The Priddis multicomponent seismograph station, local seismicity, and oilfield earthquakes

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ABSTRACT

An earthquake seismograph station is in provisional operation near Priddis, Alberta, telemetering data from a short-period vertical-component seismometer to The University of Calgary. There the data are recorded and displayed on a visual drum recorder. Three broadband seismometers have recently been acquired and will be installed in an orthogonal three-component configuration to upgrade the station to the capability of a so-called *standard* Canadian seismograph station. This final installation phase will include the construction of a small subsurface vault to house the four seismometers, and the acquisition of a microcomputer system for data steering and storage.

There are several good reasons for an earthquake station in the Calgary area, where, at present, there is no other station within 200 km. The regional seismicity is not very high but Calgary has been shaken twice in the last 11 years by earthquakes in Idaho and southern Alberta. There is low-level seismicity associated with some nearby areas where there has been significant hydrocarbon production, for example, near Turner Valley and Rocky Mountain House. There is also low-to-moderate seismicity in parts of the Rocky Mountain Trench; and in the Blairmore-Fernie-Waterton region there are geologically well documented instabilities. In general, there is a need for a more complete catalogue of earthquake activity for the southern Alberta region that could be part of environmental-impact studies (including seismicity) associated with construction of sensitive installations such as dams, power plants, etc.

INTRODUCTION

A principal mandate of the CREWES Project is to exploit the full vector wavefield as recorded with multicomponent exploration seismic sensors (geophones), as opposed to single-component (vertical) seismometers. In the realm of earthquake seismology similar advantages are derived by recording the full vector wavefield and many of the techniques of multicomponent seismic data processing and analysis are the same whether the data are recorded in the exploration frequency band (roughly, $f > 10$ Hz) or the earthquake frequency band (roughly, $f < 10$ Hz). Overall, the seismic frequency bands of interest in the earthquake case are zero to four orders of magnitude lower than in the exploration case.

Recently we have been working towards the installation near Calgary of a well equipped and fully functioning earthquake seismograph station, providing high-quality three-component broadband data (vertical, north and east components), enabling analysis of the full wavefield. Such an installation is prerequisite to significant research results in earthquake seismology in the southern Alberta region: e.g., in investigations of local or regional seismicity, including possible oil- and gasfield induced seismicity, as well as in teleseismic studies of deeper-Earth structure.

Within the Department of Geology and Geophysics at The University of Calgary (U of C) we have for several years owned a short-period Kinemetrics Ranger earthquake seismometer and Kinemetrics direct-write recording drum. This system was deployed for a short time on campus in the basement of the Earth Sciences building; but this location turned out to be unsuitably noisy. For the last few years our seismograph station has been in provisional operation with a single short-period vertical-component seismometer installed at the Rothney Astrophysical Observatory, run by the U of C Department of Physics and Astronomy, near Priddis, about 25 km southwest of the U of C campus (Figure 1). This location, on the concrete basement floor of the Observatory, has turned out to be quite sensitive and very quiet, except for isolated periods when the astrophysicists are operating telescope motors and the like. It is also located close enough to the campus with a virtual line of sight, so that a UHF radio link between the Observatory and the University, which has been in operation for about two years, is functioning very successfully. The telemetered data are recorded on the visual drum that is displayed in the window of the Gallagher Library, near the main entrance of the U of C Earth Sciences building.

