More seismic evidence on the location of Grenville basement beneath the Appalachians of Québec-Maine

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Summary. High-quality multichannel seismic (=133 fold) and refraction/wide-angle reflection (1 to 3 km receiver spacing and 30 to 60 km shot spacing) data have been collected across the northern Appalachians in Québec and Maine. An integrated interpretation of the seismic data from the southeastern Québec-western Maine region provides strong evidence that the rocks of the predominantly oceanic "Dunnage" zone are allochthonous having been thrust westwards over Precambrian Grenville basement during and subsequent to the closing of the Iapetus Ocean.

1. Introduction

Insights into the structure of the southern Appalachians provided by reflection seismology have stimulated widespread discussion as to the applicability of the 'thin skinned' tectonics concept to the northern Appalachians (Cook et al. 1979; Williams 1980; Cook et al. 1980; Cook & Oliver 1981; Ando et al. 1983; Cook 1984; Keen et al. 1986). An important series of investigations of the crustal structure in the Québec-Maine region was initiated in 1983 by the United States Geological Survey (USGS) and the Geological Survey of Canada (GSC) in collaboration with many other institutions. Early results of the multichannel reflection work have been presented by Stewart et al. (1986) and Green et al. (1986).

Multichannel seismic reflection and high-density refraction/wide-angle reflection surveys were conducted across the entire orogenic belt but in this paper we shall restrict the discussion to preliminary results from southeastern Québec and northwestern Maine. Further results from Maine are given by Unger et al. (1987). The geology of this area is shown in Fig. 1, along with line locations of the USGS/GSC sponsored seismic reflection and refraction lines and older reflection data collected for exploration purposes (MERQ 1979). Examples of the refraction data are shown in Fig. 2. The geology of the region may be divided into two major zones. The Humber zone lies to the northwest of the Baie Verte-Brompton Line and the Dunnage zone to the southeast (St.-Julien & Hubert 1975). The two zones correspond to regions of predominantly continental and predominantly oceanic derived sediments respectively. In order to unravel the processes associated with the closing of the Iapetus Ocean it is important to determine the lateral extent of Grenville basement beneath the Palaeozoic cover rocks of the Humber and Dunnage zones. It has long been known that rocks between Logan's line and the Baie Verte-Brompton Line are allochthonous,
having been thrust westwards over Grenville basement during the Taconic and Acadian orogenies. However, the required amount of lateral transport is small compared with that observed in the southern Appalachians (Ando et al. 1983). Recently Green et al. (1986) in an interpretation of the reflection data postulated that Grenville basement extends a considerable distance eastwards beneath the Dunnage zone.

Green et al. (1986) were unable to delineate the southeastern limit of the Grenville continental margin because of poor data quality on the QM2 line across the Chain Lakes region. We shall use reprocessed reflection data and the new refraction/wide-angle reflection data to further test their hypothesis.

2. Reflection data

High-quality data were recorded on the southeasterly trending seismic reflection line QM1 (see the section in Green et al. 1986). Acquisition and processing parameters are described in Stewart et al. (1986). A strong band of reflections (marked 'b' in Figure 3a) is observed dipping to the southeast from two-way times (TWT) = 3.5 s near kilometer 140 to TWT = 7.8 s near kilometer 190. Green et al. (1986) associated this band of reflectors with the decollement zone and/or the sedimentary package between the near-surface allochthonous terrains and the underlying Grenville basement. Reflection line QM2 intersects line QM1 and extends in a southeasterly direction across the Chain Lakes Massif, a block of exotic Precambrian material (Williams & Hatcher 1983). Initial data processing was carried out commercially with a processing sequence similar to that used successfully on line QM1. Remarkably, the initial processing of line 2 produced a section with no discernable coherent events and as a result no interpretation could be made in this important area. It was apparent from looking at line QM2 shot gathers that the data were of low signal-to-noise ratio. Possible reasons for this might be that the data were recorded on a busy highway and that the
line followed a valley with variable amounts of glacial till along its length. In the light of this we have reprocessed the line 2 data using our AURORA (Trade Mark of Veritas Software Ltd.) processing system.

The chief modifications to the processing sequence were a) adjacent traces were mixed in groups of three, b) 'true' amplitudes were maintained as far as possible since shot gathers showed that arrivals had poor spatial coherence but often had significant amplitudes, c) offsets were limited by restricting the stack to 40 fold and d) coherency-based trim statics were applied to CMP gathers in an attempt to resolve the statics problem.

