El'gygytgyn Lake Workshop Report
Science Results & Plans for Deep Drilling

Held November 10-12, 2001

Lord Jeffery Inn, The Garden Room,
Amherst, Massachusetts USA

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http://icdp.gfz-potsdam.de/

To the Department of Geosciences, University of Massachusetts-Amherst

Participants from the countries of:
United States, Germany, Russia, Austria,

Executive Summary

Twenty-six scientists from 4 countries met Nov. 9-12, 2001, in Amherst Massachusetts, USA, to discuss past and future research plans, at El'gygytgyn Crater Lake, northeast Siberia. The focus on of the workshop was to sketch an initial blueprint of the science to eventually justify deep drilling. Science presentations by most of the participants were followed by discussions for framing the scope of a science management plan, a list of serious logistical considerations, and a political roadmap for accomplishing the collective goals of such an international project.

Two emerging themes from the workshop focused on (1) the unique paleoclimatic history and potential of the lake sediments and (2) impact studies of the crater origin and bedrock stratigraphy. 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 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 the lake at this latitude provides a means of determining from a terrestrial perspective how the arctic climate evolved and adjusted from Milankovitch-driven glacial/interglacial cycles every 41ka and later every 100ka. 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 may 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.

While secondary to the paleoclimatic studies, physical access to remote El'gygytgyn Crater offers the impact science community compelling reasons for collaboration in this research effort. El'gygytgyn crater is unequaled on earth because of its well-preserved morphology found in volcanic target rocks, offering new insights into planetary cratering processes. What can be uniquely learned from this region is how igneous target rocks respond to impact at shallow and deep levels and just how bolide composition influences crater morphology and genesis. Such studies will provide the basis for important inferences related to cratering processes on Mars. Moreover, impact studies offer the potential for identifying instantaneous geochemical markers from El'gygytgyn within distant depositional environments, such as the Arctic Ocean, to better understand regional or global significance of the impact itself on pre-impact climate. Deep drilling into impact rocks may also offer unique study opportunities for astrobiologists concerned with the origin of life in our solar system and its evolution. Links to other related and existing programs include those with NSF – ARCSS, PARCS, RAISE, and CHAMP, the Aurora Borealis Initiative, Nansen Arctic drilling, PAGES - PEP2 Transect, PAGES-CAPE, ESF – QUEEN, NASA – Astrobiology, ICDP – Bosumtwi projects, and high resolution CONTINENTal climate records in Lake Baikal.

A science management team was identified and an outline was formed for future operations management and political networking. Current and future data sharing will be coordinated through Norbert Nowaczyk, GFZ. A schedule of critical milestones were laid out focused on pre-drilling research at the lake in 2003 and 2004 in anticipation of

submitting proposals for deep drilling to the US-NSF, the Germany Ministry, Russian Ministry, and the ICDP in January 2004.

Introduction

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. One approach towards the understanding of ice-land-ocean interactions to evaluate the Arctic climate system, as well as linkages between the Arctic and the global climate, is to compare glacial, terrestrial, and marine archives over several glacial/interglacial cycles when Milankovitch-forcings and northern hemisphere boundary conditions were not always same. Long high-resolution paleoclimate records are available in the Arctic from the Greenland Ice Sheet (e.g., Grootes et al. 1993, Johnsen et al. 1995). Long marine records, generally having lower temporal resolutions, have been recovered in the Arctic and sub-Arctic oceans (e.g., Aksu et al. 1988, Wolf & Thiede 1991, Bond et al. 1993, Keigwin et al. 1994, Rea et al. 1995, Spielhagen et al. 1997, Keigwin 1998). In contrast, no continuous terrestrial record exists from the Arctic with a comparable time resolution and duration.

Such a terrestrial record <u>can</u> be recovered from El'gygytgyn Lake, in northeastern Siberia, and it provided the impetus for an ICDP workshop to explore the potential of future science at this site. Lake El'gygytgyn is located in northeastern Siberia, ca. 100 km to the north of the Arctic Circle (67°30' N, 172°05' E; Fig. 1). The 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.

Preliminary results from cores taken during a pilot expedition in spring 1998, and from seismic profiling conducted in 2000, show that the lake contains a limnic sediment fill with a composition that mirrors the climatic and environmental history of northeastern Siberia over several glacial/interglacial cycles, and probably since mid-Pliocene time. A record like this from the arctic is unprecedented. Moreover, having formed 3.6 million yrs. ago from a meteorite impact, El'gygytgyn also offers the impact science community with the opportunity to study a well preserved crater uniquely found in igneous rocks for direct comparison with craters found in igneous terrains on Mars.

For three days, November 10-12, 2001, 26 scientists from four countries met in Amherst Massachusetts to review all available bedrock and paleoenvironmental data from El'gygytgyn Lake and its surroundings. Despite years of effort, this was the very first time all of the scientists engaged in research at El'gygytgyn were assembled in one place. This workshop established an international scientific party with broad interests into the investigation of its sediment fill and underlying impact rock sequences in the coming years, The gathering made concrete plans to develop proposals for submission in January, 2004 seeking financial support of a future drilling expedition.

Science Highlights

The workshop was organized as a series of thematic sessions consisting of science talks summarizing past and present research conducted at Lake El'gygytgyn. This was followed by two sessions to explore the nature and context of future research needed as a precursor to deep drilling having laid out a strategy for filling gaps in our knowledge of the lake as a system. Also necessary was an open review and discussion of logistical and political limitations to be overcome. This discussion then lead to the development of common overarching science goals and a consensus as to the structure and function of a science management team, an operations management team, core archiving and data management. Ambitious yet realistic milestones were then outlined to move the research plans forward. A copy of the program and abstracts are attached; these same documents, as well as a copy of this report are available on the web at http://www.icdp-online.org.

Bedrock and Impact Science

The impact origin of the crater has been questioned by only a few. Paul Layer opened the meeting with a review of the regional bedrock and tectonic setting for El'gygytgyn Crater within the Okhotsk-Chukotka Volcanic Belt. While the volcanic stratigraphy in the vicinity of Lake E 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 Ma (Layer, 2000). This tight age control, the presence of glassy bombs and shock-metamorphosed quartz and the concentric fractures and reverse faults surround Lake E lend persuasive support to the impact origin of the basin (Gurov et al., 1978; Masaitis, 1999). The chemistry and morphology of spherules collected from streams surrounding the basin are also typical of those found in other impact sites, like the Arizona Meteor Crater and the area surrounding the Zhigansk iron meteorite impact (Smirnov et al., this meeting). David Stone then presented some generalized model simulations of the impact process that produced an estimate of 1.57 km for the diameter of the bolide with an impact velocity in the range of 25km/sec (or nearly 56,000 mph). Though the models are admittedly rudimentary, he suggests that the volume of material ejected from the crater was about the same as that ejected with the eruption of Katmai in 1912, the largest eruption of the 20th century. Despite an immediate fall out of breccia, Stone asserted that a significant portion of fine melted eject probably made it into the stratosphere eventually producing a recognizable horizon for some hundreds of kilometers downwind of the impact. Smirnov et al. (this meeting) then went on to speculate that Lagherny Creek, the largest drainage of the crater, might actually represent a second, nearly simultaneous impact. Though not impossible, most agreed that the hypothesis needs further testing with additional study of the impacted rocks and local fracture systems.

The conference greatly benefited from the presence of Christian Koeberl who is an integral partner in the Bosumtwi Crater project and chair of the European IMPACT program (Response of the Earth System to Impact Processes). Koeberl outlined the ongoing science program at Bosumtwi and provided a description of the research management structure. As young impact craters, we acknowledged the striking scientific parallels between Bosumtwi in the heart of Africa and El'gygytgyn in the heart of Chukotka. Notably similar is the motivation for collaborative study intensely focused on the retrieval of a long, continuous paleoclimate record coupled with impact studies.

Impact studies and paleoclimatic investigations of the sediment fill are intimately linked by defining the seismic architecture of the original crater floor and the character and thickness of the overlying unconsolidated deposits. Frank Niessen reviewed the air gun seismic and 3.5 kHz echo-sounding data collected at the lake during the summer of 2000. Equipment limitations prevented precise definition of a central uplift peak typical of larger craters and there remain significant differences of opinion about its exact location. However, existing data supported by refraction seismics using sonobuoys suggest that the sediment fill is on the order of 350 to 400 meters. A real need was identified for detailed pre-drilling gravity and seismic site surveys to determine the location of the central uplift. These data will determine the future location of cores to optimize the science return for both impact and paleoclimate studies.

Modern processes and Paleoenvironmental science

The strongest impetus for research at El'gygytgyn Lake comes from the potential for paleoclimatic studies at millennial and finer timescales. Because El'gygytgyn basin was never glaciated in the late Cenozoic, the potential is high for eventually recovering a continuous record of arctic climate evolution over the past 3.6 million years, since the time of impact. The 13-meter record retrieved from the Lake in 1998 extends back 300 ka and is already the longest most continuous terrestrial record in the Arctic. Work to date demonstrates that the magnetic susceptibility record in this lake mimics major millennial scale events recorded in the first 110 ka of the Greenland ice sheet isotopic record. Nowaczyk et al (2002) and Brigham-Grette et al. (submitted) show that the magnetic susceptibility record is largely controlled by oxic/anoxic shifts which are in turn governed by changes in lake ice cover as dictated by changing climate implying circum-arctic teleconnections.

The seismic data presented by Frank Niessen clearly show the presence of debris flows from around the margins into the center of the lake at various times in the past. Cross profiles suggest however, that a large area in the center of the lake in the vicinity of the 1998 core site is free of debris flows at least in the upper 160 meters of the sediment record. The upper 160 m of sediment is characterized, in general, by well-stratified reflectors whereas the lower part of the sediment fill appears more massive. By extrapolating the sedimentation rates documented in the cores retrieved to date, the timing of this transition from massive to well stratified sedimentation may coincide with significant arctic cooling, the aggradation of permafrost, and the onset of cyclic glaciation of the Northern Hemisphere. Sedimentation rates in the massive sequence could be as much as twice the rates seen in the upper part of the cores, offering a high resolution record of this significant global climate shift from a ice-free, forested arctic ecosystem to a tundra and ice dominated ecosystem.

Modern processes operating at the lake provide our best index of how the lake works as a system today and how it may have operated under different climatic conditions in the past. Matt Nolan reviewed what we know of the limnology, watershed hydrology, and local meteorology as they relate to the surface energy balance. Based upon remote sensing data collected over the past three years (ERS-2, Radarsat-1 and Landsat-7 scenes) he and others have developed a comprehensive understanding of the seasonal lake ice dynamics at El'gygytgyn. These data are essential since the duration of ice cover and the onset of breakup is critical to understanding proxies of climate change from the sediment archive and to planning for future drilling operations using the ice cover as a platform. Intriguing are the observation of a consistent pattern in the concentration of bubbles in the ice canopy from one year to the next. Should these bubbles contain methane or carbon dioxide, this pattern may be mirroring an important pattern of biogeochemical processes ongoing at the sediment/water interface. Nolan also outlined the notion that brecciated rocks and sediments beneath the lake presumably form a talik possibly providing a large thawed conduit to the surface for deep ground waters and possible gas hydrates.

Modern processes in the lake basin operate across a spectrum of subtle terraces and large alluvial fans related to the changing lake levels since the time of impact. Fifty streams enter the lake today from the crater rim and Olga Glushkova has produced a detailed surficial map of the basin and all of its drainages using aerial photographs. In previous work Glushkova and others described the stratigraphy and geomorphology of a nested series of fluvial terraces found some 30 km downstream on either side of the exiting Enmyvaam River dating back to the time of impact. These terraces provide crucial evidence that the outlet to El'gygytgyn has downcut over time and that the basin doubtlessly became an open lake system shortly after the time of impact. Glushkova and others outlined their most recent work on sediments that accumulated on terraces around the lake margin lying some 12 m or less above August lake levels. Radiocarbon dates and pollen assemblages indicate the presence of sediments dating from MIS 3 up through the Holocene. These pollen sequences are especially important for comparison with pollen assemblages taken from the lake sediments, themselves.

The remainder of the session consisted of a series of talks outlining the original data and interpretation of a variety of proxies measured on cores taken in 1998 to understand the integrity of the paleoclimatic record found in the lake. Pavel Minyuk summarized his analyses of the inorganic geochemistry of the sediments. His data show that the concentration of a number of rare elements (especially Sr) and oxides (especially TiO_2 and K_2O/TiO_2) shift in parallel with climatically defined marine isotopic stages indicating systematic shifts in weathering and/or eolian sources. Martin Melles then reviewed the organic geochemistry and the significance of systemic changes in TOC, TN, TS, Biogenic silica (opal) and the $\delta^{13}C$ of TOC. Extrapolating from the simple notion that the lake record we see represents two end-members of climate shifting from warm interglacial conditions to cold dry glacial modes, Melles suggested two additional modes from the data reflecting warm intermediate interglacial conditions and alternating wetter cold periods with more snow fall. These additional modes at least in theory capture possible changes in biological productivity (esp. diatoms) as reflected by subtle shifts in biogenic opal. Anderson and Lozhkin then summarized the work they had completed on palynology of the lacustrine sediments using major assemblage shifts in vegetation to define inferred climatic change, and discussed the chronological information that can be derived from the palynological data. The down core diatom assemblages were characterized by Marina Cherapanova who has identified 232 taxa and separated the core into 10 biostratigraphic units related to climatically driven limnological change. Celeste Asikainen summarized her sedimentological research on the upper 370-cm of the cores and how shifts in the relative percentages of chlorite and illite/smectite actually track shifts in climate. These data imply that weathering processes on the landscape respond quickly to changes in atmospheric conditions. In collaboration with Celeste, Pierre Francus outlined what has been learned so far from sediment thin sections and reviewed the potential of detailed image analysis for retrieval of grain-size, bioturbation, and quantitative sedimentary fabric. The differences between laminated and non-laminated facies in the cores are not only related to the presence or absence of minor bioturbation but also to the shape and size of the sedimented grains.

The paleoclimatic record derived from any lake core is only as reliable as the geochronology on which it is based. The chronology of existing cores from El'gygytgyn (Nowaczyk et al. 2002) has been established using magnetic properties (magnetic susceptibility and event stratigraphy) and palynology anchored with numerical ages based upon optically-stimulated luminescence (OSL) dating and AMS-^{14}C dating of bulk sediments. Steve Forman reviewed the processing and results of eight samples dated by OSL and Brigham-Grette then reviewed the context of six ^{14}C ages in light of the OSL ages and other geochronology. The uncorrected ^{14}C ages are consistently older than the OSL age estimates by 2,000 years and the conversion of these dates to calendar ages makes them 4-5,000 yrs. too old. These dates, completed on the bulk sediment humic fraction, are easily dismissed as too old due to the well-known residence time of soil organic matter in permafrost. Eight new radiocarbon ages are currently being processed on plant macrofossils extracted from shallow gravity cores and it is anticipated that these new dates will help resolve the issue.

Remaining Pre-drilling Science Plans

The morning sessions of the second day were dedicated to presentations and discussions of the science both remaining to be done prior to drilling and science considered supplementary to deep drilling. This work will form the basis for modest proposals to the Germany Ministry, the Russian Foundation for Basic Research, and the NSF for fieldwork in 2003 and 2004. The range of topics included:

- Multi-channel seismics and magnetic surveys of the Crater
- The History and activity of permafrost, including the use of ground penetrating radar
- Modern process studies (seasonal limnology), sedimentology, and debris flow stratigraphy
- Monitoring, hydrology, remote sensing and modeling of the catchment and lake system
- Neotectonic investigations
- Image Analysis of existing cores
- Isotopic geochemistry of waters and organic matter
- Regional stratigraphy and mapping of the eject blanket

The preparation needed for a successful drilling proposal in the future includes a politically savvy administrative infrastructure set up to maintain communications between interested agencies. Ulrich Harms provided an outline of the purpose, structure and function of the ICDP in facilitating large drilling efforts. Equally important was a presentation by Simon Stephenson concerning the logistical capacity of the US National Science Foundations and his experiences and suggestions in managing similar large international projects of this nature. Dennis Nielson provided an overview of DOSECC (Drilling, Observation and sampling of Earth's Continental Crust, a non-profit corporation) and a summary of the ICDP/NSF-funded GLAD 800 drill rig (GLAD = Global Lake Drilling). Nielson outlined possible logistical and deployment scenarios, a topic that naturally segwayed to the transport and shipping of the drill rig to Russia. Conny Kopsch surprised most of the participants with a memorable presentation advocating the use of zeppelin-like cargo lifter to transport shipping containers by air across the Russian Arctic from ports in Germany.

Science Goals for Deep Drilling

The remaining day and a half of the meeting was consumed with hearty discussion and consensus building around the science goals, management, and timelines for eventually drilling Lake El'gygytgyn. The overarching science goals reflect the common participant interests in pursuing a paleoclimatic agenda and an impact agenda.

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.

We will investigate:

- why and how the arctic climate evolved from a warm forested ecosystem into a cold permafrost ecosystem;
- how the climate evolved into a glacial/interglacial cycle and how it is maintained today;
- other climate change events in eastern Siberia on a centennial to millennial scale;
- teleconnections with other long climate records worldwide;
- dynamic mechanisms behind these teleconnections or lack thereof;
- permafrost formation and stability through time; and
- The best locations for core drilling.

Impact craters

El'gygytgyn Crater is unique on earth because it is a well preserved crater morphology in crystalline target rocks, offering new insights in planetary cratering processes.

