Structure of the Southeastern Nechako Basin, South-Central British Columbia (NTS 092N, O; 093B, C): Preliminary Results of Seismic Interpretation and First-Arrival Tomographic Modelling

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Introduction

The Nechako Basin is an Upper Cretaceous to Oligocene basin located in the Interior Plateau of southern British Columbia (Figure 1), between the Rocky and Coast mountains. The sedimentary basin formed over, and in part from, the accreted terranes of the western Canadian Cordillera, where the oceanic Cache Creek Terrane separates the Stikine and Quesnel volcanic arc terranes (Struik and MacIntyre, 2001). Westward-directed thrusting at the boundary between the Stikine and Cache Creek terranes occurred prior to 165 Ma (Schiarizza and MacIntyre, 1999). Transpressional tectonic processes were dominant until the Eocene (Best, 2004), when there was a shift to a dextral transtensional regime (Price, 1994) and accompanying volcanism. The basin is bounded by the Cretaceous Skeena Arch to the north, the Coast Mountains and Eocene Yalakom fault to the west, the Cretaceous Tyaughton Basin to the south and the Eocene Fraser fault to the east. The major Yalakom and Fraser faults are associated with the episode of Eocene transtension.

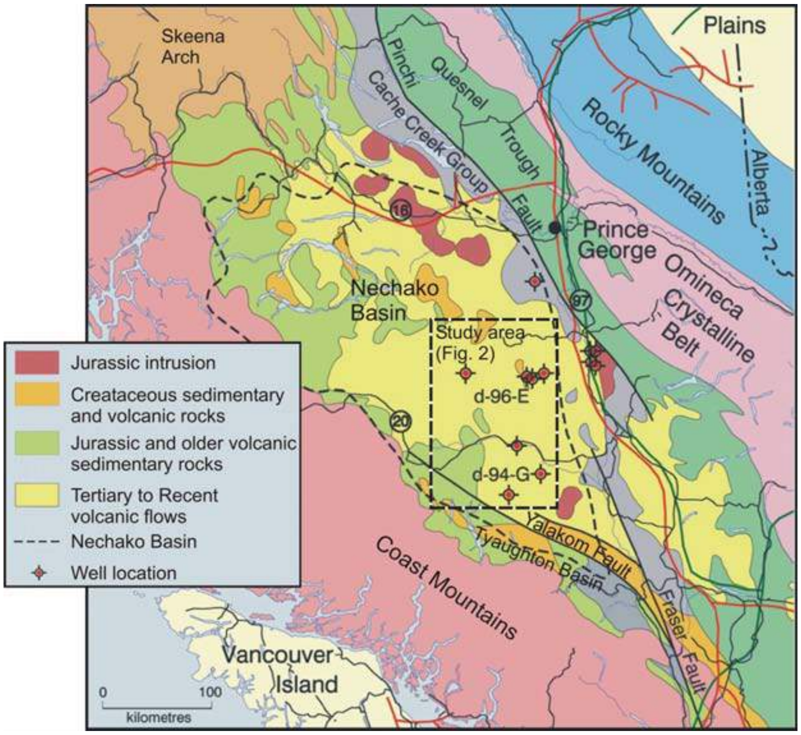

Figure 1. Location of the Nechako Basin and simplified geology of its western Canadian Cordillera setting. Black dashed box shows the study area. Red dashed box shows the focus region of this report.

The basin is extensively blanketed by volcanic rocks of the Eocene Endako and Ootsa Lake groups and the Neogene Chilcotin Group (Figure 2), and Pleistocene glacial deposits (e.g., Riddell, 2006), making interpretation of the basin's stratigraphy and structure difficult. The Endako and Ootsa Lake groups consist, respectively, of basaltic to andesitic and intermediate to felsic flows, accompanied by tuff, breccia and sedimentary rocks. The Chilcotin Group consists primarily of basaltic flows (Riddell, 2006). However, isolated outcrops (e.g., Riddell, 2006), eight wells (drilled by Canadian Hunter Exploration Limited, Esso, Honolulu Oil Corporation Limited and Hudson's Bay Oil and Gas exploration companies) and seismic reflection interpretation in the 1980s by Canadian Hunter reveal the basin to contain Lower Jurassic to Upper Cretaceous sedimentary rocks. These rocks are folded and faulted as a result of the basin's complex tectonic history.

