SUNBEAM sheds light on the Carboniferous-Permian stratigraphy, sedimentation, tectonism and volcanism of the Sverdrup Basin, Arctic Canada (Ellesmere Island, Nunavut)

Benoit Beauchamp, University of Calgary, Calgary, bbeaucha@ucalgary.ca
Daria Baranova, University of Calgary, Calgary, baranova.daria@gmail.com
Yee Ping Chau, University of Calgary, Calgary, yeeping@gmail.com
Jennifer Cuthbertson, University of Calgary, Calgary, cuthberj@ucalgary.ca
Greg Godek, Imperial, Calgary, greg.godek@esso.ca
Steve E. Grasby, Geological Survey of Canada, Steve.Grasby@NRCan-RNCan.gc.ca
Bernard Guest, University of Calgary, Calgary, bguest@ucalgary.ca
Charles M., Henderson, University of Calgary, Calgary, charles.henderson@ucalgary.ca
Maureen F. Hill, University of Calgary, Calgary, mfhill@ucalgary.ca
Pavel Kabanov, Geological Survey of Canada,Calgary,Pavel.Kabanov@NRCan-RNCan.gc.ca
Aline Labrie, University of Calgary, Calgary, alinelabrie@live.ca
Andrew Leier, University of Calgary, Calgary, aleier@ucalgary.ca
Natasha J. Morris, University of Calgary, Calgary, njmorris@ucalgary.ca
Candice V. Shultz, University of Calgary, Calgary, cvshultz@ucalgary.ca
Pierre Thériault, Statoil, Norway, pit@statoil.com
Michael, L. Wamsteeker, Imperial, Calgary, michael.l.wamsteeker@esso.ca

The Sverdrup Basin in the Canadian Arctic Archipelago is a petroleum province, with substantial proven reserves of natural gas and oil. These hydrocarbons were discovered in a variety of Mesozoic plays tested from the late 1960s through the early 1980s. Large, yet simple anticlinal structures were the primary target of this early round of exploration. In contrast, the Late Paleozoic succession, which is dominated by carbonate and chert, has yet to be targeted. While Pennsylvanian–Early Permian carbonate reefs provide obvious possibilities, more enticing structural-statigraphic plays may be possible since the basin was under-fault-controlled rift-related subsidence up until the Early-Middle Permian boundary, and that a strong tectonic control — linked to episodic global tectonics — led to the creation of third-order transgressive-regressive (T-R) sequences. To address this later aspect, a series of sections, encompassing nine Pennsylvanian-earliest Triassic T-R sequences, were measured across a 125 km east-west transect north of Greely Fiord, NW Ellesmere Island, from the Blue Mountains to the west to McKinley Bay to the east. Additional sections measured north and south of the transect by the first author and collaborators in the past 20 years complete the stratigraphic database. This stratigraphic work was complemented by a 45 km structural north-south transect, from Mount Leith to the northern coast of Hare Fiord to assess the extent of Tertiary deformation and tectonic displacement across a series of Eurekan (Paleogene) faults.

Serpukhovian Sequence

The Serpukhovian Sequence (late Early Carboniferous) lies with profound angular unconformity on the deformed Cambrian Grant Land Formation in a series of Eurekan thrust sheets north of Hare Fiord. These outcrops form an east-west oriented, south-thickening and -fining wedge (from zero to nearly

400 m thick) of locally-derived syn-tectonic red-weathering conglomerates and sandstones representing fluvial and alluvial fan sedimentation (Borup Fiord Formation), along the updip ramp-side of an assumed half graben. The presumed master listric fault of this system is concealed beneath in the subsurface along Hare Fiord or farther south. The lower half of the non-marine clastic succession is retrogradational while the upper half is gradational. These beds are truncated by a major regional, and locally incised, unconformity.

