Estimating the thickness of drift using a 3D depth-to-bedrock GOCAD model in the Ootsa Lake porphyry Cu-Mo-Au district of west-central British Columbia

Stephen M. Rowins[1, a], Deanna R. Miller[1], and Yao Cui[1]

[1] British Columbia Geological Survey, Ministry of Energy, Mines and Petroleum Resources, Victoria, BC, V8W 9N3
[a] corresponding author: Stephen.Rowins@gov.bc.ca

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Abstract

Digital datasets were used to build a three-dimensional (3D) GOCAD model that estimates the thickness of unconsolidated Quaternary glacial and non-glacial sediments covering bedrock in the Ootsa Lake area of west-central British Columbia. The area hosts several porphyry Cu±Mo±Au deposits and the past-producing Huckleberry Cu-Mo mine. Estimates of drift thickness in the depth-to-bedrock model were based on interpolation between bedrock surfaces identified in diamond drillholes, outcrop, and surface topography derived from aerial Light Detection and Ranging survey (LiDAR) data. Where combined with geophysical data, structural (fault) data, and geochemical anomalies identified in soils from Regional Geochemical Survey (RGS) data, the depth-to-bedrock model is a useful aid in ranking exploration targets and understanding subsurface paleotopography. Most simply, geochemical anomalies in areas of shallow drift may be ranked higher than similar geochemical anomalies in areas of thicker drift because drilling is less costly and drillholes are easier to complete. However, not all areas of thick drift are necessarily low ranking targets in the present study. For example, anomalies that abruptly disappear or show decreased intensity upon crossing known post-mineralization faults and entering areas of thick drift may reflect transitions to grabens that contain deeper mineralized stratigraphy. Such geological interpretations, supported by geophysical data, may allow for a high-rank assignment to such grabens. The depth-to-bedrock map also may help identify previously undocumented faults, such as where abrupt changes in drift thickness define a strong linear feature with significant strike length. The construction of a 3D depth-to-bedrock GOCAD model on a mineral exploration property with sufficient existing digital data from drilling, mapping, and geochemical surveying is an inexpensive way to further interrogate the geology of a property and assess its exploration potential.

Keywords: Ootsa Lake, Seel deposit, Huckleberry mine, porphyry, bedrock, overburden, GOCAD modelling

1. Introduction

Approximately 64% of British Columbia is covered by unconsolidated Quaternary glacial and non-glacial sediments (commonly referred to as 'drift'), which creates significant challenges for grassroots mineral exploration (e.g., Levson, 2002). Exploration tools such as airborne geophysics and regional till surveys using indicators minerals (e.g., apatite, magnetite, epidote, tourmaline, chalcopyrite, and gold) and till geochemistry have proven effective for tracing up-ice sources of mineralization (Bustard and Ferbey, 2016, Hickin and Plouffe, 2017, Mao et al., 2017). Ultimately, however, covered exploration targets must be drilled to validate and, if warranted, advance to the next stage of development. Drilling through thick drift is expensive and technically challenging. It limits the number of grassroots exploration targets that may be evaluated and is a considerable deterrent to investment. One way to reduce the cost of drilling is to test exploration targets in areas where drift is minimal. On the other hand, some areas of deep drift may cover mineral deposits and represent excellent exploration opportunities, albeit with additional technical challenges presented by drilling through drift. In either case, knowledge of drift thickness is an important factor in the design and execution of a mineral exploration program in covered terrane.

Subsurface modelling methods to determine bedrock topography and depth of sedimentary cover have been used for years in hydrogeological and geotechnical engineering projects (Tearpock and Bischke, 2002; Andrews et al., 2010). Similarly, 'isopach mapping' has been used for decades to estimate the thickness of sedimentary strata in a wide variety of geological studies, especially petroleum exploration (e.g., Levorsen, 1967). An isopach map displays contour lines (isopachs) of equal thickness over an area. Related bedrock topography maps have been developed for northeastern British Columbia by Hickin and Kerr (2005) and Hickin et al. (2008, 2016), where the geometry and depth of paleovalleys have important implications for shallow gas exploration, drilling safety, aquifer management, and seismic processing and interpretation (Levson et al., 2006).

