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Multidisciplinary evaluation of the carbonate-hosted Mississippi Valley–type Pb-Zn potential of northern Alberta[1]

Randy J. Rice

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Abstract: A multidisciplinary study of Middle and Upper Devonian carbonate sequences in northern Alberta (north of latitude 56°30′N) suggests two areas with increased potential for Mississippi Valley–type lead-zinc deposits. The first is Vermilion Chutes on the Peace River. Encouraging data for this region include 1) a Precambrian basement high; 2) the porous, bitumen-stained, and vuggy character (late calcite and dolomite cements) of the Upper Devonian upper Mikkwa and overlying Grosmont formations; and 3) a possible basement-derived structural trend in the Devonian cover that might provide access for deep-sourced metalliferous fluids. The second area is along the Clearwater River near Whitemud Falls, east of Fort McMurray, where the Middle Devonian Methy Formation is exposed. Encouraging data here include 1) two structural highs in the Keg River Formation (Methy Formation equivalent); 2) the presence of minor amounts of saddle dolomite cement; and 3) the locally oxide-altered and faulted character of the Methy outcrop.

Résumé : Une étude multidisciplinaire des séquences carbonatées du Dévonien moyen et supérieur dans le nord de l'Alberta (au nord de 56°30′N) laisse supposer qu'il existe deux zones où est accrue la possibilité de trouver des gîtes de plomb-zinc de type Mississippi-Valley. Les chutes Vermilion, le long de la rivière de la Paix, constituent l'une de ces zones. Parmi les données encourageantes pour cette zone, mentionnons 1) une hauteur du socle précambrien; 2) le caractère poreux, imprégné (bitume) et vacuolaire (ciments de dolomite et de calcite tardifs) de la partie supérieure de la Formation de Mikkwa et de la Formation de Grosmont sus-jacente du Dévonien supérieur; et 3) un linéament tectonique dans la succession de couverture du Dévonien dont la source est probablement située dans le socle et qui pourrait avoir permis l'accès à des fluides métallifères d'origine profonde. Une deuxième zone se situe le long de la rivière Clearwater, près des chutes Whitemud, à l'est de Fort McMurray, où affleure la Formation de Methy du Dévonien moyen. Parmi les données encourageantes pour cette zone, mentionnons 1) deux hauteurs d'origine tectonique dans la Formation de Keg River (qui est équivalente à la Formation de Methy); 2) la présence de très faibles quantités de ciment de dolomite à faces composites incurvées; et 3) le caractère fracturé et oxydé par endroits des roches affleurantes de la Formation de Methy.

[1] Contribution to the Targeted Geoscience Initiative (TGI) 2000–2003.

INTRODUCTION

The carbonate-hosted, Mississippi Valley–type (MVT) lead-zinc project conducted in 2001 by the Alberta Geological Survey (AGS) is part of a two-year study (April 2001–March 2003) being carried out co-operatively with the Geological Survey of Canada in Calgary and the C.S. Lord Northern Geoscience Centre in Yellowknife. The purpose of the multi-institutional project is to bring to the attention of the mineral industry the relatively poorly explored, carbonate-hosted, MVT lead-zinc potential of northern Alberta and the southern Northwest Territories.

Year 1 (2001–2002) of the AGS study involved a multi-disciplinary field program of 5 weeks duration that examined carbonate rock exposures in northern Alberta. This report summarizes the results from that fieldwork and the associated office work. Individual reports by other members of the Alberta Geological Survey MVT team are also available; these separate reports expand upon the structural, sedimentological, and hydrogeological data. Year 2 (2002–2003) of the project focuses mainly on the examination of selected core available from conventional petroleum, oil-sands, and mineral exploration in northern Alberta. The results from year 2 currently are incomplete, and will be reported on at a later date.