The interpretation of the seismic reflection and well data, on which this study is primarily based, reveals four blocks

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of different geological structure and stratigraphy (Figure 2):

1) Block A (southern Redstone area), in the southern part of the study area, is centred on the Canadian Hunter Redstone wells b-82-C and d-94-G, and seismic lines 160-01 to 160-19.
2) Block B (western Redstone area), centrally located, includes the single seismic line 160-17, which intersects Hudson's Bay well c-75-A.
3) Block C (Chilcotin area), in the northwestern part of the study area, contains the Canadian Hunter Chilcotin well b-22-K and seismic lines 161-01 to 161-09.

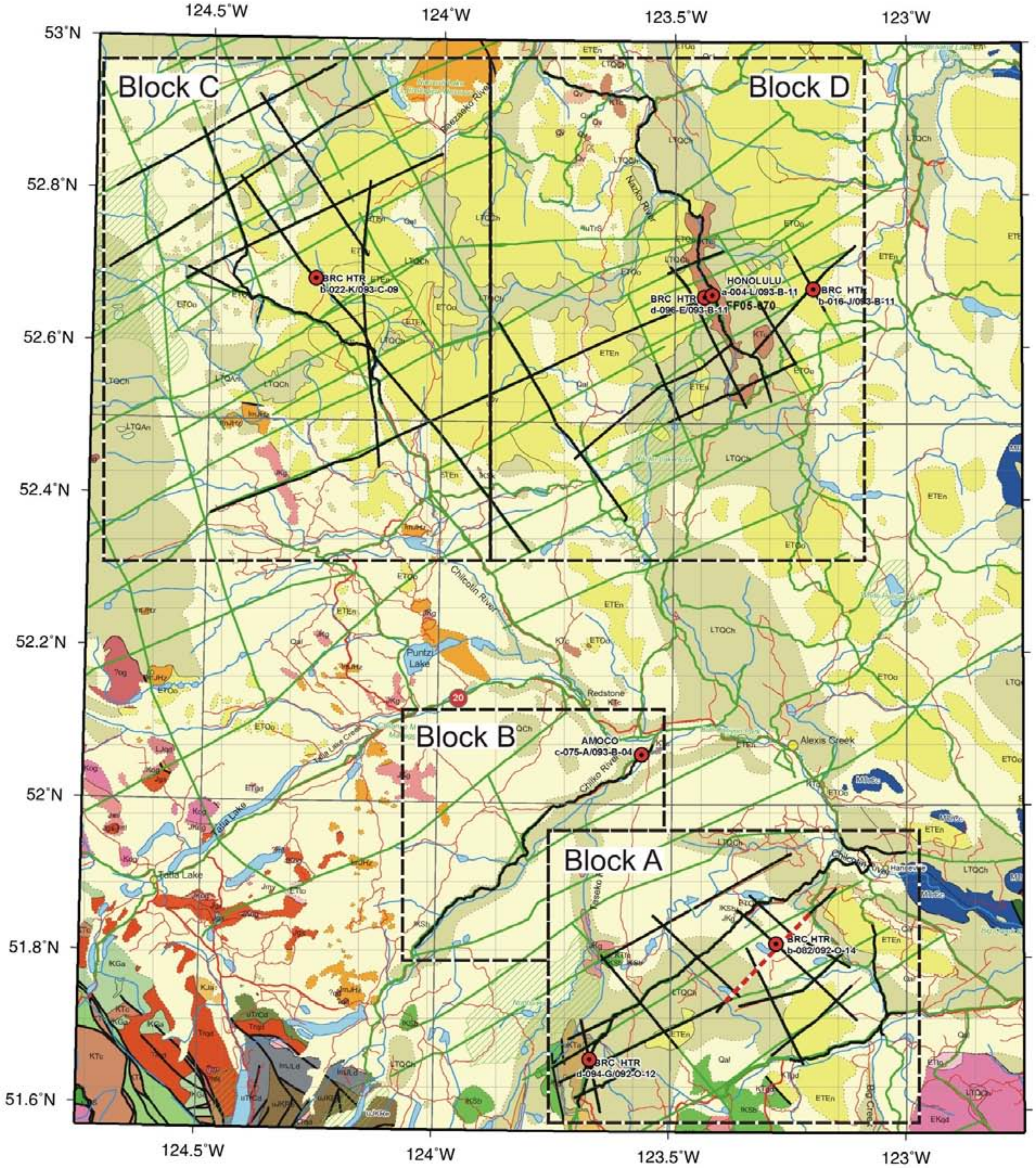

Figure 2. Geology of the study area (Riddell, 2006) and location of seismic reflection profiles (heavy black lines). Volcanic and surficial units: EtEn, Endako Group; EtOo, Ootsa Lake Group; LTQCh, Chilcotin Group; Qal, Quaternary cover; IKSb, Spences Bridge Group. Red dashed box shows the location of block A. Other blocks are shown by a black dashed box. Heavy red dashed line shows the location of the first-arrival tomographic velocity model shown in Figure 5.

4) Block D (Nazko area), in the northeastern part of the study area, includes wells Honolulu Nazko a-4-L, Canadian Hunter Nazko d-96-E and Canadian Hunter–Esso Nazko b-16-J, and seismic lines 159-01 to 159-15 and 162-02.

This study re-evaluates the stratigraphy and structure of the southeastern Nechako Basin, primarily from the reinterpretation, including tomographic velocity modelling, of more than 1650 km of Canadian Hunter seismic reflection profiles. These interpretations are aided by their integration with all relevant geological and geophysical information, including well logs, geology and potential field data. This paper presents a preliminary interpretation of the block A area (Figure 2).

Seismic Interpretation of Block A

