2.1 The International Continental Scientific Drilling Program

Victor A. Melezhik

The International Continental Scientific Drilling Program (ICDP) was founded in 1996. Its main goal is to enable geoscientific research by obtaining continuous rock sections through key geological formations which are not accessible by any other means but crucial for understanding Earth's surface processes and their evolution, and providing direct information on processes operating at depth. ICDP has overseen 15 years of successful coordination of multinational efforts in continental scientific drilling (Harms et al. 2007). Drilling operations are expensive and a series of robust criteria must be met for projects to obtain financial and operational support from the ICDP. Among these criteria, two of the most important are global significance and international impact, which dictate that projects must address geological problems of global significance, utilising world-class geological sites and establishing broad international cooperation by pooling resources from the best possible scientific teams. Other criteria include societal needs, need-for-drilling and depth-to-cost, which are defined explicitly by the ICDP in order to assess and concentrate on topics of high international priorities (Harms and Emmermann 2007).

Over its first decade, the thematic activities of ICDP-coordinated projects were focused on issues relating to palaeoclimate, natural hazards (earthquake, volcanism, impact events), geodynamics and alternative energy resources. In 2005, at a 10-year-anniversary forum, the ICDP expanded its scope and scientific focus to include research of the biosphere and evolution of the Earth through critical time intervals.

V.A. Melezhik (✉)
Geological Survey of Norway, Postboks 6315 Sluppen, NO-7491 Trondheim, Norway

Centre for Geobiology, University of Bergen, Allegaten 41, N-5007 Bergen, Norway
e-mail: victor.melezhik@ngu.no

2.1.1 Fennoscandian Arctic Russia–Drilling Early Earth Project (FAR-DEEP)

The Fennoscandian Arctic Russia–Drilling Early Earth Project (FAR-DEEP) was one of the responses to the ICDP's new initiatives (Melezhik et al. 2010). FAR-DEEP's main scientific objectives centre around one of the most intriguing periods in Earth history when terrestrial environments experienced a revolutionary transition from being largely anoxic during Earth's first 2100 Ma to irreversibly oxic; the environmental hallmark (Cloud 1987a, b) now often referred to as the Great Oxidation Event (e.g. Holland 2006).

Motivation and Goals of Drilling Project

The formation of Earth as a solid body at c. 4500 Ma (Manhes et al. 1980; Dalrymple 2001) was followed by a c. 2000-Ma-long period of environmentally stable conditions. From 2500 to 2000 Ma the Earth System experienced a series of fundamental upheavals (Fig. 2.1). This hallmark period, known as the Late Archaean-Early Palaeoproterozoic transition (APT), represents one of the most critical periods in Earth's history, as it reflects the emergence of an aerobic Earth System and a series of interrelated global events detailed in Chap. 1.1. Most important of the Early Palaeoproterozoic events were the establishment of an oxygenated atmosphere between 2450 and 2320 Ma (Bekker et al. 2004; Hannah et al. 2004) and the emergence of an aerobic biosphere. The remaining 1500 Ma of the Proterozoic exhibit clear evidence that the surface environments on Earth operated under oxic conditions, pretty much as they do today. Even though macroscopic multicellular organisms and plants did not evolve until much later, most biogeochemical recycling, in the oceans and on land, was dependent on highly energetic aerobic pathways. However, some workers suggest that deep marine basins or perhaps even the global deep ocean itself remained anoxic and perhaps even became euxinic (rich in H_2S) throughout much of the

V.A. Melezhik et al. (eds.), *Reading the Archive of Earth's Oxygenation*, Volume 1: The Palaeoproterozoic of Fennoscandia as Context for the Fennoscandian Arctic Russia - Drilling Early Earth Project,
DOI 10.1007/978-3-642-29682-6_2, © Springer-Verlag Berlin Heidelberg 2013

ensuing Proterozoic time slice (Canfield 1998; Anbar and Knoll 2002; Poulton et al. 2004).

