Full Proposal to the

International Continental Drilling Program

Scientific Drilling at El’gygytgyn Crater Lake, Chukotka, Northeast Siberia

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Title: Scientific Drilling at El’gygytgyn Crater Lake, Chukotka, Northeast Siberia

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Abstract: (400 words or less)
Lake El’gygytgyn, located in central Chukotka, NE Russia, is a 3.6 million year old impact crater lake with a diameter of 12 km and a water depth of 170 m. During the last 6 years the sedimentary record of the lake has become a major focus of multi-disciplinary multi-national paleoclimatic research and is now a world-class target for deep drilling. A full-length sediment core would yield a complete record of Arctic climate evolution; back one million years prior to the first major glaciation of the Northern Hemisphere. Geomorphological evidence from the catchment suggests that the crater was never glaciated during the entire Late Cenozoic. A 12.9 m long sediment core retrieved from the deepest part of the lake in 1998 revealed a basal age of approx. 250 ka, confirmed the lack of glacial erosion, and underlined the sensitivity of this lacustrine environment to reflect high-resolution climatic change. A 16.7 m long sediment core taken in 2003 confirms the reproducibility of the record and dates to nearly 300 ka. The first single channel seismic survey in 2000 and multi-channel seismic surveys in 2003 have now been processed suggesting a depth-velocity model of brecciated bedrock overlain by a suevite layer, in turn overlain by two undisturbed, lacustrine sedimentary units up to 400 m in thickness. This final pre-site survey expedition in 2003 included modern process studies, geomorphic and permafrost studies of lake and river terrace stratigraphies, additional lake sediment coring and some of the first permafrost coring. Two workshops in 2001 and 2004 provided the scientific framework for the synthesis of all available data. This proposal requests funds for a major drilling campaign in El’gygytgyn Lake in spring 2007. Our goal is to collect the longest most unprecedented record of climate change in the terrestrial arctic for comparison with lower latitude marine and terrestrial archives of hemispheric and global climate evolution. Coring objectives include replicate cores of 630 m length to retrieve a continuous paleoclimate record from the deepest part of the lake and into the underlying impact breccias and bedrock. Studies of the impact rocks offers the planetary community with the opportunity to study a well preserved crater uniquely found in igneous rocks like those on Mars. One additional core to ca. 200 m into permafrost from the adjacent catchment will allow us to test ideas about arctic permafrost history and sediment supply to the lake since the time of impact.
Scientific Objectives: (250 words or less)

Lake El'gygytgyn represents a world class drilling target for obtaining a paleoclimate record unique to the Northern Hemisphere. Having conducted three successful expeditions to the lake in the past five years and having created strong collaborative bonds between American, Russian and German researchers with similar goals, we as a group are in an ideal position to advance our knowledge of the Arctic and global systematics and promote international scientific cooperation. Our two primary objectives include:

1. Assessing the environmental dynamics recorded at El'gygytgyn against other arctic and lower latitude paleoenvironmental records and placing them in the context of exiting knowledge concerning the impacts and responses of different regions to past and future change. The influence of the Eurasian ice sheet dynamics on the flow of the westerlies and moisture diversions is one of many perturbations that may or may not have confounded circumarctic teleconnections over time. We will also be able to compare the record from El'gygytgyn to records from other Asian lakes, like Lake Baikal, to compare paleoenvironmental changes possibly linked to global reorganizations of the ocean / atmospheric system over the North Atlantic /Greenland sector of the Northern Hemisphere or sourced from the tropics. This work will place El'gygytgyn into an interhemispheric context.

2. Evaluate El’gygytgyn has the only currently known impact structure formed in siliceous volcanics, including tuffs. The impact melt rocks and target rocks provide a unique opportunity on Earth to study shock metamorphism of volcanic rocks. As no impactites and shocked rocks occur at the crater in situ, a drill core is the only possibility to obtain exact information on impactites of known location and to study the depth progression of shock metamorphism of volcanic rocks.

Summary of Support Requested from ICDP

<table>
<thead>
<tr>
<th>Requested ICDP funds: (in US$)</th>
<th>Estimated Total Project Budget (ICDP funds plus other sources):</th>
<th>$4.61 Million</th>
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<tr>
<td>mobilization in late 2006</td>
<td>Estimated Duration in Month (On-site operations only):</td>
<td>3.5 months</td>
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<td>Planned Start:</td>
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| Operational Support:         |                                                               |                |
|-------------------------------|                                                               |                |
| Drill Engineering             |                                                               |                |
| (Please contact ICDPs OSG if required) |                                                               |                |
| Downhole Logging              | $27,001                                                      |                |
| (Please contact ICDPs OSG if required) |                                                               |                |
| Field Lab Equipment           |                                                               |                |
| (Please contact ICDPs OSG if required) |                                                               |                |
| Training Course              |                                                               |                |
| (Please contact ICDPs OSG if required) |                                                               |                |

Details such as a Budget Plan, Management Plan, and Drilling Plan to be provided as attachment to the Proposal. OSG contact: U. Harms (ulrich@gfz-potsdam.de), Phone: +49 331 288 1085
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1 INTRODUCTION

The Arctic is currently experiencing environmental change at rates unprecedented in historical times. National and international programs have been launched by a number of countries to monitor this change and develop models for predicting the magnitude and direction of environmental change into the future. Without question, the polar regions are known to play a major role in the global climate system influencing both oceanic and atmospheric circulation through strong feedback interactions involving ocean, atmosphere, cryosphere, and terrestrial processes. Our ability to make accurate predictions about future climate evolution and related environmental changes depend on our capacity to understand the role of the Arctic region in modulating past periods of change under different climate-forcing conditions, including those forced on the Arctic from the tropics (Clement and Cane, 1999; Cane and Clement, 1999; Burns et al., 2003; Deser et al., 2004; Diaz and Bradley, in press).

High-resolution records of millennial and finer time scales are necessary from depositional archives recording different parts of the earth system in order to properly evaluate systemic sensitivity and dynamics across the globe. Moreover it is important to determine the mechanisms and linkages that produce the heterogeneity we see in emerging paleoclimate records in order to be accurate about societal impacts of future regional change. Only recently have enough long high-resolution lake records become available from different parts of the world for evaluating time series of the terrestrial response to global change (e.g., Baker et al., 2001; Seltzer et al., 2003) for comparison with the growing wealth of marine and ice core records being studied by the science community. Exciting millennial-scale records are also rapidly emerging from areas of the tropics and subtropics (e.g., Santa Barbara Basin – Behl and Kennett, 1996; Hendy and Kennett, 1999; the Cariaco Basin – Hughen et al. 2000; eastern and western Pacific – Stott et al., 2002; Koutavas et al., 2002; Ortiz et al., 2004) causing us to rethink the role of the tropics vs. the high latitudes in climate change on millennial and finer time scales.

A similar and equally exciting terrestrial record can now be recovered from Lake El’gygytgyn in northeastern Siberia – a crater lake that has been collecting sediments for the past few million years and rests squarely within the largest contiguous region of the terrestrial Arctic to have escaped continental-scale glaciation. This concept provided the impetus for our field investigations in 1998, 2000 and 2003 and for a capstone ICDP workshop in 2001 and workshop synthesis in 2004 to fully explore the potential of future science at this site. Two
emerging themes from our field efforts and the workshop have focused on (1) the unique paleoclimatic history and potential of the lake sediments and (2) impact studies of the crater origin and bedrock stratigraphy. El’gygytgyn also offers the planetary science community with the opportunity to study the only crater on Earth on volcanic rocks, and is a well-preserved lake-filled crater for direct comparison with e.g., craters on Mars thought to have once held water (Squyres et al., 2004).

Having completed the pre-site survey fieldwork, we submitted a pre-proposal to the ICDP in January, 2004, outlining the status of our science and planning efforts to submit a persuasive deep drilling proposal for Lake El’gygytgyn to the ICDP in January of 2005. A review of that pre-proposal by the ICDP Science Advisory Group (SAG) was very encouraging for submission of a full proposal with the caveat from the Executive Officers of the ICDP that we secure some high level confirmation of approval of the project “in principle” from agencies in the Russian Government, in alignment with scientific agreements/memoranda of understanding, etc between Russia and participating countries.

Having made great strides in initiating the recognition of this project under national bilateral agreements with Russia, this proposal requests funds for a major drilling campaign in El’gygytgyn Lake in spring 2007. Our goal is to collect the longest most unprecedented record of climate change in the terrestrial arctic for comparison with lower latitude marine and terrestrial archives of hemispheric and global climate evolution. Coring objectives include replicate cores of 630 m length to retrieve a continuous paleoclimate record from the deepest part of the lake and into the underlying impact breccias and bedrock. Studies of the impact rocks offers the planetary community with the opportunity to study a well preserved crater uniquely found in igneous rocks like those on Mars. One additional core to ca. 200 m into permafrost from the adjacent catchment will allow us to test ideas about arctic permafrost history and sediment supply to the lake since the time of impact.

2 REQUISITE SITE INFORMATION

Lake El’gygytgyn is located ca. 100 km to the north of the Arctic Circle (67°30’ N and 172° 05´ E; Fig. 1) and was formed by an impact that created a crater about 18 km in diameter (Gurov et al., 1978, 1979a,b) roughly 3.6 million years ago (Layer, 2000; Fig. 2).

At that time, most of the Arctic was forested all the way to the Arctic coast, and a million years passed before the first glaciation of the Northern Hemisphere began (Brigham-Grette and Carter, 1992). The lake is currently about 170 m deep and about 12 km in diameter.
Fig. 1: Location (top) and digital elevation model (bottom) of the El’gygytgyn Crater, illustrating the crater rim, the location of Lake El’gygytgyn in the southeastern part of the crater, the lake bathymetry and the positions of piston cores recovered in 1998 and 2003 (after Kopsch et al., unpubl.).

Its bathymetry is that of a deep, flat-bottomed bowl with steep sides to depths of 150 m grading across a low sloping floor to the deepest point in the center at 170 m. Lake level lies at 492 m a.s.l. and it is surrounded by hills outlining the crater rim rising to about 850 – 950 m a.s.l. About 50 streams drain into the lake, all being less than about 7 km long.
El’gygytgyn Crater Lake is situated in a remote, rarely-visited area of Chukotka and is inaccessible by road. Equally impressive is the fact that the crater is one of the best-preserved on Earth of its size (Dietz and McHone, 1976; Dence, 1972), and the lake is only one of a handful formed inside an impact crater (Lehman et al., 1995). Also, it is the only impact crater on Earth in siliceous volcanic rocks (e.g., Gurov et al., 1979a,b; Gurov and Koeberl, 2004).

Lake El’gygytgyn has several outstanding attributes for an Arctic paleoclimate sediment-coring site. Because of its size, location and outlet-river terrace history (Glushkova, 1993; Glushkova et al., 1994), it likely has never evaporated completely, meaning that the 3.6 million year deposition record is continuous throughout its history. This region of Chukotka has never been glaciated, meaning that the sediments at the bottom have never been disturbed on a large scale. All of the sediments entering the lake via streams or rivers are locally derived from within the crater rim; the only externally derived sediments entering the lake are blown in with the wind. This means that the core record is much easier to interpret compared to most cores from complex large lakes (e.g., Lake Baikal).

El’gygytgyn Crater precisely straddles the crest of the Anadyr Mountains forming the modern drainage divide between the East Siberian and Bering seas. This same divide
coincides with a regional vegetation boundary delineating the arctic and subarctic ecotones. Today, mean July temperatures are 4 - 8 °C and January temperatures –32 to –36 °C. Mean annual precipitation is roughly 200 mm/yr falling primarily as snow. The modern vegetation in the catchment is herb-dominated tundra with occasional local patches of low shrubs, particularly willow (*Salix*). Modern treeline lies about 150 km to the SW of the basin.

The regional bedrock and tectonic setting for Chukotka is fairly well known (Fig. 2). El’gygytgyn Crater lies within the Okhotsk-Chukotka Volcanic Belt which extends from the Chukotka Peninsula, adjacent to Alaska, through to northern China, a distance of about 3000 km (review by Layer, 2000 and Layer et al., 2001). This belt is composed of subaerial calc-alkaline volcanic rocks including andesites, rhyolites, andesite-basalt sequences, diorites, tonalites, granodiorites, quartz monzonites and granites (Belyi, 1994). Such an assemblage of rocks was deposited in Late Cretaceous time, apparently as the result of subduction along a continental margin, similar to the western margin of South America today. Extrusive and intrusive rocks of the same age and general characteristics also extend across interior Alaska down as far as southern British Columbia. The volcanic belt in the region around Lake El’gygytgyn is composed of predominantly rhyodacite tuff and ignimbrite; with rhyolite, andesite tuff, and basalt also present (Gurov and Gurova, 1979).

The impact origin of the crater has been questioned by only a few. While the volcanic stratigraphy in the vicinity of Lake El’gygytgyn dates from ~90 Ma down to ~67 Ma based upon newer ⁴⁰Ar/³⁹Ar whole rock ages, the impact-melted volcanic rocks consistently date to 3.58 ± 0.04 Ma (Layer, 2000; Layer et al., 2001). This tight age control, the presence of glassy bombs and shock-metamorphosed quartz (e.g., Gurov et al., 1978, 1979a,b; 2005; Gurov and Koeberl, 2004), and the concentric fractures and reverse faults that surround Lake El’gygytgyn lend persuasive support to the impact origin of the basin (Gurov et al., 1978; Masaitis, 1999).

3 WHY LAKE EL’GYGYTGYN: GOALS FOR DRILLING

3.1 Introduction

The ICDP funded a three-day workshop in Amherst, USA, in November of 2001 to stimulate scientific interests in deep drilling at Lake El’gygytgyn. A second workshop, funded by the German Federal Ministry for Education and Research (BMBF), was held in March, 2004, in Leipzig, Germany, to synthesize results from the 2003 expedition and galvanize
interdisciplinary interests in share research goals for drilling. The science themes emerging from both workshops focused on (1) the unique paleoclimatic history and potential of the lake sediments and (2) impact studies of the crater origin and bedrock stratigraphy.

3.2 Paleoclimate

Lake El’gygytgyn is the only place in the terrestrial Arctic with a continuous 3.6 million year climate record, and such a record is required to fully understand the Arctic’s role in global climate dynamics. Of primary interest to the scientific community is determining why and how the arctic climate system evolved from a warm forested ecosystem into a cold permafrost ecosystem between 2 and 3 million years ago. A continuous depositional record in a lake at this latitude provides a means of determining from a terrestrial perspective how the arctic climate evolved and adjusted from Milankovich-driven glacial/interglacial cycles every 41 ka and, later, every 100 ka. Our present understanding of the lake as a system suggests we can interpret higher resolution climate change events across eastern Siberia on centennial to millennial scales and test for atmospheric teleconnections with other long climate records worldwide. Such comparisons will offer insight into the dynamic mechanisms behind these teleconnections or the lack thereof, and an understanding of the conditions for permafrost formation and stability through time, especially in the context of modern warming.

For example, like well known teleconnections exist between the Santa Barbara Basin and the Magdalena borderlands of southern California/Baja with the North Atlantic (Hendy and Kennett, 1999; Ortiz et al., 1997), recent evidence suggests millennial scale teleconnections also exist between tropical sea surface temperatures in the western Pacific and D/O events in the North Atlantic (Stott et al, 2002; Koutavas et al., 2002). These changes likely produced changes in the North Pacific system that may have influenced the climate over NE Russia (Mantua and Hare, 2002). One of the primary goals of our current work is to confirm or revise our understanding of the proxy geochemistry from the lake record to consider why shifts in atmospheric circulation (as inferred from some matches with the Greenland ice core record) persist long enough that they show up in a lake record like this. While there are most likely linkages to the tropics that cause shifts in the Aleutian Low, it is harder to understand what can shift the large Siberian High (c.f., Bartlein et al., 1998). Shifts in the mean location and strength of these systems related to orbitally-driven changes in continental cooling can be extracted from model runs in the future (Elia et al., 2004).

Lake El’gygytgyn is arguably one of several lakes known to have long records, however, this lake is located in the remote Russian arctic where we are data poor in paleoclimate
information but climatic anomaly patterns persist linking the tropics, the north Pacific and the Arctic. Situated 100 km north of the Arctic Circle El´gygytgyn lies in a region of Chukotka, NE Siberia, that just like Greenland has been cooling in recent decades in contrast to significant warming over most of the Asian and North American continents, including Alaska (Chapman and Walsh, 1993; Walsh, 2002). This cooling (or nonwarming) in Chukotka is related to its proximity to the Siberian High and the Aleutian Low, two persistent and robust atmospheric features in the Arctic (Mock et al., 1998). The Aleutian Low is a fundamental part of the atmospheric system thought to have produced climatic changes across western North America, e.g., in marine isotopic stage 3 (MIS 3) that are similar in pattern to Dansgaard-Oeschger (D/O) events in the North Atlantic. The strength of the Aleutian Low is intimately linked to systematic changes in the tropics as reflected by analyses of variations in the robust Pacific-North American pattern (or PNA) versus other features like the decadal-El Niño like pattern (Vimont et al., 2003). The systematics that produce the PNA pattern are known by atmospheric scientists to have robust linkages over long time scales with global circulation (Hartmann et al., 2000), allowing an evaluation of interhemispheric teleconnections under variable boundary conditions. Because of its proximity to this low, the Lake El´gygytgyn record has the potential to provide us with information on its strength and position over the past 3.6 million years — a full 3.5 million yrs longer than the Greenland Ice core record. The fidelity of emerging marine records back to more than a million years from the Sea of Okhotsk (Nürnberg and Tiedemann, 2004) demonstrates further the hemispheric teleconnections communicated both oceanographically as well as via the atmosphere.

3.3 Impact Research

El´gygytgyn is the only known impact crater on Earth that formed in silicic volcanic rocks. The variety of volcanics present at the crater covers the whole range of silica-rich volcanics. Target rocks that are in situ in the crater walls are all more or less unshocked. Limited studies exist on impactites found as float samples within the crater – none in-situ have been found so far. The impact melt rocks and target rocks provide an excellent opportunity to study shock metamorphism of volcanic rocks. The shock-induced changes observed in porphyritic volcanic rocks from El´gygytgyn can be applied to a general classification of shock metamorphism of siliceous volcanic rocks.