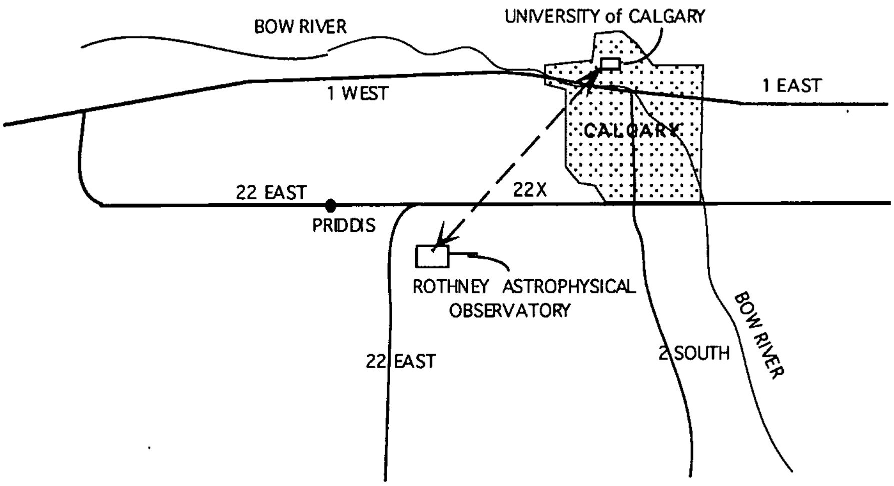
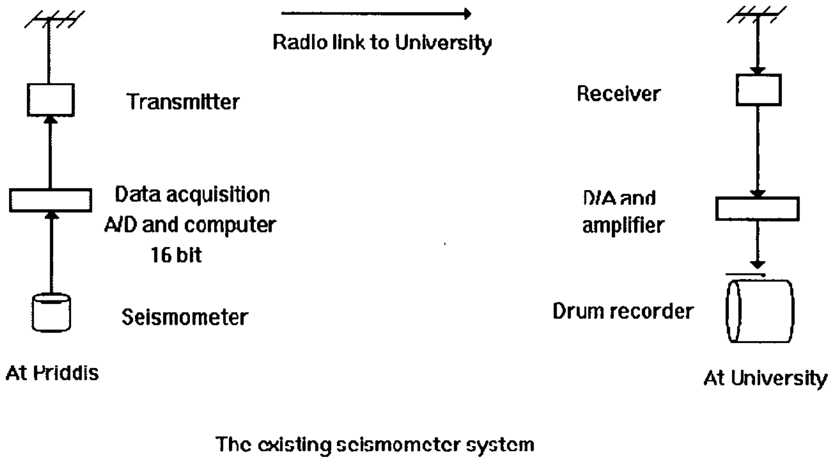


FIG. 1. Schematic map showing the location of the seismograph station at the Rothney Astrophysical Observatory, near Priddis, and The University of Calgary ~25 km away.

In order to outfit our station properly, we have recently bought three broadband Kinemetrics seismometers that will be installed in an orthogonal three-component configuration and, together with the short-period vertical, will constitute a so-called four-component station. There is also a Kinemetrics chronometer at the Observatory, owned by the Department of Physics and Astronomy, which is available to us for accurate timing of the seismograms. With all the essential elements of our system up and running (or ready to install), and with a grant in hand from the University of Calgary Research Grants Committee, we now are going ahead to complete the installation of a permanent station. This final installation phase will include: (1) the construction of a small subsurface vault to house the four seismometers, which will be sited on bedrock; and (2) the acquisition of a microcomputer system dedicated to data steering and storage (Figure 2). Funding to date, for purchase of the three broadband seismometers, radio-telemetry components (transmitter-receivers, antennas, analogue-digital converters, amplifiers, etc.) and the short-period sensor and drum, has come from a portion of some Alberta government matching funds and Department capital-budget funds designated for the earthquake station.



