EARTHQUAKES IN THE BEAUFORT SEA

An Earth Physics Branch Report
to the ADM (Earth Sciences)

by
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Seismological Internal Report No. 82-2

Earth Physics Branch
Energy, Mines and Resources Canada
Ottawa, Canada

September 1982

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Development of Earthquake Monitoring

Before 1961, three earthquakes were known for the general vicinity of the Beaufort Sea, based on observations from global seismograph stations including the stations then operating in southern Canada. The largest event, a potentially damaging Richter magnitude 6.5, occurred in 1920 but, because of the poor seismographic data from that period, its location is uncertain by at least 100 km. A smaller, magnitude 5.5, event has subsequently been relocated about 250 km to the south, on land.

The development of the Canadian standard seismograph network in the 1960's included stations at Mould Bay (1961) and Yellowknife (1964), and improved the capability of monitoring Beaufort Sea earthquakes. Many earthquakes of magnitude 4 could be located and the general patterns of seismicity became apparent (Figure 1). However, the location accuracy remained poor as there were no stations within about 800 km of the main cluster of seismicity in the Beaufort Sea.

In 1969, the last seismograph station of the standard network was installed at Inuvik (INK). During the following decade the seismicity was monitored to lower magnitudes and the patterns became more clearly defined (Figure 2). An analysis of these data, published in 1979, demonstrated that the spatial dimensions of the seismicity cluster was approximately as shown in Figure 2, and was not due to mislocation scatter of events that occurred very near to each other. The largest earthquake during this period, magnitude 5.1 in 1975, was found from seismological analysis to have occurred on a steeply dipping fault beneath the continental slope. No geological evidence was available to establish the extent of such faulting.

When petroleum exploration in the Beaufort Sea started, the potential for earthquake damage to engineering structures and possible resulting economic losses and oil spills had to be considered. However, the information available on the Beaufort Sea earthquakes was not sufficient for earthquake-resistant design decisions. A thorough earthquake hazard assessment required answers to the following questions. How close to exploration and production activity can the earthquakes be expected to occur? What is the frequency of significant earthquakes and what is the maximum magnitude to be reasonably expected? What seismic ground motions are expected in the different areas of the Beaufort Shelf?

A Joint Venture with Dome Petroleum Ltd.

The above considerations led to a joint venture between the Earth Physics Branch (EPB) and Dome Petroleum Ltd. (DPL). Under the terms of the Memorandum of Understanding, the permanent seismograph stations were supplemented with additional regional stations at Sachs Harbour (SWT), Tuktoyaktuk (TUK), Komakuk Beach (KBT) and Nicholson Point (NPT) in late 1980 (see Figure 3). EPB provided expertise in instrumentation, installation and data interpretation; DPL provided capital, operating funds and one PY on contract to assist EPB with data analysis. A fifth station at Shingle Point (SPY) is planned for installation in 1982. The new stations were initially plagued by difficult Arctic logistics and high seismic noise from local sea ice, but they are now operating well. Data are analysed as part of EPB's western Canadian seismicity program at the Pacific Geoscience Centre. The earthquakes located in 1981, after the new stations became operational, are shown in Figure 3.

Although EPB and DPL will both benefit from the better understanding of Beaufort Sea seismicity that will result from the improved seismic monitoring, the requirements of the two agencies differ and go beyond the terms of the joint venture. DPL's immediate and longer-term requirements are site-specific in nature. Estimates of potential seismic effects are required for design of individual artificial islands, for the assessment of slope stability and liquefaction potential of seabottom sediments in the area of drill sites, and for the design of pipelines and terminal facilities. These estimates are based on the best available interpretation of the nature of the earthquake zones, and are usually provided to DPL by geophysical and geotechnical consultants.

To illustrate a typical concern, Figure 4 shows the estimated effects of a hypothetical "design earthquake" of magnitude 6.5 located at the southern boundary of the seismicity cluster, nearest to current drilling activity. Peak ground vibrations in bedrock (i.e., beneath unconsolidated sediments) would exceed 0.05 the acceleration of gravity (g) at distances less than about 100 km, and exceed 0.2 g at distances less than about 40 km. Bedrock vibrations of 0.2 g would be expected to produce liquefaction in water-saturated sediments. Lower levels of ground motion could produce slumping of unconsolidated material on steep slopes.

The Earth Physics Branch Program

The EPB has the responsibility for accumulating the required knowledge base for earthquake hazard assessment on a regional basis. This knowledge is used to provide advice in three general categories: to industry as a regional framework for site-specific considerations; to EMR and related agencies in cases where earthquake risk can influence the economics of alternative petroleum transportation scenarios; and to regulatory agencies as part of the earth sciences review of environmental impact statements. The improved definition of Beaufort Sea seismicity that will be the result of the joint venture with DPL is one component of this knowledge base. Other activities in the EPB program are currently limited by the lack of financial and personnel resources, but the appropriate studies have been identified and some have been started with the staff and extra funding (i.e., OERD) available.