Seismic reflection profiles form the basis for the re-examination of the structure and stratigraphy of the southeastern Nechako Basin. The seismic reflection data acquired by Canadian Hunter in the 1980s were recovered and reprocessed in 2006 by Arcis.

Surface mapping (e.g., Riddell, 2006) does not provide a usefully long stratigraphic section, due to the extensive veneer of Tertiary volcanic and Pleistocene glacial deposits (Figure 2). Therefore, data from the Canadian Hunter Redstone wells b-82-C and d-94-G provide the primary stratigraphic control.

Integration of Well Data with Seismic Profiles

Stratigraphic, structural, geophysical and material property data from wells in the southeastern Nechako Basin aided in the interpretation of seismic profiles. To correlate the data with the seismic profiles, thicknesses were converted to seismic traveltimes using the well sonic logs and the Petrel software package (Schlumberger Ltd.). The measured depth (2169 m) of well d-94-G was calculated to correspond to a two-way traveltime of ~1.02 s. For well b-82-C, the total depth of 1719 m was calculated to correspond to a two-way traveltime of ~1.1 s.

Synthetic seismograms were generated from density and sonic log data, also using the Petrel software package, to aid in seismic-to-well correlation. For well b-82-C, an estimate of the density variation through the well was derived from the neutron porosity log, assuming an intergranular fluid density of 1030 k/gm^3 and a grain density of 2670 kg/m^3, as the well's density log only covered a short interval of ~520 m. The synthetic seismograms show a general correlation with changes in reflection character, but the matching of specific reflections was not possible.

Well stratigraphy and geochronology have been re-evaluated by Ferri and Riddell (2006) and Riddell et al. (2007). Stratigraphic columns (Ferri and Riddell, 2006) were converted to time via the sonic logs, in order that more accurate correlations could be drawn with seismic reflections (e.g., Figure 3).