We will investigate:

- The response of volcanic target rocks to shock as a function of depth in the central uplift of the crater structure;
- The correlation between seismic data and actual lithological information from the drill core (s)
- The distribution and nature of various impactities (suevitic breccia, impact melt rock) with depth in the crater;
- The chemical composition of the various impact breccias;
- The existence of possible impact-induced hydrothermal processes;
- The siderophile trace element composition of the impact breccias to obtain clues regarding the composition and nature of the bolide that created the crater;
- The radiometric ages of various impact melt rock samples to refine the actual age of the crater structure and compare to ejecta;
- Inferences for impact craters in similar terrain on Mars
- The potential for instantaneous geochemical markers from El'gygytgyn within distant depositional environments, such as the Arctic Ocean, to better

understand regional or global significance of the impact itself on pre-impact climate.

Astrobiology

Unique opportunities exist at Lake El'gygytgyn to study the origin of life in our solar system and its evolution

Modern Processes and proxy development

The Lake El'gygytgyn system is in a unique and valuable location in the Arctic, and the modern processes occurring there today need to be understood before the full climate record can be created

We will investigate:

- the development and calibration of new proxy interpretations;
- post-depositional modification of sediments;
- the dynamics of the modern depositional and biogeochemical environment;
- the local climate signal and how it relates to the regional and circum-arctic climate;
- the modern surface energy balance and its influence on lake ice cover and duration;
- the modern water and sediment balance;
- the role of the open talik under the lake, in terms of fluid and gas migration into the lake from below
- how the local biological and geochemical dynamics relate to the arctic system; and
- The influence of permafrost on the lake catchment and sedimentation.

Science Holes

A program and lake system of this scale is inherently complex and the expedition to the lake in 2000 served to reinforce this point. Clearly the scope of the questions we are trying to address require the expertise of many specialists. We identified an initial list of topics that highlight gaps in our existing field of interested scientists. These areas include:

- Sediment transport modeling
- Modern vegetation mapping and remote sensing
- Investigate existing gravity data and possibilities to expand the data base
- Land-based seismic surveys
- Bacteria studies and NASA Astrobiology
- Copepods studies
- Endemic species evolution
- Physical limnology

The group identified possible individuals and types of individuals to be contacted in the near future.

Links to other programs

The research at El'gygytgyn is easily linked in scope with a variety of existing national and international projects and programs with parallel science goals. These include Arctic System Science (ARCSS) programs under the jurisdiction of US National Science Foundation's Office of Polar Programs such as the Paleoclimate of the Arctic (PARCS), The Russian Arctic Shelf Initiative (RAISE), and Circum-arctic Hydrology and Mapping Project (CHAMP). Ocean drilling for long records in the high latitudes is the focus of the International Nansen Arctic Drilling Project. The geographic location of El'gygytgyn Lake places is it at the northern end of the Asian Pole-Equator-Pole transect, which is a major effort of the International Geosphere/Biosphere Program's on Past Global Changes (IGBP-PAGES - PEP2 Transect). The particular transect includes Lake Baikal and the higher resolution focus of the CONTINENTal project. The PAGES program also facilitates CircumArctic PalEoclimatic (CAPE) syntheses of data linking the northern end of all three PEP meridonal transects. The Quaternary Environments of the Eurasian North program (QUEEN) funded by the European Science Foundation is near completion but its focus has been on interdisciplinary field programs and syntheses of the paleoclimatic history of the Russian arctic from Taymyr Peninsula and the Laptev Sea westward to Scandinavia.

The impact and astrobiology science community with links to NASA have great interest in El'gygytgyn. Equally exciting is the potential for partnerships via the European Science Foundation IMPACT program as well as comparative studies with the ICDP – Bosumtwi Project in Ghana.

Science Management – make up and responsibilities

The final day of the workshop allowed participants to agree on a common administrative structure to the science plans. It was agreed that a Science Management Team be established with the following responsibilities:

- Coordinate all aspects of Principle investigators and new PIs
- Oversee the Operations Management
- Proactively facilitate agreements and government relations
- Proactively seek avenues for useful public relations
- Oversee implementation of data management

The membership of the Science Management Team as currently configured includes

- Julie Brigham-Grette (USA)
- Martin Melles (Germany)
- Pavel Minyuk (Russia)
- plus someone identified as an impact person with $$$$ and time (possibly Buck Sharpton, John Pohl, Philippe Claeys, Boris Ivanov or Christian Koeberl)

Operations Management – makeup and responsibilities

Large international projects typically rely on an operations management team to focus on all aspects of the logistical issues associated with mobilizing equipment and personnel to/from the drill site. We agreed on the need for a Logistics Manager with experience who speaks Russian and would likely work intimately with the Drilling

Manager (e.g., Dennis Neilson and DOSECC, should we use the GLAD 800 rig). These two individuals would respond to the broader science management team with oversight by funding agencies.

Following the model set up for the Cape Roberts Project in Antarctica, The Operation Management team could involve representatives on behalf of

- Russian: Ministry of Industry and Science;
- Russian Academy of Science;
- Russian Foundation for Basic Research;
- Chukotka Governor (Roman Abramovich);
- Germany: Ministry of Science;
- US: NSF (Margaret Leinin and Karl Erb via Simon Stephenson);
- NASA;
- ICDP: Executive Committee.

The assorted logistical needs for drilling have yet to be defined however the range and scope includes issues related to:

- Transport weight;
- Ice strength studies;
- Drill date;
- Number of personnel;
- Building requirements;
- Safety;
- Food supplies;
- Fuel;
- Transport methods:
  - Plane/helicopters,
  - Ocean/Land,
  - Cargo-lifter;
- Permits.

At the workshop we agreed in principle on the concept of requesting funds from NSF/ICDP for an Operations Manager to get started on the feasibility and logistical issues needed as adequate information for a successful drilling proposal. After the workshop, it became clear that such a position could not be funded without appearing to pre-ordain the funding of a future drilling proposal. It was decided that through additional fieldwork in 2003 and through the resources available to DOSECC, requisite site information and site visits to Pevek could still be accomplished.

Data management, analysis, and archiving

One of the many major tasks facing the project is the management and archiving of data generated by the project. Norbert Nowaczyk of the GFZ has agreed to set up a secure web site for the archiving and exchange of data among various working groups. We agreed that all data to date must be filed with Norbert early in 2002 to facilitate synthesis. As material is published in the future, then the archived data will then be submitted to national data archive sites on line, including NOAA's NGDC, and JOSS as well as mirrored sites on PANGEA.

Public Web sites for information and educational purposes will also be maintained and consolidated. Lake El'gygytgyn is currently featured on the following sites;

http://www.uaf.edu/water/faculty/Nolan/lakee.html
http://www.geo.umass.edu/projects/chukotka/elg.html
http://hpkom21.geo.uni-leipzig.de/~geologie/melles_elgygytgyn.htm (in German)
http://www.gfz-potsdam.de/pb3/pb33/methods/maglab/result_7.html
http://www.icdp-online.org

Papers submitted or in prep from existing work

Submitted/Published Publications

Matt Nolan, Glen Liston, Peter Prokein, Rachel Huntzinger, Julie Brigham-Grette, and Buck Sharpton "Analysis of Lake Ice Dynamics and Morphology on Lake El'gygytgyn, Siberia, using SAR and Landsat", in press JGR 2002

Norbert Nowaczyk, P Minyuk, M. Melles, J. Brigham-Grette, O. Glushkova, M. Nolan, A.V. Lozhkin, T.V. Stetsenko, P.M. Andersen, S.L. Forman, "Magnetostratigraphic results from impact crater Lake El'gygytgyn, northeastern Siberia: a 300 kyr long high resolution terrestrial paleoclimatic record from the Arctic", in press, Geophys. J. Intern.

Shilo, N.A., A.V Lozhkin, P.M. Anderson, B.V. Belaya, T.V. Stetsenko, O. Yu. Glushkova, J. Brigham-Grette, M. Melles, P.S. Minyuk, N. Nowaczyk, S. Forman, "The first continuous Pollen Record of Climate and Vegetation Change During the Last 300,000 Years", Doklady Akademia Nauk 376(2): 231-234 (in Russian)

V. Smirnov, O. Glushkova, P. Minyuk, B. Sharpton, "New data on morphostructure of El'gygytgyn Crater" in Russian

N Savva, V. Smirnov, O. Glushkova, P. Minyuk, B. Sharpton, "Spherules at El'gygytgyn Crater" in Russian

Brigham-Grette, Julie**,** Olga Glushkova, Pavel Minyuk, Martin Melles, Norbert R. Nowaczyk, Anatoly V. Lozhkin, Marina V. Cherepanova, Celeste Asikanien, Matthew A. Nolan, Steve L. Forman, *Submitted*, Millennial-scale paleoclimate events of the past 400 ka recordedIn El'gygytgyn crater lake, NE Siberia, to *Science Feb 2002*

Future publications

Mike Apfelbaum and Julie Brigham-Grette, Sedimentological record of the last interglacial from El'gygytgyn Lake, Julie Brigham-Grette, "Arctic climate evolution: a compilation of discontinuous records"

Marina Cherepanova, and J. Brigham-Grette "Diatoms of El'gygytgyn Crater Lake Sediments".

Steve Forman et al, "IRSL dating of Lake El'gygytgyn"

V. Smirnov, et al "Morphostructure of El'gygytgyn Crater"

Pavel Minyuk et al: "Inorganic geochemistry data of El'gygytgyn sediments as a proxy of paleoclimate"

Martin Melles et al: Organic and isotopic geochemistry of PG1351, to be submitted February

Olga Glushkova and Grisha Federov: Construction and composition of the 9-11 m terrace of E Lake

Celeste Asikainen et al, 'Climate signals in clay mineralogy and grain size from Lake El'gygytgyn crater sedimentary sequences'

Matt Nolan: The Crater Chronicles: a travelogue of the IMPACT PROJECT 2000

Celeste Asikainen et al, 'Sedimentary transport mechanism for micro-conglomerate structures in Lake El'gygytgyn Crater'

Niessen, Frank, C Kopsch, and B Wagner, 'First seismic stratigraphy of 3.6 million year old Lake El'gygytgyn, NE Siberia', target - JRl

Nolan, Matt, and others, 'Hydrology and limnology investigations of Lake E', target - Nordic Hydrology

Stone, David, M. Raikevitch, and Paul Layer, "Paleomagnetism and geochronology of the Okhotsk-Chukotka volcanic belt near Lake El'gygytgyn, Chukotka", in prep

Milestones for Future Science

2002

February

- ICDP Drilling Workshop Report – emailed for participant comments Feb 13th
- NSF Science Proposals (Feb. 15) – submitted by Brigham-Grette and Nolan
- raw data, pdf, excel, etc, for/from working group (deadline Febr. 28) -- pending

2003

April 15 - May 7: Winter Expedition

- Ice coring
- Spatial variability in bubble morphology and gas content
- Ice for sediment/diatom content
- Ice for biomarkers
- Sub-ice sampling for biomarkers
- Water sampling/measurement
- Dissolved oxygen
- pH
- Temperature
- Isotopes and pore waters
- Thermistor strings
- Water current/circulation measurements
- Install sediment traps
- Snow sampling
- Sediment sampling
- Density/water equivalent
- Aircraft runway considerations

- Download/maintain met stations
- Permafrost (including Ground Penetrating Radar, GPR, shallow drilling)

June: Mobilization and shipping
July 15 - Sept 15: Summer Expedition

- Lake and land geophysics (shallow and deep seismic, magnetic)
- Field mapping of impact features
- Bathymetry
- Shallow lake sediment coring (old site and modern debris flow)
- Exposures in lake surroundings
- Permafrost (including active layer dynamics, permafrost structure)
- New cores (5m)
- SAR site
- Sediment source investigations
- Gravity coring around streams
- Coring within streams
- Biological investigation of stream sediments
- Stream water filtering
- Stream hydrology
- Discharge measurements of inlets?
- Discharge/stage measurements of outlet
- Monitoring of lagoon formation and destruction
- Water temperature of lagoons
- Solifluction processes
- Neotectonics (soil mercury survey)
- Enmyvaam float trip
- Neogene terrace history
- Vegetation transects

December: write drilling proposals

2004

January: Submit drilling proposal
April/June: funding decision
Fall: mobilize drill rigs

2005

March 1 - May 7: Drilling Expedition

- Arrive March 1 2005
- Drill 3 holes on lake, with Glad-800:

Below are some rough ideas that require refinement after the seismic work in 2003. One hole needs to be over the central uplift, but not precisely in the center, but somewhat off center on the flank to go through shock isobars in the rocks and do detect impact rocks and breccia. These could be 100s of meters thick, not 10-20m

1) 1 hole through breccia to 500-650 m (170 m water plus 350 m sediment plus 10-50 m fallback rock plus 10-20 m melt rock plus 10 m breccia),
2) 1 hole near #1 to 500-650 m (with overlapping sections to #1)
3) 1 hole near center cone to 500-650 m

- Possibly drill 5 holes with shallow drill (200 m), depending on land seismic survey:
  4) 1 hole on western shore 200 m through permafrost
  5) 4 holes in lake (30 m – 100 m in sediments)
- Thermistor strings in permafrost and 1 lake borehole
- ICDP borehole logging system

Archival of cores at LACORE, Minnesota, or AWI core storage, Bremerhaven

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El'gygytgyn Lake Workshop

Program and Abstracts

November 10-12, 2001,

Lord Jeffery Inn, The Garden Room,
Amherst, Massachusetts USA

To the Department of Geosciences, University of Massachusetts-Amherst

Final Program

November 9th, Friday – Arrive at the Lord Jeffery Inn, no formal plans but there will be an informal reunion in the Boltwood Tavern of the Lord Jeff from 7:00 to 9:30 PM.

November 10th, Saturday

8:00 Breakfast and Registration in the Garden Room

9:00	Welcome, introductions, and charge for the meeting	Julie Brigham-Grette

Scientific Presentations (Past Work on Impact Crater and Sediment Architecture)

Morning Session—Chair: Martin Melles

9:20	Long Road to El'gygytgyn: Background, funding, and 1998/2000 field campaigns	Julie Brigham-Grette
9:40	Volcanostratigraphy of the El'gygytgyn Basin and the Age of the Impact Event	Paul Layer
10:00	The impact rocks of El'gygytgyn Crater	Eugene Gurov, & Christian Koebrel
10:20	Coffee Break	
10:40	Spherules from the El'gygytgyn Meteorite Crater	Vladimir.N.Smirnov, N.E.Savva, Olga.Yu.Glushkova, Pavel.S.Minyuk, Buck Sharpton
11:00	Modeling the 3.58 Ma El'gygytgyn Impact	David Stone
11:20	New Data on the Morphology of the Impact Crater of El'gygytgyn Lake	Vladimir Smirnov, Olga Glushkova, Pavel Minyuk and Buck Sharpton
11:40	Seismic Stratigraphy of El'gygytgyn Crater	Frank Niessen

12:00 – 1:30 Lunch at the Lord Jeff

Scientific Presentations (Past Work on Modern Processes and Paleoenvironments)

1st Afternoon Session – Chair: Julie Brigham-Grette

1:30	Modern Process Studies at Lake El'gygytgyn	Matt Nolan
1:50	Stratigraphy and paleogeography of the Late Pleistocene and Holocene in region surrounding El'gygytgyn Lake	Olga Glushkova, Tanya Stetsenko, Vladimir Smirnov, and Pavel Minyuk
2:10	Inorganic Geochemistry Data of El'gygytgyn Sediments as a Proxy of Paleoclimate	Pavel Minyuk, V.Ya Borkhodoev, Olga Yu.