The line drawing from the reprocessed section arid other sections in the region are shown in Fig. 3. Reflectors important to the present discussion occur at the western edge of the section extending from approximately 190 - 200 km with TWT between 7 s and 10 s. These correlate with the strong band of reflections seen on line QM1. The strongest and most continuous reflector is at 7.5 s and shows a small apparent dip to the east. This corresponds to the reflector observed on line QM1 with apparent dip to the south. The band of reflectors between 7 s and 10 s is not seen to the southeast on line QM3, thus it is reasonable to assume that the disappearance of the events on line QM2 is real and not a consequence of poor data quality.

3. Refraction Experiment

In 1984 the reflection work was supplemented by a large-scale refraction/wide-angle reflection experiment. Approximately 120 USGS FM recording systems and 24 Canadian digital instruments were used to give a relatively high-resolution survey with a station spacing of ~ 750 m (Spencer et al. in prep.). The refraction experiment has not only yielded velocity information, it has also provided structural information based on many wide-angle reflections. These wide-angle reflections correlate well with normal-incidence reflection zones in one area and in other regions they fill-in some important gaps in the normal-incidence data. Models produced from the refraction analysis have proved useful in determining the structure at depth of several of the near-surface rock formations, but here we
Figure 3. A combined interpretation of all the seismic data applicable to the region. a) shows line drawings taken from the various normal-incidence sections. b) shows wide-angle reflectors as heavy solid lines and geological boundaries and faults seen in the seismic data as light solid lines. Dashed lines delineate those geological boundaries inferred to exist but not seen in the seismic data. The interpretation of the section to the southeast of kilometer 200 is outside the scope of this paper and the termination of the Chain Lakes Massif there should not be given geological meaning.
shall deal with the reflections only. These data, samples of which are plotted with normal-moveout corrections in Fig. 2, show continuous reflectors. The strongest reflector is observed at distances of 45 km to 120 km to the northwest of the shotpoint C2 at TWT 6 s. This same event is also observed at distances of 20 km to 45 km to the southeast of the shot. An abundance of midcrustal reflectors seems to be a characteristic of this area of Québec and Maine.

4. Interpretation

Fig. 3 is a summary diagram showing reflector positions from both experiments together with the earlier exploration data (MERQ 1979). The uncertainties inherent in interpreting the MERQ (1979) data have been discussed by Cook (1984), the intention here is to outline how the new data allows firmer conclusions to be made. The most important point to note is that the basement reflector, which on the MERQ data was obscured by instrumental noise to the southeast of the Richardson fault, can now be traced to a point beneath the Chain Lakes massif, except for a short section beneath shotpoint C2. Is the gap significant? We believe that the reflector is hidden within a noise train associated with the passing of the surface wave/ground-roll. It is therefore reasonable to propose that the band of reflectors, which in the northwest part of the line certainly lie above Grenville basement, is continuous beneath the Notre Dame anticlinorium, the Connecticut Valley-Gaspé synclinorium and the Chain Lakes Massif. Beneath line QM1 the reflection zone shows evidence of both normal and thrust faulting and interpretation becomes complex. Strong reflectors are observed at 3 s in the normal incidence data, whilst reflectors at 3 s, 4 s, and 6 s can be seen in the wide-angle data (Fig. 3(b)). The offsets of these reflectors have been interpreted by Green et al. (1986) as indicating thrusting, which may possibly be associated with movement on the Guadelope fault during the Acadian orogeny. The large-scale diffraction events associated with this complicated region may well indicate a basement of small sections fragmented by faulting. A final interpretation awaits the production of migrated sections. The basement is seen to continue on line QM2 where it terminates in the central part of the section. It is impossible to give a more precise location for the edge of the Grenville basement since some of the events near the edge of the basement are likely to be diffractions. The major tectonic implication of this interpretation is that the northern Appalachians, at least in this region, have undergone more than 120 km of lateral displacement over Precambrian basement. Exotic terrains such as the island-arcs south of the Baie Verte-Brompton Line and the Chain Lakes massif have been thrust over Grenville basement in a 'thin-skinned' fashion. Moreover, features previously interpreted as being of major tectonic importance, such as the Baie Verte-Brompton Line (Williams & St. Julien 1982), are probably confined to upper crustal levels.

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