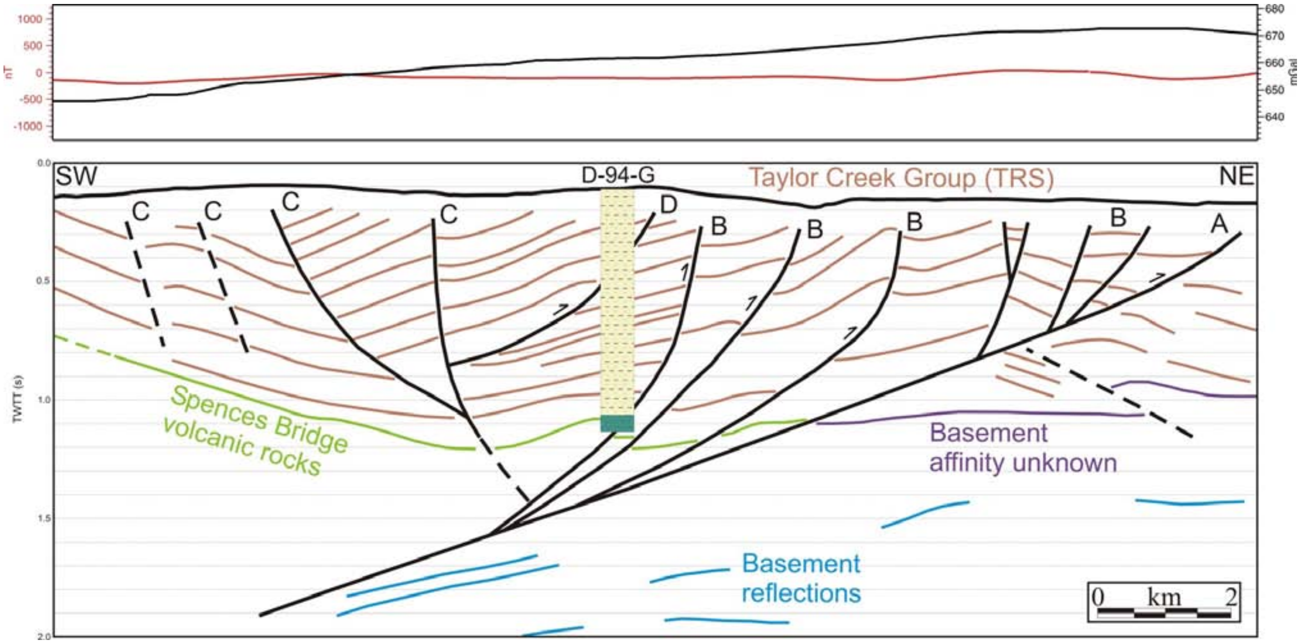

Figure 3. Structural and stratigraphic interpretation of a seismic reflection section from block A. Well d-94-G stratigraphic columns (time converted) from Ferri and Riddell (2006). Upper box shows the Bouguer gravity (black line) and total field magnetic (red line) anomalies. Abbreviation: TRS, Taseko River strata.

Structure of Nechako Basin Block A

The preliminary interpretation of the structure and stratigraphy of block A is shown in Figure 4. Magnetic anomalies (Figure 4) are dominated by the Tertiary volcanic rocks, but many anomalies indicate subsurface structural grain. Magnetic anomalies guided the interpretation of the orientation of structures, especially where only intersected by a single seismic profile.

Structure and Stratigraphy Adjacent to Well d-94-G

Near well d-94-G, a sub-basin containing ~2 km of middle/late Albian to Cenomanian sedimentary rocks of the Taylor Creek Group overlies the Spences Bridge (Riddell et al., 2007) andesite basement (Figure 3). This sub-basin has a corresponding Bouguer gravity low of ~660 mGal, relative to highs of ~670 mGal to the north and east. The Taylor Creek Group and Spences Bridge volcanic rocks are truncated against basement of unknown affinity by a southwest-dipping, low-angle primary fault (A; Figures 3, 4), which maybe of a compressive origin. The orientation of the contact of the Spences Bridge volcanic rocks with the fault plane is oblique to the surface trace of the fault (Figure 4).

