BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS

RECORD

1986/28

REPORT ON A VISIT TO THE SOVIET UNION
8-22 June, 1986

by

Barry Drummond

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TABLE OF CONTENTS

2

SUMMARY

This report summarises my activities during a visit to the Ministry of Geology of the Soviet Union from 8-22 June, 1986. The visit was arranged under the terms of the Australia - USSR Scientific and Technological Program. The purpose of the visit was to review recent advances in the Soviet program of deep scientific drilling of the continental crust, to discuss with Soviet scientists Australian proposals for possible scientific research using the results from the Soviet deep drill holes, and to bring back to Australia proposals from Soviet scientists for co-operative research. I visited the A.P. Karpinsky All-Union Order of Lenin Geological Research Institute and the Leningrad Mining Institute in Leningrad, and the All-Union Institute for Geophysical Prospecting Methods in Moscow. Australian proposals for scientific co-operation based on the Soviet program of deep drilling are aimed at testing hypotheses founded on surface geological and geophysical mapping by comparing Australian data with Soviet results which have been correlated with the data from deep drill holes. They cover theories on the nature of the mid-crustal (Conrad) seismic discontinuity, studies of the distribution of heat producing elements in the crust, the use of fission tracks in zircons and apatites combined with the loss of radiogenic argon to develop and calibrate systems for measuring the thermal history of rocks, and geochemical projects to study the role of fluids in the crust, especially in metamorphic processes. Soviet proposals which I brought back to Australia include comparative studies of the stratigraphy of the Pilbara and Yilgarn Blocks with that of the Baltic, Ukrainian, Anabar and Aldanian shields; a study of the role of the basalt/eclogite transition in Archaean crust; and a request for isotope geochemical analysis of rocks from the vicinity of deep boreholes.

3

INTRODUCTION

The Australia-USSR Scientific and Technological Co-operation Program was established in 1975 but has been in abeyance for several years. In 1985, efforts were made to re-establish the program, and my visit was one of a number by Australian scientists during 1986. My visit was in my capacity as coordinator of a set of proposals by Australian scientists for co-operative research with Soviet scientists using data collected during the Soviet program of deep scientific drilling.

Under the terms of the Co-operation Program, the travel costs of Australian scientists to the Soviet Union are borne by the Australian Department of Science, and travels costs within the Soviet Union are borne by the Soviet institutes hosting the visit. The host institutes are also responsible for setting up a suitable itinerary for the visit. The Soviet Ministry of Geology is largely responsible for the deep drilling program and provided a general itinerary before my departure. This was necessary to ensure that a visa was issued by the embassy in Canberra. The details of my visit were not provided until I reached Moscow.

The purpose of this report is to chronicle my visit to the Soviet Union in order to (a) provide a permanent record of my visit, (b) summarise my observations for the benefit of the other Australian scientists whose scientific proposals I was representing, and (c) list some of my experiences for the benefit of other Australian scientists who will make visits to the Soviet Union in the future.

SUMMARY OF AUSTRALIAN PROPOSALS

Prior to my visit, the Soviet Ministry of Geology had been provided with a set of proposals for co-operative research based on the results of their deep drilling program. The proposals were all aimed at achieving a better understanding of the crust in shield regions in Australia by using the results from the deep drilling on the Archaean Baltic shield of the Kola Peninsula. The proposals were:

(i) Compare and contrast seismic data from the Australian and Kola shield regions, and compare the interpretation techniques and seismic models to find out if the seismic boundaries in the Australian shield are similar to those in the Kola Peninsula.

(ii) Undertake petrological, petrophysical and geochemical analyses of rock samples from the borehole using the procedures adopted for the Australian studies of shield rocks, and compare and contrast the rocks with samples from similar terranes in Australia.

(iii) Undertake ion-microprobe analysis to determine the temporal history of the rocks in the drill hole.

(iv) Undertake fission track studies to determine the thermal history of the rocks in the borehole.

(v) Study the chemistry and origin of fluids in the drill hole, and compare and contrast the results with models for the evolution of the mineral provinces in the Australian shield.

(vi) Study the movement of fluids in the drill hole. Determine whether the observed porosity and fluid content of the pores can account for the changes in seismic velocity with depth through the crust in shield regions.

(vii) Integrate the results from the different disciplines to study the nature of rock types and seismic discontinuities in the crust in shield regions and the implications for mineralisation.

The following people also contributed to these proposals:

Dr. Prame Chopra
Geophysics Division
Bureau of Mineral Resources
GPO. Box 378
Canberra ACT 2601

Dr. Bruce Chappell
Dr. David Ellis
Geology Department
Australian National University
GPO. Box 4
Canberra ACT 2601

Dr. William Compston
Dr. Peter Zeitler
Dr. Ian McDougall
Research School of Earth Sciences
Australian National University
GPO. Box 4
Canberra ACT 2601

Dr. Vic Wall
Department of Earth Sciences
Monash University
Clayton VIC 3168

Dr. John Lovering
Dr. Andrew Gleadow
Department of Geology
University of Melbourne
Parkville VIC 3052

Shortly before leaving for the Soviet Union, I received more specific proposals from Dr. Ellis who is seeking information on the concentration of heat producing elements, mainly K, Th and U, in the upper crust, and a joint proposal from Drs. Zeitler and McDougall at the Research School of Earth Sciences and Dr. Gleadow of the University of Melbourne who want to combine fission track studies with analysis of argon loss from minerals in the well to establish ways of studying the thermal history of various isotopic systems.

