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External Affairs and
International Trade
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Right Hon. Joe Clark
Minister

Affaires extérieures et
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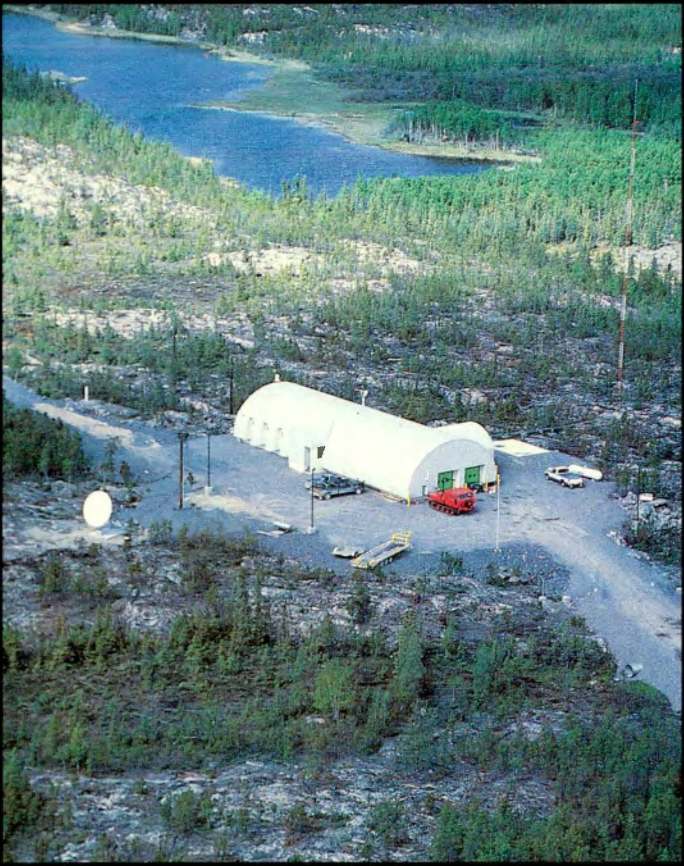
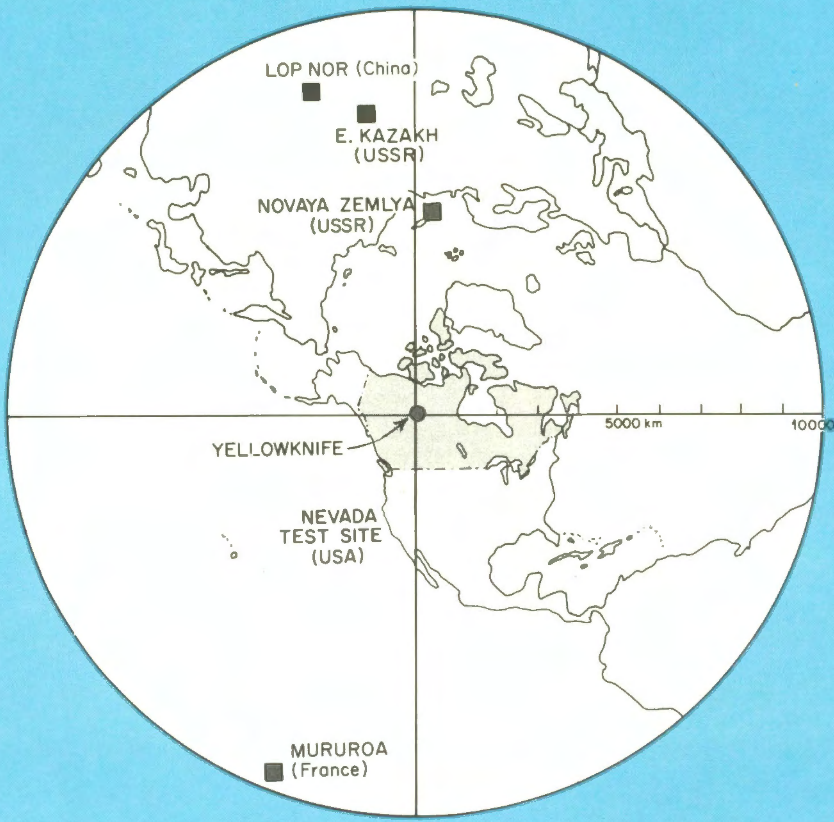
Le très hon. Joe Clark
Ministre

