Vibroseis Survey Acquisition in the Central Nechako Basin, South-Central British Columbia (Parts of NTS 093B, C, F, G)

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Introduction

The Nechako Basin, located in the interior plateau of British Columbia between the Coast Mountains and the Rocky Mountains, has seen very little exploration for hydrocarbons, in marked contrast to the Western Canadian Sedimentary Basin. Ferri and Riddell (2006) provided an overview of this exploration history, which is summarized here. Investigation of reports of surface oil and gas in the Kersley area, south of Quesnel, led to the drilling of the first well in 1931, with some further wells drilled in the same area in the 1950s, but no oil and gas shows were identified (Hayes, 2002). In 1960, Honolulu Oil Corp. acquired 44 line-kilometres of seismic data near Nazko, west of Quesnel, and drilled one well, a-4-L (Figure 1), which was dry with a few live oil shows (Ferri and Riddell, 2006). In an attempt to better define the basin stratigraphy, Hudson's Bay Oil and Gas Co. Ltd. drilled well c-75-A near Redstone in the southern part of the basin, also in 1960. In 1972, another well was drilled near Punchaw, southwest of Prince George; although some oil stains were noted at fault contacts, the well intersected 250 m of unconsolidated material above volcanic rocks identified as being from the Cache Creek Terrane (Ferri and Riddell, 2006). The only extensive exploration of the Nechako Basin was carried out by Canadian Hunter Exploration Ltd. between 1979 and 1986. The company acquired approximately 3000 line-kilometres of gravity data and 1300 line-kilometres of seismic data, and drilled two wells in 1980, another two in 1981 and a final well in 1985, before abandoning its exploration of the area. Ten gas shows were reported in three wells, and 26 live oil and 49 dead oil shows were detected during drilling (Hannigan et al., 1994).

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The structure and hydrocarbon potential of the basin were most recently reviewed by Hannigan et al. (1994), but remain poorly understood. Some key results of their study are summarized below. Exploration wells have penetrated Early Eocene to Pliocene sedimentary rocks, but no hydrocarbon shows were detected in these rocks. These sedimentary rocks are typically interbedded with volcanic sequences, whose thicknesses can exceed 1000 m. Porosity in sand units averages approximately 8%. The Late Cretaceous oil and gas plays involve open and transitional marine to terrestrial sediments, which filled the Nechako Basin from the east. Structural traps would likely involve compressional folds and drag folds over thrust faults, together with normal fault blocks that formed in the Middle to Late Eocene. Primary porosity in these rocks appears to be very low, but secondary fracture porosity does exist. Carbonaceous and bituminous shale and sandstone, plus some coal, suggest a potential for the generation of gas. The most significant oil and gas plays in the Nechako Basin are in sedimentary rocks of the Taylor Creek (Riddell et al., 2007) and Skeena (Hannigan et al., 1994) groups, which can be as thick as 400–3000 m and were derived mostly from the east by uplift of the Omineca Belt in the Early Cretaceous. Potential reservoir sand units have been suggested within marine and nonmarine sandstone and shale sequences. Five wells have penetrated these Early Cretaceous strata, where all the oil and gas shows in the Canadian Hunter wells were identified. Jurassic rocks in the Nechako Basin are generally metamorphosed and likely to be overmature with regard to hydrocarbon preservation.

The evolution of the Nechako Basin is poorly known because much of the basin is covered by Tertiary and more recent volcanic rocks and glacial deposits. Jurassic–Cretaceous rocks found along the southern and northern margins of the basin probably continue beneath the volcanic/glacial cover, but their subsurface extent has not been defined. Early Cretaceous rocks are exposed along the Nazko River valley and define a north-northwesterly trend at the surface in the central part of the basin (Figure 1). Rocks of this age are also found farther south in a few limited surface outcrops and the three southern exploration wells. The gravity data recorded by Canadian Hunter exhibit a variation of 50 mGal across the basin (Ferri and Riddell, 2006), and one interpretation of the distribution of gravity anomalies is that a number of sub-basins are present. However, with the extensive volcanic cover and limited geophysical data, it is not clear whether the Early Cretaceous sedimentary rocks were deposited within separate sub-basins or are the rem-

