THE SALMI COMPLEX OF KARELIA, NORTHWESTERN RUSSIA: POTENTIAL HIGH-LEVEL RADIOACTIVE WASTE REPOSITORY

David V. LeMone[1], Petr Vaganov[2], Stanislav Turchenko[3], Rebecca Dodge[4], and Hongjie Xie[1]

[1]Department of Geological Sciences, University of Texas at El Paso, El Paso, TX 79968
[2]University of St. Petersburg, Department of Ecogeology 7/9, Universitetskay a nab., St. Petersburg 199034, Russia
[3]Institute of Precambrian Geology and Geochronology of the Russian Academy of Sciences, 2 Makarova nab., St. Petersburg 199034, Russia
[4]Geology Department, State University of West Georgia, Callaway Bldg., Carrollton GA 30118

ABSTRACT

Russian scientists from the University of St. Petersburg and the Institute of Precambrian Geology and Chronology of the Russian Academy of Science have been involved in an evaluation of northwestern Russia for potential high-level radioactive waste repository candidate sites. They have determined that the Kola-Karelian region within the Precambrian Fennoscandian Shield appears to be the most favorable on the basis of its characteristically very low seismic activity. Satellite and aerial data combined with geophysical information suggest that the Salmi rapakivi granite-anorthosite Complex is deserving of further research. The Salmi Complex covers an area of approximately 4000 square kilometers (km^2) and is 1540 million years (Ma) in age. It is bordered by regional fracture zones and emplaced along an upthrust zone between Archean and Palaeoproterozoic domains. The complex intrudes supracrustal and volcanic-sedimentary rocks of both domains. A 9 km^2 block within the complex appears to be tectonically very stable and resistant. This is the area of interest for the HLRW repository.

In addition to the studies conducted and ongoing in Russia, remote sensing studies of this area were undertaken at the Pan American Center for Environmental Studies (PACES) and the University of West Georgia Remote Sensing Laboratory. Utilizing LANDSAT Thematic Mapper (TM) data, two finished images have been printed: one at 1:250,000 scale (approximately 180 km x 180 km) and a subscene at 1:100,000 scale (approximately 70 km x 70 km). The imagery has been georeferenced using published topographic maps and gridded to latitude-longitude and Universal Transverse Mercator references. Red, green, and blue bands applied to the image (RGB = 472) were selected for maximum separation, elimination of atmospheric effects, and de-emphasis of vegetation. After comparative examination of these images, it may be determined that utilization of the LANDSAT data and the selected thematic spectral bands has produced a useful tool for site evaluation in the Salmi Complex.

INTRODUCTION

The establishment of a high-level radioactive waste (HLRW) repository in northwestern Russia is consistent with the primary priorities of the Russian national nuclear energy programs. Russian reactors (e.g., RBMK-1000, VVER--1000, etc.) produce more radioactive waste than any comparable reactors globally. Bradley (1) reports, for example, that the 30-year accumulation from RBMK reactors is on the order of 34,500 cubic meters (m^3) of solid and bitumenized solid radioactive wastes. An installation that can be used as an example of the problem in northwestern Russia is the Leningrad (Sosnovy Bor) Nuclear Power Plant at St. Petersberg.

The Leningrad Plant has four RBMK-1000 reactors (Sosnovy Bor Units 1, 2, 3, and 4). The first reactor came on line in November 1974, the last (Unit 4) in August of 1984. RMBK-1000 reactors are light-water-cooled graphite monitored units that have an output of 925 Mwe. These reactors have three principal operational advantages: RBMK-1000 reactors have low core power densities that enable the reactor to withstand station blackouts and loss of power for over a period of 1 hour with no expected core damage; they may be refueled while in operation; and their graphite modular design allows for use of fuels not suitable for conventional water-moderated nuclear reactors (2). The primary deficiency of the reactor design is the lack of a massive steel and concrete containment structure as a final barrier to large radiation releases as occurred at Chernobyl. Additionally, accident mitigation systems would seem to be limited and ineffective (e.g., inadequate fire protection, limited steam suppression capability in the graphite stack, flawed separation and redundancy of the electrical and safety systems, etc.) (2). It is certainly worth noting that there have been literally hundreds of improvements in the RBMK systems made since 1986, many of which have been financially supported by the United States. While significant progress has been made in training and the overall safety culture at the plants, additional improvement is desirable. However, the fundamental design flaw of the RBMK remains.