Bashkirian–Kasimovian Sequence

The Bashkirian-Early Moscovian TST comprises open to restricted marine carbonates that pass upward into increasingly restricted dolomitic carbonates and eventually deep subaqueous evaporites (Otto Fiord Formation). These deposits, exposed north of Hare Fiord and in the westernmost part of the studied transect in the Blue Mountains, accumulated in various tectonic depressions, which were at times partially to completely cut off from open marine sedimentation. This was the result of differential, presumably fault-controlled, subsidence and local uplift and half-graben rotation, as observed on seismic profiles in the western Arctic (Harrison, 1995; Beauchamp et al., 2001). A low angle normal fault locally cutting across the Borup Fiord-Otto Fiord contact north of Hare Fiord is likely contemporaneous with this phase of rifting. The maximum flooding surface (MFS) around the Early-Late Moscovian boundary is a major collapse event, associated with termination of orthogonal rifting in the Sverdrup Basin — extension at 90^o to basin axis and basement structures — that generated rapid accommodation space and a full reconnection of the Sverdrup Basin with the open ocean, thus marking the end of evaporite sedimentation. A thick (up to 600 m) aggradational platforms and isolated offshore reefal structures (Hvitland Peninsula formation, Tellevak member) grew rapidly in response to the base level rise, only to be drowned later. A long regime of passive subsidence encompassing the Late Moscovian to Kasimovian interval followed and led to the widespread progradation of a thick (up to 1.5 km) reef-rimmed, warm-tropical carbonate platform (lower Nansen Formation) and adjacent foreslope deposits (lower Hare Fiord Formation). A significant base level fall led to erosion and subaerial exposure of the platform top around the Kasimovian-Gzhelian boundary, resulting in a major sequence boundary.

Gzhelian-Asselian Sequence

Renewed base level rise during the latest Carboniferous (Gzhelian) led to the rapid flooding of the previously exposed depositional areas. This was accompanied by renewed tectonism across the Sverdrup Basin, in response to extensional and compressional tectonic stresses at an angle relative to the previous rift-related extension. This resulted in complex mosaic of fault-controlled highs and lows, as observed in the western arctic and on seismic profiles. In the study area, this led to the creation of an east-west oriented sub-basin, bounded to the south by a stratigraphic, and presumably structural, high (Emerson High) on top of which significant thinning and pinching out of contemporaneous strata is recorded. Sedimentation within the sub-basin includes up to 300 m of laminated dolostone and varve-like evaporites (Mount Bayley Formation) indicative of relatively deep-water, restricted marine sedimentation. These strata pass westward into a thick accumulation of bioclastic grainstone at Borup Fiord Pass and then open marine carbonates in the upper part of the Nansen Formation as recorded at Oobloyah Bay. The grainstone belt provided an efficient circulation barrier between the main Sverdrup Basin to the west and the restricted evaporite sub-basin to the east. The MFS around the Gzhelian-Asselian boundary was, as before, associated with the rapid reconnection of the area with the open ocean, cessation of evaporite sedimentation, and rapid accommodation rise recorded in a series of biogenic mounds both south (Tolkien Reefs) and north (Simpson Reefs) of Emerson High. This was followed by widespread progradation (RST) of mostly open marine carbonates, reefal shelf-edge (upper Nansen) and foreslope carbonates (upper Hare Fiord) westward. Regional base level drop led to erosion and to a sequence-bounding unconformity around the Asselian-Sakmarian boundary.

Sakmarian-Artinksian Sequence

Renewed flooding of the shelf during the Sakmarian was accompanied by reactivation of the sub-basin north of Elmerson High. This led to the thick (250 m) accumulation of deepening-upward succession of laminated dolostone, minor evaporite and mixed clastic-carbonate deposits, recording renewed restricted marine sedimentation (Raanes Formation). An efficient circulation barrier was provided by a grainstone belt, centered as before around Borup Fiord Pass. Heterozoan (cool-water) grainstone and packstone accumulated to the west of the barrier. The MFS around the Sakmarian-Artinskian boundary was accompanied once again by full reconnection of the sub-basin with the main Sverdrup Basin. This event was also accompanied by an interval of submarine volcanism centered just west of Oobloyah Bay. Pillow basalts interfingering with pyroclastic and volcanoclastic deposits attest to a complex magmatic and extrusive history. Transported and resedimented pumices associated with explosive events have been found in contemporaneous slope deposits at Ricker Glacier to the west in contemporaneous strata (uppermost Hare Fiord Formation). These events were followed by widespread progradation of nearshore sandstone and cool-water shelf carbonate and over large distances (Great Bear Cape Formation). These sediments pass westward into sigmoidal slope clinoforms of the distal Trappers Cove Formation. An oceanographic shift associated with the closure of the Uralian seaway is believed responsible for the Sakmarian-Artinskian cooling along NW Pangea. A major sequence-bounding subaerial unconformity truncates Great Bear Cape strata.

