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THE NEW SEISMOGRAPH STATION AT RESOLUTE, NORTHWEST TERRITORIES

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The New Seismograph Station at Resolute Northwest Territories

P. L. Willmore

ABSTRACT: In 1957, the Dominion Observatory seismograph station at Resolute, N.W.T., was replaced by a larger station with modern instrumentation. The new station contains three seismographs of short period, three of intermediate period and three of long period. The construction of the station and the procedure for setting up the instruments are described. Calibration curves for all the instruments are included.

RÉSUMÉ: En 1957, la station sismographique des Observatoires fédéraux érigée à Resolute (T. du N.-O.) était remplacée par une station plus considérable équipée d'instruments modernes. La nouvelle station contient trois sismographes à courte période, trois autres, à période moyenne, et trois autres, à grande période. Cette étude décrit la construction de la station et la façon dont on a installé les appareils. On inclut les courbes d'étalonnage de tous les appareils.

INTRODUCTION

In 1950, the Department of Mines and Technical Surveys established a seismograph station at Resolute Bay, N.W.T. (Bremner 1952). Resolute, as it is now officially renamed, is on Cornwallis Island in the Arctic Archipelago, and is so far from ordinary lines of communication that the establishment and maintenance of a single research station there would normally be quite uneconomic. It is, however, the site of a joint weather station, which is kept supplied by the Department of Transport and the Royal Canadian Air Force, and it has thus become a centre for a steadily expanding group of geophysical, atmospheric and ionospheric investigations.

The original seismograph station consisted of a small vault sited on bedrock and covered over with gravel, connected by underground cables to a recording hut about 1,000 feet away. The vault contained two Sprengnether Series H horizontal seismometers and a short-period vertical. In 1952 an early model of the Columbia long-period vertical seismograph was installed. At that stage the recording room, which measured 8 feet square, contained a three-component and a single-component drum, together with their associated galvanometers: further expansion of instrumentation within the limits of the old building was clearly impossible.

In spite of its limitations, the station soon proved to be of exceptional importance. Being almost completely unaffected by man-made disturbance, it was able to record a greater number of distant earthquakes than any other in Canada. The value of these records was enhanced by the extreme isolation of the site, which filled a major gap in the world network. It was therefore agreed that the station should be enlarged, and the project received further support when the Lamont Geological Observatory of Columbia University requested facilities for the operation of a matched set of long-period seismometers during the I.G.Y. Plans for a new building were drawn up early in 1957, and construction was completed during the summer. The new instruments were installed during October and November of the same year. The coordinates of the new station are

74° 41.2′ N
94° 54.0′ W.

DETAILS OF CONSTRUCTION

The station is located on rising ground south of the permanent living quarters of the scientific group. The foundation is on Palæozoic limestone, the upper layers of which have been broken into small pieces by frost action. The shattered material is permanently frozen except near the surface, where a thin layer thaws in the summer. The foundations were excavated by scraping away successive layers with a bulldozer as the melting extended downwards. The process was continued to a depth of 6 to 8 feet from the original surface, where the individual rock fragments

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were several inches across, and were packed together in their original positions.

When the floor of the excavation had been levelled, a waterproof membrane was laid on it, and a flat concrete raft, 6 inches thick, was poured. Using this raft as a footing, the shell of the building was constructed from heavy lumber and plywood (Figure 2), and was then completely encased in waterproof material (Figure 3). Rock fragments were packed around the wall and over the roof, covering the building to a depth of 2 feet 6 inches. Instrument piers were constructed from concrete blocks resting directly on the raft. The walls, ceiling, and the floor between the piers was sheathed with plywood, leaving a 4-inch or 6-inch space between the inner and outer shells. This was packed with fibreglass for insulation.

In plan (Figure 4), the building is a rectangle measuring 20 x 28 feet, with an entrance vestibule protruding 8 feet from the shorter wall. An interior view of the finished vault is shown in Figure 5. When the plans were under consideration, it was expected that the foundation slab could have been laid within a foot or so of the surface, and that the protective cover of rock fragments would have formed a fairly high mound above the original surface. The vestibule would then have provided an entrance at ground level, which could have been kept clear of snow. As the foundations are much deeper than was expected, the outer door opened on to a hollow several feet deep and it soon became evident that this would fill with snow in the winter. During the winter of 1957-58, a trench was dug into the snow to the front door, and covered with an igloo to prevent snow from drifting in (Figure 6). The following summer, a permanent enclosed staircase was constructed leading up from the front door of the vault to ground level, and the hollow was filled up with gravel (Figure 7).

Figure 1.

The foundation of the vault. The forms for the footing are in the foreground, and the bedrock material may be seen behind the blade of the shovel.

In heating the vault, thermostats are not used as it has been found that the sudden disturbance produced when they turn on or off produces a much more serious effect on the instruments than a slow change of temperature, even if the amplitude of the slow change is comparatively large. Instead, electric heaters, supplied by a variable transformer are used. In this way the operator may correct any long-term drift of temperature by changing the supply of energy to the heaters. The insulation of the vault is good enough to keep short-term variations down to a very low value.

The inside of the vault is maintained at the lowest temperature acceptable to the operator, as this both minimizes the load which the heaters impose on the camp's generators, and ensures that the loose material surrounding the vault remains permanently frozen together. A temperature of 30° F has been adopted, and this requires a power supply, including the recorder power, of about 600 watts in winter and about 200 watts in summer.

The station is designed to record nine components of earth motion. Each of the large piers is intended to provide space for three seismometers and their associated galvanometers, and each pair of small piers carries a three-component recorder. Power and time-signal outlets for the recorders are mounted beside

Figure 2. Interior view of construction.