Liquid radioactive wastes at the plant were reported (1) to be at 86.2% capacity 7 years ago (storage capacity = 21,400 m^3). Annual solid radioactive wastes are on the order of 400 m^3 annually with 24,000 m^3 temporary storage area that has recently been estimated to be at a 58.9% capacity (1). Spent fuel assemblies are stored for 3 years before being moved to an adjacent building with five pools, each with a capacity of 4000 assemblies. Bradley (1) estimates the reactor fuels to be on the order of 2600 tonnes. Plant inventory is estimated to have produced 14,680 kilograms (kg) of plutonium, 149 million curies of strontium 90 (Sr-90), and 154 million curies of cesium 137 (Cs-137).

If the average plant life of a nuclear power facility is assumed to be on the order of 30 years, Unit 1 would be scheduled for decommissioning in 2004 and the fourth and final unit in 2012. The two oldest Leningrad reactors have been selected to be among the first four RBMK reactors to be decommissioned in Russia (2). The process of decommissioning of the average RBMK-1000 reactor will generate 36,000 tonnes of concrete, 2,500 tonnes of scrap metal, and 15,000 tonnes of equipment. The example of the St. Petersberg nuclear power facility clearly indicates the immediate need for an adequate HLRW repository.

The HLRW problem is not solely confined to conventional reactor wastes. Military and other governmental wastes will also present a major problem in this region. Navy nuclear reactors in inactivated submarines, for example, are known to have undischarged nuclear fuel on board which will also have to BE disposed of in a HLRW repository (1).

In response to these needs, preliminary investigations by Russian scientists from the University of St. Petersburg and the Institute of Precambrian Geology and Chronology of the Russian Academy of Science have determined that a large stable terrain in Karelia (northwestern Russia) is worthy of further investigation as a potential site for a deep geological HLRW repository. Satellite and aerial data combined with geophysical information suggest that the rapakivi granite-anorthosite Salmi Complex is deserving of further research.

The Salmi Complex covers an area of approximately 4000 km^2 and is 1540 million years (Ma) in age. It is bordered by regional fracture zones and emplaced along an upthrust zone between Archean and Palaeoproterozoic domains. The complex intrudes supracrustal and volcanic-sedimentary rocks of both domains. A 9 km^2 block within the complex appears to be tectonically very stable and resistant. This is the area of interest for the HLRW repository. The site, dependent on the Russian evaluation of its characteristics, also may be considered as a repository for toxic industrial wastes as a combined or substituted alternative repository.

LANDSAT STUDIES

In addition to the studies conducted and ongoing in Russia, remote sensing studies of this area were undertaken at the Pan American Center for Environmental Studies (PACES) and the University of West Georgia Remote Sensing Laboratory. Utilizing LANDSAT Thematic Mapper (TM) data, two finished images have been printed: one at 1:250,000 scale (approximately 180 km x 180 km) and a subscene at 1:100,000 scale (approximately 70 km x 70 km) (Figures 1, 2). The imagery has been georeferenced using published topographic maps and gridded to latitude-longitude and Universal Transverse Mercator references. Red, green, and blue bands applied to the image (RGB = 472) were selected for maximum separation, elimination of atmospheric effects, and de-emphasis of vegetation. Subsequently the PACES images were sent to St. Petersburg for further analysis and evaluation. PACES and the Remote Sensing Laboratory at the University of West Georgia are continuing with further studies at both locations. The goal of these further studies is to establish detailed structural subdivisions within the targeted study area in order to identify a tectonically stable terrain and plan a field program to ground check the interpretation. This work will be done with close cooperation among the members of the study group.