STUDY AREAS IN NORTHERN ALBERTA

The MVT lead-zinc study region in northern Alberta extends from latitude 56°30′N (Fort McMurray) northward to the boundary with the Northwest Territories (Fig. 1). This region is large and offers a large amount of petroleum-exploration data, so a subdivision into smaller areas was necessary. The purpose of this work was to isolate regions in northern Alberta with greater potential for *mineable* carbonate-hosted MVT lead-zinc deposits; therefore, a primary consideration was depth to carbonate bedrock. With this important restriction, the areas of northern Alberta in which a focused study could be justified were limited. Certainly the most prospective region of northern Alberta lies within the boundaries of Wood Buffalo National Park. Carbonate bedrock is at or close to the surface throughout this region and there are old reports of galena samples coming from this area (e.g. Godfrey, 1985). All exploration work is prohibited, however, since it is a national park. Exposure of Devonian carbonate bedrock in northern Alberta, outside of Wood Buffalo National Park, is mainly restricted to the drainage system of the Fort McMurray region (Clearwater and Athabasca rivers and their tributaries), to the Vermilion Chutes exposures on the Peace River, and to exposures along Harper Creek south of the Peace River. As a result, two study areas have been defined in northern Alberta that incorporate these three regions.

The Vermilion Chutes study area includes townships 97 to 115 and ranges 13W4 to 12W5 (Fig. 1), and centres on the Upper Devonian (Grosmont and Mikkwa formations, Woodbend Group) carbonate exposures at Vermilion Chutes. The 2001 fieldwork in this region examined the exposures at Vermilion Chutes, as well as those in the lower kilometre or so of the nearby Mikkwa River and on Harper Creek. During the 2002 core-study program, the Vermilion Chutes area was expanded to incorporate the southern flank of the Cariboo Mountains and the northern flank of the Birch Mountains, so that it essentially covered the trough of low-lying ground between these two topographic highs. The northern flank of the Birch Mountains was included because it lies roughly on-strike with the southwest extension of the axis of Lake Athabasca, which could represent a regional structural lineament (*see also* Godfrey, 1985; Pana et al., 2001). The extension of the core-study area to the southern flank of the Cariboo Mountains was considered prudent because the Vermilion Chutes are located near the axis of a Devonian structural trough known as the Hotchkiss Embayment, which lies on-strike with the southwest projection of shear zones mapped on the Precambrian Shield of northeastern Alberta.

The Fort McMurray study area covers townships 87 to 109 and ranges 1W4 to 13W4 (Fig. 1), and focuses on Middle Devonian (including Waterways and Methy formations, and Beaverhill Lake and Elk Point groups) carbonate exposures along the main rivers (Athabasca and Clearwater) that were examined during the 2001 field program. With respect to the 2002 core program, the Fort McMurray area was expanded to include cored wells drilled for conventional oil, oil-sands, and mineral exploration, both west and east of the Athabasca River (Fig. 1).

PREVIOUS INVESTIGATIONS

The potential for carbonate-hosted lead-zinc deposits in northern Alberta has been previously addressed four times through provincial or joint federal-provincial work. For example, Godfrey (1985) conducted a province-wide lead and zinc commodity appraisal for Alberta Energy and Natural Resources in which all previous occurrences, workings, and small mines were tabulated, including the Oldman River lead-zinc occurrence (Holter, 1977) in southwestern Alberta. Subsequently, Dubord (1987) did a literature appraisal of the potential for MVT deposits within Alberta. Although he did not log or sample core, he did provide a list of 18 wells with zones of lead-zinc mineralization. Olson et al. (1994) included a review of the MVT lead-zinc potential in a regional evaluation of the metallogenic potential of Alberta.

Turner and McPhee (1994), in a study funded under the Canada-Alberta Mineral Development Agreement (1992–1995), did considerable core logging and sample analysis (trace elements). The only significant result from their trace-element work was 3.1% Zn with 0.05% Pb over 20.7 m (including 5.1% Zn with 0.03% Pb over 10.8 m, and 6.9% Zn with 0.05% Pb over 2.6 m) from faulted, dolomitized Keg River Formation at approximately 1300 m depth in petroleum-exploration well 16-34-118-21W5, located in the vicinity of the Great Slave Lake Shear Zone in northwestern Alberta. The maximum Zn value for this interval is unknown (no repeat analysis), but exceeded 9.99%. The zinc-mineralized zone associated with the maximum zinc content occurred in an interval of intense fracturing, up to 1 m thick, that exhibited very little host rock alteration, minor sparry dolomite, and up to 20% finely crystalline pyrite and