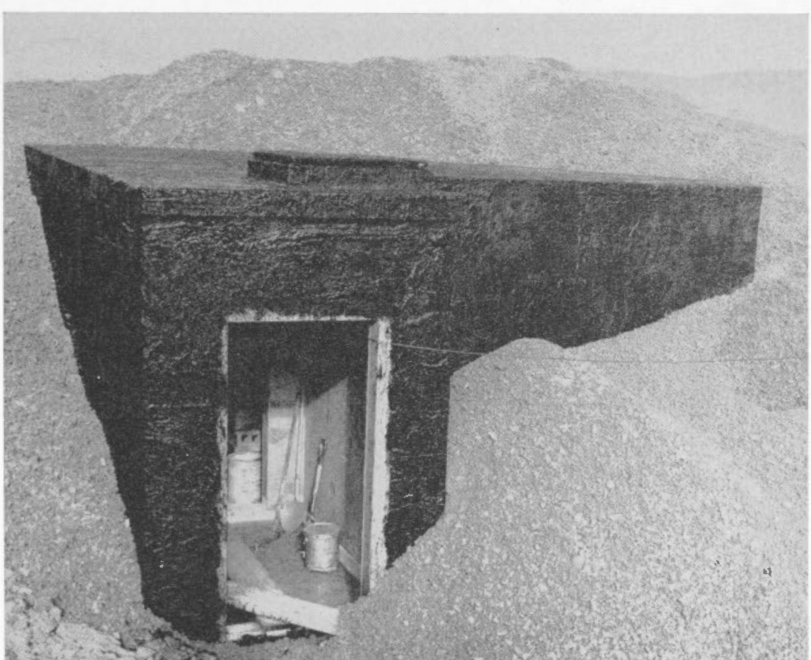

Figure 3.

The building shell, waterproofed, before final burial.

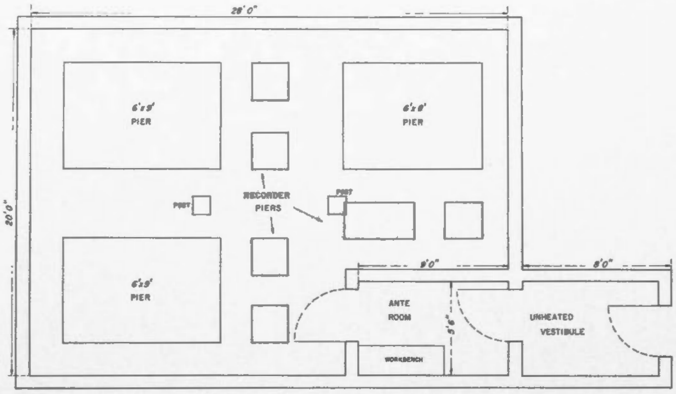

Figure 4. The floor plan.

each pair of small piers. With this arrangement it is possible to walk in front of the recorders to adjust the galvanometers, and the seismometers and galvanometers may be connected with the minimum of wiring. The large piers could, if necessary carry a considerable amount of equipment in addition to the primary installation.

The ante-room contains a small work bench, storage for paper and spare parts, the relays which supply the time circuits, and the heater controls. Time impulses are supplied by a buried cable from a master clock in the staff living quarters.

INSTRUMENTATION

The object of building the new vault was to provide a first-class station for recording P, S, and surface waves over the widest practicable range of frequency. In 1957 it was not clear which instruments would best serve this purpose, and the objectives at that time were, firstly, to meet the urgent requirement of Columbia University, secondly, to perform comparative tests on sensitive short-period instruments and, thirdly, to transfer the old equipment to the new vault, where it could be operated more conveniently.

The new equipment was flown in by the Royal Canadian Air Force on October 25th, accompanied by the writer and Hugh Wright of Columbia University. It consisted of the three long-period Columbia seismographs, a short-period Benioff and a short-period Willmore seismograph, and their associated recorders. In addition to the seismic equipment, a large coil and galvanometer for recording short-period magnetic variations were taken in at the request of Dr. Hugo Benioff, and a recording gravimeter was installed by the Gravity Division of the Dominion Observatory.

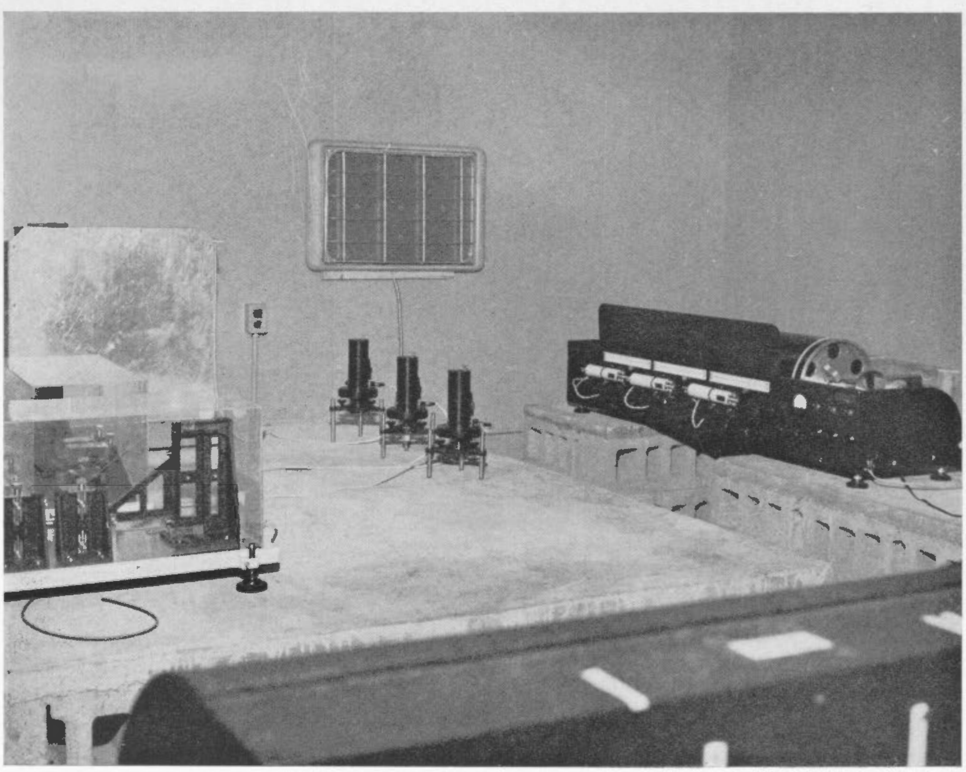

Figure 5.