YELLOWKNIFE SEISMOLOGICAL ARRAY



A Canadian contribution to the verification of compliance with a Nuclear Test Ban Treaty

Canada



Geological Survey of Canada

Energy, Mines and Resources Canada

Arms Control and Disarmament Division

External Affairs and International Trade Canada

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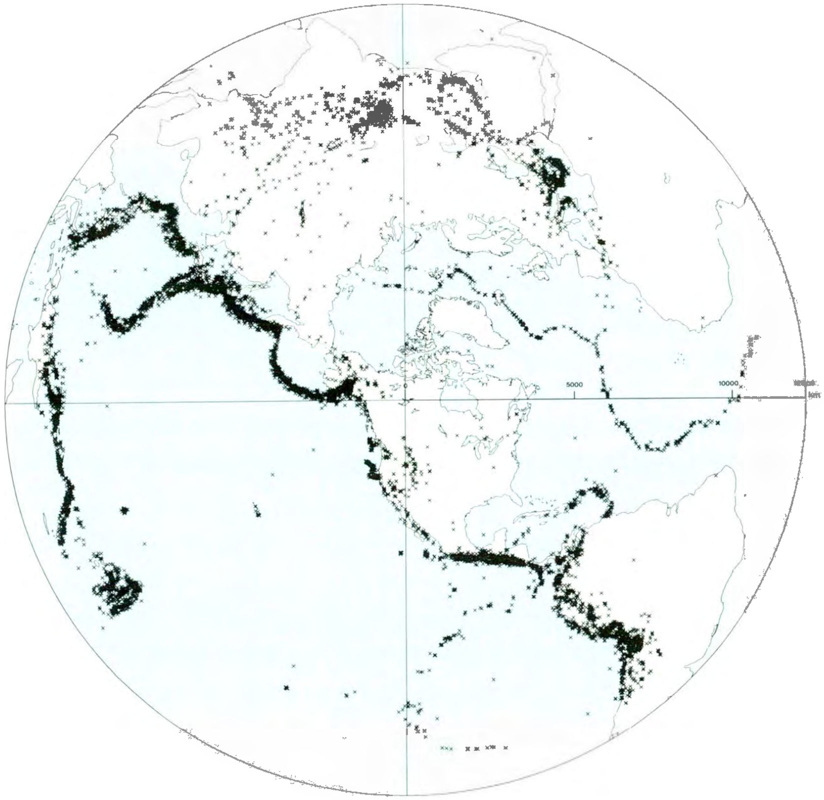
FOREWORD

One objective of Canada's arms control and disarmament policy is to achieve a complete ban on the testing of nuclear explosive devices at the earliest possible date. In attempting to attain this goal, Canada is co-operating with the international community in developing a reliable means of verifying compliance with a treaty banning underground nuclear explosions. Since inception of the Geneva Conference on Disarmament's Ad Hoc Group of Scientific Experts in 1976, Canadian experts have been actively participating in international co-operative measures to detect and identify seismic events.

As a national contribution to an eventual global seismic monitoring system, Canadian scientists have, since the early 1960s, used the Yellowknife seismological array and other Canadian and global seismograph facilities to undertake research on the detection and identification of underground nuclear explosions. During the period 1986-89, the Canadian government has completely refurbished the Yellowknife array using modern seismograph, computing and data communications technology.

This brochure describes the Yellowknife array in its current (mid-1989) configuration and outlines its history.

The Yellowknife array is operated, and seismic verification research conducted, by the Geological Survey of Canada, a sector within the Department of Energy, Mines and Resources Canada. These activities support the arms control and disarmament policies of External Affairs and International Trade Canada.



Sample of seven years of events detected by the Yellowknife seismological array (1978-84). The majority of these are earthquakes, but some are underground nuclear explosions at the test sites shown on the previous illustration.

