✣ CHAPTER ONE ✣

Devil in the Mountain

Devil, ***n.*** Superhuman malignant being; fighting spirit, energy or dash in attack; mischievously energetic, clever or self-willed person; literary hack doing what his employer takes the credit and pay for. (*OED*)*

A Simple Question

In Bolivia, the local silver miners consider the entrance tunnel of a mine, so laboriously hewn into solid rock, as the gateway into a mysterious realm ruled by earth spirits. The miners are burglars in this underground world, stealing its riches. They are at the mercy of the wicked Tio—the devil in the mountain—who decides the fate of each mine. The miners place a grotesque statue of the devil near the mine entrance to constantly remind themselves of his presence. Each time that they pass this statue, they adorn its head with small presents of cigarettes, money, coca leaves, or sticks of dynamite, hoping that these will keep the devil happy, ensuring the success and safety of their mine.

To a certain breed of scientist—geologists—the devil in the mountain can be interpreted another way. It is geology, the sum total of things that make up the bedrock of our world—the stuff we live on. This bedrock contains a story of events going back to the remote past of our planet, a story that will show, among many other things, why one mountain contains a rich seam of silver while another is just barren rock. In the past two hundred years, scientists have completely lost their fear of the devil in the mountain, developing techniques to chronicle the sequence of events that make up the history of the Earth.

*The chapter opening epigraph definitions throughout the book are paraphrased from the Oxford English Dictionary.

Today, geologists are not content to just reveal the planet's history. Like historians who delve into long past human conflicts, they also want to know why these events happened, searching for the underlying fundamental laws that govern them. There are many lines of geological investigation, and different geologists have pursued answers to their own particular questions. Some geologists—or rather geophysicists—have searched for the fundamental engine that drives the restless Earth, exploring the deep interior of the planet. Others have tried to understand the causes of past changes in the Earth's climate, probing the behavior of the planet's atmosphere and oceans. Yet others—paleontologists—have puzzled over the factors that have controlled the course of the evolution of life, triggering great explosions of life or its demise during mass extinctions. Most geologists are content with tackling one small part of the overarching themes, exorcizing their own particular "devils" and thereby fitting a few extra pieces into the overall jigsaw puzzle of scientific understanding. They have their own fascinating tales to tell of their particular scientific investigations, and the combined effect of all these endeavors has slowly begun to reveal a much bigger picture of how our planet works.

This book describes how I, as a geologist, tried to solve a scientific problem that has long fascinated me. It is the story of the search for the answer to a simple question: why are there high mountain ranges on the face of the Earth, in the continents? Most of the world lies far beneath the sea, and dry land is on average only a few hundred meters above sea level. So, high mountain ranges, reaching more than 2,000 meters (6,500 feet) above sea level, form only a tiny fraction of the Earth's surface. Despite this, they are hardly features of the planet that one can miss. The great mountain chains seem to tower above the rest of the world, following distinct zones that snake across Europe and Asia, from the Pyrenees and along the Alps to the Himalayas and Tibet, or along the western edge of the Americas from Alaska down to Patagonia. From the perspective of our busy lives, on the plains or deep down in the valley bottoms, they can appear vast and forbidding. And from their summits our human world looks decidedly small and unimportant.

Exploring mountainous regions has always been difficult. For this reason, I suppose, I have always been intrigued by these parts of the Earth, where a high ridge of rock can wall off a valley from its neighbors, creating an isolated world. But what forces or processes in the Earth govern their location, overall shape, and height? Some of the greatest scientists, going back at least as far as the ancient Greeks, have tried to answer this question. And it is not a dry and dusty academic question, but one that is central to understanding many important aspects of our planet, including our own evolution. With the specter of global warming looming on the horizon, scientists have been looking ever more closely at the planet's climate. It has become clear that mountain ranges can exert an enormous influence on this climate, determining not only its temperature but also the distribution of rainfall. It follows that the rise of mountain ranges in the past, or their subsequent demise, has driven profound changes in the climate. Biologists are beginning to see that these changes are one of the ways that the planet steers the course of life's evolution.

By chance, my own search for an answer has led me to the high Andes of Bolivia, where over the past fourteen years, on many expeditions, I have tried to chronicle the geological history of these mountains. And so the book contains another story, the day-to-day story of my journeys in this extraordinary part of the world.

A Conversation with Rocks

Anybody listening to two geologists talking would be struck by one thing above all—the sheer range in scale of the subject matter. Geologists habitually think about processes that occur on time scales that are far outside the human experience, taking place over thousands to billions of years. They will observe phenomena that are on a scale of microns (millionths of a meter) to thousands of kilometers. And they will try to weave all these time and size scales into an overall understanding of the way the planet works.

At some point in any geological investigation, a geologist will venture out of the laboratory into the real world, or as a geologist will say, into the field. A considerable part of a geologist's training is concerned with the basic craft of fieldwork—something that some people are naturally better at than others. Good field geologists have an uncanny ability to make the right observations at the right time, to sort out the simplicity of the natural world from all its complexity. Being among them is a rare chance to hear nature speaking clearly. The apparent ease with which they make their observations is often deceptive—on one's own again, the world looks as cluttered and messy as ever.

Geologists go where the rocks are. The rocks are not always in easy places. And, unlike tourists, who usually accept much of what they are told on their fleeting visit, geologists continually observe and ask questions, getting under the skin of the landscape they study. Ideally, a geologist would like to be able to flit from one place to another with an all-seeing eye, effortlessly taking in the key observations. Reality is very different. Much of your time is spent just getting around. And often you have no clear idea of where to look, or even, sometimes, what you are looking for. But somehow, if you persevere, the observations start to create patterns or ideas in the mind, and these grow and grow until you seem to be involved in a curious dialogue: the rocks speak, you reply with a question, and they answer back.