ITINERARY

6 June	Leave Australia
8 June	Arrive Moscow
9 June	Fly to Leningrad
10-11 June	A.P. Karpinsky All-Union Order of Lenin Geological Research Institute (VSEGEI)
12-13 June	Leningrad Mining Institute
14-15 June	Saturday and Sunday - rest days

16-19 June	VSEGEI; return to Moscow by train overnight on 19/20 June.
20 June	All-Union Research Institute for Geophysical Prospecting Methods; meet with Prof. Oleg Kuznetzov of the All-Union Research Institute for Nuclear Physics and Geochemistry and Vice-Chairman of the International Lithosphere Program's Coordinating Committee 4 on Continental Drilling.
21 June	Saturday - rest day
22 June	Leave the Soviet Union
24 June	Arrive Australia.

DISCUSSIONS

In order to place the discussions in the context of the Soviet program of deep drilling, some comments on the Ministry of Geology and a summary of my discussions with **Prof. Oleg Kuznetzov** are provided.

In the Soviet Union, the exploration for minerals (but not petroleum) is undertaken by the Ministry of Geology, which also performs all of the tasks which would be undertaken in Australia by the state geological surveys. It is also responsible for a large part of the mission oriented research program which would be undertaken in Australia by the Bureau of Mineral Resources and CSIRO. Research of a less applied nature is undertaken by research institutes of the Soviet Academy of Sciences. The program of superdeep drilling is the responsibility mainly of the Ministry of Geology, but because of the program provides results which are used across the broad spectrum of Earth sciences, the Academy has an interest in the scientific drilling, and the efforts of the Ministry and the Academy are co-ordinated by a joint committee.

The Ministry employs about 200,000 scientists and 400,000 support staff. It is divided into 40-45 institutes. Each institute is responsible for a particular section of the Earth sciences or for mapping the geology of particular areas. In addition to the institutes of the Ministry, many of the republics of the Soviet Union have their own Earth science institutes (or Geological Surveys in our parlance). Institutes of the Ministry of Geology work in all republics, but the 'Geological Surveys' of the republics work only within the republics.

Dr. Kuznetzov is Director of the All-Union Research Institute for Nuclear Physics and Geochemistry in the Ministry of Geology in Moscow. His institute was responsible for developing many of the tools used to log the physical properties of the rocks in deep and superdeep wells. The high temperatures and pressures coupled with the corrosive nature of the fluids rich in dissolved salts made this a difficult task. The institute is also involved in the measurements of the physical properties of the core removed from the well. This includes measurements at elevated pressures to recreate the environment in the well. Prof. Kuznetzov is also Vice-chairman of the International Lithosphere's Co-ordinating Committee 4 (Continental Drilling). Before leaving for the Soviet Union, I had requested a to see with Prof. Kuznetzov in his capacity as vice-chairman of CC #4.

Prof. Kuznetzov described briefly the program of deep drilling in the Soviet Union. The drilling is undertaken by one of the institutes of the Ministry of Geology. The planning of each hole is the task of the institute responsible for the geological research in the region. Thus, for example, the Kola drillhole is the responsibility of VSEGEI in Leningrad, which is responsible in a large part for the geological mapping and research in the Kola Peninsula. Drillholes are classified as deep if their expected total depth is less than 7 km and superdeep if they are expected to reach depths greater than 7 km. Currently three superdeep wells are in the process of being drilled. They are in the Kola Peninsula, currently at a depth of 12,060 m, at Saatly near the Caspian Sea where the current depth is greater than 8,500 m, and the newest well near Krivoy Rog which is currently at about 2 km depth. Three more wells are planned. They are at Urengoy in western Siberia, somewhere in the Urals, and somewhere in middle Asia. I was under the impression that the final position of these three wells has not been decided yet. Each well is in a different geological environment and was planned to intersect different kinds of geological phenomena. The Soviets regard the wells as valuable geological research laboratories and an important national asset. All scientific research undertaken using the data from the wells must first be approved by the Ministry of Geology.

A network of geotraverses is planned linking the superdeep wells. Each geotraverse will comprise detailed seismic profiling of the crust and upper mantle, and presumably will also involve studies in other disciplines. The data for each drill hole are stored in a database, mostly in digital form. Prof. Kozlovsky assured me that extensive use is made of computer storage for this purpose. The databases are separate for each well.

A few days before my meeting with Prof. Kuznetzov, **Prof. Karl Fuchs** from the University of Karlsruhe, Federal Republic of Germany and President of the International Lithosphere Program had visited Moscow and held discussions with **Prof. Ye.A. Kozlovsky**, Soviet Minister of Geology. Prof. Kuznetzov was present at the discussions. The outcome of the discussions was a resolution that their two nations should co-operate in their scientific drilling programs and link a proposed superdeep drillhole in the Federal Republic of Germany to the Soviet superdeep holes by extending the network of geotraverses into Germany. Profs. Fuchs and Kozlovsky also agreed to hold an international symposium on scientific drilling in September, 1988, somewhere in the Soviet Union and preferably at one of the superdeep drill sites. The details of the symposium have still to be announced.

Visit to VSEGEI - 10-11 June and 16-19 June

Most of my time in the Soviet Union was spent at the **A.P. Karpinsky All-Union Order of Lenin Geological Research Institute (VSEGEI)** in Leningrad. VSEGEI is the latter day extension of the Geological Committee founded in 1882, and is therefore the oldest geological institute in Russia. VSEGEI is the lead institution in the Ministry in the fields of regional geological mapping and the study of mineral resources. It is not involved in petroleum research or exploration. Research at VSEGEI has four main directions:

(i) Regional studies in the fields of geology, tectonics, geophysical properties, palaeontology, petrography, mineralogy, geochemistry and geochronology, resulting in the production of generalised maps at 1:2,500,000; 1:5,000,000 and 1:10,000,000 scale. VSEGEI also contains the cartography factory where all geoscientific maps in the Soviet Union are edited and printed.