Interior view of the vault, showing the Sprengnether horizontal seismometers, and the medium-period vertical seismometer behind them.

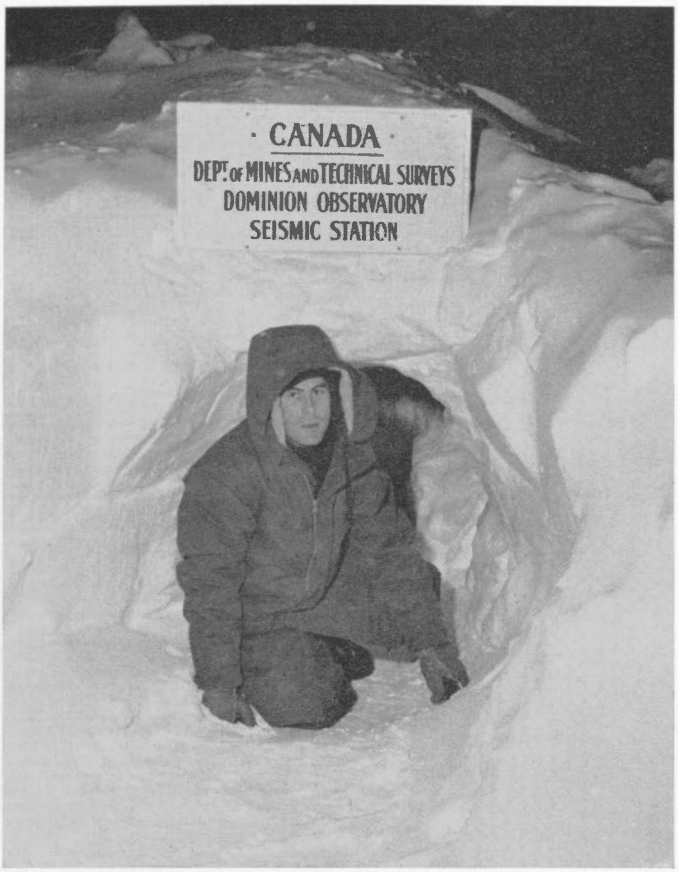

Figure 6. The igloo entrance during the first winter.

In order to minimize the loss of recording time resulting from the change-over, the recorders and the new seismographs were set up first. The equipment in the old vault was then calibrated by an electronic bridge method (Willmore 1959) before being transferred to the new vault and recalibrated.

When the instruments in the old vault were examined, it was found that their constants had changed considerably from the values which have been quoted in the Observatory's Seismological Bulletin since 1954. Table 1 gives the observed values, in comparison with the ones previously published:

TABLE 1

Instrument	Observed in Nov., 1957		Listed in Bulletins	
	T_s	T_g	T_s	T_g
Sprengnether Z....	1.48	1.50	1.40	1.40
Sprengnether N-S..	7.1	7.25	14.1	14.1
Sprengnether E-W	15.8	21.9	16.0	16.0
Columbia Z.......	15.9	9.7	12.2	12.5

The calibration curves for the instruments are given in Figure 8 from which it will be seen that the scatter in instrumental constants resulted in wide variations in performance. In particular, the shortened period of the Sprengnether N-S seismometer had resulted in the instrument being quite heavily underdamped, so that the characteristic shows a sharp peak at a period close to that of the seismometer. On comparing the response of the E-W seismograph with that of the N-S instrument, we see that the N-S has about three times the response of the other for waves of about 6 seconds periods, and about one-tenth of the response for periods of 30 seconds or over. Thus the N-S seismograph, having about half the seismometer period and one-third of the galvanometer period of the E-W, accentuated microseisms in comparison with long earthquake waves in the ratio of about 30:1. This difference had long been puzzling the operator, who had found it very difficult to pick out corresponding phases on the two instruments.

When the equipment was transferred to the new vault, an effort was made to match the characteristics more closely. The galvanometers having periods of 7.25 and 9.7 sec. respectively were coupled to the horizontal seismometers, and the 21.9-sec. galvanometer was coupled to the vertical. This spread in galvanometer period does not eliminate the possibility of obtaining matched characteristics, for it has been shown (Grenet and Coulomb, 1935) that if a given galvanometer is used in a classical "Galitzin"

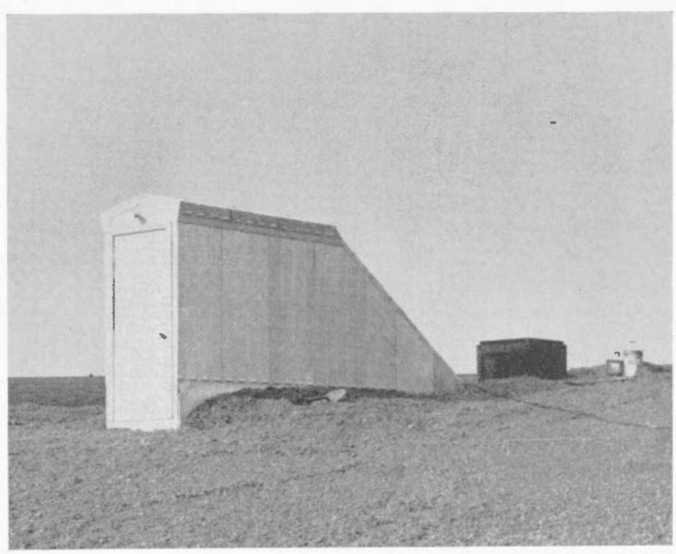

Figure 7. The permanent entrance.

seismograph arrangement, then "false Galitzin" seismographs, having identical characteristics, can be constructed with galvanometers whose periods are as much as $(3 + 2\sqrt{2})$ times that of the original. This wide latitude in galvanometer period assumes that the seismometer period and the damping constants of both seismometer and galvanometer can be varied to an unlimited extent by the operator, and it is by no means easy, in practice, to utilize the theoretical equations to obtain an exact match with given equipment. The actual procedure was therefore to proceed by trial and error, subject to the guidance of the following principles:

(i) If a seismometer and galvanometer are coupled together and have equal damping coefficients, then the response of the coupled system, when portrayed on a logarithmic plot, will be symmetrical about the geometric mean of the natural periods of the galvanometer and seismometer. If the damping coefficients are not equal, the response curve will be higher on the side which contains the resonance of whichever part of the system (seismometer or galvanometer) is less heavily damped.

