Sequence Biostratigraphy and Depositional Modelling of the
Pennsylvanian-Permian Belloy Formation Peace River
Embayment, Alberta Canada

Lindsay A. Dunn* and Charles M. Henderson
Applied Stratigraphy Research Group, Department of Geology and Geophysics,
The University of Calgary, 2500 University Drive NW Calgary, AB T2N 1N4

ABSTRACT
The Pennsylvanian-Permian Belloy Formation within the Peace River Embayment (PRE) exhibits excellent reservoir potential and includes approximately 2% of the Western Canada Sedimentary Basin’s (WCSB) proven oil and gas reserves. However, it is currently under explored. The formation has been largely overlooked as an exploration target because of difficulties with regional correlations and the lack of a basin wide sedimentological model. This presentation is part of an ongoing project that seeks to address these shortcomings utilizing conodont biostratigraphy and detailed core analysis.

The PRE forms a fault-controlled reentrant that dissected the North American cratonic margin during the Mississippian to Triassic. Previously, it was believed that the mixed carbonate and siliciclastic Pennsylvanian-Permian succession passively filled this embayment. However, it is becoming increasingly clear that block faults that disrupted the underlying Mississippian Stoddart Group also caused offset, differential synsedimentary subsidence and/or up doming in the Belloy.

Eight depositional sequences have now been identified within the Belloy Formation. These sequences are being placed into a sequence biostratigraphic framework constructed through lithostratigraphic core based studies and conodont biostratigraphy. Lithofacies maps for each sequence have also been constructed that include previously unrecognized terrestrial sequences. Insights into the nature of the depositional system, in particular the potential tectonic control on lithofacies distribution will greatly enhance economically important exploration strategies and basin evolution models.

A contemporaneous outcrop section at Tunnel Mountain, Banff has also been included in this study. This section, despite a markedly contrasting depositional environment from the PRE, has been successfully correlated into the subsurface with the use of outcrop gamma logging and the acquisition of sequence biostratigraphic data. The outcrop studies have extended the applicability of the sequence biostratigraphic framework to the entire WCSB indicating that regional relative sea level fluctuations are the primary control on sequence development for this interval.
INTRODUCTION
Pennsylvanian and Permian aged strata were deposited in two major areas within the Western Canada Sedimentary Basin: the Ishbel Trough (Prophet Trough in the Carboniferous), and the Peace River Embayment (PRE)(Fig.1) (Henderson et al., 1994). The Pennsylvanian-Permian in PRE is represented within the Belloy Formation that Halbertsma (1959) subdivided into three informal members: the lower carbonate, the middle sandstone, and the upper carbonate. However, regional scale correlations of these subdivisions have proved problematic due to the close juxtaposition and amalgamation of sequence boundaries, the lithological similarity of sequences, and the paucity of macrofauna (Naqvi, 1972; Henderson et al., 1994).

Later workers subdivided the Belloy Formation into two packages: a regionally extensive eastern facies, composed of cherty sandstone with minor shale and limestone interpreted as shoreline associated, basin margin to proximal shallow marine deposits (Barclay et al. 1990); and a more restricted western facies composed of siltstone and fossiliferous carbonates interpreted as outer shelf to basinal deposits (Henderson, 1989; Barclay et al.1990). A recent study indicated that there was at least 6 unconformity bound transgressive-regressive sequences that subdivide the Pennsylvanian and Permian strata (Henderson, 1997) (Fig. 2).

This core display represents the initial stages of an ongoing project that has two principal aims: firstly to increase the resolution of definable, correlatable units within the Pennsylvanian and Permian; through the integration of sequence stratigraphy and detailed biostratigraphy (Sequence Biostratigraphy); and secondly to develop a sedimentological model for the Permian Belloy Formation. Henderson's (1997) sequences 5 and 6, which broadly correlate to the middle and upper sandstone and the eastern facies as outlined are the focus of this study.

METHODS
Twenty-five Belloy Formation cores from the Peace River region (townships 52 to 92, and ranges 16 west of the fifth meridian to 13 west of the sixth meridian) form the basis of this study. The cores were logged lithostratigraphically and sampled for biostratigraphic data; particular attention was given to the identification of sequence stratigraphically significant surfaces. Three cores are being presented 12-14-078-1W6 (Belloy Type well; Fig. 3), 16-10-073-26W5 (Fig. 4) and 10-21-092-3W6 (Fig. 5).

In addition, sedimentological and stratigraphic comparisons and correlations have been made between these cores and the outcrop section at Tunnel Mountain, Banff (Johnston Canyon and Ranger Canyon formations Fig. 2). A gamma-log profile was constructed using a hand held gamma-ray scintillometer and was plotted against a lithologic log for the section (Fig 5). Figure 6 is an overlay of the gamma log on the outcrop section.

Within the outcrop section, sequence stratigraphic bounding surfaces, systems tracts, and parasequences have been defined on the basis of the lithological and geophysical data. The bounding surfaces once identified were sampled and processed for micropaleontological data (conodonts) that provide the chronostratigraphic framework for the sequence stratigraphic correlations.

RESULTS
Sequence Stratigraphy
Two previously unrecognized sequence boundaries have been defined in the Tunnel Mountain section through the integration of lithologic, gamma log and biostratigraphic data. These sequence boundaries subdivide Henderson's (1997) sequence 5 into three sequences 5a, 5b and 5c respectively (Figs. 2-7). The Kungurian sequence is only 30 cm thick is displayed in figure 7.