HISTORY OF THE YELLOWKNIFE SEISMOLOGICAL ARRAY

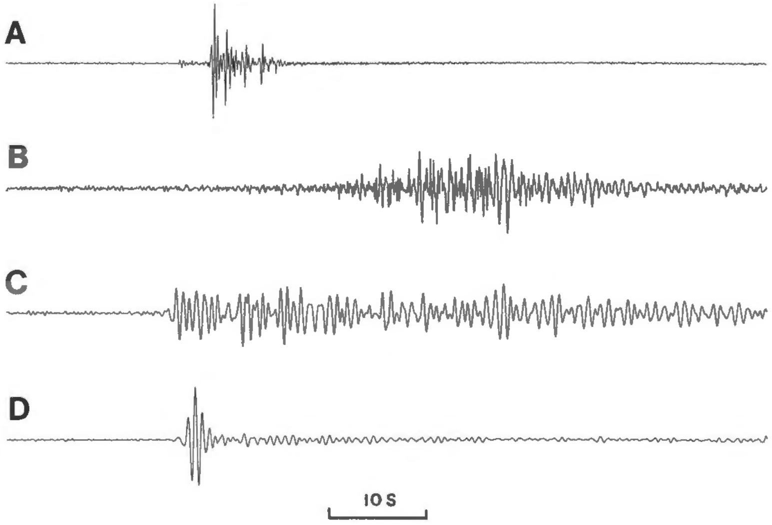
The first series of negotiations in Geneva on a comprehensive ban on nuclear explosion testing among the then nuclear weapon states (U.S.S.R., U.K., and U.S.A.) began in the late 1950s. Seismologists from a number of countries, including Canada, were included in the technical delegations of the 1958 "Conference of experts to study the methods of detecting violations of a possible agreement on the suspension of nuclear tests." The experts agreed that underground nuclear explosions in the range 1- 5 kilotons could be detected and identified if seismograph facilities were established in 170 land-based control posts. Although later studies revised these initial recommendations, research on the appropriate type of seismograph facilities began almost immediately.

The U.K. experimented first with a small seismological array installed in Wyoming, U.S.A., which demonstrated that seismic waves from nuclear explosions at distances around 3000-10 000 km could be relatively efficiently detected. In contrast to a standard seismograph station, which houses one or more detectors (seismometers) at a single location, an array consists of a number of seismometers spread out over an area. Computer processing of the recorded data allows the array to be steered like an antenna ,not only to enhance detection of seismic signals but also to estimate independently the locations from which they came.

The U.K. therefore focused its research attention on this far- distance (teleseismic) range (3000-10 000 km), and re-designed its arrays to have 20 seismometers spread over a region of 25 km diameter. Four such arrays were installed in Scotland, Canada, Australia and India in the early 1960s, and these arrays are still in operation (1989).

In April 1962 the British Ministry of Defence approached the Canadian Defence Research Board about the possibility of locating a seismic array in Canada. Agreement was reached whereby the U.K. would supply and install all equipment and Canada would provide the site, do the necessary construction and, through the Department of Mines and Technical Surveys (now Energy, Mines and Resources Canada), supply the personnel required to operate the array.

The Yellowknife area was selected for the array because of its location with respect to known nuclear test sites, its remoteness from coastlines, urban areas and other sources of cultural seismic noise, its good communications facilities, and its location on the stable Canadian Shield. Installation was completed in late 1962.



Samples of seismic events detected at Yellowknife. (A) Blast in a gold mine near Yellowknife. (B) Moderate earthquake in the Nahanni region of the Northwest Territories, about 500 km west of Yellowknife. (C) Earthquake in the Kuril Islands (U.S.S.R.). (D) Underground nuclear explosion at the French test site in the south Pacific, about 10 000 km from Yellowknife.

Array station showing the electronics box mounted on the radio mast and the propane tank used to fuel the thermo-electric power generators. The seismometer (not shown) is nearby in a shallow vault in the granite rock.