Understanding of the causative relationships between the series of the APT global palaeoenvironmental events, (Fig. 2.1) and the combined processes that led to the irreversible alteration of Earth's surface environments, represents one of the most challenging fundamental problems in the geosciences (e.g. Melezhik et al. 2005). Essential to this is the need for a continuous rock record spanning the APT supported by studies that integrate the various proxy datasets that document the various processes operating at this time. However, obtaining a continuous rock record and, consequently, an enhanced understanding of Earth System behaviour and evolution during the APT period is hindered by three major shortcomings: (1) limitation of exposures of key stratigraphic intervals; (2) samples compromised by anthropogenic contamination; and (3) modification by recent oxidation and weathering. These can be overcome by implementing scientific drilling that targets key geological formations containing a record of the 2500–2000 Ma global events. Such a drilling project should have three major goals: (*1*) establish a well-characterised, well-dated and well-archived succession of rocks for the period of 2500–2000 Ma; (*2*) document the changes in the biosphere and the geosphere associated with the rise in atmospheric oxygen; and (*3*) develop a self-consistent model to explain the genesis and timing of the establishment of the aerobic Earth System.

Scientific Background for Implementation of the Drilling Project

There are five areas where significant Palaeoproterozoic successions occur that could be used to study the 2500–2000 Ma interval; northern and southern America, South Africa, Western Australia and Fennoscandia (Fig. 2.2). Consequently, any of these areas could have been potential targets for implementing an ICDP drilling project. Fennoscandia was chosen as a result of discussions initiated during the 2004 Nordic Academy for Advanced Studies field course held in NW Russia. Then, an international group of scientists from several European countries, the USA and Australia deliberated in the field and reached the conclusion that the eastern part of the Fennoscandian Shield contains the finest archive of the hallmark events that typify the APT. This was elaborated further during subsequent field studies and an ICDP Workshop during 2004–2005 and a decision was reached to undertake a multidisciplinary international research programme and scientific drilling project on the APT. Target intervals and drilling sites were identified and overall objectives defined.

The Fennoscandian Shield is a composite craton composed of late Archaean granite-greenstone belts and several extensively developed Palaeoproterozoic greenstone and orogenic belts (Fig. 2.3). Well-preserved igneous and sedimentary rocks record a long period of rifting and opening of a series of oceans and break-up of an Archaean continent followed by several orogenic episodes (see Chap. 3.4). The Palaeoproterozoic successions reach a cumulative thickness of over 20,000 m and provide a rich information of nearly 700 Ma of Earth history. The eastern (Russian) sector of the shield area was selected for scientific drilling (Fig. 2.3) because it is characterised by exceptionally well preserved and lithologically diverse rocks 2500–1900 Ma in age. They are considered to contain a fairly complete record of the hallmark events of the APT (Melezhik et al. 2005), including c. 2500 Ma global rifting (Chap. 3.4), the global Huronian-age glaciation (Chap. 7.2), an apparent upper-mantle oxidising trend and related redox change of volcanic rocks (Chap. 7.4), the oldest record of subaerial hydrothermal processes (Chap. 7.9.4), a rise in atmospheric oxygen (Chaps. 7.1 and 8), the protracted and large-magnitude carbon isotope excursion (Chap. 7.3), changes in the sulphur cycle and a substantial increase in the seawater sulphate reservoir (Chap. 7.5), changes in phosphorus cycle and accumulation of earliest sedimentary phosphates (Chap. 7.7), a radical modification in recycling of organic matter (Chap. 8), an unprecedented accumulation of organic-matter-rich sediments and the oldest known significant generation of petroleum (Chap. 7.6).

Implementation of the Scientific Drilling Project

The ICDP FAR-DEEP implemented in Fennoscandia represents a novel type of project among the ones typical of the ICDP in that it aimed to obtain geological material by drilling numerous holes in several areas (Fig. 2.3). Collectively, these provided a representative geological record of the most important global events occurring through the APT. The drilling operations were largely co-sponsored by the ICDP, with additional funding received from DFG (German Research Council), NFR (Norwegian Research Council), NASA Astrobiology Institute and the US NSF (National Science Foundation), the Centre for Geobiology of the University of Bergen, and the Geological Survey of Norway.

