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Critical reviewers
Gilles Bellefleur

Authors' addresses - Author's address

G. Buffett (gbuffett@nrcan.gc.ca)
D. White (dowhite@nrcan.gc.ca)
B. Roberts (broberts@nrcan.gc.ca)
Central Canada Division
Geological Survey of Canada
601 Booth Street
Ottawa, Ontario K1A 0E8

M. Colpron (Maurice.Colpron@gov.yk.ca)
Yukon Geological Survey
Box 2703 (K-10) Whitehorse, Yukon Y1A 2C6

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Preliminary results from the Whitehorse Trough seismic survey, Yukon Territory

G. Buffett, D. White, B. Roberts, and M. Colpron

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Abstract: The Whitehorse Trough is a Mesozoic sedimentary basin in south-central Yukon Territory that has been identified as an immature, gas-prone basin, based on a limited geoscience database. One hundred and seventy kilometres of regional, multi-channel, multi-component Vibroseis seismic-reflection data were acquired in 2004 across the northern Whitehorse Trough in order to improve understanding of its structural architecture. Preliminary seismic images show reflectivity at shallow, mid-, and deep crustal levels, which are consistent with current geological models. Subsequent analysis will include in-depth processing of both compressional and shear-wave data, and a comprehensive geological interpretation.

Résumé : La cuvette de Whitehorse est un bassin sédimentaire du Mésozoïque dans le centre sud du Territoire du Yukon; d'après une base restreinte de données géoscientifiques, elle a été reconnue comme étant un bassin immature susceptible de donner du gaz. En 2004, des données de sismique réflexion ont été obtenues sur 170 km dans le nord de cette cuvette, dans le cadre d'un levé utilisant une source vibrosismique multivoies et multicomposantes et dont l'objet était de mieux comprendre la structure de la cuvette. Les images sismiques préliminaires montrent une réflectivité à des niveaux crustaux peu profonds, intermédiaires et profonds, ce qui est compatible avec les modèles géologiques courants. L'analyse ultérieure comprendra un traitement poussé des données tirées des ondes de compression et des ondes de cisaillement ainsi qu'une interprétation géologique exhaustive.

INTRODUCTION

The Whitehorse Trough is an elongated, northwest-trending Mesozoic marine sedimentary basin which extends some 650 km from just north of Carmacks, Yukon Territory, to near Dease Lake, British Columbia (Fig. 1). It originated as a forearc basin in the Middle to Late Triassic, adjacent to the emerging Lewes River Arc, and had received more than 7000 m of clastic deposits by Middle Jurassic time (e.g. Wheeler, 1961; Tempelman-Kluit, 1979). It is underlain by late Paleozoic and early Mesozoic arc volcanic rocks of Stikinia and is structurally overlain, in southern Yukon Territory and northern British Columbia, by the oceanic Cache Creek terrane (Fig. 1). The Whitehorse Trough overlies Stikinia at its northern apex, where it is bounded on three sides by polydeformed and metamorphosed mid- to late Paleozoic rocks of the Yukon-Tanana terrane.

The Whitehorse Trough has been identified as an immature, gas-prone basin in which potential source rocks, reservoirs, and seals occur (National Energy Board, 2001). Potential for some 7.3 trillion cubic feet (Tcf) of gas, and possibly some oil, is estimated for the basin, with 2.6 to 4.8 Tcf in Yukon Territory (K. Ozadetz, pers. comm., 2004). However, current assessments of hydrocarbon potential in the Whitehorse Trough rely on limited stratigraphic studies and are based on conceptual plays. No private seismic surveys or wells have been completed in this region. A recent LITHOPROBE seismic survey crosses the central part of Whitehorse Trough near the Yukon-British Columbia boundary (SNORCLE line 3, Fig. 1; Cook et al., 2004) and provides an interpretation of the crustal structure in the area. However, the LITHOPROBE survey was designed primarily to image deep crustal features and offers limited information about the upper crust.

In 2004, the Yukon Geological Survey and Geological Survey of Canada commissioned a regional, multi-channel, multi-component Vibroseis seismic-reflection survey across the northern part of Whitehorse Trough and into adjacent terranes (Fig. 2), with the aim of enhancing the geoscience database of the area for use in future hydrocarbon-potential assessment. The survey comprises two seismic profiles totaling 170 km in length acquired along the Robert Campbell and North Klondike highways (Fig. 2). The Whitehorse Trough seismic survey was designed to obtain optimal resolution in the upper 5 km of the crust, while allowing sufficient depth penetration to image crustal-scale features. We present here some preliminary observations on crustal structures imaged by this survey.