(ii) As the damping coefficients are reduced, the response curve tends to develop peaks at the resonant frequencies of the seismometer and galvanometer. If the two resonant frequencies are close together the peaks will coincide, and reducing the damping will sharpen the response of the coupled system. If the frequencies differ, the peaks appear on the flanks of the response curve, and their effect may be to flatten the central part of the curve, or even to produce a central 'valley'.

(iii) For wave periods remote from the natural periods of the seismometer and of the galvanometer, the response falls off in proportion to the square of the wave period.

To obtain approximately matched response, each seismometer was first adjusted so that the geometric mean of its period and that of the associated galvanometer was about 14 seconds. The galvanometers used with the horizontal Sprengnether seismometers

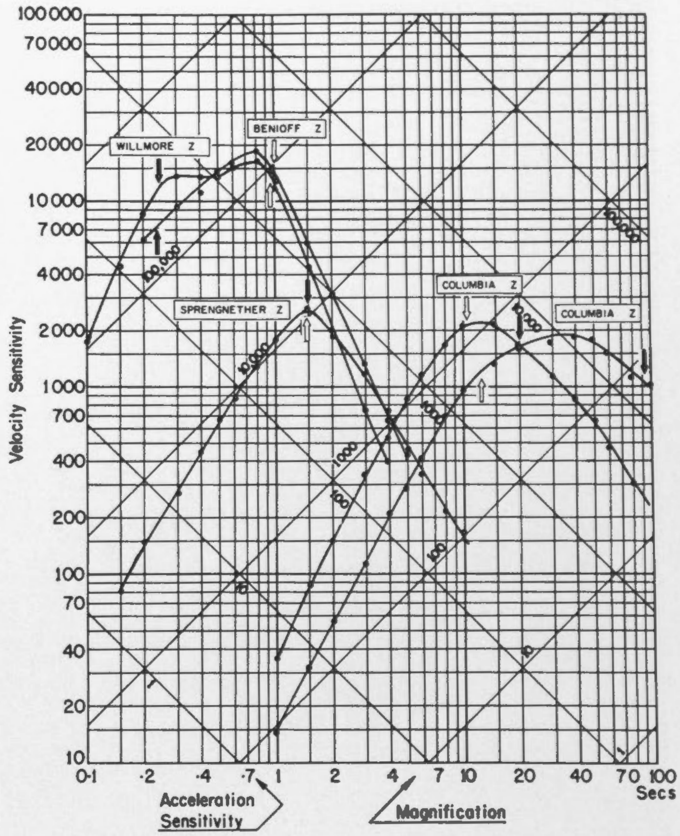

Figure 9. Calibration curves for the vertical instruments in the new station, December, 1957.

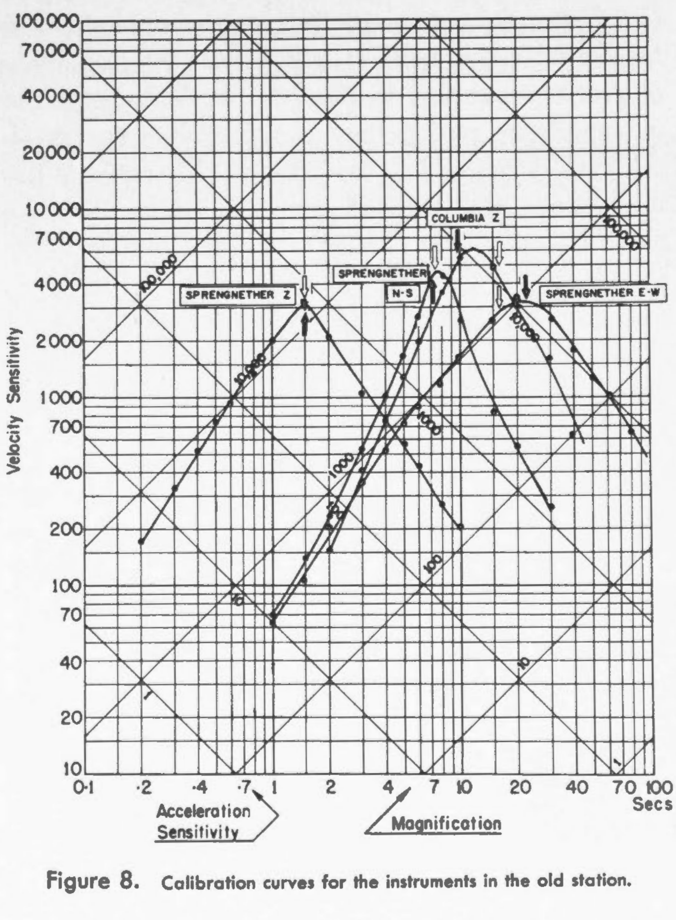

Figure 8. Calibration curves for the instruments in the old station.