Several high-angle, southwest-dipping reverse faults sole into the primary fault (B; Figures 3, 4). The rocks of the Taylor Creek Group form a broad faulted anticline that plunges to the northwest. To the southwest, the Taylor Creek Group rocks thin and are cut (Figure 4) by a number of northeast-dipping faults that show a component of reverse or undetermined sense (C; Figure 3) and a concave trace (C; Figure 4). The outcrop of Spences Bridge volcanic rocks (Figure 2) and faulting (e.g., Riddell, 2006) just beyond the western extent of the seismic profiles marks the western edge of the sub-basin.

Although faults near well d-94-G are interpreted as partly compressive, the relative offset across the structures suggests a strong strike-slip component and possible reactivation. This motion was likely coincident with Eocene dextral transtension (Struik, 1993; Price, 1994), which included the Yalakom and Fraser fault systems, and suggests that motion was directed to the northwest (Figure 4).

A low-angle fault (D; Figure 3), trending oblique to previously discussed structures, is truncated by younger rocks of

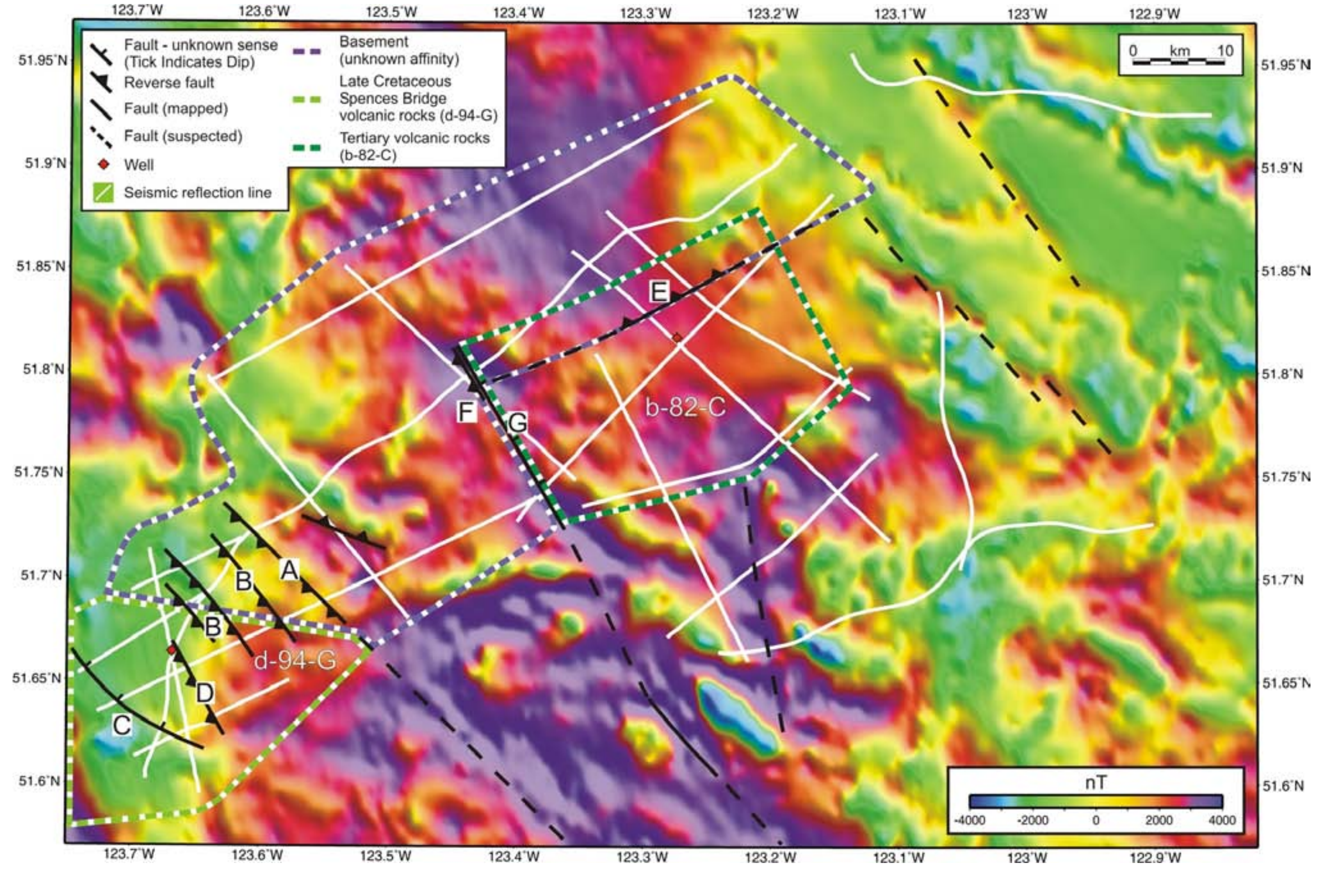

Figure 4. Structure of block A, overlain on the total magnetic field (illumination from the southwest). See legend for feature explanations. Letters mark structures shown in Figure 3. Heavy dashed coloured lines indicate basement affinity. Heavy black lines show regional faults from geological mapping (Riddell, 2006). Heavy black dashed lines show possible extension of these faults based on magnetic anomalies.

the Taylor Creek Group near the surface on some seismic profiles. This structure intersects and may be truncated at depth by steeply dipping faults (C; Figure 3), thus suggesting an earlier origin, perhaps related to pre-Eocene transpression.

Structure and Stratigraphy Adjacent to Well b-82-C

To the east of fault A (Figure 4), Albian sedimentary rocks of uncertain affinity (either Taylor Creek Group, Skeena Group or Silverquick Formation), sampled by well b-82-C (Riddell et al., 2007), are not as intensely deformed as the Taylor Creek Group rocks to the west. Broad folds have a generally northeasterly strike. In the region of well b-82-C, the sampled Albian