nature

The Living Record of Science

《自然》百年科学经典

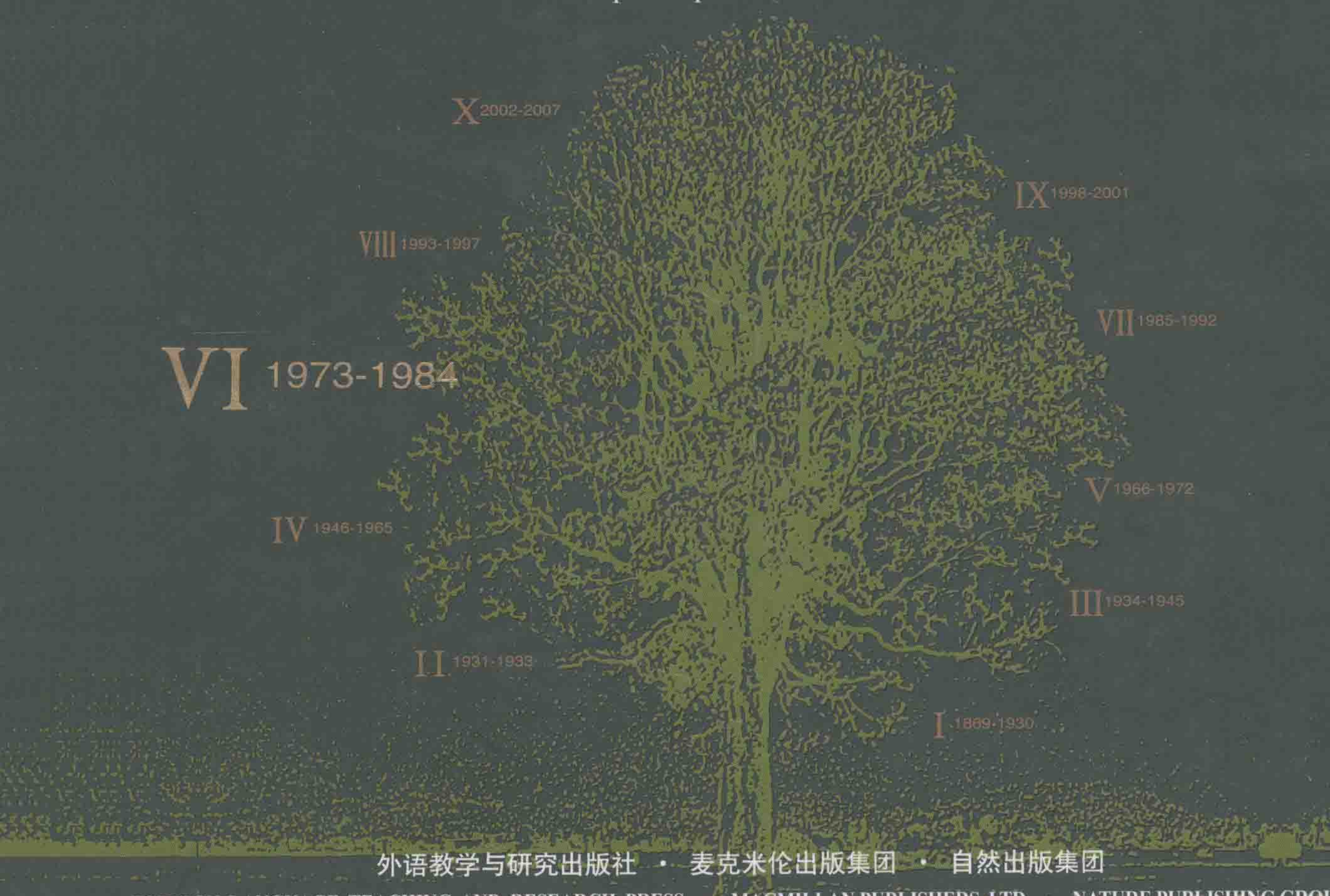
（英汉对照版）

第六卷

总顾问：李政道（Tsung-Dao Lee）

英方主编：Sir John Maddox
Philip Campbell

中方主编：路甬祥



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Monitoring Underground Explosions