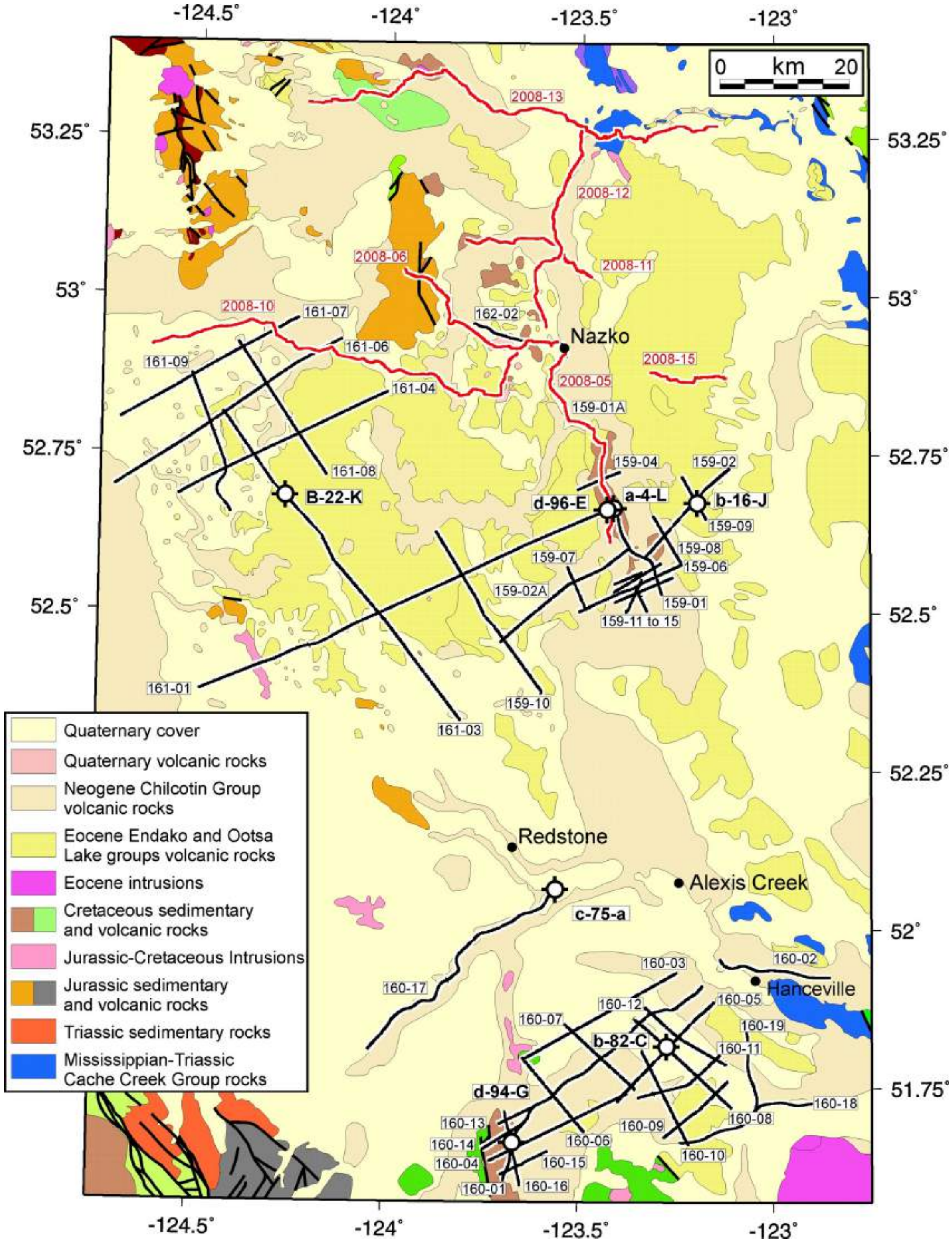

Figure 1. Geology of the Nechako Basin, showing the 1020 line-kilometres of the Canadian Hunter Ltd. seismic lines (black) that were reprocessed by Geoscience BC, and the seismic lines acquired by Geoscience BC in the summer of 2008 (red).