(ii) Studies of the regional distribution of mineral deposits and evaluation of potential resources of the most important solid minerals in the USSR.

(iii) Studies of the ways by which the methods of geological mapping and cartography can be improved, leading to better methods in the search for mineral deposits.

(iv) Development of an information service, largely based on computer databases, which will aid in the search for mineral deposits.

VSEGEI has a staff of about 2,500. About 500 of these are scientists who have reached the academic level of 'Doctor' (in Russia, the title 'Candidate' is applied to those people who have what the west would call a Doctor of Philosophy, and 'Doctor' refers to what we would call a Doctor of Science). The other 2,000 are either scientists of lower grades or technical and support staff. Each year, VSEGEI has about 170 field parties working in all parts of the Soviet Union. Most field work is done during the northern summer because of the harsh conditions in winter, although I gather that some people work in the field the year round.

Tuesday 10 June at VSEGEI

I was welcomed to VSEGEI by Deputy Director **Nikitin** who explained the operations of the institute and listed the sections which I would visit over the next few days. He then introduced me to Dr. Oleg Sobolev, the director of the museum at VSEGEI. We then visited the museum, and I spent several hours being shown the exhibits by **Mr. Eugene Davidov** who explained the geology of the Baltic, Ukrainian and Siberian shields with the aid of the comprehensive rock and mineral collection of the museum. We then discussed the Kola superdeep drill hole. The museum has a comprehensive display covering the geology in the region of the hole, and summaries of the crustal structure. The crust has three layers in the region of the hole. Upper crustal velocities are about 6.0 km/s, and overlie layers of 6.5 and 6.8-7.0 km/s. The upper mantle velocity is 8.0-8.2 km/s (I learned a few days later when visiting the Leningrad Mining Institute that in the vicinity of the well, the greenstones form a high velocity lid obscuring much of the detail in the upper crust). The display has a comprehensive range of the rock types found in the well. The upper section contains metamorphosed volcanics with some interbedded sedimentary rock. The volcanics were deposited in a shallow water environment. At about 8,000 m, the drill encountered grey gneisses, and is still in the gneisses at 12,060 m where drilling has been stopped to recondition the drill rig and ream the hole prior to the final push to 15,000 m. Between 8,000 and 12,000 m, the drill passed through several seismic discontinuities without encountering any obvious changes in bulk rock chemistry or mineralogy. However, it did pass through some zones in which the rock is quite porous. Representative cores from these zones are apparently overpressured and when brought to the surface had to be placed in boxes for up to an hour because they were likely to explode. The core on display from these zones is very abraded and non-cylindrical, unlike the core from the rest of the hole which is quite circular in section and regular in shape.

I spent some time in the afternoon talking to **Dr. Vasiliev** and **Prof. Alexander N. Oleynikov** of the Division of Mathematical Methods in Geology. This division is responsible for the standardisation of geological documentation in the Soviet Ministry of Geology. It is introducing mathematics into geological studies and using computers for the storage and retrieval of geological data. They are about to publish the 'Treatise on Geology' in 14 languages.

I had some communications problems when talking to these gentlemen because of the technical nature of some of the terms, but I think that my conclusions are generally correct. I found that they recognised many of the terms I was using (bits, bytes, etc.) before my interpreter could find an appropriate literal translation.

The division uses micro, mini and medium sized computers. Their medium sized computer has 1 Mbyte of memory, 32 bit architecture and can perform 200,000 floating point operations per second. Some of the other institutes in the Ministry, especially those doing seismic processing, use supercomputers. I was not able to ascertain any specifications on Soviet supercomputers (Jon Claerbout reported in 'The Leading Edge' Volume 5(3), 1986, p29 that the Central Geophysical Expedition of the Ministry of Petroleum runs four computers. The slowest was an IBM with 16 Mbytes RAM, 2 Gbytes of disc, the CPU is capable of 10 million instructions per second and has an array processor capable of 30 million instructions per second). Most scientific programming at VSEGEI is in Fortran IV and a language of Russian derivation, and Algol and Cobol are used for administrative work. Terminals are scattered throughout the building; interactive graphics are rare. The Soviets do not make extensive use of telephone lines for the transmission of data and computer-computer communication, and I gather that they are having problems with protocol when they try to network computers. Dr. Vasiliev is aware of fibre optics but does not use them. He was not aware of array processors.

The division maintains a pool of programmers who write much of the core software and some of the applications programs for users, but many of the scientists do their own programming.

Wednesday 11 June at VSEGEI

Wednesday 11 June was devoted to visiting the geochemical laboratories at VSEGEI. The laboratories are very extensive and cover a broad range of geochemical activities.

I met first with **Dr. Irene Zagruzina**, head of the Isotope Geochemistry Department. We discussed in general terms the abilities of the VSEGEI laboratories. They can perform K/Ar, Pb/Pb and Rb/Sr isotopic analyses, but cannot do Sm/Nd analyses. Dr. Zagruzina asked me if I could arrange for Sm/Nd analyses to be done on some core from the Kola drillhole. The details of this request are given in a later section where other requests for co-operative work are also summarised. Dr. Zagruzina and most of her colleagues are fully aware of the work of Rod Page, Lance Black, Bill Compston and other key Australian workers in the field of isotope geochemistry. I suspect that they have greater access to results published in the proceedings of conferences than to results in journals,

9

perhaps because Russian delegates to conferences are always likely to take copies back to Russia. I was told that the VSEGEI library gets the key English-language journals.