Birth of a Project

Look at any map of the world and your eye will be caught by the long, sinuous mountain chain on the western margin of South America. These are the Andes, forming the second largest mountainous region on Earth after the great ranges of Asia. The name conjures up images of high mountain countries, once ruled by the Inca empire and conquered by the Spanish conquistadors in the sixteenth century. The Spanish subsequently extracted a vast mineral wealth of silver and gold from the mountains—a wealth that financed the

Spanish empire. Today, the region is alive with geological activity, rocked by large earthquakes and explosive volcanic eruptions, a region rich in pickings for a geologist.

The Andean project was the idea of John Dewey, professor of geology at Oxford University. In the early 1970s Dewey was one of the few geologists who saw how to use the new, exciting theory of plate tectonics to make sense of a vast range of geological ideas and observations. He had shown that the rocks in the continents contained a record of plate tectonics going back hundreds of millions of years. And he could explain the variety of rocks found in many mountains in terms of the opening and closing of long vanished oceans.

John Dewey believed that the Andes were the place to solve many fundamental problems about the Earth, such as the reasons for earthquakes and volcanoes, the forces that drive the movements of its surface, and, ultimately, the origin of the continents themselves. Though the Andes were deeply embedded in the geologist's jargon—a common type of volcanic rock, found in many parts of the world, is called andesite after the Andes—they were somehow being neglected by geologists. The eye of the geological community was turned toward the Himalayas and Tibet. Yet, as we shall see, many geological clues to the way the Earth works were first found in the Andes.

The late 1980s was a good time to think about working in South America because a number of big, multinational oil companies had decided to invest heavily in oil exploration there, both in the Andes and along its eastern margin. One of these companies agreed to pay for a five-year research project that would provide background information for their own geologists working in the region. They left the details deliberately vague. The idea was to let the project have the room to develop in its own way. Whether the company was right, time will tell, though without doubt this unusual freedom gave rise to a very unusual research project.

In 1989 I was at a loose end. I had recently returned from New Zealand, where I had been studying the effects of earthquakes and fault lines along the boundary between two great tectonic plates.

I had just presented the results of some of this work at a conference in Greece. Here, I met up again with Philip England, who had been recently appointed as a geophysicist at Oxford University. Philip passed on my name to John Dewey, who was on the lookout for somebody to run his South American project. I had no idea that the job would occupy more than a decade of my life. During this period, Dewey gave me complete freedom to travel where I wanted and develop my own research.

Destination Bolivia

Our choice of Bolivia as the focus for the project started with a telephone call. I rang up the Foreign Office in London for advice about working in South America and was put through to a man on the South American desk. I told him that I was running a scientific research project in the Andes. Did the Foreign Office have any particular advice about undertaking this sort of work in South America? His reply made me feel rather gloomy:

"Well, I wouldn't go to the northern part of South America—it is far too dangerous with the various drug wars. Peru is out because of the Sendero Luminoso guerrillas—the Peruvian government have lost control of most of the country. There have been a number of military rebellions in Argentina—the country is still very unstable after the Falklands disaster and they don't like the English. Chile is a bit tricky at the moment because there is strong popular feeling against General Pinochet and it is unclear whether he is going to give up power voluntarily."

He paused for a while, then said rather doubtfully:

"Well, there is Bolivia."

I knew that Bolivia was very poor and that it was supposed to have been the scene, near San Vicente, of many of Butch Cassidy and the Sundance Kid's more daring robberies, stealing money from the rich mines. Also, I had always thought that Bolivia was the most dangerous and difficult South American country of all.

"Bolivia?" I echoed.

"Yes"—he sounded much more confident now—"do yourself a favor and go to Bolivia. I can't see any real problems there at the moment. The currency is fairly stable and they have a democratic government."

This final comment has to be seen in the light of the fact (as I subsequently discovered) that in the roughly two hundred years of the Republic of Bolivia, there has been on average a change of president every six months—usually as a result of a military coup. Also, in the late 1980s Bolivia had just emerged from an unusually severe bout of hyperinflation, with an annual inflation rate of 24,000 percent. When I first arrived in La Paz in 1989, the smallest note denominations were one million and ten million pesos—these had been optimistically relabeled as one and ten Bolivianos. A standard scam was to palm off on unsuspecting tourists million-peso notes as change instead of ten million pesos—you had to be quick thinking to notice whether there were six or seven zeros after the one.

Curiously enough, it made good scientific sense to base our project in Bolivia. The mountain ranges of the Andes are highest and widest there, and there is an intriguing swing in their general orientation, following the curve of the coastline. Since first looking at maps of South America, I had a feeling—which I had never quite thought through properly—that the key to understanding the origin of the Andes lay in the high peaks of Bolivia. For this reason, after my initial reaction, I was very receptive to the idea of working there.

I probed the man on the South American desk a bit more to reassure myself that he was serious about his suggestion, then hung up with a feeling of excitement. I was beginning to feel that what at first had seemed to be an academic exercise was developing into an adventure. But, if you really want to know how this adventure unfolded, I need to prepare you for it, trying to put you into my shoes, as it were, when I first embarked on my research. The best way to do this, I think, is to begin telling a story stretching back over two thousand years—a story that I find fascinating in its own right—of how geologists have struggled to make sense of mountains. Their discoveries formed the basis of the stock of ideas and

preconceptions that I set out with—some of these I soon discarded, but others I came to value more and more.

In everything that follows, I have tried to be as self-explanatory as possible. However, it is difficult to discuss many geological phenomena without making use of some basic ideas or jargon. Though I have gone to great lengths to unpack these wherever I first use or introduce them, you may still find it helpful to remind yourself of the meanings of particular terms, especially when they reappear later on, by dipping into the selected glossary at the back of the book.