PREFACE

Do you know why the land and ice in the surroundings of the North Pole are called Greenland—in French, Groenland? You might think that the name comes from an old *inuk* word, but Erik the Red supposedly named the island when he founded a Viking colony there in 984 A.D. Some historians claim that Erik the Red invented the term *green land* to entice his kinsmen to that desolate land. This is perhaps not really true, because even if Greenland seems today to be a huge white expanse, along certain fjords one can still see green fields where animals are raised. Between 984 and the fifteenth century this was "the most distant fore-posts of European civilization." "Scandinavians 1,500 miles from Norway built a cathedral and churches, wrote in Latin and Old Norse, wielded iron tools, herded farm animals, followed the latest European fashions in clothing—and finally vanished."[1] The stone church in Hvalsey endured; the Vikings of Greenland, who numbered five thousand in 1000, disappeared, while their neighbors the Inuits barely survived.

Around the year 800 Scandinavia was warming up, but the cultivatable lands in its mountainous regions and along its rocky coasts were too few to feed the large Viking population. On their fast-sailing ships that were capable of long voyages, the Vikings set off in search of more abundant lands. Some eventually settled under the Sicilian sun, but in the North Atlantic they founded several colonies: in the Orcades, the Shetland Islands, the Feroe Islands, in Iceland, and in Greenland. From there, the descendants of Erik the Red even tried to settle in a land they called Vinland, which today would include the coasts of Canada south of Labrador as well as Newfoundland, the Gulf of Saint Lawrence, and part of the coast of New England. But their attempts quickly failed, it seems, owing to a lack of means and men to fight the Indians. Those intrepid adventurers thus returned home to the shores of Greenland, which were more peaceful though less hospitable. Four hundred years after Erik the Red landed, only the ruins of farms where his countrymen attempted a life remained.

"The climate became too cold, and they began to die off," wrote an archaeologist. In fact, between the ninth and fourteenth centuries the climate could have warmed to such an extent that when the Scandinavians reached Greenland around the year 1000 they found its climate a bit more propitious for farming and raising livestock. But the cooling of the Little Ice Age, which lasted until the nineteenth century, doesn't explain everything. It was above all the Vikings' inability to adapt their way of life, their values, their social structures, and their economy that caused them to die off. As Jared Diamond explains, in a hostile environment, collapse is not inevitable; it depends on the choices a society makes: "Environmental damage, climate change, loss of friendly contacts with Norway, rise of hostile contacts with the Inuit, and the political, economic, social, and cultural setting of the Greenland Norse. Greenland provides us with our closest approximation to a controlled experiment in collapses."[2]

Today an even greater possibility of collapse threatens us because it involves the entire planet. We must turn to the icy lands to fully understand the nature and magnitude of the threat. But it is no longer a question of the ability or inability of some to react adequately to a temporary and local change in climate—our current situation is unlike that of the Mayan lords who were exhausted by wars and unable to foresee the consequences for their people of repeated droughts and overexploited land.

We are dealing with a perceivable degradation of living conditions in our society that is exacerbating the crises that already exist: poverty, access to clean water and to sources of energy, migrations, geopolitical destabilization and conflicts. Subsequently, the Inuits are protesting; the polar bear, the largest living land carnivore, is threatened; and the krill, very useful little shrimp, as well as the seals and the penguins in the southern seas that eat them, seem at risk. More than a sixth of the world's population, most of which is in Asia, lives in regions that rely on the water from snow and glaciers: if those shrink in volume that could affect the future of those regions. One hardly dares mention the consequences on tourism of the melting of the glaciers in the Alps or the Pyrenees or of a shrinking of the snow cover that might be caused by a "mere" increase of 2°C. Our vacations would be seriously affected—but that would be the least of our problems.

"The Vikings were doomed from the beginning," Jared Diamond has written. And the petty Mayan kings were too concerned with their wars to sense

any danger. Will we be able to react? The 2007 Nobel Peace Prize attributed to, Al Gore and to the Intergovernmental Panel on Climate Change (IPCC) testifies that there is a growing awareness of the threat that climate change is posing to the planet. Glaciology and glaciologists have contributed to this heightened awareness.