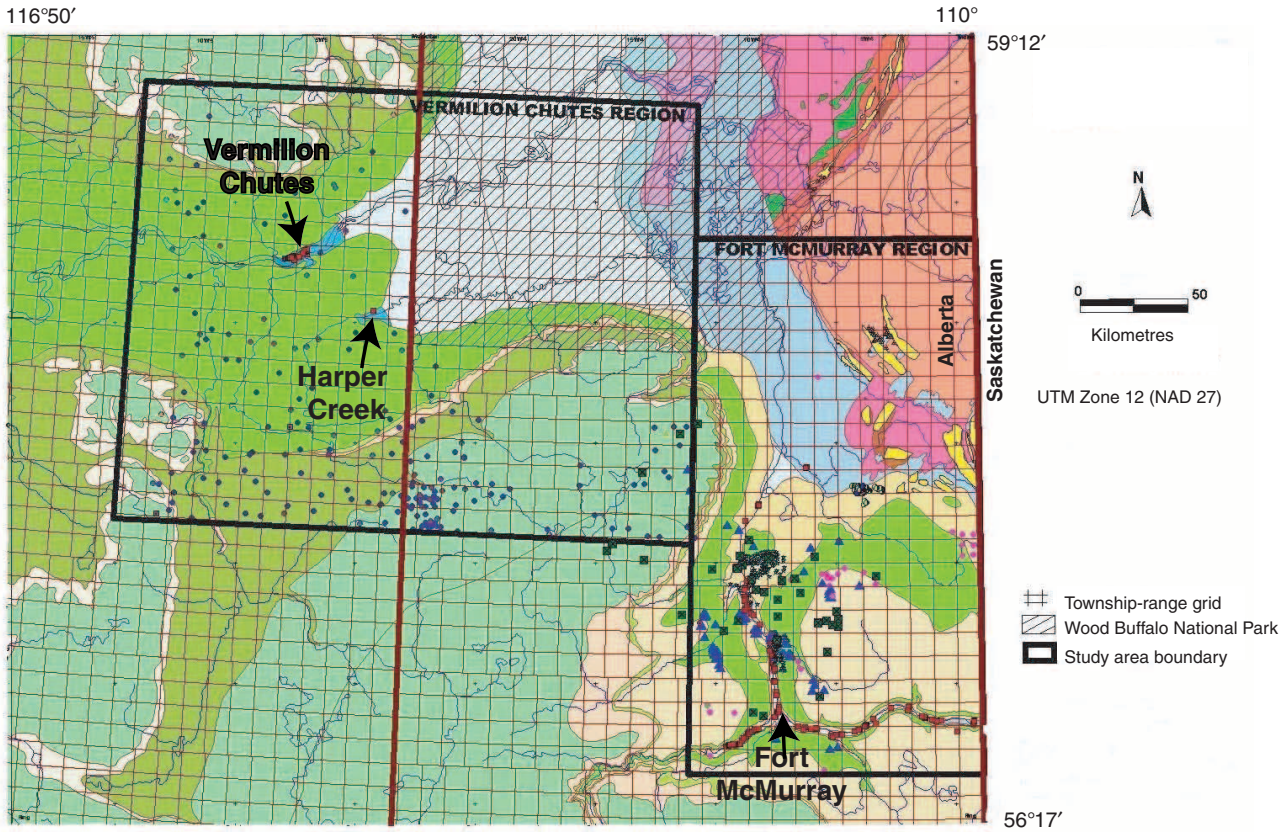

Figure 1. *Geology of northern Alberta, showing the two study areas selected for the carbonate-hosted Pb-Zn (MVT) project. Symbols indicate field stations from 2001 fieldwork (red squares) and wells available for 2002 core study (other symbols).*

sphalerite as fracture fillings. In contrast, the style of mineralization associated with lower contents, such as 3.76% Zn, consisted of a dusting of the core with up to 10% disseminated fine sphalerite.

