

# The wake of a legendary earthquake

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**Although quiet this century, the Cascadia subduction zone has produced big earthquakes in the past. But how big? An ingenious study involving documents written 300 years ago suggests that they can be giants.**

WHETHER a giant earthquake could occur in the Cascadia subduction zone, off the Oregon and Washington coast of North America, has been a subject of hot debate for the past decade because of the tremendous destructive potential of such an event. Many lines of evidence, from plate tectonics to sea-floor sediments, have been used to argue 'convincingly' both for and against the possibility of giant earthquakes in the region. Evidence of extensive coastal subsidence of at least 1 metre, dated by carbon-14 and by tree-ring studies, suggests that the last such earthquake may have occurred about 300 years ago<sup>1</sup>. An uncertainty in timing of about 20 years seemed as good as one could get for these old events. However, a study by Satake and colleagues<sup>2</sup> (reported on page 246 of this issue) combines an investigation of old Japanese documents with computer simulations of tsunamis to determine the size of this event and its timing — not only the date, but even the hour. As Satake *et al.* mention, this timing seems to agree with American Indian legends saying that coastal flooding occurred on a cold winter's night.

In the past century no subduction zone in the world has exhibited such low seismic activity as Cascadia<sup>3</sup> — no earthquake with moment magnitude ( $M_w$ ) larger than 6 is known to have occurred there for the past 70 years. It is human nature not to worry too much about seismic hazard if the present level of activity is very low. However, between the late 1960s and the early 1980s, as the study of plate tectonics and giant earthquakes ( $M_w > 9$ ) advanced, Cascadia began to look less safe. The oceanic plate there is young (about 10 million years old), and large amounts of sediment are dumped on the trench by the Columbia river. Other sites of giant earthquakes have similar features, suggesting that giant earthquakes could also occur in the Cascadia subduction zone<sup>4</sup>.

In opposition to this view some scientists argued that Cascadia is different because of the extreme youth of its subducting plate, and that the combination of probable high temperatures and the quantity of water-saturated sediment deposited there would effectively lubricate the plate, and prevent the level of strain accumulation that produces giant earthquakes. This controversy excited the interest of geologists, and extensive

efforts began in the late 1980s to identify geological evidence for giant earthquakes in the area<sup>5</sup>. They found alternating layers of peat and mud in estuarine sediments at several places along the Cascadia zone, a pattern that indicates sudden subsidence and submergence by the ocean. The subsidence could be interpreted as due to crustal deformation during a giant earthquake. Similar subsi-

with  $M_w \sim 7.5$  would cause very strong ground shaking, but its effect would be limited to a distance of about 200 km from the rupture zone. Tsunami height from such earthquakes rarely exceeds 2 metres. In contrast, an  $M_w = 9$  earthquake could rupture the entire 1,000 km length of the subduction zone, and would cause strong ground motion up to a distance of several hundred kilometres from the rupture

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Seattle, in Washington state. The city is about 150 km from the Cascadia rupture zone. Anchorage, at roughly the same distance from the Alaskan subduction zone, was strongly shaken by a magnitude 9.2 earthquake in 1964.

dence occurred during the two largest earthquakes this century — in Chile in 1960 ( $M_w = 9.5$ ), and in Alaska in 1964 ( $M_w = 9.2$ ). Each subsided peat layer is overlain by a distinct layer of sands which look like those deposited by tsunamis; similar features were found after the 1960 Chilean earthquake. The palaeoseismic studies were followed by tree-ring studies, which document the widespread death of trees near sea level about 300 years ago<sup>6,7</sup>.

These observations have convinced most scientists that during the past 2,000 years the region has experienced at least several large earthquakes. However, one of the important questions was whether these earthquakes were really giant earthquakes with  $M_w > 9$ , or a series of somewhat smaller earthquakes with  $M_w > 7.5$  (ref. 8). In terms of the implications for seismic hazard, especially tsunami hazard, the distinction between these two possibilities is very important. An earthquake

zone. The maximum tsunami height would probably exceed 20 m, and considering the large population in the coastal areas of Oregon and Washington, such huge tsunamis would have devastating effects.

With all the limitations of comparative and palaeoseismological studies, it seemed that reducing these uncertainties would be extremely difficult. The study of Satake *et al.* has changed that view. In tsunami catalogues and old Japanese doc-

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6. Atwater, B. F., Stuiver, M. & Yamaguchi, D. K. *Nature* **353**, 156–158 (1991).
7. Nelson, A. R. *et al.* *Nature* **378**, 371–374 (1995).
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uments they found reports of flooding that occurred at several places in Japan on the night of 27/28 January 1700. There was no large earthquake at that time in Japan, Kamchatka, the Aleutian–Alaska region, or South America. By elimination, they concluded that these inundation events must be due to tsunamis caused by a giant earthquake in Cascadia. From their computer simulation of tsunami production and propagation, they found that it must have happened at about 21:00 on 26 January, local time, and had a magnitude of about 9.