D. Davies

Editor's Note

During the Cold War, the testing of nuclear weapons proceeded in parallel with international discussions about whether they might be banned. One of the obstacles to a ban was the problem of verifying a nation's adherence to it. The Soviet Union was particularly reluctant to agree to external inspections of its weapons facilities, so that verification would need to rely on a capacity for detecting tests from afar. Underground tests, still being conducted in the early 1970s, create seismic waves, but to use these for verification they would need to be distinguished from earthquakes. Here David Davies of the Massachusetts Institute of Technology reviews progress towards a sufficiently discriminating seismology, concluding that techniques were becoming adequate but still not infallible.

Seismological means for detecting and identifying underground nuclear explosions have improved steadily during the past ten years. A technique exists for separating explosions from earthquakes. The problem now is lowering the threshold and understanding the occasional problematic event.

AN underground nuclear explosion converts about 1 percent of its energy into seismic waves and these carry information about the time, size, and location of the event. They may also indicate that the event is indeed an explosion and not an earthquake. This information is somewhat more difficult to extract, and research in many countries for the past few years has been intensively directed towards discrimination between natural and artificial events. There is no other known way of identifying underground explosions that can be used on a world-wide basis. In this article, I shall describe the progress that has been made recently in this science, which has such obvious implications for arms control. The conclusions that I reach should not, however, be construed as a measure of the prospect of a total test ban. Many ingredients go into the making of a treaty, and ability to police it is only one of them. Seismological capability is thus not sufficient, but it may be necessary, at least down to some level of explosive yield. What would constitute an adequate level is a matter of some discussion at present. The science reported here is the result of the research of many seismologists. In order to reduce the number of references to a manageable level, however, I have cited only a few large compilations of results in which the genealogy of the various ideas and instruments may be found.

监控地下爆炸

戴维斯

编者按

冷战期间，核武器试验在进行的同时，国际上对于是否应该禁止核试验的讨论也在继续。禁止核试验的障碍之一是如何证实一个国家是否遵守此禁令。苏联特别不情愿外界对其核武器设施进行监测，因此，证实是否进行核试验将需要依赖于从远处监测核试验的能力。地下核试验直到20世纪70年代早期还在进行，试验会产生地震波，但是利用这些地震波进行核实的话需要将其和天然地震区分开来。本文中，麻省理工学院的戴维·戴维斯综述了地震学识别的进展，并得出结论，该技术已经能够胜任监测需要，但还不是绝对可靠的。

在过去的十年里，监测和识别地下核爆炸的地震学方法取得了稳步发展。这门技术可以将爆炸和地震区分开来。目前的问题是要降低阈值和理解偶然性的有问题事件。

一次地下核爆炸所释放的能量中，有百分之一转化为地震波，而这些地震波中就携带着关于这一事件的时间、规模和地点等信息。它们也可以说明，这一事件确实是一次爆炸而不是地震。这种信息的提取还要更难一些，因而在过去的几年中，很多国家的研究都集中指向了对天然事件与人为事件的识别。还不知道有其他识别地下爆炸的方法能够应用于全世界范围。在本文中，我将描述这一学科在最近所取得的进展，这些进展对于武器控制具有如此明显的作用。但是，我所得到的结论并不能被解释为完全禁止核试验前景的一种度量。促进条约制定的因素有很多，监管能力只是其中之一。由此看来，地震学方法的作用并不足够强，但是，至少具体到某些爆炸当量水平时，它可能是必要的。如何制定出合适的水平标准目前还是一件有争议的事情。这里所报道的是很多地震学家的研究成果。不过，为了将参考文献数量减少到可控制的限度，我只引用了一些大型的研究结果汇编，其中汇集了各种研究思想和研究工具。

The reason for testing nuclear weapons underground is not, of course a matter of public discussion, but a paper by Neild and Ruina[1] probably provides a reasonably complete list of purposes. Between 1968 and 1971 there was an average of about twenty-five underground tests a year announced by the United States compared with about ten presumed tests a year for the Soviet Union, one test per year for China and about five a year for France—all but one of the Chinese tests and all of the French tests being atmospheric. Britain has not announced a test for seven years.

