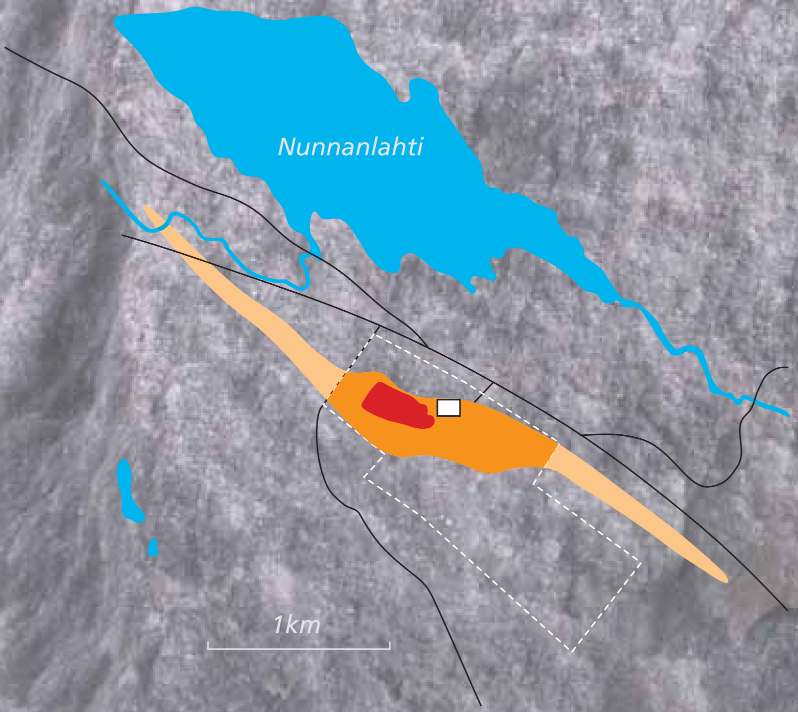
Summary of the results of the materials research conducted in 1994-2001 for the MammuttiStone mine of Nunnanlahden Uuni Oy

Research of Kivitieto Oy, Finland,
under Aulis Kärki and Seppo Gehör



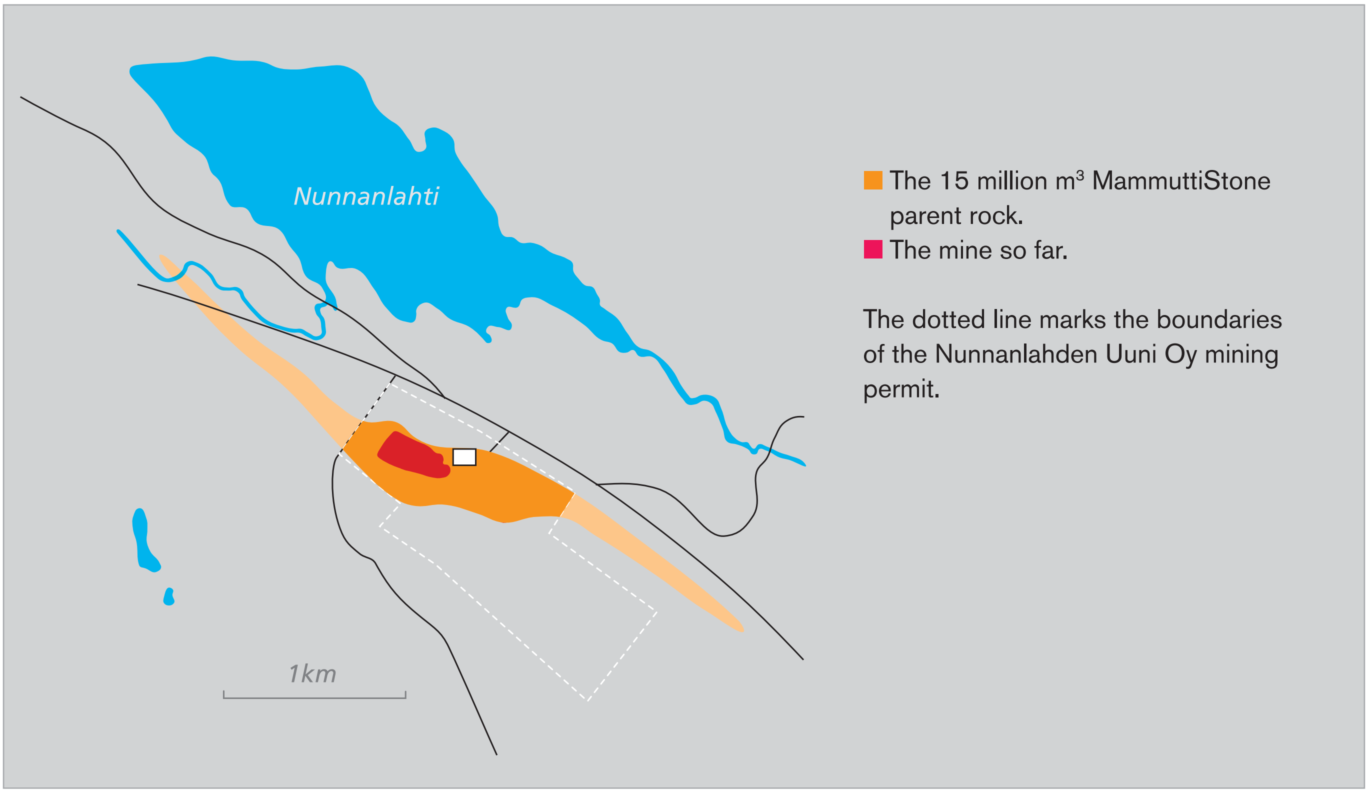
Sintef, Norway: 1994
XRAL, Canada: 2000
Institute of Electron Optics of the University of Oulu,
Finland: 1994-2001

SOAPSTONE – A RARE COMPONENT OF THE EARTH’S CRUST

Soapstone is a metamorphic rock. It originated from mineral reactions that occurred at quite high pressure and temperature. Globally **soapstone** is rather rare, and it in fact consists of foreign formations in the earth’s crust, since the source material originates from the rock material in the layer below the earth’s crust – the mantle. The mantle is ultra-alkaline in nature, as it consists of stone types with a significantly lower ratio of silicon to other major elements than the typical stone types in the crust do. Instead of silicon, the ultra-alkaline stones consist largely of magnesium and iron, which is why their specific weight is considerably greater than that of more common stone types. The higher density in comparison to stone types found in the earth’s crust, approximately 3.0 t/m^3, is characteristic of ultra-alkaline soapstone as well.