The investigation and evaluation of the Salmi Complex site offers an important possibility with reference to establishing a mined, deep geological HLRW repository for northwestern Russia. The storage of spent fuel and solidified high level wastes from the Russian nuclear power plants, other defense and military HLRW, and reprocessing HLRW is in a state of critical status. These wastes need to be transported from their current storage areas to a regional and/or national safe, deep geological repository.

GEOLOGICAL CHARACTERISTICS OF THE SALMI SITE

The Kola-Karelian region within the Fennoscandian Shield appears to be the most favorable for development of either a HLRW repository or a toxic industrial and high-level radioactive waste (TIHLRW) repository. It manifests a very low to nearly complete absence of seismic activity in comparison to the other parts of Fennoscandia based upon the instrumentally detected earthquake data from the interval between 1951 and 1980 (3). Such conditions are especially typical for the Central Karelian Province, which displays the major Archaean domain of the Fennoscandian Shield with a continental crust formed during the interval between 3.1 and 2.6 billion years (Ga) as a typical Archaean granite-gneiss terrain. It was covered by Early Proterozoic (2.5-2.0 Ga) epicratonic basin deposits and partly tectonically destroyed (in the eastern part only) by intracratonic rifting with a similar age interval (4). Along its southwestern boundary, where continental crust was formed during tectonic events between 2.0-1.85 Ga, the Central Karelian Province is in contact with the Svecofennian Province. Considerably later in time (1546-1530 Ma based on U-Pb age determination), another tectonic event took place within the Central Karelian Province: the emplacement of the Salmi rapakivi granite-anorthosite intrusion (5). Based on the above-mentioned tectonic features (stability of tectonic conditions began 1.5 Ga and is marked with modern seismic steadiness), the Central Karelian Province was chosen for remote sensing structural study in order to select favorable sites for developing a geologic model of the TIHLRW repository.

Remote sensing data (from visible, infrared, and microwave bands) were processed and underwent expert structural evaluation. For each candidate site, an integration of geological, structural, and geophysical data sets was carried out, accompanied by a transition from small- to mid- and large-scale information ranges (1:2,500,000 to 1:25,000 scales). This integration included the following:

- structural interpretation of satellite imagery and aerial photographs
- data on structural, tectonic, and seismic zonation
- results of interpretation of gravity and magnetic potential fields
- petrological and petrophysical features of rocks
- glaciation and neotectonics effects

Small-scale remote sensing imagery for the Central Karelian Province was done (space images in the 1:10M scale, the «Meteor» and ESSA-8 systems, made in visible and infrared spectral bands for different seasons and in 1:2.5M scale made by «Meteor 30, 31», series «Ocean», with a resolution of 350 m, in spectral bands at 500-700 and 700-1100 nm). Results show that the latter is bounded by a system of lineaments that are at a rather short distance from one another with their axes about in the same direction. These lineaments coincide well with structural-tectonic linear zones inherited from Archaean-Proterozoic fault systems. These are the North-Norwegian-Karelian paleorift (6) on the northeastern side of the Central Karelian Province and the Raahe-Ladoga zone on the southwestern side. These separate the Archaean and the Early Proterozoic blocks of continental crust in the Fennoscandian Shield. The southeastern boundary of the Central Karelian Province is limited by a platform cover of Vendian-Paleozoic sedimentary deposits. Within this old and stable province, there are districts with an enhanced density of faults with the lengths of 5 to10 km, coinciding with the above-designated directions, as well as relatively undisturbed districts. Shorter faults do not display any sign of systematic organization.