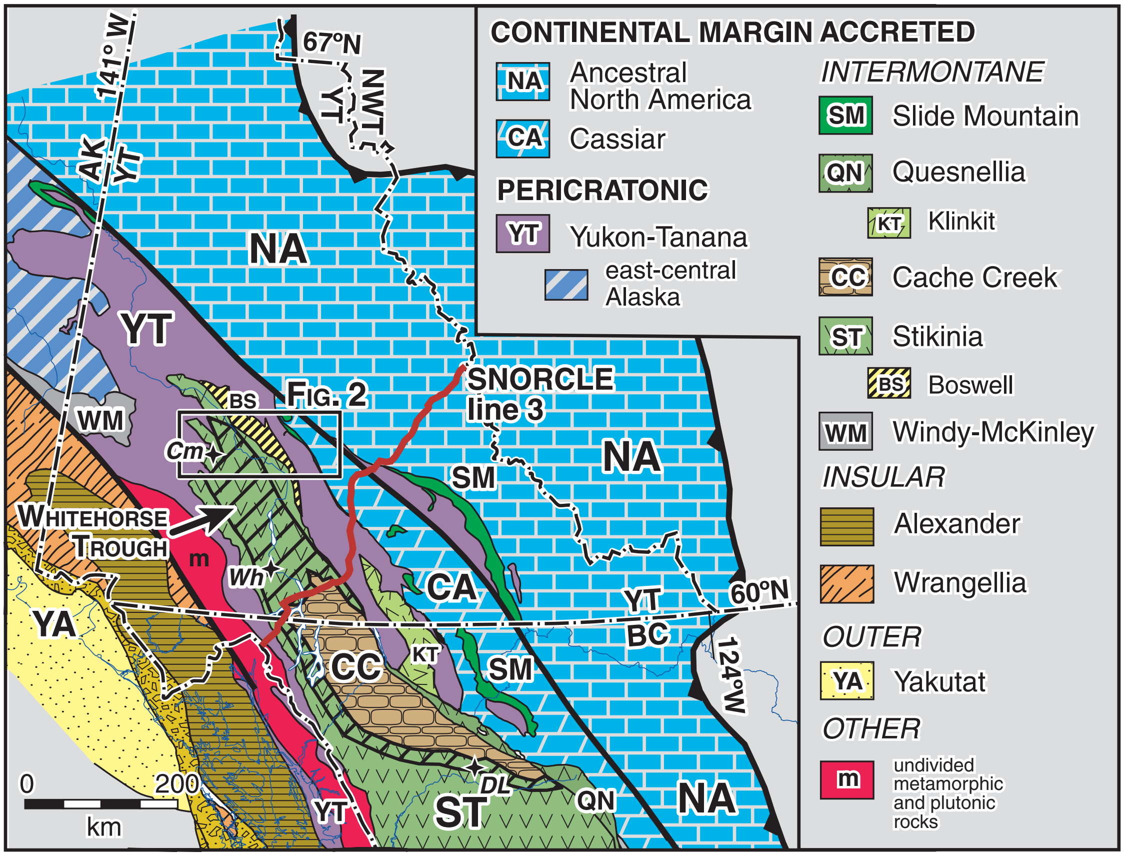

Figure 1. Terrane map of Yukon Territory and adjacent northern British Columbia. The cross-hatched area in northern Stikinia indicates regional distribution of the Whitehorse Trough. Abbreviations: Cm – Carmacks; DL – Dease Lake; WH – Whitehorse.