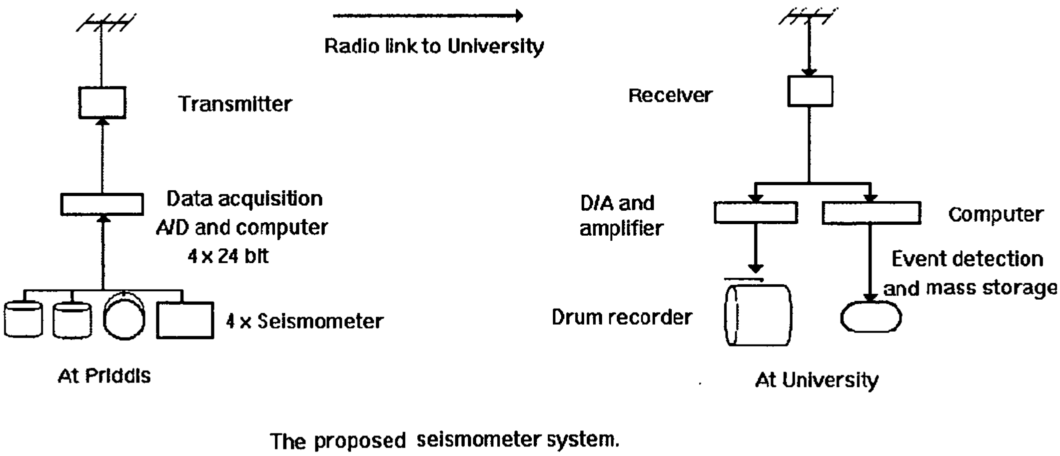


FIG. 2. Schematic diagram of the seismograph data-acquisition, telemetering and recording system; top: the existing system; bottom: the proposed system.

RATIONALE FOR AN EARTHQUAKE STATION

There are several reasons for having an earthquake station functioning near Calgary. The area is relatively quiet seismically but just makes it into Zone 1 on the seismic zoning map (based on peak-horizontal-velocity) of the National Building Code of Canada (Heidebrecht et al., 1983; Basham et al., 1985). [Zones range from 0 (least active) to 6 (most active).] Calgary has been shaken twice in the last 11 years, once by the Borah Peak (central Idaho) shock of 1983 (e.g. Wallace, 1984; Bucknam and Stein, 1987) and again by the Milk River (southern Alberta) quake of 1984. These events, particularly the former, alarmed many Calgarians on upper floors of tall buildings but were also felt near ground level. There is low-level seismicity – of uncertain origin – associated with some areas where there has been significant removal of hydrocarbons from the subsurface, such as near Turner Valley, within 20 km of our station, and Rocky Mountain House (Rebollar, et al., 1982; Wetmiller, 1986), about 150 km north of Calgary. There is, in fact, great current interest worldwide in this question of oil- and gasfield seismicity, particularly in instances where fluids (gas, oil, water) are injected into the subsurface. This is discussed further below.

The three so-called *standard* stations (with 6 components: 3 short-period and 3 long-period) of the Geological Survey of Canada (GSC) that are closest to the Priddis site are those at Waterton, Alberta (~200 km south), Edmonton (~300 km north), and Penticton, B.C. (~425 km west-southwest). There is also a so-called *regional* station (with 1 component: a short-period vertical) at Mount Dainard, B.C. (~350 km northwest) (see Munro et al., 1990). There is therefore a large area around Calgary with no seismograph station (particularly to the southeast since the station formerly at Suffield was last year moved to Waterton). There are of course stations in the USA, but these are at least 400 km from Calgary. So for seismicity studies, both local (Calgary) and regional (southern Alberta and adjacent B.C., Idaho and Montana), a station near Calgary would fill a large void. Our station will have the capability of a Canadian standard station in that we will be recording the full 3-component wavefield and be able to filter out both short- and long-period records from the broadband recordings. Our fourth component, the short-period vertical, will still be very useful as the one that is recorded in real time on our visual display.

There is low-to-moderate seismicity in the Rocky Mountain Trench, about 125 km from Calgary at its closest approach (e.g. Ellis and Chandra, 1981). Roughly where the Trench intersects the US border, there is some activity in the Waterton-Glacier area, as well as to the north in the Blairmore-Fernie coal-mining district and to the south near Flathead Lake, Montana (Qamar et al., 1982). The GSC station at Waterton is also rather isolated, the nearest Canadian standard stations lying about 425 km west at Penticton and 500 km north at Edmonton. Seismologists at the Geological Surveys of both Canada (GSC) and the USA (USGS) have told me that our planned station near Calgary, about 200 km north of Waterton, would contribute a lot towards constraining the source parameters of events in the Waterton region (which requires observations at several stations) and that they could make good use of the data of our station in future collaborative studies.