Districts with minimum density of linear structures are concentrated in the southwestern part of the Central Karelian Province between lakes Ladoga and Onega. Large ring structures (diameter of 50-100 km) are typical in this region. Such structures contain only relatively small ring fractures, and radial faults that are restricted within the ring fractures. One of those structures is well marked out near the northeast side of Ladoga Lake as a minimally structurally-strained area. Structural deciphering of this area in the medium-scale range (1:1,000,000) shows that there are local oval structures (10 x 20 km) and some linear faults with a lengths of 2 to 5 km within a large ring structure (diameter of 45 km). Most of this area is occupied by a monolithic section composed of unbroken segments or parts. Comparison of vector formats of linear and ring structures allowed separation of structural factors of endogenous origin from superposed exogenous glacial-geomorphologic structures.

Vector structural data were processed by a special computer code designated as "Edges.1.0", which is designed for lineament analysis. The densities of the filtered lineaments were used for the drawing of maps at equal density in the computer code Surfer 6.0. These processed data allowed recognition and separation of minimally disturbed areas that are favorable for TIHLRW repository geologic modeling. The evaluation of the depth of penetration of the faults and fractures (between 2 to 10 km depth) was carried out by the special method of remote sensing lineament analysis along the profiles crossing the studied area. These data were correlated with magnetic and gravity fields in the area, and the character of its deep fracturing was preliminarily evaluated by remote sensing methods. Large scale (1:100,000) satellite data show that the selected area and the site within it are characterized by structurally uniform (homogenous) rocks. The photo tone of such sites corresponds with those typical for spreading areas of magmatic rocks, particularly granitoids.

Geological studies have shown that the site selected with the aid of remote sensing for geologic modeling of a TIHLRW repository in the Precambrian rocks corresponds to the location of the plutonic rapakivi granite-anorthosite Salmi Complex (1546-1530 Ma). The Salmi Complex is about 100 km long in a northwest-southeast direction along the Ladoga Lake shore, 40 km long in a northeast-southwest direction, and covers an area of about 4000 km^2. According to gravity and magnetic data, the Salmi Complex comprises a shallow plate-like body with the thickness of about 10 km in the central part and 2 to 5 km in the northwestern part. The thickness of this body is over 10 km in the southeastern part, where a feeder channel is predicted to be present. The Salmi Complex was emplaced along an upthrust zone between the Archaean and Early Proterozoic domains, and intrudes supracrustal rocks in both domains. The southwestern part of the complex is overlain by Late Proterozoic volcanic-sedimentary rocks (circa 1330 Ma) hosting a small, stratiform type uranium deposit. Uranium mineralization, located in Late Proterozoic sedimentary deposits close to the plutonic Salmi Complex, will be considered as a possible natural analog of a HLRW repository.

The structure of the Salmi complex is not simple. It is composed of six main rock types or phases: 1) anorthosite, gabbronorite, gabbro; 2) monzonite, quartz syenite, syenite; 3) biotite-amphibole syenogranite; 4) amphibole-biotite rapakivi granite, including ovoidal and nonovoidal varieties; 5) even-grained biotite granite; and 6) albite-lithian siderophyllite topaz-bearing granite. Basic and intermediate rocks dominate in the southeastern part of the complex, where they are buried under modern moraines and the Upper Proterozoic-Paleozoic platform cover. Amphibole-biotite rapakivi granite makes up about two-thirds of the Salmi Complex and is located within a ring-like structure. This rock occupies the central part of the complex with the area up to 2500 km^2 and has a volume about 0.25 x 105 km^3 in a fault-free block revealed by the remote sensing data.

Remote sensing investigations conducted on a scale of 1:25,000, using aerial photography and radar survey data, have allowed the detailing of a specific area or district within the granite rapakivi outcrop. At this site, there is a regional fracture zone observable on the image of smaller scale and non-oriented, chaotic local fissures. The lengths of these fissures are more than 50 to 150 m and penetration depth is not more than 2 m. The depth of the longest fractures does not exceed 200 to 300 m and veined rocks (granite-aplite or pegmatite) are confined to them. The depth of the bulk of fissures ranges between 3 and 25 m.