Thus, there is no question that zones of lead and zinc mineralization occur in places in carbonate rocks in the subsurface of northern Alberta. As well, sphalerite has been known in wells from petroleum fields in west-central (Grande Prairie region) and central (Leduc region; *see* Haites, 1960) Alberta, but occurs at too great a depth (1500–1600 m) to be considered economic. It remains to be demonstrated, however, that these lead-zinc zones are, in fact, Mississippi Valley–type (MVT) mineralization. Perhaps most intriguing of all are the reports, mentioned in Godfrey (1985), of hand specimens containing galena from within what is now Wood Buffalo National Park.

YEAR 1 (2001–2002) RESULTS

Satellite imagery

Multibeam RADARSAT-1 satellite imagery was acquired for northern Alberta, for identification of structural features associated with lineaments and faults, and the karst features that are indicators of near-surface Paleozoic bedrock (Grunsky, in press).

Field data compilation

Field data from 2001 were compiled in an Access database (entitled 'Bedrock') and a GIS summary of these data was produced (Waters and Rice, in press).

Subsurface fluid-flow systems

An evaluation of subsurface fluid-flow systems in northern Alberta, as potentially relating to prior MVT mineralizing processes (Adams and Eccles, in press) revealed the following:

Hydraulic heterogeneities

Hydraulic heterogeneities (Adams and Eccles, in press, Fig. 3a), associated with the distribution of Paleozoic aquifers in northern Alberta, could have resulted in a complex flow system at a regional scale. That is, fluids could have been funnelled to the north along the Grosmont and Wabamun Formation aquifers, whereas the Sulphur Point and underlying Pine Point aquifers, as well as the Gilwood Formation, would have preferentially focused water in a northeast-southwest direction (Adams and Eccles, in press). They also suggested (Adams and Eccles, in press, Fig. 2) that the Sulphur Point–Pine Point–Keg River (Methy equivalent)–Winnipegosis aquifer system of northern Alberta is the same system that mineralized the Pine Point deposits in the Northwest Territories.

Digital elevation maps

Digital elevation maps (Adams and Eccles, in press, Fig. 3b) of selected hydrostratigraphic units in northern Alberta indicate 1) a high in the Precambrian basement near Vermilion Chutes, where previous industry exploration (Gulf Minerals, 1975) had returned 0.1% Zn from the Upper Devonian Grosmont Formation; and 2) several highs in the Middle Devonian Keg River Formation in the southern Fort McMurray study area. The 2001 field investigation of the Methy Formation (Keg River equivalent) at and near Whitemud Falls on the Clearwater River, where Carrigy (1959) reported a minor galena occurrence in the Methy Formation associated with organic matter, showed that this area is extensively dolomitized and has some other features favourable for MVT lead-zinc deposits (e.g. *see* data in Buschkuehle, in press; Pana, in press).

Total dissolved solids

An evaluation of total dissolved solids (TDS) of selected formation waters in northern Alberta shows that the Elk Point Group (which contains the Keg River and Methy formations) in the Fort McMurray study region has both the highest TDS values (up to 300 g/l) and Cl concentrations exceeding 150 g/l. These high salinities, if they reflect past rock-fluid chemistries, could therefore have acted to mobilize metals from rocks at 100°C (Adams and Eccles, in press, Fig. 5a).

Lithogeochemical data

An evaluation of potential metal sources in Alberta's basement rocks, using lithogeochemical data from samples provided by R. Burwash (Department of Earth and Atmospheric Sciences, University of Alberta), shows a band of high metal concentrations east of the Peace River Arch (Adams and Eccles, in press, Fig. 4). High Pb and Zn are coincident here and also in the basement region south of the Great Slave Lake Shear Zone. Generally, Zn concentration is greater than that of Pb for most of the basement samples, as is the case globally for most MVT ore districts.

Stratigraphy and sedimentology

A stratigraphic and sedimentological evaluation of Middle and Upper Devonian carbonate units in the two study areas (Buschkuehle, in press) revealed that the depositional environments of, and diagenetic features within, Middle Devonian carbonate rocks of the Beaverhill Lake Group (Waterways Formation) and Elk Point Group (Methy Formation) in the Fort McMurray study area, and of Upper Devonian carbonate rocks of the Woodbend Group (Grosmont and Mikkwa Formations) at Vermilion Chutes on the Peace River in the Vermilion Chutes study area, include the following.