Clasts of volcanic rocks, which range in composition from rhyolite to dacite, represent all stages of shock metamorphism, including selective melting and formation of homogeneous impact melt. Four stages of shocked volcanic rocks were identified (cf. Gurov and Koeberl,
2004; Gurov et al. 2005): stage I ($\leq 35$ GPa; lava and tuff contains weakly to strongly shocked quartz and feldspar clasts with abundant PFs and PDFs; coesite and stishovite occur as well), stage II (35 – 45 GPa; quartz and feldspar are converted to diaplectic glass; coesite but no stishovite), stage III (45 – 55 GPa; partly melted volcanic rocks; common diaplectic quartz glass; feldspar is melted); and stage IV (>55 GPa; melt rocks and glasses). A drill core is the only possibility to obtain exact information on impactites of known location and to study the depth progression of shock metamorphism of volcanic rocks. The preferred location of the deep drill core is on the outer flank of the central uplift as defined by the refraction seismic data. A drilling depth of at least 800 m is required. Core log and lithological information from such a deep drillhole will also allow to provide ground truth for surface geophysical data, and geomicrobiological studies will be of importance for astrobiology and comparative planetology.

4 PAST STUDIES

4.1 Introduction

Our past work on the El`gygytgyn Crater is based upon three field campaigns. The scope of our work includes investigations of the modern processes taking place in the crater, the geomorphology and geocryology in the lake catchment, the Late Quaternary paleolimnology, the thickness and internal structure of the entire crater fill, and the shock metamorphism associated with the impact 3.6 Myr ago. Besides other peer-reviewed publications, a complete issue of the Journal of Paleolimnology is currently pending; the papers can be viewed at www.geo.umass.edu/lakejopl (user name: elgylake; password: yuri2007).

4.2 Field Campaigns

Exploratory site survey studies aimed at deep drilling in Lake El´gygytgyn were conducted by an international science team in spring 1998, summer 2000 and spring and summer 2003. The expeditions were funded by the US National Science Foundation, the German Alfred Wegener Institute, the German Federal Ministry of Education and Research, the Russian Foundation for Basic Research and the Russian Ministry for Natural Resources.

The success of the 1998 spring campaign was to recover the first sediment cores from Lake El´gygytgyn. Coring was conducted in 170 m water depth at two sites (PG1351 and
Composite sediment sequences of up to 12.9 m length were obtained with gravity and percussion piston corers, operated from a 4 m tripod with hand winches through holes in the lake ice. Two Americans, two Russians and two Germans participated in this field work.

The initial coring expedition was followed in August 2000 with the ambitious goal of acquiring the first geophysical studies of the basin stratigraphic architecture, employing both airgun seismic (5 cubic inches airgun volume, single channel streamer of 8 m length) and 3.5 kHz subbottom profiling. In addition, the team composed of four Americans, four Russians, and three Germans carried out geomorphological and stratigraphic studies of the catchment, made open season limnological measurements, and collected a series of gravity cores to evaluate the recent sedimentary environment. The deepest portion of the lake was instrumented with year-around temperature and pressure recorders and an automated weather station was set up at the outlet to hourly record a host of standard meteorological parameters and soil temperature and moisture measurements. These instruments continue to operate today.

Based on our workshop discussion in November, 2001, a spring and summer field campaign was planned and funded largely by the German Federal Ministry of Education and Research from April to September 2003 to finalize the pre-site survey work. On this expedition 8 Germans, 6 Russians and 1 American participated. A fresh suite of representative bedrock samples were collected along with fully melted impactites. Modern process studies of the lake hydrology, limnology, meteorology, and sedimentology took place over this entire period to better understand the various proxies being used to decipher the paleoclimate record of the sediment fill. Geomorphic and permafrost studies of lake and river terrace stratigraphies were carried out to contribute to our understanding of the climate dependent landscape evolution. A 16.7 m long sediment core (Lz1024; see Fig. 1, p. 3) was collected from the central part of the lake. Additional cores from the shelves (Lz1027, Lz1028 and Lz1074) were taken to reconstruct lake-level changes, and two cores from the western slope (Lz1041 and Lz1039) were taken to study the impact of debris flows on sediment redeposition in parts of the lake during Late Quaternary times.

Critical to deep drilling were improvements in the seismic records. In 2003, airgun reflection seismic were conducted with a larger airgun (26 cubic inches) and a multi-channel streamer (15 hydrophones, 270 m length). In addition, a 3.5 kHz profile network of lines complemented the array to supply more detailed information on the uppermost 30 - 40 m of the sediment fill, and new echo-sounding data was acquired to finalize a high-resolution 3-D topographic model of the lake floor and the catchment. The summer 2003 season also allowed
us to download data from the lake basin sensors and the automated meteorological station; moreover, we deployed automated temperature sensors and rain gauges at two other sites in the basin.

4.3 Impact Studies

Impact research at El’gygytgyn dates back mainly to the 1970s and 1980s, when several expeditions returned samples for petrographic and geochemical work (e.g., Gurov et al., 1978, 1979a,b). Recently detailed shock petrographic and trace element geochemical work was done on some of the original sample collections. Rocks of the crater rim do not display any characteristic shock metamorphic effects (Gurov et al., 2005). Only weak cataclasis of these volcanic rocks is displayed in the NE parts of the crater wall. However, megabreccia is widespread in some areas of the inner crater wall, especially in the northern and northwestern sectors (Gurov and Gurova, 1983; Gurov and Yaminchenko, 1995).

Shock metamorphosed rocks and impact melt rocks occur in the El’gygytgyn crater as redeposited material in lacustrine terraces inside the crater and, locally, in terraces of little streams on the outer slope of the crater rim. Deep drilling has not yet been carried out in the El’gygytgyn crater; lithic impact breccia, suevite, and impact melt rock are expected from comparison with other impact structures to occur under the lake sediments in the central part of the crater.

The source of the impact rocks in the terrace deposits were ejecta that have been completely eroded. The original ejecta blanket was composed of lithic impact breccia, suevite, and impact melt breccia. The material is thought to have been transported to the areas of final deposition in the terraces due to slumping off the rim, thus only covering short distances. Fragments of unshocked and shocked rocks are mixed together with fragments of impact melt rocks and impact melt breccias in terrace deposits. Fragments of shocked rocks are generally of irregular form and have generally not been rounded by disintegration of ejecta over short transport distances. Rounded cobbles and pebbles of impact rocks occur only in the recent terraces of the crater. The size of fragments of shock–metamorphosed rocks and impactites ranges from 2 to 15 cm. Remnants of dark impact melt glass on the surface of some fragments of shocked rocks are evidence that they originally were part of suevite and/or impact melt breccia.

Fragments of impact melt breccia in terrace deposits are up to 1 m in size. Aerodynamically shaped glass bombs occur together with shock metamorphosed rocks in the lacustrine terraces inside the crater and also in terraces of some streams around it. All types of
impactite are generally fresh and most of them do not display significant post–impact hydrothermal alteration and weathering.

The stages of shock metamorphism of volcanic rocks and tuffs observed range from weakly shocked rocks to partially and completely melted rocks. The classification scheme of shock metamorphosed crystalline rocks of Stöffler (1971) was used to classify the shocked siliceous volcanic rocks of the El’gygytgyn crater (Gurov and Gurova, 1979). Five stages of shock metamorphism and shock melting of siliceous volcanic rocks of rhyolitic to dacitic composition were recognized (Gurov et al., 2005):

Stage 0: Shock pressures up to 10 GPa. Unshocked and weakly shocked volcanic rocks without any sign of shock metamorphism.

Stage I: Shock pressures of 10 to 30-35 GPa. Tuff and lava contain weakly to moderately shocked phenocrysts and clasts of quartz and feldspars. Stishovite and coesite occur in quartz. Shock metamorphism of the fine-grained matrix is not detectable.

Stage II: Shock pressures up to 45 GPa. Phenocrysts and clasts of quartz and feldspars in lava and tuff are converted into diaplectic glasses. Coesite is abundant in diaplectic quartz glass, but stishovite was not determined in diaplectic quartz glass. Groundmasses are isotropic.

Stage III: Shock pressures up to 55-60 GPa. Phenocrysts of diaplectic quartz glass are the last phase that remains unmelted. Coesite is still abundant in diaplectic quartz glass. Feldspar phenocrysts and clasts are melted and have irregular or lensoid, vesicular forms, but mainly preserve sharp contacts with matrix. The matrix is composed of heterogeneous vesicular glass. The most highly shocked rocks of this stage are transitional to the rocks of stage IV.

Stage IV: Shock pressures up to 80 GPa. Impact melt rocks and glasses formed by the complete melting of volcanic rocks.

The aerodynamically shaped impact melt glass “bombs” are composed of homogeneous glass (Koeberl and Gurov, 2002). The composition of the glasses is almost identical to that of rhyolites from the uppermost part of the target. Cobalt, Ni, and Ir abundances in the impact glasses and melt rocks are not or only slightly enriched compared to the volcanic target rocks; only the Cr abundances show distinct enrichment, which points towards an achondritic projectile. Data for siderophile element contents (the PGEs, especially iridium) resulted in very low values. Thus, the presently available data do not allow to unambiguously identify a meteoritic component in the El’gygytgyn impact melt rocks. This will require more detailed
analyses, probably Os and Cr isotopic work (e.g., Koeberl et al., 2002), preferably on melt rocks from defined locations in the crater interior.

4.4 Modern Process Studies

An understanding of the modern interactions between the land, atmosphere and water in the El’gygytgyn Crater, and their impacts on sedimentation and diagenesis, is a precondition for accurate paleoenvironmental and paleoclimatic interpretations from the fossil sediment composition. Because little was known about the modern settings in that remote area, a multidisciplinary systems approach was employed including remote sensing techniques, meteorological and hydrological monitoring, and extensive field sampling conducted on all three expeditions since 1998.

Meteorological stations, recording temperature, precipitation, wind direction, wind speed and air pressure, were set up in summer 2000 at three different locations in the crater. The dynamics and characteristics of the lake ice cover were studied using more than 400 combined ERS-2, Radarsat-1 and Landsat-7 scenes over the past years (Nolan et al., 2002; Nolan and Brigham-Grette, subm.). Lake ice cores drilled in spring 2003 provided necessary ground-truthing of these observations. The gas content in these cores, and in a gas trap deployed on the lake bottom in 2003, has being quantified and analyzed to study the rate and composition of gas emission from the sediments via the water column and the lake ice towards the atmosphere.

Collections of plants, soils and rocks sampled in the lake catchment are being used to characterize the source materials for the lake sediments. Information on the eolian sediment supply comes from sediments sampled from snowfields and lake ice. The fluvial sediment supply is characterized using sediment and water samples from the brooks entering the lake. Solifluction measurements provide information concerning gravitational sediment supply.

The annual and interannual variability in the hydrology of the lake has been investigated using a wide spectrum of field measurements and laboratory analyses, both conducted on water samples taken along depth profiles at different sites and during different times of the year. In addition, a series of thermistor strings provides complete records of water temperature fluctuations in the lake since summer 2000. Information on the annual variability in lake-internal biological production comes from diatom and biomarker investigations of the ice and water samples (Cremer and Wagner, 2003; Cremer et al., in press.). The flux of particles through the water column is partly quantified by sediment traps. Finally, the impact of all these processes on the modern sediment formation in Lake El’gygytgyn is being investigated.
by comparison with the composition of 56 surface sediments collected in a dense grid over the entire lake (Dehnert, 2004).

4.5 Geomorphology and Geocryology

Pliocene through late Pleistocene fluvial deposits, found interbedded with ejecta in exposures along the Enmyvaam River, indicate that the El’gygytgyn Crater has remained an open lacustrine basin that has never been glaciated since the time of impact (Glushkova, 1993, Belyi et al., 1994, Glushkova et al. 1994, Glushkova and Smirnov, subm.). The crater was subject to permafrost conditions since at least early Quaternary times (Kaplina, 1981; Glushkova, 2001; Heiser and Roush, 2001; Hubberten et al., 2004, Brigham-Grette, 2004). Today, permafrost thickness reaches about 500 m and slope processes and fluvial activity are regarded as primary agents for erosion, transport and sedimentation in the area (Yershov, 1989).

Field studies in 2000 and 2003 were focused, firstly, on the collection of additional stratigraphic information from river terraces along the Enmyvaam River that drains Lake El’gygytgyn. Terraces at 35-40 m and 9-12 m above the modern lake level are interpreted to be of middle Pleistocene and late Pleistocene age based on relative elevation and pollen stratigraphy. In addition, the field team identified what is likely a submerged shoreline scarp at about –11m depth around the southern shore of the lake. This scarp largely defines the deepest margin of the shallow lake shelf and may mark the extent to which lake level was lowered during the arid interval of the last glacial maximum.

Secondly, frozen alluvial fan deposits in the catchment grading to the outlet river system are currently being studied as a crucial means to better interpret the lake sediment record. The uppermost unit of the permafrost deposits is now known to be of late Pleistocene/Holocene age (Schwamborn et al., 2004). First results from Ground Penetrating Radar (GPR) profiles, short permafrost cores, and natural exposures with active ice wedges indicate increased mobility of the fan deposits during the early Holocene, a time when regional summer temperatures throughout Beringia are known to have been much warmer than present (Kaufman et al., 2004). In the western and northern lake catchment a prominent onshore ramp protrudes into the lake basin. A 5 m long permafrost core illustrates a heterogenic detrital composition and indicates sedimentation rates on the order of 2 to 3 m per 10,000 years (Schwamborn et al., 2004). According to the geometry of reflectors in GPR profiles and support from geomagnetic measurements, the total thickness of these deposits is at least several tens of meters. Seismic profiles from the adjacent lake slope have shown
particularly frequent debris flows (see below), suggesting that the mobility of the permafrost deposits in this region triggers the sediment input into the lake.

4.6 Paleolimnology

First sediment cores from Lake El’gygytgyn we recovered in spring 1998. A 12.9 m long core (PG1351) from the deepest part of the lake (Fig. 1, p. 3) revealed a basal age of approx. 250 ka, based on radiocarbon, luminescence, paleomagnetic and pollenstratigraphic data, and tuning of the susceptibility data with the local summer insolation (Shilo et al., 2001; Forman et al., subm.; Lozhkin and Anderson, subm.; Nowaczyk et al., 2002; Nowaczyk and Melles, subm; Fig. 3 and Fig. 4). The record is complete and undisturbed, confirming the lack of glacial erosion or lake drying. It is the longest terrestrial Arctic paleoclimate record thitherto recovered, recording climate changes more than twice as long as the longest Greenland ice core.

![Graph showing Age versus depth of cores PG1351 and Lz1024 based on pollen stratigraphy, radiocarbon (14C) ages, Infrared Stimulated Luminescence ages (IRSL) and paleomagnetic event stratigraphy, with tuning of magnetic susceptibility variations with regional insolation (after Nowaczyk et al., 2002; Nowaczyk and Melles, subm.).]
Fig. 4: Correlation of cores Lz1024 and PG1351 based on variations in magnetic susceptibility and the occurrence of turbidites (T1 to T20) and volcanic ashes (A1 and A2) in both cores. Correlation of the susceptibility with regional summer insolation (red lines) was employed to create the insolation-tuned age models presented in Figure 3 (after Nowaczyk and Melles, subm.).

The composition of the 12.9 m long sediment core records not only the past glacials and interglacials, but also short-term climate events (Shilo et al., 2001; Asikainen et al., subm.; Minyuk et al., subm.). Four different lake modes can be distinguished that probably reflect relatively warm, peak warm, cold and dry, and cold but more moist climate states (Melles et al., subm; Fig. 5). While temporal variations between glacial/stadial and interglacial/interstadial settings are predominantly controlled by variations in regional summer insolation, the intensity of the warm periods and the wetness of the cold periods are also influenced by more irregular alterations in the atmospheric circulation patterns. Millennial-scale climate changes are recorded in the high-resolution magnetic susceptibility data, measured in steps of 1 mm (Nowaczyk et al., 2002). The data show strong correlations and broad similarities to the δ¹⁸O stable isotopic record from Greenland Ice Cores (GISP/GRIP), with the occurrence of the Younger Dryas (YD) event, stronger Dansgaard/Oeschger-Heinrich tandems and all
 substages of the MIS 5. The existence of teleconnections to the north Atlantic is also indicated by an interstage 5d warming at Lake El’gygytgyn like that seen in the North Atlantic (Keigwin et al., 1994; Chapman and Shackleton, 1999), and the "YD-like" event at the stage 5/6 transition seen in many Northwest European records (Seidenkrantz, 1993).

In 2003, a 16.7 m long core (Lz1024) was recovered from a different locality in the central part of Lake El’gygytgyn (Fig. 1, p. 3). This new core is a perfect match with the core from 1998 (Fig. 4), giving us great confidence that the sediment composition in all parts of

Fig. 5: Major paleoenvironmental modes that have occurred in Lake El’gygytgyn during the past ca. 250 ka, as indicated by the sedimentological and chemical composition of core PG1351 (after Melles et al., subm.); in the mode reflecting cold but rather moist climate the hatching illustrates blanketing snow on the lake ice cover.

In 2003, a 16.7 m long core (Lz1024) was recovered from a different locality in the central part of Lake El’gygytgyn (Fig. 1, p. 3). This new core is a perfect match with the core from 1998 (Fig. 4), giving us great confidence that the sediment composition in all parts of
the central lake basin is representative of the climatic and environmental history of the region. According to preliminary IRSL ages (Preusser et al. unpubl.) and insolation tuning the record in core Lz1024 is complete and undisturbed, probably penetrating to 300 ka, about 50 ka deeper into Earth history (Fig. 3, p. 14). Additional radiocarbon and luminescence dating, and Ar/Ar dating of the two tephra layers occurring in the record (Fig. 4), are currently being processed. The results will further improve the chronology for both cores but they likely will not require large modifications in the currently accepted age models.