More than fifty years ago, in 1957, one of the authors of this book, Claude Lorius, went to Adélie Land. His intention, within the framework of the International Geophysical Year, was to explore and learn more about Antarctica. Temperatures, the thickness of the ice, snow accumulation, the advance of the glaciers: everything was new, and there was much to learn. A few years later, around 1965, a new path was opened: ice analysis enabled glaciologists to determine the temperature of the atmosphere at the time the snow had fallen. These new data were a true gold mine, which has been developed in France in collaboration with the Commissariat à l'Energie Atomique (CEA) within which one of the authors of this book, Jean Jouzel, spent the greater part of his scientific career. At the Laboratoire de Glaciologie et de Géophysique de l'Environnement (LGGE) du CNRS (Centre National de la Recherche Scientifique) in Grenoble, we analyzed the impurities contained in the ice, in particular the air bubbles that are evidence of past atmosphere, a realm that our third author, Dominique Raynaud, brought to the forefront.

In 1987 we demonstrated that the variations in temperature and the amount of greenhouse gases in the atmosphere were connected throughout the last climatic cycle (in the last 150,000 years). With the work of American, Danish, and Swiss researchers, who focused more on Greenland, and the Franco-Russian collaboration centered on Antarctica, the study of glacial archives was well under way. We could henceforth attempt to reconstruct and to understand the mechanisms of climate variations in the past. And from that, it becomes possible to speculate about the future climate and its effects worldwide.

It is the development of this new discipline that we wish to reveal in this work. We are fortunate to have been able to contribute to its inception. But we owe a great deal to the researchers, technicians, administrators, and people on-site who have accompanied us during this amazing scientific adventure. We wish to thank them all.

These glacial archives are of interest not only to the scientific community. They are of huge interest to the broader public because the polar regions in

particular remain synonymous with adventure. And at present everyone senses their fragility. Anyone who is interested in the climate, in its history, its future, cannot ignore these regions of extreme conditions.

Several recent films have used the climate as their central theme. One of the two we will mention is a documentary that has become emblematic of the "global warming" concern for the future: *An Inconvenient Truth*, of which Al Gore is the indisputable star. The other, *The Day after Tomorrow*, is a work of fiction that quickly departs from the realm of the believable. Both assign a large role to the results obtained from deep glacial core drilling. These two films placed a camera lens on the research undertaken in the polar regions, which have gained new life during the International Geophysical Year, whose fiftieth anniversary we celebrated during the International Polar Year 2007–2008.

We can reconstruct the climates of the past using various methods, and the ice of the ice sheets are a precious memory of our climate. But they above all contain a unique treasure with their air bubbles. As the climate has evolved these bubbles have recorded the composition of our atmosphere, including greenhouse gases. This is the central theme of our book: we will retrace the campaigns of exploration and of core drilling that have reached close to four thousand meters in depth and present the measurements and interpretations that they have allowed. But first we will familiarize the reader with what we scientists call the "cryosphere" and summarize what we know about the "ice of yesteryear," which has impacted the life of our planet from the time the Earth almost became a snowball up to the heat and the cold of the last two million years.

Our shared enthusiasm for the wealth of results offered by deep core drilling in Antarctica and Greenland comes from the fact that beyond what they teach us about the way in which our climate evolved in the past, they are rich in information on its future evolution. That is why this book also looks at the future while emphasizing the impact of climate warming on the white planet, particularly on the polar regions, which are particularly sensitive to it.

At the end of the journey, we will better understand why, since the beginning of the nineteenth century, we have entered a new era, the Anthropocene, which is characterized by an increase in pollution due to the activities of humankind, which puts its stamp on the environment and on the climate of our planet and thus on our future. This book does not propose a miracu-

lous solution. Its object is to describe the progress of a science that gives us every reason to be concerned and aims to inspire citizens and policymakers to confront the enormous challenge before us.

Let us now look at the icy expanses that will first take us back in time.

Acknowledgments

This work presents scientific results that are the fruit of work carried out by many researchers, engineers, and technicians in areas relating to the history of our climate and of our environment, as well as their future evolution. We wish to thank everyone involved, with special thanks to those we have collaborated with, in France and abroad, during the many years that we have spent deciphering the glacial archives. It has been a fantastic collaborative adventure. In France, since the 1960s, we have enjoyed a close collaboration among the teams from Grenoble, Saclay, and Orsay, and that collaboration has benefited from the unfailing logistical support of the Expéditions polaires, then of the IPEV (Institut Polaire Français Paul Emile Victor), and from that of various departments of the CNRS and the CEA, as well as from European programs (European Union and the European Science Foundation). The adventure has unfolded within a context of remarkably organized and extremely stimulating international collaborations that were enhanced through many friendships. Our thanks go out to everyone. Thanks, too, to Volodia Lipenkov and to Jean-Robert Petit and Valérie Masson-Delmotte for advising on certain chapters in the book.