I was shown machines used for XRF, atomic emission spectroscopy, and mass spectrometers for the analysis of isotopes of sulphur, oxygen and strontium (one machine for each). I was also shown ion microprobes. Most of the equipment is Soviet-built but the microprobes that I was shown were all foreign - 2 were French and the other was American. One was a Cameca built in about 1978, and one had a DEC computer controlling it.

On many occasions I was told that the Soviet equipment lacks the precision of foreign equipment. For example, the precision on Pb/Pb ages is such that they use the system only on Precambrian rocks, and errors are usually of the order of 100-400 m.y. This has encouraged them on several occasions to develop new analytical techniques. Those which were especially brought to my attention were the electron emission spectrometry for Pb/Pb of **Dr. Anatoly Chuchonin** and the technique of **Dr. Andrey Kirikov** who has developed a method of using laser beams to analyse small spots (~20 micrometres) on individual grains of zircon. I was not able to obtain any clear description of the technical aspects of this method. Dr Zagruzina likes it because it is dry and therefore unlikely to cause contamination of the sample which can happen during the wet chemistry part of other techniques. In the afternoon Dr. Kirikov demonstrated an (XRF?) machine for field use. It operates on crushed samples and is about 40 cm in all dimensions. Its accuracy is about 10%, and it has the ability to do multiple scans of the rock, sum the results in an accumulator and display them on a small video screen. They can also be plotted on a chart recorder.

I was shown the extraction techniques for C, O, Sr and Si. They seem fairly straight forward to my unpractised eye. Generally the mineral or rock is crushed, dissolved in acid and in the case of C, the material to be analysed is collected as CO_2. S is collected as H_2S, and Sr is bound to Ga for collection and analysis. They use a different mass spectrometer for each element.

Dr. Ignaty Serikov showed me over the XRF laboratories. They have 3 machines each capable of analysing for 6 elements at a time, but each machine was set up for only two. Samples were passed from one machine to the next and so analysed for 6 elements. These machines gave their readouts in digital form; the numbers were written down by the operators and then entered into a microcomputer for further processing. These three machines annually produce about 115,000 (elemental) analyses each year. A fourth XRF machine was controlled by a microcomputer which also recorded the data for later transcription on magnetic cassette. This machine can perform 10's of elemental measurements on each sample. It is new and has not gone into full scale production yet, but its expected throughput is about 50,000 (elemental) measurements per year.

I was shown the atomic emission spectrometers. One records on film and one was computer controlled with the data recorded by the computer. The computer controlled machine is new and has just finished its development stage. I was later shown an apparatus for digitising the photographically-recorded spectrograms.

I was introduced to the head of a laboratory which deals with the analysis of water samples. They have developed a technique at VSEGEI which gives reliable results on very small amounts of water. Unfortunately I was not able to obtain any technical details of the method. This group has not looked at the water from the Kola drillhole, but they expect that one day they will.

I was then taken to meet a fellow who has been using impulse XRF and a laser to study the zoning in minerals. He has found that the zoning in an apatite crystal can be mapped using the decay of fluorescence after irradiation, and this also maps the concentration of LIL elements. He thinks he can therefore use the decay of fluorescence to study the pH and eH of the fluids which deposited the mineral. He has also found that the decay of photoluminescence of zircons from the crust is vastly different from the decay in zircons removed from kimberlites and therefore formed in the mantle. The method is therefore a valuable way of discriminating between the different sources of zircons.

Monday 16 June at VSEGEI

I spent the day with **Dr. E. Nalivkina** who showed me maps and described some of the features of the geology of the Baltic and Ukrainian shields.

The Baltic shield has abundant grey gneisses with lesser amounts of mafic material. The gneisses are overlain by Proterozoic rocks which she equated to the Fortescue in the Pilbara region, but which seem to be more like the Warrawoona Group but much younger. They also appear similar to the Yilgarn greenstones, but not in age. Two sequences of greenstones have been identified in the Baltic shield. The older sequences range in age from 1.8 to 2.0 b.y. and the younger sequence is 1.6-1.8 b.y. old. These ages are based on K/Ar and Pb/Pb dating. The Kola drillhole intersects the younger rocks but not the older sequence.

Apart from their ages, another major difference between the Baltic shield greenstones and those from the Pilbara and Yilgarn Blocks is that in the Baltic shield the more mafic volcanics are at the top of the sequence. The sequence is:

(top)

Tholeiites with olivine
<--------
Basalts | Interbedded with thin layers
<-------- of shallow water sediments.
Andesites and trachyandesites | Pillow lavas common.
<--------
Andesites - subalkaline - 52% SiO_2

(bottom)

The underlying Archaean rocks are orthogneisses of andesitic composition. Dr. Nalivkina predicts the presence of much greater proportions (>50%) of mafic rocks at depth in the crust. She favours a model of granitisation of mafic material to generate the rocks from which the grey orthogneisses were formed. The orthogneisses and the Proterozoic greenstones are all intruded by younger cross-cutting massive granites. The positions of these granites were controlled by large faults.

Dr. Nalivkina has written a book about the geology of the Ukrainian shield. In the book, she integrated the results from geophysical studies with the known geology. In particular, she used laboratory measurements of seismic velocities in rock samples to tie *in-situ* velocities to rock types. The laboratory measurements that she had available were all made at atmospheric pressure, and the rocks had been soaked in fluid (kerosene, I think) to fill the pore spaces. Adjustments were then made to allow for the effects of pressure.

Dr. Nalivkina has identified two types of terranes in the Ukrainian shield. One has gneisses and charnockites but no greenstone belts. The closest Australian analog to this kind of terrane would be the western Gneiss Belt of the Yilgarn Block. The other type of terrane contains granitoids and greenstones, as in the Pilbara and eastern Yilgarn blocks. Dr. Nalivkina believes that this kind of terrane overlies the gneiss/charnockite type of terrane.