The genesis of the turbidites occurring in cores PG1351 and Lz1024 was investigated using two additional cores (Lz1039 and Lz1041) from the lower western slope of Lake El´gygytgyn (see Fig. 1). These cores penetrated a subrecent, acoustically transparent sediment body that was identified in 3.5 kHz subbottom profiles and interpreted as a debris flow (Fig. 6a). The debris flow in both cores is directly overlain by the late Holocene turbidite T1 (cf. Fig. 4), and underlain by sediment successions that contain the tephra layer A1 and the turbidites T4 and T3. In core Lz1041, the lower part of the debris flow shows deformed stratification, indicating an initial stage with sediment sliding and limited sediment mixture (Fig. 6b). Massive sediments above (core Lz1041) and in front (core Lz1039) of the stratified deposits probably reflect a second stage with liquefied transport (Fig. 6c). The absence of Holocene deposits including turbidite T2 in both cores indicates that the debris flow led to the basal erosion of ca. 1 m of thick unconsolidated sediments along parts of its flow path. It produced a suspension cloud in the lake water (Fig. 6d), whose deposition caused the formation of turbidite T1 not only in front but also on top of the debris flow (Fig. 6e). Hence, the turbidite was not a product of a density-driven turbidity current, but of ’pelagic rain’ following Stokes’ Law. As a consequence, it was not erosive. This suggestion is supported by radiocarbon age estimates available from the sediments closely below (cores Lz1039 and PG1351) and above (cores Lz1041, Lz1039 and PG1351) the LGM turbidite T3, which all yield very similar ages (Fig. 6e). Given that one debris flow has produced one turbidite all over the lake, the total number of turbidites in core Lz1024 from the central lake (24) reflects the number of debris flows during the last 300 kyr. For instance, the lower debris flow at the western slope, highlighted in blue in Fig. 6a, caused the formation of turbidite T5 (Fig. 4).

In addition to the deep-water and slope cores, three cores were taken in 2003 from the southern and western shelves of Lake El´gygytgyn (Fig. 1). The investigation of cores Lz1027 and Lz1071 will supply new information concerning the shallow-water deposition in Holocene times. The ca. 2.5 m core Lz1028 from the southern shelf, in contrast, will predominantly supply information on lake level fluctuations.
Fig. 6: Scheme illustrating gravitational mass movement in Lake El’gygytgyn. The lower proximal part of a subrecent debris flow penetrated by cores Lz1041 and Lz1039 (a) was deposited by initial sliding (b) followed by liquefied flow (c). The debris flow led to basal erosion of sediments including turbidite T2 but not T3 and the volcanic ash layer A1. It produced a suspension cloud (d), whose vertical settling formed a graded turbidite all over the lake (e). The non-erosive nature of turbidites in Lake El’gygytgyn is confirmed by radiocarbon dating below and above turbidite T3 (e).

With this core highly consolidated, fine-grained sediments were recovered beneath a thin veneer of coarse-grained lag deposits. The consolidated sediments probably are very old (early Quaternary or Pliocene). They were most likely deposited in deeper water during a time of higher lake level, and later became exposed by erosion of the overlaying sediments when the lake level dropped to its present position.
4.7 Seismic Surveys

4.7.1 Aims and Logistical Limitations

The aim of the seismic investigations carried out on the lake in 2000 and 2003 was to study the geometry and thickness of the sediment fill and to provide a pre-site survey for future drilling proposals. In order to obtain both high resolution and deep penetration acoustic data, 3.5 kHz echo sounding was combined with airgun seismic profiling.

One of the major problems of using marine equipment on Lake El´gygytgyn is its remote location and lack of naval infrastructure (no ship, no marina) and thus difficult logistics. Standard marine seismic equipment including heavy air gun arrays, powerful compressor units and long streamers cannot be used because (i) the only reasonable way to bring equipment to the lake is by helicopter (MI-8 type), and (ii) there is no vessel to carry the gear. During both seasons we brought to the lake an aluminium platform (frame size 4 x 3 m) equipped with 4 inflatable tubes and a 25 HP Honda outboard engine (see cover page). This vessel (RV "Helga") can only carry a small airgun system combined with small portable electronic units including echosounders.

4.7.2 Acoustic Methods

During two expeditions to Lake El´gygytgyn in 2000 and 2003, refraction and multi-channel reflection seismic data were obtained using two sonobuoys and a 270 m streamer, respectively. A single 5-cubic-inches Bolt 600B airgun was used as seismic source for the refraction data in 2000. Shooting intervals were 6 s equating an average of 8 m shot distance. Two sonobuoys were placed on two perpendicular profiles across the lake. They were deployed during calm weather and recorded the airgun-borne acoustic pulses by a single hydrophone under the buoy (e.g. Dobrin and Savit, 1988). The signals were amplified and transmitted via radio to the platform where WINRADIO on PC was used as receiver. Both sonobuoy profiles were shot and recorded in both directions. The field data were digitized using a computer program written by C. Kopsch to produce digital SEG-Y format.

The refraction seismic data recorded by the sonobuoys were processed by standard processing to identify different reflections and refractions. The overall quality of the data covering the complete offset range of up to 4.4 km (EW profile) and 3.3 km (NS profile) was good. A raytracing forward modeling technique was used to develop a starting model characterized by layer thicknesses and velocities. The initial four-layer model was used to calculate synthetic seismic traveltimes. The inversion algorithm allowed us to iteratively
adjust model parameters (i.e. layer thicknesses and velocities) of the starting model until the difference between calculated and observed traveltimes was minimized.

For the multi-channel survey in 2003, we used a 26 cubic inches Mini-GI gun (triggered in G-gun mode) at a pressure of 110 bar. Shot intervals were 10 seconds, equating about 12 m shot distance. A 15 channel streamer with an offset of 130 m and a channel interval of 10 m was used as receiving array (Fig. 7). Multi-channel seismic data were stored on DAT tapes in the field and digitised using a StrataView (Geometrix, USA) in the home laboratory. These data were initially processed by standard processing including bandpass filtering, velocity analysis, CMP stacking and predictive deconvolution. After inversion of the sonobuoy data, the resulting velocity model was used for stacking.

![Diagram](image)

**Fig. 7:** Basic principle of seismic and sediment echosounding systems used during the expedition of 2003. The multi-channel streamer was specifically constructed by AWI for the Lake El’gygytgyn expedition. The streamer consisted of 15 wide-band single hydrophones (10 Hz to 10 kHz sensitivity). Each hydrophone had a pre-amplifier and its own cable connection to the vessel to provide the power supply for amplification and signal transmission. The advantage of this scheme is that the 15 hydrophones were individually transportable. In the field the hydrophones and cables were placed at full length on the beach of the lake to assemble them into a streamer. To enable pulling this long streamer with the small vessel, full self-floatation of the entire streamer was essential, for which foam tubes (commercially available in 2 m-lengths as water pipe insulation; Tubulit, Switzerland) were mantled around the cables.

A 3.5 kHz sediment echosounder operated as high-frequency pulse source (ORE, Model 140) in 2000. Because DAT-tape storage was limited in 2000, the 3.5 kHz system could not be run simultaneously with the airgun system. Thus 3.5 kHz data were obtained on separate track lines mostly along previous air gun lines plus along additional profiles where only 3.5 kHz data were recorded. Analog-data printing and data storage were done in a similar way as described above for airgun data acquisition.
In 2003 we used the same 3.5 kHz echosounder as in 2000 (ORE, Model 140, USA) to ensure full compatibility of the data sets from both expeditions. This system was in operation on all profiling tracks simultaneously with the air gun system. A four-transducer (Massa, USA) catamaran array was towed 30 m behind the vessel (Fig. 7). The pulse length was 0.5 ms at 10 kW transmission power. Data was printed on a chart recorder (Ultra, Model 120, UK) and stored on one channel of the Sony DAT-Recorder (Model PC204Ax, mentioned above). The system was triggered at 1 or 2 seconds synchronized with the air-gun trigger using GPS time. No interference between the airgun and 3.5 kHz systems were observed during simultaneous profiling.

Navigation was performed along all track lines using a Russian GPS system (courtesy of AARI St. Petersburg) linked to a PC for data acquisition and storage. The same system was used during the expedition in 2000, which also included circumnavigation of the lake close to the shoreline to provide digitized data of the lake periphery. During circumnavigation of the lake, a constant lateral offset of a few hundred meters to the south-west was observed in the GPS positions. This offset is responsible for the fact that some track data of both the 2000 and 2003 expeditions appear to cut across the shoreline (Fig. 8).

4.7.3 Results

Our present knowledge of the seismic character of the Lake El’gygytgyn basin is based on two sources of information, of which a brief summary is given below:

- Single-channel and sonobuoy seismic data together with 3.5 kHz echosounding data obtained during the summer expedition 2000 as published in subsequent papers (Niessen et al., 2000; Niessen et al., subm.)
- Single-channel and multi-channel seismic data together with additional 3.5 kHz echosounding data of the summer expedition 2003 as described in the expedition report (Melles et al., in prep.)

In total 10 air gun profiles were recorded in 2003 with a total length of 106 km (Fig. 8a). Profiles 03/01 and 03/02 were recorded without the multi-channel streamer. For all other profiles, both single- and multi-channel data are now available (86.56 km). Together with the air-gun data of the 2000 expedition we have increased the coverage of profiles significantly to a total of 185 km. The length of the 2000 sonobuoy profiles were 3.6 and 4.39 km (one way) for profiles shot in W-E and N-S directions, respectively (Fig. 8a). In 2000, 69.4 km of sediment echosounding data were taped along seven 3.5 kHz profiles. During the 2003 expedition 19 profiles were recorded with a total length of 156.1 km (Fig. 8b). Together with
the previous data of 2000 a length of 216.5 km of high-resolution sediment echosounding profiles is now available for Lake El’gygytgyn.

The quality of the new acoustic data is significantly better than that obtained in 2000. In 2003, the airgun was more powerful, the new streamer data are almost free of noise and the 3.5 kHz echosounding data were recorded exactly on the same line as the seismic data (simultaneous operation). The sonobuoy data of the 2000 expedition is now fully processed providing a reliable depth-velocity model across the lake including the two proposed coring locations D1 and D2 (Fig. 8). Also, a fully-processed multi-channel profile (03/04) is now available which has been shot almost along the same line as the sonobuoy profiles in 2000 (Fig. 8).

The processed sonobuoy profiles (bandpass filter 0 - 60 Hz) reveal clear evidence of refracted waves after about 1 s two-way travel time (TWT) (Fig. 9). Raytracing of these refractions, including wide-angle hyperbola between 0.2 and 0.8 s TWT (Fig. 9) resulted in a five-layer depth model characterized by different velocities (Fig. 10).

The top-layer is the water column of a known thickness of up to 171 m. Based on their relatively low velocities of 1500 m/s and 1650 m/s, respectively, the upper two sub-bottom layers are interpreted as unconsolidated sedimentary units (Fig. 10). Below these sediments there is a significant increase in sonic velocity to approximately 3000 m/s, which we interpret as the transition from sediments into fallback breccia.
Fig. 9: Sonobuoy profiles 00/1-1 (east-west) and 00/1-2 (west-east). Refracted signals are overlain by yellow and wide-angle reflection hyperbolae as well as the direct wave are indicated by dots.

Fig. 10: Raytracing of sonobuoy data of profiles 00/1-2 and 00/1-1 (upper) and resulting depth velocity model (lower).

This velocity level is very similar to velocities found in other impact craters, for example 3.0 to 3.4 km/s in the suevite layer of the Ries Crater and 2.5 and 3.5 km/s in the impact breccia of the Lake Bosumtwi Crater/ Ghana (Angenheister and Pohl, 1976; Karp et al., 2002 together with Scholz et al. 2002, resp.). The lowermost layer is defined by a velocity increase to more than 3600 m/s (Fig. 10) and interpreted as bedrock. It is interesting to note
that the velocities measured on hand specimen of Cretaceous volcanic rocks from the El’gygytgyn catchment are significantly higher (about 5.0 km/s on average). We take this as an indication for the bedrock under the lake being fractured and brecciated to a significant depth of possibly more than 1.4 km below the present lake level (Fig. 10) as a result of the impact some 3.6 Ma ago.

In addition to the velocities there is morphological evidence in the depth model for a central uplift structure more pronounced in the brecciated bedrock than in the fallback breccia (Fig. 10). Central uplifts are characteristic features of large impact craters and are formed as release structure in the upper part of the target rock relatively shortly after the meteorite impact (e.g., Melosh, 1989). The coverage of our sonobuoy-data is not dense enough to exactly locate the highest peak of the uplift. There is an impact-related density anomaly in the centre of the El’gygytgyn crater some 3 km north west of the centre of the lake (Alyunin and Dabizha, 1980, Dabizha and Feldmann, 1982) and about 1 km to the north of the presented sonobuoy line. Therefore, it seems to be reasonable to assume that our depth model refers to a line across the southern flank of the central uplift.

According to the model, deep drilling at the proposed location D1 (Fig. 8 and Fig. 10) would reach the bases of the upper and lower sedimentary units at about 350 m and 500 m below lake level, respectively. The transition between fallback breccia and brecciated bedrock is expected to be reached in a depth of about 650 m below lake level. The transition from brecciated into not-brecciated bedrock is probably transitional and not indicated in the refraction data. At the proposed drillsite D1 (Fig. 8), located at the eastern flank of the uplift, the total thickness of the sediment fill is approximately 330 m and may reach a thickness of 420 m at location D2, which is more in the ring basin around the uplift. The thicknesses and velocities of the revised model are largely consistent with earlier interpretations by Niessen (2000), in which the bedrock was not detected, and Niessen et al. (submitted), which did not resolve the central uplift.

Single-channel reflection profiles exhibit well-stratified sediments to a depth of at least 180 m subbottom, locally intercalated with debris flow deposits (Fig. 11). The latter are clearly documented in 3.5 kHz profiles and are more common in the western part of the lake and along the slopes. The debris flows are acoustically structureless, have wedge or lenticular-shaped geometries, and can reach several kilometers in length. Proximal thicknesses of the debris flows can be up to ca. 20 m; those in distal areas are still in the range of 5 m or less. However, in the area of the 1998 coring location (PG1351, Fig. 1, p. 3) the upper 180 m of sediments appear to be well-stratified and largely unaffected by debris flows and faults. There
is no evidence for erosion and/or deposition from grounded ice. In all single-channel profiles, distinct multiples are clearly visible below 500 ms two-way travel time (equivalent to about 375 m below lake surface or 200 m below sediment surface in the center of the lake). In the airgun profiles of 2000, all reflections from below 200 m subbottom are completely masked by multiples.

**Fig. 11:** Profile EA03/10 single channel. Line "1" marks the top of an anticline structure draped by overlying sediments. This drape is possibly related to the underlying central uplift. Below 500 ms travel time the record is dominated by multiples so that the actual top of the impact breccia/uplift structure is not visible in this profile.

Seismic processing of multi-channel data largely reduced the multiples below 500 ms TWT and enables an almost full resolution of the basin structure (Fig. 12) across the entire lake.
In profile 03/04 (Fig. 12) one interesting feature is the clear differentiation of two sedimentary units, of which only the upper is well stratified. The lower unit appears to be rather massive. Most of the few reflectors visible in the lower unit are weak multiples, which could not be eliminated completely. Therefore, the lower sediment unit appears to be almost acoustically transparent and structureless.

The second feature clearly visible in the profile (Fig. 12) is a relative distinct downward increase of acoustic backscatter below the transparent lower sedimentary unit. The top of this layer forms steeply dipping reflectors towards both the western and eastern ends of the profile. In addition a pronounced uplift structure is notable slightly displaced to the west from the center of the profile (Fig. 12).

Overlaying velocity data from the sonobuoys (Fig. 10) indicates that the weak increase in velocities at the top of the lower sedimentary layer coincides with the boundary between well-stratified and massive sediments (Fig. 12). Further down, the onset of acoustic backscatter below the lower sediment unit is associated with the rapid increase of velocities in the breccia layer. The transition from breccia to brecciated bedrock is not visible in the reflection profile possibly due to strong reflectivity in both the upper sedimentary unit and the breccia unit not leaving enough acoustic energy for resolving reflectors below 800 m (Fig. 12).

As a first careful interpretation the different character of the sedimentary units may be related to different conditions in the sedimentary environment. It seems reasonable to assume the lower layer to be formed during the Upper Tertiary when lacustrine sedimentation was affected by a much warmer climate. The Quaternary sediments of the upper 16.7 m of Lake El’gygytgyn are known to be rather cyclic as a result of variable climate forcing between cold glacial to peak-warm interglacial conditions. Thus, at the Tertiary/Quaternary boundary, a general climatic deterioration combined with more pronounced cyclic changes in the lacustrine environment may have given rise to distinct variability of sediment-physical properties at the lake floor thereby causing more and stronger reflectors during the last 2.6 Ma.

At present there is no evidence for any major erosional events in the sedimentary record. Also, there is no evidence for an increased content of gas in the lower sedimentary unit. However, because the latter is almost structureless, at the present level of investigation a higher content of gas cannot entirely be ruled out.
Fig. 12: Multi-channel airgun profile 03/04 (Fig.6) with the first lake-floor multiple and the top of increased backscatter marked by blue and green lines, respectively (middle). In the lower graphic the velocity data of the sonobuoy profiles (Fig.9) is overlain on the multi-channel reflection data.
5 PROPOSED WORK: SCIENTIFIC DRILLINGS AND ANALYTICAL OPERATIONS

Despite its outstanding attributes as a world-class target for deep drilling, the remote nature of Lake El’gygytgyn ensures that the cost of this effort will be significant. For this reason, we have strategically planned all of our scientific progress to this point to maximize our use of funds and honestly justify our next steps toward drilling. Significant diplomatic progress in recent months following a major restructuring of Russian federal agencies now provides the necessary added momentum to our scientific interests. Additional impetus for our proposal is the timely opportunity to launch drilling operations at Lake El’gygytgyn as part of a multinational celebration of the International Polar Year set for 2007 and 2008 (http://www.ipy.org). By way of a letter of intent to the ICSU/WMO on January 14, 2005, we have proposed that lake drilling at El’gygytgyn would provide an outstanding benchmark for the IPY due to the international aspects of the science team, the unique nature of a 3.6 Million year terrestrial record, as well as the recognition of the crater as a well-preserved analog of once water-filled craters on Mars (see Science, vol 305, Aug. 2004, special issue). The following is the effective schedule of proposal timelines we now have in place.