granitic basement, which predates the Spences Bridge volcanic rocks, is not clearly imaged by seismic profiles. However, late Albian to Cenomanian (Riddell et al., 2007), fine-grained sedimentary and volcanic rocks that overlie the granitic basement produce reflections that are mapped with confidence on seismic profiles adjacent to the well.

Northwest of well b-82-C, basement rocks of unknown affinity are thrust (E; Figure 4) southeast over the late Albian sedimentary rocks. This boundary coincides with a reduction of the Bouguer gravity anomaly to the southeast from a high of ~670 mGal to a low of ~650 mGal. Several high-angle reverse or transpressive faults to the southeast appear to be contemporaneous with the basement thrust. The character of total field magnetic and gravity anomalies suggests that the rocks to the north may be intrusive; however, the structural contact implies intrusion prior to faulting. To the west, the thrust fault appears to be truncated by a pair of northwest-striking faults (F and G; Figure 4) that may be connected to faults mapped to the south (Figures 2, 4; Riddell, 2006). The faults divide a plateau of shallow basement to the west, related to high Bouguer gravity anomalies (~670 mGal), from the sedimentary basin and gravity low (~650 mGal) to the east. The northeast-striking thrust may indicate the presence of a compressional transfer zone between Eocene dextral strike-slip faults. This conclusion would be contrary to northeast-trending extensional faults that commonly link northwest-trending, dextral strike-slip faults (e.g., Struik, 1993) in the Canadian Cordillera.

First-Arrival Tomographic Velocity Modelling

First-arrival tomographic velocity modelling derives an estimate of the seismic P-wave velocity from the traveltimes of the first arrivals from the source to each receiver of a seismic reflection profile. Variations in velocity can reveal structures in near-surface rocks that may be poorly imaged by seismic reflection profiles. First-arrival tomographic velocity models have been used effectively to examine the structure of the Tofino Basin (Hayward and Calvert, 2007), the Seattle fault (Calvert et al., 2003) and the Devil’s Mountain fault (Hayward et al., 2006).

