# Taking the fingerprints of active volcanoes

**Professor David Pyle** describes the first systematic attempt to obtain detailed information about the frequency and patterns of volcanic activity in southern Chile over the last 20,000 years

**Could you provide an overview of your project on the tempo of post-glacial volcanism in southern Chile?**

Many of Chile's active volcanoes are not easily accessible, or lie some distance from major towns and cities. For these reasons, there are few historical records of eruptions from any volcano in Chile prior to about 1800 AD, and more complete observations have probably only become prevalent within the past 80-100 years or so. Even today, when we have the ability to track volcanoes from space using satellites, it is not always possible to verify reports of eruptions. We hope to use records of ash and pumice deposits left behind by past eruptions to piece together much longer histories of larger eruptions from volcanoes in southern Chile.

**Research conducted by your group examines the reaction of volcanoes in southern Chile to the disappearance of ice at the end of the last glaciation. What is your hypothesis?**

Our working hypothesis is that loss of ice from the volcanoes at the end of the last glaciation may have led to a change in the nature or rate of volcanic eruptions.

**Which volcanoes have you selected for your current case study and why?**

We have chosen to focus on a set of volcanoes about 38-40° south, which includes two of the most active volcanoes in Chile (Llaima and Villarrica) and several others known to have had major explosive eruptions within the past 20,000 years (such as Quetrupillan, Mocho-Choshuenco and Sollipulli). These volcanoes were all once glaciated and most still have a permanent snowcap. They are all relatively accessible and many lie close enough to the lakes, for which this part of Chile is well known, enabling us to use lake-core sediments to piece together their eruption records.

**By what means will you extract the ash layers from cores of lake sediment?**

Quite easily really – our colleagues at the University of Ghent, Belgium, have already collected these sediment cores; we simply need to visit their labs to scrape off tiny amounts of the layers of sediment that we are interested in, using a knife or spatula.

**How do you intend to overcome the severe lack of adequate geochemical analyses of tephra layers preserved within the lacustrine and peat sediment sections of volcanoes?**

We have undertaken a large programme of analysis using an instrument called an electron probe to measure the chemical compositions of tiny spots of glass. So far, we have examined over 1,000 samples to fill this knowledge gap, and to start piecing together the correlations between volcanic outcrops.

**Could you explain how chemically fingerprinting the major volcanic ash beds will provide insight into the tempo of post-glacial volcanism?**

It's a bit like a 3D jigsaw puzzle. Each of the lake cores we have looked at contains a record of thousands of years of deposition. We also have some idea of sediment age within these cores. Chemical fingerprinting of the volcanic units, linked with information we have from fieldwork, means that we can now join up the eruption records through time and space, bearing in mind that many eruptions may leave deposits in only one core. This database then provides the information we need about how eruption rates have changed (if at all) over the past 15,000-20,000 years.

**Mapping the tempo of volcanic behaviour will result in a detailed understanding of climate, volcanism and earthquakes in southern Chile. How can the exploration of past activity enhance current knowledge of how volcanoes might behave in the future?**

Volcanologists start with the assumption that the past record of a volcano gives us clues about the way that they behave. Knowing the past eruption record well means that we can build a better 'forward model' of what might happen in the future. This information is tremendously important for long-term planning, and for the development of strategies to reduce the risk from future eruptions, for example, early warning planning, design of evacuation routes and development of monitoring, and so on.

THE STEAMING SUMMIT CRATER OF VOLCAN VILLARRICA, CHILE © DAVID PYLE

# Small events, BIG consequences

Researchers at the **University of Oxford**, UK, are investigating sediment deposits from southern Chile to create a complete record of volcanic activity since the Ice Age and the effects of glacial ice retreat on volcano behaviour

**THE VOLCANOES OF** Chile, of which there are more than 500, form a large arc spanning the Andes mountain range along the Pacific coast. Most have been dormant for many centuries or are considered extinct, but about a quarter are potentially active and more than 100 are currently active or known to have erupted within the last 200 years. On average, at least one eruption has been recorded each year since 1850, making Chile one of the most volcanically active regions of the world. However, little is known about the occurrence and frequency of eruptions prior to 1850, especially in southern regions.

The volcanoes of the southern swathe of the Chilean Andes often rise in pairs, either as distinct mountains, such as Llaima, or as twin-peaked massifs, such as Tolhauca and Lonquimay. These volcanoes formed long ago, and many were buried under ice during the last glacial period, or Ice Age, which ended 16,000-18,000 years ago. Extending in a chain for close to 1,000 km, these volcanoes, towering thousands of metres high (and still growing), are thought to have been continually active ever since. They remain glaciered with characteristically conical snow-covered peaks, and their summit craters are filled with snow and ice to depths of many metres. In some cases, where calderas have formed, their dimensions are vast.

When such volcanoes erupt, gases and tephra (ash and pumice) are dispersed into the air, and lahars – composed of melted ice, mud and debris – may cascade down their slopes into rivers, lakes, flood plains and the sea. Lahars account for many of the deaths, and much of the destruction and displacement that ensues from volcanic activity. A major explosive eruption could potentially perturb global weather systems and air quality due to strong feedback between Chilean volcanic and climate processes, however, most historical eruptions in southern Chile have been relatively small.

Nevertheless, the consequences of even notionally small events can be severe for local communities. For example, in 1985 when Nevado del Ruiz erupted in Colombia, the town of Armero, built largely on a flood plain around 45 km away, was devastated; no evacuation measures were taken and 25,000 people died. In 1965, an avalanche of rock and ice was triggered from the summit of the Yate in southern Chile. Thought to have been weakened by atmospheric warming rather than volcanic activity, it generated a lahar that entered Lake Cabrero and created a tidal wave that washed away a settlement of 27 people. 'Small' events can also have significant effects on the local economy; when Chaitén erupted for the first time in thousands of years in May 2008, the resulting tephra fallout led to the evacuation of its namesake town. The volcano continued to erupt violently, and 10 days later a series of lahars inundated much of the town, which has still not been fully rebuilt after initial failed attempts to relocate its inhabitants.