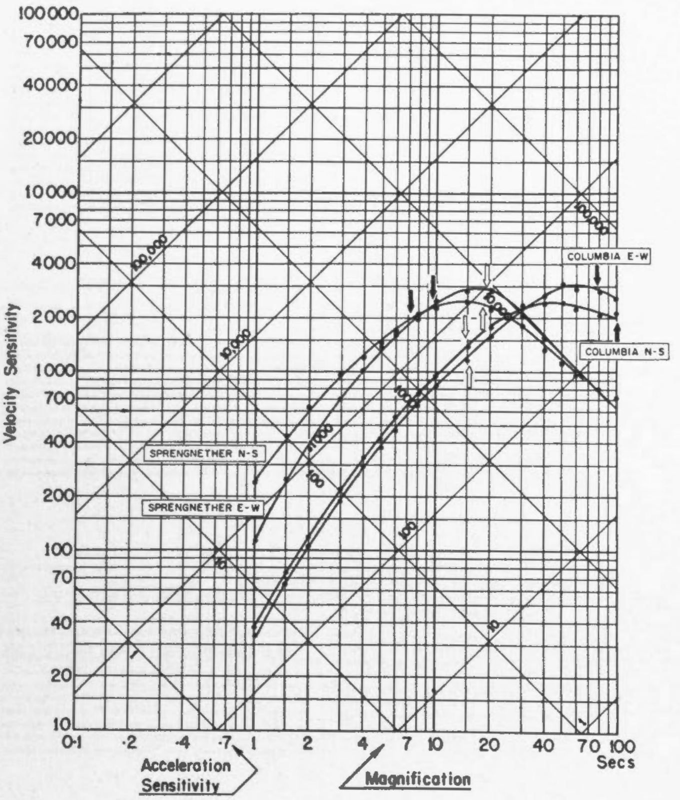

Figure 10. Calibration curves for the horizontal instruments in the new station, December, 1957.

were critically damped by the addition of shunt resistors, and the damping magnets on the seismometers were adjusted in accordance with the specifications in the Sprengnether handbook. The calibration bridge was then used to enable the sensitivities to be matched by means of the adjustable coil magnets on the seismometer, each coil adjustment being followed by an adjustment of the damping magnet to compensate for the changing mechanical reaction of the galvanometer. There remained the problem of matching the vertical seismograph to the horizontals. In this instrument, both damping and sensitivity adjustments had to be made by the choice of suitable series and shunt resistors. Nevertheless, it was found possible to find resistors, such that all three instruments gave their maximum sensitivity at frequencies between 13 and 15 seconds, and had magnifications within ± 15 per cent of the mean curve for all periods longer than 5 seconds. After a few days' run, it was decided that the vertical component of microseisms was being recorded at too large an amplitude for the records to be read conveniently. The sensitivity of the vertical instrument was therefore reduced to

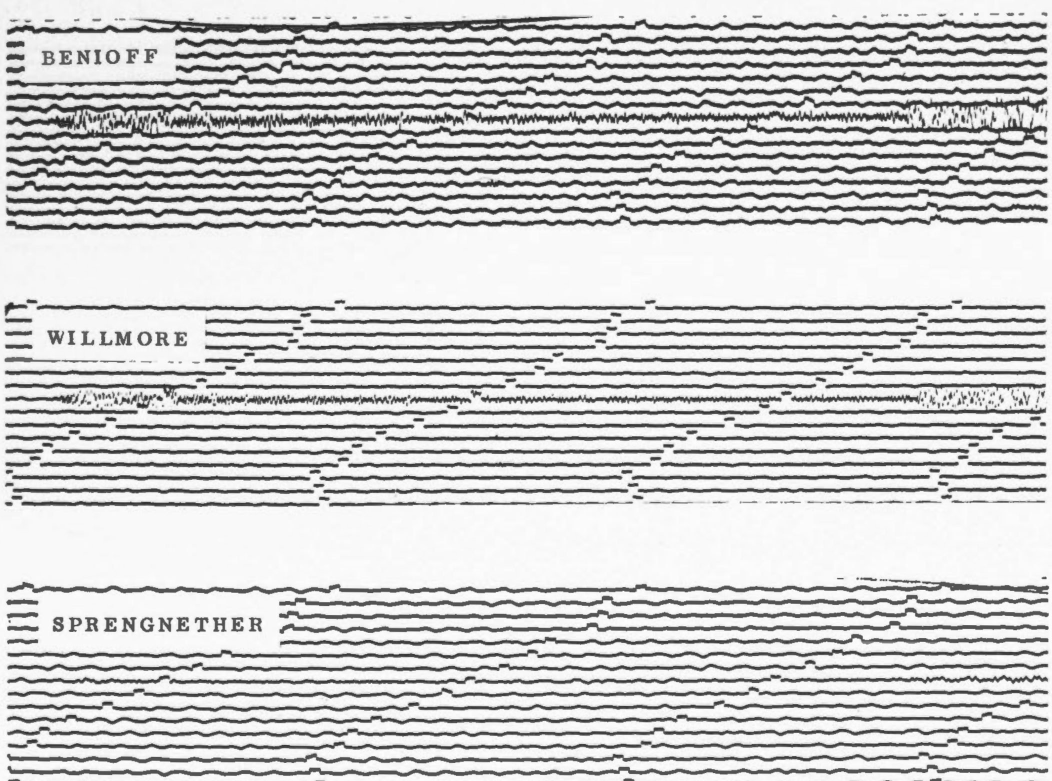

Figure 11.

Short-period vertical seismograms from Yukon earthquake, December 10, 1957, $\Delta = 16°$. On this and the three following figures, note how the similarity between the Benioff and the Willmore records is preserved, even for very minute and short-lived disturbances.

