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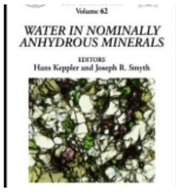

Review in Mineralogy and...

Review in Mineralogy and Geochemistry, Volume 62, Water in Nominally Anhydrous Minerals edited by Hans Keppler and Joseph R. Smyth, The Mineralogical Society of America, Washington D.C., 2006, 478 pp. US $40(ISBN 093995074-X).

In the past decade, much attention has been given to water and its cycle into the deep Earth. Water, actually simple hydrogen embedded as point defects in the atomic structure of minerals, has major effects on the chemical and physical properties of Earth even at very low concentration. Hydrogen is one of the most volatile chemical components of Earth having the largest effects on its unique global geodynamique.

The present volume published by the Mineralogical Society of America (MSA) and the Geochemical Society perfectly follow and complete the past MSA volume entitled Volatiles in Magma (edited by M. R. Caroll & J. R. Holloway, review in Mineralogy, volume 30). It reviews the latest technological advances, theories, experimental results, and computer modelling methods, from the atomic scale to planetary dimensions. A short course accompanied the MSA volume, which took place in Northern Italy in October 2006. It was a pretty unique meeting where researchers of various citizenships and from very diverse locations of work (from all five continents!) were joined by a fascination with the almost puzzling incorporation of hydrogen in Nominally Anhydrous Minerals (NAMs). This volume benefited from the activities of the European network HYDROPSEC (Human Potential-research training Network, HPRN-CT-2000-0056) that ended in 2005 which focused on the speciation and mobility of the hydrogen in minerals of the earth upper mantle.

The review volume starts with an essential contribution by one of the most prominent researchers in the field, Prof. Rossman (Chapter 1), who describes the various techniques of detection, quantification and precise apparatus calibrations, which are available to study water in NAMs. It reminds us very well how difficult it is to detect hydrogen and the long work of searching for the right recipe and the right calibration (mineral-dependent!) to achieve concentration resolution close to a single ppm. The three following chapters provide theoretical background on the physical occurrence of hydrogen in NAMs, as well as fundamental technical details on the widely used Fourier-Transform Infrared Spectroscopy (FTIR) method (Chapter 2 by E. Libowitzky and A. Beran) and the less notoriously used method of Nuclear Magnetic Resonance (NMR) in Chapter 3. Chapter 4 reviews up-to-date methods of computer modelling at the atomic scale and details current limitations. Of course, this later section will be out of date pretty soon. The compilation on the occurrences of water as a trace element in almost all NAMs on and in the planet Earth are summarized in four subsequent chapters, each dedicated to a different class of minerals: the high pressure phases and oxides in Chapter 5, the crustal minerals in Chapter 6, the pyroxenes in Chapter 7 and of course olivine, garnet and accessory minerals (rutile, kyanite, coesite, spinel and zircon) in Chapter 8.

The most indispensable chapter for students, geologists, mineralogists, geochemists, as well as geophysicists and seismologists is certainly chapter 9, which explains, details and compiles the thermodynamic properties of water solubility in NAMs. This chapter gives the fundamental equations necessary to calculate the maximum water concentration (so called *"solubility law"*) within a crystalline solid as a function of pressure, temperature and chemical composition (for example iron in olivine and aluminium in orthopyroxene). Chapter 10 pursues this topic further by reviewing experimental results on the partitioning of water between minerals and melt. Subsequently, Chapters 11 and 12 take on the difficult task of reviewing the amount and fate of water in hydrous and anhydrous minerals in the very complex subduction factory.

Now that the occurrence of hydrogen is well evaluated and catalogued, the reader is introduced to hydrogen transport by ionic diffusion in Chapter 13 and then to the implications of the presence of hydrogen on essential physical properties of minerals. Chapter 14 provides a rigorous experimental demonstration of the effect of hydrogen on the equation of state of olivine, its fashionable polymorphs, wadsleyite and ringwoodite, as well as of the other high-pressure phases and expresses the likely possibility to quantify the hydrogen content by a seismological approach. Chapter 15 presents innovative hypotheses formulated by Prof. Karato on the enhancement of electrical conductivity of the upper mantle. In Chapter 16, Prof. Kohlstedt recalls how hydrogen, linked to silicon vacancies, significantly reduces the viscosity of olivine and other silicate minerals. Chapter 17 details the effect of water on the pressure dependence of phase transitions and demonstrates the broadening and depression of the topography of the mantle discontinuity due to water in the Transition Zone (410-660). This volume concludes with Chapter 18 on the growing implication of interplanetary dust particles in the origin of terrestrial water (now present in the ocean and the mantle) and

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origin of terrestrial water (now present in the ocean and the mantle) and finally, Chapter 19 relates primordial implications of the presence of water inside our planet as the necessary condition for globally active plate tectonics on Earth.

The quality of the editing and composing of the volume by H. Keppler and J. Smyth is outstanding. The book takes the reader to the atomic scale and by simply connecting the dots at each chapter finally to reach the obvious: "Earth is the water planet - not just because of its ocean, but also because of its tectonic evolution". This RiMG volume is therefore a "must-have" to any students and researchers starting work on geological processes relating and/or potentially involving the presence water in the deep Earth.