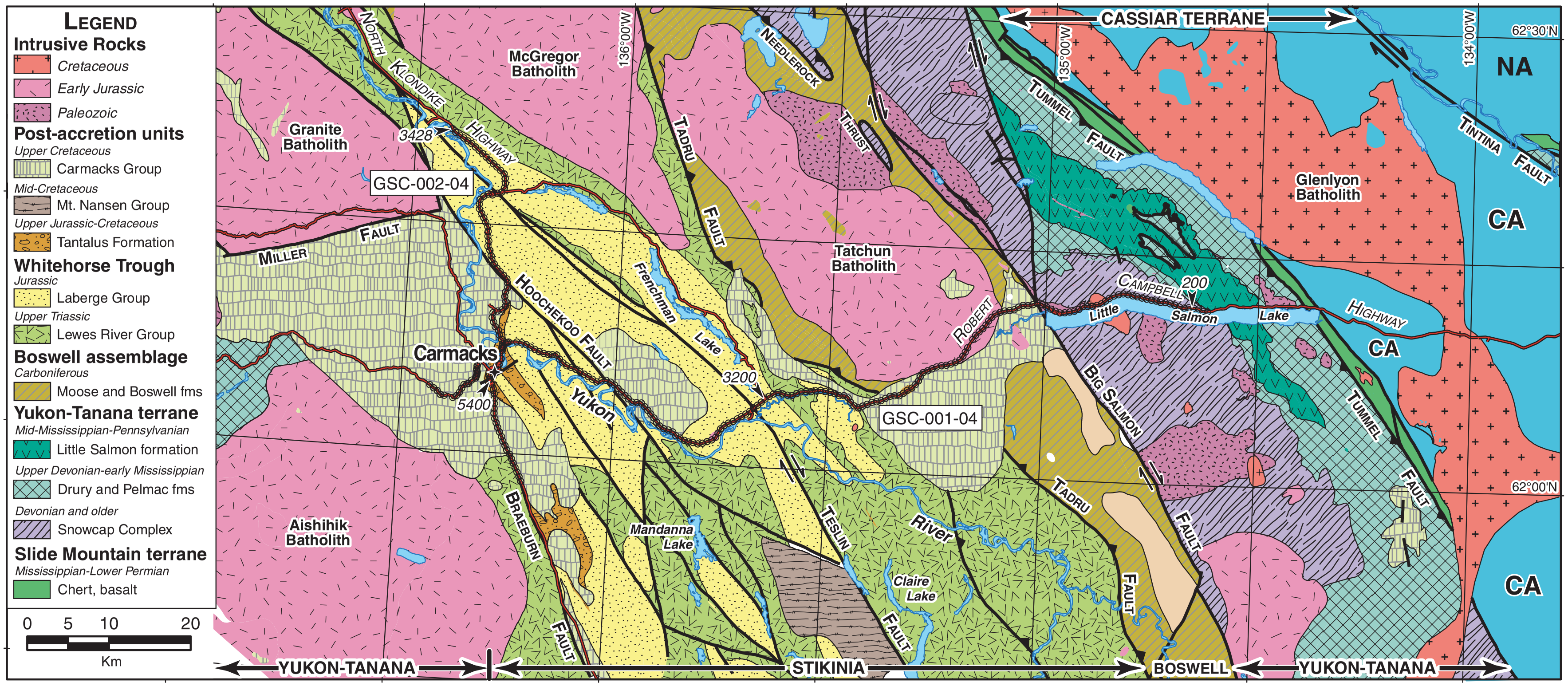

Figure 2. Geological map of the northern Whitehorse Trough and surrounding region. Compiled from Tempelman-Kluit (1984) and Colpron et al. (2002). Heavy black lines show location of seismic transects along the Robert Campbell (GSC-001-04) and North Klondike highways (GSC-002-04).

GEOLOGICAL SETTING

The Canadian Cordillera consists of a collage of terranes that were accreted to the western margin of the North American Craton between late Paleozoic and early Cenozoic time (Coney et al., 1980; Gabrielse et al., 1991; Price and Monger, 2000 and references therein). The largest of these terranes, Stikinia, comprises Late Devonian to Middle Jurassic volcanic and sedimentary strata, as well as comagmatic plutonic rocks (Monger et al., 1991). Paleozoic assemblages are mostly known in northern British Columbia.

The northern portion of Stikinia is composed of Upper Triassic arc volcanic and sedimentary rocks of the Lewes River Group and Lower to Middle Jurassic sedimentary strata of the Laberge Group (e.g., Wheeler, 1961; Fig. 3). Sedimentary facies of the Lewes River (Aksala formation) and Laberge groups define the Whitehorse Trough in Yukon (e.g., Wheeler, 1961; Hart, 1997). The Lewes River Group comprises at its base calc-alkaline basalts, andesite, and agglomerates of the Povoas formation (Tempelman-Kluit, 1984). The Povoas locally overlies Paleozoic greenstone of the Takhini assemblage west of Whitehorse. The Povoas is conformably overlain by heterogeneous clastic strata (mainly sandstone, greywacke, and argillite), limestone, and minor conglomerate of the Aksala formation (Tempelman-Kluit, 1984; Hart, 1997).