The term ‚soapstone’ is applied to various type of stone with differing mineral composition and other qualities. The only attribute common to the various soapstone types is that they can be worked fairly easily due to their high talc content. **Other qualities, such as heat resistance and heat storage capacity, vary greatly, and therefore not all types of stone in this category have the qualities required of stove-building materials.**

The soapstone in Nunnanlahden Uuni Oy’s MammuttiStone deposit drifted to the planet’s crust from the mantle as early as approximately 2,700 million years ago. In a reaction caused by mountain folding, part of the ocean floor and the mantle beneath it, as a so-called ophiolite complex, intruded into a foreign environment, among granite and other stone types in the earth’s crust. A clearly outlined section of the ophiolite complex – i.e., a specific ultra-alkaline stone type – was transformed into soapstone; the metamorphoses occurred under high pressure and at high temperatures. The introduction of carbon dioxide to the original stone mass from an external source enabled the formation of the other main component of soapstone, a carbon mineral called magnesite. The origin of the other main component, talc, is connected to these same alterations, where the chemical compo-



Picture 1. *The MammuttiStone deposit and the mine district.*

sition of the original stone type underwent a dramatic change – a phenomenon called metasomatosis.

The final appearance of the MammuttiStone deposit's soapstone is the result of a series of mountain foldings. During these tectonic events, which shaped the whole of the earth's crust, the material was ground under heavy pressure numerous times in a gruelling process lasting dozens of millions of years. The MammuttiStone soapstone constitutes an elongated, lenticular rock deposit, the geometric shape of which is the result of the above-mentioned tectonic movements.

A significant part of this deposit consists of an exceptionally high-grade soapstone variant called MammuttiStone, which mainly consists of magnesite and foliated talc. The location of the mine and the mine district outlining the MammuttiStone deposit are shown in *Picture 1*. The information about the location of the deposit is based on the studies conducted by Nunnanlahden Uuni Oy.

The ingrained foliation or the cleavage structure of MammuttiStone follows the longitudinal axis of the deposit. In the last developmental phase, the soapstone's talc cleavage planes ‚crinkled' under the north-southward tectonic pressure. Due to the combined effect of all these phenomena, the MammuttiStone is strongly foliated; in other words, there is a distinct cleavage structure. The microstructure of this rare soapstone variant makes it exceptionally suitable as a fireplace building material.

MammuttiStone as a fireplace building material

MammuttiStone consists mainly of magnesite, and of flaky, foliated talc. This type of talc-magnesite soapstone is ideal for building fireplaces.

The stone types found in the MammuttiStone deposit are not of uniform quality, nor are they the same type of soapstone. Instead, the deposit consists of several different variants, which can be applied for different purposes. **If an appropriate MammuttiStone variant is chosen for each element, MammuttiStone can be used to build long-lasting fireplaces that satisfy even the most demanding of customers.**

The highest thermal stress is exerted on specific structures in a fireplace. MammuttiStone is a durable and well-functioning material for these constructions, provided that they are manufactured from a fine-grained, correctly foliated type of MammuttiStone, which includes flaky, foliated talc. The variants that include coarse-grained magnesite are best applied in flues and other elements of fireplaces that do not reach temperatures over 500 ºC. Naturally, the coarse-grained MammuttiStone can also be used for the exterior of the fireplace, since it does not heat up to over 200 ºC.

MammuttiStone for heat storage and conduction

The materials used for fireplaces need to have a good heat storage capacity and conduct heat effectively. For stone types of small porosity, the heat storage capacity and specific heat capacity are directly determined by the mineral composition of the rock. Both magnesite and talc have distinct, scientifically determinable specific heat capacity values. The specific heat capacity of MammuttiStone consisting of half talc, half magnesite can be calculated from the constituents. The specific heat capacity of MammuttiStone has been determined by testing three samples representing the production materials; the results indicate that at 0 ºC it is 790–820 J/kgK and increases to 910–930 J/kgK at 50 ºC.

The foliation makes the MammuttiStone anisotropic; i.e., its capacity to conduct heat in different directions varies. It is proportional to qualities such as stone composition and foliation. Schist rocks, including MammuttiStone with strong planar foliation, linear crinkles, and less linear foliation ***(Picture 2)*** have their own distinct thermal conductivity and heat resistance properties.

A cleavage structural MammuttiStone with planar foliation has the highest thermal conductivity parallel to the cleavage plane and the lowest in directions perpendicular to it. The absolute thermal conductivity value depends on the temperature and is determined by the mineral composition and average grain size of the MammuttiStone. The thermal conductivity value for a cleavage structural talc-magnesite type of MammuttiStone at 50 ºC is normally 2–4 W/mK perpendicular to the cleavage plane and 4–5.5 W/mK parallel to it. Therefore, MammuttiStone with planar foliation can be applied in elements where efficient use can be made of the ratio between thermal conductivity and foliation. Different tests have also proved that the foliated, fine-grained MammuttiStone variant with magnesite can endure extreme thermal stress.

The lineated MammuttiStone variants with curly, crinkled talc have a thermal conductivity that is good in one linear direction and considerably worse in directions perpendicular to that. Also, the absolute thermal conductivity values of lineated soapstone are proportional to the temperature of the material and the grain size of the stone. The tests have shown that the thermal conductivity value of lineated MammuttiStone at 50 ºC is 4–5.5 W/mK in the direction of the lineation and, by contrast, 2–3 W/mK perpendicular to it. **Fine-grained MammuttiStone** with minimal folding or crinkles in the planar cleavage structure is of **highest quality** and withstands severe thermal stress the best; it can therefore be used for elements subjected to such thermal stress. **The high thermal shock ratings** of the MammuttiStone type clearly indicate this desirable quality.