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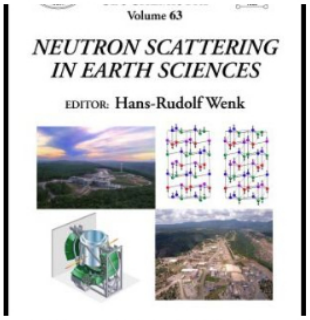
Book Review: RiMG v. 63



RIMG v.63, Neutron Scattering in Earth Sciences

Reviews in Mineralogy and Geochemistry, Volume 63, Neutron Scattering in Earth Sciences edited by Hans-Rudolf Wenk, The Mineralogical Society of America, Washington D.C., 2006, 471 pp. US $40 (ISBN 978-0939950-75-1).

Advanced photon and neutron sources are large-facility materials analysis centers that have become available to earth scientists in the last few decades. Synchrotron x-rays are perhaps more familiar because small scale x-ray diffraction sources are commonly used for atomic structure determination of geological, and indeed all, material samples. Although neutron scattering presents many advantages and opportunities for the study of geological materials, it is still a little mysterious and the user community among earth scientists is still quite small.

This volume of RiMG (#63), edited by Hans-Rudi Wenk, a distinguished earth scientist as well as an advocate for the use of neutrons in geosciences, provides a sourcebook of background knowledge, facilities, and applications of neutron scattering in geosciences. Its aim, along with the symposium that accompanied it, is to have experts present and explain the broad variety of applications that neutron scattering has for geological materials so to improve the visibility -and viability - of this powerful technique for earth scientists. This volume covers a wide range of relevant applications, with good examples and extensive references - well worth it for anyone contemplating or involved in neutron scattering measurements.

The advantages that neutron scattering offers for the study of earth science materials stem from the fundamentally different way that neutrons interact with materials, compared to x-rays and electrons. The neutron responds to the strong nuclear force and does not feel the Coulomb forces from the electrons that dominate x-ray and electron scattering. The nuclear cross section is small and varies strongly between nuclei - explaining the deep penetration of neutrons into matter, and providing a contrast almost invisible to x-rays. The ability to observe hydrogen (and so water) is noted by several authors - a photograph in chapter 2 shows a neutron image of a rose taken through several cm of lead shielding. Diffraction from crystals produces symmetry, spacing and strain information as with x-rays but with nuclear details added. Neutron scattering is sensitive to magnetic structures.

Many of the authors point out that some of these measurements can now be done using the greatly enhanced intensity of synchrotron x-rays. The combined advantages, however, of nearly-transparent sample chambers, large sample size, sensitivity to the lightest elements and elemental/isotopic contrast produces unique, complementary information for material analysis. The current commissioning and buildup of neutron beamlines at the SNS facility presents an almost irresistible opportunity for mineral and rock characterization in the earth sciences.

Chapter 1 by John Parise starts with the neutron itself and the properties that make it uniquely suited for materials analysis, but the majority of the chapter covers the details of the scattering interaction - necessary to interpret the scattered/diffracted intensities. Table 3 is a useful summary of differences from x-ray scattering. Chapter 2 by Sven Vogel and Hans-Georg Priesmeyer, covers much of the "nuts and bolts" of the production, control and measurement of neutrons. They discuss reactor and pulsed sources and the forms of experiments that can be carried out on various beamlines and the detector technologies that are used for each.

Nancy Ross and Christina Hoffmann in chapter 3 bring in the details of applications in single-crystal diffraction with neutrons, both in the instruments available and the analysis of several examples. The main drawback is the need for a relatively large crystal. Chapter 4 by Robert Von Dreele, one of the authors of GSAS, presents the use of the Rietveld method for the analysis of neutron powder diffraction data. Nearly all neutron data analysis is done with one of the handful of programs available. He covers the contributions to peak profiles and spacings from a number of factors. Karsten Knorr and Wulf Depmeier follow this in chapter 5 with a series of powder diffraction examples, to determine mineral structures where light or neighboring elements appear. They note that perhaps the most noticeable drawback for neutrons is the limited number of sources available.

Chapter 6 by Richard Harrison introduces the magnetic scattering capabilities of neutrons, deriving the expressions needed to extract magnetic structure. There are several

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examples of studies in iron-bearing minerals and lots of excellent illustrations of the moment patterns in the various crystal lattices.

Chapters 7 and 8 present applications for the kinetic processes involved in material transformations, introducing time dependence as an experimental factor. In chapter 7 Simon Redfern looks at order-disorder transformations using controlled temperature changes and time dependent diffraction measurements.He presents examples of cation ordering in a number of minerals, particularly where the neighboring elements Mg/Al/Si are involved.

Werner Kuhs and Thomas Hansen in chapter 8 discuss time-dependent processes in general and some experimental factors. They provide examples of the kinetics of phase transformations in water ices and clathrate and gas hydrates at controlled temperature and pressure. Chapter 9 by John Parise describes neutron scattering from samples at high pressure. The experimental aspects of cells which are relatively transparent to neutrons and capable of maintaining pressures up to several GPa on a relatively large sample are discussed. Experimental examples with minerals and clathrates are presented as well as a tour of the technology available at the SNAP beamline at SNS. In chapter 10 Chun-Keung Loong introduces the complications of inelastic processes where the neutron scatters with a change in energy due to collisions with protons or an exchange with lattice excitations. The information derived, displayed in a number of examples, involves changes in phonon spectra and mapping of crystal field levels in rare-earth phosphates and observation of the diffusion of water in clays.