In the summer of 1981 an experimental deployment of ocean-bottom seismographs was undertaken in the shallow water of the Beaufort Sea in cooperation with the staff of AGC and with logistic support from DPL. Two small earthquakes were located with these instruments, and an explosion was detonated to calibrate local seismic velocities. A study of the active zone and its possible relation to the geological features of the continental margin will require putting seismographs on the seabed directly over the cluster. This will require technical developments to operate the seismographs through the permanent icepack that covers most of the cluster.

A preliminary assessment of industry seismic exploration data recently released under COGLA regulations indicates that relatively recent faulting at the seafloor can be seen in these data. AGC and ISPG are analysing these data in the context of their regional stratigraphic and structural studies, but nowhere are the data being analysed to delineate faults that may be associated with seismicity. The Beaufort Sea industry data will be a valuable source of this information as it becomes available.

The Beaufort Sea seismicity cannot be fully understood by studying it in isolation. Also required is a tectonic synthesis that will relate this zone to the history of the opening of the Arctic Ocean, to the active earthquake zones in the north-central Yukon, and to the highly active tectonics taking place in the Gulf of Alaska.

The additional resources required to accelerate these EPB research activities, for the Beaufort Sea and other frontier development areas, have been identified in the earthquake hazards component of the Earth Sciences Cabinet Document being prepared in the Sector.

Recommendations

Although progress has been made, the questions posed in the first section of this report cannot yet be answered, and it is therefore not known if the hypothetical "design earthquake" illustrated in Figure 4 is an appropriate one. There may be undiscovered geological controls on the seismicity that would confine the larger earthquakes to greater distances from current exploration activity.

The joint venture with DPL is scheduled to end in September 1983. We believe it is essential to maintain the additional monitoring capability beyond that date. An extension of 3 to 5 years would be appropriate, either as a renewal of this joint venture, if DPL is willing, or by an increase in the A-base program to maintain and operate the stations and interpret the data.

Improved seismicity monitoring and the essential earthquake hazards research program described above have been recommended as part of the Earth Sciences Cabinet Document. Here we have focussed only on the Beaufort Sea: the Grand Banks and Scotian shelf on the eastern continental margin, and the west coast shelf area are frontier development areas to which a high priority can also be assigned for a significant and early improvement in the earthquake hazards knowledge base.

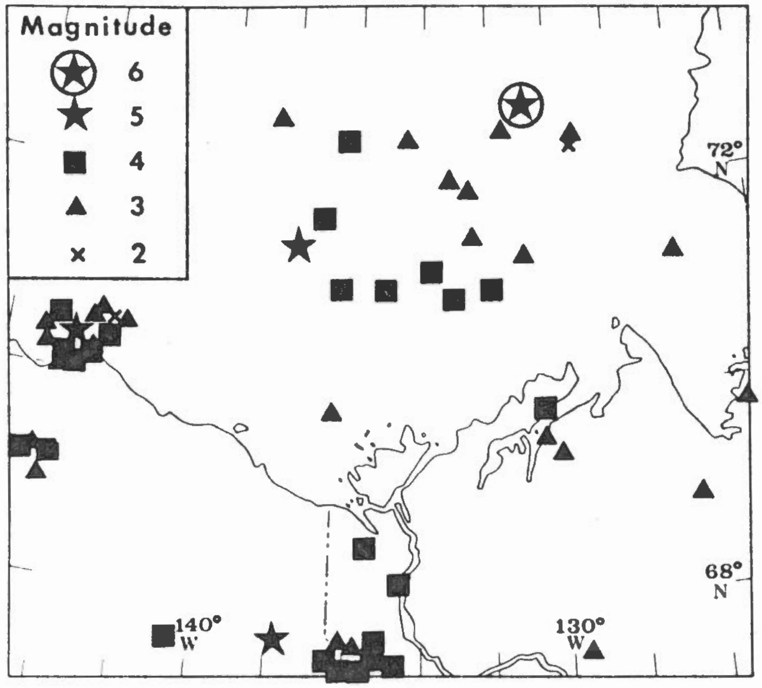

Figure 1. Beaufort Sea seismicity, 1920-1969.