A. **B.** **C.**

Picture 2.

- A. *Lineated MammuttiStone. Best applicable where the elements are subjected to the most severe thermal stress (e.g., inside the furnace, near the hottest part of the flame).*
- B. *Foliated MammuttiStone that is either fine- or coarse-grained. Best applied in those elements of a fireplace where the relationship between the direction of the foliation and the thermal conductivity can be efficiently utilised.*
- C. *Coarse-grained MammuttiStone with less foliation. Applicable in the coolest elements and the exterior of the fireplace, due to its good heat storage qualities. Because of the high thermal conductivity values, it causes heat to circulate from the hottest to the coolest stones and efficiently reduces heat loss.*

MammuttiStone with less foliation has almost isotropic qualities. The absolute thermal conductivity values thereof are determined, as explained earlier, by the temperature, the composition, and the average grain size of the material. Large grain size leads to high thermal conductivity. Coarse-grained MammuttiStone does not withstand dramatic temperature changes very well, but it can be used, for example, on the exterior structural elements, which are not heated to above 500 °C, and in which the excellent thermal conductivity in the direction of the structure can be utilised to distribute heat to all other elements of the fireplace.

Resistance to thermal stress and rapid temperature changes

The DIN 51068, Part 1 test is a widely approved method in the measurement of resistance of any material to thermal shock – i.e., to repeated sudden temperature changes. In the DIN 51068 thermal shock test, soapstone is exposed to noticeably more severe thermal stress than is encountered at any time in normal stove use. Nevertheless, the test still gives an accurate picture of the suitability of the tested material for thermally demanding conditions. The test is carried out by placing a dry stone cylinder in a temperature of 950 °C for 15 minutes, after which it is submerged for five minutes in running water at 20 °C; then, the test piece is allowed to dry in the desiccator oven. The treatment is repeated as many times as needed to split the test cylinder into two or more pieces.

Based on the results of this test, the internal structure (i.e., the texture) of MammuttiStone has proven to be the other central factor contributing to durability, the first being the stone’s mineral composition. MammuttiStone consisting of fine-grained magnesite and flaky talc, foliated in the direction of the crinkles, excels in the test and receives nearly the maximum rating for thermal shock resistance. The coarse-grained, inhomogeneous varieties of soapstone (which include other components, such as plenty of chlorite instead of talc) may disintegrate into powder after a few treatments.

Picture 3 shows a test cylinder made of MammuttiStone after the test. The sample has some cracks in it and it has split in half, but the material is still very hard after almost thirty treatments. The test cylinder has split into two pieces after 28 treatments; accordingly, it has received a **thermal shock rating of 28**. It is worth noting that the **maximum rating for any material in this test is 30**. According to the rules set forth in the DIN 51 068 standard, the test is aborted if the material tested remains unbreakable for 30 treatments.

Picture 3. *Test cylinder consisting of fine-grained, foliated, and crinkled MammuttiStone after the thermal shock test. The sample material has received* ***nearly the highest possible thermal shock rating (28 points out of 30).***

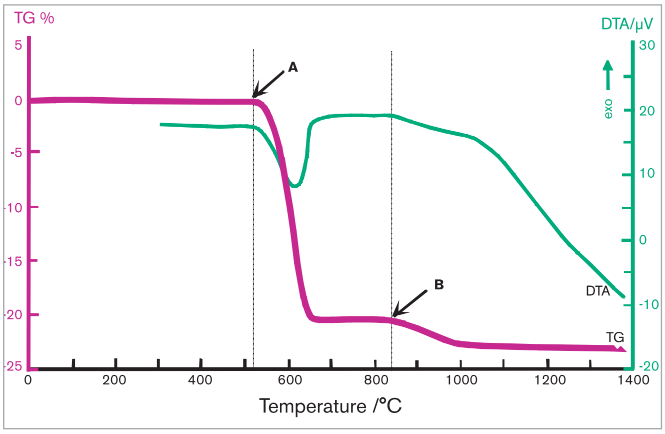
What happens to soapstone at high temperatures?

When a fireplace is heated, the burning temperature of wood is, at its highest, 800 to 1200 °C, but studies carried out by Nunnanlahden Uuni Oy indicate that the surface of the hottest stones heats up to only 650 °C in normal use.