Waterways Formation

The basal Firebag Member was deposited in an open marine, slightly to moderately agitated environment; no late diagenetic products were observed. The overlying Calumet

Member was deposited in a quiet fore-reef to basin environment; no late diagenetic products were observed. The overlying Christina Member was deposited in an intermittently storm agitated, marine environment below wave base; no late diagenetic products were observed. The overlying Moberly Member, the uppermost member examined, was deposited in the transition zone between the bank-reef and bank-margin–fore-reef areas in an intermittently agitated, high-energy environment; no late diagenetic products were observed.

Methy Formation

The Methy Formation at Whitemud Falls on the Clearwater River was deposited in a fore-reef to reef depositional environment on a carbonate platform, in moderately to highly agitated water. Minor amounts (approximately 1%) of saddle dolomite and calcite cement occur in vugs and fractures.

Mikkwa Formation

The Mikkwa Formation changes upward from basal, locally dolomitic limestone (mud-wackestone) to bank and reef dolostone. Well developed moldic porosity in places contains calcite and/or dolomite cements. Petroleum staining occurs locally.

Grosmont Formation

The overlying Grosmont Formation changes upward from a dolomitic coral bank to a reef to fore-reef dolostone. Calcite and saddle dolomite cements are present locally and the formation is petroleum stained.

Structural controls on mineralization

A structural evaluation of the carbonate sequences at selected areas of northern Alberta (Pana, in press) revealed the following.

An east-southeast-trending, high-angle, minor fault zone was identified in the Mikkwa Formation at one location on Harper Creek in the southern part of the Vermilion Chutes study area. Individual fault planes are locally sealed by coarse secondary calcite (Pana, in press, Fig. 16).

Northerly and west-southwesterly faulting in locally oxide altered Methy Formation dolostone occurs at Whitemud Falls on the Clearwater River (Pana, in press, Fig. 1, 8), in the same outcrops that Buschkuehle (in press) described as containing minor amounts of saddle dolomite and in which a minor galena occurrence was reported by Carrigy (1959).

A fault zone may exist on the eastern bank of the Athabasca River about 20 km north of Fort McMurray, in a large outcrop of the Moberly Member of the Waterways Formation, which is overlain by leached McMurray Formation oil sands (Pana, in press, Fig. 9).

Minor normal faults occur locally in the Waterways Formation along the Athabasca River in the Fort McMurray study area (Pana, in press, Fig. 10).

A metre-scale discontinuity with thrust-fault geometry occurs in the Moberly Member of the Waterways Formation on the eastern bank of the Athabasca River, about 5 km north of Fort McMurray (Pana, in press, Fig. 11).

Four joint sets have been identified in the Waterways Formation in the Fort McMurray study area. Structural data, mainly from the Moberly Member along the Athabasca River, indicate two orthogonal systems: a north- and east-trending system, and a northeast- and northwest-trending system (Pana, in press, Fig. 4, 5, 6).

Joint surfaces in Upper Mikkwa Formation outcrops at, and just east of, Lower Vermilion Chutes on the Peace River have structures that may indicate incremental, small, oblique-slip movements (Pana, in press, Fig. 1, 14, 15, 17). Two joint sets occur at Vermillion Chutes, and their orientation and geometry are similar to the orthogonal joint systems that occur in the Waterways Formation in the Fort McMurray area. The dominant, 050E to 070E (northeasterly-trending) set lies on-trend with the projection of the Warren-Leland Lakes Shear Zone from the Precambrian Shield in northeastern Alberta. The structural data could therefore indicate a basement influence on the Devonian cover sequence; this structural zone might have provided access for deep-sourced fluids. As mentioned above, a basement high was identified near this region by Adams and Eccles (in press), and industry exploration in 1975 returned 0.1% Zn at one locale; although not of economic interest, this value is nonetheless definitely anomalous.

Metallogeny

A metallogenic evaluation of the carbonate sequence in the Fort McMurray and Fort Vermilion study areas (Eccles and Pana, in press) revealed the following.