The Laberge Group consists of conglomerate, sandstone, siltstone, argillite, and tuff. In the northern Whitehorse Trough, near Carmacks (Fig. 2), the Laberge Group consists primarily of coal-bearing interbedded sandstone and mudstone of the Tanglefoot formation, which includes subordinate amounts of conglomerate, pebbly sandstone, and tuffaceous rocks (Lowey, 2004). At this latitude, the Tanglefoot formation unconformably overlies the Lewes River Group. To the south, in the central Whitehorse Trough, the Richthofen formation, dominated by thin-bedded sandstone-mudstone couplets (turbidites), and clast-supported conglomerates (but no coal), unconformably overlies the Lewes River Group (Lowey, 2005).

The Laberge Group is unconformably overlain by the Upper Jurassic to Lower Cretaceous Tantalus Formation (Fig. 3; Bostock, 1936; Tempelman-Kluit, 1984; Long, 2005), which consists primarily of fluvial sandstone and chert-pebble conglomerate representing a molasse deposit that marks the end of deposition in the Whitehorse Trough. In the northern Whitehorse Trough, occurrences of the Tantalus Formation are primarily restricted to the western edge of the Trough near Carmacks (Fig. 2), where significant coal resources have historically been mined, and in isolated exposures north of Claire Lake and beneath the Carmacks Group basalts along the Robert Campbell Highway (Tempelman-Kluit, 1984; Colpron et al., 2002).

At the latitude of Carmacks, the northern Whitehorse Trough is bounded on the west by the Braeburn Fault, a dextral strike-slip fault with an estimated 8 km of displacement, which projects underneath the Upper Cretaceous Carmacks Group (Fig. 2; Tempelman-Kluit, 1984). To the west, granodiorite gneiss of the Yukon-Tanana terrane intruded by Early Jurassic granitic batholiths dips to the east beneath the Whitehorse Trough. The eastern margin of the Whitehorse Trough is defined by the Tadru Fault, a southeast-dipping thrust fault that places mid- to late Paleozoic rocks of the Boswell assemblage onto Upper Triassic strata of the Lewes

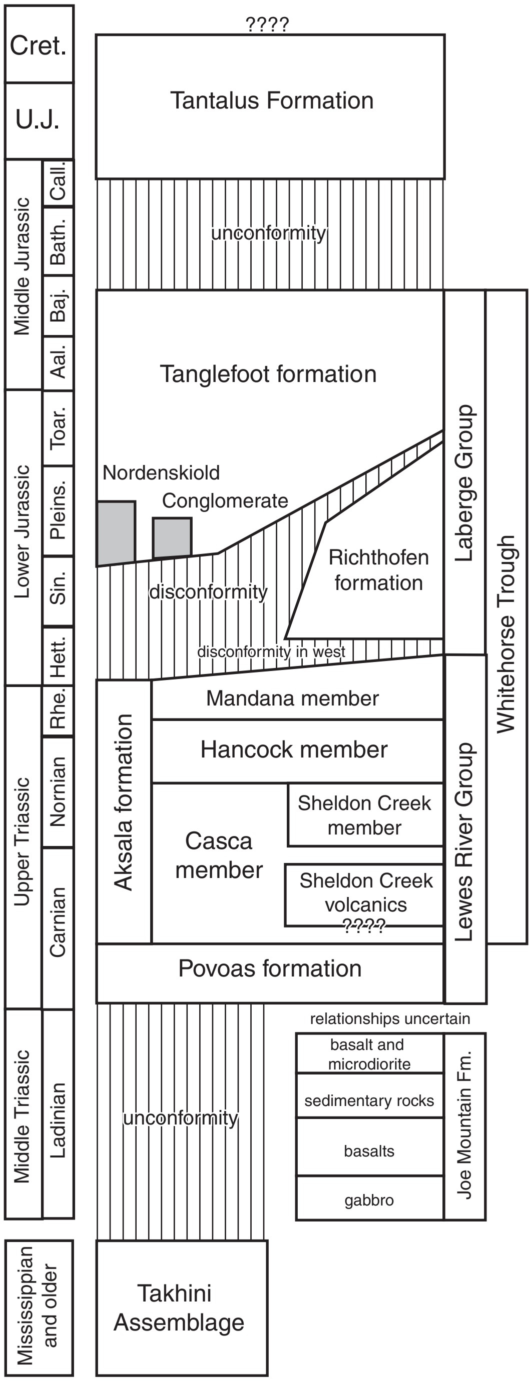

Figure 3. Stratigraphic relations of northern Stikinia. Modified from Hart (1997) to accommodate revisions to Laberge Group stratigraphy suggested by Lowey (2004).