In contrast to the Quaternary geology and sedimentological methods employed elsewhere, we have used GOCAD 3D modelling software from Mira Geoscience to build a 3D 'depth-to-bedrock' block model for the Ootsa Lake porphyry Cu-Mo-Au property (Fig. 1). This 3D modelling approach simply uses

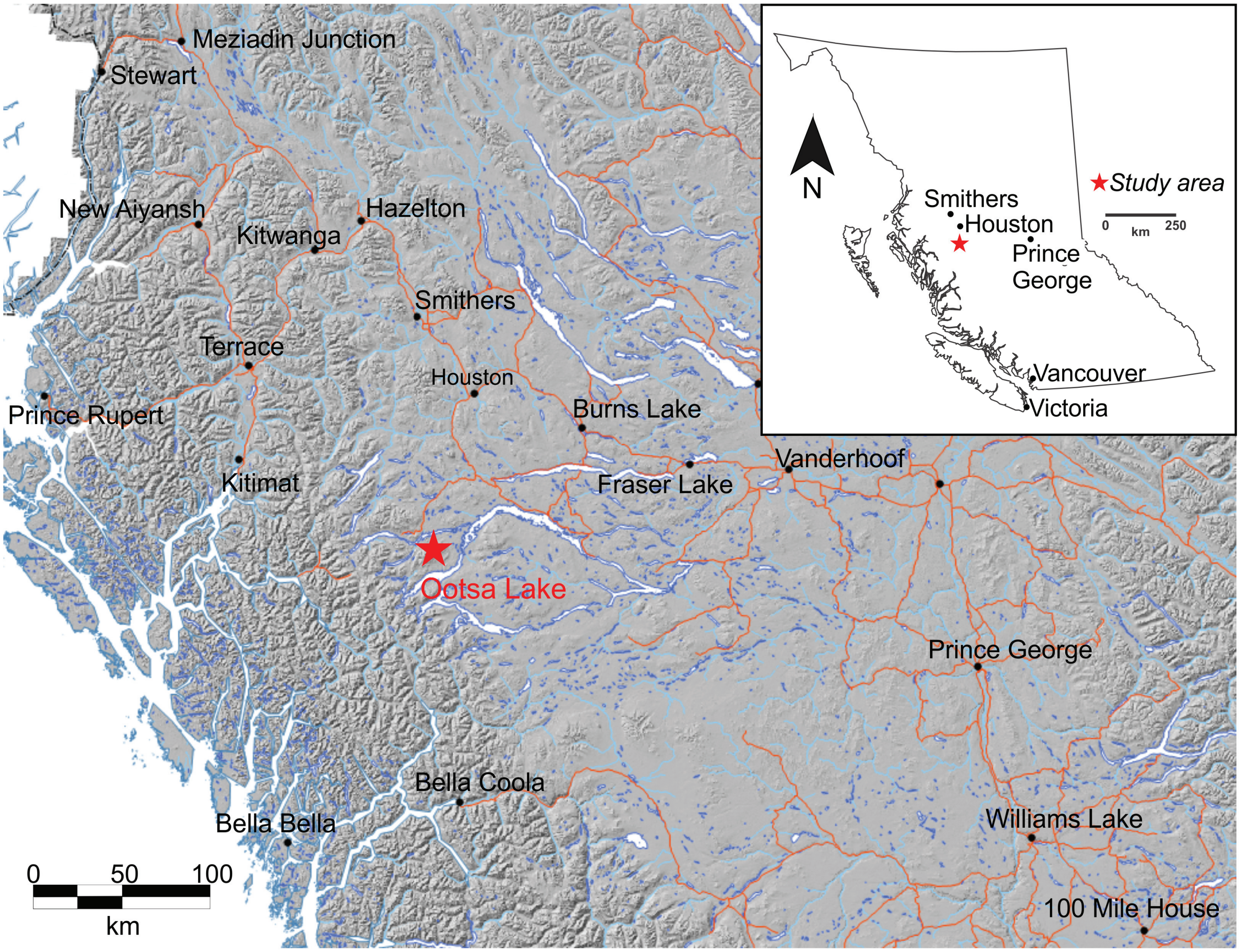

Fig. 1. Location map of the Ootsa Lake property in west-central Britsh Columbia.

available digital data from drilling (bedrock-drift contacts, chemical assays), soil geochemistry surveys, property geology (faults and lithologies), and aerial Light Detection and Ranging survey (LiDAR) data (supplied by Gold Reach Resources Ltd.) to build a block model that includes an isopach map of drift thickness plus other relevant geological features. Where combined with existing company or public geophysical and geochemical data, the depth-to-bedrock block model allows for the ranking of geochemical anomalies and the identification of new exploration targets. The Ootsa Lake area has unpredictable and variable thicknesses of drift (e.g., Ferbey and Levson, 2001a, b; Ferbey, 2010), thus, knowledge on the approximate depth of drift is an important consideration prior to drilling a target. The exercise of ranking an exploration target (e.g., geochemical anomaly), however, is more complex than simply knowing the thickness of drift in an area. Rather, the ranking of a target and identification of new targets requires careful consideration of paleotopography, structural geology, bedrock lithologies and type(s) of mineral deposit under investigation.

Our GOCAD modelling method does not replace field exploration and the collection of geological, geochemical, and geophysical data. It simply relies upon results from previous and ongoing drill programs to create a depth-to-bedrock map that may be used by mineral exploration geologists to further interpret the geology of a property.