Chapters 11, 12 and 13 describe the use of neutron scattering for disordered materials - glasses, liquids and materials where no long range order exists. Thomas Proffen introduces the pair distribution function (PDF), essentially the number distribution of pairs of scatterers as a function of separation, in chapter 11. He covers the process of taking data and backgrounds to produce the total scattering function which is analyzed with one of a number of available programs (there's a list) into the PDF. There is model dependence in the analysis, which needs some care for reliable results. His examples include measurements of bond length changes, variable-scale domain structure formation and quartz and quartz-glass structures. In chapter 12, Martin Wilding and Chris Benmore discuss the thermodynamics of liquids and the phase transformations into ordered and disordered solids, and the relationship of their properties to the structural information available from the PDF. There is a collection of studies on geologically relevant materials, water, amorphous ices, various forms of silicate glasses and oxide liquids. Chapter 13 by David Cole, Kenneth Herwig, Eugene Mamontov and John Larese discusses the application to fluids in the geochemical and geophysical environment. Water, aqueous solutions and other fluids (could be gases) play a large role in the chemistry of minerals and rocks. Local structure in fluids and the behavior of confined or surface layered fluids can be explored by PDF techniques and inelastic /quasielastic (QENS) scattering techniques. QENS, mentioned briefly in Ch. 10, has a useful primer here. For studies of structures much larger than the atomic scale - up to micron sizes - a specialized technique is available. Andrzej Radlinski discusses small-angle neutron scattering (SANS) in chapter 14. Using thin films in a transmission mode, monochromatic neutrons, and measurements of the scattered intensities close to the beam direction - usually within a few degrees, information on microstructure, such as porosity or roughness may be extracted. The author covers the theoretical basis, particularly the fractal nature of some microstructures, and examples of applications to porosity determination in hydrocarbon and water-bearing rocks and clays.

Hans-Rudi Wenk presents in chapter 15 the measurement of texture - a preferred crystallographic orientation in the grains of a polycrystalline material. The aim is a 3-D map of the preferred orientations within a macroscopic sample. The penetrating power and large sample size available to neutron scattering are employed here. Examples include the effects of uniaxial stress on samples and the reconstruction of geologic deformation histories in core samples.

The measurement of internal strains and the corresponding stresses are the subject of chapter 16 by Mark Daymond. These stresses are critical to the deformation and ultimate strength of materials, and operate at a range of scales in polycrystals. The mapping of these stresses, and the way they vary under load is done by diffraction from a defined internal volume. Many facilities have specific beamlines to apply uniaxial stresses to samples during these measurements. Chapter 17 by Bjoern Winkler covers applications of imaging with neutrons - creating 2-D and 3-D images of the internal structure of an object. The images are essentially maps of the absorption of the neutron intensity along a given path. Multiple 2-D images can be assembled as in conventional tomography to a 3-D image. The difference in absorption cross-sections for different nuclei provides the contrast in the image - hydrogen/water are "darker" than most materials producing maps of hydrogen-rich volumes inside other materials. The advances in 2-D neutron imaging detectors are discussed and applications to time-dependent processes - neutron "movies".

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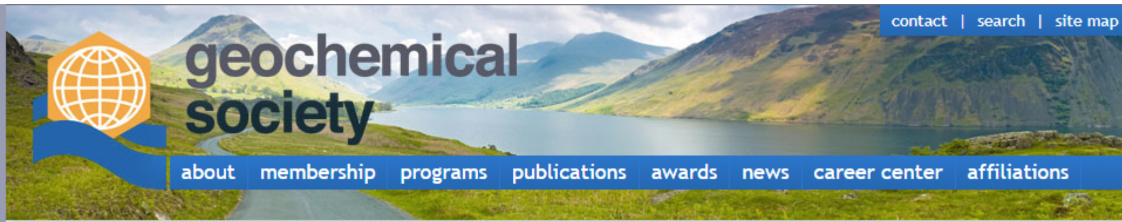

A.E. Fersman and the Kola Peninsula

Dr G.P. Glasby, Department of Geochemistry, GZG, Goldschmidtstr. 1, University of Göttingen, Germany: g.p.glasby@talk21.com

A.E. Fersman was one of the leading geologists in the Soviet Union between the wars. He is best remembered for his discovery of the huge urtite deposits in the Kola Peninsula which make up about 60% of the world's reserves of apatite. He was also heavily involved in the programme to survey and prospect 20 x 106 km2 of Soviet territory for mineral resources over a 10 year period in which geochemistry played a major role. The scale of exploration and discovery of mineral resources in the Soviet Union at that time dwarfed anything in the west. Fersman also made major contributions in mineralogy and geochemistry and was a well known popularizer of geology. In awarding Fersman the Wollaston Medal, the President of the Geological Society of London described him as 'one of the greatest in the great company of Russian geologists.'

The Early Years

Aleksandr Evgenievich Fersman was born in St. Petersburg on November 8, 1883, to a family that valued both art and science. His father, Evgeny Aleksandrovich Fersman, was an architect and his mother, Maria Eduardovna Kessler, a pianist and painter. At the family's summer estate in the Crimea, Fersman first discovered minerals and began to collect them. When his mother became ill, the family travelled to Carlsbad in Czechoslovakia where the young Fersman explored abandoned mines and added to his collection of crystals.

Fersman graduated from the Odessa Classical Gymnasium in 1901 with a gold medal and entered the Mining Academy at Novorossiysk on the Black Sea. He found the mineralogy course so dull that he decided to study art history instead. He was dissuaded by family friends (the chemist A. I. Gorbov and others) who encouraged him to delve into chemistry. He subsequently studied physical chemistry with B. P. Veynberg, who had been a student of Dmitri Mendeleev. Veynberg taught Fersman about the properties of crystals.