Method

First-arrival (the direct wave and subsurface refractions) tomographic-inversion velocity models were calculated (e.g., Calvert et al., 2003) for all straight seismic profiles (Figure 2). First arrivals picked during seismic reflection processing by Arcis were manually edited in the ProMAX^{TM} software package (Landmark Graphics Corporation) in order to correct picking errors.

The Pronto software (Aldridge and Oldenburg, 1993) was used to model the seismic velocity. First-arrival times to all locations in a subsurface velocity grid (25 m grid spacing) were derived from a finite-difference solution to the eikonal equation. Source to receiver ray paths along the steepest direction of descent were created through the traveltime grid. A one-dimensional (1-D) starting model was estimated from the results of a few trial inversions, setting the top of the model to 1700 m/s^1 with a gradient of 1.5 (m/s^1)/m^1. A perturbation in the velocity model was calculated from the difference between the calculated and observed first-arrival traveltimes for each of 15 iterations.

Although ray penetration often exceeded 1000 m, the highest density of rays (Figure 5a) was typically in the near-surface, leading to a well-constrained estimate of the P-wave velocity (Figure 5b) for depths of up to ~500 m.

Preliminary Velocity Model Results in the Vicinity of Well b-82-Cl

Well b-82-C sampled ~220 m of the Endako volcanic rocks (Ferri and Riddell, 2006) that blanket this part of the basin. In the area of well b-82-C, the modelled rays are focused on the base of the volcanic layer (Figure 5a) at a depth of ~220 m, where the velocity model has a velocity of ~3200 m/s^1 (Figure 5b). Ray density and velocity models may thus be useful for constraining the thickness and velocity of the volcanic overburden.

Conclusions and Further Investigations

Preliminary seismic reflection interpretation in the block A region of the southeastern Nechako Basin has provided a new and detailed interpretation of the stratigraphy and structure of this region. The sub-basin in the vicinity of well d-94-G has the form of a highly faulted and northwest-plunging faulted anticline that is bounded by faulting and shallow basement to the northeast and southwest, respectively. In contrast, the sub-basin adjacent to well b-82-C is more poorly deformed, with broad open folding. Faulting is concentrated at the northwest and southeast margins, which are marked by basement and Bouguer gravity highs.

Work underway will further integrate this interpretation with additional geophysical and geological information and expand the interpretation to the other blocks (Figure 2). Seismic velocity models for the crooked seismic reflection lines, which require a 3-D model approach, will be created and used in combination with the existing models to provide information on the near-surface structure and volcanic overburden.

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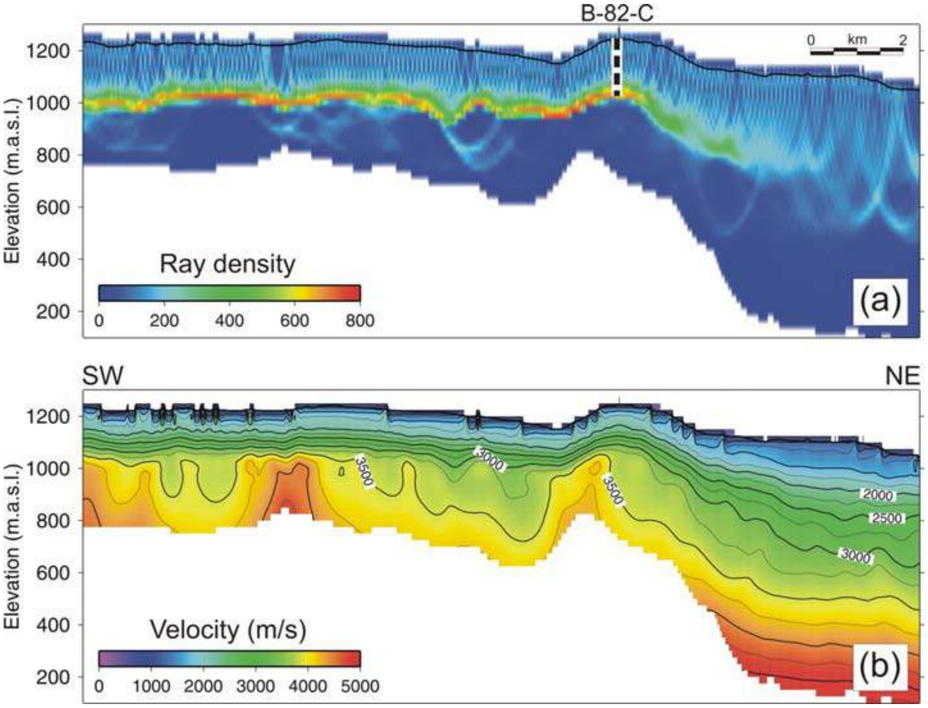