2. Geological setting of the Ootsa Lake area

The Ootsa Lake area is in west-central British Columbia approximately 140 km south of Smithers (Fig. 1). It is within Stikinia, a Paleozoic to Mesozoic oceanic arc terrane near the western margin of the Intermontane belt (Currie and Parrish, 1997). The porphyry deposits on the property form the southern end of a northwesterly trending belt of porphyry Cu±Mo±Au deposits related to intrusive rocks of the Late Cretaceous (ca.70 to 88 Ma) Bulkley Intrusive suite. The intrusions are calc-alkaline with trace element characteristics suggestive of formation in a volcanic arc setting (MacIntyre, 1985; Petersen, 2014). Other significant porphyry deposits related to Bulkley

Suite intrusions in the region include the Huckleberry Cu-Mo mine, Whiting Creek, and Coles Creek (Carter, 1981; Friedman and Jordan, 1997; Lepitre et al., 1998).

The Ootsa property hosts the East Seel, West Seel, and Ox porphyry deposits in addition to a zone of high-grade Ag and Pb-Zn veins at Damascus. The property is road accessible and 7 km southeast of Imperial Metals' Huckleberry Cu-Mo mine (Fig. 2; Jackson and Illerbrun, 1996). The Seel deposit is hosted in Bulkley Suite intrusions and marine sedimentary rocks of the Smithers Formation, part of the Hazelton Group (Lower to Middle Jurassic; Diakow, 2006). It comprises two distinct porphyry systems. The East Seel deposit contains Cu-Au mineralization whereas the West Seel deposit contains Cu-Au-Mo-Ag mineralization. Mineralization at the East Seel deposit is hosted mainly in feldspar-phyric quartz monzonite and granodiorite porphyries whereas at the West Seel deposit, mineralization is hosted in feldspar-phyric quartz monzonite, granodiorite, quartz diorite and biotite hornfels (McDowell and Giroux, 2013; Petersen, 2014).

Extensional tectonics in the late Eocene produced basin-and-range style faults throughout Ootsa Lake area (e.g., MacIntyre, 1985). On the Ootsa property, northwest-trending horsts and grabens containing Eocene and younger strata are predominant. The Seel and Ox deposits are in the Sibola Creek graben, east of the Whiting-Huckleberry horst, which hosts the Huckleberry Cu-Mo mine and Whiting Creek deposit (Fig. 3; Diakow, 2006). Evidence of faults is found in diamond drill core from the Seel deposit. The two most significant faults identified are the North fault and the East fault, both bordering the East Seel deposit (McDowell and Giroux, 2013). The Ox and Damascus deposits are also adjacent to faults. All of these faults post-date the main episode of porphyry mineralization, but localize younger vein- and breccia-style mineralization. The faults dip steeply (McDowell and Giroux, 2013) but displacements are largely unconstrained. Porphyry-related alteration and mineralization do occur, however, on both sides of most structures.

Fig. 2. Photograph (view to the northwest) of the Ootsa Lake property (September 2017) showing low topographic relief and forest road infrastructure. The Seel exploration camp is in the bottom left corner of the photo and the Huckleberry Cu-Mo mine is in the upper left corner.

The Seel deposit is beneath a gently sloped and forested area that is covered with extensive drift (Fig. 2). Detailed stratigraphic and sedimentological studies on the adjacent Huckleberry mine property indicates drift thickness ranges from a few m up to 27 m (Ferbey and Levson, 2001a, b). Development drilling undertaken on the fringes of the Huckleberry mine, within the proposed pit expansion area, identified even greater drift thicknesses indicating significant local variability (Imperial Metals, 2014). Quaternary geology studies in the Babine porphyry copper district to the north also revealed drift thicknesses up to 40 m (Levson, 2002). Collectively, these studies indicate that significant thicknesses of drift cover this entire part of west-central British Columbia.

3. Methods

3.1. Overview

The GOCAD technology is the mineral exploration industry standard for 3D modelling and visualizing geoscience data (e.g., McGaughey, 2003). Before visualization and interpretation, these data must be interpolated ('gridded') in 3D. GOCAD offers a suite of tools for interpolating both continuous variables (e.g., Cu concentrations) and categorical variables (e.g., lithologies).

The Ootsa Lake area was chosen as the study site for several reasons. First, extensive digital data are available from Gold Reach Resources Ltd. Second, the large mineral deposits (Seel and Ox) and the Huckleberry Cu-Mo mine approximately 7 km to the west attest to the high prospectivity of the area. Third, the area is covered by extensive drift (Ferbey and Levson, 2001a, b; Ferbey, 2010).

The following workflow was used to build the 3D GOCAD model.

