01	9,01
Elemental content. wt%											
Mg	0	0	0	0	0	0	0	0	0	0	0
Al	0,384	5,063	7,932	4,245	3,731	9,597	5,186	6,824	3,784	5,592	11,633
Si	47,641	22,672	34,016	22,592	20,982	36,515	22,592	27,787	14,285	12,498	30,926
P	0	0,154	0,116	0,196	0,114	0	0	0,143	0,185	3,65	0
S	0,064	0,341	0,273	0,348	0,162	0,035	0,094	0,156	0,152	0,094	0
Cl	0	0,187	0	0	0	0	0	0	0	0	0
K	0	0,187	0,391	0,588	0,764	0,279	0,37	1,621	0,739	0,206	0,942
Ca	0	1,899	2,62	2,157	0,877	1,945	1,318	0,228	0,814	12,143	2,721
Sc	0	0	0	0	0	0	0	0	0	0	0
Ti	0	0	0	0,049	0	0,042	0	0,062	0,056	0,196	0
V	0	0	0	0	0	0	0	0,043	0,048	0,699	0
Cr	0	0	0	0	0	0	0	0	0	0,407	0
Mn	0	0	0	0	4,387	0	0	0,018	0	0,543	0,036
Fe	0,03	0,061	0,077	0,154	10,478	0,075	0,089	0,213	0,43	5,221	0,748
Co	0	0	0	0	0	0	0	0	0	0,097	0
Ni	0	0	0,007	0,008	0,017	0	0	0,007	0	0,112	0,012
Cu	0	0	0	0	0,018	0	0	0	0	0,038	0
Zn	0	0	0	0	0	0	0	0	0	0,035	0
Y	0	0	0	0	0	0	0	0	0	0	0
Zr	0	0,0074	0,003	0	0,02	0	0	0,0061	0,0072	0,087	0,0059
Mo	0	0	0	0	0,0046	0	0	0	0	0	0
Ag	0,018	0,023	0,023	0,023	0,023	0,021	0,02	0,02	0,014	0	0,024
Cd	0,024	0,029	0,03	0,027	0,034	0,0027	0,025	0,026	0,018	0	0,029
Sn	0,026	0,035	0,031	0,028	0	0,034	0,033	0,027	0	0	0,025
Sb	0,034	0,041	0,042	0,041	0	0,04	0,039	0,038	0	0	0,037
W	0	0	0	0	0	0	0	0	0	0	0
Pb	0	0,0025	0,006	0	0	0,0053	0,0047	0,0028	0	0,021	0,003
Bi	0	0	0	0,0027	0	0	0	0	0,044	0,748	0
LE	51,779	69,484	54,433	69,541	58,387	51,386	70,23	62,779	73,369	57,613	52,856
Total	100	100	100	100	100	100	100	100	94	100	100
CPM	14	22	27	24	36	24	28	77	434	1719	1203

Location on quarry sketch	E16	E17	E18	E19	E20	E21	E22	E23	E24	E25	E26 (A)
Dist. from a/p-contact (m)	9,27	9,35	9,18	8,83	8,40	8,40	7,88	7,79	8,05	8,75	9,44
Elemental content. wt%											
Mg	0	0	0	0	0	0	0	0	0	0	0
Al	8,163	2,967	6,947	7,528	6,775	6,133	7,283	6,831	6,794	4,932	6,061
Si	28,878	12,971	34,181	31,525	28,972	33,7	32,485	27,544	35,553	36,675	30,926
P	0,176	0,067	0,045	0	0	0,056	0,038	0,124	0	0,159	0,152
S	0	0,077	0,029	0	0	3,11	0	0,166	0	0,042	0,09
Cl	0	0	0	0	0	0	0	0	0	0	0
K	0,63	0,56	0	13,795	0	0	14,262	9,55	0,648	5,679	0,631
Ca	0,23	1,405	1,078	0	0,605	0,168	0	0,423	1,461	0	1,609
Sc	0	0	0	0	0	0	0	0	0	0	0
Ti	0,051	0,074	0,042	0,054	0,051	0	0,127	0,121	0	0,047	0,064
V	0	0,035	0	0	0	0	0,111	0,085	0	0	0
Cr	0	0	0	0,024	0	0	0	0	0	0	0
Mn	0	0,018	0	0	0	0	0	0,023	0	0	0,022
Fe	0,1	0,129	0,043	0,053	0,046	0,081	0,044	0,055	0,096	0,143	0,314