Analytical results from the 2001 fieldwork are typically low. For example, the average base-metal concentrations are 3.8 ppm Cu, 5.7 ppm Pb, 6.8 ppm Zn, 12.6 ppm Ni, and 2.2 ppm Co, with both Ag and Au contents below the lower limit of detection. Maximum results are 1) 24 ppm Zn from an iron-stained Moberley Member carbonate on the Athabasca River; and 2) 19 ppm Cu, 233 ppm Ni, and 482 ppm Cr from Upper Mikkwa Formation limestone at Vermilion Chutes.

The existence of iron-rich horizons and/or lenses in Devonian carbonate just below the oil sands in the Fort McMurray area indicates that joints and/or faults *possibly* acted as pathways for iron-rich fluids *ascending* through the carbonate succession and depositing their iron in proximity to the reducing influence of the oil sands. An alternative interpretation is that these ferrous zones result simply by precipitation from *descending* groundwater that became enriched in iron during its passage through the oil sands. The choice is significant with respect to the mineral potential of the region because it determines whether ascending, metalliferous hydrothermal fluids have affected the carbonate sequence.

CONCLUSIONS AND RECOMMENDATIONS

Although the results to date with respect to the MVT potential of northern Alberta are not strongly positive, certain features in the Vermillion Chutes and Fort McMurray study areas nev ertheless indicate that limited exploration follow-up may be warranted. These positive results are summarized below, and additional recommendations are contained in the individual contributions from other members of the AGS MVT team (*see* in press references from 2002 in 'References' section).

Whitemud Falls, Clearwater River

Middle Devonian Methy Formation dolostone at Whitemud Falls is locally oxide altered and faulted, and contains minor amounts of saddle dolomite in small vugs. As well, a minor galena occurrence associated with organic matter was previ ously reported at this locale. The rocks at Whitemud Falls are stratigraphically equivalent to the Keg River Formation, and two structural highs are reported in the Fort McMurray region. By comparison, in northwestern Alberta, the Keg River Formation contains up to several weight per cent zinc-lead along a structural zone (Great Slave Lake Shear Zone), albeit at a depth of about 1300 m (Turner and McPhee, 1994). Therefore, a small program of exploration, comprising a few days of systematic and rigorous prospecting and sampling, is warranted on the outcrops exposed along the river at, and just upstream of, Whitemud Falls. If results from this prospecting are positive, it could conceivably be followed up with ground geophysics in the same area.

Upper and Lower Vermilion Chutes, Peace River

Upper Devonian carbonate (Mikkwa and Grosmont forma tions) crops out for several kilometres along the north bank of the Peace River between Upper and Lower Vermilion Chutes. The best exposures occur at Lower Vermilion Chutes and slightly downriver at the confluence with the Mikkwa River. In 1975, Gulf Minerals reported that a rock sample containing 0.1% Zn was collected from the Grosmont Formation at Vermilion Chutes. Unfortunately, the exact location of the sample is uncertain because the property files could not be located. Available metadata for the property, however, show that follow-up work was recommended. There is no informa tion indicating that this work was carried out. Three visits to this location focused on sampling (with less than 10 samples collected), acquisition of sedimentological and structural data, and testing the outcrop with zinc zap. No encouraging assays were returned and the zinc zap did not reveal any sec ondary zinc minerals. Nonetheless, data that could be consid ered favourable for MVT mineralization from Lower Vermilion Chutes include petroleum staining, late calcite and dolomite cements in vugs, moderate to high porosity, and a possible influence of basement structure. These positive fea tures, despite the poor analytical results from the current work, indicate that a systematic prospecting and sampling program should be carried out between Upper Vermilion Chutes and slightly downstream of Lower Vermilion Chutes.

In conclusion, although the data from the 2001 program seem either ambiguous or not strongly positive, there are, in places in northern Alberta, features that suggest potential for the presence of an important MVT lead-zinc deposit. How-ever, if such exists, it probably occurs in carbonate rocks that overlie or are adjacent to an underlying basement structural zone, in a setting analogous to that at the Pine Point lead-zinc district. Furthermore, if an important MVT deposit is present, the deposit will likely be blind due to the ubiquitous overbur den throughout much of northeastern and northern Alberta. As a result, surface prospecting and rock sampling may not be effective exploration methods; instead, indirect methods such as geochemistry or geophysics may be required in the search for such a blind MVT deposit.

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