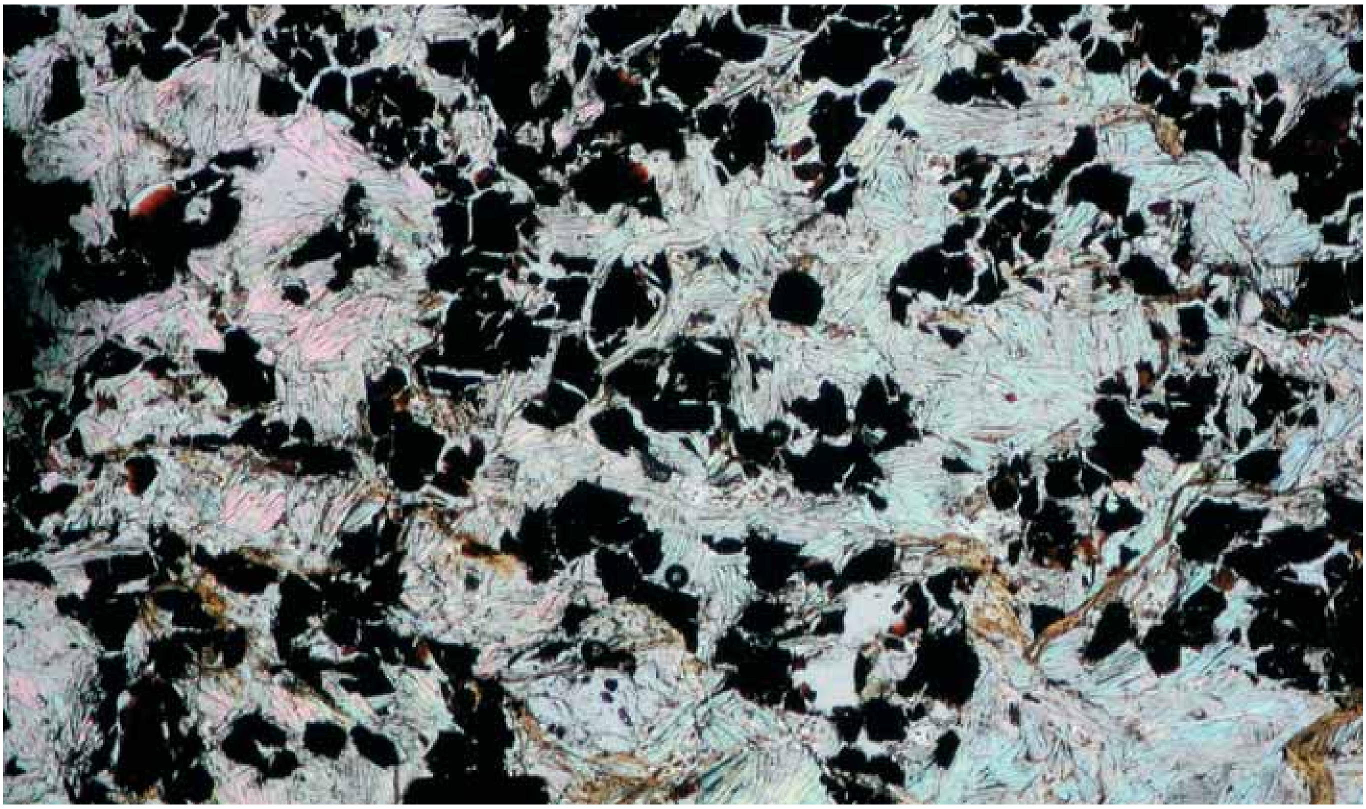
Each mineral has a well-known and thermodynamically determined stability range under given pressure and temperature conditions. In practice, with fireplaces, the only significant factor is the temperature, and especially the maximum temperature that any stone used in constructing the fireplace can achieve. The behaviour of the material and reactions that occur in it can be examined via Thermal Gravimetric Analysis (TGA) and Differential Thermal Analysis (DTA). The TGA test is used to measure changes in weight during and after mineral reactions occurring at different temperatures, whereas the DTA test provides information on how these mineral reactions produce or consume reaction heat. The TGA/DTA test results provide an accurate description of soapstone behaviour at high temperatures.

Picture 4 shows the TGA/DTA result for a typical MammuttiStone consisting of approximately half talc, half magnesite. In this picture, the purple (TGA) curve represents changes in the mass and the green (DTA) curve, without reference corrections, shows the reaction heat produced or consumed by the phase transitions that occurred in the test. The picture clearly shows that no significant changes occur before MammuttiStone heats to 520–540 °C. This temperature marks the beginning of an endothermic reaction (a reaction that requires outside heat energy) in which magnesite is transformed into magnesium oxide, or periclase, and into carbon dioxide, which is released as gas. As carbon dioxide gas is released, the mass of the stone decreases by approximately 20%. It should be noted that in this test the entire MammuttiStone mass is heated to over 520 °C. In normal use of a fireplace, the mass change concerns only that part of the stone which reaches the temperature needed for the periclase reaction to begin. This usually means a five-to-ten-millimetre-deep layer under the hottest surfaces. The resulting periclase is stable at very high temperatures, even at 1600 °C. In practice, it is not even possible to attain temperatures high enough in a fireplace for periclase to transform or to be replaced by some other mineral type.

Another typical reaction for MammuttiStone begins at 840 °C. This reaction ties up energy and simultaneously decreases the mass of MammuttiStone by approximately two per cent. In practice, the reaction involves the freeing up of hydroxyl groups that are bound to talc. Only water departs from the mass, and the solid stone material with a durable basic composition remains. **This test unambiguously shows that even at temperatures this high, talc still remains as the cohesive material, which also conducts heat *(pictures 3 and 5)*.**



Picture 4. *The TGA/DTA results for MammuttiStone consisting of talc and magnesite. The first thermal reaction occurs at 520 °C, where magnesite turns into periclase (point A). The second reaction (point B) is the dehydroxylation of talc (that is, a reaction in which the OH groups depart from the talc) at approximately 840 °C.*

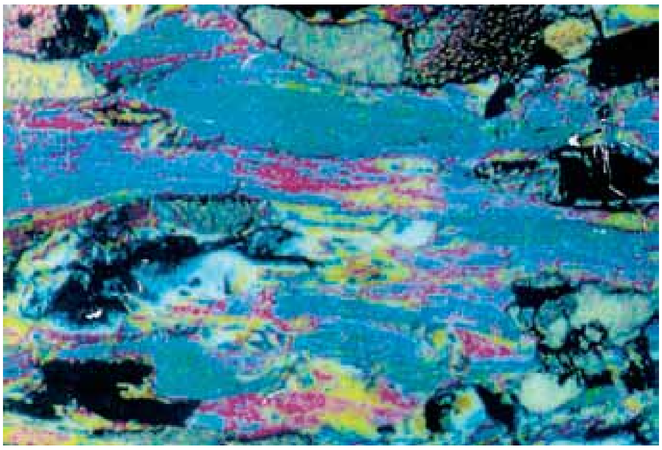


Picture 5. Polarisation microscope image of fine-grained MammuttiStone, re-crystallised at 850 °C. The mineral that is black in the picture is periclase. The picture illustrates that even after the departure of hydroxyl groups, ***talc, either pale or reddish in the picture, remains as the cohesive uniform mass.***

The maximum temperatures that materials have attained in a fireplace can be easily calculated afterwards, since those areas in which the carbonate minerals have been transformed into periclase can be unmistakably identified through an ordinary microscopic study. In the structural elements of a fireplace that has been in use for a long time, the thickness of the layer containing periclase is at its greatest approximately 30 millimetres – measured after stove temperature was increased to over 400 °C for research purposes. A temperature that high is, naturally, considerably higher than what can be attained by following the normal heating instructions.