Co	0	0	0	0	0	0	0	0	0	0	0
Ni	0	0,006	0,007	0,007	0,007	0	0	0	0	0	0,008
Cu	0	0	0	0	0	0	0	0	0	0	0,008
Zn	0	0	0	0	0	0	0	0	0	0	0,0153
Y	0	0	0	0	0	0	0	0	0	0	0
Zr	0,0042	0,0063	0,0054	0,0024	0	0,0048	0,0039	0,0048	0,0048	0	0
Mo	0	0	0	0	0	0	0	0	0	0	0
Ag	0,02	0,019	0,02	0,018	0,021	0,025	0,019	0,022	0,0023	0,019	0,02
Cd	0,027	0,027	0,027	0,026	0,03	0,028	0,023	0,029	0,026	0,027	0,023
Sn	0,035	0,025	0,026	0,031	0,027	0,028	0,03	0,035	0,029	0,031	0,022
Sb	0,034	0,038	0,036	0,037	0,042	0,043	0,04	0,043	0,04	0,031	0,034
W	0	0	0	0	0	0	0	0	0	0	0
Pb	0	0	0	0,0077	0,0041	0	0,003	0,0033	0,0017	0,0049	0,0028
Bi	0	0	0	0	0	0	0	0	0	0	0
LE	61,651	81,575	57,514	46,89	63,42	56,624	45,532	54,943	55,324	52,209	60,001
Total	100	100	100	100	100	100	100	100	100	100	100
CPM	121	37	36	36	45	33	20	45	40	91	77

Location on quarry sketch	E26 (B)	E265	E27	E275	E28	E29	E31	W34	W33	W32	W315 (A)
Dist. from a/p-contact (m)	9,44	9,01	8,92	9,09	9,09	9,61	9,44	6,32	7,01	6,75	7,10
Elemental content. wt%											
Mg	0	1,333	0,951	0	0	0	0	0	0	0	0
Al	3,708	5,021	5,041	7,369	8,155	10,12	6,541	2,531	3,97	3,93	8,161
Si	10,77	14,659	11,419	12,339	24,909	22,865	22,758	15,999	24,529	20,791	28,748
P	0,315	0,209	0,253	0,554	0,4	0,184	1,027	0,514	0,286	0,292	0
S	0,191	0,221	0,218	0,184	0,187	0,074	0,122	0,323	0,23	0,182	0,203
Cl	0	0	0	0	0	0	0	0	0	0	0
K	0,585	0,829	1,007	0,292	0,591	2,589	2,746	2,065	3,019	0,575	2,334
Ca	2,412	3,664	2,047	1,869	0,342	0,154	3,385	1,369	0,667	2,528	6,215
Sc	0	0	0,264	0	0	0	0	0	0	0	0
Ti	0,3	0,23	0	2,143	0,058	0,045	0	0,231	0,209	0,444	0
V	0,084	0	0,04	0	0	0	0	0,05	0	0	0,046
Cr	0	0	0,057	0,059	0	0	0	0	0	0	0
Mn	0,213	0,129	0,131	0,198	0	0	0,02	0,076	0,048	0,079	0,077
Fe	11,892	8,997	13,97	8,189	0,142	0,636	0,582	3,554	3,622	6,075	2,647
Co	0	0	0	0	0	0	0	0	0	0	0
Ni	0	0	0	0	0,007	0	0	0	0	0	0
Cu	0	0,044	0,013	0,019	0	0	0	0	0	0	0
Zn	0,053	0,022	0,071	0,035	0	0	0	0	0	0	0
Y	0	0	0	0	0	0	0	0	0	0	0
Zr	0,0044	0,0052	0,0061	0,097	0,0031	0,0036	0,07	0,0379	0,0259	0,011	0,0171
Mo	0	0	0	0	0	0	0	0	0	0	0
Ag	0,03	0,025	0	0,018	0,021	0,017	0,019	0,021	0,021	0,018	0,02
Cd	0,038	0,034	0,026	0,025	0,026	0,025	0,024	0,027	0,025	0,027	0,029
Sn	0	0,028	0	0,029	0,024	0,031	0,03	0,024	0,025	0,03	0,023
Sb	0,047	0,044	0,031	0,033	0,037	0,039	0,032	0,034	0,038	0,041	0,037
W	0	0	0	0	0	0	0	0	0	0	0
Pb	0,007	0,0033	0,036	0,04	0	0,0027	0,0041	0,0045	0	0,0022	0,012