Tuesday 17 June at VSEGEI

I spent the morning with **Dr. Gennady Belyaev** who explained the production of geochemical maps of the Soviet Union. These maps are very impressive and apparently tied up the resources of the geochemical laboratories at VSEGEI and about 20 other institutions for several years. The geochemistry of each formation (40 elements) was measured and then averaged over the province, converted to 'Clarks' and then illustrated on the maps. I saw a map of the Soviet Union at 1:10,000,000 scale and maps of the Baltic and Aldanian shields at 1:1,000,000 scale. They have also subjectively characterised the processes of mineralising fluids and placed them on a map. The theory is that when the two maps are superimposed, the overlap of geochemical anomalies with appropriate zones of mineralising fluids will point to mineralisation.

Dr. Belyaev described the processes by which phosphorus is concentrated in the Aldanian shield. This is his particular research speciality; he claims that the processes work for other elements of similar valency but will not necessarily work for all elements. The process involves many stages of progressive enrichment. He calls the process geochemical resonance. He has also tried to find correlations between geochemical and geophysical anomalies. Zones with high phosphorus often correlate with Fe_2O_3 and TiO_2, but phosphorus ore bodies typically have low magnetic values (I am not sure what this means. He may have been referring to low absolute magnetic values, or to small dipole anomalies)

In the afternoon, I gave two seminars, entitled:

'The organisation of Earth science research in Australia'

and

'The structure of crust in the Precambrian shield of Australia'.

The second talk provoked some discussion, but most questions were about specific aspects of Australian geology rather than the more general material covered in the talk.

Wednesday 18 June at VSEGEI

Several of the people I met on 18 June had requested a short meeting to discuss questions raised by my seminars the previous day.

Dr. M.Sh. Magid had several enquiries about crustal structure in Australia. Some people seemed to be confused about the way crustal structure varies from province to province. I had seen this earlier at the Leningrad Mining Institute (discussed later). **Dr. Vadim Kushev** wanted to talk about the control of crustal structure on the emplacement of diamondiferous kimberlite pipes. We talked for a short period and continued our discussions the next day, and the full subject matter of our talks is given later.

Dr. N.M Solovyova enquired about the production of regional magnetic maps of Australia. She is in charge of the production of the magnetic map of the world, and needs magnetic data for the Australian region. VSEGEI is also producing what Dr. Solovyova called petrophysical maps of the Soviet Union. Such maps show the density and magnetic induction of the surface rocks for the entire Soviet Union. Dr. Solovyova showed me copies of the magnetic map of the Soviet Union produced at 1:10,000,000 scale. The data are hand contoured because this allows human interpretation of the data as the contouring in performed. She seemed to dislike computer contouring because the computer is too objective in the positioning of contours. This attitude is at odds with the attitude I met a few days later at the All-Union Research Institute for Geophyscial Prospecting Methods in Moscow (see later) where the production of maps was discipline oriented with absolutely no interpreter bias or input from other disciplines. They are aware of but do not have access to image processing of computer gridded data; all maps are produced as contour plots.

I spent some time with Dr. Nalivkina talking about the nature of the 'Conrad' discontinuity. I explained that I do not like the term 'Conrad' discontinutiy because it was traditionally applied to the discontinuity between a granitic (sialic) upper crust and a basaltic (simatic) lower crust, whereas I believe that the discontinuity can be explained more logically by either a change in metamorphic grade (greenschist or amphibolite to felsic granulite) or a change from an upper crust with small amounts of water in cracks and pores overlying an anhydrous lower crust. The Kola drillhole intersected several seismic discontinuities in the 8 to 12 km depth range, but these discontinuities do no correlate with any changes in mineralogy or chemistry. Rather, they correlate, if anything, with zones of crushed rock. The crushed zones are horizontal rather than following the dip of the foliation in the gneisses which is parallel to the contact between the greenstones and the gneisses, and they contain gases and liquids.

Thursday 19 June at VSEGEI

Dr. Vadim Kushev has subdivided the shield regions of the Soviet Union into a number of cratonic areas surrounded by Proterozoic mobile belts. In many parts of the shield, the basement is covered by thick sediments and volcanics so that he has had to use geophysical properties (magnetic contours, crustal structure) to map the cratons and mobile belts. He has made a lot of use of the available geochronology and geochemistry, and his maps of the shield closely resemble models of the Precambrian shield areas of western, central and northern Australia proposed by the Proterozoic working group at the BMR (see BMR Record 1984/31). He has placed large areas of grey gneiss terranes in the Anabar and Aldanian shields in Proterozoic mobile belts, whereas other interpretations place them in Archaean nuclei despite their having the structural character of mobile belts and Proterozoic isotopic ages.

Kimberlites are found throughout the Soviet Union, but the only diamondiferous occurrences are at or near the margins of blocks which have been stable since the Archaean and abut younger mobile belts.

Thursday 12 June at the Leningrad Mining Institute

The Leningrad Mining Institute was founded over 200 hundred years ago by Peter the Great. It contains a very fine museum devoted to the rocks and minerals of the Soviet Union and to the history of mining methods. The museum was one of the first parts of the institute to be built. The institute is now devoted to the teaching of Earth sciences. Students from the institute are held in very high regard; many of them have become Members of the Soviet Academy of Sciences.

The institute teaches a full range of courses relating to the exploration for and exploitation and processing of ores. These three categories seem stamped on their teaching philosophy, and the institute has a strong emphasis on practicality. It also has a large number of foreign students from developing countries. Students take 4 years for a basic degree, and the Institute also caters for part time students (4 nights/week for 5 years) and correspondence students who must be working in some field of Earth sciences.