River Group (Colpron et al., 2002, 2003). Boswell assemblage rocks consist of basalt and limestone of the Late Devonian to Early Mississippian Moose formation, and volcanic, volcaniclastic, and sedimentary rocks of the Boswell formation (Simard, 2003).

North of the Tatchun Batholith (Fig. 2), metasedimentary rocks of the Snowcap complex, the oldest unit in Yukon-Tanana terrane, structurally overlie greenstone of the Moose formation along the Needlerock thrust (Fig. 2). Along the Robert Campbell Highway, the Boswell assemblage and Yukon-Tanana terrane are juxtaposed along the Big Salmon Fault, a strike-slip fault with up to 56 km of Late Cretaceous(?) dextral displacement (Colpron et al., 2003).

The Yukon-Tanana terrane comprises a metasedimentary basement complex (Snowcap complex), intruded by Mississippian plutons, and unconformably overlain by Carboniferous arc-derived metaclastic rocks (Dury and Pelmac formations) and mafic metavolcanic rocks (Little Salmon formation). To the east, Yukon-Tanana is juxtaposed to Cassiar terrane along the Tummel Fault, an approximately 3 km-wide zone of imbricate fault slices of Slide Mountain terrane (chert, basalt, serpentinite) and synorogenic metaclastic rocks (Colpron et al., in press).

Rocks of Yukon-Tanana terrane, Boswell assemblage, and Lewes River Group are intruded by large Early Jurassic batholiths (Fig. 2) that are coeval with deposition of Laberge Group strata in the Whitehorse Trough. Cretaceous plutons intrude rocks of Stikinia near Whitehorse, but are absent from the northern Whitehorse Trough (Gordey and Makepeace, 2000). In this region, Cretaceous plutons are mainly restricted to Yukon-Tanana and Cassiar terranes (Fig. 2).

Rocks of the northern Whitehorse Trough are extensively faulted and folded by broad open to southwest-vergent folds (Fig. 2; Tempelman-Kluit, 1984). The overall structure is that of a broad anticlinorium, occupied by strata of the Lewes River Group, flanked by two synclinoria of the Laberge Group. These structures are dissected by an array of brittle faults with a complex kinematic history.

Basalt and agglomerate of the Upper Cretaceous Carmacks Group overlie all terranes along the transect area (Fig. 2; Tempelman-Kluit, 1984). The Carmacks Group occurs as a series of erosional remnants along the survey transect which are typically only a few hundred metres thick, with the thickest accumulation (~800 m) west of Carmacks. The Carmacks Group clearly postdates some of the major faults in the area (Tadru and Braeburn faults, Fig. 2) but is possibly affected by late brittle deformation along some of the other faults (e.g., Big Salmon, Hoochekoo, and Miller faults).

SURVEY DESIGN

The seismic survey was designed to transect three distinct geological terranes, the Yukon-Tanana terrane, the Boswell assemblage, and Stikinia, which envelops the Whitehorse Trough. Two regional profiles were acquired in the winter 2004. Line GSC-001-04 is a 117 km east-west transect across the northern Whitehorse Trough, along the Robert Campbell Highway, beginning at the midpoint of Little Salmon Lake and ending 13 km west of the town of Carmacks on Mt. Nansen road (Fig. 2). This line transects all terranes generally at a high angle to the regional structures. It starts well to the east of the Whitehorse Trough in order to test whether Mesozoic strata extend in the subsurface beneath Paleozoic rocks of the Boswell assemblage and Yukon-Tanana terrane. Line GSC-002-04 is 53 km in length, starting 35 km north of Carmacks and ending 18 km south of the town, entirely along the western edge of the Whitehorse Trough on the North Klondike Highway (Fig. 2). A 2.64 km section on the North Klondike Highway is common to both lines. Data recording parameters were chosen to obtain optimal resolution in the upper 5 km while allowing sufficient depth penetration to image crustal-scale features.

Prior to the start of the survey, consultation meetings were held with the local First Nations to address concerns regarding possible environmental issues and potential damage to infrastructure. Because the survey was conducted along existing transportation corridors, it was agreed that it would have minimal environmental impact. During the survey, standard operating procedures were followed which precluded vibrating in the immediate vicinity of buildings, wells or other infrastructure. While traversing the town of Carmacks, data receivers were deployed to record reflections from vibration points located outside of town, but no vibration operations were conducted through the town. As expected, this reduced data quality somewhat near Carmacks. However, due to low population density this approach was necessary only once per line and did not affect the overall data-acquisition integrity. Acquisition parameters are summarized in Table 1.