The drilling operations were carried out from late May through late October in 2007 by the Finnish operator SMOY. The Russian State Company "Mineral", based in St. Petersburg, Russia, provided all logistical support. On-site core documentation was supported by the Institute of Geology, the Karelian Science Centre, Petrozavodsk, Russia. Fifteen drillholes were drilled, ranging from 92 to 503 m in depth, totaling 3,650 m of recovered core. In order to accomplish the proposed program, the drilling rig, the field camp, all the equipment, and on-site operating scientists travelled together over a total distance of 5,000 km. The large distances and remoteness of the drilling sites with limited infrastructure required a considerable logistical effort (Fig. 2.4).

The ICDP FAR-DEEP with its Deep Time perspective has opened a new window for multidisciplinary research, with aims of obtaining new knowledge of the processes that operated on Earth's surface and interior at the dawn of the emergence of an aerobic world. The chosen approach was a success, resulting in collection of a rich archive of geological material that is detailed in **Part 6**.

An ambitious and successful FAR-DEEP research programme (http://far-deep.icdp-online.org) requires a considerable international effort for its accomplishment. Currently 13 countries have applied for research grants from various funding agencies. Five Ph.D. students from Finland, Germany and Norway are involved in the FAR-DEEP research program. Four postdoc projects in Finland, Great Britain and Norway have been financed by national funding agencies. A large group of scientists from the USA has received support from the National Science Foundation and NASA. Several research groups from Belgium, Czech Republic, Estonia and Russia have been also successful in obtaining research grants. The FAR-DEEP core is stored in Trondheim, at the Geological Survey of Norway, and is available for coordinated international multidisciplinary research.

Fig. 2.1 A series of global events associated with the transition from an anoxic to oxic world: a "middle-age Earth crisis"?

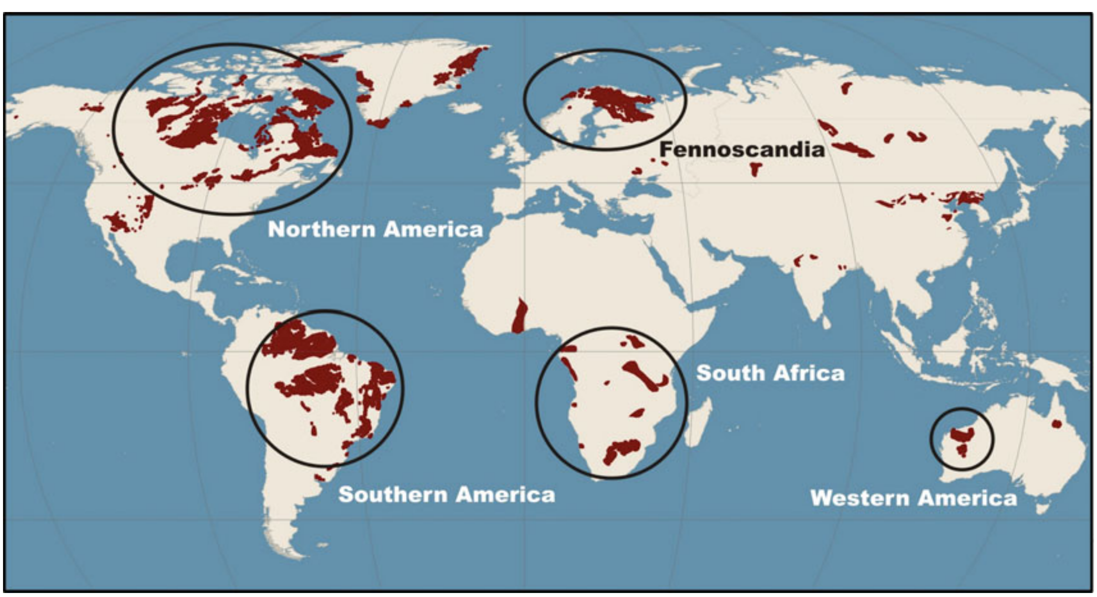

Fig. 2.2 Distribution of Palaeoproterozoic rocks (*red*) with circled areas highlighting the most continuous and thickly developed volcano-sedimentary successions sections (Map compiled by Aivo Lepland)