Geophysics has been taught for about 50 years, but the chair of geophysics was established only about 25 years ago and is currently held by **Prof. Zakharov**.

I was introduced to **Dr. Vasin** who specialises in magnetotellurics and electrical methods. He has been studying the electrical structure of the Baltic shield. He feels that electrical methods do not give a reliable picture below the base of the crust because of a combination of low resolution and non-uniqueness of the inversion techniques. The magnetotelluric method was originally thought to be providing evidence of stratification in the crust but with a greater number of probes they now find that this is not the case. The MT method has proven very successful for detecting abrupt vertical changes in the crust, especially those associated with zones of mineralisation and graphitic shale. He is very interested in SIROTEM.

14

I then spent the rest of the day with **Mrs. Ludmila Platonenkova** and **Mrs. Kira Kalnin** discussing the seismic structure of the Baltic shield. The discussion continued the next day when we were joined by **Dr. Alexey Goncharov**.

Friday 13 June at the Leningrad Mining Institute

The Leningrad Mining Institute has been largely responsible for seismic studies of the crust in the Baltic shield, particularly in the region of the Kola drillhole. The seismology group at the institute has a staff of 20-25. Only 5 are involved in the interpretation. The rest are employed for field work and data processing. Seismic coverage consists of several refraction traverses with maximum shot to station separation of 250 km. The distance between seismographs is usually 200 m. The refraction profiles generally overlap, so that they have good control on whether lateral variations in structure are present. They do not seem to do any reflection profiling to study lateral changes in structure, and seemed unimpressed with the attitude that refraction profiles were generally good for measuring average crustal velocities but reflection profiles were needed for good structural control.

I was shown their seismic recording equipment. They use several kinds of equipment.

(a) They have several sets of seismic reflection equipment which they apparently use for detailed parts of their refraction traverses. The main set of equipment is the Russian's state-of-the-art 48 channel digital equipment. The equipment records 14 bit samples with either a 4 or 5 bit exponent. It has instantaneous floating point with 160-170 db dynamic range. The equipment has a memory which turned out to be a loop of magnetic tape. The memory can save 15 s of data at 2 ms sampling rate (the smallest sample increment), and allows the data to be stacked in the field prior to display. Both the unstacked and the stacked data can then be recorded on tape. Field tapes are recorded at 800 bpi on half inch tape. The camera has self-developing photosensitive paper. They use 10 Hz geophones in strings of up to 50 and patterns which vary depending on the job. The roll-along switch is rather large and uses two slide switches to switch in any two sets of 24 geophones. They use a radio blaster. The whole set of equipment is triggered by the radio blaster which is triggered by the operator turning a key. The institute also has several sets of 'portable' 24-channel equipment. The total size of the portable equipment would be about the same as the BMR's present Sercel SN368 equipment. The 'non-portable' 48 channel equipment is about 3 times as large. All of their reflection equipment uses traditional multipair cables.

(b) They have two different kinds of portable refraction recorders. One is a 6 channel system, and the other has 24 channels. Both record frequency modulated signals on analog tape. I was shown the 6 channel systems. They usually record 6 vertical channels, but on some occasions they have recorded three components. When the 24 channel equipment is used to monitor seismicity, they usually set up local area 3-component networks. The 6-channel equipment can record for 40 minutes on half inch tape. The recorders are usually deployed in a sleep mode and are triggered by a time-coded radio signal. They also have an internal crystal oscillator. Each of the seismic amplifiers can be set in 6db steps and they have a dynamic range of 60 db. The centre frequency for modulation is 3000 Hz. In addition to the 6 seismic channels, the systems also record a timing channel and a channel of pure centre frequency to provide a basis for correcting tape speed variations during playback. The equipment can be used without the radio trigger in which case an external timing signal can be added.

The equipment is normally deployed by helicopter, with each operator dropped into position with two recorders. The recorders are set up side by side, with long cables run out to the seismometers. Six seismometers are set up on each side of the recorders:

```
                              2 recorders
                           +-----+  +-----+
    1 OPERATOR             | 0 0 |  | 0 0 |
                           +-----+  +-----+
                              |        /
                              |    ___/
                              |   /
+---+---+---+---+---+---+   +---+---+---+---+---+---+
|   |   |   |   |   |   |   |   |   |   |   |   |   |
v   v   v   v   v   v   v   v   v   v   v   v   v   v
     seismometers                 seismometers

                           ->|   |<-
                            200 m
```

After the recorders have been setup, the helicopter takes off and relays the turn-on radio signal along the line. They find this mode of operation very reliable.

They have the ability to digitise their data but seldom do. When developing their models, they work with analog playouts pasted onto sheets to produce record sections. In the interpretation stage, correlations between traces are made and then copied to tracing paper and interpreted. Because of the large number of traces (one every 200 m), correlations are often made of events which correlate over only a few kilometres but across many traces. Thus the diagram of correlated phases traced from the record sections is very complex, and the major phases are often lost among the detail. The travel times computed for their preferred models were often plotted on the diagrams I was shown. They did not always agree with the phases in the data. They invert only the travel-time data; they do not use any amplitude modelling to fine tune the models. The institute has copies of Cerveny's one and two dimensional synthetic seismogram programs on their computer but I did not see any output from them.

The models that they have derived from their refraction profiles are very detailed, with low velocity zones both above and below the discontinuity they call the Conrad at about 10-15 km depth. The models also often have abrupt horizontal changes in structure. Vertical fault-like structures cutting the whole crust and mantle are common. Nowhere in the eastern part of the Baltic shield do they observe or interpret velocities greater that 7.0 km/s at the base of the crust, although they say that velocities as high as 7.3 km/s have been observed farther west in Finland. They have not seen any of the results from the

FENNOLORA profile in Sweden.