DATA PROCESSING

Data processing is currently at an intermediate stage. The data are being processed on a SUN Microsystems ™Enterprise 450 workstation using ProMAX® (v. 7.0b) software. Table 2 describes the processing flow that has been executed thus far to produce these results. The stacked sections (Fig. 4, 5) are unmigrated, filtered common-midpoint stacks for both seismic lines.

PRELIMINARY SECTIONS

Figure 4 presents an unmigrated segment of the eastern portion of the GSC-001-04 profile that demonstrates characteristic data quality and identifies some prominent geological

Table 1. Data-acquisition parameters

Field crew	Kinetex Inc., Calgary.
Date	February–April, 2004
Clients	Geological Survey of Canada / Yukon Geological Survey
Instrumentation	I/O Vectorseis® System IV
Traces/record	600
Record length	33 s (uncorrelated)
Sample rate	2 ms
Anti-alias filter	½ Nyquist
Nominal CDP fold	100
Vibroseis source parameters	
Source type	4 Vibrators (IVI Y2400 Buggy Mount)
Source array	4 Vibrators in-line
Pattern length	12 000 m
VP interval	60 m
# Sweeps/VP	6 or 10 (with 3 vibrators operational)
Sweep length	24 s
Sweep type	Linear upsweep
Sweep frequency	10-84 Hz
Receiver array parameters	
Group interval	20 m
Geophones/group	1 (3C Sensor Buried)

Table 2. Data Processing Flow

Data preparation

- Diversity stacking of unstacked sweeps
- Vibroseis self-tapering extended correlation
- Crooked line geometry application
- First Breaks manually picked

Pre-stack processing

- AGC: 500 ms mean window
- Top mute application
- Velocity analysis: semblance and constant velocity stack
- Refraction statics correction: final datum elevation: 750 m, replacement velocity: 4800 m/s
- Normal moveout correction: Stretch mute tolerance of 50%
- Residual statics correction
- CDP Stack: method for trace summing: mean

Post-stack processing

- Semblance smoothing
- Plot threshold (1.5*RMS)

features. The most notable physical boundary evident is the clear disappearance of reflectivity at a two-way time of approximately 11 s (Feature A), which, corresponds to a depth of approximately 33 km using an average crustal seismic velocity of 6000 m/s. The drop in reflectivity at this depth delineates the seismic reflection Moho commonly associated with the crust-mantle transition. This depth is comparable to that observed in LITHOPROBE seismic studies in south-central Yukon (Cook et al., 2004; Welford et al., 2001) as well as that interpreted from magnetotelluric results (Ledo et al., 2004). The seismic Moho represents a sharp change in the elastic properties between the lower crust and upper mantle. This change is therefore inferred to be a result of a corresponding change in lithology.

Feature B in Figure 4 corresponds to a series of east-dipping reflectors, which have an apparent dip between 30 and 45°, and project near the surface expression of the Teslin Fault (Fig. 2). It can be traced almost continuously throughout the entire crustal section and perhaps below the reflection Moho (Feature A). This feature is similar to east-dipping reflectors interpreted as the Teslin Fault on SNORCLE line 3 (Cook et al., 2004, labeled Teslin Zone on their Plate 5). Truncation of reflectors along a steeply east-dipping zone beneath the surface expression of Teslin Fault (Feature C) indicates that either the Teslin Fault postdates Feature B or that it is a listric fault, which merges with Feature B at depth.

Feature D on Figure 4 has an apparent easterly dip of approximately 45° and projects near the surface location of the Tadru Fault, a thrust fault that marks the boundary between Stikinia and the Boswell assemblage (Fig. 2; Colpron et al., 2002). It appears to be truncated at a two-way time of 5.0 seconds by a horizontal reflective zone (Feature H), therefore suggesting that the Tadru Fault merges with a basal detachment at that depth.

Figure 5 is an unmigrated common-depth point (CDP) stack of the northern part of line GSC-002-04 (stations 3428 to 5400; Fig. 2). On the north end of this line a strong, primarily horizontal band of reflectivity is seen, which spans from 5.5 seconds to 11.0 seconds two-way-time (Feature A), while shallow reflectivity is less prominent (Feature B). At 11.0 seconds, we again identify the seismic-reflection Moho (Feature C), based on the sharp reduction in reflectivity. Within the band of strong horizontal reflectivity, there are significant south-dipping events (Feature D). Further south, the signal-to-noise ratio improves from the surface to a two-way time of approximately 4.0 seconds and displays both horizontal and dipping events (Feature E), whereas at greater depths, the data quality degrades considerably (Feature F). This low-reflectivity zone is asserted to be geological in nature.