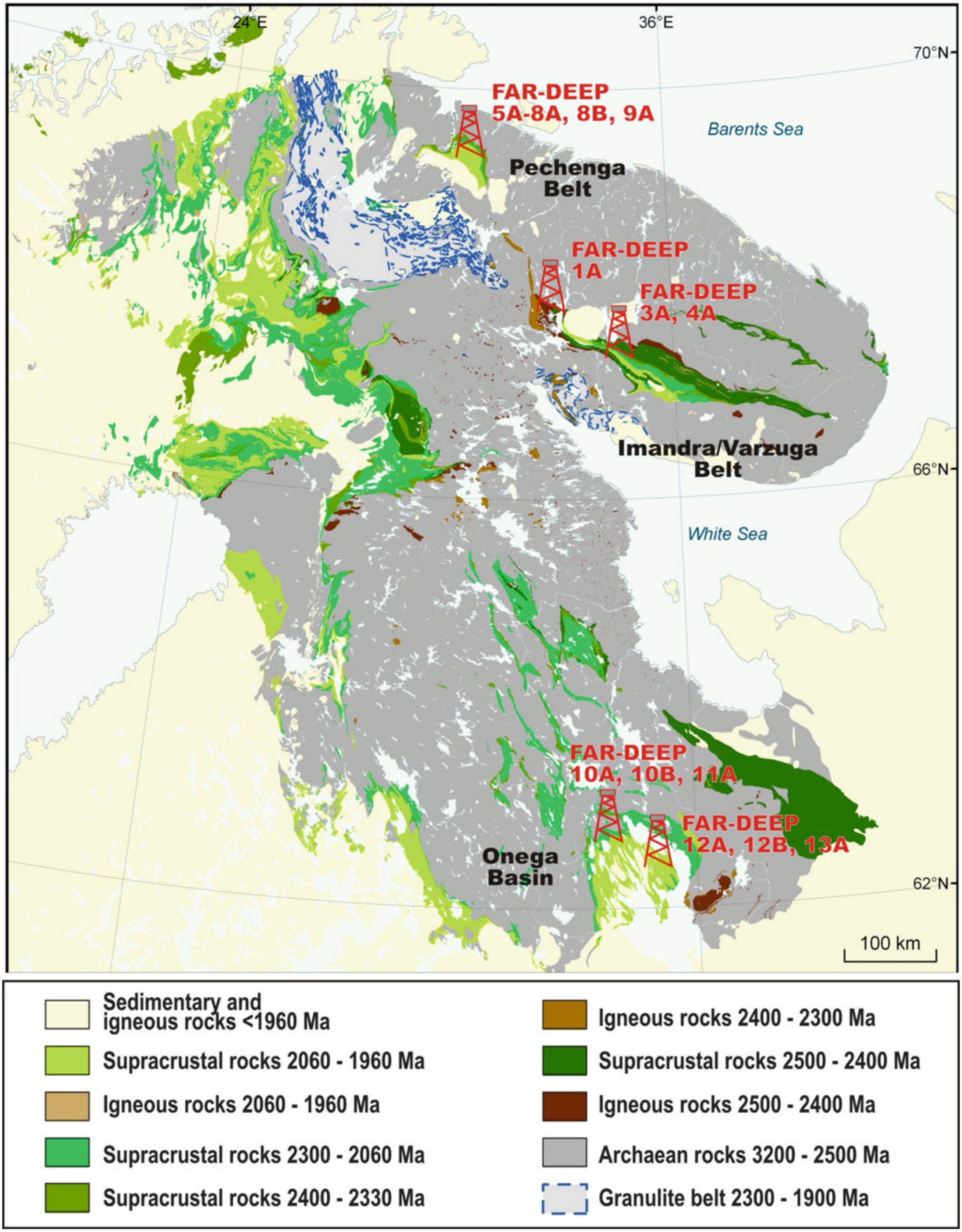

Fig. 2.3 Geological map of the eastern Fennoscandian Shield showing FAR-DEEP drilling sites and drillhole numbers (Geological map is modified by Aivo Lepland from Koistinen et al. (2001))