The Fersman family moved to Moscow in 1903. Fersman's father was a general in the Tsarist army at that time and the newly appointed commander of the Second Moscow Cadet Corps (Bailes 1990). In 1904, Fersman became a doctoral student of V.I. Vernadsky and was one of Vernadsky's favourite students based on his enormous capacity for work, a mind quick to grasp new concepts, and a total dedication to developing natural sciences in Russia (Bailes 1990). During this time, Fersman became an expert in calculating the angles in crystals and published seven scientific papers on crystallography and mineralogy. For these papers, he was awarded the Gold Medal for Young Scientists by the Mineralogical Society (Fersman 1958). When he graduated in 1907, Vernadsky encouraged him to become a university teacher. Vernadsky was to be a major influence on Fersman's work for the rest of his life.

In 1908, Fersman began postgraduate work with Victor Mordechai Goldschmidt, not to be confused with Victor Moritz Goldschmidt, the founder of modern Geochemistry, at Heidelberg University. In 1888, Goldschmidt had written his doctoral thesis on the reflection of light by crystals and its graphical evaluation. Goldschmidt sent Fersman on a tour of Western Europe to examine the most interesting examples of natural diamond crystals in the hands of the region's jewelers. This work formed the basis of an important monograph on the crystallography of diamond by Fersman and Goldschmidt published in 1911.

While a student in Heidelberg, Fersman also visited the laboratory of the French mineralogist François Lacroix's in Paris and came across pegmatites for the first time during a trip to the island of Elba. Pegmatites are coarse grained quartz- and feldspar-rich igneous rocks that often contain rare elements such as lithium, rubidium, caesium, uranium,

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Fig. 1. Map of the Kola Peninsula

Fig. 2. V.I. Vernadsky as young ...

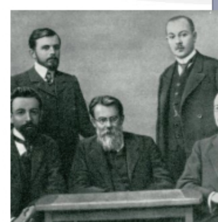


Fig. 3. Academician V.I. Vernads...

Fig. 4. Locations of the main fi...

Fig. 5. A.E. Fersman after his g...

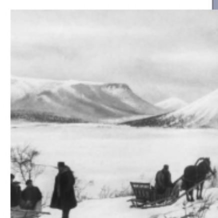


Fig. 6. A.E. Fersman (at the cen...

Fig. 7. Searching for the future ...

Fig. 8. A.E. Fersman and A.N. L...

Fig. 9. A.E. Fersman and M.P. Fi...

Fig. 10. A.E. Fersman during th...

Fig. 11. A.E. Fersman at the ap...

Fig. 12. A.E. Fersman and his co...

Fig. 13. A.E. Fersman during his...

Fig. 14. A.E. Fersman with the ...

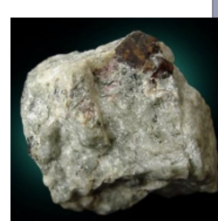
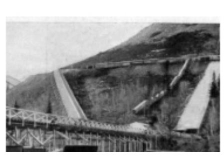


Fig. 15. Large single crystal of ...



tungsten, and tantalum. Fersman was to devote years to their study later in his career.

In 1910, Fersman returned to Russia, where he began his administrative and teaching career. He became curator of mineralogy at the Russian Academy of Science's Mineralogical Museum in Moscow and the Museum's director in 1919 following his election as an Academician. Fersman also became a Professor at the People's (Shanyavsky) University in Moscow. In 1912, he taught one of the world's first courses in geochemistry (after F.W. Clarke) at the 'Free University' where the curriculum was not controlled by the Ministry of Education (Bailes 1990). He also helped found Priroda (Nature), a popular scientific journal, during this time, to which he contributed throughout his life.

During World War I, Fersman initiated the establishment of the Commission for Raw Materials and Chemicals attached to the Committee for Military and Technical Assistance, which he chaired in 1915 (Kojenikov 2002) and advised the military on strategic matters involving geology as he would do later in the Great Patriotic War. He also participated in an Academy of Science project to catalogue Russia's natural resources starting in 1915 and travelled throughout Russia to assess mineral deposits. Lenin subsequently consulted Fersman for advice on exploiting the country's mineral resources.

After the revolution of 1917 and the war of 1914-18, Fersman realized and insisted upon the importance of developing the country's natural resources, particularly its mineral resources. Numerous expeditions were organized to the Urals, Crimea, Caucasus, Kazakhstan, Turkestan, Altai Mountains, the Transbaikal region, northern Mongolia, Karelia, Tian-Shan, Kyzyl-Kum and Kara-Kum and the Kola Peninsula. This led to the discovery of large deposits of sulphur in the Kara-Kum desert east of the Caspian Sea and deposits of uranium and vanadium ore at Tyuya-Muyan in Fergana. Fersman himself led several expeditions to the Kola Peninsula, Central Asia, Altai, Transbaikal, the Caucausus and the Crimea (Fersman 1935) but most of these are not recorded in the western literature.

After the revolution, contacts with the west became much more limited and most of the Russian scientific literature went untranslated. As a result, it is sometimes difficult to trace Fersman's activities after this time. However, in 1921, Fersman led a major expedition to the Khibiny massif in the Kola Peninsula which resulted in significant discoveries.

Accounts of Fersman's early life have been presented by Spencer (1946), Anon (1947, 2003) and Krüger (1979).

Fersman and the Kola Peninsula

Rapid industrialization in the Soviet Union began following J.V. Stalin's ascension to power in 1924. By the beginning of the first Five-Year plan of Soviet industry in 1927-29, mineralogy and geochemistry had already acquired high national status throughout the Soviet Union (Fersman 1935). From 1922-34, the Soviet Academy of Sciences organized over 250 scientific expeditions to study problems related to geology, geochemistry and mineralogy throughout the Soviet Union. These included studies of the Kola Peninsula, the southern Urals, central Asia, the Caucasus and the Baikal region. In particular, they included 15 years of expeditions to the Kola Peninsula, 10 years of expeditions to the Altai mountains and 5 years of expeditions to the Kara-Kum Desert. These expeditions led to the discovery of deposits of great economic importance including apatite and K, Ni, Sb, W and S deposits.