Interpreting old documents is not as straightforward as it sounds, especially in this case. Japanese has changed considerably since the 17th century, and descriptions are often subtle and vague. Reading and interpreting them properly is a special skill, which Satake and colleagues have

been able to combine with the more modern skills required in making rigorous computer simulations. It is probably fair to say that some uncertainty remains in their interpretations, and further studies should be made of the behaviour of water-saturated deformable sediments and the complex deforming upper plate of the Cascadia subduction zone<sup>9</sup>. Nevertheless, the evidence presented by Satake *et al.* appears strong enough to justify serious studies of how best to prepare for a giant earthquake in Cascadia, and for the tsunami that would follow. □

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## LINGUISTICS

## Making sense of rongorongo

Paul G. Bahn

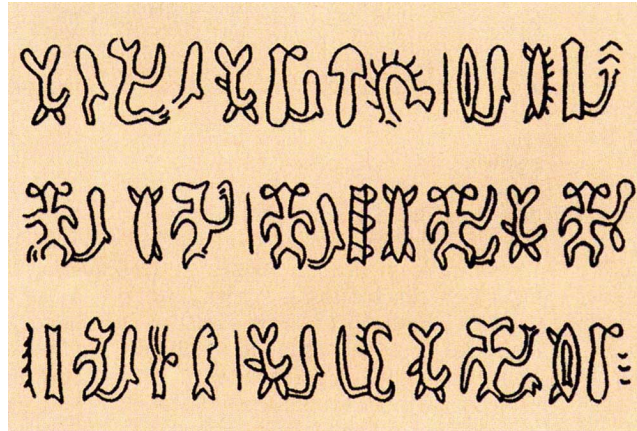
It is not often that *The Journal of the Polynesian Society* and *The Rapa Nui Journal* feature in these pages. That they do so now is because of two papers by S. R. Fischer<sup>1,2</sup> that help resolve one of the enduring enigmas of Easter Island, the tiny speck of land lost in the South Pacific. What is the meaning of its unique *rongorongo*, one of the world's few undeciphered scripts?

The script comprises parallel lines of characters, many of them bird symbols, hooks and so on (see figure), engraved on wooden tablets. Every other line is upside down, and the overall impression is of a tightly packed mass of uniform, skilfully inscribed hieroglyphics. Not one of the early European visitors who came to the island after its discovery by the outside world in 1722 ever mentioned the tablets, even though some spent days exploring ashore and entered native houses. The earliest written record of them is by a missionary in 1864, who said they were to be found in every house. Later visitors reported that they were kept apart in special houses and were strictly taboo.

It seems most likely that *rongorongo* was a very late phenomenon, directly inspired by the visit of the Spanish in 1770, when a written proclamation of annexation was offered to the chiefs and priests to be “signed in their native characters”. This was probably their first experience of speech embodied in parallel lines, and they then adopted a method of

script that employed motifs they had already been using in their rich rock art<sup>3</sup>.

The script now survives only as markings on 25 pieces of wood, scattered around the world's museums, which contain over 14,000 ‘glyphs’. Since the Peruvian slave raids of 1862 removed the last aristocratic or priestly islanders who could truly understand the tablets, their content



Detail from the Santiago staff, showing a few of the elements of *rongorongo* script. (Adapted from ref. 1.)

has remained a mystery. For many years, the foremost expert on *rongorongo* (meaning ‘chants’ or ‘recitation’) was the German scholar Thomas Barthel<sup>4</sup> who found about 120 basic elements in the glyphs (mostly stylized objects or creatures), combined to form between 1,500 and 2,000 compound signs. Barthel concluded that this was a rudimentary phonetic writing system, with picture symbols expressing ideas as well as objects — in other words, the individual glyphs did not repre-

sent an alphabet or even syllables, but were ‘cues’ for whole words or ideas, and a means of keeping count, like rosary beads. Since Barthel's work in the 1950s, *rongorongo* has largely been the preserve of the lunatic fringe, as well as of a series of bona fide scholars in Russia and elsewhere.

The new developments come from Steven Fischer, based in New Zealand, who has examined almost all of the tablets at first hand. His Rosetta stone was the Santiago staff<sup>1</sup>, a 2-kg wooden sceptre acquired by Chileans in 1870; measuring 126 cm by 6.5 cm, it once belonged to an Easter Island *ariki* or leader, and is now housed in Santiago's Natural History Museum. Fischer discovered that, uniquely among *rongorongo* inscriptions, it marks textual divisions with about 97 irregularly spaced vertical lines (see figure). He then noticed that each glyph that starts a new division (that is, is immediately to the right of a vertical line) is suffixed with a phallus-like motif.

Fischer then observed that, in the series of glyphs within each division, almost every third one (the 4th, 7th, 10th, 13th and so on) also has this phallic suffix. Not one division has the suffix on its last or its penultimate glyph; not one division contains fewer than three glyphs; and most divisions are multiples of three, with the first in each trio sporting a phallus in almost every case. In other words, the Santiago staff has a basic triad structure.

It turned out that the same structure occurred — without the helpful vertical lines — on two other *rongorongo* artefacts, the Small Santiago tablet and the Honolulu tablet I. This led Fischer to characterize the structure by the formula X'YZn: X designates the glyph with phallus suffixed; Y is a statistically more frequent glyph that follows X; Z is a statistically less frequent glyph that follows Y; and n is the constant, denoting unspecified repetition of the triad structure.

In the light of this structure, Fischer has made a tentative reading, based on information provided by an islander in 1886, who sang a creation chant, ‘*Atua Mata Riri*, which was probably pre-missionary in origin, although linguistically contaminated, and almost certainly based on an original *rongorongo* composition. The chant — a list of 41 fanciful copulations and issues, such as “God Mata Riri copulated with Sweet Lime; there issued forth the poporo plant” — also has a triad structure, X'YZ. Here the copulator is X; the ' is the phrase “copulated with”, equivalent to the phallic suffix; the copulatee is Y; and Z is the issue.

This is a common structure for ancient