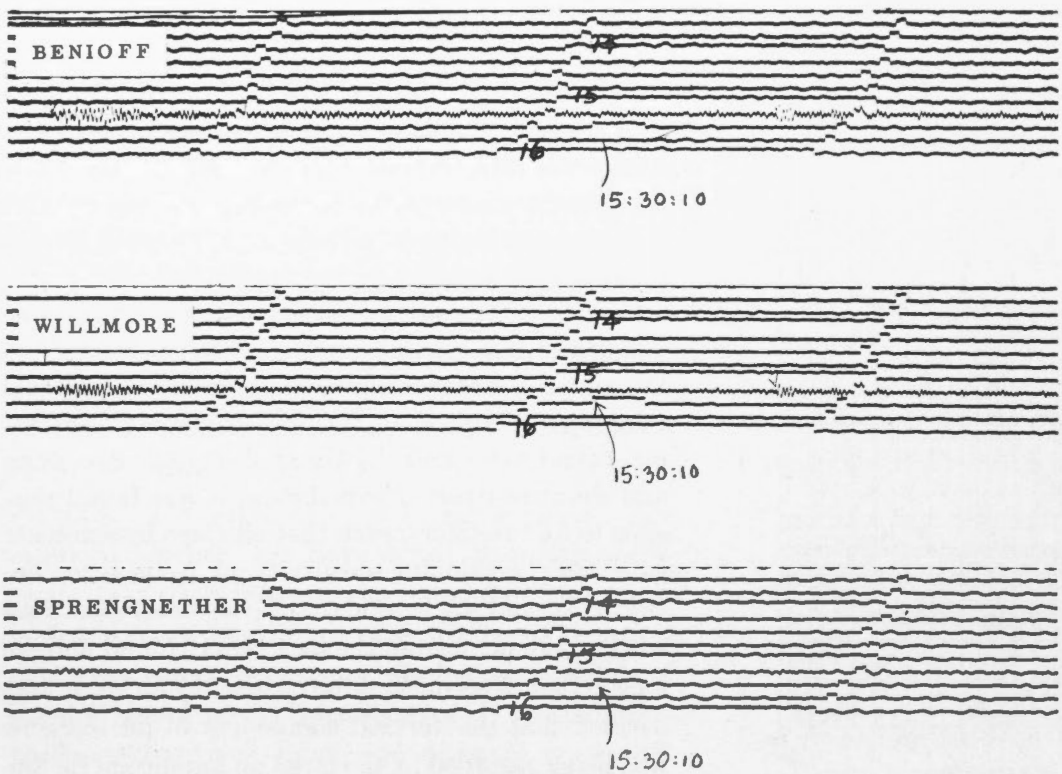

Figure 12

Short-period vertical seismograms from earthquake in the Fox Islands January 1, 1958, △ = 37°.

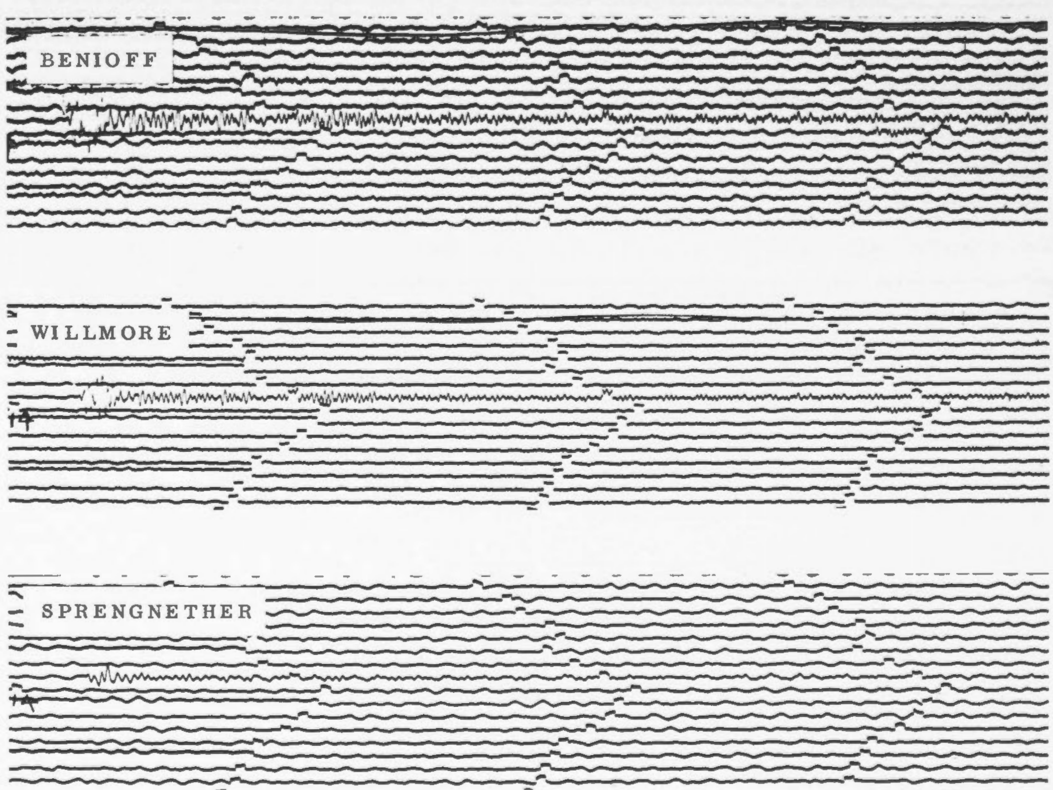

Figure 13.

Short-period vertical seismograms from earthquake in Outer Mongolia, December 4, 1957, △ = 59°.