Of particular importance to this account is the study of the great alkaline massifs of the Kola Peninsula, the Khibiny and Lovozero massifs, with which Fersman was particularly associated. The Kola Peninsula was notorious for its inaccessibility at that time, the northern half being covered by tundra intersected by numerous rivers. These two massifs rise to 1050 m above the surrounding taiga and are separated by long lakes. The larger western massif (Khibiny with an area of 1300 km^2) is separated from eastern massif (Lovozero with an area of 650 km^2) by Lake Umpyavr. These massifs are among the greatest deep alkaline massifs in the world.

The Murmansk Railway from Leningrad to the Arctic port of Murmansk was constructed in 1915-16 using prison labour, most of whom died during the construction. The railway line passed between Lake Imanda and the Khibiny Massif. At that time, this region was almost completely unpopulated. In 1920, a special train was sent to this region to assess the viability of the line. So began Fersman's first encounter with the Kola Peninsula and his first ascent of the Khibiny Mountains which he visited with Academician Karpinsky. In 1887, the Finnish geologist,


Fig. 16. Apatite mine in the Khi...


Fig. 17. Apatite mine in the Khi...


Fig. 18. Tents of geologists on t...

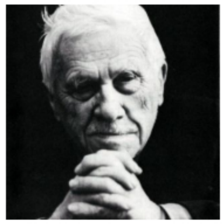


Fig. 19. N.V. Belov


Fig. 20. Academicians Vladamir ...


Fig. 22. Statue of A.E. Fersman ...

W. Ramsay, had visited the Lovozero Tundra and looked at the Khibiny Tundra from afar. He subsequently investigated the Khibiny Tundra in 1891-1892 and named the nepheline-syenite found there khibinite.

As a result of this visit, Fersman and his colleagues decided to start an investigation of this region, notwithstanding its inaccessibility and the severity of its climate, notwithstanding all the difficulties, hardships and post-war famine and poverty. Year after year, with a group of young mineralogists, geochemists and petrologists, Fersman and his colleagues concentrated all their energies on the gradual scientific mastering of Khibiny and its mineral wealth. They were attracted not so much by the natural beauty of the region or by the number of mineral bodies they found but by the unusual geochemical processes which led to the formation of these deposits.

The decisive event which led to the economic exploitation of the Khibiny deposits was the discovery of an apatite deposit in 1923-25 which convinced them that they had found a deposit of great economic importance. In 1929, scientific work on the economic development of Khibiny began. A railway line was laid to the deposit, a site chosen for a future town and mines and enrichment plants constructed. The speed of development can be judged by the fact that 2 Mt of apatite-nepheline rocks were mined in 1934 with a projected output of 7 Mt for 1937.

Many scientific observations came from these studies. The ring structure controlling the locations of these deposits was elucidated. The reserves of apatite were computed from the many boreholes sunk to the level of the main lakes and were estimated to be about 1 Gt. At that time, drilling to 2,000 m was possible. In addition, there was an immense arc of nepheline rock containing about 75-85% of urtite which amounted to about 10 Gt of this mineral in only one of its sections. Reserves of lovchorrite (mosandrite) were estimated to exceed 10,000 t and of eudialyte to be much greater.

Fersman (1935) has listed the principal minerals found in these deposits:

apatite (**Ca, REE, Sr, F**; $Ca_5(PO_4)_3(F,Cl,OH)$),

nepheline (**K, Na, Si, Al, (Ga)**; $(Na,K)AlSiO_4$),

titanomagnetite (**Ti, V, Fe**; $Fe^{2+}(Fe^{3+},Ti)_2O_4$,

titanite (sphene) (**Ti, Ca**; $CaTiSiO_5$),

*lovchorrite (**REE, Th, U, (Ti), Nb**;
$(Ca,Na,Ce)_{12}(Ti,Zr)_2[F_4|(OH)_6|SiO_4|(Si_2O_7)_3]$,

molybdenite (Mo; MoS_2),

eudialyte (**Zr, Hf**;
$Na_4Ca_{1.5}Ce_{0.5}Fe2+_{0.6}Mn^{2+}{}_{0.3}Y_{0.1}ZrSi_8O_{22}(OH)_{1.5}Cl_{0.5}$),

loparite (**Nb, REE, Th**; $Ce,Na,Ca)_2(Ti,Nb)_2O_6$),

aegirine (**Fe**, V; $NaFeSi_2O_6$) and

pyrrhotite (**S (Ni, Fe, Cu)**; FeS).

*Lovchorrite is a synonym for mosandrite found at the Lovchorrite mine which is located on Yukspor Mountain, Khibiny Massif (Fleischer 1958).

At Khibiny, there is a central ring of melteigite-urtite which is younger than the main nepheline syenites and was mainly emplaced in the nepheline syenites along major faults. The age of the alkaline magmatism has been determined to be within the range 360-380 Ma (Kramm et al. 1993). Within the urtite are lenses rich in apatite. Six of these lenses are presently mined in enormous open-cast pits or in underground mines where the near-surface ores are exhausted (Wall 2003). At present, 11 Mt of ore are mined from these deposits annually. This is equivalent to 8% of the total world phosphate production (Anon 1998).