VOLCAN LANIN, CHILE-ARGENTINA BORDER © DAVID PYLE

## INTELLIGENCE

### TEMPO OF POST-GLACIAL VOLCANISM IN SOUTHERN CHILE

### OBJECTIVES

- To piece together the eruption records of the volcanoes of southern Chile over the past 20,000 years
- To use these records to find out whether the rate, or size, of eruptions has changed over this time, and use this evidence to develop a forecast for future volcanic activity in southern Chile
- To use the outcomes of this study to develop a better understanding of the potential effects of large-scale climatic change on volcanic activity

### PARTNERS

**Dr Tamsin Mather**; **Dr Karen Fontijn**; **Harriet Rawson**; **Stefan Lachowycz**, University of Oxford, UK • **Dr Jose Naranjo**, Servicio Nacional de Geologia y Mineria (SERNAGEOMIN), Chile • **Professor Marc de Batist**, University of Ghent, Belgium • **Dr Seb Watt**, University of Birmingham, UK • **Dr Jennie Gilbert**, University of Lancaster, UK • **Dr Andrés Rivera**; **Dr Francisca Bown**, Centro de Estudios Cientificos, Chile

### FUNDING

**Natural Environment Research Council**: Tempo of post-Glacial Volcanism in Southern Chile (2011-14); Impact and extent of the 2008 eruption of volcan Chaitén (2008-09) • **International Association of Volcanology and Chemistry of Earth's Interior**: Research Grant to study ice-covered volcanoes in Chile (2010-11) • **British Council**: Darwin Now Grant, Volcanic Eruptions and the Great Chilean Earthquake of 1835 (2009)

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**PROFESSOR DAVID PYLE**'s interest in volcanoes was sparked when he first visited Chile, aged seven, but it was 30 years before he returned. In between, he studied Geology and completed a PhD in Volcanology at Cambridge. After a year at CalTech, he held lectureships in Cambridge and then Oxford, where he is now Professor of Earth Sciences.

### CREATING THE HISTORICAL RECORD

With limited reliable historical information available – for example, the record of Chaitén's activity prior to 2008 is less than 100 years old – Professor David Pyle is currently addressing the question of how many times the volcanoes of southern Chile have erupted over the past 20,000 years, since the peak of the last glaciation. According to Pyle, based at the Department of Earth Sciences at the University of Oxford, knowing more about the past behaviour of southern Chile's volcanoes is fundamental for developing realistic models to forecast potential consequences and future eruptions.

Funded by the Natural Environment Research Council (NERC), Pyle's project exploits the fact that, as the glacial period came to a close and ice retreated, moraine-bounded lakes formed near many of the volcanoes. Pyle and his team are examining in detail the layers of volcanic ash and pumice in the sediments deposited at the bottom of these lakes to establish a chronological record of past volcanic events.

For this, the researchers are using a technique known as tephrochronology to systematically analyse as many tephra deposit layers as possible, extracted from cores of lake sediment. In other words, they are 'fingerprinting' the major volcanic ash beds and tracing the distribution of tephra from particular eruptions across the landscape: "Explosive eruptions are good for this – the eruptions are short so they make a good time marker, and the tephra from single events can be spread across a wide area so they have a chance of being preserved in the geological record," Pyle explains. The age of any charcoal deposited before or during each layer provides clues for dating. Chemical analysis of the deposits across different sites then reveals the source and extent of the tephra: "This works very well when the volcanic glass is fresh and the products have a distinctive fingerprint," observes Pyle. In addition, Pyle's collaborators at Ghent University, Belgium, have discovered that even small eruptions can leave a trace in the lake sediments, washed in with mudflows that follow many eruptions.

So far, the research team has found that tephrochronology delivers better results than using observations of age and appearance alone to link volcanic deposits, although in some cases the record is uncertain due to lake sediment disturbance by events such as earthquakes, or because the tephra may have been gradually washed into the lake.


View of the peak of Volcan Choshuenco, southern Chile.

### GLACIATION, VOLCANISM AND CLIMATE CHANGE

Many of the world's existing non-polar glaciers are situated on volcanoes and store large quantities of ice and snow. Rapid melting of volcanic glaciers as a result of climate change presents additional hazards for communities in their vicinity. An example of this is the caldera formed by the currently dormant Sollipulli – at 2,200 m above sea level, it is 6 km long, 4 km wide, at least 300 m deep and filled with ice. Were this ice to melt, either due to an eruption or climate change, there are only two possible routes for the meltwater to escape, both of which converge on a river system leading to the small town of Melipeuco. At most, the residents would have only 20 minutes' warning of the flood's advance. Continued warming of glacial craters and caldera, and the subsequent retreat of ice due to climate change, means the outlook for people living near volcanoes in southern Chile may consist of more frequent catastrophic flooding events, and lahars.

Pyle aims to determine whether the loss of ice following the end of the last glaciation changed stresses in volcanic crust, making it easier for the volcanoes to erupt; or whether melting of the ice reduced pressure on the molten or partially-molten rock beneath, allowing magma to build up at depth and then erupt after the ice had disappeared: "The patterns that we find in this part of Chile will influence our understanding of the global links between volcanism and glaciation," he states. "Our preliminary work indicates that the earliest post-glacial eruptions in Chile may have been larger than usual, but we really need better evidence – and that is where this project comes in."

THE ICE-FILLED SUMMIT CRATER OF VOLCAN SOLLIPULLI, CHILE
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