5.1 Proposal Deadlines for Full Funding

- January, 15, 2006 Drilling proposal to the ICDP (collaborative)
- October 15, 2005 Submission of proposal for initial science and partial drilling costs to the US NSF ESH program (Julie Brigham-Grette)
- January, 2006 Submission of proposal for initial science and partial drilling costs to the German Ministry (BMBF) (Martin Melles)
- January, 2006 Submission of proposal for initial science and partial drilling costs to the Austrian Science Foundation (Christian Koeberl)
- January, 2006 Submission of proposal for initial science and partial drilling costs to the Russian Foundation for Basic Research (Pavel Minyuk)
- January, 2006 Submission of proposal for initial science and partial drilling costs to other national funding agencies (e.g., Canada, Pierre Francus, or The Netherlands, Holger Cremer)

5.2 Effective Drilling and Operations Schedule

(assuming successful peer review at all stages by summer 2006)

- Summer 2005 Employment of Russian Operations Manager to begin work on logistics and permitting within Russia (long lead time needed)
- Summer 2005 Lake environmental and safety project review (LEPS)
- Late Summer 2005 Site visit with drilling operators and PIs
- Spring –Fall 2006 Prepare all customs lists, and purchase all materials
- Spring –Fall 2006 Finalize all permitting with Russia
- July-August, 2006 Deploy drilling expendables by barge to Pevek
- November, 2006 Shipment of all drilling and science equipment and camp infrastructure to St. Petersburg for customs clearance
- Early-mid January 2007 Ship all materials to Pevek by cargo plane
5.3 Site Selection and Drilling Strategy

5.3.1 Introduction

For ICDP drilling two locations in Lake El’gygytgyn, and one location in the lake catchment, are proposed (Fig. 13). All three proposed sites are located on one line, for which sonobuoy and fully-processed multi-channel data are available from the lake. The major characteristics, targets and differences of the sites are summarized below; details of drilling requirements are given in Table 1 and Table 2 (p. 31 and 32).

![Fig. 13: Sketch of the general geological settings in the El’gygytgyn Crater with the position and length of proposed drill sites (numerical data in meter below lake level).](image-url)

5.3.2 Position D1

Northeastern lake: The major target is a complete undisturbed record of Quaternary and Tertiary sediments including drilling through the impact breccia into brecciated bedrock for some significant depth (up to 800 m in total below lake level). Three multi-channel seismic profiles allow a 3-d interpretation of the deposition geometry at this site. Two sonobuoy profiles cross over at the location, providing additional 3-d information of subbottom
velocities and depths of drilling targets. The present depth and velocity model from both sonobuoy and multi-channel data is well constrained to a depth of 900 to 1000 m below lake level. High-resolution 3.5 kHz sediment echo-sounding data and detailed bathymetry are available along the seismic lines. The seismic record is distal to thicker debris flows and no significant debris flow deposits are visible in sediment echosounding profiles at the proposed location down to 40 m subbottom. A 16.7 m long sediment core (Lz1024) from the location has an estimated basal age of about 300 ka. Core composition suggests a complete and highly variable record of Quaternary climatic change. The top of impact breccia (fallback) is determined from distinct reflectors and refractors to be drilled in a depth of about 500 m below lake surface. The boundary between breccia and brecciated volcanic basement is interpreted to be drilled at 650 m below lake surface. The site is at the eastern flank of the central uplift. This suggests feasibility of drilling into fractured bedrock including the recovery of a more pelagic and perhaps condensed strata of the lower sedimentary unit. However, the lack of structures do not allow a reliable interpretation of the completeness of the sedimentary record towards its lower end. This possible gap may be compensated by a full record proposed to be drilled at site D2.

5.3.3 Position D2

Western lake: The major target is a complete record of the sediment fill at the deepest part of the paleobasin on the selected line (interpreted as ring basin surrounding the central cone) to allow drilling of oldest lacustrine deposits and highest resolution. Three multichannel seismic profiles allow a 3-d-interpretation of the deposition geometry at this site. High-resolution 3.5 kHz sediment echosounding data and detailed bathymetry are available along the seismic lines. The site is located more proximal to debris flows so that some intercalation of undisturbed lacustrine sediments with debris flows may be expected. This will allow us to investigate the variability of frequency and thicknesses of debris flows in order to understand their occurrence as a function of climatic change or related processes such as permafrost development and lake-level fluctuations. The top of the breccia is estimated from single-channel seismic data to be drilled between 570 and 590 m below lake surface. The boundary between breccia and brecciated volcanic basement occurs at about 900 m below lake surface.

5.3.4 Position D3

Western lake catchment: The major target is to penetrate one of the alluvial fans in the western lake catchment into lake sediments expected underneath. The core/s shall supply
information on the thickness and age of the alluvial fans, and their transport velocities towards
the lake. From the stratigraphy and composition of the deposits detailed information on the
environmental history in the lake catchment and on periods with lake levels above the present
position is expected. Based on a temperature profile in the bore hole the heat flux and
permafrost thickness shall be calculated. These data would supply information concerning the
expansion of the talik (unfrozen sediment) beneath the lake. The upper part of an alluvial fan
is currently studied on a 5 m long permafrost core recovered in 2003. Some additional
chronological information will be obtained by exposure dating of surface boulders.
Information concerning the internal structure of the alluvial fans is available from Ground
Penetrating Radar profiles, but only down to approximately 10 m depth. In one profile a
distinct subbottom layer rises to 6 m below surface. This layer likely reflects an internal
structure within the fan deposits, because geomagnetic measurements exclude the occurrence
of volcanic bedrock or breccia at such shallow depth. However, the thickness of the alluvial
fan remains questionable. In case of low breccia depth a core transect instead of just one core
could possibly be drilled in the given time, providing more detailed information on the history
of the fan.

Table 1: List of proposed drill sites for Lake El’gygytgyn (constraints for lake sites from seismic data by
Niessen et al., unpubl.)

<table>
<thead>
<tr>
<th>core #</th>
<th>water depth (m)</th>
<th>sediment* thickness (m)</th>
<th>breccia** thickness (m)</th>
<th>total drillstring length (m)</th>
<th>total core length (m)</th>
<th>comments</th>
</tr>
</thead>
</table>
| D1     | ca. 170        | ca. 330                 | ca. 150 m               | 800                         | 630                  | northeast of lake center, flank of center cone, distal to major sediment supply from the west (→ best for paleoclimate reconstr.), through impact breccia into bedrock (→ best for impact science), at site of 16.7 m core Lz1024 
|        |                |                         |                         |                             |                      |          |
| D2     | ca. 170        | 400 - 420               | ca. 320 m               | 800                         | 630                  | southwest of lake center, deepest part of ring basin on profile, proximal to major sediment supply from the west (→ best for reconstructing history of sediment supply, permafrost development, influence of gravitational transport on D1, lake level history via debris flow frequency)          |
|        |                |                         |                         |                             |                      |          |
| D3     | ca. -10        | > 10                    | ?                       | max. 200                    | max. 200             | western lake catchment, 300 to 400 m from the lake shore, solifluction and lake deposits, partly or fully frozen (→ reconstruction of Quaternary permafrost and catchment history) |
| (onshore)|                |                         |                         |                             |                      |          |

* lake sediments have to be recovered as duplicate cores, whose correlation shall supply a complete (!) composite sequence

** permafrost deposits, breccia and bedrock shall be recovered only by single core
Table 2: Characteristics of sediment and rock units to be cores (data by Niessen et al., unpubl.).

<table>
<thead>
<tr>
<th>unit</th>
<th>p-wave velocity (m/s)</th>
<th>porosity</th>
<th>density (g/cm³)</th>
<th>sediment / rock type</th>
</tr>
</thead>
<tbody>
<tr>
<td>lake sediments</td>
<td>1500 – 1650</td>
<td>0.5 – 0.7</td>
<td>1.5 – 1.8</td>
<td>upper sediment unit: clastic muds lower sediment unit: muds to sands</td>
</tr>
<tr>
<td>breccia</td>
<td>3000</td>
<td>0.2</td>
<td>2.2 – 2.3</td>
<td>impact breccia, probably consisting of brecciated volcanic rocks</td>
</tr>
<tr>
<td>bedrock</td>
<td>&gt; 3600</td>
<td>&lt; 0.15 – 0.2</td>
<td>2.3 – 2.9</td>
<td>probably volcanic rocks</td>
</tr>
</tbody>
</table>

5.4 Coring System and Operator Options

The success of our efforts at Lake El’gygytgyn requires the selection of the right drilling system to deliver good quality core with recovery as continuous as possible. The Drilling, Observation, and Sampling of the Earth’s Continental Crust, Inc. (DOSECC) GLAD 800 drilling system was financed by the ICDP to drill lakes virtually anywhere in the world. It has been successfully utilized e.g., at Bear Lake/USA, Lake Titicaca and Lake Bosumtwi/Ghana, as well as smaller lakes in Iceland. At Bosumtwi Crater, the GLAD 800 was used for drilling both lacustrine sediments as well as impact breccia with no serious difficulty in changing tools at the interface. The rig is next scheduled for drilling at Lake Petzen Itza/Guatemala and Lake Qinghai/China. In preparation of this proposal we have worked closely with DOSECC Director Dennis Nielson in developing the cost estimates.

Because our coring site is in Russia, we felt it was important that we explore for comparison the possibility of using the Russian Federal Drilling operator “NEDRA” (Scientific Industrial Center on Superdeep drilling and Comprehensive Investigations of the Earth’s Interior). NEDRA was in charge of successful drilling operations at Lake Baikal with comparable drilling quality and core recovery (>90 %). Melles, Brigham-Grette and Bolshiyano met with Director Bilal Khakhaev in September, 2004 about our requirements for the project.

The budgets of both drilling operators can be found in appendices 1.1 to 1.5. For drilling operations alone, the DOSECC quote ($1.967 M USD) is nearly 60 % that of NEDRA ($ 3.298 M USD; based upon an exchange rate of 27.9 Rubles/$1 USD).

Representatives of VECO Polar Resources, the Arctic logistics provider for the U.S. National Science Foundation, have estimated separately costs for the transportation of equipment, logistics for personnel, and housing/food at this remote site. VECO has an notable track record of operating in Russia and with supplying support to projects throughout the Arctic, including North Pole ice drift camps. Because of the challenges of working in Russia,
we have planned for VECO to assist us with logistics, in collaboration with an Operations Manager from the Arctic and Antarctic Research Institute via an arrangement with the in-house Otto Schmidt Science Laboratory. The details of these arrangements are in the appendix.

The choice between DOSECC and NEDRA as drilling operators is an important practical matter as much as one of cost. The DOSECC rig can be containerized for shipping but it is also light enough to operate using 1.5 to 2 meters of lake ice as a drilling platform. The added cost of using the GLAD800 will be the customs cost if we can’t get them waived as in-kind support. At the same time, DOSECC indicates that they can operate with half of the crew of NEDRA, a point that will cut costs for housing, food, and field-based laundry. We have not calculated the logistics costs of using the bulkier NEDRA rig and drill team but clearly the cost would be much more.

5.5 On Ice Core Analyses

*Initial core processing*: Core processing on ice will only include documentation and cutting the drilled core sections in 1 or 1.5 m length for safe transportation of whole-core sections. The sediment accessible at the end of the sections will be described macroscopically, and smear slides will be made for microscopic description.

*Core-physical properties*: Determination of core-physical properties is now a standard procedure for initial core characterization in deep drilling projects. During the drilling operation, the data are useful for correlating the core with pre-site survey seismic lines, thereby enhancing the identification of proposed drilling targets and aiding the bore-hole logging carried out by other participants of the project. Core physical property data will be used for characterization of petrophysics of the core, indications of consolidation and cementation, identification and analysis of sedimentary cyclicity and core to core correlation. Data obtained from p-wave transmission seismograms (full wave form, sediment sound attenuation) with a very high vertical resolution will be used for the interpretation of grain-size variability and their palaeoenvironmental implications. We are planning to use the AWI whole-core logging apparatus (a modified GEOTEK Multi-Sensor-Core-Logger) in a field laboratory at Lake El’gygytgyn to log the whole cores prior to shipping. The following parameters will be logged on all core sections in depth-intervals between 0.2 and 2 cm.

- p-wave velocity
- p-wave transmission seismograms
- wet bulk density
Bore-hole logging: In deep drilling initiatives, bore-hole logging is important because the data provide the link between *in situ* conditions in the bore hole and the drilled cores. Bore-hole data is also useful for initial characterization of the lithological log and its interpretation in terms of palaeoenvironmental change, diagenesis and impact history. The Lake El’gygytgyn ICDP drilling project includes bore-hole logging in cooperation with Uli Harms and the ICDP Operational Support Group, GFZ-Potsdam. This work includes downhole wireline logging using the GEOTEK MSCL. As much as possible the project will require that the following bore-hole logging parameters be measured: spectral gamma ray, density, neutron porosity, sonic velocity, electrical resistivity, borehole geometry, temperature and magnetic field properties such as susceptibility.

5.6 Off Ice Core Analyses and Core Storage

Once the cores from Lake El’gygytgyn are safely through Russian customs the cores will be transferred to a national facility for initial studies by the coring team PIs. Due to shared interests in core storage, we have two options as to where initial studies should take place. The first choice is at LacCore, the U.S. National Lacustrine Core Repository operated for the broader science community under grants from the US National Science Foundation to the Limnological Research Center (LRC) and the Large Lakes Observatory (LLO) at the University of Minnesota. The second alternative is the Alfred Wegener Institute in Potsdam with close proximity to the Geoforschungszentrum (GFZ) and the ICDP. In either case, scientists from the initial science team will be assembled to jointly process the cores. This work will involve standard non-destructive multi-sensor core logging, photography, visual core descriptions, lithostratigraphy, smear slides, x-ray, paleomagnetics, and subsampling for a variety of sediment and organic proxies related to the geochemical and paleoecological stratigraphy. Equally important will be initial sampling for geochronology using a variety of approaches. The team has much experience in these areas and will use standard as well as state of the art equipment and technologies.

Support of the initial science on the cores will be based on separate funding from each of the member countries on the science team. A list of science collaborators with their affiliation and expertise is provided in appendix 2.3.

The off-ice science plan will include workshops for analysis and synthesis with a reasonable timeline of deliverables in the form of publications, science reports, public web
site development, press releases, and dedicated symposia at international meetings. An outreach and data management program will be a part of the science proposals, perhaps in collaboration with NASA. Visualizations already have been developed for the lake system with NASA funding (Nolan, http://www.uaf.edu/water/faculty/nolan/lakee/index.htm and Nolan et al., 2002). The science management team has been approached recently by a geologic film producer interested in producing a documentary on the drilling project.

5.7 Logistics, Feasibility, and Management

Executing a project of this scope in one of the most remote portions of Russia is a significant undertaking. The technology and expertise to complete the drilling objectives in cold weather are relatively straightforward. Several of the PIs on this project have had numerous successful expeditions to Russia, especially remote parts of the Arctic Russia. We are confident that we have assembled a Science Management Team and operations structure that can effectively forecast from experience various alternative solutions to problems and issues that inherently come up associated with projects of this size. Part of the team was deeply involved with the successful Cape Roberts Drilling Program in Antarctica and VECO, our logistics contractor has much experience working in Russia. Our science and operations management plan are outlined in appendix 2 along with the roadmap we have developed for permitting and national bilateral agreements in appendix 3.

6 EXPECTED SIGNIFICANCE

6.1 Scientific Significance

Lake El’gygytgyn represents a world-class drilling target for obtaining a paleoclimate record unique to the Northern Hemisphere, especially the Arctic. We maintain that if Lake El’gygytgyn were located on the road system in Alaska, it would likely be the most well-studied watershed in the Arctic. However, its location in remote NE Siberia has led to unique opportunities to understand the evolution of change in the Arctic climate system and its untapped potential. Having conducted three successful expeditions to the Lake in the past five years and having created strong collaborative bonds within American, German, Russian, and other researchers with similar goals, we as a group are in an ideal position to advance our knowledge of the Arctic and the global systematics and promote international scientific cooperation. This deep drilling effort is an important step toward assessing the environmental
dynamics recorded at El’gygytgyn against other arctic and lower latitude paleoenvironmental records and toward placing them in the context of existing knowledge concerning the impacts and responses of different regions to past and future change. The influence of Eurasian ice sheet dynamics on the flow of the westerlies and moisture diversions is one of many perturbations that may or may not have confounded circumarctic teleconnections over time. We will also be able to compare the record from El’gygytgyn to records from other Asian lakes, like Lake Baikal (e.g., Colman et al., 1995), to compare paleoenvironmental changes possibly linked to global reorganizations of the ocean/atmospheric system over the North Atlantic/Greenland sector of the Northern Hemisphere or sourced from the tropics. This continuing work will place El’gygytgyn into an interhemispheric context. The goals of this project are in line with the efforts of the science community to focus in part on understanding modes of variability in arctic climate on millennial time scales, as well as the spatial—temporal patterns and consequences of past warm arctic scenarios. Given the excitement of the science community over the acquisition of cores this past summer from the Lomonosov Ridge, we argue that the scientific payoff in knowledge gained for drilling at Lake El’gygytgyn will be equally as great, especially given the higher sedimentation rates in this lacustrine system. Comparisons between our 330+ m record of the last 3.6 yrs and the ARCEX/IODP Lomonosov Ridge 425 m long record of the last 85 million years (with only 70 m in the past 3 My; Leg 302 Shipboard Data) affords an outstanding opportunity to learn much more about Arctic change.

6.2 Relevance to Society

The vulnerability of societies and global and regional economies to global change remains an area of great concern. Education and outreach to communicate issues of adaptability and sustainability are the focus of international efforts, like the International Geosphere/Biosphere Program (IGBP) or International Human Dimensions of Global Change Program (IHDP). The science we plan to carry out will contribute to the science community information about the role of the Arctic in the climate system that can then be communicated to the general public about how the entire Earth works as a system – a point not appreciated by even western societies who largely remain rather poorly informed about climate change and our vulnerability to future change.