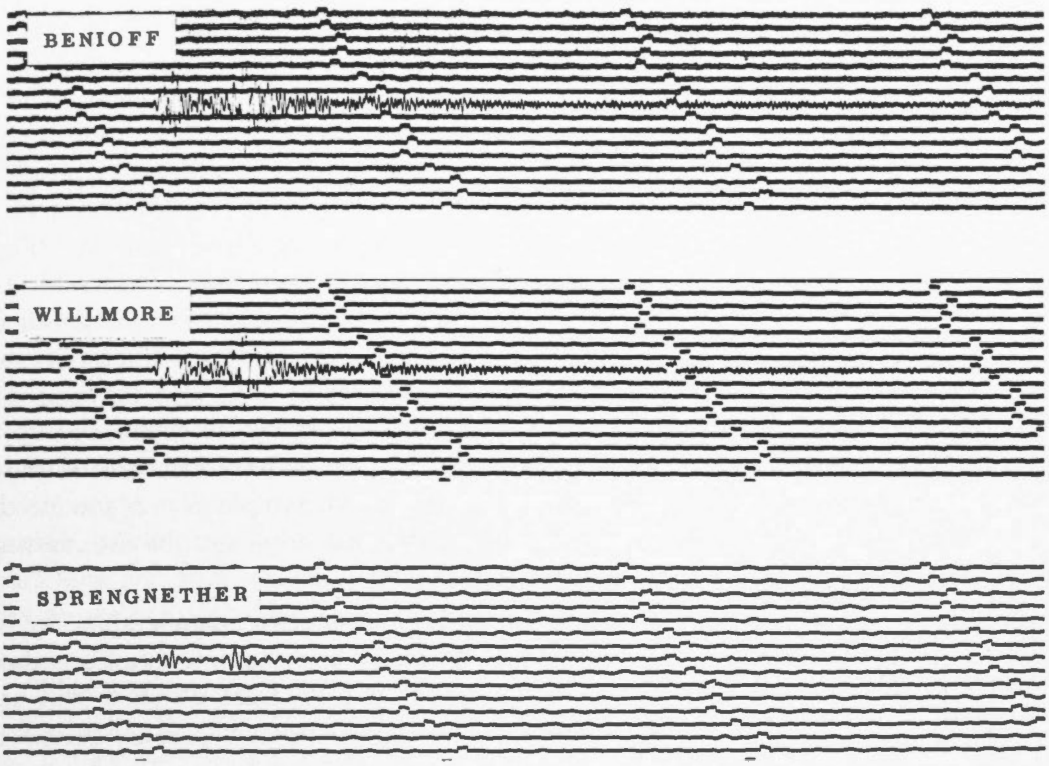

Figure 14.

Short-period vertical seismograms from earthquake in the Kermadec Islands, March 9, 1958, $\Delta = 122°$.

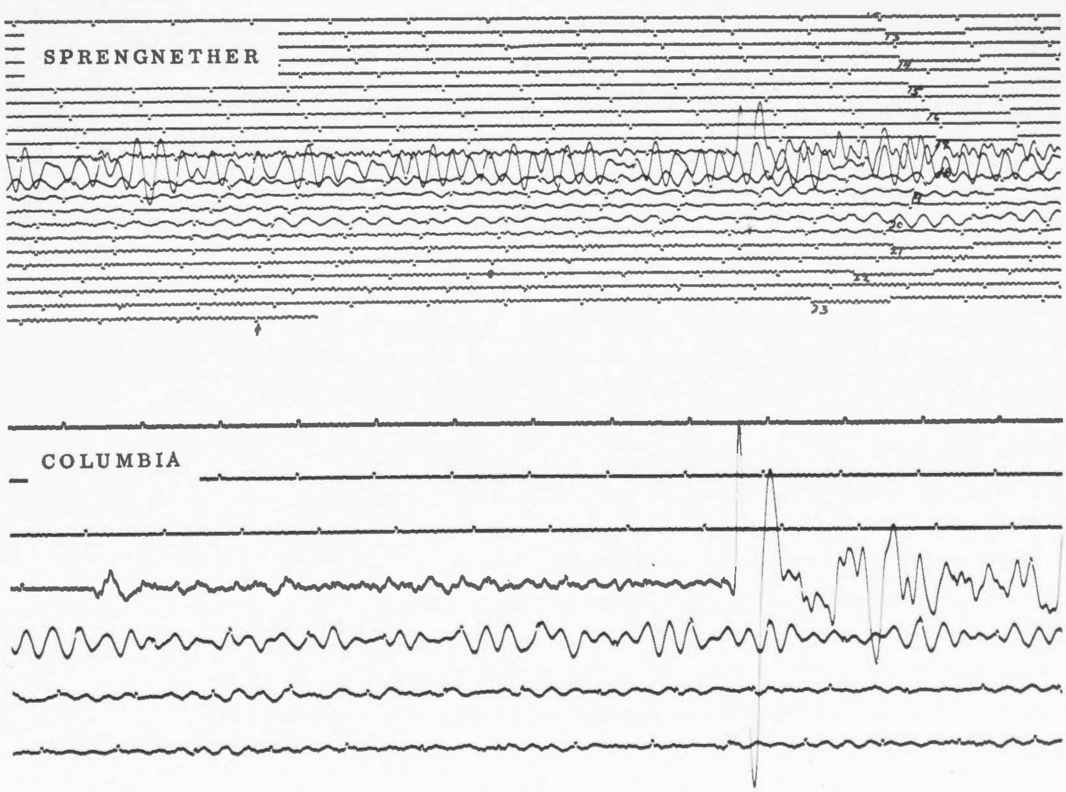

Figure 15.

Columbia and Sprengnether N-S seismograms from the earthquake near the west coast of Greece, November 15, 1959, $\Delta = 60°$. The records have been reduced to a common time-scale by photographing the Sprengnether record at half the scale of the Columbia, so the apparent magnification of the Sprengnether is only half of its true value

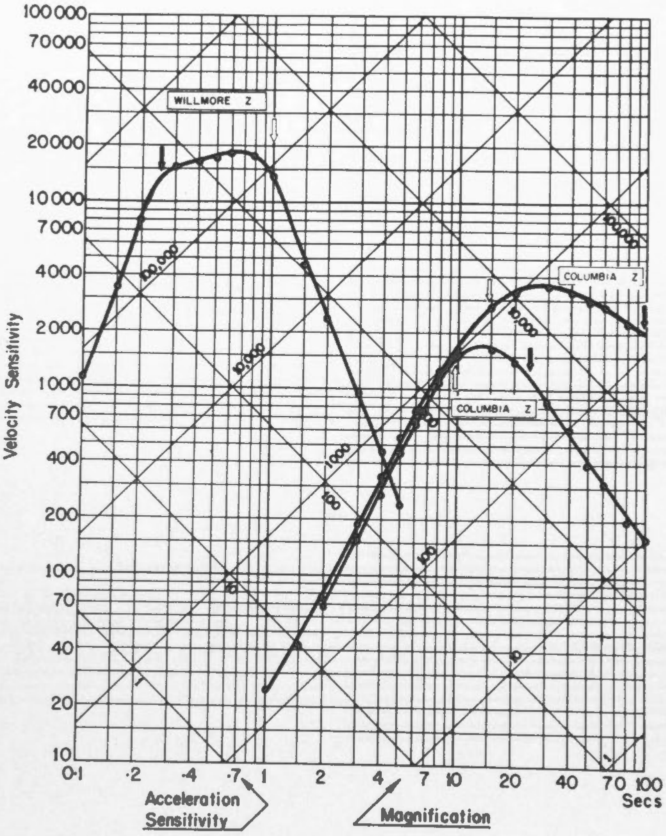

Figure 16. Calibration curves for the vertical instruments, after August, 1958.

about two-thirds of its previous value by changing the resistance network, and the system was re-calibrated. It would have been better to have reduced the horizontals in the same ratio, but it was unfortunately impossible for the writer to remain at Resolute long enough to undertake this work. The calibration curves for the instruments, (as they were left at the end of 1957) are shown in Figures 9 and 10.

For short-period recording, the Benioff, Sprengnether and Willmore seismometers were set up side by side, with the object of deciding which of the three types of instrument gave the best record. The calibration curves shown on Figure 9, indicate that the sensitivity of the Benioff is a little higher than that of the Willmore for periods longer than half a second, and a little lower than the Willmore at the shorter periods. These two instruments produce closely similar seismograms, except that the higher low-frequency sensitivity of the Benioff causes both teleseisms and the microseismic background to be recorded on a slightly larger scale. The Sprengnether is not as effective as the other two instruments, for a reason which is clearly shown on the calibration curve. As the maximum sensitivity of the instrument is obtained for wave periods of about 1.5 seconds, it records microseisms with about the same amplitude as the others, but has only about one-tenth of the sensitivity for periods less than 1 second. At other stations in Canada it has been found that seismographs having a response curve like the Sprengnether are suitable for stations in which the sensitivity is limited by industrial or traffic noise, but instruments with a much higher sensitivity to high-frequency waves are needed in regions where natural microseisms dominate the record. Sample records produced by the three short-period seismographs are shown on Figures 11 to 14.

The Columbia long-period seismographs were set up by Mr. Wright. Their characteristics are also shown on Figures 9 and 10, from which it will be seen that they run approximately parallel to those of the Sprengnethers for periods up to about 15 seconds, but that the Columbia curves rise above

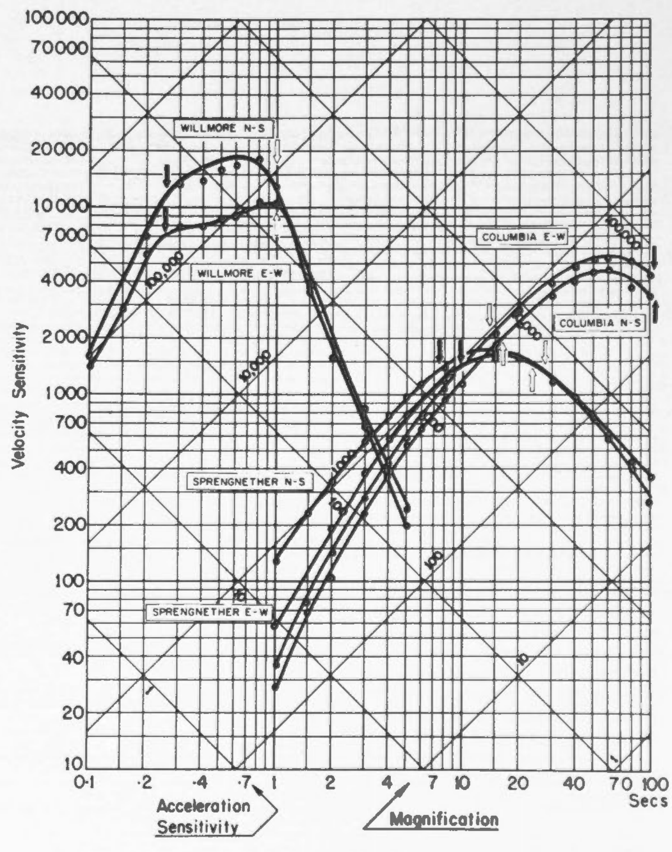

Figure 17. Calibration curves for the horizontal instruments, after August, 1958.

those of the other instruments at the longest periods investigated. The consequence of this type of calibration is that the amplitude ratios for P waves, microseisms and S waves are similar for the Columbia and Sprengnether instruments, but that the Columbia instruments are capable of recording longer surface waves.* (*See* Figure 15).

In August 1958, the station was visited by F. Lombardo of the Observatory, who readjusted and recalibrated the instruments. The short-period Benioff and Sprengnether verticals were removed, and replaced by short-period Willmore horizontals, to complete a three-component set of short-period instruments. The intermediate-period and long-period instruments were readjusted to improve the matching components, and to bring the long-period set more closely into line with Columbia instruments in other parts of the world. The calibration curves made during this final visit are shown in Figures 16 and 17.

Since its completion, the Resolute station has fully justified expectations in regard to its performance, and is now detecting about 6 times as many earthquakes as is Ottawa. One surprising feature is the large number of shocks which seem to originate within a few hundred miles of the station. At present the source of these tremors cannot be located, but additional Arctic stations are now being planned and a start will be made in mapping local seismicity when the new stations come into operation.

*Note that this remark applies to the Sprengnether Series H seismometers which were transferred from the old vault. The current production of the Sprengnether company now includes some very powerful new seismometers, which can detect earth movements up to extremely long periods.

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