Fig. 2.4 Scientific drilling implemented in the eastern part of the Fennoscandian Shield. *The Pechenga Greenstone Belt*: (**a**) Peat bog near site 7A. (**b**) Military-terrain vehicle assists the mobile drilling rig to negotiate a swamp on its way to site 6A. (**c**) A field camp at site 8A and 8B. (**d**) Loading core in to terrain vehicle at the site 8B. *The Imandra/Varzuga Greenstone Belt*: (**e**) . . . even don't have a dream to step on it. . . (**f**) On the way to the site of Huronian-age glacial deposits. (**g**) Breakdown on the way to sites 3A and 4A

References

Anbar AD, Knoll AH (2002) Proterozoic ocean chemistry and evolution: a bioinorganic bridge? Science 297:1137–1142

Bekker A, Holland HD, Wang PL, Rumble D, Stein HJ, Hannah JL, Coetzee LL, Beukes NJ (2004) Dating the rise of atmospheric oxygen. Nature 427:117–120

Canfield DE (1998) A new model for Proterozoic ocean chemistry. Nature 396:450–453

Cloud P (1987a) Oasis in space: Earth history from the beginning. W.W. Norton and Co, New York, p 515

Cloud P (1987b) Trends, transitions, and events in Cryptozoic history and their calibration: apropos recommendations by the subcommission on Precambrian Stratigraphy. Precambrian Res 37:257–264

Dalrymple GB (2001) The age of the Earth in the twentieth century: a problem (mostly) solved. Spec Pub, Geol Soc Lond 190:205–221

Hannah JL, Bekker A, Stein HJ, Markey RJ, Holland HD (2004) Primitive Os and 2316 Ma age for marine shale: implications for Paleoproterozoic glacial events and the rise of atmospheric oxygen. Earth Planet Sci Lett 225:43–52

Harms U, Emmermann R (2007) History and status of the international continental scientific drilling program. In: Harms U, Koeberl Ch, Zoback MD (eds) Continental scientific drilling: a decade of progress, and challenges for the future. Springer, Berlin/Heidelberg, pp 1–52

Harms U, Koeberl Ch, Zoback MD (eds) (2007) Continental scientific drilling: a decade of progress, and challenges for the future. Springer, Berlin/Heidelberg, p 366

Holland HD (2006) The oxygenation of the atmosphere and oceans. Philos Trans R Soc B 361:903–915

Koistinen T, Stephens MB, Bogatchev V, Nordgulen Ø, Wenneström M, Korhonen J, (comps.) (2001) Geological map of the Fennoscandian Shield, scale 1:2 000 000, Espoo/Trondheim/Uppsala/Moscow

Manhes G, Allègrea CJ, Dupréa B, Hamelin B (1980) Lead isotope study of basic-ultrabasic layered complexes: speculations about the age of the earth and primitive mantle characteristics. Earth Planet Sci Lett 47:370–382

Melezhik VA, Fallick AE, Hanski E, Kump L, Lepland A, Prave A, Strauss H (2005) Emergence of the aerobic biosphere during the Archean-Proterozoic transition: challenges for future research. Geol Soc Am Today 15:4–11

Melezhik VA, Lepland A, Romashkin A, Rychanchik D, Mesli M, Finne TE, Conze R, the FAR-DEEP Scientists (2010) The great oxidation event recorded in Paleoproterozoic rocks from Fennoscandia. Sci Drill 9:23–29

Poulton SW, Fralick PW, Canfield DE (2004) The transition to a sulphidic ocean 1.84 billion years ago. Nature 431:173–177

Springer

http://www.springer.com/978-3-642-29681-9

Reading the Archive of Earth's Oxygenation
Volume 1: The Palaeoproterozoic of Fennoscandia as Context for the Fennoscandian Arctic Russia - Drilling Early Earth Project

Melezhik, V.; Prave, A.R.; Fallick, A.E.; Kump, L.R.; Strauss, H.; Lepland, A.; Hanski, E.J. (Eds.)
2013, XX, 490 p. 152 illus. in color. With online files/update., Hardcover
ISBN: 978-3-642-29681-9