These data demonstrate the possibility of selecting a site for developing a model for a TIHLRW repository in Precambrian complexes. A major criterion of this selection includes the availability of a tectonically stable terrain and the absence of deep faults and fractures. The site selected after the depth analysis of remote sensing materials is characterized by the accessibility for further investigation. At the same time, this site is sufficiently distant from populated areas with its accompanying human impact as to make a further monitoring survey practical.

The possible effects of glaciation and neotectonics on the integrity and safety of a TIHLRW repository will be evaluated by reviewing the observations of present-day glacial conditions and the evidence from past glacial periods. Cyclic glacial and interglacial periods have occurred within comparatively recent geological time. It is reasonable to assume that they will probably continue to occur. Climatic changes during the Quaternary period show that several glaciation events could be expected within the next 100,000 years. Therefore, it is prudent to consider the TIHLRW repository performance assessment in the light of a glaciation perspective. In this connection, several important effects of glaciation must be considered in siting the repository, such as erosion, isostatic movements, postglacial neotectonic activity, and eustatic changes in sea-level. These considerations will be evaluated.

CONCLUSIONS

Comparative analysis of the Russian data to the LANDSAT TM scene (1:250,000) and subscene (1:100,000) allows some basic observations to be made. Glacial moraine features are clearly discernable from other soil origin types. New structural details that are displayed within the associated ring structures of the Salmi complex help to confirm their polygenic/multiphase origin. The scenes serve to identify the most stable blocks within the Salmi Complex. Additionally, these features are observable in the Ulyalega rapakivi massif displayed in the northeast portion of the scene. On the basis of these observations, it may be determined that utilization of the LANDSAT data and the selected thematic spectral bands has produced a useful tool for site evaluation in the Salmi Complex. More importantly, thoughtful manipulation and variations of the thematic mapping spectral bands should produce critical observable details of the geological structures not readily detectable by other means. Finally, it may be concluded that the application of LANDSAT data in repository siting in a complex geological terrain exemplified by the Salmi Complex is a worthwhile evaluation tool.

REFERENCES

1. D. J. BRADLEY, "Behind the Nuclear Curtain: Radioactive Waste Management in the Former Soviet Union." D. R. Payson (ed.) Batelle Press, Columbus, Ohio, 716 p. (1997).

2. INTERNATIONAL NUCLEAR SAFETY PROGRAM, "Leningrad (Sosnovy Bor) Nuclear Power Plant." U. S. Department of Energy, Office of International Nuclear Safety and Cooperation, http://insp.pnl.gov:2080/?profiles/leningrad/le, (November 21, 1999).