SUMMARY

Preliminary images from the Whitehorse Trough seismic survey provide a first look at the crustal architecture of the region. Notable features are 1) prominent easterly dipping structures on line GSC-001-04 which are likely expressions of the Teslin and Tadru faults, and 2) the seismic-reflection Moho, indicating a crustal thickness on the order of 33 km. Further processing of these data will seek to improve the signal-to-noise ratio, thus improving temporal and spatial resolution and to migrate data to their true subsurface locations. In addition, processing of shear-wave components will commence. Interpretation will continue concurrent with further data processing. Interpreted results will be studied against current geological models to assess the hydrocarbon potential of the Whitehorse Trough and advance the understanding of the tectonic history and structural framework of central Yukon Territory.

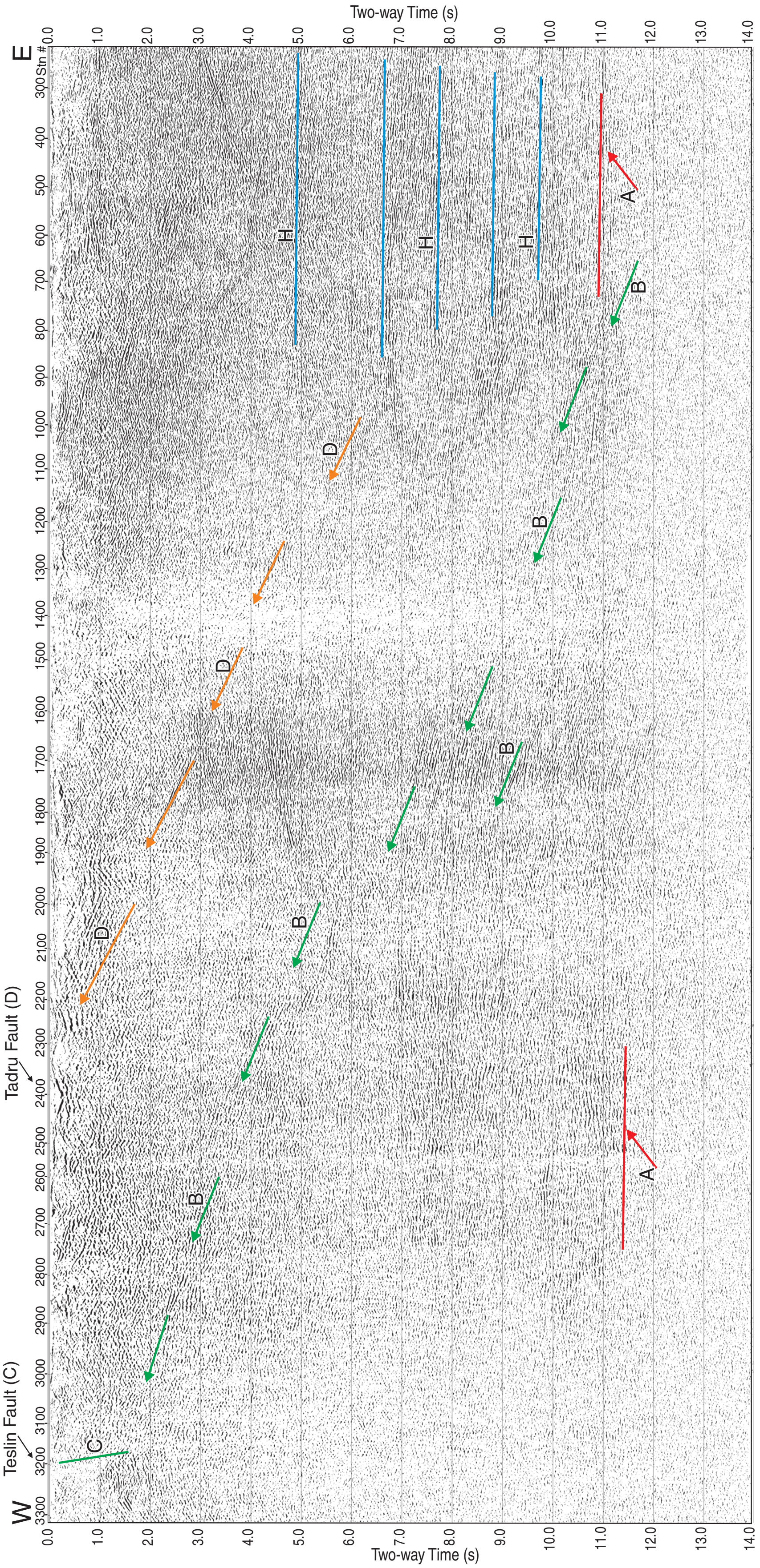

Figure 4. Preliminary stacked section for the eastern portion of GSC-001-04 (stations 200-3300).