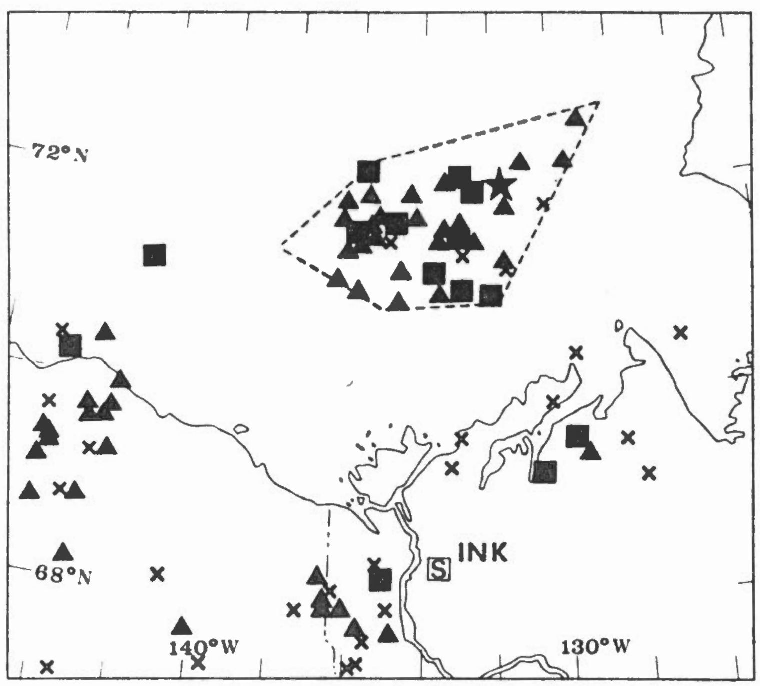

Figure 2. Beaufort Sea seismicity, 1970-1980. Symbols as in Figure 1.

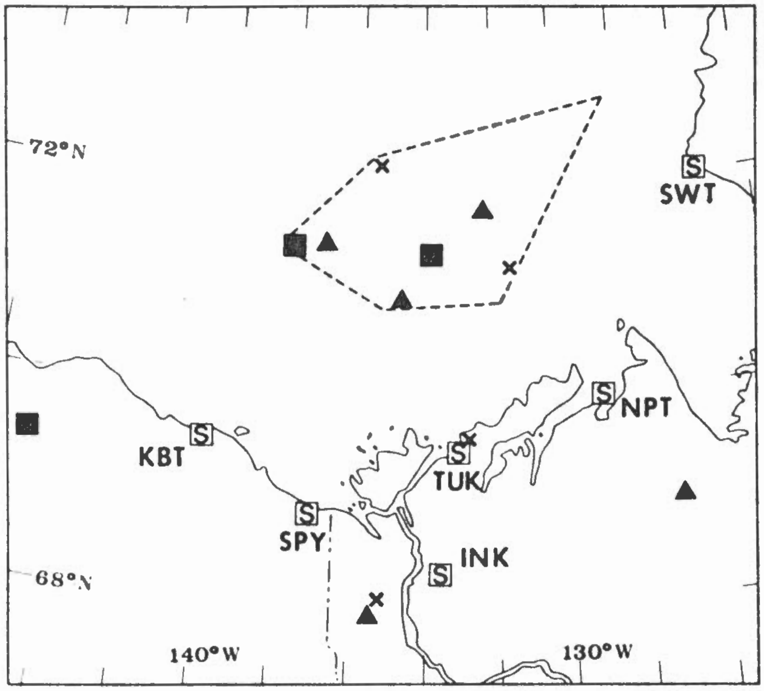

Figure 3. Beaufort Sea seismicity, 1981. Outline of seismicity cluster from Figure 2.

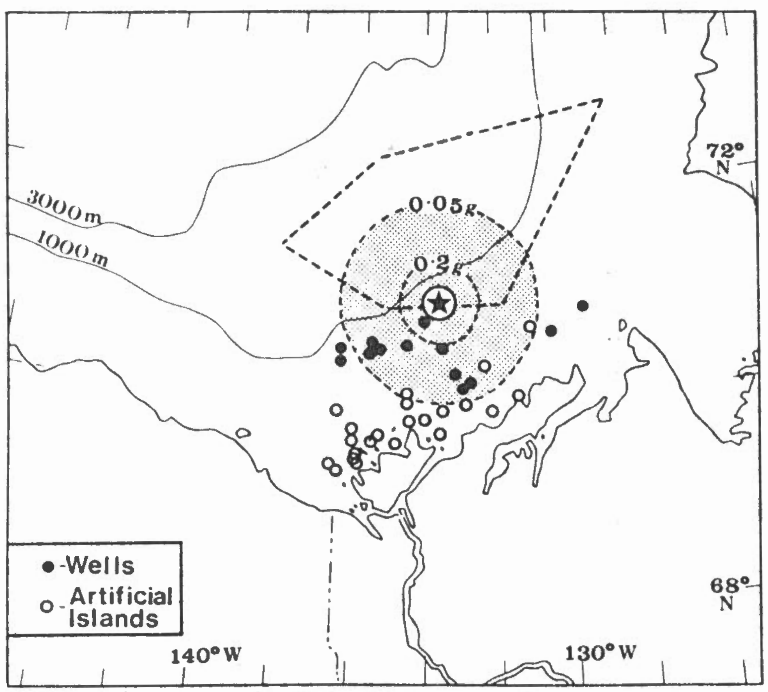

Figure 4. Artificial islands and wells from 1972 to 1981. The 1000 m bathymetry contour marks the approximate location of the continental slope. Peak bedrock accelerations are illustrated for a hypothetical magnitude 6.5 earthquake.