Kungurian Sequence

Rapid flooding of the shelf in latest Artinskian time is recorded in a thin retrogradational red-weathering non-marine to marine sandstones contemporanous to rapid accommodation rise (TST) in the eastern part of the study area. In the western area (Borup Fiord Pass to Ricker Glacier), this interval is in part contemporaneous to a thick (up to 300 m) succession of non-marine volcanic flows (Esayoo volcanics) interstratified with red-weathering, possibly fluvial overbank strata and paleosols, suggesting renewed tectonism in the area, and creation of highs and lows, presumably in response to fault-controlled differential subsidence. The volcanics end abruptly in relatively deep-water black shale, indicating they accumulated in part during the widespread collapse of the shelf and development of the MFS. This was followed by widespread progradation of fluvial, nearshore and shallow marine sandstones (Sabine Bay Formation) that filled the space thus created. Progradation of this sandstone was in part contemporaneous and ultimately followed by one of the most significant base level drop in the history of the Sverdrup Basin, which led to much erosion on the underlying succession and development of incised valleys. The unconformity reached far offshore beyond Ricker Glacier to the west, beyond which shelf clastic pass basinward into deep-water slope to basinal mudrocks (upper Trappers Cove Formation). This unconformity marks the onset of regional passive subsidence across the Sverdrup Basin.

Roadian-Wordian Sequence

Major flooding and collapse of the shelf led to the rapid flooding of the shelf and establishment of open marine sandstone deposition (Assistance Formation). Following the MFS at the Roadian-Wordian boundary, cool-water heterozoan carbonates (Degerböls Formation) prograded as far west as Borup Fiord Pass, but gave way to clastic sedimentation later during the Wordian, a unique feature of this area. A widespread unconformity marks the top of the Wordian sequence.

Capitanian Sequence

The shelf was flooded once again, and the clastic system retrograded eastward substantially during the latest Wordian. When Capitanian progradation resumed following the MFS, the shallow shelf was now completely dominated by siliceous sponge spicules in a clastic-starved environment. The eradication of carbonates has been recently linked to intensification of ocean acidification along the western margin of

Pangea during the Late Permian (Beauchamp and Grasby, 2012). A widespread unconformity truncates the top of that chert.

Wuchiapingian Sequence

Significant flooding resumed cross the Middle–Late Permian boundary which was followed, once again, by progradation of shallow-water biogenic chert (Lindström formation) over large area to the west. These pass laterally into significantly deeper-water dark chert and mudrock (Black Stripe Formation). The top of this succession is truncated by a major sub-Triassic unconformity accompanied by the largest mass extinction in Earth history and a major shift to clastic sedimentation in the Sverdrup Basin.

Conclusions

Eight third-order sequences in the tectonically-active Late Paleozoic history of the Sverdrup Basin recorded a similar recurring pattern that can only be explained through episodic base level shifts associated with tectonic movements. Each sequence started with a regional uplift that led to widespread erosion and created the sequence boundary. Up until the Early-Middle Permian boundary, the TST was contemporaneous with rift-related fault-controlled differential subsidence and uplift. Development of the MFS was invariably associated with rapid collapse of the crust, rapid creation of accommodation space, cessation of fault activity, onset of passive subsidence conditions, and locally, rapid extrusion of volcanic material. The RST always recorded the widespread progradation of shelf carbonate (warm and cool), marine clastic or biogenic chert at a time of passive subsidence.

SUNBEAM Program

To help improve our understanding of the energy potential of the Sverdrup basin, as well as to train a whole new generation of young geoscientists in the many scientific and logistical aspects of doing research in the High Arctic, Natural resource Canada (NRCan) has been supporting university research and education through the SUNBEAM program. For the first four year of its existence, SUNBEAM (Studies to Unlock Northern Basin Energy along Arctic Margins) has focused on the Sverdrup Basin, taking advantage of a major GSC-led field operation on Ellef Ringnes Island in 2010 and 2011, and two additional field operations on Ellesmere Island (2010 and 2011). This first round (2009-2013) of the SUNBEAM Program , was funded jointly by NRCan (through its GEM program), NSERC and Total, also benefited from additional generous support from the Polar Continental Shelf Program and the Geological Survey of Canada. This program allowed 17 students (2 post-doctoral fellows, 1 Ph.D., 12 M.Sc., 2 B.Sc.) to work on as many research projects, all but two of which were based on field work in the High Arctic. SUNBEAM also invoked 11 from the GSC researchers, 5 scientists from Total and six university professors, four of whom had never set foot in the Arctic but who are now fully engaged in research program in Canada's north. This presentation is a summary of the geological findings, some of them major breakthrough in our understanding of the Sverdrup basin geology, of the SUNBEAM team of students and professors who were involved in 11 people-operation on NW Ellesmere Island in the summer of 2011.

References

Beauchamp, B., Harrison, J.C., Utting, J., Brent, T.A., Pinard, S., 2001. Carboniferous and Permian subsurface stratigraphy, Prince Patrick Island, Northwest Territories, Canadian Arctic. Geological Survey of Canada Bulletin 565, 93 pp.

Harrison, J.C. 1995. Melville Island's salt-based fold belt, Arctic Canada. Geological Survey of Canada, Bulletin 472, 331 p.