They are convinced that the crust throughout the Baltic shield, and elsewhere for that matter, has a constant thickness. Thus the crust/mantle boundary tends to be at the same depth in all of their models, and they vary the velocity within the lower crust to allow for variations in the Pn intercept times. They showed me a copy of Report S-11 on the University of Helsinki which has record sections from seismic refraction experiments in the Baltic shield in Finland. There the Pn intercept times varied between 6 and 8 s and this was causing them some bother because they were having difficulty finding models in which the lower crustal velocities were acceptable. They were concerned when, in response their questions, I stated that Pn intercept times in the Archaean shield of Australia varied between 6 and 10 s.

I showed them a graph of mean crustal velocity versus crustal thickness for Australia. This also caused concern because they insisted that the two parameters were dependent - crustal thickness would vary if the crustal velocity was varied. I took some time to explain that the velocities in the crust could usually be fairly well determined from the travel time correlations on the record sections, and the velocities coupled with observed intercept times then defined crustal thickness.

Notwithstanding their ideas about crust of constant thickness, their models of the upper crust in the Baltic shield are very similar to those from Archaean shield areas elsewhere in the world. Velocities in the upper crust are generally in the range 6.0-6.2 km/s. In some regions, greenstone supracrustals form high velocity lids which obscure the detailed structure of the upper crust. In some of the models where Dr. Goncharov was trying to model the nature of the lower crust, velocities at the base of the crust were as low as 6.4 km/s and as high as 7.5 km/s because he was not prepared to change the depth to the crust/mantle boundary but was still trying to fit the observed intercept times.

Visit to the All-Union Research Institute for Geophysical Prospecting Methods - Friday 20 June

Prof. Yvgeny Kozlov, Deputy Director of the institute briefly described the role of the institute and its role in the Ministry of Geology. The institute is not involved in the search for new ore bodies. Rather, its main tasks are to develop new methods of geophysical prospecting, to adapt old techniques to new kinds of problems, and to provide computer software support for the new techniques it develops. Many of the problems tackled by the institute are brought to it by other institutes in the Ministry of Geology but it also has a charter to look for new methods which it thinks should be developed.

Most of the day was spent with **Dr. Yuri Shchuchin** and **Dr. G.V. Krasnopevtseva** who are seismologists, and **Dr. Semin** who is a geologist. We discussed the progress of controlled source seismology for studying the crust in the Soviet Union. They started by showing me a map with a network of detailed seismic refraction profiles which cover the entire Soviet Union. Some of these have already been recorded, and they hope to obtain the funding to finish the project in the next decade. The profiles comprise the geotraverses which Prof. Kuznetzov wants linking the super-deep drill holes. They showed this map at the International Geological Congress in Moscow in 1984 and had a lot of favourable comment from western scientists. They are now using this comment as evidence that the project has scientific merit.

I was shown a map of the Soviet Union at 1:5,000,000 scale (4 sheets) with all of the existing seismic refraction profiles marked. There are many tens of thousands of kilometres of profiles of varying quality, and they represent 20 years of work by institutes in both the Ministry of Geology and the Academy of Sciences of the Soviet Union. The next set of maps at the same scale showed contours of the depth to the Moho, with the values of Pn velocity marked with shading. Both of these sets of maps will be published soon.

The seismic reflection and refraction data have been combined with drill-hole data and electrical models of the upper crust to produce maps of the thickness of sediment cover across the Soviet Union. This map has been produced at both 1:5,000,000 and 1:2,500,000 scales. The sediment thickness is contoured and colours are used to show the different ages of basement.

The institute is currently looking at ways of characterising the seismic properties of the crust. They look for three characteristic velocities. In the upper crust, they expect velocities of 6.2-6.3 km/s. This phase is usually easy to observe because it is a first arrival. In the lower crust, they expect velocities of 6.6-6.7 km/s, also observed as first arrival phases. In the middle crust, they expect velocities of 6.4-6.5 km/s, but these are difficult to observe because the phases are seldom first arrivals. Velocities greater than 7.2 km/s in the crust are usually associated with a Moho with a more complex character. They see low velocity zones at several levels in the crust, and Dr. Shchuchin interprets them as zones of crushing.

The next mapping project will be to produce maps of the character of the crust at 10, 20, 30 and 40 km depth for the entire Soviet Union. The maps produced to date have been drawn with no reference to the geology. Likewise, the maps of the horizons of the crust will be produced on the basis of seismic models only.

This approach seems to dominate the thinking at this institute. The production of maps of the crust of the Soviet Union has been neatly pigeon-holed and will be carried out without reference to any other discipline or institute. Such projects obviously used large amounts of manpower and resources.

PROGRESS ON PROPOSALS FOR CO-OPERATIVE RESEARCH

The scientists with whom I had discussions clearly did not have the authority to agree to any form of co-operative research. Every proposal has to be vetted by the Ministry of Geology. I gather that there are two reasons for this. Firstly, the scientists work for the Ministry and their research must fall within the general scientific program of the Ministry and the specific tasks defined for their institutes. Secondly, the superdeep drillholes are regarded as a national resource for research purposes. Foreign research proposals must be for work that will benefit

Soviet science and not just the research goals of the foreign scientists.