Bringing ore deposits of this magnitude into play in this remote region posed very considerable logistical problems. In December 1929, an industrial combine was founded which led to the development of a great industrial centre located 150 km from the ice-free ports of the Arctic Ocean within five years. This region remains a major source of minerals today.

In 1929, the township of Khibinogorsk was founded and named after the Khibiny mountains surrounding it. It was renamed Kirovsk in 1934 in honour of Sergey Kirov who had been in charge of planning the development of the mineral deposits there. It is presently the home of the joint stock company "Apatit", the largest mining and concentrating enterprise in Europe. The settlement of Apatity was subsequently founded in 1935 some 23 km west of Kirovsk."Apatit" is also the main employer there. The

Kola Science Centre was founded in 1930 by Fersman as the Khibiny Alpine Station of the USSR Academy of Sciences. Fersman was its director from 1930 to 1945. The Kola Science Centre of the Russian Academy of Science as it is now called consists of 10 resesearch institutes with its Headquarters located in Apatity. It is the largest research complex within the Arctic Circle.

Recently, there have been a number of new publications on the Kola alkaline deposits which update understanding of these deposits (Wall 2003; Wall and Zaitsev 2004; Yakovenchuk et al. 2005). In particular, Wall (2003) has pointed to some negative aspects of mining in the Kola Peninsula.

Within the communist system, production was everything and environmental problems of no concern. By the 1990s, 19 Mt of phosphate fertilizer were being produced in this region each year resulting in huge spoil tips. As a result, rock falls were not uncommon and one tip collapsed forming a 'rock glacier' on the hillside. In addition, emissions from smelters at Monchegorsk and Nikel caused devastation and resulted in areas of up to 30 km^2 almost completely devoid of vegetation. Unfortunately, such scenes can be seen all around Russia today wherever there are smelters.

Fersman was, without a doubt, the key player in the discovery and exploitation of the alkaline massifs in the Kola Peninsula and his work there almost certainly ranks as his finest achievement in a long and distinguished career.

Fersman as Mineralogist

In 1919, Fersman was elected a member of the Soviet Academy of Sciences and appointed Director of the Museum of Mineralogy in Leningrad (Spencer 1946; Anon undated). From 1919 to 1935, he was also a Professor at Leningrad University.

Peter the Great (1672-1725) is credited with being the first Russian mineral collector. His personal collection consisted of a small set of stone objects acquired abroad. Peter gave it, along with his other collections, to the first state museum in Russia, the Kunstkammer. This collection gradually expanded with time. In 1836, the Mineral Room of the Kunstkammer became an independent museum and ultimately developed into the main national depository of minerals, the Fersman Mineralogical Museum of the Russian Academy of Sciences.

Under Fersman's leadership, the museum activities were directed towards solving practical economic problems, researching the country's mineral deposits and developing research and laboratory techniques using the latest methods. Fersman engaged many talented scientists. In 1930, the museum was renamed the Institute for Mineralogy and Geochemistry and in 1932 the Geochemical, Mineralogical and Crystallographic Institute. Fersman also recruited another group of scientists including A.V. Shubnikov and N.V. Belov to the new Institute of Crystallography.

Fersman commissioned Belov to investigate the chemistry of nepheline and apatite, two major phases in the Khibiny and Lovozero massifs. As a result, Belov developed a method for tanning leather using nepheline from these massifs as well as a commercial method for extracting rare earths from apatite. Fersman also appointed Belov to be Associate Editor of the journal Priroda (Nature) of which Fersman was editor. Belov subsequently published 70 scientific-popular articles in this journal. Belov also played a key role in unravelling the crystal chemistry of the complex and unusually diversified group of minerals within the nepheline syenites from the Lovozero massif. Belov was a close colleague of Fersman whose principal interests were crystallography, crystal chemistry and mineral chemistry. He died in 1982 aged 91 (Moore 1984).

In 1934, the Soviet Academy of Sciences, including the Museum of Mineralogy, moved to Moscow. Thirty railway carriages were required to move the museum's collection of more than 60,000 specimens. The relocation and setting up of the exhibition took 3 years of energetic work. In 1936-1937, the museum was able to organize independent exhibitions. The exhibits of the museum were put on display in 1937 in time for the XVII International Geological Congress which was held in Moscow. Fersman was the General Secretary of the Praesidium and played an important role in organizing this congress. He also organized a scientific station in the southern Urals which formed an important centre for the congress (Fersman 1935).

The 17th IGC demonstrated the considerable achievements of Soviet geologists in regional studies of the USSR, the discovery of mineral resources and the elucidation of several theoretical problems in the geosciences. There were also a number of congress excursions lasting 20-30 days to major areas of geological interest within the Soviet Union

(Milanovsky 2004).However, the congress was held in 1937 during the Great Terror unleashed by J.V. Stalin. As a result, the Soviet masses feared contact with foreigners and were suspicious of them. This was reflected in the atmosphere within the congress and during excursions. For example, some of the Russian delegates were refused permission to participate in interesting excursions at the last moment and some were arrested during the congress or immediately afterwards. The outstanding Russian geologist, Yu.M. Sheinmann, was amongst those arrested. However, the geological excursion to Karelia and the Kola Penisnsula has been described in glowing terms by Hurlbut (1939) from Harvard University.

When the Great Patriotic War began in 1941, the most valuable parts of the collections of the Museum of Mineralogy, about 80,000 specimens, were evacuated from Moscow and returned at 1944. Fersman remained Director of the Museum until his death in 1945. In 1955, the museum was renamed the Fersman Mineralogical Museum in honour of his achievements.