The impact science emerging from this project is also relevant to societies eager to learn more about the real risks of large impacts, and will lead to an improved understanding of the formation and effects of medium-sized impact craters. Impact craters of the size of the
El’gygytgyn crater are known to form on Earth about once per million years. Such impact events have a disastrous effect on local climate, agriculture, etc., and will lead to massive loss of life. As El’gygytgyn is a relatively young and well-preserved example of a medium-sized crater, important results for the understanding of local and regional effects of such a geological catastrophe will follow from the drilling project.

7 REFERENCES


Asikainen C., Francus P. & Brigham-Grette J. (subm.): Relationship between sedimentology and climate over the last 35,000 yrs in El’gygytgyn Lake. - *J. Paleolimnology*.


Minyuk P., Brigham-Grette J., Melles M., Borkhodoev V. & Glushkova O. (subm.): Inorganic geochemistry of Elgygytgyn Lake sediments (northeastern Russia) as an indicator of paleoclimatic change for the last 250 kyr. - *J. Paleolimnology*.


Nowaczyk N.R. & Melles M. (subm.): A revised age model for core PG1351 from Lake El’gygytgyn, Chukotka, based on magnetic susceptibility variations correlated to northern hemisphere insolation variations. – *J. Paleolimnology*. 39


APPENDICES

Appendix 1  Budget Plan

The proposed budget for drilling at Lake El’gygytgyn has several components each listed here separately. Drilling is planned to take place using the lake ice (typically 1.5 to 2 m thick) as a stable platform from February to May, 2007. Sites D1 and D2 will be drilled first from near the center of the lake; the rig will exit the ice surface by May 1 for drilling into the western alluvial fan and permafrost (site D3). Based upon our experience at the lake and the meteorological assessments of Nolan and Brigham-Grette (subm.), May 1 is a conservative estimate for the earliest we might expect to get surface melting of snow in the lake ice. Standing water on the lake surface, especially if sleds and skids are refrozen in would make the logistics of moving the GLAD 800 to land more difficult.

Our primary route for all of the logistics, in general, will be for shipments and freight to pass through Russian customs in St. Petersburg before being either flown by charter or shipped by sea to Pevek (town of about 7,000 on the Chukchi Sea coast). Transportation from Pevek to Lake El’gygytgyn will involve a cat-train for heavy, nonsensitive cargo, and MI-8 and MI-26 helicopters for other cargo and personnel.

The first cost estimate below is from DOSECC (appendix 1.1) for drilling costs at the lake with additional components listed for customs costs. The second cost estimate is from VECO Polar Resources (appendix 1.2) for all transportation to and from the site, set up of the remote field camp, operations at the camp, and demobilization of the campsite, equipment, and cores from the lake site. The third budget item (appendix 1.3) is for necessary materials and supplies related to on-site core processing, stowage, and readiness for shipping to the U.S. LacCore or the AWI-Potsdam. The forth budget item (appendix 1.4) is for downhole logging by the ICDP Operational Support Group. All of these costs (in US dollars) have been inflation-adjusted to out-year dollars for drilling in 2007 using today’s relative currency rates.

The cost estimates for Russian customs (ca. $500k, appendices 1.1 and 1.2) remain in our budget assuming we are unable to arrange waivers or a reduction in costs via diplomatic means. However, it is our intent to seek this cost reduction if at all possible.
Total Budget Estimate (see following pages for details):

<table>
<thead>
<tr>
<th></th>
<th>USD</th>
</tr>
</thead>
<tbody>
<tr>
<td>DOSECC Drilling</td>
<td>$1.967 M</td>
</tr>
<tr>
<td>VECO Logistics</td>
<td>$2.662 M</td>
</tr>
<tr>
<td>Core site Supplies</td>
<td>$0.015 M</td>
</tr>
<tr>
<td>ICDP-OSG</td>
<td>$0.027 M</td>
</tr>
<tr>
<td>Total USD</td>
<td>$4.671M</td>
</tr>
</tbody>
</table>

The alternative cost estimate for coring and downhole logging we received from the Russian company NEDRA (appendix 1.5) amounts to 91,351,000 rubles ($3.298 M) and excludes a number of costs (e.g., for transportation, facilities, fuel) otherwise covered in the estimates of DOSECC and VECO. The significantly higher overall costs, however, does not exclude that NEDRA could be involved in some aspect of the operations as further discussion may lead to lower estimates. Moreover, the supply of consumables by NEDRA, including drill pipes, could reduce the custom fees (estimated by DOSECC to be $195,000) and its possible experienced Russian personnel are cheaper using DOSECC's GLAD800. The added expense of housing 23 drillers as suggested by NEDRA would require a significant increase in the camp and transportation costs.

One important point that must be clear is that NEDRA belongs to the Russian Ministry for Natural Resources, a ministry responsible for aspects of the required permissions. Most of these aspects we expect will be sorted out by the Science and Operations Management Teams during the coming months. As we proceed, we will continue to seek cost reductions for customs and helicopter transport via diplomatic means, although the past has shown that this is rather unlikely to achieve. In any case, it should be obvious to all concern that the total budget for drilling operations will definitely not fall below $3.5 M given that budgets are projected out to 2007.

We ask ICDP for 2.3M $, representing almost 50% of the currently estimated operational costs, not far from the maximum allowed. The remaining money we will apply for via our national agencies in late 2005 and early 2006; by that time, we plan that any open questions remaining of our cost estimates are answered.
### GLAD800 Cost Estimate

**Principal Investigator:** Julie Brigham-Grette  
**Project Name:** Lake El’gygytgyn  
**Number of Sites:** Holes/Site:  
**Water Depth:** 175 m  
**Sample Depth:** 750 m

<table>
<thead>
<tr>
<th>Item</th>
<th>Units</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Project Preparation</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Site Visit</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Equipment preparation</td>
<td>10</td>
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<tr>
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<tr>
<td>Visas and work permits</td>
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<tr>
<td>Health/innoculations</td>
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<td><strong>Equipment</strong></td>
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<td>Drill bits</td>
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<td></td>
</tr>
<tr>
<td>Trucking</td>
<td>6</td>
<td>$7,800</td>
</tr>
</tbody>
</table>
| Shipping                  |       | $-
| Customs                   | 1     | $195,000 |
| Crew transportation       | 10    | $32,500 |
| Forklift rental           | 2     | $650  |
| Crane rental              | 2     | $3,900 |
| **Drilling Operations**   |       | $612,755 |
| Unload containers          | 2     | $11,206 |
| Transport to site #1       | 5     | $28,015 |

**Total Cost:** $612,755
<table>
<thead>
<tr>
<th>Description</th>
<th>Quantity</th>
<th>Rate</th>
<th>Amount</th>
</tr>
</thead>
<tbody>
<tr>
<td>Drill 1a 500 m mud</td>
<td>20</td>
<td>$7,361.25</td>
<td>$147,225</td>
</tr>
<tr>
<td>Drill 1b 500 m mud</td>
<td>20</td>
<td>$7,361.25</td>
<td>$147,225</td>
</tr>
<tr>
<td>Change to diamond coring</td>
<td>1</td>
<td>$7,361.25</td>
<td>$7,361</td>
</tr>
<tr>
<td>Core breccia (100 m)</td>
<td>6</td>
<td>$7,361.25</td>
<td>$44,168</td>
</tr>
<tr>
<td>Move to site #2</td>
<td>2</td>
<td>$5,603.00</td>
<td>$11,206</td>
</tr>
<tr>
<td>Drill 2a 600 m</td>
<td>24</td>
<td>$7,361.25</td>
<td>$176,670</td>
</tr>
<tr>
<td>Drill 2b 600 m</td>
<td>24</td>
<td>$7,361.25</td>
<td>$176,670</td>
</tr>
<tr>
<td>Change to diamond coring</td>
<td>1</td>
<td>$7,361.25</td>
<td>$7,361</td>
</tr>
<tr>
<td>Core breccia (100 m)</td>
<td>6</td>
<td>$7,361.25</td>
<td>$44,168</td>
</tr>
<tr>
<td>Move to site #3</td>
<td>2</td>
<td>$5,603.00</td>
<td>$11,206</td>
</tr>
<tr>
<td>Drill site 3 to 200 m</td>
<td>8</td>
<td>$7,361.25</td>
<td>$58,890</td>
</tr>
<tr>
<td>Pack containers</td>
<td>4</td>
<td>$5,603.00</td>
<td>$22,412</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td><strong>125</strong></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td><strong>$893,783</strong></td>
</tr>
</tbody>
</table>

**Demobilization**

<table>
<thead>
<tr>
<th>Description</th>
<th>Quantity</th>
<th>Rate</th>
<th>Amount</th>
</tr>
</thead>
<tbody>
<tr>
<td>Forklift rental</td>
<td>2</td>
<td>$325.00</td>
<td>$650</td>
</tr>
<tr>
<td>Crane rental</td>
<td>2</td>
<td>$1,950.00</td>
<td>$3,900</td>
</tr>
<tr>
<td>Shipping</td>
<td>1</td>
<td>$9,100.00</td>
<td>$9,100</td>
</tr>
<tr>
<td>Trucking</td>
<td>6</td>
<td>$1,300.00</td>
<td>$7,800</td>
</tr>
<tr>
<td>Crew transportation</td>
<td>10</td>
<td>$3,250.00</td>
<td>$32,500</td>
</tr>
<tr>
<td>Unpack</td>
<td>1</td>
<td>$13,000.00</td>
<td>$13,000</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td><strong>$66,950</strong></td>
</tr>
</tbody>
</table>

Subtotal: **$1,573,488**  
Administrative, Insurance 25.0%: **$393,372**  
Total: **$1,966,859**
Friday, January 14, 2005

Dr. Julie Brigham-Grette  
Department of Geosciences  
University of Massachusetts, Amherst  

Dear Julie-  

VECO Polar Resources, in our role as the National Science Foundation’s Arctic logistics Contractor, has received and reviewed the logistics requirements for your proposed collaborative drilling project at Lake El’Gygytgyn. At your request, we have prepared a logistics budget for submission with your proposal to the International Continental Drilling Program.  

Though this estimate covers the entire logistics budget, we understand that the actual field logistics may likely be funded and implemented by a number of different organizations that are participating in the collaborative. We look forward to working with you, your collaborators, and the pertinent Program Officers at NSF to determine what part of the logistics program VPR will undertake if your proposal is funded.  

Best of luck,  

Diana Garcia-Novick  
Planning Manager  
720.320.6156  

Attachments:  

Budget Estimate
# Budget Estimate - VPR support of Brigham-Grette, et al., Lake E' Drilling Proposal

<table>
<thead>
<tr>
<th>Item</th>
<th>2005</th>
<th>2006</th>
<th>2007</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flights CONUS &gt; Moscow &gt; Pevek</td>
<td>2 RT</td>
<td>4 RT</td>
<td>2 RT</td>
<td>8 RT</td>
</tr>
<tr>
<td>Site Visit</td>
<td>2005 $24,000</td>
<td>2006 $</td>
<td>2007 $</td>
<td>$24,000</td>
</tr>
<tr>
<td>Gear Shipping &amp; Sample Return to/from Moscow</td>
<td>2 RT</td>
<td>2 RT</td>
<td>2 RT</td>
<td>6 RT</td>
</tr>
<tr>
<td>Transport: CONUS to/from St. Petersburg</td>
<td>11 containers</td>
<td>6 containers day</td>
<td>20' ISO Containers</td>
<td>8 each</td>
</tr>
<tr>
<td>Gear Shipping/Sample Return to/from Lake E</td>
<td>4 MD3 Helicopter flights</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>20' ISO Containers</td>
<td>3x 20' container</td>
<td>22 RT</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
| grandma & travel were made using worst case scenario - chartered IL86 flights from/to St. Petersburg and MI26 from/to Pevek.

## Transportation Costs
- Flights CONUS > Moscow > Pevek
- Site Visit
- Gear Shipping & Sample Return to/from Moscow
- Transport: CONUS to/from St. Petersburg
- Gear Shipping/Sample Return to/from Lake E
- 20' ISO Containers
- grandma & travel were made using worst case scenario - chartered IL86 flights from/to St. Petersburg and MI26 from/to Pevek.

## Camp Costs
- Warm workspace @ drill site
- Bath/Laundry facilities
- Outhouse facilities
- On-shore lab space/toomrm/room manager's office
- Cook/mess tent to seat 20

## Overall Cost
$39,600 $841,914 $1,780,574 $2,662,088

## Assumptions
1. Outyears include 3% increase for inflation for non-Russian procured goods. 11% increase within Russia beginning 2006
2. Gear shipment costs to/from Lake E were made using worst case scenario – chartered IL86 flights from St. Petersburg and MI26 from to Pevek.
3. Camp size estimate of 13 scientists, 10 drillers, 6 crew = 39 personnel for drilling period. Additionally 10 crew will be required during set-up/tear-down
4. Per-week time-dependent costs for this camp are $16,023.40

Prepared by Polar Field Services, Inc.
for VECO USA, Inc.
## Pre-drilling costs and Equipment

<table>
<thead>
<tr>
<th>Item</th>
<th>Quantity</th>
<th>Price per</th>
<th>Total Price</th>
</tr>
</thead>
<tbody>
<tr>
<td>Core boxes</td>
<td>800</td>
<td>$12,00</td>
<td>$96,000</td>
</tr>
<tr>
<td>Each box contains 4 cores</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Waxed inside and out.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.55m x 15 cm x 15 cm</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Shipping of boxes</td>
<td>1</td>
<td>$600,00</td>
<td>$600,00</td>
</tr>
<tr>
<td>Boxes shipped by ground to</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Utah and included in DOSECC</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>shipment</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pallets</td>
<td>31</td>
<td>$65,00</td>
<td>$2,015,00</td>
</tr>
<tr>
<td>Pallets will be 1.6 x 1.6 m</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>square holding five core</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>boxes per level with three</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>levels maximum.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pallet Strapping</td>
<td>1</td>
<td>$350,00</td>
<td>$350,00</td>
</tr>
<tr>
<td>Pallet Shelving</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$500,00 Done locally</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$13,065,00</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

## On-Ice core processing Items

<table>
<thead>
<tr>
<th>Item</th>
<th>Price</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hand Drill</td>
<td>$250,00</td>
</tr>
<tr>
<td>Pipe Cutter</td>
<td>$100,00</td>
</tr>
<tr>
<td>Hacksaw</td>
<td>$30,00</td>
</tr>
<tr>
<td>Buckets</td>
<td>$30,00</td>
</tr>
<tr>
<td>Cleaning Supplies</td>
<td>$70,00</td>
</tr>
<tr>
<td>Acetone</td>
<td>$60,00</td>
</tr>
<tr>
<td>Squeeze Bottles</td>
<td>$20,00</td>
</tr>
<tr>
<td>Duct Tape</td>
<td>$200,00</td>
</tr>
<tr>
<td>Electrical Tape</td>
<td>$60,00</td>
</tr>
<tr>
<td>Marking Pens</td>
<td>$75,00</td>
</tr>
<tr>
<td>Tape Measures</td>
<td>$70,00</td>
</tr>
<tr>
<td>Gloves</td>
<td>$300,00</td>
</tr>
<tr>
<td>Hard Hats</td>
<td>$300,00</td>
</tr>
<tr>
<td>Misc. Tools</td>
<td>$200,00</td>
</tr>
</tbody>
</table>

**total = USD $1,765,00**
### Cost Breakdown for OSG Logging: Lake El'gygytgyn

ICDP Project  
Personel on-site only for logging sessions (total 20 d)

<table>
<thead>
<tr>
<th>Item</th>
<th>Single Costs /EUR</th>
<th>Job param.</th>
<th>Sub-totals /EUR</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of days for personnel (incl. stand-by &amp; travel)</td>
<td>20</td>
<td></td>
<td></td>
</tr>
<tr>
<td>No. of people</td>
<td>3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Transportation effort: short = 2, long = 1</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>DLL slim</td>
<td>1050</td>
<td>1</td>
<td>1050</td>
</tr>
<tr>
<td>SGR slim</td>
<td>900</td>
<td>1</td>
<td>900</td>
</tr>
<tr>
<td>BS slim</td>
<td>950</td>
<td>1</td>
<td>950</td>
</tr>
<tr>
<td>DIP/MAG slim</td>
<td>2150</td>
<td>1</td>
<td>2150</td>
</tr>
<tr>
<td>MSdH slim</td>
<td>600</td>
<td>1</td>
<td>600</td>
</tr>
<tr>
<td>T/P slim</td>
<td>300</td>
<td>1</td>
<td>300</td>
</tr>
<tr>
<td>FAC40 slim</td>
<td>300</td>
<td>1</td>
<td>300</td>
</tr>
<tr>
<td>FS slim</td>
<td>1000</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>MP</td>
<td>250</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>DIL</td>
<td>250</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>BCS</td>
<td>250</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>SGR</td>
<td>250</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>MSFL</td>
<td>250</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>SP-Redox</td>
<td>500</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>BG250/125</td>
<td>500</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>BGST</td>
<td>1500</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Transport / Insurance</td>
<td>6000</td>
<td>1</td>
<td>6000</td>
</tr>
<tr>
<td>Supplies onsite</td>
<td>0</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Travel EUR/person</td>
<td>2000</td>
<td>1</td>
<td>6000</td>
</tr>
<tr>
<td>Expenses EUR/day/person</td>
<td>42</td>
<td>1</td>
<td>2520</td>
</tr>
<tr>
<td>Hotel costs EUR/day/person</td>
<td>0</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Rental car etc.</td>
<td>0</td>
<td>1</td>
<td>0</td>
</tr>
</tbody>
</table>

Transport, Travel & hotel costs will be charged by the actual costs.  
Expenses will be charged by the actual no. of days.

| External personnel EUR/day | 500 | 0 | 0 |
| GFZ engineer EUR/day       | 450 | 1 | 0 |
| GFZ technician EUR/day     | 350 | 1 | 0 |