In the mountains of the Blairmore-Fernie-Waterton region, there are geologically well documented instabilities, such as led to the Frank slide, which can be monitored seismically. We have also received urgent requests for information and collaboration from two of the coal-mining companies in the Blairmore-Fernie area who recently experienced collapses of large rockmasses in their mines – at virtually the same time – and wanted to investigate a possible link to seismic activity. In an environmental-impact study (including seismicity) preceding construction of the Oldman River dam, just north of Waterton, there was a regrettably inadequate catalogue of earthquake activity for the area. The resulting earthquake design entailed rather large uncertainties. Finally, an explosives company in Calgary that supplies many of the mines blasting near Calgary and other towns in this area, has approached us to collaborate in the monitoring and analysis of the vibrational effects of their blasting. We have not to date been equipped to contribute very much to such undertakings.

OIL- AND GASFIELD SEISMICITY

Interest in the subject of induced oil- and gasfield earthquakes has increased dramatically in the last few years. Within the last year or so, a local study group has formed, under the umbrella of the CSPG, to delve into this emerging area of awareness. There are several documented cases of such induced events in a number of sedimentary basins throughout the world. In Alberta there has been seismic activity at hydrocarbon fields near Turner Valley, not far from Calgary, Rocky Mountain House (Wetmiller, 1986) and Snipe Lake (Milne, 1970). Also, an international group of earth scientists is proposing to monitor seismicity before, during and following gas injection at a proposed gas-storage site near Crossfield, Alberta.

Teng et al. (1973) documented seismicity associated with water flooding in Los Angeles. Gibbs et al. (1973) and Raleigh et al. (1976) have reported on fluid injection and induced earthquakes at Rangely, Colorado. Rothe and Lui (1983) reported on possible induced oilfield seismicity in Nebraska. The recent destructive Northridge (Los Angeles) earthquake of 17 January 1994, occurred within a few km of a field which is now a natural-gas storage site and it has been speculated that the injection of gas into the reservoir may have had some triggering effect (J.R. Century, pers. comm.). Horner et al. (1994) are continuing to monitor probable induced seismicity at the Eagle, Eagle West and Stoddart oil- and gasfields near Fort St. John B.C. These fields are located on the Peace River Arch, on the northern flank of the St. John Graben and are controlled by several NE-SW trending faults. They observed both a spatial and a temporal correlation of activity with production. The Eagle West and Eagle fields were discovered in 1976 and 1972, respectively; water injection began in 1980 and 1985-86, respectively. Earthquakes located to these fields began to occur in 1984 and 1992, respectively. Focal depths were estimated to be less than 5 km, consistent with the reservoir depths of about 2 km. Although the seismograph network would have detected similar events occurring since the mid-1960s, no earthquakes were observed there prior to 1984 (Horner et al., 1994).

SITING AND INSTALLATION

There are several practical considerations involved in the siting and installation of an earthquake seismograph station. Hard competent bedrock, either crystalline or well indurated sedimentary rock, is required for good coupling of seismometers to the ground. Often a concrete pier poured onto the bedrock surface is suitable for providing a flat surface for the seismometers. The site should be culturally quiet, be secure from intrusion by animals, vehicles and unauthorized people, and have electric power available. It should also be close enough to one's base, in our case The University of Calgary, to allow occasional maintenance visits as well as trouble-free telemetering of the data back to base. Additionally, installing the seismometers even just a couple of metres below the surface dramatically reduces the noise level found at the surface.

The Rothney Astrophysical Observatory near Priddis, where we have our provisional installation – a seismometer on the concrete floor and a functional telemetering system – is in all these respects a good seismometer site. The Rothney Observatory is constructed on top of a hill or ridge. There are ample areas on the slope up to the Observatory where a vault could be excavated into the hillside to take advantage of the noise suppression of a buried structure without the expense of a full excavation from surface. Sites are available that are sufficiently removed from the telescopes that their noise will not be a problem, yet close enough to the Observatory for electric power and antenna connection. We intend to construct a concrete floor that is mechanically isolated from the vault walls and in contact with consolidated rock. Local geologists and the contractor who built the Rothney Observatory tell us that such rock is accessible close to the surface. Some trenching to the Observatory building will be necessary and at least part of the vault will need to be insulated.