In the basic structural elements of the furnace and flues *(**Picture 6**)*, the periclasial layer extends only a few millimetres from the hottest surfaces, which clearly indicates that **only a small part of the entire mass of the fireplace has reached the temperature needed to set off the reaction in which magnesite is transformed into periclase.**

Picture 6. *MammuttiStone taken from the furnace of a normally heated fireplace.*



Picture 7. *Polarisation microscope image of highly foliated* ***MammuttiStone****, in which magnesite grains can be distinguished by their grey or dark colour. The diameter of the grains is approximately 0.5 millimetres. The foliated talc flakes are bluish-green in the picture.*

The qualities of soapstone – as is the case for all other stone types – depend on those of its basic components, the minerals. Some minerals are hard and some are soft; some can endure extremely high temperatures, whereas others remain stable only up to 100 °C.

The various types of soapstone can contain a wide range of minerals with very different qualities, and therefore the qualities of different soapstone types may differ fundamentally. **In order to understand the qualities of different varieties of soapstone**, one must know and understand the qualities of their basic constituent minerals.

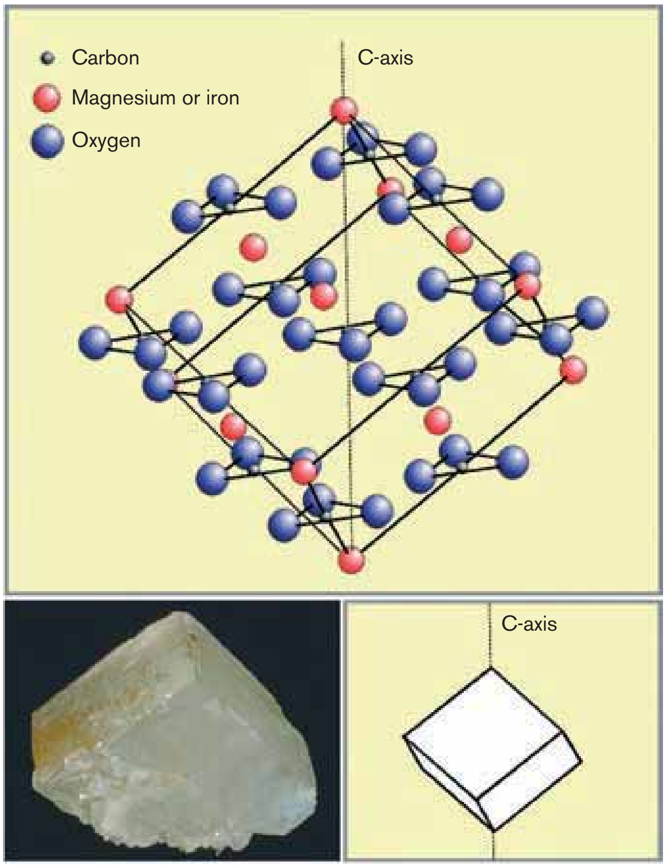
A mineral is a solid, crystalline material that is balanced and stable in its original environment. It has a definite chemical composition and crystal structure, which can be determined mineralogically; that is to say that inside each mineral – in its crystal lattice – is an explicitly specified position for each chemical element. Only a few specific and limited changes in composition are possible.

The stone in the MammuttiStone deposit with the best heat resistance properties consists for the most part of only two types of mineral, magnesite and talc. The heating of MammuttiStone to a temperature over 520 °C can lead to the formation of a new mineral type, periclase. Below is a brief overview of the distinct qualities of these minerals.

Magnesite

Magnesite ($MgCO_3$), or magnesium carbonate, is white, greyish, or tinted yellow or brown, and its hardness is slightly greater than that of the human nail. On the Mohs hardness scale its hardness varies from 3.5 to 4.5, while for example the hardness of window glass on the same scale is 7. The specific weight of magnesite varies from 2.96 to 3.1, which is to say that it is three times heavier than water. The chemical composition of an ideal magnesite consists of 47.8 per cent MgO and 52.2 per cent CO_2. Iron is known to bind to the crystal lattice in magnesite's place, and, in fact, the majority of iron in MammuttiStone is bound in the magnesite carbon mineral, replacing approximately one tenth of the magnesium cations in the crystal structure.

Picture 8 shows a model of the crystal structure of carbonate with magnesite. As a result of magnesite's crystal structure, its qualities depend to some extent on the orientation of the structure. For example, the heat expansion is slightly greater parallel to the c-axis than in directions perpendicular to it. The heat expansion coefficient parallel to the c-axis is $22.9*10^{-6}$/°C and in perpendicular directions is $6.75*10^{-6}$/°C. Also, the extent to which iron has replaced magnesium in the mineral structure has an effect on the properties. For instance, the specific weight increases linearly with any increase in the amount of iron. The ratio between iron and magnesium in the magnesite found in the MammuttiStone is approximately 1:9, which results in a specific weight of 3.05, slightly greater than the specific weight of ideal magnesite. In a mineral grating, all structural components are positioned as mass points on three levels, which intersect at an oblique angle. The same basic structure is also repeated in bigger mineral grains ***(Picture 8)***, and the good cleavage of carbonate in three dimensions – determined by the crystal plane directions in the euhedral grain – follows closely the plane directions of the above-mentioned basic structure.