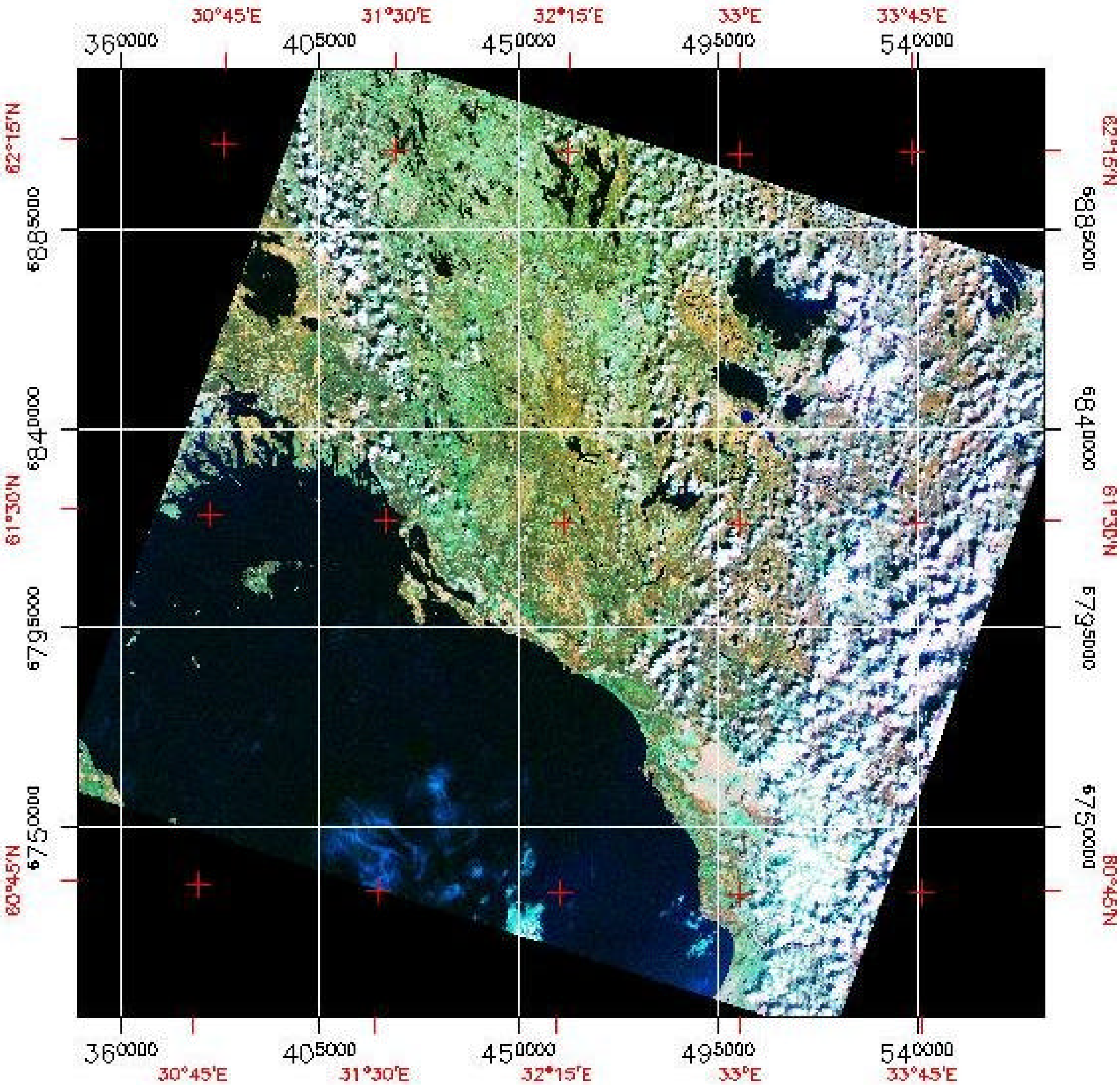
3. S. GREGERSEN, H. KORHONEN and E. S. HUSEBYE, "Fennoscandian dynamics present-day earthquake activity," Tectonophysics, Vol. 189, pp. 333-344, (1991).

4. S. I. TURCHENKO, "Precambrian metallogeny related to tectonics in the eastern part of the Baltic Shield," Precambrian Research, Vol. 58, pp.121-141, (1992).

5. YU. V. AMELIN , A. M. LARIN and R. D. TUCER, "Chronology of multiphase emplacement of the Salmi rapakivi granite-anorthozite complex, Baltic Shield: implication for magmatic evolution," Contribution Mineralogy and Petrology, Vol. 127, pp. 353-368, (1997).

6. S. I. TURCHENKO, V. S. ANTIPOV, E. P. VOSTROKNUTOV, G. V. GALPEROV, and A. V. PERTSOV, "Remote sensing and geologic evidences of Proterozoic rift and gold mineralization distribution in the eastern part of the Baltic Shield," Earth Research from Space, No. 3, pp. 3-17, (1997).

TM IMAGE 472 (Path 184, row 017), 07/13/1988



TM IMAGE 472 (Path 184, row 017), 07/13/1988