Sequences 5b and 5c as recognized in outcrop have also been documented within the Belloy Formation in the subsurface. Sequences 2, 5b, and 5c are present within the 12-14 well (Fig. 3).
The 16-10 and 2-27 wells contain sequences 5b and 6 (Fig. 4).

Sedimentology
The Johnston Canyon Formation is composed of rhythmically interbedded dolostone and thin shales (Fig. 8) interpreted as reflecting deposition on a starved continental shelf. This is consistent with the condensed nature of the unit, the abundance of authigenic minerals and the paleogeographic position of the interval at the eastern margin of the Ishbel Trough (Fig, 1) (Henderson et al., 1993; Henderson et al., 1994).

The previous studies outlined above have interpreted the Belloy sands as marine. It has now been recognized that the Belloy Formation also includes a significant terrestrial component including fluvial/alluvial sands and silcrete/calcite overprinting fabrics. This terrestrial component is particularly significant in Kungurian sequence that represents a major global eustatic lowstand (Ross and Ross, 1995). A model for the Belloy depositional system is presented in figure 9.

CONCLUSIONS
The sequences identified within the Belloy Formation can be correlated across the Peace River Embayment to the Tunnel Mountain section in Banff indicating that regional, relative sea level fluctuations are the primary control on the succession in this interval. However, sequences 5b 5c and 6 are not uniformly distributed throughout the basin and the principal depocentre has been observed to migrate through time, presumably as a result of local tectonics. Such insights including the potential tectonic control of facies distribution will greatly enhance exploration strategies and basin evolution models.

ACKNOWLEDGEMENTS
The Applied Stratigraphy Research Group (ASRG) and the Department of Geology and Geophysics at the University of Calgary, provided funding for this project. For more information regarding the ASRG see http://www.geo.ucalgary.ca/asrg/. The ASRG would like to take this opportunity to thank our corporate sponsors including: ANDERSON, CRESTAR ENERGY (GULF), ENCAL, NUMAC ENERGY INC., PANCANADIAN PETROLEUM LTD., PETRO-CANADA, RICHLAND, SAMSON, SUNCOR INC., and TALISMAN ENERGY INC.

REFERENCES


Figure 1. Simplified map of the Asselian deposits in the Western Canada Sedimentary Basin. Displays the position of the two principal depocentres, the Ishbel Trough and the Peace River Embayment. Adapted from Henderson, (1989).
Figure 2. Correlation chart illustrating the standard chron stratigraphic units, position of Henderson's (1997) six sequences, conodont biozonal schemes, and the Pennsylvanian-Permian lithostratigraphic units from the PRE and Banff Region. Subdivision of sequence 5 into 5a, 5b and 5c are as a result of the current study. Adapted from Henderson et al. (1994).
Figure 4. Lithological and gamma log for wells 10-21-092-03W6 and 16-10-073-26W5.
Figure 5. Lithological and gamma logs for the Tunnel Mountain section. Includes interpretation of depositional environment, and sequence stratigraphic correlations.
Figure 6. The outcrop section at Tunnel Mountain Banff. 4a: Base of section with gamma log and sequences boundaries overlain. 4b: Top of section with gamma log and sequences boundaries overlain.

Figure 7. Johnston Canyon Ranger Canyon contact. Kungurian sequence 5b bound by the intra-Permian unconformity below and a second unconformity above. The two unconformities merge to the right of the photograph.
Figure 8. Dolostone-shale parasequences, Tunnel Mountain section ~39m. Note book 18cm.
Figure 9. Proposed depositional model for the Artinskian (5b) and Kungurian (5c) sequences

**KEY**

**Lithologies**
- Dolostone
- Silty-sandy dolostone
- Bioelastic dolostone
- Pebby sandstone-pebble conglomerate
- Silicified sandstone
- Shale
- Paleokarst breccia
- Silty shale with mm sandstone lenses
- Carbonate

**Physical structures**
- Massive bedding
- Planar bedding
- Trough cross-bedding
- Ripple laminations
- Graded bedding
- Loading
- Vugs
- Pebble defined cross-lamination

**Biogenic structures**
- Pervasive bioturbation
- Firmground burrow
- Macroworm
- Lined channel burrow
- "Problematic" burrow
- Ancylostomus
- Tectognoma
- Shelly fragments
- Bryozoan
- Solitary rugose coral
- Tabulate coral
- Sponge spicules
- Silicified burrow

**Organic matter**
- Carbonaceous laminite
- Carbonaceous matter
- Wood imprints
- Rostlets

**Accessories**
- Anhydrite pseudomorphing selenite
- Phosphate nodules
- Chert nodules
- As
- Anhydrite
- Pyrite
- Glauconite
- Silica
- Biofilm
- Contact not present
- S Conodont sample location
- PS Productive condont sample location

**Stratigraphic units**
- Parasequences
- Highstand systems tract
- Transgressive systems tract
- Lowstand systems tract

**Stratigraphic surfaces**
- MFS Maximum flooding surface
- TSE Transgressive surface of erosion
- SB Sequence boundary
- RSE Regressive surface of erosion
- FGG Firmground