Picture 8. *Crystal-chemical structure of magnesite (upper picture), euhedral magnesite grain (lower left picture), and geometric position of the c-crystal axis in the magnesite grain.*

Periclase

The formation of periclase, or magnesium oxide (MgO), occurs according to the following formula in heating magnesite:

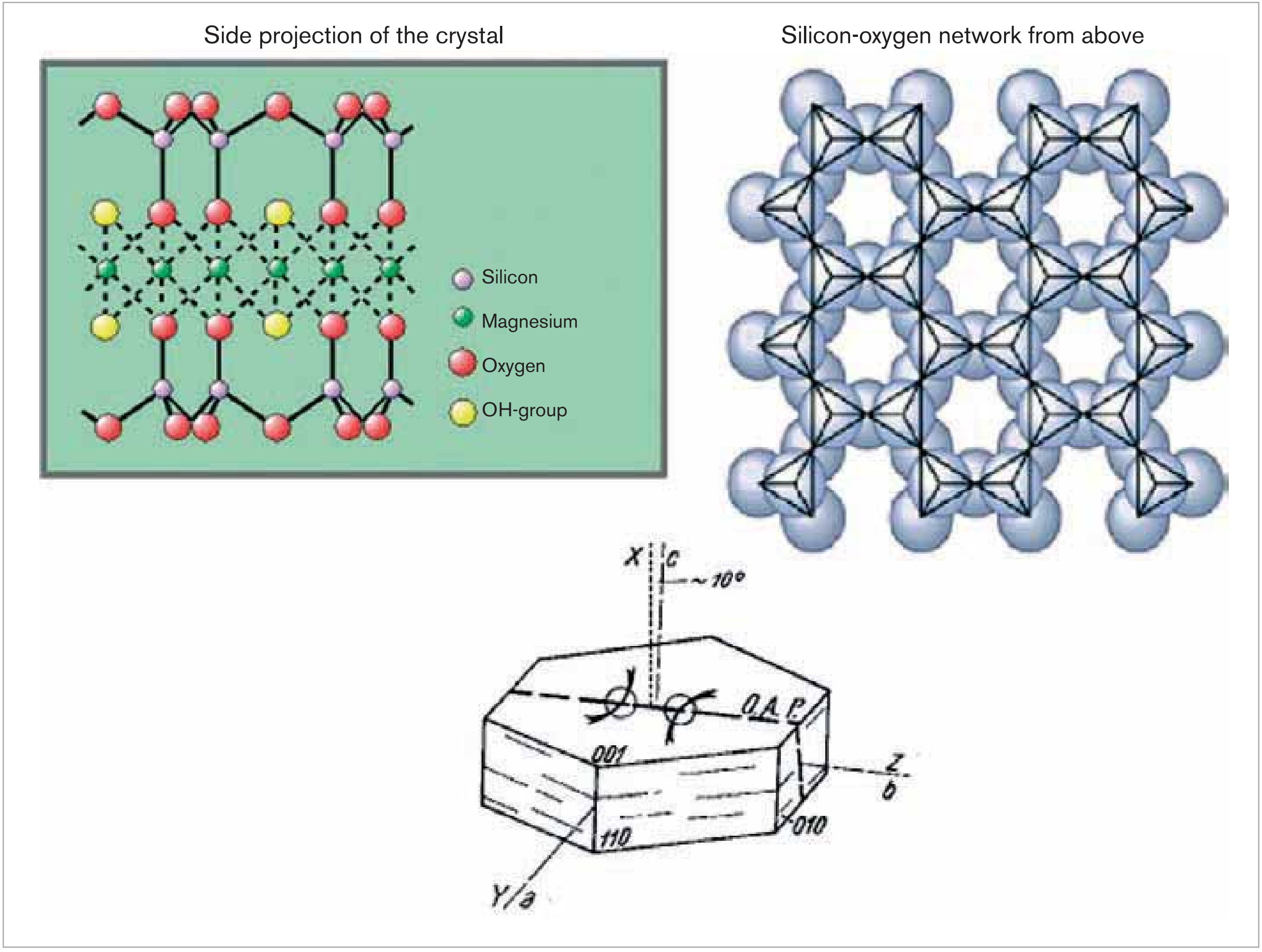
$$MgCO_3 + \text{heat } (T > 520\ °C) \rightarrow MgO + CO_2$$

Solid periclase is very hard – it has a hardness rating of 6 on the Mohs scale – and its specific weight varies from 3.58 to 3.90. However, the grains of periclase formed from magnesite are extremely small and not visible to the naked eye. The result of transformation can be seen in the brownish or black microcrystalline mass *(**Picture** 5)*.

Talc

Talc is classified mineralogically as among the phyllosilicates, and its qualities are easiest to understand by examining its basic crystalline structure more closely. The ideal chemical formula of talc is: $Mg_3Si_4O_{10}(OH)_2$. Silicon and oxygen produce a sheet-like structure *(**Picture** 8)*, in which **the components are linked by the most resilient chemical bonds there are, ionic and covalent bonds.** This makes the silicon-oxygen framework very durable, and the microscopically small **flaky talc grains form a resilient network**. Nevertheless, according to the Mohs scale the hardness of talc is only 1, which makes it one of the softest minerals known to man. The softness is caused by the fact that the magnesium cations between the silicon-oxygen networks are attached to them with only weak chemical bonds.

Also, the hydroxyl groups (OH) are weakly bound to the grating. For this reason, the microscopically small individual talc flakes split off easily and glide well if rubbed against one another. The resulting greasy and slippery surface of the mineral is one of the qualities most typical of talc, among its identifying features. The specific weight of talc varies from 2.7 to 2.8; i.e., its density is somewhat lower than the corresponding figure for magnesite yet higher than the average density for all stone types found in the earth's crust.