2:30	Organic and Isotopic Geochemistry of Lake El'gygytgyn Lake Sediments since 300 kyr BP	Glushkova, Martin Melles & Hans-W. Hubberten
2:50	Paleoenvironmental Reconstructions from El'gygytgyn Lake Based on Palynological Data	Anatoly (Tolya) Lozhkin, Pat M. Anderson and T.V. Stetsenko
3:10	**Coffee Break**	

2nd Afternoon Session -- Chair: Matt Nolan

3:30	Quaternary High Resolution Diatom Stratigraphy of Pelagic sediments in El'gygytgyn Lake of Chukotka, PG 1351	Marina Cherapanova, Julie Brigham-Grette
3:50	Investigations into the Relationship Between Climate Change and Sedimentary Processes from Core PG 1351 from El'gygytgyn Crater Lake	Celeste Asikainen, Julie Brigham-Grette, and Pierre Francus
4:10	Optically-stimulated Luminescence Dating of Late Quaternary Sediments from Lake El'gygytgyn, Russia	Steve Forman and James Pierson
4:30	An Appropriate Age Model for Sediment Cores from El'gygytgyn Lake?	Julie Brigham-Grette, Norbert Nowaczyk, Celeste Asikainen.
4:50	*Stretch Break*	

Plenum Discussion – Chairs: Julie Brigham-Grette, Martin Melles, Pavel Minyuk

5:10	Wrap up Discussions of Today's Talks Including Crucial Science Questions	
7:00	***Dinner at the Lord Jeffrey Inn***	

November 11th, Sunday

8:00 Breakfast in the Garden Room

Scientific Presentations (Future Work Supplementary to Deep Drilling)

1st Morning Session—Chair: Julie Brigham-Grette

9:00	Introduction to Needs and Current Planning for Supplementary Work	Martin Melles, Julie Brigham-Grette and Pavel Minyuk
9:15	Description of the GLAD-800 Drilling Rig System	Dennis Nielsen (DOSECC)
9:30	Extended Seismic and New Magnetic Survey of the El'gygytgyn Crater	Frank Niessen
9:45	History and Activity of Permafrost in the El'gygytgyn Crater	Hans-W. Hubberten
10:00	Use of Ground Penetrating Radar (GPR) in Lake El'gygytgyn permafrost studies	Georg Schwammborn et al.
10:15	**Coffee Break**	

2nd Morning Session – Chair: Martin Melles

10:45	Future Work on the Late Quaternary Sedimentation in El'gygytgyn Lake	Martin Melles
11:00	Neotectonics of the El'gygytgyn Depression on the Basis of Lake Terrace Investigations	Dimitry Bolshiyanov
11:15	Geomorphology and Neogene Stratigraphy	Olga Glushkova and Pavel Minyuk
11:30	Modern Process Studies and Sedimentation	Julie Brigham-Grette
11:45	Monitoring, Hydrology and Remote Sensing	Matt Nolan
12:00	Image Analysis to study the thin sections of El'gygytgyn Lake sediments: a tool for understanding sedimentary processes and deciphering their climatic signal	Pierre Francus and Celeste Asikainen

12:15 – 1:45 Lunch at the Lord Jeff

Scientific Presentations (Future Drilling Prospects)

1st Afternoon Session – Chair: Frank Niessen

1:45	Drilling into El'gygytgyn Crater: What we can Expect Based on the Terrestrial and Planetary Cratering Records	Buck Sharpton
2:05	Isotope Geochemistry in Future Work at	Steve Burns

	El'gygytgyn Lake: Linking Lake Processes and Climate	
2:20	Lake Drilling in ICDP: Proposals, Requirements and Support	Ulrich Harms (ICDP)
2:40	The Bosumtwi Impact Structure: Preparations for an ICDP Deep Drilling Program	Christian Koeberl

3:00 Coffee Break

3:30	Cargo Lifter: A Solution for the Problematic Transport of a Drilling Rig to El'gygytgyn Lake?	Conrad Kopsch
3:50	US Arctic Logistics Support and International Collaborations	Simon Stephenson (NSF)
4:10	Impactites in Lake El'gygytgyn (Siberia)	Philip Claeys
4:30	The 10 m Terrace of El'gygytgyn Lake and Neotectonic movements	G. Fedorov and D. Bolshiyanov

4:50 Stretch Break

Plenum Discussion – Chairs Julie Brigham-Grette, Martin Melles and Pavel Minyuk

5:10 Wrap up Discussions of Today's Talks
Including Crucial Science Questions

7:00 ***Dinner at the home of Julie Brigham-Grette*** Transportation Provided Starting at 6:45

November 12th, Monday

8:00 Breakfast at the Lord Jeffery Inn

Morning Session -- Scientific Directions and Planning

9:00 – 9:15 Charge to Breakout Groups *Brigham-Grette, Melles and Minyuk*

9:15 Breakout groups (each group with a chair and a reporter/recorder)

- Scientific Goals of Drilling for Impact Studies
- Scientific Goals of Drilling for Modern Process and Paleoenvironmental Studies
- Scientific Goals of Surficial Geology and Permafrost Studies

(we could combine the last two groups)

10:30 Coffee Break

10:50 Reports and discussion from the Breakout groups – consensus building

12:30 Lunch at the Lord Jeffery Inn

Afternoon Session – Future Funding and Logistics Issues

2:00 Funding of International Programs – challenges and realities
Discussion of realistic timetables for proposal submission to various countries

3:00 Coffee Break

3:20 Logistical issues for Drilling, core logging and archiving (LACORE Minnesota?) and post drilling science.

5:00 Official Farewell

7:00 Dinner at the Lord Jeffrey Inn for those remaining.

November 13th, Tuesday

Departures to the various airports by arrangement

A 150,000 year sedimentological record from El'gygytgyn Crater Lake using the 1998 pilot core

Mike Apfelbaum, Celeste Asikainen, Julie Brigham-Grette

Department of Geosciences, University of Massachusetts, Amherst, MA 01002

Geochronological age models of sediments in core PG1351 suggest that the upper 6.5 meters of the core represents ~150 ky of paleoenvironmental change from northeast Siberia (Nowaczyk et al., in press). The magnetic susceptibility record from the 1998 core shows a distinct, strong pattern of correlation with the Greenland Ice Sheet Record (GISP2) in the upper 6.0 meters of the core where significant age control exists, based upon optically stimulated luminescence ages (Forman and Pierson, this volume), magnetic events, and significant shifts in pollen (Lozhkin et al., this volume). The marine isotopic stages derived from SPECMAP have been correlated to the magnetic susceptibility record of core PG1351. In particular, isotope stages 1-6 have been identified, along with several other climate episodes (i.e. the Younger Dryas). The original work by Asikainen (in progress) has yielded a complete sedimentologic record of the upper 2.75 m of core PG1351. This work has been expanded to cover the interval of 2.75-6.50 m, which spans marine isotopic stages 4-6. The climate signal contained within the sediments of the last interglacial are particularly important, as the extensive length of the sediment may provide a high resolution record of interglacial climate patterns for comparison with the Holocene. As a result, a composite sedimentological record has been constructed for the upper 6.5 m of core PG1351. The core is almost entirely composed of silt and clay (25-85% silt and 20-75% clay) with a few intervals containing sand. In order to highlight sedimentary changes, the volume percentages generated by the laser particle analyzer were expanded to include the following intervals: fine clay, coarse clay, fine silt, medium silt, coarse silt, and sand. Clay mineralogy analyses using x-ray diffraction has revealed that the abundance of chlorite increases during colder periods within the upper 200 cm of the core, representing roughly the last 40ka (Asikainen, in progress). This work has been expanded to examine the relationship within the last interglacial (marine isotope stage 5). A series of gravity cores along a northwest transect were obtained during the 2000 return trip to the lake. Sediment and clay analyses on these shorter cores at varying water depths will provide insight on spatial the spatial variability of sediment transport into El'gygytgyn Crater Lake.

Investigation into the relationship between Climate Change and Sedimentary Processes from Core PG 1351 from El'gygytgyn Crater Lake, NE Siberia

Celeste A. Asikainen, Julie Brigham-Grette, and Pierre Francus

Department of Geosciences, University of Massachusetts, Amherst MA 01003

Sedimentological analyses completed at UMass from the upper 300 cm of the 1998 pilot core shows that Lake El'gygytgyn records large climate shifts for the last ~60 ka. The preliminary chronology is based on magnetic susceptibility and OSL correlated to the GISP2 $\delta^{18}O$ curve (Nowaczyk, et al., in revision). Magnetic susceptibility varies by an order of magnitude and reflects the climatic and environmental history of northeastern Siberia over several glacial/interglacial cycles. High susceptibility in the sediments correlates with warm conditions (interglacial-like) with more oxygenated bottom waters. Low susceptibility correlates to cold (glacial) periods when perennial ice-cover causes anoxia and the dissolution of magnetic carrier materials. Oxygen deficient conditions preserved laminated sequences of the core. A bioturbation index (c.f., Kennett, et al., 1995) correlates well to the susceptibility and TOC (Melles, this volume) curves.

The clay mineral assemblages in the sediment are illite, highly inter-stratified illite-smectite (I-S) and chlorite. Clay mineralogy is sensitive to changes in climate and can be used as a proxy for paleoclimate reconstruction. Under warm hydrolyzing conditions chlorite weathers more easily and I-S abundance increases, producing an inverse relationship in the relative abundance of these clays (Chamley, 1989). Trends in relative abundance show distinct downcore changes that correlate with susceptibility. These trends can be divided into eight climate-related zones beginning with isotopic stage 3. Fluctuations in zones 6 - 4 suggest a change in climate that may be correlative with the transition from the Bølling-Allerød (13-11 ka) into the Younger Dryas (11-10 ka).

Grain-size downcore indicate that changes in magnetic susceptibility are not a function of grain size. The mean grain-size is in the silt fraction, with few grains larger then 60 μm. Terrigenous input to the lake comes from over 50 streams that are filtered through storm berms, limiting clastic deposition into the lake system.

Bleb structures, from the laminated segments of the core, were analyzed in thin-section using SEM (scanning electron microscope) in BSE (backscatter mode). The bleb composition suggests modes of deposition different from the surrounding laminae.

Using the BSE imaging technique we hope to improve our understanding of the climate controlled sedimentary processes operating in this lake system through quantification of the detital input and redox conditions that control diatom abundance, vivianite diagenesis, and bioturbation measurements (c.f., Francus, 2001, 2000, 1998).

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An Appropriate Age Model for Sediment Cores from El'gygytgyn Lake?

Julie Brigham-Grette[1], Norbert Nowaczyk[2], Celeste Asikainen[1] and Steve Forman[3]

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Sediment cores from Lake El'gygytgyn (167°N, 172°E), a 3.6 million year old meteorite impact crater in northeastern Siberia, have been analyzed to extract a multi-proxy record including millennial-scale events to nearly 300 ka, with distinct fluctuations in sedimentological, physical, biochemical, and paleoecological parameters. The lake sediment recovered contains both the best-resolved record of the last interglacial and the longest terrestrial record of millennial scale climate change in the Arctic. There are several problems, however, yet to be resolved concerning details in the geochronology.

The geochronology of the cores to date has been established using a variety of relative and numerical methods. First, infrared-stimulated luminescence (IRSL) ages were determined on unopened core sections at correlated depths as indicated in Table 1 and discussed by Forman and Pierson (this volume). This method produces finite age estimates (± 10 to 15%) consistent with ^{14}C, U-Th and biostratigraphic control in a variety of other studies. The IRSL ages are complemented by uncorrected accelerator mass spectrometer (AMS) radiocarbon age estimates on humic acids extracted from bulk sediments at levels throughout parts of the Holocene and LGM. The ^{14}C ages fall in stratigraphic order but are consistently too old compared to the IRSL ages by about 2-3,000 yrs. If the dates are calibrated to calendar ages for direct comparison with the IRSL ages, the ^{14}C age estimates are nearly 5 ka years older. We suspect that there may be some minor issues with the IRSL ages however, much of the difference may be caused by the long residence time of organic matter, especially the humic fraction (the oldest faction), residing in permafrost soils on the slopes of the crater. Radiocarbon samples on macrofossils found in gravity cores collected in 2000 from El'gygytgyn Lake have been submitted to the University of Arizona Accelerator in collaboration with Bernd Wagner (AWI-Potsdam) to hopefully shed light on the residence time. We also propose that we move ahead with AMS dating of aquatic vs. terrestrial biomarkers to determine both the relative contributions of each source and to further gage the terrestrial residence time.

Relative age information is also provided at key points by the identification of major shifts in enclosed pollen assemblages, especially the abundance of trees and shrubs (see Lozhkin and Anderson, this volume). A significant shift in high shrub pollen at about 75 cm corresponds with the late glacial/Holocene transitions. Moreover the elevated values in tree and shrub pollen, including especially pine, between about 540 and 600 cm corresponds with the peak of the last interglacial, or marine oxygen isotope substage 5e.

The magnetic susceptibility (MS) (Nowaczyk et. al, in press) shows strong variations throughout the sediment cores recovered at site PG1351. The susceptibility pattern in the upper part of the core where we have geochronological control shows a correspondence between low susceptibilities in sediments during glacial times and at distinct intervals within the full Last Interglacial between 350 cm and 610 cm sediment depth when we believe the lake bottom was anoxic. Because susceptibility measurements on ignimbrites in the catchment of Elgygytgyn Lake yield very high values (Minyuk, unpublished), we interpret intervals with high susceptibilities in the lake sediment cores to reflect times when the short-distance terrigenous sediment flux is high relative to the biogenic flux, there is more snow in the catchment leading to enhanced fluvial sediment transport and the lake bottom is oxic preserving magnetic minerals. The order of magnitude change in susceptibility is best explained by changes in anoxic to oxic conditions on the lake floor driven by changes in the seasonal duration of lake ice cover. Particle grain-size of the bulk sediment is nearly uniform down core (Asikanen et al. and Apfelbaum et al, this volume) proving that MS is not controlled by grain size in this system.

Positive ChRM inclinations throughout core PG1351 indicate that the entire sediment sequence was deposited during the Brunhes Chron, and thus the base of the core is younger than 780 ka. Low to slightly negative ChRM inclinations occur in two thin horizons at about 470 and 925cm depth. These horizons are associated with the Blake (ca. 115 - 120 ka) and probably the Jamaica (190ka) or Pingle Falls (ca.223 ka) excursions; however the low sedimentation rate does not allow for full resolution of these events. Nevertheless, low to negative inclinations occur at positions in the core where the ages of these events are consistent with the trend in IRSL and AMS ^{14}C ages.

The remarkable similarity between the MS record and the GISP $\delta^{18}O$ allows us to speculate about how to adjust our age model and sedimentation rates, especially for the upper part of the core. We use several key pinning points, that is the identification of interstadials 19 and 20 from GISP at 320 and 330 cm in our core and the Younger Dryas event at 91 cm in the core. This model does not change the basic interpretation of Nowaczyk et al but allows us to better accommodate several of the IRSL and ^{14}C age estimates. Without new dates on the aquatic vs. terrestrial input it is difficult know how to adjust sedimentation rates that must be occurring between 150 and 280 cm during what we believe to be isotope stage 3. Discrepancies between this age model and the age model suggested by the pollen work (Lozhkin and Anderson, this volume) will hopefully be resolved with discussions at this meeting and further dating efforts.

Table 1. Numerical age control on core 1351 from El'gygtgyn Lake

Correlated Depth	Lab ID	IRSL Age Estimate (*38*)
66-70 cm	UIC-705	10.2 ± 1.2 ka
116-120 cm	UIC-706	18.0 ± 1.6 ka
244-247 cm	UIC-662	48.2 ± 3.9 ka
436-451 cm	UIC759	104.2 +/- 7.5 ka
678-693 cm	UIC-675	163.6 ± 12.2 ka
849-856 cm	UIC760	212.3 +/- 16.1 ka
1269-1277 cm	UIC-674	>>150 ka

Correlated Depth	Lab ID	□ ^{13}C PDB	AMS Age Estimate
21-23 cm	OS-22643/NSRL-11027	-26.4	6780 ± 55
64-66 cm	OS-22644/NSRL-11028	-25.0	12250 ± 70
88-90 cm	OS-22645/NSRL-11029	-25.0	19000 ± 110
118-120 cm	OS-22646/NSRL-11030	-27.5	20500 ± 130
134-136 cm	OS-22647/NSRL-11031	-28.8	24600 ± 220
142-144 cm	OS-22648/NSRL-11032	-28.4	26300 ± 170

Isotope Geochemistry in Future work at Lake El'gygytgyn: Linking Lake Processes and Climate

Stephen Burns
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One of the challenges of any lacustrine paleoclimate study is to identify useful proxies for climate parameters in the sediment record. As is the case for many high-latitude lakes, El'gygytgyn lacks authigenic or biogenic carbonates typically used for such work. However, the organic matter in the sediment may be a rich source of useful climate information. For example, distinct increases in TOC during glacial periods coincide with negative shifts in $\delta^{13}C$ of TOC to values of near –33 $^{0}/_{00}$, a shift that is opposite to that observed in most lakes with persistent ice cover. Why does $\delta^{13}C$ of TOC become more negative while organic C concentrations increase? Both changes are almost certainly climate driven. We may be able to understand these changes by sampling the water column at the end of the spring before breakup. We hypothesize that perhaps the direction of change in chemistry that occurred during glacial periods will be observable after 9 months of ice cover today. Because the biological carbon cycle is driven by photosynthesis and respiration we will make a variety of analyses that will allow us to characterize the chemical response of the lake to ice cover. Water samples will be collected throughout the spring-summer-fall field season from the shoreline, throughout the depth of the lake and from incoming and outflowing streams. The samples will be analyzed for the amount and $\delta^{13}C$ of dissolved inorganic carbon (DIC), nitrate, phosphate, cations and anions. These data will then be used to characterize the isotopic, nutrient, and geochemical changes in lake chemistry associated with ice cover.

A second useful climate proxy would be a tracer of changes in the O or H isotopic composition of lake water. Recent advancements in compound-specific isotope analyses suggest that the sedimentary organic matter may be used to monitor such changes. If a biomarker for aquatic organic matter can be identified and separated from the bulk organic matter, then H and/or O isotopic analyses of this fraction of the organic carbon should hold a record of lake water H or O isotopic composition. Applying this technique will require study of the primary organic matter of the modern lake and recent sediments.

QUATERNARY HIGH-RESOLUTION DIATOM STRATIGRAPHY OF PELAGIC SEDIMENTS OF El'GYGYTGYN LAKE OF CHUKOTKA, SITE PG 1351

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The study of the Diatom sequences in the deep-lake sediments of the El'gygytgyn Lake and their fundamental proxy of changing lake paleoenvironments in paleolimnology had been began rather recently. The information on fossil diatom species diversity and paleogeographic events recorded in the lake sediments was obtained from small (up to 25cm) piston cores (Sechkina, 1956; Jousé, Sechkina, 1960). Some decades later, V.G. Charitonov (1980, 1993) has also described full data about a taxa composition and a specific structure of diatom assemblages in recent planktonic and benthic ecotypes (309 taxa), and thanatocoenoses in uppermost layer of contemporary sediments of the El'gygytgyn Lake. Unfortunately, the adduced list diatom species leave outs of new views on a Bacillariophyta systematic, therefore it requires careful revision in details.