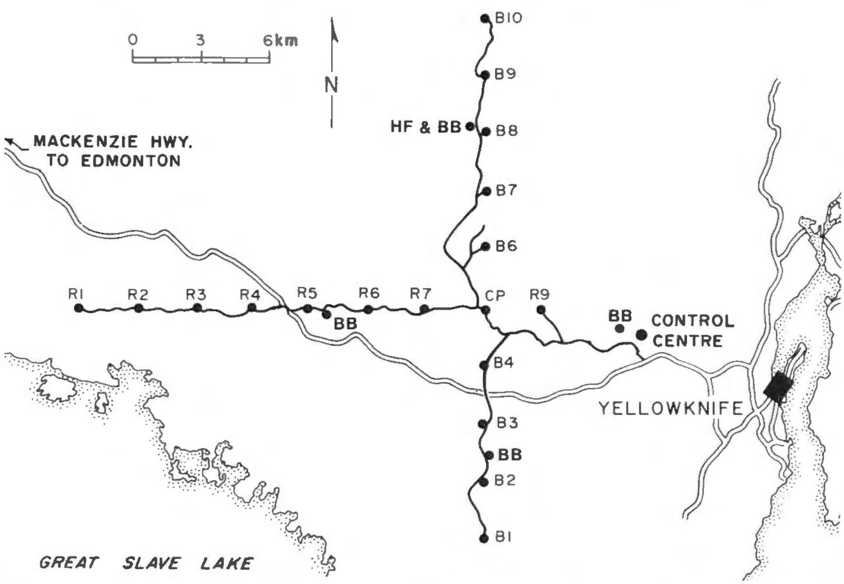
The original array had 19 seismometer vaults in the form of a cross, with a distance of 2.5 km between vaults. Each seismometer output was used to modulate the amplitude of an audio tone that was transmitted to the control centre on cables suspended from wooden tripods. In the control centre, the signals were recorded on 24-channel FM magnetic tape, each reel holding 3 days of data. Power from the control centre to the vaults was supplied via the same cables.

A major problem encountered by this original array was cable maintenance. Severe lightning strikes could cause enough cable breaks and equipment damage to put the array out of operation for several days. This problem was solved in 1971 by replacing the signal cables with VHF radio links between each vault and the control centre, and by installing a propane-fuelled thermo-electric power generator at each vault.

Various improvements in processing the seismic data from the FM tapes were made during the early years. However, a major breakthrough came in the early 1970s with the declining cost and increasing power of small computers. In 1974 the FM tape recording system was replaced by an on-line computer which was programmed to automatically detect seismic signals, steer the array to locate the source of the signals, and store the data on digital tape. The array operated in this configuration until the recent refurbishing completed in mid-1989.

THE 1989 YELLOWKNIFE SEISMOLOGICAL ARRAY

In January 1986, the Federal Cabinet approved a joint Energy, Mines and Resources/External Affairs proposal for a major upgrade of the Yellowknife array, and allocated funding of $3.5 million for this purpose for 1986 to 89.



New configuration of the Yellowknife array. The new teleseismic array occupies the same vaults as the old array. The four broad-band vaults are indicated as "BB", and the high-frequency site as "HF".

The new configuration of the Yellowknife array has preserved the "cross" layout of the original teleseismic array, but the outstation equipment, consisting of seismometer, power supply and radio telemetry hardware, has been completely replaced. The most notable improvements are high-resolution digitization of the seismometer output at the site and UHF digital radio telemetry to transfer these data to the Control Centre.

In addition, four new "broad-band" stations have been installed in tunnel vaults, each equipped with three-component seismometers that are sensitive to ground motions over a very large range of frequencies and amplitudes. In one of these new vaults, a set of three-component high-frequency seismometers, sampling ground vibrations 100 times per second, has also been established. The signals from all these sensors are, like those from the teleseismic array, digitized on site and relayed to the Control Centre by radio telemetry.

Broad-band vault. To maintain a stable temperature and to minimize ground tilting due to atmospheric pressure changes, the broad-band vaults are located in horizontal tunnels dug about 10 m into a granite cliff. The seismometers are further protected by two insulated doors.

The Control Centre, housed in a new building, contains the computers and telemetry equipment necessary to acquire, archive onto optical disk and reformat the data for transmission by an Anik satellite to Ottawa in near real time. Time signals from another satellite are used to ensure synchronous sampling of ground motion by all seismometers. Elaborate data correction and retransmission procedures minimize the possibility of data loss on the radio and satellite links.

Upon receipt in Ottawa, the data are subjected to both routine automatic processing and interactive analysis in order to detect event signals recorded in Yellowknife, and then to provide a rapid estimate of the time, location and size of the earthquakes or explosions that generated them.

Control Centre building in Yellowknife. The red and white tower on the right carries the UHF antennas that receive data from the array stations. The red all-terrain vehicle parked at the garage is the only means of ground transportation for servicing these stations. The dish for the up-link to the Anik satellite is in the left centre of the photo.

The Ottawa Seismology Building with the down-link from the Anik satellite on the roof.

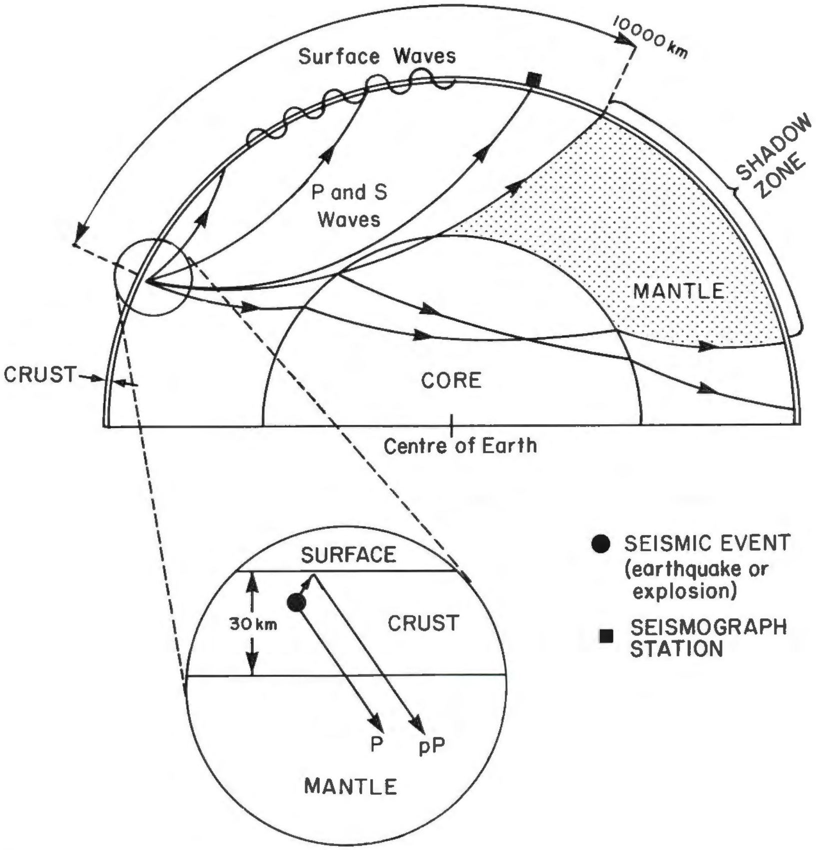
The new processing systems are much more accurate and flexible than those they replace. Two optical disk systems record both the continuous data and those related to detected events.

The design of the new systems places great emphasis upon reliability. The computers in both Yellowknife and Ottawa are backed up by redundant computers. Uninterruptible power supplies, comprising battery banks and a diesel generator, are also provided. The software incorporates measures for data catch-up over the satellite link if that link or the processing systems in Ottawa are interrupted.

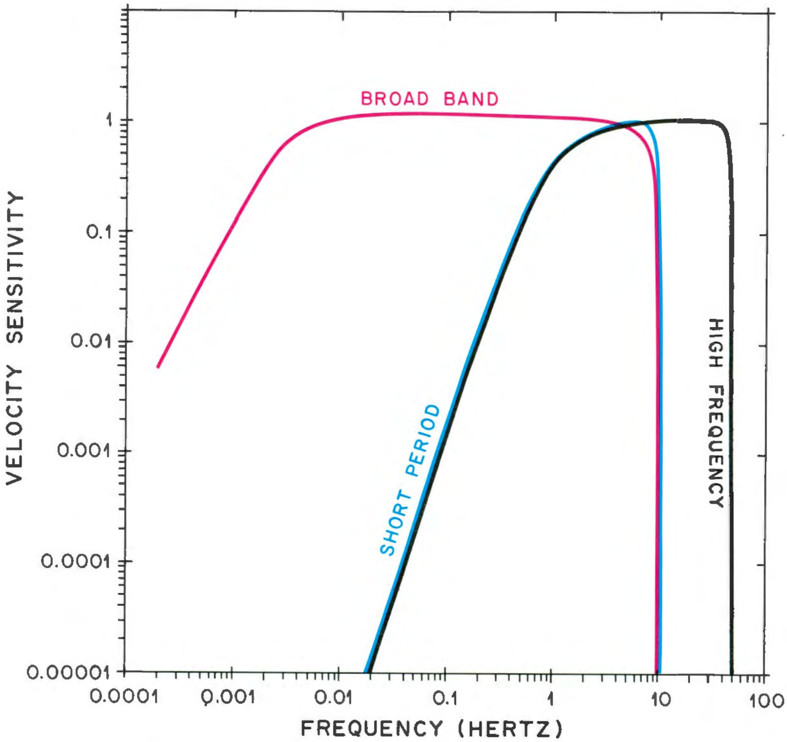
Computers (background) for automatic processing and analysis in the Seismological Laboratory, Ottawa, the main control centre for the Canadian seismograph network.

YELLOWKNIFE'S SEISMIC EVENT "WINDOW"

Because of the internal structure of the Earth, seismic "body" waves, which travel through the Earth, are quite easily detected by sensitive seismographs to distances of about 10 000 km (the teleseismic window) from the source of the disturbance, either earthquake or underground explosion. Stations beyond this distance are in a "shadow zone" because the waves have been deflected into the Earth's core.



Cross-section of the Earth showing the paths taken by seismic body and surface waves.



Response curves for the three types of seismographs in the Yellowknife array. The teleseismic (SP) sensors are restricted to a narrow band between 2 and 7 Hertz. The high frequency (HF) instruments can detect seismic energy at frequencies up to 50 Hertz. The broad-band instruments (BB) cover a much wider frequency band, from 0.003 Hertz (300 seconds) to 7 Hertz.

Through Yellowknife's teleseismic window, the array can monitor many of the active earthquake zones of the Earth, and all of the explosion test sites currently being used by the five nuclear weapon states. (The U.K. uses the U.S.A. Nevada Test Site.) The newly modernized array permits a more detailed view through this window.

"HIGH-FIDELITY" BROAD-BAND SEISMIC SIGNALS

In order to record seismic signals, older seismograph systems focused on narrow short- and long-period bands to maximize the probability of detecting signals from distant events. However, the details of the seismic source, particularly for larger events (magnitude greater than 5), are contained in the broad spectrum of seismic waves. The largest events generate surface waves with oscillation periods as long as one hour. It is only recently that instruments capable of registering waves over a large range of periods, and the electronics that can accurately digitize the signals, have been developed.

Data from the broad-band array, formed by the four broad-band sites, are, after appropriate filtering, very effective in detecting surface waves. The relative amplitudes of body and surface waves are one of the best means of discriminating explosions from earthquakes. Additional information on the characteristics of the source, also of use in this discrimination, is derived from the broader band signals now recorded at Yellowknife.

LOCAL AND REGIONAL SEISMIC EVENTS

Regional seismic events, occurring within 2000 km of a seismograph station, produce very complex seismic waves due to the complicated structure of the Earth's crust. Local events (up to 400 km distance) can produce ground vibrations with oscillation frequencies exceeding 50 Hertz (cycles per second). Recent studies in Scandinavia have shown that frequencies up to 20 Hertz can be recorded from events as far as 4000 km away. The special three-component, high-frequency instrumentation installed within the upgraded Yellowknife array produces high-quality data for similar studies within North America of regional and local sources.

Near-in recordings of small seismic events may become very important in monitoring compliance with a test ban treaty on the territories of the nuclear weapon states. New studies with Yellowknife data may help establish specifications for future near- in stations.

CONTINUING INTERNATIONAL CO-OPERATION

The Geneva Conference on Disarmament's Ad Hoc Group of Scientific Experts is currently planning a large-scale, international, seismic data exchange experiment. Canada continues to strongly support the work of this group, and also plans to contribute data from the Yellowknife array, and from other sensitive stations of the national seismograph network, during the forth-coming experiment, planned for 1990. It is hoped that, in the near future, a global seismic monitoring system will be ready to assist in the verification of compliance with a nuclear test ban treaty.