**Total** 20770
### CONSOLIDATED ESTIMATION OF COSTS
of drilling operations to be conducted on the Elgygydgyn Lake

<table>
<thead>
<tr>
<th>No.</th>
<th>Estimate chapter No.</th>
<th>Denomination of costs</th>
<th>Cost, thousands rubles</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Chapter 1</td>
<td>Development of design estimates for drilling operations, technology and equipment</td>
<td>436.098</td>
</tr>
<tr>
<td>2</td>
<td>Chapter 2</td>
<td>Construction of living facilities and drilling equipment</td>
<td>897.176</td>
</tr>
<tr>
<td>3</td>
<td>Chapter 3</td>
<td>Drilling rig rent</td>
<td>2150.503</td>
</tr>
<tr>
<td>4</td>
<td>Chapter 4</td>
<td>Acquisition of standard equipment, materials, tools</td>
<td>10638.785</td>
</tr>
<tr>
<td>5</td>
<td>Chapter 5</td>
<td>Drilling operations</td>
<td>76632.00</td>
</tr>
<tr>
<td>6</td>
<td>Chapter 6</td>
<td>Logging operations</td>
<td>597.39</td>
</tr>
<tr>
<td></td>
<td><strong>Total:</strong></td>
<td></td>
<td><strong>91351.00</strong></td>
</tr>
</tbody>
</table>

General Director  
FGUP NPC Nedra / Bilal N. Khakhaev
## CHAPTER 1

### Development of design estimates for drilling operations, technology and equipment

<table>
<thead>
<tr>
<th>No.</th>
<th>Denomination of costs</th>
<th>Cost, thousands rubles</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Project development (geological part, technical part)</td>
<td>28.254</td>
</tr>
<tr>
<td>2</td>
<td>Hardware and drilling technology of 800m deep-water well drilling project development</td>
<td>167.258</td>
</tr>
<tr>
<td>3</td>
<td>Making up an estimate</td>
<td>14.778</td>
</tr>
<tr>
<td>4</td>
<td>Development of drilling head for soft sediments</td>
<td>9.019</td>
</tr>
<tr>
<td>5</td>
<td>Development of drilling head for drilling of breccias</td>
<td>17.358</td>
</tr>
<tr>
<td>6</td>
<td>Development of drilling mud composition and methods of mud parameters regulation</td>
<td>15.531</td>
</tr>
<tr>
<td>7</td>
<td>Development of technique that allows prevention of ice thawing under drilling rig during the process of drilling</td>
<td>19.115</td>
</tr>
<tr>
<td>8</td>
<td>Development of design documentation for core receiving device meant for deep-water wells drilling</td>
<td>43.862</td>
</tr>
<tr>
<td>9</td>
<td>Development of project for arrangement of the area providing self-sufficiency of deep-water well drilling</td>
<td>62.145</td>
</tr>
<tr>
<td>10</td>
<td>Field supervision over project implementation</td>
<td>58.773</td>
</tr>
<tr>
<td></td>
<td><strong>Total:</strong></td>
<td><strong>436.098</strong></td>
</tr>
</tbody>
</table>

## CHAPTER 2

### Construction of living facilities and drilling equipment

<table>
<thead>
<tr>
<th>No.</th>
<th>Denomination of costs</th>
<th>Cost, thousands rubles</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Development of hydropercussion mechanism for core receiver to ensure core recovery from rocks with increased density</td>
<td>65.708</td>
</tr>
<tr>
<td>2</td>
<td>Production of tentative drilling tools, incl.:</td>
<td>167.258</td>
</tr>
<tr>
<td></td>
<td>- hydraulic reamer RL-212.7/300</td>
<td>59.735</td>
</tr>
<tr>
<td></td>
<td>- aluminc riser string</td>
<td>305.8</td>
</tr>
<tr>
<td></td>
<td>- corer UKSB 178/66-79</td>
<td>310.622</td>
</tr>
<tr>
<td></td>
<td>- plastic liners</td>
<td>155.311</td>
</tr>
<tr>
<td></td>
<td><strong>Total:</strong></td>
<td><strong>897.176</strong></td>
</tr>
</tbody>
</table>

## CHAPTER 3

### Drilling rig and component equipment rent

<table>
<thead>
<tr>
<th>No.</th>
<th>Denomination of costs</th>
<th>Cost, thousands rubles</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Drilling rig and component equipment rent</td>
<td>2150.503</td>
</tr>
<tr>
<td></td>
<td><strong>Total:</strong></td>
<td><strong>2150.503</strong></td>
</tr>
</tbody>
</table>
### CHAPTER 4
Acquisition of standard equipment, materials, tools

<table>
<thead>
<tr>
<th>No.</th>
<th>Denomination of costs</th>
<th>Cost, thousands rubles</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Acquisition of standard equipment, materials and tools required for well drilling</td>
<td>384.535</td>
</tr>
<tr>
<td>2</td>
<td>Acquisition of K 212.7/80 St drilling heads</td>
<td>396.000</td>
</tr>
<tr>
<td>3</td>
<td>Acquisition of bits for continuous drilling</td>
<td>630.000</td>
</tr>
<tr>
<td>4</td>
<td>Acquisition of upper spinner with 80 t load capacity</td>
<td>1680.000</td>
</tr>
<tr>
<td>5</td>
<td>Acquisition of drill pipes with flush join LBT-147/13</td>
<td>1980.000</td>
</tr>
<tr>
<td>6</td>
<td>Acquisition of UBT-178</td>
<td>600.000</td>
</tr>
<tr>
<td></td>
<td>Expenses for transportation and purchasing of materials and equipment</td>
<td>1308.250</td>
</tr>
<tr>
<td>7</td>
<td>Acquisition of creeper tractor to provide communication between housing estate and drilling site</td>
<td>1300.00</td>
</tr>
<tr>
<td>8</td>
<td>Acquisition of snowmobile to provide efficiency of work</td>
<td>600.00</td>
</tr>
<tr>
<td>9</td>
<td>Acquisition of two electric power plants with 200 kW output</td>
<td>1280.00</td>
</tr>
<tr>
<td>10</td>
<td>Acquisition of two electric power plants with 50 kW output (in order to provide housing estate and drilling complex with electric power in case of emergency)</td>
<td>480.00</td>
</tr>
<tr>
<td>11</td>
<td>Acquisition of satellite communication</td>
<td></td>
</tr>
</tbody>
</table>

**Total:** 10638.785

### CHAPTER 5
Drilling operations

<table>
<thead>
<tr>
<th>No.</th>
<th>Denomination of costs</th>
<th>Cost, thousands rubles</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Charges for assembling and disassembling of drill derrick and near-derrick installations, mounting and dismounting of drilling equipment</td>
<td>1032.00</td>
</tr>
<tr>
<td>2</td>
<td>Drilling of two 800 m deep wells and one 200 m deep well</td>
<td>75600.00</td>
</tr>
</tbody>
</table>

**Total:** 76632.00

*Current drilling market cost — 1500 US dollars/rm

### CHAPTER 6
Logging operations

<table>
<thead>
<tr>
<th>No.</th>
<th>Denomination of costs</th>
<th>Cost, thousands rubles</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Logging operations</td>
<td>597.39</td>
</tr>
</tbody>
</table>

**Total:** 597.39
P.S.

I. The preliminary estimate does not include the costs related to:
   1. Transportation of dwelling units, drilling equipment and materials from Yaroslavl to
      the place of wells construction and back.
   2. Production of facilities.
   3. Construction and disassembling of facilities.
   4. Acquisition and servicing of means of communication.

II. Total weight of drilling equipment and materials required to drill three wells is 293.5 t.

III. Number of drilling and coring specialists is 23.
Appendix 2  Management Plan

Appendix 2.1 Science Management

Based on the collective discussions at our ICDP workshop, a Science Management Team has been effectively established since 2001 and charged with the following responsibilities to:

- Coordinate all aspects of Principle investigators and new PIs
- Oversee the Operations Management Team (below)
- Proactively facilitate agreements and government relations
- Proactively seek avenues for useful public relations
- Oversee implementation of data management, web site development
- Coordinate sample distribution and publication output.

Membership of the Science Management Team includes

- Julie Brigham-Grette (USA)
- Martin Melles (Germany)
- Pavel Minyuk (Russia)
- Christian Koeberl (Austria)

Appendix 2.2 Operations Management

Large multinational projects typically rely on an operations management team to focus on all aspects of the logistical issues associated with mobilizing equipment, personnel, and core samples to/from the drill site. This proposal is configured to rely on the services of VECO Polar Resources (www.vecopolar.com) who manage all Arctic logistics for the U.S. National Science Foundation. The VECO logistics contractor will work closely with the Operations Manager to implement the planned movements of cargo, people and goods. Due to the complexities of operating in Russia, and the urgent need to get certain permitting and customs issues initiated, we have elected to secure alternative funding for an experienced Russian Operations Manager (Ops Manager) to start activities on behalf of the project as early as March, 2005. Both the University of Massachusetts-Amherst and the Alfred Wegener Institute administrations have agreed to co-fund the operations manager for one year (letters of support, appendices 8.1 and 8.2). This manager will be affiliated with the Otto Schmidt Laboratory, a Russian-German institution located at AARI-St. Petersburg with a long track record of success in difficult arctic logistics and in navigating the maze of permitting and
customs regulations among the various agencies. VECO and the Ops Manager will both work intimately with the Drilling Manager (e.g., Dennis Neilson and DOSECC). These three individuals will constitute the Operations Management Team and respond to the needs of the Science Management Team (outlined above) with oversight by participating funding agencies. Borrowing from the model set up for the Cape Roberts Project in Antarctica, the Operation Management team could involve periodic contact with representatives on behalf of

- Russian Ministry of Industry and Science;
- Russian Academy of Sciences;
- Russian Foundation for Basic Research;
- Chukotka Governor Roman Abramovich;
- German Federal Ministry of Education and Research;
- US National Science Foundation (Simon Stephenson and Program managers)
- US NASA;
- ICDP Executive Committee.

The Operations Management Team will supervise most aspects of the following issues:

- Transport weight;
- Ice strength studies;
- Drill target dates;
- Personnel travel and visas;
- Building requirements;
- Safety;
- Camp housing and Food supplies;
- Mud/Rock Core storage and shipping;
- Fuel;
- Transport methods: Planes/helicopters, shipping, cat train;
- Permits;

It should be noted that the PIs continue take seriously the need for coordination between the drilling operators and the science team. This past August, 2004, post-doc Olaf Juschus, Leipzig, participated in the ICDP drilling workshop held at Lake Bosumtwi on the GLAD 800.
Appendix 2.3 Collaborators

Patricia M. Anderson, University of Washington – palynology

Dimitry Bolshiyanov, Arctic and Antarctic Research Institute – geomorphology

Julie Brigham-Grette, University of Massachusetts – stratigraphy, sedimentology

Steven Burns, University of Massachusetts – isotope geochemistry

Charles Cockell, SETI Institute/NASA Ames – impact microbiology

Holger Cremer, University of Utrecht, The Netherlands – diatoms

Marina Cherepanova, Biology and Soil Science FEB RAS – diatoms

Charles Cockell, Open University – geomicrobiologist/astrobiologist

Bernhard Diekmann, Alfred Wegener Institute, Potsdam – XRF scanner

Tim Eglington, Woods Hole Oceanographic Inst. – organic geochemistry, dating

Grigory Federov, Arctic and Antarctic Research Institute – geomorphology

Steve Forman, University of Illinois at Chicago – luminescence dating

Pierre Francis, University of Montreal – microstratigraphy, sedimentology

Michal Gasiorowski, Polish Academy of Science, Warsaw – Crustacea/Cladocera

Catalina Gebhardt, Alfred Wegener Institute, Bremerhaven – physical properties

Olga Yu. Glushkova, NEISRI Magadan – geomorphology


Sabine Hanisch, Alfred Wegener Institute, Bremerhaven – biomarker

Ulrich Harms, International Continental Drilling Program – downhole measurements

Hans Hubberten, Alfred Wegener Institute-Potsdam – permafrost

Olaf Juschus, University Leipzig – paleolimnology

Christian Koeberl, University of Vienna – impact science

Conrad Kopsch, Alfred Wegener Institute-Potsdam – geophysical surveys

Scott Lamoureux, Queen's University, Ontario – paleohydrology

Jan Lange, Museum for Mineralogy and Geology, Dresden – fission track dating

Isabelle Larocque, Institut National de la Recherche Scientifique, Québec – chironomids

Isabelle Laurion, Institut National de la Recherche Scientifique, Québec – bio-optic

Paul Layer, University of Alaska Fairbanks – bedrock stratigraphy

Bernard Long, NEISRI Magadan – palynology

Anatoly Lozhkin, NEISRI Magadan – palynology

Tatiana Matrosova, NEISRI Magadan – palynology

Martin Melles, University Leipzig – paleolimnology

Pavel Minyuk, NEISRI Magadan – paleomagnetics, rock magnets

Norbert Nowaczyk, GFZ-Potsdam – paleomagnetics

Frank Niessen, Alfred Wegener Institute Bremerhaven – seismic stratigraphy, logging

Matt Nolan, University of Alaska Fairbanks – lake hydrology, remote sensing

Steven Petsch, University of Massachusetts – organic geochemistry

Reinhard Pienitz, Université Laval, Quebec – diatoms

Frank Preusser, Institute of Biological Sciences, Bern, Switzerland – dating

Marc Richer-Lafleche, Institut National de la Recherche Scient., Québec – lead isotopes

Vladimir Sakhno, Far East Geological Institute, RAS, Vladivostok – Tephra Layers

Lutz Schirrmester, Alfred Wegener Institute-Potsdam – permafrost

Georg Schwamborn, Alfred Wegener Institute-Potsdam – permafrost

Vladimir Smirnov, NEISRI, Magadan – mineralogy, geomorphology

David B. Stone, University of Alaska – paleomagnetics and gravity

Jeffrey Synder, Bowling Green University, – diatom stratigraphy

Dirk Wagner, Alfred Wegener Institute Potsdam – microbiology

Warwick Vincent, Université Laval, Québec – bio-optic

Local Collaborators – Pevek Airport, Chukotka Mining Company
Appendix 3

Last year at this time, we submitted a pre-proposal to the ICDP and the proposal was very highly ranked by the Science Advisory Group. As a result, the Executive Officers of the ICDP encouraged us to move forward with a full proposal this year. One of the caveats was the requirement that we secure some high level confirmation of approval of the project “in principle” from agencies in the Russian Government and agreements between countries. In September, Melles (University of Leipzig, Germany), Bolshiyanov (AARI-St. Petersburg), and Brigham-Grette (UMass) met or made contact in Moscow with several leaders from the Russian Academy of Sciences (RAS), Roshydromet (NOAA-like agency), the Earth Sciences Director of the Russian Foundation for Basic Research, the Ministry of Natural Resources, the Ministry for Science and Education and Alexander Borodin, a close advisor to Chukokta’s Governor Abramovich. We know we also have the support of the Chairman of the Far East Branch of the Russian Academy of Sciences (Academician Valentin Sergienko) as well as that of the directors of the Russian institutes who are partners in the project i.e., The Arctic and Antarctic Research Institute – St. Petersburg (AARI, under Roshydromet), and the North East Interdisciplinary Scientific Research Institute - Magadan (NEISRI, under RAS).

Appendix 3.1 Russian-German Agreements

For nearly 10 years a bilateral science agreement for shared research has existed between the Ministry for Industry, Research and Technology of the Russian Federation and the German Federal Ministry for Education and Research (BMBF). This protocol, titled, Agreement on Collaboration in the Fields of Marine and Polar Research, has supported annual meetings, at which time the projects and interests of both sites are discussed, listed, and agreed upon. Scientists routinely distribute documents describing project progress to the Ministries at this meeting and it is clear that the Lake El’gygytgyn Project has been continuously included on the list of joint projects since 1999. The last (and 9th) meeting of representatives from both ministries took place on the island Helgoland, Germany, in December, 2003 at which time Melles was invited to give a presentation on the El’gygytgyn project; this meeting was chaired by R. Ollig (BMBF) and V.N. Zhivago (Russian Ministry).
The next (10th) meeting of the Russian and German ministries concerning agreements for future projects is scheduled for sometime early in 2005. It is our understanding that the Lake El’gygytgyn Project will remain a high priority project among the list of projects in the protocol. The details of the overall agreements are confidential, however, the German BMBF (Barbara Tanner) has indicated that confirmation of the agreement involving Lake El’gygytgyn can be forwarded to the ICDP upon request.