The diatoms were studied from sediments of a small piston core (11cm) and Hole PG1351 (1244 cm), obtained from a pelagic lake part. This hole shows consistent changes in species diversity, paleoecological structures, and relative abundance of diatom species throughout the entire cored sediment succession. These changes can be used for high-resolution diatom stratigraphy and paleolimnology throughout the Middle-Late Pleistocene and Holocene requiring of high accuracy in paleoclimatic data interpreting.

The diatom flora of 120 hole samples is represented by 232 taxa relating to 2 systematic classes, 12 families and 25 genera. The class Pennatophyceae (221 taxa) is represented by high species diversity of some genera, namely Pinnularia (31), Cymbella (26), Eunotia (26), Achnathes (24), Navicula (24 species). The class Centrophyceae is not so rich by genera and species diversity, but its genera Cyclotella and Pliocaenicus founded in both the thaphocoenoses and thanatocoenoses are represented throughout core diatom sequences by absolute dominance of Cyclotella ocellata, C. krammeri, Pliocaenicus costatus var. sibiricus.

Ten clarified here biostratigraphic units are correlated to paleolimnologic events under the major paleoclimatic fluctuations of the end Middle, Late Pleistocene, and Holocene. The units corresponding to relatively warm and temperate paleoclimates of, Last Interglacials and Holocene, and interstades of Middle Pleistocene Glaciation and Last Glaciation are characterised by high diatom species diversity dominated by the species of genera Cyclotella along with presence of marsh diatoms (e.g., Pinnularia, Eunotia, Stauroneis, Neidium, etc.). The genera Cyclotella marks the planktonic ecotopes of the oligotrophic lakes with soft water and pH>5. The fact that species of Cyclotella are abundance throughout the entire cored sediment succession allows us to establish that the lake eutrophity, water depth, and littoral had been changed not so significantly during sedimentation time. An interval 50-80 cm of the core sediments is exception, because it is represented by Pliocaenicus costatus var. sibiricus, which has ecological optimum in lake with highest contents of nutrient. Most likely that this interval of sediments was formed during Holocene Climatic Optimum.

The deposits characterised by warm water and temperate diatom assemblages contain usually very high number of diatoms (20-30 millions valves per 1 gram dried sediment), whereas their content in deposit of the "cold" and glacial periods is sharply reduced, sometimes up to full absence. To explain this event only by ice cover within all glacial stages, probably, will be not absolutely correct. It is obviously, that thick layer of ice had made difficult a photosynthesis process and reproduction of the diatoms, but in this cases it is necessary to answer a question critically: what was the source of sedimentation in the lake? From the other hand, what was the way for input terrigenous sediments into completely closed by ice cover lake? We also should admit, that biogenic sedimentation in the El'gygytgyn Lake under the ice cover was absent. It is quite reasonable to argue, that extremal phases of glaciations correspond to hidden interruptions in lacustrine deposition. Therefore, most likely, the examined sediments without diatoms or poor frequency had been formed not during the extremal glacial periods, but most probably during some surface water temperature rise. The ice melted and terrestrial sediments were redeposited to pelagic side as a result of wave and turbulence effects lake depth. But temperature of surface water and spring-summer duration were still not ecological acceptable for diatom active reproduction.

Not only ecological, but also evolutionary changes of the diatom species were recorded in the sediments. The transitional forms between Cyclotella kuetzingiana-C. rossii-C. krammeri as well as phenotypic diversity among some Cyclotella and Pliocaenicus species observed in the lowermost layers of deposits is real arguments to suspect Middle Pleistocene age for the Units 7-10 from upper to bottom.

In whole, the Diatom flora of the El'gygytgyn Lake is unique. It strikes by the high specific diversity, in spite of the fact that El'gygytgyn Lake is characterised by severe natural environments and as well low-level diversity of ecological niches. In it as well as it origin is a riddle of the Diatom flora. The high degree of endemism is characteristic for Diatom flora of the lake, that is conditioned durable and strong geographic and ecological isolation of the El'gygytgyn Lake. It is necessary to specify also presence of a number of the typical species of the Baikal Diatom flora.

Impactites in lake Elgygytgyn (Siberia)

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B) Research Goal

To study the subsurface structure and crater fill of a well preserved young impact structure, and the relationship between impactite and possible ejecta material.
Our contribution can cover the following topics : core description and impact petrology, shock metamorphism, geochemistry major, trace and platinum group elements. We are also interested in using Elgygytgyn as an analog to study impact-crater lakes as an harbor for early life development.

C) Study of Impactites and Ejecta Material

We plan to contribute to the study of the impact breccia, suevite and melt rocks units recovered by the drilling. Sample material from lake Elgygytgyn cores will be examined from the point of view of petrology, geochemistry and shock metamorphism. The impactites will be classified in terms of mineral and modal compositions, rock textures, clast type and abundance, degree of shock metamorphism, major and trace element (including PGE) bulk abundances. This data will be acquired by using the optical microscope, SEM, microprobe, and laser ablation ICP-MS. Microscope and SEM investigation on breccia clasts will characterize the type, variety, volume and composition of basement and cover rocks. This approach will document the target-rock composition and how the different lithologies reacted to the impact event. The Elgygytgyn event probably caused the formation of ejecta material. We will search for possible ejecta material in stratigraphic sequence encompassing the crater age, either in . If found, the ejecta debris will be analyzed using the same approach as that applied to the impactite material. The characterization of the shock damage on quartz and eventually on other minerals in found in clasts of the impact breccias will provide information on the P/T conditions during the impact event. Shock metamorphism will be examined under the microscope and selected samples will be studied under the TEM. Petrological examination of melt matrix or melt inclusions will constrain the original melt volume and document the crystallization behavior and cooling history of the impactites. The careful analysis of major and trace elements (including PGE) in the melt may also help to identify or better constrain the projectile type and size and to evaluate the heterogeneity and fractionation of impact melts. Melt material from the crater will also be dated by ^{40}Ar / ^{39}Ar.

E) Impact hydrothermal system as haven for early life on Earth and other planetary bodies.
Phylogenic studies indicate that the earliest surviving life forms on Earth were likely thermophilic autotrophes. By analogy with actual forms, they may have lived in the hydrothermal settings. On early Earth impact rate was high and craters also hosted hydrothermal systems. Few terrestrial impact hydrothermal systems have been studied and little is known about their potential for supporting and preserving traces of life. With this idea in mind and financial support from the NASA Exobiology program our group is currently investigating the hydrothermal potential of two large impact structures Sudbury and Chicxulub. Although much smaller, the Elgygytgyn crater may also have contained directly after the impact a hydrothermal system. These conditions may have influence the first sedimentary units deposited in the newly formed lake . We anticipate that rapidly after the impact an environment was created, strongly influence by the active hydrothermal system, with a variety of mixing fluids, disequilibrium chemistry, and nutrients that may have favored the synthesis of organic compounds and, thus active microbial activity. The rapid, low-temperature crystallization of carbonates and silicates in the early Elgygytgyn crater has most likely preserved fossilized microbial life and their chemical signatures. We plan to study the petrology, geochemistry and paleobiology of the contact between the impactites and the first sedimentary units deposited in the Elgygytgyn lake to constrain the chemistry of percolating fluids and the organic productivity. We will develop a detailed temperature history for the hydrothermal system using mineral alteration sequences and fluid inclusion microthermometry. The chemistry of the hydrothermal fluids will be investigated with stable isotopes and fluid inclusion analyses.

F) Equipment available

On top of the classical geological/mineralogical instrumentations the Dept. of Geology at the VUB hosts:
-Two stable isotope mass spectrometers.
A new DELTA plusXL Thermo Finnigan MAT mass spectrometer
A Delta E Finnigan Mat stable isotope mass spectrometer
4 lines for CO2 extraction
Dual inlet system
H/D collector
Conflow III interface
Kiel III carbonate device for automatically processing carbonate samples

-NA 1500 C and N (Carbon and Nitrogen) analyzer Carlo Erba

-Two noble gas mass spectrometers
MAT 240 mass spectrometer equipped with a Baur-Signer source and a Faraday collector
MAP 216 mass spectrometer equipped with a Baur-Signer source, a Faraday collector and a Johnston photomultiplier
Extraction and purification lines with SAES and Ti-Zr getter, developed at the VUB
3 induction heating ovens, resistance vacuum-oven with Eurothem head controller
A Quintal Brilliant II quadrupled Nd-YAG laser (IR., visible and UV) for small samples and single crystal analysis
UV-localization system
High resolution CCD-camera, micro-objective and monitor coupled to a microscope.

We also have access to the following instruments:

-Laser ablation ICP-MS for trace element analysis is accessible through the VUB Dept. of Analytical Chemistry and the Royal Museum of Central Africa.

-Two solid source mass spectrometers for the analysis of the Bp, Sr, and Sm. isotopic systems, and a brand new laser ablation Nu-instrument MC-ICP-MS, along with 3 clean labs for sample preparation are available at the University Libber de Brussels.

G) Publications relevant to the proposed research.

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10 m terrace of El’gygytgyn Lake and neotectonic movements

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Three main systems of lineaments in the region of El’gygytgyn Lake have been revealed on the base of remote sensing data analysis. Modern drainage system is submitted to the lineaments. There are lineaments of N-E, N-W directions and lineaments surrounding the lake depression in a radial way.

N-E and N-W lineaments are combined in line zones with long distance extension. This fact testifies to regional character of disjunctive dislocations. The youngest activation of the tectonic movements along N-W and N-E faults can be revealed from the base of drainage system analysis. Rivers Chivirynnet and Enmyvaam are controlled by zones of the most active and the youngest faults. Evidences of young activity of these faults are gained from the 9-11 m Lake terrace structure. In the east part of the Lake all terraces are of abrasional genesis whereas along the south and south-west shoreline they are accumulative. In the direction from east to west along the south shoreline the degree of 10 m terrace base jointing increases. The sediment thickness on the base of the terrace increases at the same direction. Granulometric composition becomes finer. Thus this terrace is abrasional to N-E from the mouth of Lagerny Creek. The base of the terrace is covered by 4 meters of bad sorted sediments 1,5 km to the south of the same Creek. To the west of Enmyvaam River this terrace is completely accumulative and the foot of sediments is under the Lake water level.The west side of Enmyvaam fault is downcast and the east is upcast. Probably the south side of Chvirynetskii fault is upcast relatively to the north side of the fault. Thus shoreline types are controlled by neotectonic movements.

Optically-stimulated luminescence dating of Late Quaternary sediments from Lake Elgygytgyn, Russia

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An exciting recent development in geochronology is the advent of optically-stimulated luminescence (OSL) for dating late Quaternary sediments. OSL of mineral grains, as in TL dating, is reset by exposure to sunlight prior to deposition and a time-sensitive charge is acquired from exposure to ionizing radiation post burial. The OSL signal is orders of magnitude more sensitive to solar resetting than TL providing potentially a more accurate measure of the time since burial and improved precision with potential one-sigma errors as low as 3%.

Polymineral fine-grained (4-11 µm) extracts from Lake Elgygytgyn sediments were dated by infrared stimulated luminescence (IRSL) analysis, using the multiple-aliquot additive dose method. Similar procedures were used in OSL dating of loess from North America and Europe that yielded ages in agreement with radiocarbon control up to c. 40 ka. Prior to analysis all aliquots were preheated at 140 °C for 10 hours and then stored for 24 hours. This preheat, similar to previous is effective in largely circumventing an instable luminescence component (e.g. anomalous fading) associated with laboratory irradiation and has yielded IRSL ages in agreement with independent chronologic control. Tests on luminescence signal stability were preformed by comparing changes in luminescence emissions for an additive dose between 0.74 kGy and 1.52 kGy after preheating at 140 °C preheat for 10 hours and storage for 24 hrs separate aliquots were measured immediately and after storage at 25 °C for 33 to 66 days (Table 1). Stability of the laboratory dose-induced luminescence is indicated by the ratio of luminescence emission after storage divided by the immediate measurement; a ratio of 1.0 indicates stable luminescence. The stability ratio for the lake sediment studied range between 0.96 and 1.02, which indicate little to no signal instability and the deviation from a ratio of 1.0 is within analytical resolution.

All samples analyzed by the total-bleach method with the solar reset residual level measured on four aliquots of each sample. The residual level was obtained by exposure to 1 hr of sunlight, which results in near-total resetting of the IRSL signal. The rate of IRSL in growth was evaluated by applying additive beta doses to the natural TL signal by a series of irradiations with a calibrated $^{90}Sr/^{90}Y$ source. The highest radiation dose added to the natural TL signal was at least five times the calculated De, which is usually sufficient for accurate extrapolation. The natural and additive-dose data were fitted by a saturating exponential function for emissions from the 2nd to 89th second of infrared excitation that encompasses over 95% of the measured IRSL signal and exhibits a pronounced plateau in De values. However, De determinations are limited by the extent of growth of luminescence with additive dose; if there is little increase in the resultant luminescence the response is "saturated. We consider De's calculated with <150% increase in luminescence emission with additive beta compared to the natural level to provide insufficient differentiation in dose response to calculate a finite equivalent dose.

A critical analysis for luminescence dating is the dose rate, which is an estimate of the exposure of the sediment to ionizing radiation during the burial period. Most ionizing radiation in the sediment is from the decay of isotopes in the U and Th decay chains and ^{40}K. The U and Th content are determined by thick-source alpha counting, which assumes secular equilibrium in the decay series or by ICPMS. A small cosmic ray component, 0.12 ± 0.02 Gy/ka, is included in the estimated dose rate following. The alpha efficiency is determined for infrared stimulation for multiple aliquots of the polymineral fraction and has a rather narrow range from 0.03 to 0.07. A moisture content for the burial period was derived from the measured moisture content of the core and decreased down core.

IRSL ages on Lake Elgygytgyn exhibit coherency down core (Fig. 1). The youngest sediments dated at 66-70 cm and 116-120 cm depth yielded ages of 10.2 ± 1.0 ka and 17.0 ± 1.5 ka, respectively. However, these IRSL ages are about 5 ka younger than corresponding ^{14}C ages on disseminated organic material from the upper 1.5 m of the core. This age disagreement may reflect the millennial-scale residence time of carbon on Arctic landscapes or fundamental instabilities of the luminescence signal that were not adequately removed in the laboratory. We also attempted to date the upper most 2 cm of lake sediment from a gravity core but this level was dominated by clay and did not render statistically significant luminescence signal. A deeper sample in this core (20-21 cm) yielded an apparent age of c. 100 ka, indicating the occurrence of old sediment in the near surface. There is remarkable consistency of IRSL ages and correlation-based ages between c. 20 and 150 ka indicates that the measured luminescence signal is chronologically significant. Two deep levels in the core (12.3 and 8.85 m) dated >175 ka and were at saturation of the luminescence signal. It appears that the effective upper limit of IRSL dating is 175 to 200 ka. This "200 ka" limit reflects a dynamic equilibrium between electron trap occupation and trap emptying with an infinite matrix dose.

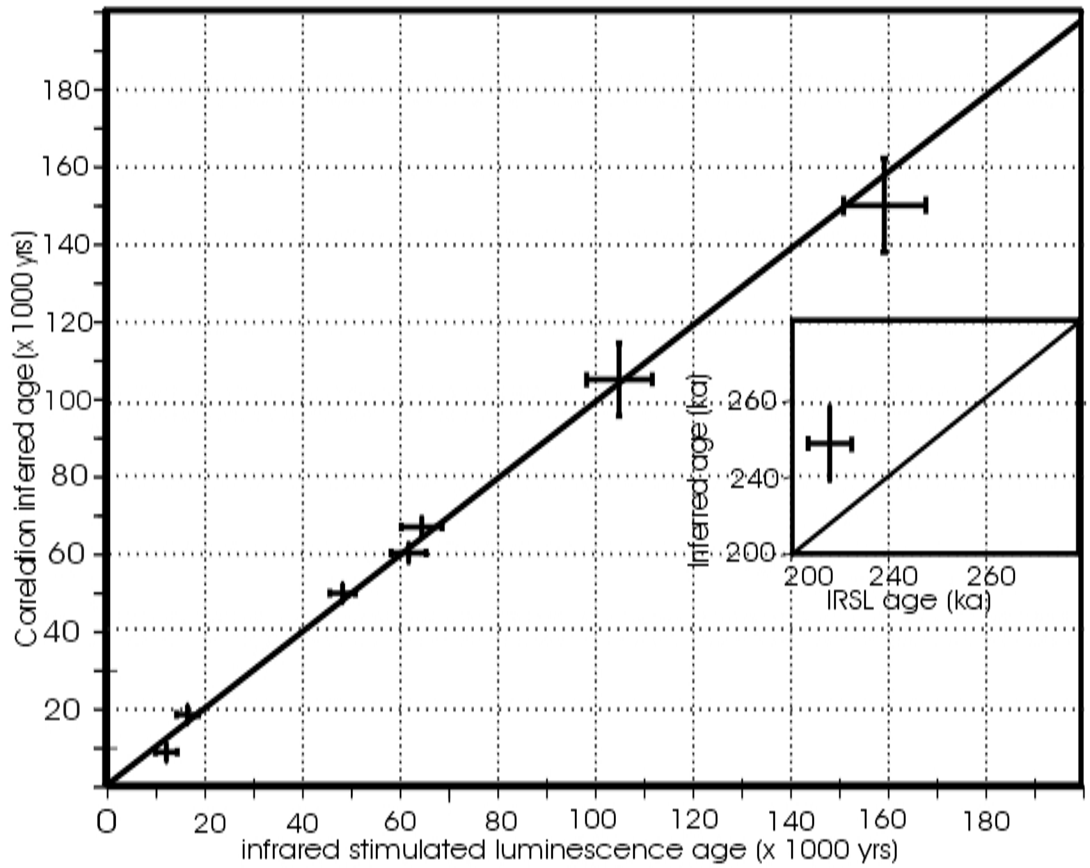

Fig. 1: Correlation-inferred age versus IRSL ages for Lake Elgygytgyn Lake, Russia

Image Analysis for studying thin sections of El'gygytgyn Lake sediments: a tool for understanding sedimentary processes and deciphering their climatic signal

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The study of the 12.5 m long pilot core has raised some questions about the sedimentary processes occurring in Lake El'gygytgyn that need to be resolved prior to undertaking deep drilling. In order to decipher sedimentary processes in relation to the climate background in which they occur, we suggest using a recently developed technique for image analysis of thin-section. The technique relies on backscattered electron microscope photographs digitized at a 1280 x 960 resolution from undisturbed thin-sections, cut by freeze-drying (Francus and Asikainen, 2001; Lotter & Lemcke, 1999). Processing of the 256 grey-scale pictures produces binary (black and white) images, where white pixels represent the clay-rich sedimentary matrix and black pixels represent siliciclastic grains. Measurements include grain surface, perimeter, shape, orientation and center of gravity. Processing of the data allows the retrieval of grain-size, bioturbation, and quantified sedimentary fabric information.

During interglacial periods, the sediment is non-laminated, while during glacial periods, the sediment is laminated, rich in vivianite and in blebs. Our preliminary microfabric analysis shows that the difference between the non-laminated and laminated fabric is not only the result of mixing due to bioturbation, but is also due to differences in shape and size of the sedimented grains. This observation implies a different mode of sedimentation. Because of this difference, it is necessary to assess wheter the changing mode of sedimentation modifies the proxy record.

Redox conditions in the lake must also be investigated in detail because they affect the preservation of some important proxies. Oxygenated water will favor the oxidation of the organic matter. Oxygenated water also enhances the dissolution of biogenic silica, which can dramatically alter the diatom assemblage recorded in the sediment (MacKay et al., 1999). Oxygen conditions in the water column and water/sediment interface can induce or exclude the formation of diagenetic neoformed minerals as vivianite, pyrite, greigite. Such neoformed minerals are known to influence the magnetic signal. Finally, bioturbation will mix the sediment, reducing the resolution of the record. Our preliminary measures on test thin-sections show that the image analysis methodology developed by Francus (2001) is able to differentiate laminated from bioturbated sections in very high resolution.

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NEW DATA ABOUT THE MORPHOSTRUCTUREOF THE ELGYGYTGYN METEORITE CRATER

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As a result of studies conducted in 2000 by a team of specialists, new data have been obtained about the morphostructural characteristics of the Elgygytgyn Lake area, which serve as a basis for us to suggest the occurrence of a satellitic crater in the Lagherny Creek area.

The Crater's morphostructure.

The crater's mountain rim has the external (drainage divide) and internal (basement) uplifts, which are separated by a well-defined arcuate faulting. These morphostructural elements, together with the piedmont plain and the lake bottom, have in general a concentric pattern of their occurrence. The axial line of the external uplift is bounding the area of Elgygytgyn Lake. It corresponds well (with the exception of the Lagherny Creek area) to a circumference of radius about 9.6 km, with its central point somewhat displaced to the lake's western shore. The internal uplift is an arcuate system of mountain blocks surrounding the lake in the west, south and east. It is separated from the external uplift by a set of deep saddles and has in general lower elevations. There is not a crater's rampart, but, presumably, the evidence of it may be the mass occurrences of large impactite boulders on surface of the interior uplift.

Faulting.

Both external and internal uplifts are subject to rimming arcuate and radial fracturing. An arcuate concentric fault was for the first time reported in 2000; it bounds the interior uplift in the east of the depression from Otveghirgyn Mountain to the right side of the Enmyvaam River for about 12 km; in its southern part it is associated with crush belts in river bluffs and the lake terrace basement.

The Lagherny Creek area as a possible satellitic crater.

The Lagherny Creek area displays an obvious concentric zoning in its morphostructure, that is much similar to that of the Elgygytgyn Crater and can be as well distinguished into three main structural elements. The external uplift is marked by a drainage divide, that corresponds well to a circumference of radius 3.2 km and with its central point placed 3.4 km to the east of the lake shore. The internal uplift is also well-defined and is separated from the external one by arcuate fracturing. It is rimming an equant depression, that, in fact, perfectly corresponds to a circumference of radius about 1 km and is tangent to isohypse 580 m.

In its mouth area, the Lagherny Creek is crossing a mountain ridge, the drainage divide of which is bounding both the areas of Elgygytgyn Lake and the Lagherny Creek. There are gentle (10-15°) thrust faults in the Mount Rozovaya bluffs, which have amplitude 15 cm and are directed toward the lake. But these thrust faults have a southeastern dip (140°) directed away from the lake, which fact suggests a former pressure directed to the south-east (320°) and coming from the central depression of the Lagherny Creek area.

The southern part of this ridge is featured by an intense tectonic fracturing consisting of many short (from 100 m to 1 km) fractures having northwestern, northeastern and submeridional directions, and, due to this, this area structurally resembles «a broken plate». On the lake side, the ridge is bounded by an arcuate fault associated with a crush belt. Bedrocks occurring to the south of Mount Rozovaya reveal a greater rock crushing intensity till block brecciation. Rock crushing intensity reaches its maximum in the basement of the lake terrace, to the south of the Lagherny Creek mouth, where there are lenticular boudins of volcanites placed nearly horizontally and hosted in fine clastic and mylonitized matrix.

The above-mentioned features of the western part of the Lagherny Creek area are in general anomalous and differ drastically from those of its northern and eastern areas characterized by a massive and uniform topography and scarce fracturing, and also from other areas of Elgygytgyn Lake mountain rim. Using these facts as a basis, we may assume that such characteristics of the boundary ridge, that occurs between the lake and the Lagherny Creek area, as highly crushed rocks and thrust faults directed toward the lake may be due to a greater dynamic activity from the east of this area. The field data obtained and the similarity established between the concentric structure of the Elgygytgyn Crater and the Lagherny Creek area have served as a basis for us to make a conclusion about a satellitic crater in this area. There are many examples of double meteorite craters, which are supposed to be due to a destruction of a cosmic body near the Earth. These are the well-known Karskaya and Ust-Karskaya, Kamenskaya and Gusevskaya double astroblemes of Cenozoic, in the territory of Russia.

NEW DATA ABOUT THE LATE PLEISTOCENE AND HOLOCENE SEDIMENT SEQUENCES FROM THE ELGYGYTGYN LAKE AREA

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The lake terraces at 2.5-3 m and 9-12 m height and the lower bank terraces of creeks flowing into the lake and the Enmyvaam River were for the first time studied by O.U.Glushkova in 1991.
Sediments sampled from the lake terrace of 9 m height in the mouth of Creek 4 (sampling site O-100) contain, in their upper part, spore-and-pollen spectra typical of the Karginsky Interstage. Cool spectra from the middle part of the sedimentary core are typical of the Sartan Ice Age (analyst B.V.Belaya).
Plant residues sampled at depth 0.4 and 0.8 m in the source area of Creek 3 (sampling site O-107) have the following radiocarbon age datings: 4850+/-400 (MAG-1434) and 5080+/-35 (MAG-1435), respectively. Their spore-and-pollen spectra (analyst T.B.Solomatkina) are typical of the late Atlantic time of Holocene.
The first above-floodplain terrace of the left tributary of the Enmyvaam River, that has height 2.0-2.1 m (sampling site O-109), consists of gray-yellow sandy loam with intercalations of plant residues, peat, pebbles, and loam, and contains many stems and branches of large shrubs up to 10 cm in diameter, which do not exist there at present. Radiocarbon age datings ranging from 6620+/-30 (MAG-1476) to 9250+/-90 (MAG-1477) were obtained for peat, plant residues and wood sampled at depth 1.05-1.7 m. The spore-and-pollen spectra obtained are typical of the Boreal time of Holocene (the conclusion of T.B.Solomatkina).
During summer 2000, seven rock sequences of lake terraces were examined over the western, southern and eastern shores of Elgygytgyn Lake. There were 76 samples taken for palynologic studies and 20 samples for radiocarbon age determinations. The established spore-and-pollen spectra range from the Karginsky Interstage (Stage 3) to the Recent (analyst T.V.Stetsenko).

On the lake southern shore, 0.5 km to the west of Creek 4 (sampling site GS-10), the lake terrace (height 10-12 m) consists of coarse pebbles, gravel and sand. The spore-and-pollen chart obtained is distinguished into three pollen zones, which are correlative with EG-10, 11 and 12 zones of bottom sediments from the lake central part (borehole PG-1351). A sedimentary core taken from 7.8 - 3.05 m depth interval shows a climate warming through the Karginsky Interstage (stage 3). A maximum Sartan cooling was at depth from 3.05 to 0.35 m (stage 2). The uppermost 0.35 m interval demonstrates a drastic change in plants, that has been typical of majority of Pleistocene-to-Holocene transitive zones throughout western Beringia during the last 12300 years. The same change in plants has been established for core samples from borehole PG-1351, for the time point 12250+/-70 years ago.
The lake terrace, that is placed to the south of Creek 50 and has 7-9 m height (sampling site GS-19), consists of gray-brownish sandy pebbles and gravel containing spore-and-pollen spectra typical of birch-and-alder tundra. Only the uppermost 0.45 m interval has an increased pollen content of mountain pine, that was typical of interior Chukotka 8000 years ago.

The lake terrace, that is placed over the western shore, 250 m to the north of the mouth area of the Lishainokovy Creek (GS-26) and has 3-5 m height, contains three pollen zones. The herbaceous zone of 1.15 - 0.78 m interval reflects a maximum cooling through Sartan (stage 2). These spectra are similar, by their compositions, to EG-11 zone of bottom sediments. Within the interval from 0.78 to 0.25 m, there was a drastic change of mosaic herbaceous tundra by high birch and alder shrubs; this event can be compared with 0.74 m borehole interval of 12250+/-70 years ago.

The first above-floodplain terrace, that is placed in the mouth area of the first left tributary to the Enmyvaam River and has 2.5 m height (GS-24), contains three pollen zones established by 15 spore-and-pollen samples. Pollen spectra from 2.50 - 2.10 m interval (zone 1) reveal a change in vegetation cover, that was typical of western Beringia during the Pleistocene-to-Holocene transition. Spectra from 2.10 - 1.34 m interval (zone 2) testify to a significant warming 9.5 - 8.0 thousand years ago. Zone 3 is not uniform by its composition and shows a gradual replacement of birch-and-alder tundra by grass-and-moss tundra, which was typical of mid-Holocene.

A terrace 2.5-3.0 m high in the mouth area of the Lagherny Creek consists of pebbles and sand with thin humic and peat interbeds. Twenty spore-and-pollen spectra (sampling sites GS-12/1 and GS-12/2) are typical of maximum climate cooling through Sartan. Spectra from the middle sequence display a Pleistocene-to-Holocene transition. The uppermost 0.7 m interval demonstrates the climatic conditions similar to the modern ones. Spore-and-pollen spectra from GS-32 sampling site are typical of a warming event in Holocene.

During field studies in 1991 and 2000, lake sediments were found over the southern and eastern shores of the lake at 45-50 m height. Unfortunately, we still lack their age determinations.

Sediments, which range by their spore-and-pollen ages from mid-Pleistocene to late Pliocene (analysts B.Belaya and T.Prokhorova), were found in river terraces, which have height from 15-25 to 120 m and are placed in the Enmyvaam and Chanuvenvaam river valleys, 25-45 km to the south of Elgygytgyn Lake. A thorough and accurate examination of the Enmyvaam River terraces must be continued, which would allow us to have a reliable interpretation of age determinations of the lake bottom sediments.

Morphology of the rim of the El'gygytgyn impact crater in Chukotka, Russia

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The Elgygytgyn impact crater is located in Chukotka peninsula, Russia. The crater is a circular basin about 15 km in diameter surrounded with uplifted original rim. The rim crest diameter of the structure is 18 km. The floor of the crater is occupied with the Elgygytgyn lake about 12 km in diameter. The lake is surrounded with a complex system of terrases, the highest ones are elevated up to ~40 m and ~80 m above the lake level [1, 2]. The original crater rim elevates above the floor of the basin up to 200-300 m in the western part of the structure to 100 m and less on the east.

Twenty four radial profiles of the structure across each 15° were made using the topographical maps of the crater to compose the summary morphological profile of the rim from the foot of inner wall of the crater outward to the distance of two crater radii (Fig.1).

The rim has asymmetrical profile with steep inner walls and gentle outer slopes. The outer foot of the rim gradually turns to the level of the surrounding area at the distance of about 1.6 crater radii from the center of the structure [3]. The height of the rim flanks above the initial surface level at the distance from 1.125 to 1.625 crater radii has an exponential character corresponding to the empirical formula proposed in [4]: $h_r = h_R\,(R/r)^B$

where h_r is the height of the rim at the distance r from the crater center, h_R is the initial height of the rim crest and R is the crater radius. The power index B is equal to 8 in the case of the Elgygytgyn crater differing from its meaning from 3 to 6 of the lunar craters [4]. It is suggested that more abrupt lowering of the Elgygytgyn rim in comparison with the rims of lunar craters depends on the difference in the gravity on the Earth and the Moon. The initial height of the rim crest was 230 m accordingly to this relationship. The measured mean height (1) and calculated by the present formula height of the rim (2) at the distances from 0.825 to 2.125 crater radii is presented in table 1:

Table 1

The distance from the crater center, R	0.825	1.0	1.125	1.250	1.375	1.500	1.625	1.750	1.875	2.0	2.125
1	56	142	88	37	18	9	4	14	7	7	0
2	-	230	88	37	17	8	4	2	1	1	0.5

The weakly expressed outer rim was established around the Elgygytgyn impact structure at the distance of about 1.750 crater radii. It is separated from the foot of the main rim with the gentle lowering of the surface, which was used by the sections of some creeks and river valleys oriented concentric to crater rim at the distance of about 1.600 – 1.650 crater radii [3]. A similar subtle concentric feature was discovered around the Bosumtwi impact crater at a radial distance of about 8 to 10 km or 1.6 – 2.0 crater radii [5].

The Elgygytgyn crater is surrounded with a complex system of faults those play an important part in the structure of the rim and surrounding area. The main type of faults are the radial ones, while arcuate concentric faults rarely occur around the crater basin. The faults are distinctly expressed on the surface and clearly recognized on the aerial photographs. They are the lows in relief from about 0.5 km to 6-8 km long and 1m to 10 m width. The fault zones are composed of unconsolidated detrital material weakly cemented with loose finegrained matrix. The main faults were used by the drainage system of the crater rim and its flanks. The faulting caused extensive erosion of the rim and determined the gentle dome-shaped profile of its crest.

The schematic map of faults was composed by use of the aerial photograhs and was verified with the surface study (Fig. 2). Density of the faults was determined across the crater rim to the distance of four crater radii along the longitudinal and latitudinal profiles [6, 7]. The fault density was calculated as a number of faults per km^2. The faults from 0.5 km long and more were took into account. The highest density of faults was observed at the inner walls of the crater rim. The transition from the megablock breccia of the crater basement to the hardly faulted rocks of the rim occur in the north-eastern part of the structure. The density of faults drops down to the distance of 2.5 – 3.0 crater radii, where it reaches the regional density of faults in the area.

The width of faulting zones around some terrestrial impact structures is from 1.9 to 2.2 of their radii [8, 9]. Near the same relative extent of faults was determined for the lunar craters [10].

The Elgygytgyn is one of the best preserved complex impact structures on the Earth surface, that enables to get some regularities of the rim morphology and crater structure.

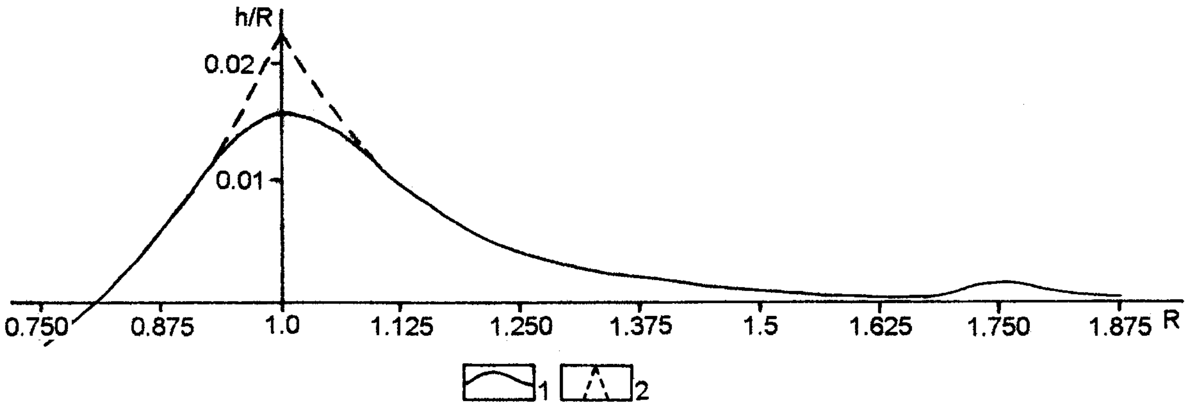

Fig. 1. Morphology and height of the Elgygytgyn crater rim.
1 – Measured mean height; 2 – Calculated height

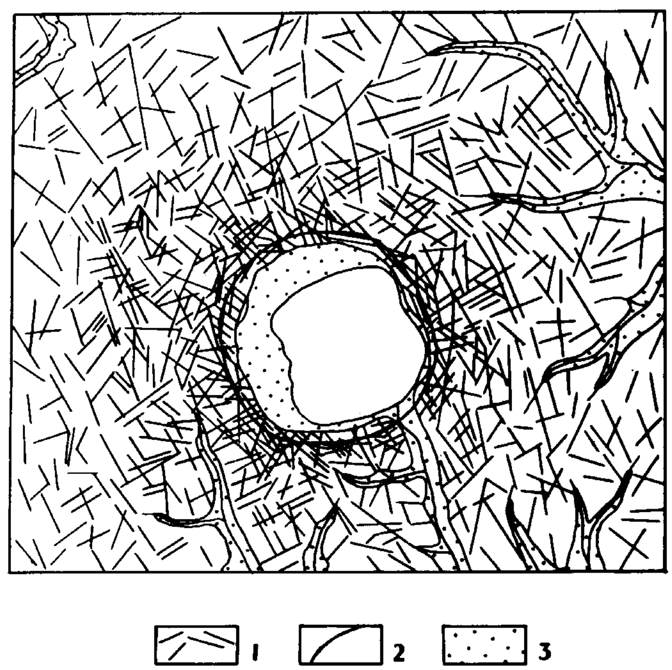

Fig. 2. Faults around the Elgygytgyn crater.
1 – Faults; 2 – Crater rim; 3 – Alluvial and lacustrine deposits.

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Lake Drilling in ICDP: proposals, requirements, support

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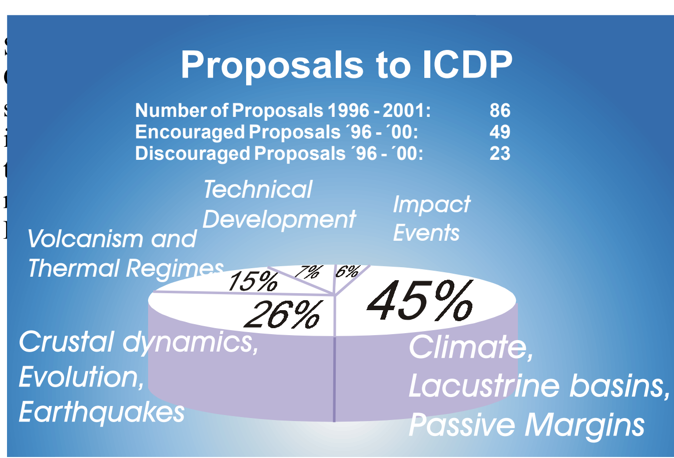

...lling are co-ordinated within the International ...aims at challenging themes of geoscientific and ...ronment. The principle advantages of such an ...ng sites of global significance, concentration on ...ants arising from international co-operation. A ...deal with paleo-climate related scientific goals. ... to assist in the development of full research programs and technical plans, e.g. through international workshops. Fully developed projects have already received financial support towards drilling operations. Thereby, ICDP's policy is to seed money to get projects started and to initiate commingled funding through various national and international organisations.

In addition, technical, managerial and operational support for drilling is an important component of ICDP's funding strategy. The GLAD 800 Global Lake Drilling facility has been funded by the program in response to the need for affordable lake drilling and is now operated in a Joint Venture with DOSECC. The Operational Support Group of ICDP has developed geophysical slimhole tools as well as core scanning and logging facilities and information management systems which are available for approved projects.

ICDP projects are open to scientists from ICDP member countries upon request to the Principal Investigators. Detailed information on ICDP and current projects is available at "http://www.icdp-online.org"

The Bosumtwi Impact Structure: Preparations for an ICDP Deep Drilling Program

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Background

The Bosumtwi impact crater is located about 30 km southeast of the town of Kumasi in the Ashanti Province, Ghana (West Africa), centered at 06°32'N and 01°25'W. The crater is almost completely filled by Lake Bosumtwi and has a rim-to-rim diameter of about 10.5 km. The lake has a diameter of about 8 km and a current maximum depth of about 80 m. The crater rim rises about 250 - 300 m above the lake level. On topographic maps a subtle concentric outer ridge (with a total diameter of about 18 km) appears in some sections of the structure, but its origin is still not clear (cf. Jones et al., 1981, and Reimold et al., 1998). The crater has an age of 1.07 Ma (cf. Koeberl et al., 1997a) and was excavated in lower greenschist facies metasediments of the 2.1-2.2 Ga Birimian Supergroup. In general, the regional geology around the Bosumtwi crater is dominated by graywackes and sandstone/quartzitic rocks, but especially in the northeastern and southern sectors shale and minor mica schist are also present (Woodfield, 1966; Moon and Mason, 1967; field observations by WUR and CK, 1997). Several Proterozoic granitic intrusions occur in the region around the crater, and a small number of strongly weathered granitic dikes were observed in the crater rim as well (Jones, 1985a; Reimold et al., 1997, 1998). The most detailed geological survey of the crater area was reported by Junner (1937), and is the basis of the schematic geological map of Jones et al. (1981).

Lake Bosumtwi has been known to the scientific community since late last century, but its origin was the subject of a controversy. During the past decades, though, it's origin my meteorite impact has been confirmed (see, e.g., Chao, 1968; Jones et al., 1981; Littler et al., 1961). The Bosumtwi crater is of special interest as the likely source crater for the Ivory Coast tektites, which were first reported in 1934 (Lacroix, 1934) from a small area of about 40 km radius within the Ivory Coast (Cote d'Ivoire), West Africa. A variety of arguments was used to conclude that Bosumtwi is most likely this source crater, including similar chemical compositions (Schnetzler et al., 1967; Jones, 1985a), and similar isotopic characteristics for the tektites and rocks found at the crater (e.g., Schnetzler et al., 1966; Shaw and Wasserburg, 1982), and the similar ages of tektites and Bosumtwi impact glasses. While these early published ages range from 0.71 to 1.2 Ma for Ivory Coast tektites, recent precise fission track and step-heating ^{40}Ar-^{39}Ar dating on both Ivory Coast tektites and Bosumtwi impact glass established a reliable age of 1.07 ± 0.05 Ma for the Bosumtwi impact event (Koeberl et al., 1997a).

Up until 1997, our knowledge of the Bosumtwi impact structure was fairly limited. Detailed petrographic studies of rocks of the crater rim and of ejecta (suevitic breccias) were done only recently (Koeberl et al., 1998) and refer only to rocks available at surface exposures. Only recently some structural geological work along the crater rim was done (Reimold et al. 1998). Before 1997, no detailed geophysical studies of the area were available, and the existence of a central uplift (characteristic of complex craters) was unknown. Recently, additional field work was conducted at the Bosumtwi impact crater, e.g., to study the structural aspects of the crater rim (Koeberl et al., 1997b; Reimold et al., 1997). In addition, a high-resolution aerogeophysical survey across the structure was conducted in early 1997, to obtain more detailed information of the subsurface structure below and beyond the lake (cf. Koeberl et al., 1997b; Pesonen et al., 1998, 1999a). Petrographic and geochemical studies of rocks from the Bosumtwi impact crater were recently performed by Koeberl et al. (1998).

Motivation and Goals of Drilling Project

The motivation for the drilling proposal includes two main aspects:

- to obtain a complete paleoenvironmental record over the duration of one million years in an area for which so far only limited data exist;
- to obtain detailed information on the subsurface structure and crater fill of one of the best preserved large young impact structures, to correlate these data with the geophysical studies that were recently completed or are in progress, to determine the presence and composition of melt bodies in the crater fill, and to perform comparative geochemical (including isotopic) and petrographical studies of the crater fill breccias, possible melt rocks, basement rocks, and known ejecta.

The presence of a 1 million year old lake in a geographically and climatically important location, the lake sediments has the potential of providing a 1 million year record of paleoclimatological data. Bosumtwi is one of only few large natural lakes in Western Africa. The crater is situated at a crucial location between the influence zones of the West African monsoon and the Sahel drought. Only minor variations in the regional (and global) climate are likely to cause significant changes in the rainfall over the Bosumtwi area. Influx of wind-borne sands from the Sahara (the Harmattan winds) may change as a result of local changes in the rainfall pattern and wind directions. The study of the past record of rainfall and paleoclimate in the area will help to correlate similar record in other tropical areas and may allow a better understanding of future climate developments, which should be beneficial to the Western African agriculture. Most countries in this area depend heavily on agriculture.

Early paleoclimatic studies at Bosumtwi were made in the 1960s and 1970s by taking shallow sediment cores in the lake. The results of these studies allowed to obtain a record for local climate and vegetation, as well as lake level and water composition, over a period of more than 25,000 years (see, e.g., Smit, 1964; Talbot and Delibrias 1977, 1980; Talbot and Johannessen 1992). Recent hydrological studies include those of Turner et al. (1996). It would be of great importance and interest to extend the paleoclimatic record in the area by a factor of 40 compared to the earlier studies. This can only be done in a deep drilling project.

Understanding the subsurface crater structure is not only important for a correlation between the various basement rock types (so far mostly unknown), crater-fill and ejected breccias, and melts, but also to determine if a proposed subsurface gas pool underneath the crater lake (Jones, 1983) is actually present. The new seismic studies (1999-2001) have actually indicated severe gas-charging of the lake sediments on the margins of the lake basin, which obscures the subsurface images of the lake margin.

Because the crater is buried under the lake sediments, and due to the lack of deep drill cores, geophysics is the only way to investigate its subsurface structure. The results of the new geophysical surveys indicate the presence of a central uplift. Deep drilling within the framework of an ICDP project would allow to tie the seismic record to actual subsurface lithologies, and would provide the basis for the paleoclimatic studies mentioned above.

Current Geophysical and Geological Work: Recent Results and Background Data for Deep Drilling

Deep drilling at Bosumtwi would be an ideal project, because basically all necessary pre-drilling surveys are currently being undertaken as parts of independent research programs.

Currently, three groups are actively involved in studies of the Bosumtwi crater, covering various aspects. Two groups (Germany; U.S.) are mainly interested in geophysical measurements (gravity, seismics) to study the subsurface topography of the crater and, especially, Lake Bosumtwi, and have already done part of their field work (1999-2000). In addition, the U.S. group has paleoclimatology as a main topic and they have already taken some shallow cores from the lake bottom. A third group (Austria/South Africa/Finland) has been involved in geological fieldwork and aerogeophysics since 1997 and has just completed a shallow drilling program outside the crater rim to study ejecta deposits.

At the beginning was a high-resolution airborne geophysical survey across the Bosumtwi structure, which was carried out in 1997 by the Geological Survey of Finland (GSF) in co-operation with the University of Vienna and the Ghana Geological Survey Department (Ojamo et al., 1997). It included measurements of the total magnetic field, electromagnetic field and gamma radiation (for details of the survey, see Pesonen et al., 1998, 1999; Koeberl et al., 1997b). The results of the aeromagnetic magnetic measurements, together with modeling calculations, have been published by Plado et al. (2000) and indicate the presence of a magnetized body, probably consisting of impact melt rock.

The first magnetic field studies of the structure were made in 1960 by Hunting Surveys Ltd for the Ghana Geological Survey Department (Jones et al., 1981). Up to 1999, no good gravity data of the crater area, and none over the lake, existed. During the 1999/2000 field season, densely spaced gravity and magnetic data were taken by the German research group (University of Munich, within the Kiel-Munich-Frankfurt collaboration) immediately around the crater lake and in the surroundings of the impact structure. The results show a decrease of gravity towards the crater as a result of fractured and brecciated rocks. For the next season, the group plans to take gravity data over the lake.

Most important of the current studies are seismic investigations, which are done by both, the U.S. group (Syracuse University, C. Scholz) and the German group (B. Milkereit, Univ. Kiel). The U.S. group has used a catamaran (the R/V Kilindi) to perform multichannel reflection imaging of the subcrater below the lake bottom. The German studies, which involve also refraction seismics, are still ongoing.

The results from the seismic studies (e.g., Karp et al., 2000; Scholz et al., 2000) show clearly the presence of a central uplift with a diameter of about 2 km and collapsed center. The central uplift is slightly off-center in the crater, towards to the NW. This should have interesting consequences for modeling efforts and a connection with the Ivory Coast tektites. The peak of the central uplift is estimated to be only about 150 m below the lake bottom. The maximum thickness of the sedimentary section is about 350 meters – it is this section that would contain the important paleoclimatic record. The seismic velocity was found to be uniform within the sediment section. However, the presence of a gas curtain around the lake margin obscures the subsurface images in that area, and it has also not yet been possible to distinguish between fractured bedrock and fallback ejecta. In addition, during the work of the R/V Kilindi, several shallow cores were taken of the lake sediments, and preliminary results show that they can be correlated with cores taken in the 1970s. These studies will provide the basis for the deep drilling and the understanding of the paleoclimatic record.

Upon completion of the fieldwork and data reduction of the three groups in about 1-2 years it is expected that the database will allow development of a detailed knowledge of the sub-crater structure (thickness and structure of post-impact infill, breccia and melt rock occurrences inside the structure, existence of a central uplift, etc.). These studies are necessary and welcome background conditions for the development of a deep drilling project. The geophysical studies will allow deciding on a good location for the deep drill hole.

The goals of such a deep drilling project, to be supported by ICDP, include the following:

1. Because of its unique location, climate sensitivity, and paleoenvironmental potential it is expected that obtaining a complete post-impact lacustrine section will allow to place important constraints on the paleoclimatology of the area during the past 1 million years; e.g., a detailed understanding of long-term variations in the West African monsoon.

2. Bosumtwi is one of only two large (>10 km diameter) young (about 1 Ma) impact structures on Earth and the best preserved one. Its interior crater structure is currently not known. Drilling will contribute to our understanding of the formation of a medium-sized impact structure and will provide ground truth for the situation on other planets.

3. Bosumtwi is the source crater of the Ivory Coast tektites; only 4 tektite strewn field are know on Earth and it is hoped that a drilling program will allow to place constraints on the question why tektites have formed at this impact structure.

4. The composition and nature of the subcrater basement rocks, and of probable melt rocks is not known; such data would be important to understand the composition of the crater-fill and ejected breccias, and to help with modeling the formation of tektites, which is currently an open problem in impact studies.

Workshop

In view of the new results from the three main research groups mentioned above, and for planning a detailed full proposal to ICDP, a workshop was held September 22-24, 2001, at the GFZ Potsdam (ICDP Headquarters) in Germany. This 2 ½ day workshop consisted of ½ day of informal exchanges, 1 day of reviews of the current state of knowledge of the Bosumtwi crater, including previous work on Bosumtwi (split in one half day for each, impact cratering studies and paleoenvironmental studies), and 1 day of planning for the drilling proposal. It involved about 30 key researchers who are either currently working, or have worked, or have expressed interest to work, on various aspects of the Bosumtwi structure. All researchers who want to participate in the ICDP project were asked to write up their past/recent and the proposed work on Bosumtwi.

Some of the goals of an ICDP project at Bosumtwi that were summarized at the workshop are:

- ***Importance of Bosumtwi***
- Largest young impact structure known on Earth
- Extremely well preserved (and accessible)
- All pre-drilling, site surveys already finished
- One of only 4 craters with tektites
- Only the Ries has been studied in similar detail (larger, older and more eroded)

- ***Drilling program goals (Impact Cratering Studies)***

- Crater Morphology and Geometry Studies
- Study of Crater Fill Breccias and Melts
- Geophysical Studies (Ground Truth for Seismic, Gravity, Magnetic, etc. studies)
- Study Post-Impact Events
- Astrobiological implications (extreme environments and extremophiles)
- regional impact-induced destruction and localized trauma to living systems and climatic influences from impact event

- Drilling program goals (Paleoenvironmental Studies)

  - 1 M.yr. high-resolution record: lake level change; Sahara/Sahel dust transport; geomagnetics; cosmic ray flux
  - Biological evolution within lake basin
  - High-resolution record of seasonal variability over several time windows
  - Sensitivity to climatic forcing
  - Catchment hydrological modeling
  - Environmental background to human occupation in West Africa

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Volcanostratigraphy of the El'gygytgyn Basin and the Age of the Impact Event

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Regional Geology and Volcanostratigraphy

Lake El’gygytgyn lies in the Okhotsk-Chukotka Volcanic Belt (OCVB), which extends from the Chukotka Peninsula, adjacent to Alaska, through to northern China, a distance of about 3000 km. This belt is composed of subaerial calc-alkaline volcanic rocks including andesites, rhyolites, andesite-basalt sequences, diorites, tonalites, granodiorites, quartz monzanites and granites (Belyi, 1994). It was formed in Late Cretaceous time, apparently as the result of subduction along a continental margin such as is seen along 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 OCVB 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 rhyodacite is dense and nonporous and is crystalline to microcrystalline. Belyi (1994) has proposed that there are three recognized basic-acidic cycles of volcanic activity in the OCVB. The first cycle forms the lower Chaun series, which is widely exposed north and west of the lake. At Lake El’gygytgyn, six stratigraphic units from the upper two cycles are exposed. From bottom to top, the Pykarvaam, Voron'in and Koekvun' make up the upper components of the Chaun series, and make up the second cycle of volcanism, and the overlying Ergyvaam, Emuneret and Enmyvaam, form the third cycle. Units of the Chaun series (cycles I and II) are sometimes referred to as the “external zone”, while those of the third cycle are referred to as the “inner zone”. The boundry between these two zones passes along the southeast corner of Lake El’gygytgyn, although the nature of that boundary is not clear to us. In this location the volcanic rocks of the OCVB lie directly on rocks ascribed to the Chukotka Alaska terrane, although depth to this “basement” is uncertain.

Units of the OCVB in the vicinity Lake El’gygytgyn have been dated by the $^{40}Ar/^{39}Ar$ whole-rock step-heating method and span an age range of ~90 Ma down to ~67 Ma. Elsewhere in the OCVB, the lower units have been dated to be 105 Ma. Geochemical analysis of OCVB samples from Chukotka through Magadan indicates that there is a major change in tectonic style at approximately 85 Ma, corresponding to the transition from the Chaun series to the third cycle. The older units have a significant proportion of andesite and have geochemical signatures indicative of subduction while younger units show “bimodal” volcanism, indicative of an extensional setting. We attribute this transition to the accretion of the Koryak terrane (Harbert et al., 2000) and an eastward jump of the subduction zone.

Age of the impact event

It is generally accepted that Lake El’gygytgyn lies in the center of an impact basin (e.g. Masaitis, 1999). Gurov et al. (1978) conducted extensive field investigations of the region and reported glassy bombs and shock metamorphosed rocks, lending support to an impact origin. They noted the presence of radial and concentric fractures and reverse faults, features seen in other terrestrial impact structures. Gurov and Gurova (1979) also found that the chemical composition of the impactites was very similar to the average composition of the target rocks, although we have found that the impactites are depleted in volatile elements relative to the target rocks.

Belyi (1982; 1998), however, questions the impact origin hypothesis and instead presents arguments for an "endogenic impactogen" origin for the feature. This process involved extensive Cenozoic magmatic reactivation in the Beringia province and simultaneous formation of a neotectonic depression. One of the lines of evidence presented by Belyi (1998) for a volcanic origin are K-Ar ages that range in from 5.8 ± 0.5 to 8.4 ± 0.7 Ma indicating a protracted time of formation.

Laser $^{40}Ar/^{39}Ar$ dating of impact-melted volcanic rocks from the rim of Lake El'gygytgyn yields a 10 sample weighted plateau age of 3.58 ± 0.04 Ma (Layer, 2000). The argon step-heating method was critical in this study in identifying inherited argon in the samples due to incomplete degassing of the Cretaceous volcanic rocks during impact melting. This age is consistent with, but more precise than, previous K-Ar and fission track ages and indicates an "instantaneous" formation of the crater. This tight age control, in conjunction with the presence of impactites, shocked quartz and other features, is consistent with an impact origin for the structure and seems to discount internal (volcanogenic) origin models.

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Paleoenvironmental Reconstructions from El'gygytgyn Lake Based on Palynological Data

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The rich palynological data from El'gygytgyn Lake (Lake E) provide the most ancient, continuous record of vegetation and climate change from the Arctic. The pollen diagram spans the Holocene, late Pleistocene, and second part of the Middle Pleistocene and indicates relatively long periods of both stable (e.g., zones 9, 11) and fluctuating climates (e.g., zones 2, 3, 4, 10). We make tentative correlations to the marine isotope stages (MIS) based on pollen stratigraphic changes (Shilo et al., 2001, *Doklady Akademii Nauk* 376(2), 231-234). It should be noted that examination of modern pollen samples from El'gygytgyn and other lakes in northeastern Siberia suggest that the large crater lake is monitoring a regional and not a local signal, which is of benefit for interpreting broad-scale climatic changes. The modern vegetation in the Lake E catchment is predominated by herb-dominated tundra with occasional local patches of low shrubs, particularly willow (*Salix*).

The upper 75 cm of the Lake E core encompass the Holocene (MIS1) and late glacial transition. The late glaciation is characterized by a major shift from full-glacial herb tundra (MIS2; zone 11) to shrub birch (*Betula*) tundra and high shrub birch-alder (*Alnus*) tundra (zone EG12). The radiocarbon date of 12,250 +/- 70 (NSRL-11028) near the zone 11-12 boundary is in good agreement with the generally accepted age of 12,300 BP for the post-glacial increase in shrub birch in northeastern Siberia. Following this transitional period, pollen of dwarf stone pine (*Pinus pumila*) increases dramatically (zone 13). Other pollen records indicate that pine spread throughout the region ca. 8000 BP, indicating an increase in cold season precipitation.

The rise in shrub pollen percentages in zone 10, as compared to the herb-dominated spectra marking the last glaciation (zone 11), suggest a slight amelioration of climate likely associated with MIS3. Although the zone is dominated by grass (Poaceae), changes in shrub birch, shrub alder, and wormwood (*Artemisia*) pollen suggest shifts from relatively warm to relatively cool conditions. Such climatic fluctuations are consistent with the Karginskii interstadial environments of Siberia (Anderson and Lozhkin, 2000, *Quaternary Science Reviews* 20 (1-3), 93-126) and while the current data are inadequate, are also reminiscent of shifts marked in the North Atlantic during this period. During cool times, grass-wormwood tundra dominated the vegetation in the area of the lake. When climate was somewhat warmer and/or wetter, shrubs, especially shrub birch, were present, although they likely were not common across the entire landscape.

Full-glacial conditions are in place during zone 9 (MIS4), as indicated by the abundance of herb pollen taxa. A mosaic of grass-herb communities were present, and climate was harsh.

Lake E provides the first and best picture for northeastern Siberia of the last interglaciation (MIS5; zones EG6-EG8) and the transitions into and out of this warmer than present period. Changes in the main taxa suggest vegetation shifts that correspond to the substages within MIS5: MIS5e (zone 6), MIS5d (zone 7), and MIS5c-MIS5a (zone 8). As in the early Holocene, the maximum warming is marked by the appearance of tall shrubs and high percentages of birch and alder pollen. Pine became abundant regionally, suggesting an increase in winter precipitation. Such a climatic shift is consistent with indications of increased glaciation during MIS5d. Substage shifts in zone 8 are only suggestive and need further work.

Zones 1-5 represent the Middle Pleistocene. Pollen of wormwood and grass and spores of *Selaginella rupestris* dominate the zone 1 assemblage. Shrub pollen is absent or occurs only in low amounts. The vegetation cover is inferred to be discontinuous, and climate was likely extremely cool and dry. Shrub birch is present in moderate amounts in zones 2-4, but changes in its percentages and those of alder suggest a succession from herb-birch shrub tundra to herb-birch-alder shrub tundra. Conditions were more moderate than previously but still cooler and drier than present. Zone 5 (MIS6) is characterized by high percentages of wormwood and grass with relatively high frequencies of poppy (Papaveraceae) pollen. The tundra vegetation was likely discontinuous and climate was dry and cool.

Organic and isotope geochemistry of El´gygytgyn Lake sediments since 300 kyr BP

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The ca. 13 m long sediment core PG1351, recovered in 1998 from El´gygytgyn Lake, was investigated for total organic carbon (TOC), total nitrogen (TN), total sulphur (TS) and biogenic silica (opal) contents, and for TOC stable isotope ratios (δ^{13}TOC). Measurements were conducted at the Alfred Wegener Institute, in Potsdam and Bremerhaven. The results show widely coincident fluctuations in TOC, TN, TOC/TN, TS, and δ^{13}TOC. Opal, in contrast, fluctuates more independent on the other proxies. This chemical composition of the core, together with the sediment structures and colours, mirrors changes in the temperature and presumably precipitation development of the El´gygytgyn Lake region during at least the last two glacial-interglacial cycles. Four sediment units of individual composition are distinguished, reflecting different climatic and environemtal settings.

Unit 1 is characterized by low contents of TOC, TN, and TS, low TOC/TN ratios, high δ^{13}TOC values, and weakly stratified to massive sediments of olive gray colour. It is interpreted as reflecting a relatively warm climate that allows summer melt of the lake ice cover, significant fluvial sediment supply, and wave and melt-water induced mixing of the water column. In consequence, the lake has annual gas exchange with the atmosphere and the bottom water is oxygenated, enabling decomposition of organic matter and activity of an endobenthic fauna that leads to bioturbation and thus lack of sediment lamination. A relatively high biogenic primary production is indicated by high opal contents.

Unit 2 includes the near-surface sediments. It differs from Unit 1 by higher contents of TOC and TN, by higher TOC/TN ratios, and by partly higher opal contents and lower δ^{13}TOC values, but shows comparable TS contents, structures and colours. Unit 2 is interpreted as reflecting a peak warm period. Both an increase in aquatic primary production, and particularly an increase in the supply of terrestrial plant remains, possibly due to a more dense vegetation in the lake catchment, would explain the higher biogenic accumulation and TOC/TN ratios. The sediment structures and colours argue for an oxygenated bottom water comparable to the time of Unit 1 formation.

Unit 3 is characterized by high contents of TOC, TN and TS, by high TOC/TN ratios, by low opal contents and δ^{13}TOC ratios, and by distinct lamination, occurrence of clasts and brownish sediment colours. This composition can best be explained by a cold and dry climate that led to a permanent lake ice cover, a stratification of the water column, and an anoxic bottom water. By that means, the gas exchange with the atmosphere was hampered, and oxidation and grazing of the organic remains was excluded. A reduced but still present planctonic primary production, indicated in the opal contents, requires sufficient light penetration, which could be due to a widely missing snow cover on the lake ice. Such a setting also explains the clast occurrence, which could be due to agglomeration of particles during sediment transport through the ice along melt channels, as described for permanently ice-covered lakes without snow cover in Antarctica.

Unit 4 differs from Unit 3 by slightly lower contents of TOC, TN, and opal, slightly higher contents of TS and δ^{13}TOC, dark grey to black instead of brownish sediment colours, and the wide absence of sediment clasts. This composition indicates a permanent lake ice cover as during Unit 3 formation, but with a significant amount of blanketing snow on the lake ice, which reduces light penetration into the water column and thus biogenic production and excludes clast formation. In consequence, Unit 4 likely represents a cold but more moist climate than that during Unit 3 formation.

Taking the unit interpretation, and the currently available chronological information from core PG1351 (Nowaczyk et al. in press), peak warm conditions (Unit 1) at El´gygytgyn Lake only have occurred during Eemian (Marine Isotopic Stage 5.5) and middle to late Holocene times. Other interglacials and interstadials down to MIS 8 did not reach a comparably warm climate (Unit 2). Cold and dry conditions (Unit 3) occurred during the first part of MIS 2, the stadials of MIS 5 (MIS 5.2 and 5.4), and two cold stages in late MIS 6. A cold but more moist climate (Unit 4) existed during MIS 4, two stages in early MIS 6, and one stage at the end of MIS 8.

Future work on the Late Quaternary sedimentation in El´gygytgyn Lake

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Past work on the El´gygytgyn Crater, with joint Russian-American-German expeditions in 1998 and 2000, has supplied extensive information on the modern climate and sedimentation processes in the crater, on the Late Quaternary sedimentation history in the lake, on the thickness and architecture of the entire lake sediment fill, and on the Neogene surficial geologie of the area. The available data already justify a deep drilling of the sediment fill that promises to supply the first continuous, undisturbed, millennial-scale record of climate variablility in the Arctic since Pliocene time.

However, both the positioning and the interpretation of the core(s) would doubtless benefit from additional information that is planned to be obtained on a joint expedition in summer 2002. In order to adress some of the still open questions, the German collaborators from the University Leipzig and the Alfred Wegener Institute (AWI) in Sept. 2001 have submitted a research proposal to the German Research Ministery that seeks for financiation of the German proportion of the expedition costs and the investigation of the expected data and sample sets. Within the scope of the proposed project, the AWI Bremerhaven (Frank Niessen et al.) indends to extent the existing geophysical data set by additional seismic profiles and by a magnetic survey that may supply more detailed information on the crater morphology. The AWI Potsdam (Hans-W. Hubberten et al.) plans to conduct extensive investigations on the modern conditions and history of the permafrost in the western lake catchment, whose activity seems to have triggered graviational mass transport in the lake. Finally, the University Leipzig (Martin Melles et al.) wants to further improve our knowledge of the modern and Late Quaternary sedimentation in El´gygytgyn Lake.

For that purpose, the University Leipzig, firstly, plans to penetrate a subrecent slump in the western lake part that is well recorded in shallow seismic profiles, using up to 5 m long piston cores along a transect normal to the slump direction. Objectives are to determine the composition of the slump, whether the slump has generated a turbidite and, if it has, how that looks like, how well the slumped deposits are visible in the seismic profiles, and where and with which intensity the slump has generated erosion of the underlaying sediments. This knowledge would support the identification of slumps or turbidites in seismic profiles and cores from the lake center. By that, it would promote to study changes in slump source areas and variations in slump frequency, and to conduct calculations of the lake sediment budget.

Secondly, the University Leipzig wants to repeat coring of the uppermost sediments at site PG1351. In 1998, the uppermost 80 cm of the sediment record were split into 2 cm thick horizons already in the field, because their transport in the liner was regarded as too dangerous given the likelyhood of sediment mixture due to the high water content of the sediment. In consequence, neither a detailed core description nor a photographic documentation, microtexture studies on thin sections, or whole-core measurements of susceptibility data in 1 mm spacings are available from the upper 80 cm of core PG1351. The new core to be taken shall comprise at least the uppermost 1 m of the sediments and be transported to the lab in the liner. After core opening, the missing data shall be obtained by those scientists who have conducted the measurements already on the old core. Subsequently, the core shall be subsampled in 0.5 cm horizons, enabling to produce data sets with a much higher time resolution for the period since at least 20 kyr BP also from other proxies.

Finally, the planned expedition in 2002 shall be used to extent the currently available data and sample set that mirrors the modern sedimentation processes in the El´gygytgyn Crater. The work shall be conducted in close collaboration particularly with the American colleagues. Of particular interest are additional sediment samples from the brooks entering the lake in order to detect regional differences in fluvial sediment supply. The characterists of eolian sediment supply shall be studied on samples from snow fields and lake ice. The latter may also supply new information on the formation of sediment clasts. In the water column, special attention shall be drawn on the differences in the biological activity in the surface waters of the ice-covered and the ice-free lake, and on the flux of sediment compents to the lake bottom. The obtained data shall be compared with climatological and hydrological data and with the composition of an extended set of the surface sediments in order to study how the climatic and environmental setting becomes preserved in the fossil sediment record, and how that differs regionally in the lake.

Most of the work proposed here requires either the full season or the summer season, when the lake is ice free and the brooks are active. In consequence, the work cannot be conducted simultaneously with the planned deep drilling campaign, because the drilling likely would take place from the lake ice cover in winter/spring. The proposed work, therefore, has to be done independent and, in order to supply the data in time, should predate the drilling.

Inorganic Geochemistry Data as Climate Proxy in Elgygytgyn Lake Sediments , NE Russia.

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Elgygytgyn Lake is located in occurrence area of volcanic rocks of Late Cretaceous age. According to V. Belyi and B. Belaya (1998), volcanic rocks are distinguished into the Ergyvaam (tuff, ignimbrite), Koekvun (basalt, andesite-basalt, tuff, tuff-breccia, tuff-sandstone, tuff-siltstone), Voronin (ignimbrite, tuff) and Pykarvaam (ignimbrite and tuff) suites. Weathered rocks of these suites (predominantly the Pykarvaam Suite) are the sources for the modern lake sediments.

Inorganic chemistry data were obtained from 12.5m long sediment cores (muds). The entire core was regularly sampled for its geochemistry. About 190 samples were examined.

Concentrations of rare elements such as Rb, Sr, Y, Nb, Zr and also SiO_2, Al_2O_3, Fe_2O_3, TiO_2, MnO, MgO, CaO, Na_2O, K_2O and P_2O_5 were measured by X-Ray fluorescence analysis.

The geochemical data obtained were compared with oxygen isotope records of ODP site 677 from the equatorial Pacific and of core MD900963 from the Indian Ocean (Bassinot et al., 1994) and of core V19-30 in Pacific (Martinson et al., 1987).

As it has been established, all warm intervals in the core have low concentrations of TiO_2, MgO, Al_2O_3 and high concentrations of SiO_2, partly K_2O and high intensities of K/Mg and K/Ti ratios. Such regularity can be directly related to the specific weathering of volcanic rocks surrounding the Lake during different climates.

According to C.Cosby et al.(2000), clay minerals from the lake sediments differ by their composition in warm and cold periods. The warm climate periods were dominated by Illite-Smectite, and the cold climate periods were dominated by Chlorite. Illite has higher contents of SiO_2, and chlorite has higher contents of MgO (Brownlow, 1979). Titanium seems to be present in chlorite as an admixture.

Compositional differences in above-mentioned rock-forming (major) minerals, especially in TiO_2 and K_2O/TiO_2 agree well with oxygen isotopic curves and correspond to 1-8 stages. Many stages have substages. The comparison results were used by us as a basis to determine the age of the hosting lake sediments. The age determinations obtained agree well with paleomagnetic data, as well as with IRSL and AMS^{14}C determinations. A relationship between geochemical data obtained and climatic conditions has been also reported form other areas. Thus, for example, the sedimentary cores obtained from the Norwegian Sea, demonstrate the K/Ti intensity ratio coinciding with stadial-interstadial water fluctuations inferred from magnetic susceptibility records (Richter et al., 2000).