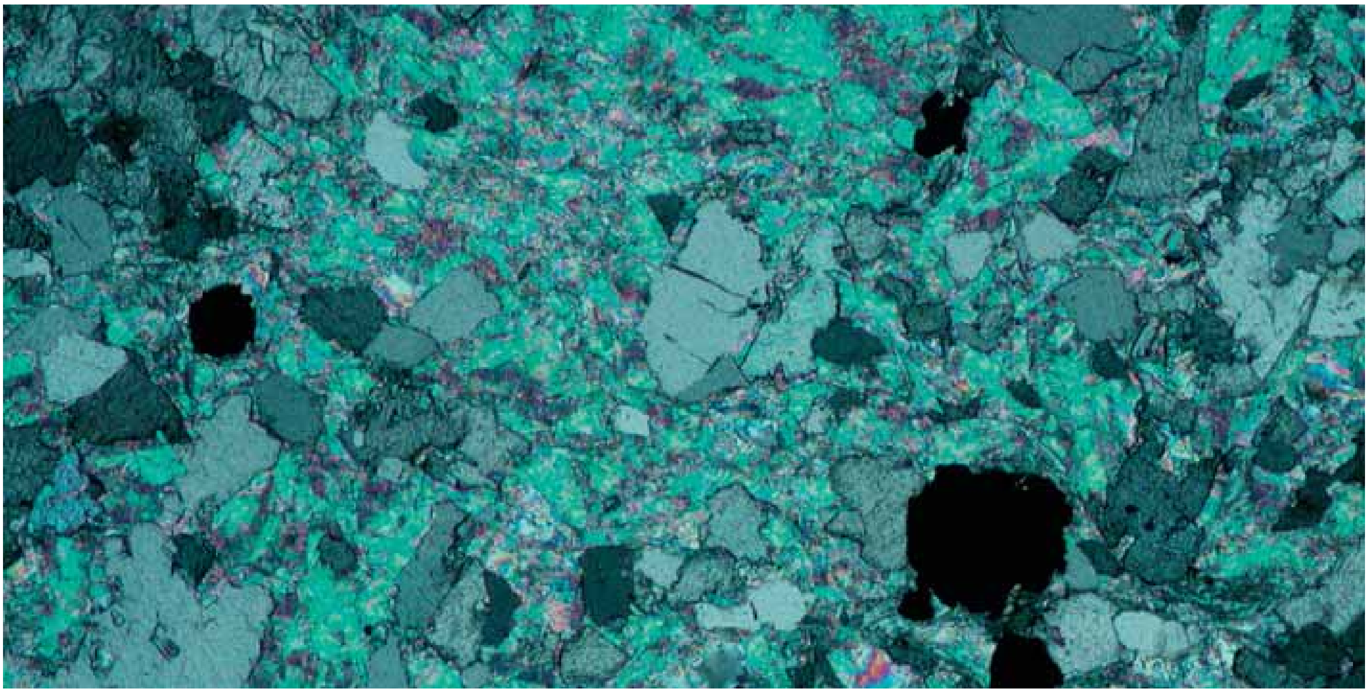
Picture 9. *Crystal-chemical structure of talc, a projected diagram of the silicon-oxygen network from above, and the geometric position of the crystal axes (X, Y, and Z) and optical axes (a, b, and c) in a chlorite flake.*

Shape, size, and foliation vary from one type of MammuttiStone to the next. **The talc in MammuttiStone consists of small flakes and forms a uniform and foliated network surrounding the magnesite grains**. Magnesite, on the other hand, can exist in a foliated talc mass as elongated granules or circular grains. The diameter of magnesite grains can vary from less than 0.5 mm to as great as 10 to 15 mm. Some individual grains can be even bigger. On the basis of their internal structure, the different varieties of MammuttiStone can be divided into three main categories, which all have their own distinct qualities.

All grains of MammuttiStone types with strong schistosity or cleavage structure are clearly foliated on a certain plane. Especially flaky minerals are systematically foliated in the direction of a particular plane. These types of MammuttiStone cleave easily in one direction, and, for example, their thermal conductivity is significantly better in the direction parallel to the cleavage plane than in those perpendicular to it. If positioned correctly, this type of fine-grained MammuttiStone can withstand extremely high thermal stress.

The linearly symmetric structure of **strongly lineated and crinkled MammuttiStone types** is caused by the manner in which the elongated magnesite grains are systematically positioned in a certain linear orientation, and by the stacks of talc flakes, which have crinkled into folds. These types of MammuttiStone have almost identical mechanical strength in all directions, but the thermal conductivity is better in the direction parallel to the fold ridge than in any other direction. These types of fine-grained, crinkled MammuttiStone are the most suitable for withstanding thermal stress, such as repeated intensive heating and cooling. The talc forms a network surrounding the magnesite grains, or a mineral mass, which encloses the grains ***(Picture 10)*** and increases the ability of MammuttiStone to withstand intense thermal stress and high temperatures. Of the various types of MammuttiStone, this soapstone variant represents the highest quality.

In more mass-like and poorly foliated MammuttiStone, the talc is randomly foliated but the dimensions of magnesite grains can be alike in all directions. The thermal conductivity of mass-like MammuttiStone variants is nearly the same in all directions and proportional, in addition to temperature, to the average grain size of the stone.

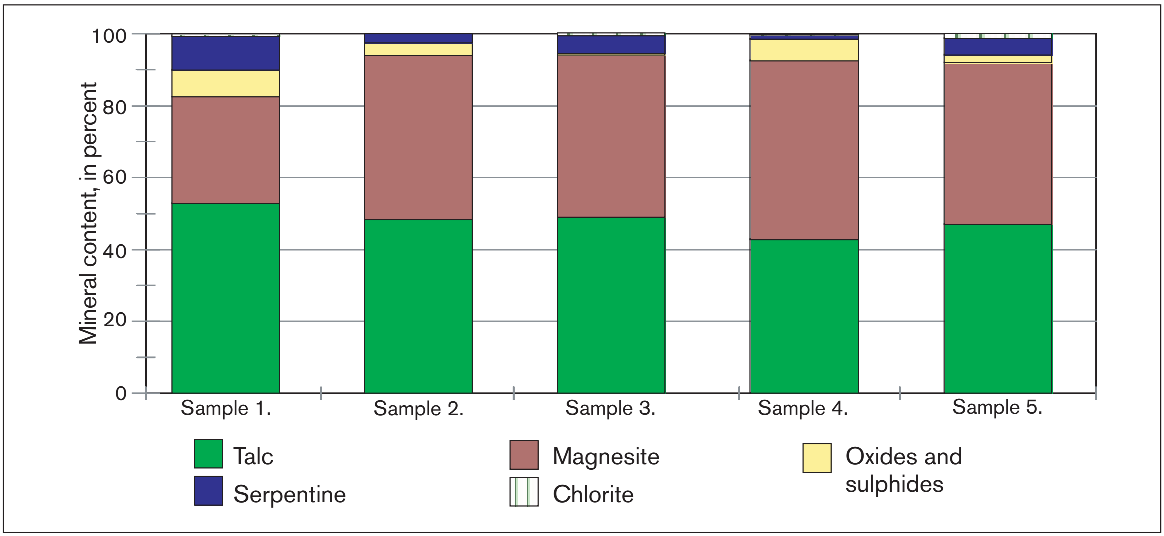


Picture 10. *Polarisation microscope image of a fine-grained talc-magnesite type of MammuttiStone. The talc consisting of small flakes is green in the picture. The talc mass surrounds the magnesite grains, which are approximately 0.5 millimetres in diameter; they are grey in the picture. The photograph is taken from the direction of the lineation; i.e.,* ***the longest dimensions*** *of talc and grey magnesite grains* ***extend from the direction from which the picture is taken.***