Fersman was, of course, first and foremost a mineralogist. At Khibiny, he had unique opportunities. In 1926, he reported the occurrence of about 90 minerals in the nepheline syenites and their contact zones based on the collection of over six tonnes of samples over a distance of about 3,000 km during a period of five years by parties ranging from two to eleven men (Fersman 1926). This work was carried out in exceedingly trying conditions owing to the bitter cold, the swarms of insects, the absence of roads and even pathways and the lack of habitation.

A new mineral, fersmannite, was discovered by A.N. Labuntsov (Labuntsov 1929). A. Lacun subsequently described this mineral which was named in honour of Dr S.A. Fersman, the eminent Russian mineralogist and leader of expeditions to the Chibina Tundras (Lacun 1931). Sokolova et al. (2002) subsequently described this mineral in detail. The mineral fersmite was also named after Fersman (Bonstedt-Kupletskaya and Burova 1946; Fleischer 1947). Fersman himself named 19 new minerals, many of them from the Kola Peninsula (Spencer 1947).

Wall (2003) has pointed out that there are more mineral species at Khibiny than anywhere else in the world. So far, 360 well-characterized minerals have been identified from there out of a total of 3700 minerals accepted as species worldwide. A number of factors contribute to this diversity, including the extreme variation in chemical composition of the nepheline syenites from which many of these minerals are derived (in particular, their high Zr, Nb, REE and Ti contents) which results in the formation of many complex silicate minerals. In addition, there are many pegmatitic veins associated with the second ring complex which contains many 'odd' elements which do not fit into the main rock-forming minerals. The presence of these pegmatites is therefore responsible for the formation of many rare minerals.

However, Pekov (2001) has subsequently reported about 1,000 mineral species from the Kola Peninsula and estimated that this region is the type locality for 180 mineral species. He also suggested somewhat improbably that there are economic concentrations of more than 60 elements there. More than half of these minerals are found in the world's largest alkaline igneous complex, the Khibiny-Lovozero complex. The Khibiny complex is the type locality for 130 of the 180 type minerals. The extensive mining in the region has been responsible for the avalanche of new mineral discoveries there. Yakovenchuk et al. (2005) have recently published a magnificent book on the minerals of the Khibiny alkaline massif which, according to one reviewer, ranks with the very best of the topological mineralogies which have been published in recent years (Tarassoff 2006).

During this period, Fersman also continued his interests in pegmatites.He visited localities in which they occur in the Urals, Transbaikal, Karelia and the Kola Peninsula (Spencer 1946) and recognized the succesive stages of their formation: magmatic (900-800°C), epimagmatic (800-600°C), pneumatolytic (600-400°C), hydrothermal (400-50°C) and hypogenetic (50-0°C). His book 'Pegmatites, vol. 1, Granite-pegmatites' published in 1931, reached the third edition in 1940. In the Kola Peninsula, the rich bonanza of pegmatites is the result of several unique igneous intrusions. Some were rich in alkali metals, especially sodium, and poor in silica and aluminum. Pegmatitic rocks produced from these unique intrusions are called agpaitic pegmatites and are found scattered all around the world. The agpaitic pegmatites (in which $Na + K > Al$) of the Kola Peninsula are amongst the most famous pegmatites in the world.

In the early 1920s, Fersman devoted himself to a study of the distribution of the chemical elements in the earth's crust. Fersman worked out the percentages for most of the elements and proposed that these quantities be called "clarkes" in honour of

F.W. Clarke, the American chemist who had pioneered the study of geochemistry (Clarke 1924). Clarkes had traditionally been expressed in terms of weight percentages but Fersman calculated them in terms of atomic percentages. His work showed different reasons for the terrestrial and cosmic distribution of the elements. Fersman was also interested in the ways in which elements are combined and redistributed in the earth's crust. He coined the term "technogenesis" for the role of humans in this process, concentrating some elements and dispersing others through extraction and industrial activities.

Fersman published several books on geochemistry in Russian. These included Geochemistry in Russia (1922), Chemical Elements of the Earth and the Cosmos (1923), four volumes on Geochemistry between 1933 and 1939 (e.g Fersman 1933) and The Search for Mineral Deposits on the Basis of Geochemistry and Mineralogy (1939). His books on Precious and Semi-Precious Stones (1920) and the Geochemical Migration of the Elements (Fersman 1929) were published in German. Fersman was also editor of Minerals of the Urals (vol. 1, elements and sulphides) which appeared in 1941. Two books on geochemistry were published in English after his death (Fersman 1952, 1958).

Fersman was also a popularizer of Soviet science and published a number of books of general geological interest. These include Three Years beyond the Arctic Circle (1924), Mineralogy for Everyone (first edition 1928, fifth edition 1935) and Reminiscences about Minerals (1945, written in Prague during a bout of illness brought about by overwork) all written in Russian, and The Scientific Study of Soviet Mineral Resources (1935), Twenty-Five Years of Soviet Natural Science (1944), The March of Soviet Science (1945) and Geochemistry for Everyone (1958) which were translated into English. These books were ‘best sellers’, a testimony to Fersman’s clarity of style (The President 1943).

Fersman’s book Geochemistry for Everyone (1958) is of particular interest because it emphasizes the point that the Russian school of geochemists made extensive use of geochemistry for solving practical problems. This approach is quite different from that of V.M. Goldschmidt whose Geochemistry was published at almost the same time (1954) as Fersman’s.