Appendix 3.2 Russian-American Agreements

During our visit to Moscow last September, it was the recommendation of Dr. Vladimir Lapshin (new in Earth Sciences, Russian Foundation for Basic Research; RFBR) and Dr. Boris Levin (formerly of RFBR, now Director of the RAS Sakhalin Science Center) as well as that of Dr. Valarie Martyschenkov (Roshydromet) that we seek some high level agreement (Memorandum of Understanding, or MOU) between the USA and Russia for the El’gygytgyn Project to serve in parallel with the Russian-German agreement for collaborative science. Based upon discussions with program managers in the Office of Polar Programs (OPP) at the US National Science Foundation (NSF), it was suggested that we seek adaptation of the El’gygytgyn Project under the diplomatic umbrella of an existing MOU between the RAS and NOAA (National Oceanographic and Atmospheric Administration). This document was signed in December, 2003 by Vice-Admiral Lautenbacher (NOAA) and Vice-President Lavyerov (RAS) and embraces themes of “Arctic Climate change” including NSF related science. Conversations with Kathy Crane, in the NOAA Arctic office, Washington D.C., in early December 2004 confirmed that placing the Lake El’gygytgyn project under this MOU, in her opinion, would be appropriate. It is our understanding that subsequent to that, Crane and John Calder (Director of the NOAA Arctic Research Office) were in Moscow in mid-December when Lake El’gygytgyn came up in their informal discussions with Vice President Lavyerov. Written confirmations from Russia and the USA placing the El’gygytgyn Project within the protocols of the MOU between NOAA and the RAS are pending as of January 15, 2005. Dr. Thomas Pyle, Section Head for Arctic Programs in NSF-OPP, working in collaboration with John Caldor at NOAA are expected to agree to this recognition. A letter to the PIs from Academician Lavyerov is also anticipated in the near future. We will send this letters to the ICDP office as soon as they arrive.
Appendix 3.3 Permitting for Drilling at Lake El’gygytgyn

We anticipate that parallel bilateral science agreements in Russia will allow us to move forward with access, science, sampling, and land use permits for drilling at Lake El’gygytgyn. Personnel clearances, communications and any routine, yet necessary military/customs clearances will be pursued by the Science Team, in collaboration with the Operations Manager as deemed appropriate based on collective experience during previous expeditions in Russia.
Appendix 4  Membership of Russia in ICDP

The Russian government is not currently a member of the ICDP, however, its membership in the near future may significantly enhance and expedite our efforts in acquiring proper permitting and customs clearance. Moreover, membership will also have benefits for Russian scientists collaborating in ICDP projects. Over the past year, our Russian colleagues have initiated conversations about membership within the Russian Academy of Sciences (RAS). It is our understanding that an encouraging letter concerning membership was sent by the Vice President of the RAS, Academician N.P Lavyerov, to Academician V.I. Sergienko, Chairman of the Far East Branch of the RAS, in early May 2004. At the urging of Uli Harms, ICDP, we extended an invitation to Academician Lavyerov to visit the ICDP to discuss possible membership during our September diplomatic trip to Moscow. It is our understanding that Academician Lavyerov will be invited among other dignitaries to the 10th Anniversary Conference of the ICDP at the end of March, 2005.
Appendix 5 Environmental Impact Reviews

Lake El’gygytgyn and its catchment is protected by Russian law as a unique national treasure and considered a “geological monument of nature” according to Law N41-03 of the Duma (Congress) of the Chukotka Autonomous Region (enacted 27 October, 1997). In addition, the region of Lake El’gygytgyn is included in the conceptual framework of a bilateral Beringia National Park, established to exist from 2001 to 2010 in collaboration with the US National Park Service, by special order of the Government of the Russian Federation (Law N 725-r, enacted 23 May 2001).

Such designations require that the Science Management Team obtain access-permissions from the Agency on Protection of Environments of the Chukotka Autonomous Region (Ecology Committee of Chukotka). Permits for access will require documentation that the drilling can be carried out without influencing the regional ecology. This will require a detailed description of the drilling methods, all technical characteristics of the fieldwork, and a comprehensive list of safety precautions, accident prevention measures, and human waste controls to be implemented. The North East Interdisciplinary Scientific Research Institute (NEISRI, PI-Minyuk’s home institution) has obtained the access-permissions for our past field work on Lake El’gygytgyn (including shallow coring and geophysical surveys), and agreed to assist us with the preparation of the necessary documents for the Deep Drilling operation.
Appendix 6  Scientific Rationale for Drilling (Impact Research)

This seismic information available so far has helped to define the best locations for drilling, i.e., those that will allow us to satisfy the goals of the two main aspects of the drilling program (paleoenvironmental studies and impact-cratering studies). The requirements of the impact studies and the post-impact sediment studies are somewhat different, but overlapping. From the point of view of the impact studies, it is desirable to obtain a continuous drillcore to a maximum depth of about 0.8 – 1 km below lake surface. The most desirable location is near, but not exactly centered over, the central uplift (somewhat offset from the center of the central uplift, towards an intermediate position between the center of the central uplift and the deepest part of the crater fill, between the central uplift center and what might be called the “crater moat”). Besides a near-central sedimentological record, this hole should provide information on fall-back (crater-fill) impact breccias, melt rocks that are expected to be in situ, breccias and melt rocks that are located above the central uplift, but also penetrate (at least) the upper parts of the central uplift into less disturbed target rocks. This will provide important new information on deposition of impact breccias in the region of central uplifts of moderately sized, complex impact structures, which to date is limited to recent studies from the Bosumtwi crater in Ghana. In addition, the upper parts of the central uplift will be drilled and detailed deformation studies of basement material, with regard to both shock and thermal metamorphic effects and their respective distributions, will be possible. Dike breccias, impact-produced in situ or injected, may be intersected and become accessible to analysis; their genesis and classification has been the subject of some controversy in recent years. In addition to study of the contact metamorphic effects below crater-fill breccias, it may be possible to investigate hydrothermal effects caused by the impact event. Data from these studies will also improve the general understanding of fluid movement in impact structures, which has recently proven to be of interest in astrobiology, especially for the study of Mars analogs. In addition, hot brines in a post-impact situation may provide an unique oasis for life forms, and for returning life after the devastating impact event. Evaluation of borehole geophysical data will allow to provide ground truth for the existing geophysical studies done from the surface.

At the suggested location the water depth is 170 m, the lower limit of the post-impact crater-fill lake sediments is at about 450 – 500 m (below lake surface), below which a brecciated zone occurs (probably also containing melt rocks and impact glasses), and the interface between the fallback breccia and the fractured, brecciated and uplifted rocks of the
centeral uplift is expected at about 600 to 700 m depth. From there on it is desirable to drill at least another 100 m into the uplifted tareget rocks, resulting in a minimum core depth of 800 m, preferably to 1000 m. This is well within the capabilities of the GLAD-800 in its upgraded version.

Standard downhole logging, especially within the breccia and bedrock sequence, is desirable, using the ICDP slimline tools. These tools performed extremely well during logging operations at the Bosumtwi crater in Ghana in 2004.
Table 3: El’gygytgyn Crater Drilling: Goals from the Impact Perspective

**IMPORTANCE OF EL’GYGYTGYN**
- One of the largest young impact structures known on Earth, fairly well preserved
- Only impact structure on Earth in siliceous volcanics
- All pre-drilling site surveys already finished
- Contains abundant impact glass bombs (re-melted from volcanics)
- Can be compared with the slightly smaller and younger Bosumtwi crater in Ghana (in metasediments)

**DRILLING PROGRAM GOALS**

**CRATER MORPHOLOGY AND GEOMETRY STUDIES**
- Determine crater depth (apparent and to basement)
- Determine exact location and structure of central uplift
- Characterize target stratigraphy (central uplift stratigraphy)
- Measure post impact modification processes and effects (e.g., slumping)

**STUDY OF CRATER FILL BRECCIA AND MELT ROCKS**
- Determine if melt rocks are present in crater fill
- Quantification of melt volume and breccia volume
- Origin of various impact breccias, constraints on cratering process
- Determine source rocks for impact glass bombs and breccias found as float samples within crater
- Search for meteoric component in crater-fill breccia and melt rocks
- Determine meteorite type
- Occurrence of dyke breccias / pseudotachylitic breccias
- Comparison between fall-out and fall-back breccias
- Refine crater age from dating of impact melt
- Internal breccia stratigraphy
- Study clast population
- Melt breccias occurrence and distribution
- Origin of melt rocks
- Search for 0.8 Ma Australasian tektite (microtektite) occurrences in crater-fill sediments

**GEOPHYSICAL STUDIES**
- Provide ground-truth for inferences drawn from previous aeromagnetic and other geophysical studies
- Petrophysical data for interpretation of gravity and magnetic models and seismic studies
- Obtain boundary conditions for modelling calculations

**SHOCK METAMORPHISM STUDIES**
- Study of shock deformation within central uplift, including crater floor (= shock barometry)
- Distribution through core of different grades of shock metamorphism: origin of ejecta clasts/melt, implications for cratering physics
- Search for impact diamonds
- Search for shocked zircons
- Paleomagnetic study of shocked rocks and melts

**STUDY OF POST-IMPACT EVENTS**
- Search for possible evidence of other <1 Ma impact events (Australasian tektites) in post-impact sediments
- Study the interface between fall-back breccia and lake-fill sediments
- Study possible post-impact hydrothermal system
- Examine hydrothermal mineralogy and isotope systematics
- Metamorphic as well as hydrothermal overprint on crater floor and sub-crater strata
- Thermal profile of post-impact heating
- Search for chemical/fossil evidence of post-impact life forms
- Astrobiological implications (extreme environments and extremophiles)
- Implications for regional impact-induced destruction and localized trauma to living systems
- Climatic influences from impact-event
**EXPRESSION OF INTENT**
FOR ACTIVITIES IN IPY 2007-2008.

Deadline for Submission - January 14, 2005
Email to jcel@bas.ac.uk or Fax to +44-1223-221270

1.0 PROPOSAL INFORMATION

1.1 Title of proposed activity

Deep Drilling at Elgygytgyn Crater Lake, Northeastern Siberia, Russia

1.2 Acronym or short form title of proposed activity

Lake Elgygytgyn Deep Drilling

1.3 Concise outline of proposed activity

Lake Elgygytgyn, located in central Chukotka, NE Russia, is a 3.6 million year old impact crater lake with a diameter of 12 km and a water depth of 170 m. During the last 6 years the sedimentary record of this remarkable lake has become the major focus of a multi-disciplinary multi-national paleoclimatic effort and is now a potential target for deep drilling. The sediment record in the crater will yield a complete unprecedented record of Arctic climate evolution, starting nearly a million years prior to the first major glaciation of the Northern Hemisphere. Our site survey confirms that the crater was never glaciated during the Late Cenozoic and that the lake sediments sensitively reflect regional and hemispheric climate change on millennial time scales. We propose a major drilling campaign to retrieve replicate cores to over 630 m to retrieve a continuous paleoclimate record from the deepest part of the lake and into the underlying impact breccias and bedrock. Studies of the impact rocks offers the planetary science community with the opportunity to study a well preserved crater uniquely found in igneous rocks like those on Mars. One additional core to 200 meters into permafrost in the surrounding catchment will allow us to test ideas about arctic permafrost history and the sediment supply to the lake since the time of impact.

Lake Elgygytgyn represents a world-class drilling target for obtaining a paleoclimate record unique to the terrestrial Arctic. Having conducted three successful expeditions to the Lake since 1998, creating strong collaborations among predominantly American, Russian and German researchers with similar goals, this project provides the ideal framework for advancing our knowledge of Arctic climate and paleoenvironmental systematics while promoting international scientific cooperation. This deep drilling effort is an important step toward assessing the environmental dynamics recorded at Elgygytgyn against other arctic and lower latitude paleoenvironmental records and toward placing them in the context of
existing knowledge concerning the impacts and responses of different regions to past and future change. This work for the IPY will place Elgytgyn into an interhemispheric context. The goals of this project are paralleled with the efforts of the science community focused on understanding modes of variability in arctic climate on millennial time scales, as well as the spatial temporal patterns and consequences of past warm arctic scenarios.
1.4 Which IPY 2007-2008 theme(s) will be addressed by the project (see Note 1)

| Theme 1 — The current state of the polar environment | Y |
| Theme 2 - Change in the polar regions | Y |
| Theme 3 - Polar-global linkages and interaction | Y |
| Theme 4 - Investigating new frontiers | Y |
| Theme 5 - The polar regions as vantage points | N |
| Theme 6 — Human societies in polar regions | N |

1.5 What is the major target of the proposed activity (specify one — see Note 1)

| Natural or social science research | Y |
| Education/Outreach and Communication | N |
| Data Management | N |
| Legacy | N |
| Other Targets | N |

1.6 What significant advance(s) in relation to the IPY themes and targets can be anticipated from this project?

The continuous 3.6 million year climate record in Lake Elgygytgyn is unique in the terrestrial Arctic. It is necessary to determine why, how and when the arctic climate system evolved from a warm forested ecosystem into a cold permafrost ecosystem in the late Pliocene. Also important is characterizing climate dynamics during the subsequent Milankovitch-driven glacial/interglacial cycles. Furthermore, higher resolution climate change events across eastern Siberia on centennial to millennial scales can be tested for atmospheric teleconnections against other long climate records worldwide. This offers insight into the conditions for permafrost stability through time, especially in the context of modern warming.

1.7 What international collaboration is involved in this project? (see Note 2)

Leading countries in this international collaboration are Russia, Germany, United States and Austria. In addition, collaborating scientists come from The Netherlands and Canada and we anticipate the participation of scientists from other countries. These participating countries include scientists from over 16 academic institutions.

2.0 FIELD ACTIVITY DETAILS

2.1 Outline the geographical location(s) for the proposed field work (see Note 3)

Lake Elgygytgyn is ca. 100 km north of the Arctic Circle at 67.30° N and 172.05° E in the Anadyr Mountains of eastern Chukotka, N.E. Russia. The lake, found some 250 km southeast of the remote village of Pevek, measures about 170 m deep and about 12 km in diameter.
2.2 Define the approximate timeframe(s) for proposed field activities?

<table>
<thead>
<tr>
<th>Arctic Fieldwork time frame(s)</th>
<th>Antarctic Fieldwork time frame(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>03/07 — 05/07</td>
<td>na</td>
</tr>
<tr>
<td>Alternatively 03/08 — 05/08</td>
<td>na</td>
</tr>
</tbody>
</table>

2.3 What significant logistic support/facilities will be required for this project? Can these resources be usefully shared with other projects? (see Note 4)

All equipment and consumables must be flown to Pevek. Further transport to the lake is only possible via helicopter and/or sled convoys in winter. If drilling takes place in 2008, then project operations would benefit from any ship operating in the Arctic Ocean supplying equipment to Pevek in summer 2007.

2.4 Will the project leave a legacy of infrastructure? (see Note 1)

No, however, we anticipate leaving remote camp facilities with the Chukotka Science Support Group for future science projects if beneficial to local authorities.

2.5 How is it envisaged that the required logistics will be secured? (one or more options can be identified)

<table>
<thead>
<tr>
<th>Option</th>
<th>Y</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>Consortium of national polar operators</td>
<td>Y</td>
<td></td>
</tr>
<tr>
<td>Own national polar operator</td>
<td>N</td>
<td></td>
</tr>
<tr>
<td>Another national polar operator</td>
<td>N</td>
<td></td>
</tr>
<tr>
<td>National agency</td>
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<td></td>
</tr>
<tr>
<td>Military support</td>
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<tr>
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<td></td>
</tr>
<tr>
<td>Own support</td>
<td>N</td>
<td></td>
</tr>
<tr>
<td>Other sources of support</td>
<td>N</td>
<td></td>
</tr>
</tbody>
</table>

Logistics will be coordinated by an operations management team consisting of the leading international scientists and experienced national logistics operators. Past experience from three successful expeditions to Lake Elgygytgyn have strengthened connections and trust with local operators willing to support the project.

2.6 Has the project been "endorsed" at national or international level (see Note 5)

Y Necessary site surveys for this project were funded by national agencies in Russia, the USA and Germany. A pre-proposal for a deep drilling campaign at Lake Elgygytgyn submitted to the International Continental Drilling Program in January 2004, was highly ranked; we were encouraged to submit a full proposal in 2005.
3.0 PROJECT MANAGEMENT AND STRUCTURE

3.1 Is the project a component (established over the IPY 2007-2008 timeframe) of an existing plan, programme or initiative or is it a new autonomous proposal?

<table>
<thead>
<tr>
<th>New Project</th>
<th>Component of an existing or planned activity</th>
</tr>
</thead>
<tbody>
<tr>
<td>?</td>
<td>?</td>
</tr>
</tbody>
</table>

The Elgygytgyn Lake project integrates along the framework of the older PAGES PEP III transect and within the spirit of new international interests in regional and hemispheric climate and ecosystem dynamics. This research project is included in the broad framework of the IPY-proposed Bipolar Climate Machinery (BIPOMAC) and the European initiative Arctic Paleoclimate and Its Extremes (APEX).

3.2 How will the project be organised and managed? (see Note 6)

The project will be managed by a Science Management Team and an Operations Management Team. The Science Management Team will coordinate the interactions of principle investigators, oversee the Operations Management Team, proactively facilitate agreements and government relations, proactively seek avenues for useful public relations, and oversee implementation of data management. The Operations Management Team will focus on all aspects of the logistical issues associated with mobilizing equipment and personnel to/from the drill site. They will also be instrumental in securing the deportation of the core materials to other countries.

3.3 What are the initial plans of the project for addressing the education, outreach and communication issues outlined in the Framework document? (see Note 7)

Our outreach efforts will include the publication of an educational CD regarding science at Lake E. Preliminary efforts towards this CD have already begun and can be found at [www.uaf.edu/water/faculty/nolan/lakee.html](http://www.uaf.edu/water/faculty/nolan/lakee.html). The Elgygytgyn Management Team has been approached by members of the film industry and freelance journalists about promoting the science to the general public.

3.4 What are the initial plans of the project to address data management issues (as outlined in the Framework document)? (see Note 8)

All data from the project will be archived in easily accessible web based databases such as PANGAEA or the NOAA NGDC.

3.5 How is it proposed to fund the project? (see Note 9)
We seek funding from the International Continental Drilling Program for parts of the operational costs. The remaining operational costs and especially the scientific investigations of the core materials, shall be funded by national agencies.

3.6 Is there additional information you wish to provide?

No

4.0 PROPOSER DETAILS

4.1 Lead Contact for the Expression of Intent

Title
Prof. Dr.

First Name
Martin

Surname
Melles (Principle Investigator, PI)

Organisation
University Leipzig

Address 1
Institute for Geophysics and Geology

Address 2
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Postcode/ZIP
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Country
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Telephone
+49-341-9732-902/900

Mobile

Fax
+49-341-9732-809

Email
melles@rz.uni-leipzig.de

Repeat Email

4.2 List up to six other project members and their affiliation.

Name 1
Julie Brigham-Grette (PI)

Organisation
University of Massachusetts, Amherst, USA

Name 2
Pavel Minyuk (PI)

Organisation
NEISRI FEB-RAS, Magadan, Russia

Name 3
Christian Koeberl (PI)

Organisation
University Vienna, Austria

Name 4
Matt Nolan

Organisation
University of Alaska Fairbanks, USA

Name 5
Hans-W. Hubberten

Organisation
Alfred Wegener Institute, Potsdam, Germany

Name 6
Dimitri Yu. Bolshiyavanov

Organisation
Arctic and Antarctic Research Institute, St. Petersburg, Russia
Herrn
Prof. Martin Melles
Institut für Geophysik und Geologie
der Universität Leipzig

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Ihr Zeichen/ihre Nachricht vom
Unser Zeichen
Haushalt/Mt
Datum
12.01.2005

"El’gygytgyn See"
AWI-Anteil in 2005

Sehr geehrter Herr Prof. Melles,

das Alfred-Wegener-Institut bewilligt im Rahmen des „El’gygytgyn See“ Projektes
eine Finanzierungsüberschuss von 8.000.-- US$. Die Mittel sollen dazu verwendet
werden, Verhandlungen mit russischen Firmen voranzustreben, um für das geplante
Tiefbohrprojekt „Scientific Drilling at El’gygytgyn Crater Lake“ die logistischen Vor-
aussetzungen für eine erfolgreichen Einvernehmen von Drittmitteln im Rahmen des
ICDP (International Continental Drilling Programme) zu schaffen.