Bi	0	0	0	0,047	0	0	0,023	0	0	0	0
LE	69,352	64,503	64,42	66,459	65,097	63,215	62,617	73,14	63,284	64,976	51,43
Total	100	100	100	100	100	100	100	100	100	100	100
CPM	105	38	26	41	37	35	125	29	29	60	297

Location on quarry sketch	W315 (B)	W31	W30	W29	W28	W275	W27	W26	W25	W24	W23
Dist. from a/p-contact (m)	7,10	7,27	6,93	6,41	6,24	4,59	3,81	2,86	2,77	2,42	2,34
Elemental content. wt%											
Mg	0	0	0	0	0	0	0	0	0	0	0
Al	1,943	9,327	7,308	1,636	7,217	1,522	4,123	4,67	5,839	0,957	0,722
Si	8,537	30,52	30,552	8,144	29,933	25,713	20,714	16,67	20,808	48,447	44,209
P	0,4	0	0,195	0,225	0,077	0,314	0,316	0,304	0,736	0,056	0,179
S	0,699	0,064	0,047	0,684	0	0,332	0,266	0,29	0,249	0,172	0,226
Cl	0	0	0	0	0	0	0	0	0	0	0
K	1,833	2,249	0,086	1,527	4,09	0,546	7,445	8,869	4,918	0,106	0
Ca	1,698	1,571	2,993	2,171	0,516	0	0	0,33	0,239	0	0
Sc	0	0	0	0	0	0	0	0	0	0	0
Ti	0,161	0,06	0	0	0,058	0,04	0,072	0,088	0,065	0	0
V	0	0	0	0	0	0	0,065	0,088	0	0	0
Cr	0	0	0	0	0	0	0	0	0	0	0
Mn	0,033	0,03	0	0	0,02	0	0	0	0	0	0
Fe	0,918	0,24	0,068	0,061	0,655	0,285	0,193	0,284	0,221	0,112	0,076
Co	0	0	0,008	0	0	0	0	0	0	0	0
Ni	0	0	0	0,007	0	0,006	0	0,012	0	0	0,006
Cu	0	0	0	0	0	0	0	0	0	0	0
Zn	0	0	0	0,0057	0	0	0	0	0	0	0
Y	0	0	0	0	0	0	0	0	0	0	0
Zr	0,133	0,0052	0,005	0	0,002	0	0	0,0025	0,0025	0	0
Mo	0	0	0	0	0	0	0	0	0	0	0
Ag	0,015	0,017	0,018	0,02	0,021	0,018	0,02	0,019	0,024	0,018	0,018
Cd	0,021	0,026	0,028	0,03	0,024	0,024	0,029	0,024	0,029	0,021	0,025
Sn	0,026	0,024	0,029	0,031	0,03	0,024	0,033	0,028	0,028	0,03	0,028
Sb	0	0,035	0,035	0,046	0,04	0,035	0,042	0,041	0,046	0,032	0,036
W	0	0	0	0	0	0	0	0	0	0	0
Pb	0,022	0,0082	0,0026	0,013	0,0021	0	0	0	0,0022	0	0
Bi	0,009	0	0	0	0	0	0	0	0	0	0
LE	83,553	55,823	58,625	85,4	57,316	71,142	66,681	68,28	66,793	50,048	54,475
Total	100	100	100	100	100	100	100	100	100	100	100
CPM	310	121	28	25	34	16	32	31	29	27	40

Location on quarry sketch	W226	W223	W223	W22	W216	W213	W213	W213	W213	W213	W21
Dist. from a/p-contact (m)	2,42	2,42	2,42	2,51	2,17	1,91	1,91	1,91	1,91	1,91	2,34
Elemental content. wt%											
Mg	0	0	0	1,055	0,999	0	0	0,914	0	0	0
Al	1,865	5,103	9,642	1,037	0,724	0,58	1,279	2,359	0,486	0,861	2,458
Si	37,442	34,178	73,117	7,899	2,281	4,169	3,683	7,992	1,377	3,731	19,243
P	0	0,11		0	0,019	0,053	0,139	0,053	0,021	0,027	0,126
S	0,134	0,273		0,057	0,048	0,193	0,19	0,073	0,036	0	0,24
Cl	0	0		4,466	6,443	5,618	7,578	1,288	9,121	5,133	0
K	0	0,824	0,993	2,019	0,528	0,86	1,066	0,723	0,561	1,108	1,111
Ca	0	2,219	3,105	1,044	0,879	1,077	1,279	1,099	1,742	0,88	2,383
Sc	0	0		0	0	0	0	0	0	0	0
Ti	0	0		0,069	0,081	0	0,099	0,058	0,136	0,044	0,342
V	0	0		0,051	0	0	0,071	0	0,16	0,035	0,06
Cr	0	0		0	0	0	0	0	0,12	0	0,03
Mn	0	0	0	0,016	0,013	0,036	0,065	0,022	0,464	0,03	0,094
Fe	0,103	0,291		0,618	0,36	0,604	1,055	0,601	3,648	0,619	0,636
Co	0	0		0	0	0,031	0,152	0	0,477	0	0,129
Ni	0	0		0,007	0,011	0,034	0,263	0,011	0,644	0,016	0,212
Cu	0	0		0,009	0	0,014	0,139	0	0,505	0,007	2,051
Zn	0	0		0,01	0,0075	0,013	0,101	0	0,214	0	0
Y	0	0		0	0	0	0	0	0	0	0
Zr	0	0,0035		0,0021	0	0,08	1,179	0,0047	0,09	0,0088	0,033
Mo	0	0		0	0	0	0	0	0	0	0,0065
Ag	0,021	0,021		0,023	0,021	0	0	0,02	0	0,017	0
Cd	0,026	0,026		0,03	0,026	0	0	0,025	0	0,023	0
Sn	0,029	0,026		0,031	0,025	0	0	0,032	0	0,029	0
Sb	0,041	0,035		0,033	0,038	0	0	0,004	0	0,034	0
W	0	0		0	0	0	0,048	0	0,27	0	1,105
Pb	0	0,0023		0,0042	0,005	0,182	0,085	0	0,056	0,013	0,071
Bi	0	0		0	0	0,264	0,217	0	0,279	0	0
LE	60,339	56,889	13	81,52	87,489	86,193	81,312	84,678	79,595	87,337	69,606
Total	100	100	100	100	100	100	100	100	100	100	100
CPM	27	27		40		1600	1600			278	328

Location on quarry sketch	W20	W203	W20	W19	W18	W179	W17	W17	W16	W155	W15
Dist. from a/p-contact (m)	2,60	2,42	2,60	2,51	2,34	2,34	2,42	2,42	2,25	2,08	1,82
Elemental content. wt%											
Mg	1,614	1,091	0	0	0	0	0	0	0	0	0,96
Al	4,623	6,526	5,04	6,647	6,764	3,344	4,148	8,146	6,419	6,629	4,1
Si	17,031	23,071	40,378	28,565	23,064	11,933	26,505	17,45	32,927	30,117	12,583
P	0,027	0,07	0,038	0,038	0,295	0,389	0	0	0	0,048	2,664
S	0,074	0,108	0,13	0,156	0,106	0,378	0,453	0,171	0,28	0,161	0,279
Cl	0	0	0	0	0	0	0	0	0	0	0
K	0	1,54	0,853	0,924	6,066	0,786	3,885	4,56	0,402	0	0,528
Ca	2,238	2,116	1,139	2,019	0,496	1,826	1,675	4,587	2,899	3,805	1,403
Sc	0	0	0	0	0	0	0	0	0	0	0
Ti	1,22	1,096	0	0	0,09	0,116	0,056	0,06	0	0	0,325
V	0,054	0	0	0	0,121	0,629	0	0,042	0	0	0,056
Cr	0	0	0	0	0,105	0,465	0	0	0	0	0
Mn	0,151	0,279	0	0,024	0,064	0,606	0	0,048	0	0	0,164
Fe	12,081	23,255	0,274	0,469	0,508	2,63	0,201	2,707	0	0,079	10,108
Co	0	0,189	0	0	0	0,057	0	0	0	0	0,092
Ni	0	0	0,014	0	0,014	0,046	0	0	0,008	0	0,092
Cu	0,013	0	0	0	0	0,013	0	0	0	0	0,111
Zn	0,019	0,048	0	0	0,013	0,015	0	0	0	0	0,057
Y	0	0	0	0	0	0	0	0	0	0	0
Zr	0	0	0,006	0	0,0054	0,049	0	0,003	0,0057	0,0047	0,988
Mo	0	0	0	0	0	0	0	0	0	0	0
Ag	0,025	0	0,024	0,022	0,021	0	0,022	0,023	0,023	0,025	0
Cd	0,029	0,025	0,028	0,033	0,027	0	0,03	0,028	0,029	0,029	0
Sn	0,035	0	0,03	0,035	0,035	0	0,028	0,055	0,029	0,029	0
Sb	0,046	0,036	0,04	0,045	0,039	0	0,039	0,044	0,035	0,032	0
W	0,013	0	0	0	0	0	0	0,014	0	0	0
Pb	0	0	0,002	0,0027	0,0043	0	0,0033	0,0056	0	0	0,053
Bi	0	0	0	0	0	0,57	0	0,01	0	0	0,151
LE	60,708	40,55	52,007	61,02	62,162	76,148	62,957	62,045	56,786	59,041	65,282
Total	100	100	100	100	100	100	100	100	100	100	100
CPM			80	62	165	762	19				1883

Location on quarry sketch	W15	W14	W13	W12	W11	W10	W09	W08	W075	W075	W075
Dist. from a/p-contact (m)	1,82	1,73	1,30	0,87	0,52	0,26	0,26	0,00	0,17	0,09	0,04
Elemental content. wt%											
Mg	0	0	0	0	0	0	0	0	0	0	1,305
Al	6,757	6,252	9,08	4,671	5,521	3,326	4,853	4,794	8,511	5,31	5,82
Si	32,454	31,639	30,114	29,626	33,637	29,459	36,715	35,573	31,736	30,934	19,662
P	0,045	0	0,101	0,052	0	0	0	0	0	0	0,04
S	0,213	0,143	0,055	0,382	0,319	0,455	0,147	0,292	0,112	0,209	0,115
Cl	0	0	0	0	0	0	0	0	0	0	0
K	1,578	0	1,164	0,36	0	1,13	7,193	0,117	0,245	0,81	1,888
Ca	1,616	0,788	0,561	2,902	3,307	1,985	0	2,014	3,67	2,233	1,671
Sc	0	0	0	0	0	0	0	0	0	0	0
Ti	0	0	0	0,054	0	0	0,066	0	0	0	0,549
V	0	0	0	0	0	0	0	0	0	0	0,053
Cr	0	0	0,022	0	0	0	0	0,023	0	0	0
Mn	0,019	0	0	0,023	0	0,025	0	0	0	0,02	0,112
Fe	0,149	0,081	0,135	0,258	0,096	0,309	0,129	0,116	0,179	0,208	10,03
Co	0	0	0	0	0	0	0	0	0	0	0
Ni	0	0	0,008	0	0	0	0,008	0	0	0	0
Cu	0	0	0	0	0	0	0	0	0	0	0
Zn	0	0	0	0	0	0	0	0	0	0	0
Y	0	0	0	0	0	0	0	0	0	0	0
Zr	0	0,0044	0	0,004	0,0042	0,0049	0	0	0,0042	0,0044	0,0229
Mo	0	0	0	0	0	0	0	0	0	0	0
Ag	0,018	0,019	0,022	0,016	0,022	0,02	0,026	0,02	0,025	0,023	0
Cd	0,024	0,028	0,031	0,026	0,029	0,029	0,028	0,029	0,027	0,028	0,024
Sn	0,03	0,026	0,031	0,027	0,029	0,028	0,025	0,032	0,027	0,027	0
Sb	0,038	0,033	0,041	0,032	0,041	0,037	0,039	0,044	0,04	0,041	0,03
W	0	0	0	0	0	0	0	0	0	0	0
Pb	0,0059	0	0,005	0,0021	0	0	0,0092	0,0019	0,0037	0,0033	0
Bi	0	0	0	0	0	0	0	0	0	0	0
LE	57,052	60,988	58,63	61,565	56,995	63,191	50,763	56,945	55,42	60,148	58,679
Total	100	100	100	100	100	100	100	100	100	100	100
CPM		136	28	36	25		23	29			

Location on quarry sketch	W075	W075	W07	W06	W05	W04	W03	W02	W01
Dist. from a/p-contact (m)	0,03	0,00	0,17	0,13	0,00	0,09	-0,43	-0,52	-0,95
Elemental content. wt%									
Mg	0	2,102	4,582	0,7	0	0	0	0,811	0