A shallow refraction survey was carried out over the prospective installation area at the Rothney Observatory during the summer of 1994. The results of interpreting this survey, in terms of depth to bedrock, will help determine the actual site of the vault excavation.

The Design Office of the U of C Physical Plant prepared a vault design and construction estimate for us, incorporating the features we wanted to have included. Some of these ideas were obtained while visiting the University of Saskatchewan seismic vault outside Saskatoon about two years ago. However, this estimate exceeded $20,000, more than we can afford to spend. Subsequently, a much cheaper alternative has materialized involving a cheaper design (including a concrete culvert section) and a partial donation from a local company. We are pursuing this option.

In order to manage the incoming telemetered data we will need a microcomputer: we believe a 486 IBM clone will be most efficient for that purpose with a 300- to 400-megabyte hard disk drive. We believe this will be adequate to store triggered events for a few days at a time. These will then be transferred to existing disk storage on the Department's geophysics computing system, a Sun platform with several Sparc II workstations and many more networked stations. Such a system will cost about $2200 to $2300, according to estimates from the Micro Store and others.

CONTINUING RESEARCH

The establishment of the recording station and data-storage system are short-term objectives that can be achieved in 12 to 18 months with the funding already in hand. With the 4-component station fully operational, and a database steadily growing, we can then start to build up an earthquake catalogue for the southern Alberta region, on which studies of seismicity (earthquake frequency and distribution; seismic risk) and seismotectonics (focal mechanisms; mapping of faults) can be based. As in other areas that are relatively quiet seismically, detection of microearthquakes (Brown, 1979) is important in providing frequency-of-occurrence information that can be extrapolated to higher magnitudes.

Our station configuration, particularly the three broadband components, will enable all kinds of full-wavefield studies of body waves (P and S) and surface waves, carrying information on the Earth's internal structure: crust, mantle, and core. A specialized area of such research is in seismic anisotropy, an area we have been specializing in for the last few years (Cheadle et al., 1991; Brown et al., 1991; Brown et al., 1993). Just as anisotropy has been recognized as playing a key role in many exploration situations (due, e.g., to aligned cracks and thin layering), it is also very important in the global setting (due, e.g., to stress-aligned crystals near mid-ocean ridges). Observations of anisotropic effects such as shear-wave splitting are only possible with full-wavefield or 3-component data, such as our three orthogonal broadband seismometers will provide. The long-term flow of data will sustain studies of this sort for years to come and these projects will no doubt engage many graduate students in M.Sc. and Ph.D. thesis-research projects.

As mentioned above, interest has been expressed by seismologists at both the GSC and the USGS in the establishment of a seismological station near Calgary. Our earthquake records will be available to essentially anyone who has a serious interest in them. We are well equipped to do file transfers of data by e-mail and most other current means. Data complementary to our own, e.g. on a local shock, will be available on a reciprocal basis from these other agencies and from other universities. We also have available to us, through Internet, earthquake bulletins and data from several international seismological data centres.

Once our capability in this area has been firmly established and a significant amount of data acquired, we will be able to support in-house graduate-student research, either for theses in seismology or as ancillary data in structural, tectonic or engineering studies. We will have a first-rate educational capability, so that students – undergraduates and graduates – can be given a good grounding in observational seismology, with hands-on laboratory exercises. Additionally, the public and the local press, who always react with anxious interest to news of a large nearby earthquake, have a right to expect some authoritative information from their local university. Knowing that local seismologists are monitoring the regional seismicity by systematically collecting records of earthquakes, both local and distant, seems to reassure people. In fact, only after building up a large database over several years will we be in a position to provide detailed seismic-risk assessments.

SUMMARY

In summary, the immediate goals of this proposal are to complete the construction of a seismograph vault, to install the four seismometers, to connect them into the telemetered data-transmission link, and to set up a computerized data-storage system. The project proposes in the longer term to help in providing data for scientific research into the local seismicity (both natural and induced), deep-Earth investigations, as well as assessment of the possible earthquake and rockburst hazards in this region associated with certain engineering undertakings related to hydrocarbon and mining production, and to large construction projects.

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