Mit freundlichen Grüßen

i.A. [Signature] Münster
January 11, 2005

Dr. Julie Brigham-Grette
Department of Geosciences
University of Massachusetts
Amherst, MA 01003 USA

Dear Dr. Brigham-Grette,

The University of Massachusetts recognizes the tremendous scientific value of a major scientific deep drilling project at Lake Elgygytgyn in North East Siberia. We also appreciate the courage and perseverance required of the international science team in pursuing a world-class drilling project of this magnitude.

In support of your current proposal to the International Continental Drilling Program, we agree to provide matching funds in support of a Russian Operations Manager to the level of $8,000 USD for the coming year. We agree that it is critical to the success of the planning effort that an Operations Manager begin work full time as soon as possible, pending the decision of the ICDP, to secure a path for the difficult logistics of getting a large drill rig into a remote location in Chukotka. It is my understanding that the Operations Manager will collaborate very closely with the Science Management Team consisting of yourself and colleagues from Germany, Russia, and Austria.

I wish you success with your continuing planning efforts for drilling at Lake Elgygytgyn.

Sincerely,

Paul Kostecki, Ph.D.
Vice Provost for Research

cc: Provost Charlena Seymour
    Dean Lee Osterweil, NSM
    Dr. Mike Williams, Dept Chair


Julie Brigham-Grette

Dept of Geosciences, University of Massachusetts, Amherst, 01003 USA
Office (413)545-4840 / FAX (413)545-1200 / Email: juliebg@geo.umass.edu

A. Professional Preparation

B.A., Geology Magna cum laude 1976 Albion College, Albion Michigan
M.Sc., Geology, August 1980 University of Colorado, Boulder, Colorado
PhD, Geology, May 1985 University of Colorado, Boulder, Colorado

B. Appointments

Professor, Department of Geosciences, University of Massachusetts, Amherst, September 2001 to the present.


Associate Professor, Department of Geosciences, University of Massachusetts, Amherst, September, 1993 to 2001.

Assistant Professor, Department of Geology and Geography, UMass Amherst, September, 1987 to 1993.


C. Relevant Papers


Other Significant Papers/Edited Volumes

Brigham-Grette, J., Melles, M., and Minyuk, P., (Guest Editors), Paleolimnology and History of the last 300 ka at El’gygytgyn Crater Lake, NE Siberia, (10 manuscripts in review and revision), Journal of Paleolimnology special issue. Status: Web address: http://www.geo.umass.edu/lakejopl


Elias, S.E. and Brigham-Grette, J. (Guest Editors), 2001, Paleoenvironments of Beringia, (34 papers). Quaternary Science Reviews 20(1-3) 574 pg.


**D. Synergistic Activities (education, outreach and synthesis):**
1995-96 *Lilly Program Teaching Fellowship*, UMass Center for Teaching
1999 – present. Practitioner of Inquiry based Learning Approach to Teaching Oceanography to large classrooms through the UMass/NSF Science Technology, Engineering and Mathematics Teacher Education Collaboration, (http://k12s.phast.umass.edu/~stemtec/)
1998 Member of Writing Task Force for *National Science Foundation PARCS* Paleoenvironmental Arctic Sciences document.
2003 Member of Writing Task Force for National Science Foundation “Arctic Research and Support and Logistics” Report under ARCUS.
2004-2006 Elected Chair, IGBP-PAGES (Past Global Changes) International Science Steering Committee, [http://www.pages.unibe.ch/contact/people.html](http://www.pages.unibe.ch/contact/people.html); as such, SSC member of the International Geosphere/Biosphere Program.
2004-2006 Elected President, American Quaternary Association; as such, ex-official member of the U.S. International Quaternary Association National Committee Member of Editorial Boards of *Quaternary International, Quaternary Science Reviews, Arctic*.

**E. Collaborators and other affiliations**

i) close collaborators not named in papers above
- Driscoll, Neil, Scripps Oceanographic Institution
- Keigwin, Lloyd, Woods Hole Oceanographic Institution
- Eglinton, Tim Woods Hole Oceanographic Institution

ii) Graduate Advisors
- Dissertation: G.H. Miller, University of Colorado, INSTAAR; & D.M. Hopkins, USGS/University of Alaska-Fairbanks (deceased)
- Post doctoral Fellowship, Norway 1984: Hans-Petter Sejrup, Univ of Bergen
- Post doctoral Fellowship, Canada 1985-86: Steven Blasco, Bedford Institute of Oceanography

iii) Students supervised in the past 5 yrs
- Masters Theses: David Korewjo, Tammy Rittenour, Trent Hayden, Michael Apfelbaum, Celeste Asikainen, Zach Lundeen, Beth Caissie, Caitlin Majocka, David Elia
- Dissertations: Lyn Gualtieri
- Senior Honors Theses: Amy Patrick and Rebecca Greenwood

**F. Honors**
- Elected Fellow, Geological Society of America, 2002
- Albion College Distinguished Alum Award, 2003
CURRICULUM VITAE  Prof. Dr. Martin MELLES
Institute for Geophysics and Geology, University Leipzig
Talstrasse 35, D-04105 Leipzig
phone: +49-341-9732902, fax: +49-341-9732809, email: melles@rz.uni-leipzig.de

Professional Preparation

- Diploma, Geology/Paleontology, summa cum laude, Oct. 1987, University Göttingen
- PhD, Geology, summa cum laude, Nov. 1990, University Bremen
- Habilitation, Geology, Aug. 2000, University Potsdam

Appointments

- since 2/01  Associate Professor, Institute for Geophysics and Geology, University Leipzig
- 4/00 - 1/01  Substitutional Professor, Institute for Geophysics and Geology, University Leipzig
- 1/92 - 3/00  Scientific Associate, Alfred Wegener Institute, Potsdam
- 12/90 - 12/91  Post-doctoral Research Fellow, Alfred Wegener Institute, Bremerhaven
- 12/87 - 11/90  PhD Research Fellow, Alfred Wegener Institute, Bremerhaven

Relevant Papers


Nowaczyk N.R. & Melles M. (subm.): A revised age model for core PG1351 from Lake El’gygytgyn, Chukotka, based on magnetic susceptibility variations correlated to northern hemisphere insolation variations. – J. Paleolimnology.

Minyuk P., Brigham-Grette J., Melles, M., Borkhodev V.Ya. & Glushkova O.Yu. (subm.): Inorganic geochemistry of El’gygytgyn Lake sediments (northeastern Russia) as an indicator of paleoclimatic change for the last 250 kyr. - J. Paleolimnology.


Other Significant Papers


74
Selected Soft Money Grants

- 5/04: “Pilot Study Lake Ohrid, Macedonia/Albany” (Wagner & Melles)
  German Academic Exchange Office” (DAAD)
- 10/02 - 9/05: “Pilot Study Lake El’gygytgyn, Siberia” (Melles)
  German Federal Ministry for Education and Research (BMBF)
- 9/02: “Scientific Stay in Mexico” (Melles)
  German Academic Exchange Office” (DAAD)
- 11/01: “El’gygytgyn Lake Workshop” (Brigham-Grette, Melles, Minyuk)
  International Continental Drilling Program (ICDP)
- 08/01 – 07/04: “Environmental History Amery Oasis, East Antarctic” (Melles & Hubberten)
  German Research Foundation (DFG)
- 06/01 – 05/06: “Climate Variability at Warm-Cold Transitions” (Melles & Junge)
  German Federal Ministry for Education and Research (BMBF)
- 07/98 – 01/01: “Eurasian Ice Sheets” (Hubberten & Melles)
  European Science Foundation (ESF)
- 05/98 – 04/03: “Palaeoenvironments of the Antarctic coast, from 50E to 120E” (Gore & Melles)
  Australian Antarctic Science Advisory Committee (ASAC)
- 08/93 – 07/96: “Environment. History Bunger Oasis, Antarctica” (Melles, Hubberten, Wand, Hermichen)
  German Research Foundation (DFG)

Teaching (since 1998)

- 2 x Lecture “Environmental History of Polar Regions”, University Potsdam (2 hrs/week)
- 5 x Lecture “Quaternary Geology”, University Leipzig (4 hrs/week)
- 5 x Lecture “Sedimentology”, University Leipzig (4 hrs/week)
- 5 x Laboratory Course “Sedimentology”, University Leipzig (2 hrs/week)
- 4 x Lecture and Practice “Introduction Geoscientific Documentation”, University Leipzig (2 hrs/week)
- 12 x Seminars, undergraduate and graduate level, University Leipzig (2 hrs/week)
- 4 x Seminar, University Leipzig (2 hrs/week)
- 5 x Field Course “Introduction Geological Field Methods”, University Leipzig (5 days)
- 8 x Geological Mapping Course, University Leipzig (13 days)

Supervision

- 8 Diploma Theses: Oliver Stock (1/97), Steffen Popp (12/01), Eva Hoßbach (12/02), Jana Hoffmann (9/04), Andreas Dehnert (12/04), Martin Klug (12/04), Katharina Stolz (12/04), Doreen Hoyer (1/05)
- 6 PhD Theses: Thomas Kulbe (2/97), Markus Schwab (6/98), Stephanie Harwart (12/98), Bernd Wagner (3/00), Johannes Müller (7/00), Alexandra Raab (12/00)

Award

- 3/91: Annette Barthelt Award for Marine Research 1991

Polar Field Experience

- 6/03 - 9/03 Arctic, El’gygytgyn Lake, Siberia
- 9/98 - 1/99 Antarctica, Windmill Islands, Wilkes Land
- 7/97 - 8/97 Arctic, southern Taymyr Peninsula, Siberia
- 6/96 - 7/96 Arctic, Severnaya Zemlya Archipelago, Siberia
- 8/94 - 10/94 Arctic, East Greenland
- 12/93 - 5/94 Antarctica, Bunger Oasis, Wilkes Land
- 7/93 - 9/93 Arctic, southern and northern Taymyr Peninsula, Siberia
- 10/91 - 3/92 Antarctica, Schirmacher and Untersee Oases, Dronning Maud Land
- 1/91 - 3/91 Antarctica, Weddell and Lazarev Seas, RV "Polarstern"
- 12/87 - 3/88 Antarctica, Weddell Sea, RV "Polarstern"
CURRICULUM VITAE  Prof. Dr. Pavel Sergeevich MINYUK

Head of paleomagnetism lab of North-East Interdisciplinary Scientific Research Institute, Magadan, Russia

16 Portovaya st., Magadan, 685000, Russia;
Ph. +7˚413 22 30681
Fax +7˚413 22 30051
Email: Minyuk@neisri.magadan.ru.

Birthday: 08 March 1954.
1971—1976 — student of Geology Faculty of Saratov University (Saratov)
1976 — present — the Junior Scientist, Senior Scientist, director of lab. paleomagnetism of North-East Scientific Research Institute Far East Branch of Russian Academy Science.

1986 — dissertation of candidate (Phd) of Geology and Mineralogy Paleomagnetic stratigraphy Pliocene and Quaternary sediments of Central and Northern Yakutiya.

Topic interest:
Cenozoic magnetostratigraphy, paleomagnetic dating of Cenozoic climate events, magnetic mineralogy, environmental magnetism of lake sediments, tectonic reconstructions, inorganic geochemistry. Mainly studied areas are Yakutiya, Chukotka, Magadan region, Kamchatka.

Publications:
4 books (one authored) and 50 publications.
Some recent publications:

CURRICULUM VITAE   Prof. Dr. Christian KOEBERL
Department of Geological Sciences, University of Vienna
Althanstrasse 14, A-1090 Vienna, Austria (christian.koeberl@univie.ac.at)
phone: +43-1-4277-53110, fax: +43-1-4277-9531

Education and Scientific History
• Born in Vienna, Austria, 18.Feb.1959; from 1978 studies in “technical chemistry” at the Technical University of Vienna, - from 1980 also astronomy and chemistry at the University of Vienna; from 1981/82 also at the University of Graz.
• Graduation, Ph.D. (in astronomy and chemistry), May 1983, University of Graz, Austria
• 1983 - 1985: Research Assistant, Geo- and Cosmochemistry, at the Institute of Analytical Chemistry, University of Vienna.
• 1985 - 1990: Assistant Professor, Institute of Geochemistry at the University of Vienna.
• 1986 - 1996: Lecturer for Chemistry in Art at the University of Applied Arts in Vienna;
• 1989/90 "Habilitation" in "Geo- and Cosmochemistry", named "Universitätsdozent".
• 1990 - present: tenured as Associate Professor for Earth Sciences (Geo- and Cosmochemistry); Institute of Geochemistry, University of Vienna (from 2003, at the Department of Geological Sciences, University of Vienna).
• 1994 - 2000: Adjunct Professor, Department of Earth Sciences, Dartmouth College, NH, USA.

Research Activities and Interests
Research interests: impact cratering; archean geology; general planetary sciences; meteorites; active research in different fields of earth and planetary science, related mainly to geochemistry, cosmochemistry, petrology, geology, and geophysics (integrated/interdisciplinary studies).
Multidisciplinary and integrated studies of all aspects of impact crater studies and impact process; analytical geo- and cosmochemistry; antarctic meteorites, lunar meteorites, cosmic dust; upper mantle; diamonds; peridotites; ore deposits and environmental aspects; most research in collaboration with international institutions, including chemical, mineralogical, petrological, and isotopic studies to arrive at integrated studies.

Teaching
Since 1987 teaching of classes and lab courses from different areas within geo- and cosmochemistry and planetary sciences; e.g., classes on planetary sciences, geochemistry; classes and lab courses on topics in analytical geochemistry, rock and mineral analysis, and general chemistry for earth scientists; at the University of Vienna, University of Salzburg, and University of Applied Arts, Vienna; teaching also during visiting professor appointments at the Dept. of Geology, University of the Witwatersrand (Johannesburg) and at the Dept. of Earth Sciences, Dartmouth College (USA).
Supervision of M.Sc. (diploma) and Ph.D. theses: completed MSc theses – 6, completed PhD theses: 12. Currently (2004) 1st advisor for 4 Ph.D. students (at the Univ. of Vienna) with the following topics: impact cratering (2), granitic rocks (1), Snowball Earth geochemistry, etc. (1).

Visiting Appointments (long duration)
• 8-10/1993: Visiting Professor, Dept. Geology, Univ. Witwatersrand, Johannesburg, South Africa.
• January-March 1994: Visiting Professor, Dept. Earth Sciences, Dartmouth College, New Hampshire, USA.

Honors and Awards
• 1987, "Antarctica Service Medal of the United States of America".
• 1988, Fulbright Senior Visiting Scholar, USA.
• 1994, Fellow of the Meteoritical Society
• 1995, Meritorious Service Award, Geochimica et Cosmochimica Acta
• 1996, START-Award of the Federal Ministry of Science, Austria
• 1997, Novartis Award for Chemistry
• 2004 – elected corresponding member of the Austrian Academy of Sciences
Scientific Service and Administrative Activities

- 1985-1988 Member, Scientific Advisory Committee, Austrian Space Agency (ASSA)
- Chairman of the Organizing Committee and the Program Committee of the "52nd Annual Meeting of the Meteoritical Society" (450 participants, held in Vienna, Austria, July-August 1989).
- Scientific Organizer (with W.A. Cassidy, Univ. Pittsburgh) and local organizer of the "Workshop on Differences between Antarctic and Non-Antarctic Meteorites", sponsored by NASA and University of Vienna, held in Vienna, July 1989.
- Local Organizer for the "Workshop on Cosmogenic Nuclide Production Rates", sponsored by NASA and University of Vienna, held in Vienna, July 1989.
- Member of the Organizing Committee, 8th International Conference on "Modern Trends in Activation Analysis", held in Vienna, Austria, September 1991.
- Member of the Organizing Committee, 3rd International Conference on "Nuclear and Radiochemistry", held in Vienna, Austria, September 1992.
- Member of the "Conference Committee", 3rd International Conference of Natural Glasses, Jena, Germany, 21.-23.3.1996.
- Member, Organizing Committee, 62nd Annual Meeting, Meteoritical Society, Johannesburg, South Africa, July 1999.
- Chairman, Organizing Committee and Program Committee, International Meeting on “Catastrophic Events and Mass Extinctions: Impacts and Beyond”, Vienna, Austria, July 9-12, 2000.
- Co-Convener, Field Forum “Bolide Impacts on Wet Targets”, Geological Society of America, April 22-28, 2001, Nevada and Utah, USA

- Associate Editor, *Geochimica et Cosmochimica Acta* (since 1990)
- Associate Editor, *Geochemical Journal* (from 1998)

- Member, EUROMET Working Group
- Scientific Secretary, European Science Foundation Network on "Impact Cratering" (1993-1995)
- Member, Nominating Committee, Meteoritical Society (1997/8)
- Member, Publications Committee, Meteoritical Society, and Joint Publications Committee, Meteoritical and Geochemical Societies (2002-2004)
- Member, European Space Agency (ESA) review panel (Stone-Biopan) (2001)
- Team Leader (Geochemistry/Petrology), Chicxulub deep drilling project (ICDP)
- Member, Science Advisory Group, International Continental Scientific Drilling Program (ICDP) (from 2002)
- Co-ordinator + principal investigator, ICDP deep drilling project, Bosumtwi structure (Ghana) (2002-2005)
- Member, Science Board of the International Geological Program (IGCP) of the UNESCO (from 2004)

Publications

Total: 8 books (3 authored or co-authored, 5 edited or co-edited); ca. 260 peer-reviewed research publications; over 300 abstracts and other non-reviewed publications.

5 relevant publications:


