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A scientific journey: Nikolay Vasiliev's quest to perfect the tools to drill into deep Antarctic ice

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Abstract. Since the early 1950s, when extensive exploration of Antarctica began, drilling has become an integral part of many large-scale scientific projects carried out on the sixth continent. Thanks to the rapid development of drilling equipment and technology, numerous scientific discoveries have been made in the fields of paleoclimatology, geology, glaciology, and other natural sciences. Since 1968, the St. Petersburg Mining University has played a leading role in this area's development, and several generations of ice drilling specialists were trained within its walls. One of the most outstanding was Nikolay Vasiliev, who led Antarctic research at the university from 2002 to 2021. His contribution to the development of ice core drilling in Antarctica cannot be overestimated. Professor Vasiliev's extensive and highly creative work laid the foundation for many achievements in this field over the past 30 years. His path is a brilliant example of hard work and dedication to one's cause. This article is a tribute to Professor Vasiliev, who is cherished by his friends and colleagues who had the good fortune to work and study with this talented person and scientist.

Keywords: Antarctica, glacier drilling, electromechanical drill, warm ice drilling, Lake Vostok

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The main thing, in my opinion, is a spark in the soul, personal motivation, belief in success, the desire to go forward despite difficulties, and the ability to never give up.

Nikolay Vasiliev (1948–2021)

Introduction

Professor Nikolay Vasiliev was, for many years, the permanent leader of the deep core drilling project at the Russian Antarctic Vostok Station. Under his direct supervision, the deepest ice borehole (3769.3 m) [1] was drilled, and the largest subglacial water body on our planet — Lake Vostok [2] — was penetrated twice. Vasiliev spent two wintering periods (lasting over a year each) and 12 field seasons (two to three months at

Professor Vasiliev at the Mining University
Профессор Горного университета Н.И. Васильев

a time) at Vostok Station, as well as five field seasons on the glaciers of the Severnaya Zemlya archipelago, as part of the high-latitude expedition A-162 and the international PEGAIS project "Global Arctic Climate Change" [3].

Vasiliev's achievements in the field of deep ice drilling have made him famous as an outstanding specialist both in Russia and abroad. He contributed to the development of international scientific and technical cooperation in the polar regions and was one of the key participants in the Russian-French-American project on ice core drilling and research at Vostok Station (1989–1998), as well as in long-term Russian-French collaboration on ice core research and paleoclimate studies (2001–2019). Professor Vasiliev was a regular participant in numerous international events dedicated to ice drilling techniques and technology, such as ice drilling symposia, Russian-French seminars, competitions, and engineering exhibitions.

Vasiliev successfully combined his scientific work with teaching. He taught at the well drilling department of St. Petersburg Mining University for over 20 years, 13 of which he served as head. He is the author of 120 published works and patents for inventions, and supervised three doctors of science who participated in drilling operations at Vostok Station.

During his career, Professor Vasiliev received a number of awards, including the Order "For Merit to the Fatherland" (fourth class) and the Award of the Government of the Russian Federation in the field of science and technology.

In this article, we would like to discuss Vasiliev's life, his key scientific achievements, and the significance of his work for the development of Russian science.

The beginning of the journey

Nikolay Vasiliev's admission to the Leningrad Mining Institute in 1966, specializing in mining machines and complexes, marked the beginning of his development as an engineer and inventor. While still a student, young Nikolay became involved in the scientific life of the Department of Mining Machine Design; his first scientific article was on the development of gearing theory [4]. After qualifying as a mining mechanical engineer in 1971, Vasiliev started working at his university department as a laboratory assistant, focusing on problems related to upgrading vibratory conveyors. The results of

Graduation photograph of Nikolay Vasiliev, aged 23, at the Leningrad Mining Institute, now the St. Petersburg Mining University (1971)

Фотография 23-летнего Николая Васильева из выпускного альбома 1971 года Ленинградского горного института (ныне Санкт-Петербургский горный университет)

his work, carried out between 1971 and 1978, were reflected in scientific publications, copyright certificates, and patents. Vasiliev's successes in designing mining machines and equipment attracted the attention of the management of the Mining Thermophysics Laboratory, which included the Antarctic Research Department (ARD).

Beginning in 1967, scientists from the Antarctic Research Department and their colleagues from the Arctic and Antarctic Research Institute (AARI) carried out deep drilling and ice core research in Antarctica. The result of a decade of cooperation was a 'dry' borehole drilled at Vostok Station to a depth of 952.8 m, which is still the deepest borehole drilled in ice without using drilling fluid [5]. Vasiliev received an invitation to take up the position of senior engineer at the Antarctic Research Department. The romance of Antarctic research quickly captivated him, and from that moment on, Vasiliev's entire life was inextricably linked with polar science.

The origins of mechanical ice drilling technology

At the initial stages of his work in the ARD, Vasiliev worked on improving the theory of thermal and, subsequently, mechanical ice destruction, which became a priority for him. Anticipating the huge potential of electromechanical ice drilling technology, under the guidance of his mentor, Professor Boris Kudryashov, he took over the baton in the development of this area from his colleague, Gennady Stepanov, who developed the first version of a core cable-suspended electromechanical drill (KEMS).

Vasiliev improved the design of KEMS [6], and the changes he made increased the reliability of the drill and reduced the chances of complications and accidents during drilling. With the help of this modernized drill, in 1988, as part of the A-162 expedition, a borehole was drilled to a depth of 459 m on Severnaya Zemlya. This was the first time that the bedrock under the glacier had been reached and 4.4 m rock cores had been recovered using a core cable-suspended electromechanical drill [7]. In the same year, Vasiliev successfully defended his PhD thesis entitled "The electromechanical drill and the technology of drilling boreholes in ice and subglacial rocks".

At that time, drilling at the Vostok station was conducted in borehole 4G-2 at depths exceeding 2,000 m using the thermal drilling method. This process was accompanied by occasional complications due to imperfections in the drilling rig design [8].

Nikolay Vasiliev and Vladimir Zubkov carrying out maintenance work on the drill at Vostok Station, 2011

Николай Васильев и Владимир Зубков во время технического обслуживания бурового снаряда на станции Восток, 2011 г.

Successful testing of the upgraded KEMS drill on Severnaya Zemlya made it possible to switch to electromechanical drilling technology at Vostok station at a depth of 2428.5 m, during the 34th Soviet Antarctic Expedition (SAE) in 1989 — Vasiliev's first Antarctic expedition. Improvement of deep ice core drilling technology continued in the newly drilled 5G borehole in early 1990.

Developing a standard for deep ice drilling

Drilling the 5G-1 hole at Vostok with an electromechanical drill was carried out at a high rate of penetration (with a run length of 2.8 m) up to a depth of 2930 m. This success was largely due to Vasiliev developing a telemetry and drilling control system, which was capable of operating in temperatures up to –70 °C and with a drilling fluid pressure of up to 40 MPa.

Subsequent drilling was accompanied by some complications and a significant reduction in the rate of penetration due to changes in the ice structure and its physical and mechanical properties with depth. Individual ice crystals were found to have increased in size (up to 1 m) and the temperature increased as the drill approached Lake Vostok. This type of ice is known as warm ice in the scientific community, and many researchers have sought to improve the efficiency of drilling it [9, 10].

The professor at work

Профессор за работой

At that time, there were no specific guidelines for ice drilling at great depths, so the drilling team led by Vasiliev had to take on the role of pioneers and inventors. The deep modernization of the drill included improvements to the geometry of the drill head [11, 12], the development of new designs for filters [13] and an anti-torque system; extensive theoretical research also had to be undertaken [14]. These efforts enabled the team to continue drilling work.

The results of this work were summarized in Vasiliev's doctoral dissertation, 'Rational technology of drilling boreholes in ice using a core cable-suspended electromechanical drill', which he successfully defended in 2004.

The last 100 m to the surface of subglacial lake Vostok were especially challenging: the drill got stuck at the bottom twice. In the first instance, the accident was resolved by a special fishing tool, designed by Vasiliev and reproduced in wintering conditions by Alexander Krasilev and Vladimir Zubkov [15]. The second time the drill got stuck proved fatal, and after numerous attempts to retrieve it, it was decided to divert

The vivid outcome of Vasiliev's innovations – a perfect quality ice core recovered from the super-deep hole at Vostok.

Наглядный результат инноваций Н.И. Васильева – керн отличного качества, поднятый из суперглубокой скважины на станции Восток.

the borehole, bypassing the drill left at the bottom. For the first time, Vasiliev's technology for deviating from the parent hole was applied [16], allowing branch holes to be drilled without significant changes to the design of the electromechanical drill.

A new world record of 3769.3 m was set for drilling boreholes in ice when Subglacial Lake Vostok was finally unsealed on February 5th, 2012. This technology was developed by a team of scientists from the Mining Institute and AARI in 2000 [17]. In anticipation of the lake's unsealing, large-scale preparatory works were carried out. Together with the perseverance and consistency of the drilling crew, these efforts made it possible to reach Lake Vostok just one day before the team had to leave Vostok Station on the last plane at the end of the field season [18].

Professor Vasiliev's personal qualities, such as his attention to detail and intuition, were particularly important for the success of this project. These innate characteristics were well complemented by his deep understanding of the downhole processes involved in drilling.

An in-depth analysis of the hydrodynamic process of water rising into the borehole during the first unsealing of the lake in 2012 allowed for a more controlled second unsealing in 2015 [19]. The result of these two operations was the recovery of samples of congelation ice, which formed as a result of the freezing of lake water that entered the borehole.

Vasiliev shared his accumulated knowledge and experience through monographs, scientific articles, and textbooks. His contributions have enabled the following: deepening fundamental understanding of the complex processes that occur in ice when it is drilled; establishing the main patterns of changes in the structural and physical properties of the Antarctic ice sheet with depth, which determines mechanical and rheological properties that affect borehole drilling and maintenance; and creating safe and competitive technologies for drilling through ice and environmentally friendly techniques for accessing subglacial water bodies. He is rightfully considered to be the creator of modern international standards for deep ice drilling.

Conclusion

A friendly cartoon by a colleague depicting Professor Vasiliev hard at work

Дружеский шарж, изображающий профессора Васильева за работой

Professor Vasiliev was an outstanding scientist and researcher who made a significant contribution to the history of Antarctic research. His work continues to be the foundation for the development of technology and tools for drilling into Antarctic ice. The technology he created, using the KEMS-135 drill, which he painstakingly developed and improved, serves as a model for best practices in deep ice drilling. The professor himself said that this achievement was the most significant result of his creative activity.

His reverent attitude to his work, perseverance, and ability to dream, which are inherent in many outstanding scientists, became the defining features of his personality

Vasiliev's friends and younger colleagues: staff of the Mining University and AARI during the 67th Russian Antarctic Expeditions

Друзья и последователи Н.И. Васильева: сотрудники Горного университета и ААНИИ в составе 67-й Российской антарктической экспедиции

and the key to his success. Even during periods of insufficient funding, Vasiliev was able to make scientific progress.

As a leader, Professor Vasiliev has inspired and continues to inspire others to achieve results. His colleagues, including the polar researchers at the Vostok station, remember him with warmth and respect. They affectionately call him 'professor'. His close friends call him *Kolya-golova* ('Kolya the brain'), due to his extensive knowledge and far-reaching abilities.

It is thanks to Vasiliev that a strong, experienced, and effective drilling team was established at Vostok station. He was passionate about everything new and promising in science and technology. He gave all his strength and time to his work. He was democratic in approach, kind, accessible, benevolent, and friendly. He had an unflagging sense of humour. He was honest in his judgments and exacting in business.

His work lives on through his students. They rely on the knowledge he left behind, and continue to explore the Antarctic continent.

Competing interests. Authors have no competing interests.

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Творческий путь Николая Васильева – создание современной технологии бурения глубоких скважин во льду

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Аннотация. С начала 50-х гг. XX в., когда началось активное изучение Антарктиды, бурение стало неотъемлемой частью многих масштабных научных проектов, осуществляемых на ледяном материке. Благодаря стремительному развитию техники и технологий бурения было сделано множество научных открытий в области палеоклиматологии, геологии, гляциологии и ряда других естественных наук. С 1968 г. и по сей день одну из ведущих ролей в развитии данного направления играет Санкт-Петербургский горный университет. В его стенах было воспитано несколько поколений специалистов по бурению льда. Особое место среди них занимает бессменный руководитель направления антарктических исследований в период с 2002 по 2021 г., профессор, доктор технических наук Николай Иванович Васильев. Его вклад в развитие отечественного бурения в Антарктиде невозможно переоценить. Многолетняя творческая деятельность Н.И. Васильева заложила основу для многих достижений в этой области за последние 30 лет. Его путь является ярким примером трудолюбия и преданности своему делу на протяжении всей жизни. Эта статья — дань уважения и памяти профессору Н.И. Васильеву, которую хранят его друзья, последователи и коллеги, имевшие счастье работать с этим талантливым человеком и ученым и учиться у него.

Ключевые слова: Антарктида, бурение ледников, электромеханический буровой снаряд, бурение теплого льда, озеро Восток

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