When the banning of nuclear tests first became an international issue in 1958, a conference on the technical problems in Geneva clearly indicated that the science of seismology would need substantial advances to reach a stage at which instrumental observations could indicate unambiguously that an explosion with a yield of a few kilotons (kton) had been detonated. Indeed the rather meagre data available during that conference and the subsequent negotiations (there had at that time only been two or three quite small underground tests) suggested that a first objective could reasonably be an international network of about 170 stations which could detect seismic signals down to a certain threshold but not necessarily identify their source. It was expected that most seismic events would clearly indicate their earthquake nature by their location and depth, their radiation pattern and the shape of their signal, but there would be a residue which would need further investigation. In the early days of international negotiations, inspections of the sites of a fraction of these suspicious events were discussed in detail—the number and nature of such inspections being particularly contentious topics. With time, the position of the Soviet Union on the inspection issue hardened to the assertion that inspections were unnecessary, and that purely national means of policing would be satisfactory. Thus the "Geneva network" was never built.

The two issues which were seen as central in 1958 are central today. Background seismic noise (from wind, traffic, ocean waves, and so on) placed a limitation on the detection of events; and a certain number of earthquakes did not immediately reveal themselves as such. The advances in seismology have been substantial since 1958, but increasing the signal-to-noise ratio (s.n.r.) and finding improved methods of separating earthquakes and explosions are still the principal fields of research. The rather narrow frequency bands involved in seismology have controlled techniques rigorously, and because the work is concentrated in situations of low s.n.r., the problem has been that of finding the frequency at which the s.n.r. is highest, and aiming improvement at that frequency, rather than trying to encompass the whole spectrum of the seismic signal. This "mission-oriented" approach to seismology, when combined with the intellectually stimulating problems that have arisen on the way, has exerted a vital role in the development of seismology since 1958.

在地下进行核武器试验的原因，显然不是一个公开讨论的问题，不过尼尔德和鲁伊纳的论文中基本上为此提供了合理的完整解释[1]。在1968年至1971年间，美国宣称平均每年进行大约25次地下核试验，与之相比，苏联每年大约进行10次核试验，中国每年1次，而法国大约每年5次——不过中国所进行的除1次以外的所有试验和法国进行的所有试验为地上试验。英国已有7年没有宣布过核试验。

1958年，禁止核试验首次成为国际问题，在日内瓦举行的关于技术问题的会议明确指出，地震学需要取得实质性的进展，使得仪器观测毫不含糊地指出具有几千吨（kton）当量水平的爆炸的发生。确实，那次会议和随后的商谈中可用数据甚少（当时只有两次或者三次规模很小的地下试验），因此，首要目标是建立包括大约170个台站的国际台网，该台网能够检测到一定阈值之上的地震信号，但是不必确定其来源。人们期望，绝大多数地震事件可以通过其位置、深度、辐射模式和信号形状明确地体现出天然地震的特征，但还剩余少数事件有待于进一步研究。在早期的国际磋商过程中，详细讨论了如何对一小部分可疑事件发生的地点进行检查——检查的数量和性质是争议较大的问题。同时，苏联对于检查问题的立场渐趋强硬，并最终断言检查是不必要的，而单纯的国家监管方式就能满足需要了。因此“日内瓦国际台网”从未曾建立起来。

1958年时所关注的两个中心议题到今天仍然是焦点。地震背景噪声（来自风、交通工具、海浪等）限制了地震事件检测的进行；而且某些地震也不是马上就显现出天然地震的性质。自1958年以来，地震学已经取得了显著进展，不过提高信噪比（s.n.r.）和寻找区分地震与爆炸事件的改进方法仍然是主要研究领域。地震学中所涉及的极为狭窄的频率段严格地限制着这项技术，由于研究工作集中于低信噪比条件下，因此关键是找到具有最高信噪比的频率，集中在该频率下取得进展，而不是试图包揽震动信号的全部图谱。地震学中这种“任务导向式”的方法，再加上研究过程中产生的理性所激发出的问题，对于地震学自1958年以来取得的发展具有重要的作用。