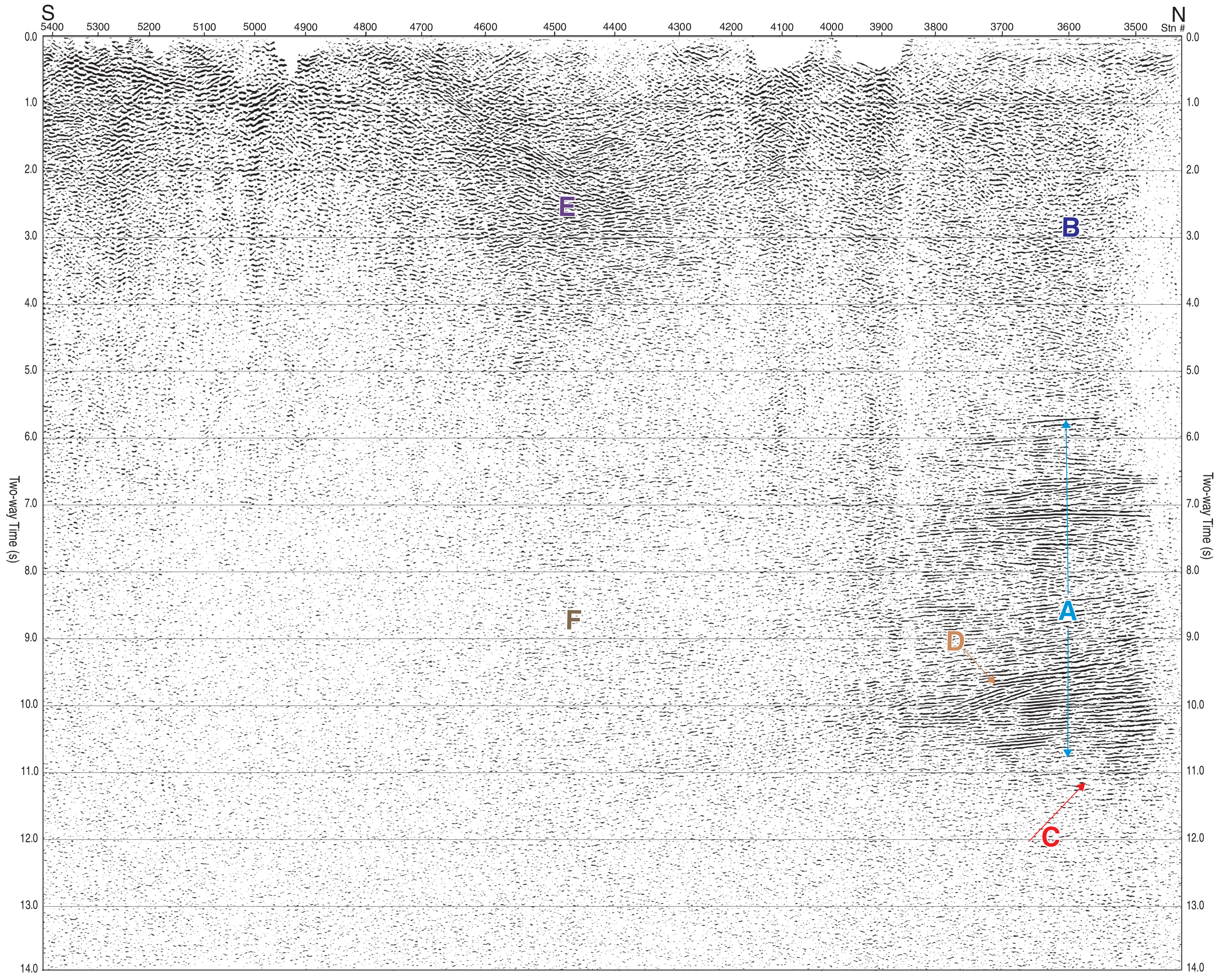

Figure 5. Preliminary stacked section for the northern portion of GSC-002-04 (stations 3428-5400).

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