Among the rare elements Strontium (Sr) appears to be the best proxy of changing climate. Warm climate intervals in the core coincide with high concentrations of Sr. We presume that the excess Sr was introduced by diatom algae so that high diatom concentration coincide with warm climate and high Sr levels in the sediment. Interval from 300 cm depth to the top of the core is characterized by high concentrations of Yttrium (Y) and Niobium (Nb). The base of this interval coincides with the beginning of accumulation of «edoma» (=loess) complex in Northeast Russia. It is possible that enrichment of sediments Nb and Y connected with eolian processes.

There is a positive correlation between P_2O_5 and MnO. For some intervals in the core the concentrations are similar to those seen in the volcanic rocks, but in others the concentrations of both elements increase. We assume that Phosphorous (P) in the sediments is mainly derived from organic material. It would accumulate in the skeletons of fish and shells which eventually decomposed or dissolved. The large concentration of P produced conditions suitable for the growth of the authigenic mineral - Vivianite. Aggregates and nodules of this mineral were found at different levels in the core. So peaks of P in sediments corresponds of occurrence of vivianite. Manganese (Mn) also accumulated in vivianite as an element admixture. Data from electron microprobe analyses of vivianites from the lake cores confirm this. As a rule intervals with high concentrations of P and Mn correspond to higher concentrations of Fe.

The inorganic geochemistry data shows that such analyses may be very useful as a rapid method for determination of warm and cold intervals in future cores from Elgygytgyn Lake.

Seismic Investigation of Lake El'gygytgyn, NE Russia - Implications for Sediment Thickness and Depositional Environment

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As part of a multidisciplinary expedition to Lake El'gygytgyn during this summer (THE IMPACT project, Terrestrial History of El'gygytgyn International Multidisciplinary Paleoclimate Project) airgun seismic and 3.5 kHz echo sounding investigations were carried out. The aim was to study the geometry and thickness of the sediment fill and to provide a pre-site survey for future drilling proposals. Lake El'gygytgyn, located in central Chukotka, NE Russia, is an impact crater lake with a diameter of 12 km and water depth of 170 m. A 13.0 m long sediment core retrieved from the deepest part of the lake in 1998 revealed a basal age of approx. 300 ka, and is now the longest lacustrine paleoclimate record in the Arctic. A full-length sediment core would yield a record back 3.6 million years, a million years prior to the first major glaciation of the Northern Hemisphere. Refraction seismics using sonobuoys indicate velocities in the range of 1500 to 1700 ms $^{-1}$ for the sediment fill. This is underlain by a refractor characterized by velocities of c. 3400 to 3900 ms $^{-1}$ and interpreted as bedrock or brecciated bedrock. Based on preliminary field estimations the depth of the refractor is in the range of 350 to 400 m subbottom. Single channel reflection profiled exhibit well stratified sediments to a depth of at least 160 m subbottom, locally intercalated with debris flow deposits. The latter are clearly documented in a 3.5 kHz profiles and are more common in the western part of the lake and along the slopes. The lower part of the sediment fill appears to be more massive. However, most of the lower sediments including the sediment/bedrock contact are not well documented in field-recorded analog reflection profiles where masked by multiples. Nonetheless, the top of a cone-shaped sediment drape is identified in the center of the lake at about 150 m sediment depth. This drape may reflect the presence of a bedrock center cone typically observed in large impact craters. The drape is completely leveled by overlying sediments and not visible in the modern bathymetry of the lake. At both the 1998 and newly proposed drill sites the sediments appear to be well-stratified and largely unaffected by debris flows. This suggests undisturbed, continuous hemipelagic sedimentation to at least a sediment depth of 160 m.

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DESCRIPTION OF THE GLAD800 DRILLING SYSTEM

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INTRODUCTION

The GLAD800 (Global Lake Drilling 800) system was developed in response to the requirements of the paleo-climate community to collect long continuous core in recent lake sediments. Modern lake sediments preserve climate proxies that document regional variability in climate change. Therefore, collection and analysis of lake sediment cores is critical for documenting the global climate record. The GLAD800 was built under a joint venture between DOSECC (Drilling, Observation and Sampling of the Earth's Continental Crust, Inc.) and the International Continental Scientific Drilling Program (ICDP), and it is operated by DOSECC. More descriptive material concerning DOSECC and the GLAD800 can be found at www.dosecc.org.

The collection of core from modern lakes presents technical challenges that have been solved with the GLAD800. The concept for the system was developed over period of time and involved discussions between lake scientists and DOSECC's drilling engineers. The technical requirements included the following.

- Tools that can continuously sample sediments of different composition and stiffness.
- A barge system that can anchor in water depths up to 200 meters and safely support the drilling rig and drilling and scientific crews.
- A drilling rig that can be used on vessel of opportunity as well as its own modular barge system.
- A modular system design that can be easily shipped worldwide and deployed at remote locations.
- A cost structure that takes into consideration long times of mobilization with relatively short drilling campaigns.

There were explicit limitations on system design that reduced the initial cost of construction. First, the depth capability is a total depth of 800 m (water + sediment) using HWT drill rods. This size drill rod collects continuous core in plastic liners that is the standard size collected by the Ocean Drilling Program. This standard size was selected for compatibility with analytical and archiving facilities. The use of a smaller HQ drill string will result in a total depth capability of about 1200 m.

The GLAD800 was constructed in the first half of 2000 and has drilled campaigns on the Great Salt Lake and Bear Lake in Utah in summer of 2000. In early 2001, the GLAD800 drilled three sites in Lake Titicaca in Bolivia. Anchoring depths were up to 10 m in the Great Salt Lake and 52 m in Bear Lake. Maximum depth of a single hole on these two projects was 120 m. In Lake Titicaca, the GLAD800 was successfully anchored in water as deep as 232 m where it collected core of 139 m.

Modern Process Studies at Lake El'gygytgyn

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We are studying a variety of modern process at Lake El'gygytgyn, focusing on the limnology, watershed hydrology, and local meteorology, primarily as they relate to the surface energy balance. We are using a combination of field measurements, computer modeling, and remote sensing to do this. We have found that Lake E is a large oligotrophic lake (110 km2, 14 km3, 175 m deep), which mixes completely in summer with an average water temperature of about 3C. It is fed by about 50 inlet streams, most of which were gauged at least once during the summer of 2000. A digital elevation model of the crater area and bathymetry has allowed us to measure most of the statistics important to surface hydrology and limnology. We analyzed a time-series of more than 400 combined ERS-2, Radarsat-1, and Landsat-7 scenes acquired over the past three years to develop a fairly complete picture of lake ice dynamics on Lake El'gygytgyn, Siberia (67.5ºN, 172ºE). The duration of lake ice cover and the onset of lake ice breakup are important to both interpretations of the archived sediment core record and future drilling projects that will use the ice as a stable platform. Ice formation, snow melt, and ice breakup were found to occur in late October, mid-May, and early July, respectively. Perhaps more importantly, we also found that certain variations in SAR backscatter on the lake ice likely mimic the level of biological productivity in the sediments directly beneath the ice. Higher productivity leads to increased bubble production and entrainment in the ice, creating a higher SAR backscatter. For example, the shallow underwater shelves extending from much of the shoreline are the warmest and most biologically productive areas of the lake, and also show the highest backscatter. Curiously, a small region of high backscatter exists near the deepest part of the lake, surrounded by a ring of very low backscatter. We propose two hypotheses to account for this pattern, both of which may be true. First, this deep region of the lake may receive and store water warmed by the shelves and driven downward by gravity. Second, the lake is underlain by highly shattered bedrock that is likely not frozen (unlike the surrounding terrain for 100s of km), creating a convenient conduit for regional groundwater to percolate upward, being focused towards the central peak by lithological and sedimentological bedding controls, Both of these processes would result in increased bubble production in the center region, and therefore increased bubble production and higher backscatter from the ice. Further, it is likely not a coincidence that the deepest part of the lake is collocated with the central peak of the crater, as these process act to consolidate the sediments here over time, consistently keeping the two collocated and consistently focusing gravity flows from the surface to this location. Further field research is required to determine the dominant process, but regardless of cause, the fact that large differences exist in biological productivity in the center of the lake has serious implications for selecting the locations of future sediment cores.

The use of ground penetrating radar (GPR) at Lake Elgygytgyn permafrost deposits

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Ground penetrating radar (GPR) is an electromagnetic method for high-resolution detection, imaging and mapping of subsurface soil and rock conditions. It has been used for several decades as a non-destructive means of locating subsurface stratigraphy in various sedimentary environments like fluvial deposits, aeolian deposits, lake sediments or permafrost deposits. Case studies have shown that successful mapping of massive ice bodies within permafrost terrain is feasible and boundaries of slumping structures can be delineated. GPR surveys at Lake Elgygytgyn are intended to be part of investigations into the permafrost sediments around the shores of the lake. GPR transects and/or grids from two locations are planned with sedimentological detail revealed from cores drilled along the profiles at key locations. Accurate subsurface assessment and interpretation of the stratigraphic and textural changes rely on carefully combined geophysical and sedimentological datasets. The GPR data (post-processed sections and velocity measurements) are calibrated by core logging of the frozen material, which includes the recording of dielectric changes, ice/water content and grain size distributions. The core material may serve, furthermore, for dating the permafrost successions and linking the lake sediments with their relevant source areas (i.e. heavy mineral studies).

SPHERULES FROM THE ELGYGYTGYN METEORITE CRATER

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In summer 2000, samples of heavy minerals were taken by a team of specialists from the Elgygytgyn Crater to find the traces of meteorite substance in them. Samples were taken from fluvial deposits of 19 creeks, the sources of the Enmyvaam River, from the lake shore terrace and above-floodplain terrace, and also from the occurrences of crushed rocks and on surface of a basement uplift, where impactite rocks were abundant. The amount of washed rock-and-soil material was 10 liters for each sample.

Spherules from the magnetic fraction sampled from this area are small (0,5 - 1,5 mm) black lustrous magnetic nodules with scarce knobs on their surface. When polished, some of them show silicate inclusions contained in them. By their composition, these spherules correspond to titanomagnetite and are presumed to be magnetite and titanomagnetite melt inclusions released from pyroxene. This assumption is based on the fact that pyroxene from heavy mineral samples, as well processed and polished, also contains similar inclusions.

A black and dull on its surface spherule having 0,5 mm in its diameter was found in a magnetite fraction, from the Lishainikovy Creek sediments, on the crater's western slope. By its inner structure and composition, it seems to be a typical «cosmic dust», that has been already described in many papers, and is similar to those established by us in the impact area of the Zhigansk iron meteorite. The silicate matrix of this spherule reveals a fine destruction texture of its metallic component.

Heavy minerals sampled from the mouth area of the Vazhenka Creek, on a northern slope of the crater, 4 km away from the Enmyvaam River source area, also contain magnetic spherules. One of them is exotic by its composition and structure. It is ovoid and has length 1,2 mm by its long diagonal, and its surface is gray and dull. This spherule has a concentric-zoned inner structure, and its outer part, that is a shell 0,2 mm thick, is a decomposed silicate glass; the interior portion of this spherule consists of titanomagnetite featured by a geometric structural pattern of contraction joints. The outer part of the spherule contains (in weight %): SiO_2 - 68,3, TiO_2 - 0.3, Al_2O_3 - 10, 5, FeO - 16,7, K_2O - 2,6, MgO - 2,8; its inner part contains SiO_2 - 4,7, TiO_2 - 6,5, Al_2O_3 - 5,2, FeO - 83,1 and MgO - 0.3.

From magnetic fraction of this area was studied a small fragment (2 by 3 mm) of crust of weathering, which displays, under a microscope, two high-reflecting bay-shaped particles, which look like a native iron. A high content of phosphorous and a small admixture of nickel in them allows us to suggest a cosmic origin of metallic particles, since phosphorous is always present in iron meteorites, which contain iron phosphide, i.e. rhabdite.

The most striking are the drop-like and irregularly shaped particles of black glass from the magnetic fraction, which we call the «magnetic glass».These particles are from 0,5 to 2,0 mm. By its composition, this glass is similar to impactite glass from the Elgygytgyn Crater reported by V.I.Feldman. By its K_2O/Na_2O ratio, the «magnetic glass» corresponds to the target rocks, but has a higher MgO content (for about 2 weight %).

When examined under microscope, this glass displayed two metallic phases of titanomagnetite and titanohematite with myrmekite chaotic destruction texture. These phases are contrasting by their reflection power. The dark phase is low-reflecting and has 10 to 17 weight % of titanium, and the light phase is high-reflecting and has 2,5 to 4,7 weight % of titanium. It is peculiar that the dark phase is immediately contacting the glass, and the light phase myrmekite is close to the central part. This glass is well-preserved owing to that sample N 41 has been taken from beneath impactite rocks, which are being destroyed now, whereas a similar ovoid particle from sample N 42 seems to have been already released and affected by hypergenic processes.

As the preliminary study results show, the cosmic substance relics from the meteorite impact area are well-preserved, despite that a long period of time has passed since then. This is due to the impact-related glass shell surrounding melted metallic particles and also to a clay rock cover of an old weathering crust.

These particles must be studied further, as they reveal much similarity in their composition and structure with the described spherules from the Arizona meteorite crater.

Modeling the 3.58 Ma El'gygytgyn Impact

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Many compilations of data related to terrestrial impact features have been published, and most come up with similar relationships between the impacting projectile or bolide and the resultant crater diameters, depths, ejecta volumes and mass of melt rock produced. We have used these relationships to produce an idealized model for origin of the El'gygytgyn crater. For consistency we selected the relationships used by Cintala and Grieve, (1994) and Grieve et al., (1980) plus data from Dence et al., (1976).

The starting point for the development of our El'gygytgyn model is the final crater diameter, commonly taken to be the diameter of the actual crater plus any ring-like structures related to it. For this we used the drainage divide of the outer rim surrounding Lake El'gygytgyn as a guide. This gives a final crater diameter of 23 kilometers. The models also assume that the impactor stuck with a velocity of 25 km/second, which is the average velocity at which an earth-crossing asteroid would contact the earth.

The principal features of the model are:

1. The transient crater, which is only in existence for a few tens of seconds and represents the immediate elastic response of the region to the impact. In craters of the size of El'gygytgyn the rebound will commonly result in the formation of a central peak. This central peak will excavate and bring to the surface rocks from the deepest stratigraphic levels involved. For the El'gygytgyn model the central peak should rise to a level close to the pre-impact surface. In practice, El'gygytgyn does not have a central peak, but shows evidence of a subdued peak in the center of the lake basin which is not at the center of the larger crater.
2. The excavation crater is the crater formed when the impact/explosion ejects large amounts of material, but before it starts to fill with slump deposits and other fall-back material. The back filling will include the slumping of the over-steepened rim walls.
3. The final crater diameter of 23 km as selected above, includes the effects of later ring faults and release of stresses outside the diameter of the excavated crater.

From the crater diameters, and the assumed velocity of the bolide, the bolide dimensions and energy released can be calculated.

The volume of melt produced is significant, although only a proportion is left in the crater, the remainder being ejected. The material falling back into the excavation crater buries the melt not ejected. We have made estimates of the thermal properties of the buried melt, and modeled the time necessary to cool it below the boiling point of water. The boiling point of water was chosen since it represents the time at which all phreatic events will cease. So far we have only tried geometrically simple models to test the situation. For a rectangular body 2 km thick with its upper surface at a depth of 1 km, in country rock with the characteristics of the El'gygytgyn area volcanic rocks, the cooling time for the center of the body to get below the boiling point of water will be less than 300,000 years.

It is of interest to note that the volume of material ejected from the crater is about the same as that ejected during the eruption of Katmai in 1912, the largest eruption of the 20th century. Of the material ejected during crater formation, a significant portion will have reached the stratosphere, and thus will have been distributed over large distances. The rate at which material from an impact would be removed from the atmosphere is probably higher than that commonly found for volcanic eruptions since the particle sizes and densities are probably higher. However, the material should be present in detectable quantities within a few hundred kilometers downwind. Since much of it will be glass, and a proportion derived from the bolide, it could make a recognizable horizon for which we have good age control.

Although the relationships used to build this model apply well to many (most?) terrestrial impact structures, there is still room for wide variations. These can arise from such unknowns as the angle of impact, the density of the bolide, variations in velocity, and variations in the target material.

Modeled parameters for the Elgygytgyn crater-forming impact

Observed Crater	
Watershed diameter	23 km
Lake basin	11 km
Commonly quoted diameter	18 km
Present water depth	0.175km
Rim to lake bottom (approx)	0.4 km

Bolide (Cintala and Grieve, 1994):	
Diameter	1.57 km
Density	2900 kg/m^3
Velocity	25 km/s
Volume	1.34 km^3
Mass	3.9×10^{12} kg
Energy	1.25×10^{21} J

Crater, (Cintala and Grieve, 1994)	
Transient crater	20 km
Total melt volume	55 km^3
Total volume ejected	13.5 km^3
Volume of bolide ejected	0.15 km^3
Mass ejected into stratosphere	4×10^{12} kg

Crater continued using (Grieve et al., 1980).	
Final crater depth	1.85 km
Excavation crater depth	1.9 to 2.9 km
Transient crater depth	5.4 km
Disruption depth	approx 7 km
Stratigraphic (central peak) uplift	1.9 km

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