nants of a much larger basin. This fundamental question on the nature of the Nechako Basin was not resolved by the seismic data acquired by Canadian Hunter because the quality of the images was often poor, likely due to the combined effects of the volcanic cover and the seismic acquisition technology available at the time (Hayward and Calvert, 2008). There is therefore a strong argument for acquiring extensive regional geophysical data across the basin. Seismic data are key, due to their greater resolution in depth and their ability to define subsurface structural boundaries that are required for the interpretation of data from other geophysical surveys (e.g., gravity or magnetotelluric). In the summer of 2008, Geoscience BC therefore acquired 330 line-kilometres of seismic data near Nazko along and across the north-northwesterly surface trend of Early Cretaceous rocks in the central Nechako Basin (Figure 1). The primary objectives of the survey were to

- evaluate the effectiveness of modern seismic acquisition technology in this volcanic-covered area and optimize ties of the surface seismic to well-log data; and
- map the extension into the subsurface of the outcropping Early Cretaceous rocks and identify the primary structural controls on their distribution in the central part of the basin.

Survey Planning

An initial program for a vibroseis survey along existing roads was defined with input from the Geoscience BC Oil and Gas Technical Advisory Committee, and a Request for Proposals was issued by Geoscience BC on April 6, 2007, with submissions due on May 18. Four formal bids for the acquisition of the seismic survey were received, and the competitive nature of this process played an important role in maximizing the number of line-kilometres acquired within the fixed budget. The contract was awarded to CGGVeritas of Calgary, who undertook the preparatory work for permitting during the summer of 2007 through a subcontractor, Bighorn Land and Field Service. Information meetings with First Nations in the area began in late 2006. A formal application for a permit to conduct the survey was submitted to the BC Oil and Gas Commission (OGC) on September 17, 2007. A second permit application was submitted in November 2007 to add further seismic lines in the central part of the basin, which would also be coincident with a number of magnetotelluric survey lines acquired in the fall 2007 by the Geological Survey of Canada. This second permit was issued by the OGC on May 7, 2008, and the original permit was issued on June 17, 2008, after it was revised by the removal of several lines located in the southern part of the basin. Thus, the seismic survey, which had originally been conceived as a more regional study to investigate structures and well ties in the southern Nechako Basin and Nazko area, evolved into a study focused primarily on the north-northwesterly trend of the Early Cretaceous rocks that are partly exposed in the central part of the basin and were the focus of Canadian Hunter's extensive exploration effort near Nazko.

Seismic Acquisition Parameters

The quality of the Canadian Hunter seismic data, which was shot in the early 1980s, is generally poor, likely due to the effects of the near-surface volcanic rocks, which can reach a thickness of 600 m (Hayward and Calvert, work in progress, 2008). In one or two areas, very few first arrivals can be observed in these data, suggesting that it may be difficult to generate a sufficiently strong source waveform. In areas with no surface volcanic rocks, the data quality is usually reasonable given the technology of the time. Therefore, much of the new survey design was directed towards maximizing the signal-to-noise ratio, and the main characteristics of the survey were

- a large array of vibrators and long sweeps to maximize source effort;
- a high stack fold through the use of a short source interval and large number of recording channels;
- restriction of the sweep to lower frequencies to improve transmission through near-surface volcanic rocks;
- long offsets to record deeper, subvolcanic reflections and first arrivals that can constrain the thickness of the volcanic layer, and perhaps the depth to the igneous basement; and
- extended correlation of long sweeps to record mid-lower crustal reflections that will constrain the evolution of any sub-basins and provide data quality control in areas where shallower reflections may not be present.