Al	2,262	5,24	5,31	4,711	2,116	3,923	2,91	4,577	5,102
Si	13,455	21,905	22,322	36,006	36,98	29,612	23,855	15,145	16,767
P	0,122	0,078	0	0	0	0,123	0,044	0,324	0,191
S	0,638	0,158	0,082	0,268	0,542	0,512	0,235	0,269	0,348
Cl	0	0	0	0	0	0	0	0	0
K	1,459	0,381	1,147	2,445	0,344	0,871	0,049	2,997	0,724
Ca	1,946	1,951	4,333	3,149	2,749	6,699	1,355	5,396	7,194
Sc	0	0	0	0	0	0	0	0	0
Ti	0,471	0,538	0,659	0,534	0,203	0,269	0	0,333	0,454
V	0,065	0,076	0,069	0	0	0,07	0	0,064	0,059
Cr	0	0	0	0	0	0	0	0	0
Mn	0,102	0,18	0,205	0,125	0,121	0,423	0,016	0	0,146
Fe	10,742	17,023	14,451	6,733	6,358	10,348	0,297	7,769	8,34
Co	0,108	0	0	0	0,104	0	0	0	0
Ni	0	0	0	0	0	0	0	0	0
Cu	0	0	0	0	0	0	0	0	0
Zn	0,016	0,021	0,018	0,016	0	0,022	0	0,013	0
Y	0	0	0	0	0	0	0	0	0
Zr	0,0067	0,0042	0,0034	0,0044	0,0095	0,0054	0	0,0094	0,01
Mo	0	0	0	0	0	0	0	0	0
Ag	0	0	0,024	0,021	0,02	0,021	0,02	0,017	0,021
Cd	0	0,029	0,033	0,028	0,029	0,029	0,027	0,026	0,032
Sn	0	0	0,026	0,03	0,026	0,036	0,028	0,023	0,026
Sb	0	0,031	0,033	0,037	0,033	0,037	0,036	0,032	0,04
W	0	0	0	0	0	0	0	0	0
Pb	0	0	0	0,0035	0,009	0	0	0	0
Bi	0,012	0	0	0	0	0	0	0	0
LE	68,595	50,277	46,702	45,191	50,355	46,993	71,129	62,073	60,545
Total	100	100	100	100	100	100	100	100	100
CPM	26		25	17	22	17	21	16	21

Location on quarry sketch	0,5 m into "a"	1 m into "a"	1,2 m into "a"	1,7 m into "a"	2 m into "a"
Dist. from a/p-contact (m)					
Elemental content. wt%					
<b>Mg</b>	0	0,741	0	1,812	0,941
<b>Al</b>	8,141	10,6	4,096	3,791	2,994
<b>Si</b>	26,962	33,573	17,857	16,566	12,554
<b>P</b>	0,102	0,104	0,27	0,196	0,328
<b>S</b>	0,06	0,062	0,229	0,215	0,391
<b>Cl</b>	0	0	0	0	0
<b>K</b>	0,907	0,623	1,761	0,9	1,171
<b>Ca</b>	4,588	4,451	4,848	5,807	4,674
<b>Sc</b>	0	0	0	0	0
<b>Ti</b>	0,491	0,268	0,701	0,47	0,451
<b>V</b>	0,078	0	0,134	0,081	0,072
<b>Cr</b>	0	0	0	0	0
<b>Mn</b>	0,141	0,12	0,152	0,152	0,191
<b>Fe</b>	8,689	6,897	9,855	9,294	9,71
<b>Co</b>	0	0	0	0	0
<b>Ni</b>	0	0	0	0	0
<b>Cu</b>	0	0	0	0	0
<b>Zn</b>	0	0	0,026	0	0,042
<b>Y</b>	0	0	0	0	0
<b>Zr</b>	0,0087	0,009	0,0042	0,008	0,0084
<b>Mo</b>	0	0	0	0	0
<b>Ag</b>	0,022	0,02	0,031	0,02	0,023
<b>Cd</b>	0,025	0,027	0,032	0,029	0,028
<b>Sn</b>	0,025	0,024	0,03	0	0,029
<b>Sb</b>	0,042	0,035	0,036	0,037	0,036
<b>W</b>	0	0	0	0	0
<b>Pb</b>	0	0	0	0	0
<b>Bi</b>	0	0	0	0	0
<b>LE</b>	49,718	42,367	59,937	60,621	66,357
<b>Total</b>	100	100	100	100	100
<b>CPM</b>					