Australian Proposals

Most of the Soviet scientists with whom I had discussions had read the Australian proposals for co-operative research and they remarked that they all had worthwhile scientific merit. The proposals were being considered by the Ministry and we would be informed in due course whether they had been accepted. Some of the research goals have already been considered at least in part by Soviet scientists and the results reported in the (Soviet) literature. Many of them can be found in the book *Kola Superdeep* for which an English language translation will be published in 1986, probably by Springer-Verlag in Berlin.

My enquiries about specific aspects of the Australian proposals solicited the following responses:

(1) Soviet geochemists have detected no change in the bulk rock chemistry with depth in the hole, except of course for those associated with changes in rock type, for example from greenstones to gneisses. The drill has now passed through about 4 km of grey gneisses. If it continues through another 3 km to reach the expected total depth of 15 km, further analyses will probably be necessary. No significant change has been measured in the distribution of the heat producing elements K, U and Th with depth in the hole.

(2) Fluids found in zones of crushing between 8 and 12 km have been analysed to see if they have played a role in the metamorphic processes at depth. The results so far seem inconclusive. The main problem is in collecting fluids at specific horizons without getting them contaminated by water and mud circulated in the hole during the drilling phase.

(3) The proposal from Gleadow, Zeitler and McDougall for an integrated study using fission tracks and various isotopic systems to study the thermal history of the rocks from the drill hole received enthusiastic support. No work seems to have been done on the thermal history of the area based on fission tracks, and the Soviets have not used Argon loss from the samples as a quantitative indicator of thermal history.

(4) Various studies have been made of the physical properties of rocks from the drill hole. They are made both down the hole using wire line logging and in the core samples in the laboratory. I saw several examples of the velocity logs from the well being tied to the seismic horizons detected by the seismic refraction technique. The Soviets use the velocity logs as an indicator of the regional properties rather than a sample at one place.

Measurements in core samples in the laboratory include density, magnetic properties and seismic velocity. The measurements of seismic velocity reported in the book *Kola Superdeep* were at confining pressures up to 0.2 GPa (2 kbar). If the hole continues through grey gneisses to 15 km depth, measurements will be required at pressures to 0.3-0.4 GPa to ensure direct comparison with the observed *in situ* velocities, and at even greater pressures if the results are to be extrapolated into the lower crust. To date, **Prof. Volorovich** from the Institute of Physics of the Earth, Academy of Sciences, has been charged with the task of measurements at high pressure (and high temperature) of seismic velocity in the core samples, and the All-Union Research Institute for Nuclear Physics and Geochemistry also has a role in such measurements.

(5) The role of fluids in the character of the seismic discontinuity at 10-15 km depth in shield regions has been studied briefly. **Prof. Kuznetzov** assured me that an article has been published in the papers of the Soviet Academy of Sciences suggesting, on the basis of seismic models and the data from the drill hole, that the upper crust is fluid filled while the lower crust is dry. He could not remember the details of where or when the paper was published. Other scientists did not seem too keen on such a model.

Soviet Proposals

In addition to any other proposals already received by the Australian Government for co-operative research, I was asked to bring back to Australia three more proposals for consideration. These proposals were presented simultaneously to the Soviet Ministry of Geology in a bid to have them become part of the formal Ministry proposals.

(1) **Dr. Nalivkina** of VSEGEI would like to come to Australia, or send someone else, to sample the type regions of the granitoid/greenstone terranes of the Pilbara and Yilgarn blocks of Western Australia, so that comparisons can be made between the geology of the shield regions in Australia and the Soviet Union. Such a visit would take about 4 weeks, and would include a comprehensive sampling program. She would need to be accompanied in Australia by someone familiar with the geology.

(2) **Dr. Nalivkina** of VSEGEI would like to visit the laboratories of **Prof. A.E. Ringwood** at the Australian National University and **Prof. D.H. Green** at the University of Tasmania to study the

basalt - mafic granulite - eclogite

transitions. She would like to view thin sections of the samples from the high pressure/high temperature laboratory experiments.

(3) **Dr. Zagruzina** of VSEGEI would like to send some of the core samples from deep and superdeep wells in Krivorozhskaya, the Urals and the Kola for Sm/Nd analysis. The total number of analyses would probably be about 8. She offered a joint authorship to the scientists who agreed to do the analyses. **Dr. Nalivkina** later modified this proposal, saying that the rocks to be sent to Australia would more likely be representative samples from surface outcrop. She also asked that the rocks be dated using Rb-Sr and U-Pb systematics.

All of these proposals are outside my immediate area of interest and responsibility so I promised only to bring them back to Australia for consideration.

ACKNOWLEDGEMENTS

I thank the Department of Science for the financial support which allowed me to visit the Soviet Union, and the A.P. Karpinsky All-Union Order of Lenin Geological Research Institute and the All-Union Research Institute for Geophysical Prospecting Methods for being my hosts and meeting my expenses while I was in the Soviet Union. I thank Trevor Gay of the Department of Science and Dr. John Truswell and David Newham of the BMR for their administrative support in setting up the visit. The staff of the Australian Embassy in Moscow were especially helpful with their advice on local matters and habits.

Finally, I thank my interpreter Alexey Balyasnikov for his hard work, his local knowledge as a guide, and his friendship.

APPENDIX - Addresses of Institutes Visited

VSEGEI (All-Union Geological Research Institute)
Ministry of Geology of the USSR
Sredny Prospect 74
Leningrad 199026 USSR

Leningrad Mining Institute
VO 21 Line No.2
Leningrad 199026 USSR

All-Union Research Institute of Geophysical
Prospecting Methods
Ministry of Geology of the USSR
22, Ul. Tchernyshevskogo
Moscow 101000 USSR

All-Union Research Institute of Nuclear
Geophysics and Geochemistry
Ministry of Geology of the USSR
8, Varshavskoye shosse,
Moscow 101000 USSR

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