Fersman was the recipient of a number of major honours including the Lenin Prize in 1929, the Stalin Prize in 1942 for the study of ‘useful minerals of the Kola Peninsula’, the Wollaston Medal of the Geological Society of London in 1943 (one year before V.M. Goldschmidt) in recognition of ‘his fundamental contributionsin the field of geochemistry and his researches on the economic mineralogy of Russia’ and the Order of the Red Banner of Labour. In 1937, he was also added to the select list of Correspondents of the Mineralogical Society of America. He was also elected vice-president of the Soviet Academy of Sciences for the period 1927-29 and Presidium member from 1929 onwards. In addition, the Russian Academy of Sciences has an award for outstanding achievements in mineralogy and geochemistry named after A.E. Fersman and the research vessel, R/V Geolog Fersman, was named after him as well. In the citation for the Wollaston Medal, the President of the Geological Society of London concluded by stating that the society was honouring one of the greatest in the great company of Russian geologists (The President 1943). At the 18th IGC in London in 1948, the Russians reciprocated and awarded the Stalin Prize to L.R. Wager who used the money to buy an Austin 12 saloon!

Conclusions

A.E. Fersman was one of the leading Soviet geologists of the first half of the Twentieth Century. He was totally dedicated in all he did. He had many scientific interests but he is best remembered for his discovery of the huge apatite deposit at Khibiny which led to the development ofa major industry north of the Arctic Circle to mine and process these deposits.

However, Fersman had wide scientific interests which included detailed investigations of diamonds and pegmatites and the development of geochemistry as an important scientific discipline in the Soviet Union. He was also a great popularizer of geology as demonstrated by the number of books he wrote for a lay audience. In addition, he had many administrative responsibilites which he used to further the geological sciences in Russia. Fersman’s status in Russian geology can perhaps best be judged from his obituary by Academician V.A. Obruchev which appeared in the Moscow News of May 25, 1945 (Spencer 1946).

‘It is difficult to believe that Academician Alexander Fersman is dead. We always knew him as such a vigorous, buoyant, optimistic person. To say that an outstanding scientist has departed from us would be insufficient, we have lost a big man, a man tireless in insufficient, we have lost a big man, a man tireless in work and in quest, a man with a limitless range of interests and boundless potentialities and talent, a trail-blazer in science, a fine orator and popularizer, and with the priceless gift of infecting all around him with his dynamic energy and enthsiasm.'

A.E. Fersman died in the Soviet Georgian city of Sochi on May 20, 1945. His untimely death was the result of bad health and overwork over a number of years (Anon 1947).

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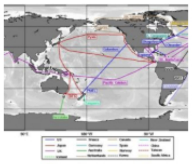
Studying the oceans to predict climate change



Map of different national con...

Swire Shipping MV Pacific Cel...

The SNOMS sensor tank and d...

Jon Campbell (NOC) showing ...

David Hydes training the engi...

Chief Engineer, Valeri Didenk...

A major factor influencing climate change is the accumulation of carbon dioxide in the Earth's atmosphere. The role of the oceans in the CO_2 carbon cycle is important. They soak up a third to a half of all the extra CO_2 generated. But to predict the course of future changes we need an accurate knowledge of the processes occurring now. To help meet this challenge an innovative partnership has been established between one of the world' major industrial groups, the Swire Group and the UK's National Oceanography Centre, Southampton to launch the SNOMS (Swire NOCS Ocean Monitoring System) Project. The Swire Group Charitable Trust has funded the design and assembly by NOCS of a system to measure the partial pressure of CO_2 in the surface waters of the world's oceans. In June 2007 the equipment was installed on the Swire Shipping's vessel *Pacific Celebes*, which trades out of Singapore on a five-month round-the-world service.

Using large commercial vessels like *Pacific Celebes* to collect scientific data enables samples to be taken over sustained time periods and long distances, at little or no cost to the scientific community, and modern communications systems enable information to be transmitted to shore for analysis in real time.

Long-term monitoring is essential to distinguish progressive climate change from natural oscillations, which tend to have time scales in the five and ten year range. This is where liners like *Pacific Celebes*, which stick to well-defined routes, come in. They have huge potential to allow repeated observations over many years. SNOMS is a part of the wider International Ocean Carbon Coordination Project (IOCCP http://ioc.unesco.org/IOCCP), which has promoted the use so-called "ships of opportunity" to assist with data collection. Information from the SNOMS project is made available to a network of scientific organisations linked to the United Nations via UNESCO and the World Meteorological Organisation, and to the wider public via the project's website: www.noc.soton.ac.uk/snoms. (The current position of the *Pacific Celebes* can be found on the website.)

The system was designed to be serviceable by the ship's crew, who are now key members of the science team. It centers around an enclosed stainless steel tank located at the bottom of the engine room. The tank is connected to the ship's seawater supply and contains devices for measuring dissolved carbon dioxide and oxygen, total dissolved gas pressure (for estimating dissolved nitrogen), temperature and conductivity. The information is collected by a data-logging control computer, which also receives input from a temperature sensor mounted on the ship's hull and from measuring equipment on the highest deck on the ship. There sensors measure humidity, air temperature and atmospheric CO_2 content, and ship's position. An Iridium satellite communications modem transmits the information to NOCS.

David Hydes comments: "More data will continue to be needed for some time yet to help us determine regional differences, and understand the interaction of biogeochemical and physical processes through time. Extending the marine CO_2 system database is crucial to aid improved accounting of the Earth's carbon budget and ultimately to guiding amelioration strategies. Even at this early stage the SNOMS project has been very impressive in showing how well commercial and research organisations can work together to reduce the serious short fall in human knowledge about our small green planet. SNOMS provides a perfect example of how the aims of the IOCCP Ship of Opportunity project can be met very effectively when cross sector partnerships such as SNOMS evolve."

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