Figure 5. First-arrival tomographic ray density **(a)** and velocity model **(b)** derived from seismic reflection data in the vicinity of well b-82-C. See Figure 2 for model location.

References

Aldridge, D.F. and Oldenburg, D.W. (1993): Two dimensional tomographic inversion with finite difference traveltimes; Journal of Seismic Exploration, v. 2, p. 257–274.

Best, M.E. (2004): Qualitative interpretation of potential field profiles, southern Nechako Basin; *in* Summary of Activities 2004, BC Ministry of Energy, Mines and Petroleum Resources, p. 73–78.

Calvert, A.J., Fisher, M.A., Johnson, S.Y. and SHIPS Working Group (2003): Along-strike variations in the shallow seismic velocity structure of the Seattle fault zone: evidence for fault segmentation beneath Puget Sound; Journal of Geophysical Research, v. 108, doi:10.1029/2001JB001703.

Ferri, F. and Riddell, J. (2006): The Nechako Basin project: new insights from the southern Nechako Basin; *in* Summary of Activities 2006; BC Ministry of Energy and Mines and Petroleum Resources, p. 89–124.

Hayward, N. and Calvert, A.J. (2007): Seismic reflection and tomographic velocity model constraints on the evolution of the Tofino forearc basin, British Columbia; Geophysical Journal International, v. 168, p. 634–646.

Hayward, N., Nedimović, M.R., Cleary, M. and Calvert, A.J. (2006): Structural variation along the Devil's Mountain fault zone, northwestern Washington; Canadian Journal of Earth Sciences, v. 43, p. 433–446.

Price, R.A. (1994): Cordilleran tectonics in the evolution of the Western Canada Sedimentary Basin; Chapter 2 *in* Geological Atlas of the Western Canada Sedimentary Basin, G. Mossop and I. Shetsin, (comp.), Canadian Society of Petroleum Geologists, Calgary, Alberta and Alberta Research Council, Edmonton, Alberta.

Riddell, J.M., compiler (2006): Geology of the southern Nechako Basin, NTS 92N, 92O, 93B, 93C, 93F, 93G; BC Ministry of Energy and Mines and Petroleum Resources, Petroleum Geology Map 2006-1, 3 sheets, 1:400 000 scale.

Riddell, J., Ferri, F., Sweet, A. and O'Sullivan, P. (2007): New geoscience data from the Nechako Basin project; *in* Nechako Initiative Geoscience Update 2007, BC Ministry of Energy and Mines and Petroleum Resources, Petroleum Geology Open File 2007-1, p. 59–98.

Schiarizza, P. and MacIntyre, D.G. (1999): Geology of Babine Lake–Takla Lake area, central British Columbia (93K/11, /12, /13, /14; 93N/3, /4, /5, /6); *in* Geological Fieldwork 1998, BC Ministry of Energy and Mines, Paper 1999-1, p. 33–68.

Struik, L.C. (1993): Intersecting intracontinental Tertiary transform fault systems in the North American Cordillera; Canadian Journal of Earth Sciences, v. 30, p. 1262–1274.

Struik, L.C. and MacIntyre, D.G. (2001): Introduction to the special issue of Canadian Journal of Earth Sciences: The Nechako NATMAP Project of the central Canadian Cordillera; Canadian Journal of Earth Sciences, v. 38, p. 485–494.