Table 1 shows that the Geoscience BC survey employed approximately 3.5 times the source effort of one of the Canadian Hunter surveys, and that the stack fold is 10 times greater. Modern vibrator-drive control systems will also produce more accurate transmission of the sweep signal from the base plate into the ground.

Following further input from industry (C. Szelewski and B. Goodway of EnCana Corporation), source positions were also located on the half station between receivers to provide a more even offset distribution within CDP gathers, approximating the stack array response (Anstey, 1986) and resulting in less coherent noise (e.g., from the vibrator trucks or ground roll) leaking through into the stack section (Table 2).

Although the source interval was 40 m on all lines, a 22 km section of line 6 was acquired with a 20 m source interval to evaluate the effect of the closer shot spacing and increased source effort.

Table 1. Comparison of key parameters between the Canadian Hunter Ltd. seismic survey and the 2008 Geoscience BC survey.

Parameter	Geoscience BC (2008)	Canadian Hunter (1981)
Source interval (m)	40	100
Receiver interval (m)	20	50
No. of channels	960	96
Maximum offset (m)	14 390	2 550
Nominal fold	240	24
Fold at 0.5 s (estimated)	50	20
No. of vibrators x weight (kg)	4 x 24 000	5 x 7467
No. of sweeps per VP	4	16
Peak force (%)	80	60-75
Sweep duration (s)	28	15
Sweep bandwidth (Hz)	8–64	10–70
Source effort (kg•s/km)	215×10^6	61×10^6

Table 2. Acquisition parameters used in the 2008 Geoscience BC Nechako Basin seismic survey.

Source:	Vibroseis
Vibrator model	Mertz HD 18 Buggy 52,800 lbs
Source point interval	40 m on half station
No. of sweeps per source point	4
Static array	4 vibrators inline over 45 m
Total drag length	60 m with 5 m moveup after listen time
Drive level	80%
Sweep length	28 s including 0.9 s tapers
Listen time	6 s
Sweep type	8 64 Hz linear upsweep
Receivers:	
Geophone model	Oyo GS32CT vertical
Receiver group interval	20 m
Receiver array	6 geophones over 16.7 m
Recording Spread	Asymmetric 240 720 split
Recording system:	
Instrument type	Sercel 428
No. of channels	960
Uncorrelated record length	34 s
Correlated record length	6 s
Sample interval	2 ms
Anti-aliasing filter	0.8 Nyquist linear phase
Recorded to tape	4 x 34 s sweeps, 1 x 6 s correlated diversity sum

Field Survey

The CGGVeritas crew began laying the recording spread on June 22, 2008 (Figure 2) and, after four hours of initial parameter testing, production recording began in the early morning of June 23 (Figure 3).

Initially, the daily production rate varied between 5 and 9 km, but this rate increased to 10–14 km per day when the crew began to operate three 12-hour shifts instead of two; individual shifts were spending up to four hours per day in transit from the crew base in Quesnel. Heavy logging traffic represented a significant source of noise, and was particularly heavy on parts of lines 6, 12 and 15. The recording crew shut down when large convoys of logging trucks travelled over the recording spread, and also when rain, strong winds and thunderstorms were present in the survey area. The survey was completed on August 4.

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Figure 2. CGGVeritas equipment laid out in the initial staging area on June 22, 2008, prior to deployment on line 15.

Figure 3. CGGVeritas vibrators shaking on July 2, 2008 on line 5, with dust rising from the base plates.

vey and supported the pre-survey community workshops. M. Broughton of CGGVeritas cheerfully arranged the employment on the seismic crew of several members of Nazko First Nation. The successful completion of the survey would not have been possible without the efforts of CGGVeritas crew number 5.

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