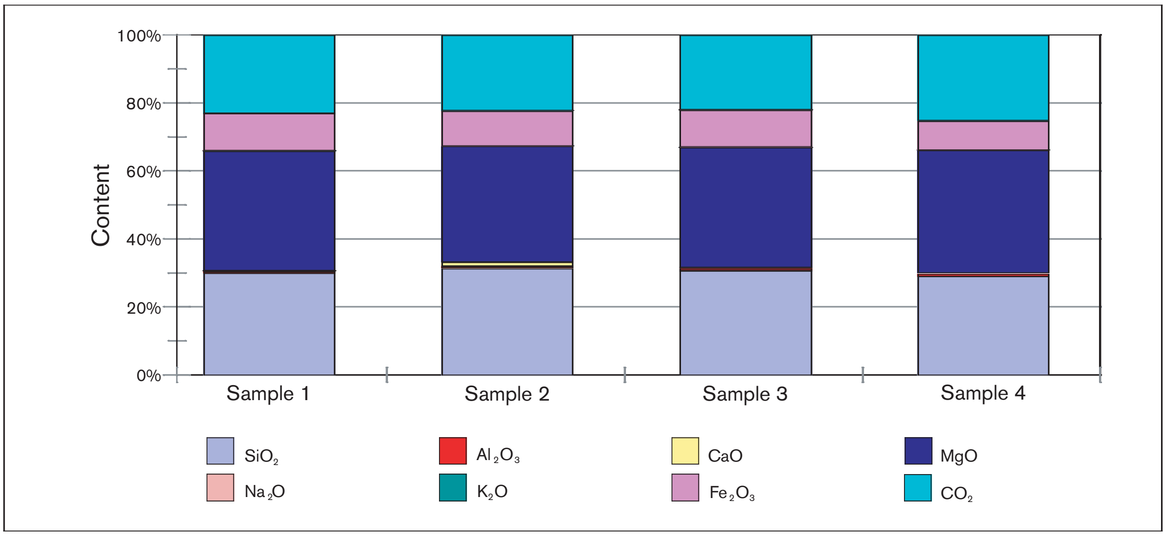
The stone in the MammuttiStone deposit is a strongly foliated cleaving stone, which at its best consists in the main of only two minerals: talc and magnesite. The additional constituents include small amounts of other silicate minerals (serpentine and chlorite) and also ferrous oxide minerals. In the high-quality MammuttiStone in the deposit, these additional minerals account for a maximum of a few per cent of the volume; therefore, based on its mineral composition, the MammuttiStone definitely belongs to the talc-magnesite category.

The microscopic tests have shown that the mineral composition of the MammuttiStone deposit's stone is somewhat constant. A typical MammuttiStone consists of 45–55% talc; 30–50% magnesite; and, on occasion, additional components in the form of chlorite, serpentine, and oxide ore minerals *(**Picture 11**)*. The samples analysed consist of less than 10% serpentine, and the chlorite content ***does not exceed two per cent.***

Description of the chemical composition of the MammuttiStone deposit‘s stone was contracted out to a Canadian analysis laboratory, XRAL. The chemical composition of various MammuttiStone types proved very similar *(**Picture 12**)*: the stone from the deposit included approximately 30% silicon in SiO_2, 35% magnesium in MgO, 10% iron in FeO, and slightly over 20% carbon dioxide as a structural element of carbonate.



Picture 11. *Modal mineral compositions of the deposit’s MammuttiStone.*



Picture 12. *Chemical composition of different stone types in the MammuttiStone deposit.*

In MammuttiStone, carbon dioxide is bound to the carbonate minerals and the carbon dioxide content indicates the magnesium content of the stone. The MammuttiStone samples include only a very small amount of other chemical elements; for instance, the average aluminium content is merely 0.6% (Al_2O_3), and concentrations of other elements are even smaller. The aluminium content is significant in the chemical composition of MammuttiStone, because aluminium is one of the key chemical elements in chlorites and micas. An excessive amount of either is disadvantageous for soapstone used in fireplaces. By contrast, if the rock material does not include aluminium, the above-mentioned aluminium-rich mineral types cannot be formed, which is why low aluminium content is characteristic of high-quality MammuttiStone.

According to the definition of soapstone, all soapstones have to include a considerable amount of talc, but the proportions and types of other minerals may vary considerably. In addition to talc, the main mineral components of the most typical types of soapstone include mica, chlorite, amphibole, pyroxene, and serpentine minerals. Based on its mineral content, soapstone can be categorised as a type with mica content, one with chlorite content, and so on. Variants including magnesite are quite rare as soapstone goes, but magnesite has, nevertheless, a significant role in increasing the heat storage capacity of the stone.

According to our own information, the MammuttiStone deposit consists of talc-magnesite-type stone with very homogeneous chemical and mineral composition. Based on internal structure, or the texture of the MammuttiStone, various stone variants can be differentiated in the MammuttiStone deposit, and through utilising the distinct qualities of each stone type to the maximum, the value of MammuttiStone as a building material for fireplaces can be significantly increased.

28th May 2001; Oulu, Finland

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This new version introduces MammuttiStone, a trade name registered by Nunnanlahden Uuni Oy and used to refer to all soapstone variants of the mine district of Nunnanlahden Uuni Oy.

Apart from the new naming convention, the content of this account is the same as that of the original research report published in 2001.

31st January 2005; Oulu, Finland

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