1. Data compilation, assessing completeness of datasets, and preparation for modelling.
2. Interpretation of datasets to optimize use (i.e., removal of elements not used from geochemistry datasets; reduction in the point density of the LiDAR dataset to enable software processing).
3. Creation of a topographic surface, fault network, top of bedrock surface, and block model.
4. Physical property creation, i.e., the confidence map and the depth-to-bedrock map.
5. Generation of 2D and 3D products for visualization.

The final block model has a 10 x 10 x 10 m cell size that represents the estimated drift thickness, and a confidence map to assess the level of reliability of a thickness estimates for any given location on the map. Together with geochemical data (e.g., Cu, Au, Ag abundances from drill core and soil geochemistry) and mapped faults projected to depth from surface, several areas on the property were identified as favourable for further exploration.

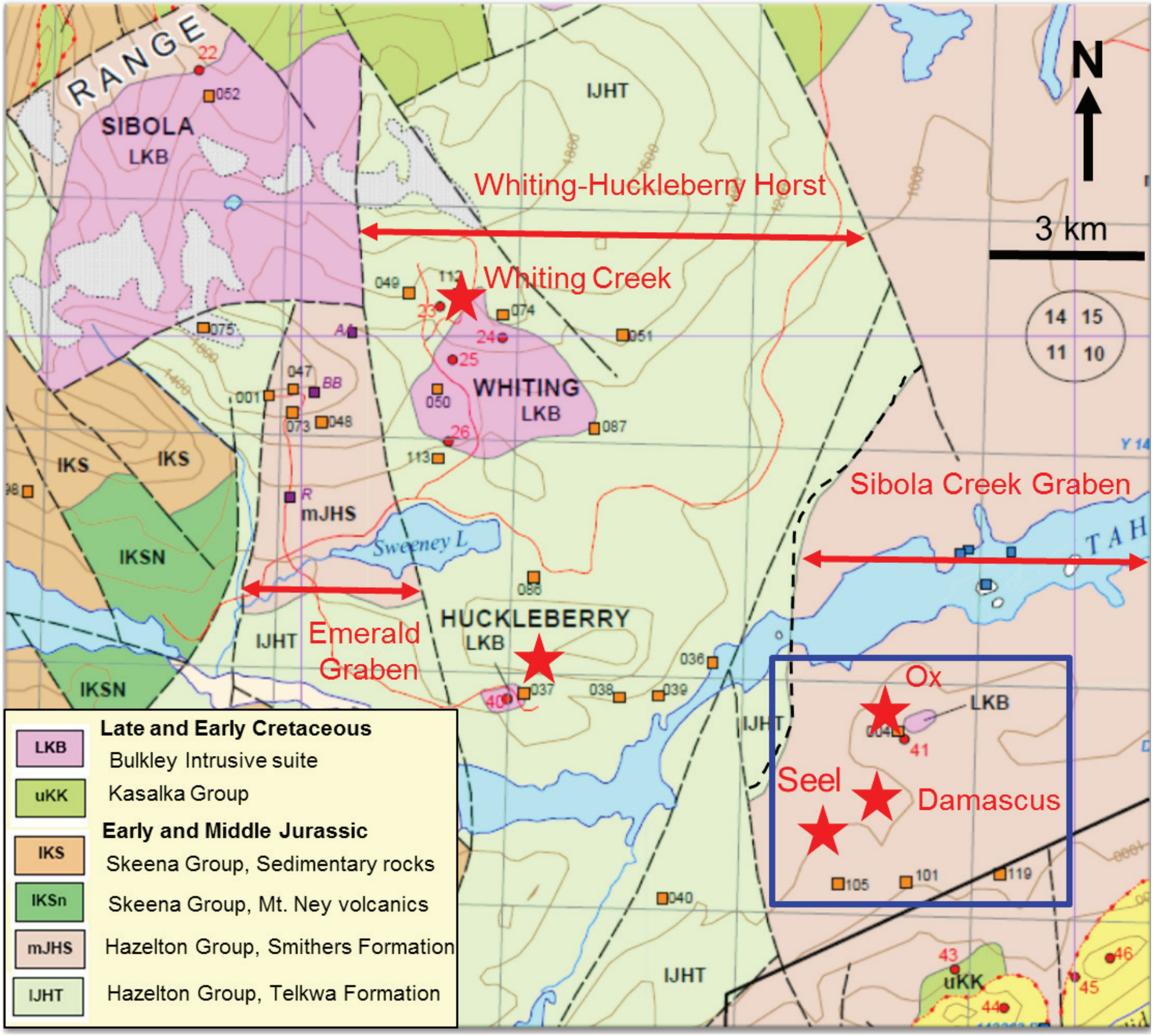

Fig. 3. Local geology of the Ootsa Lake property (modified from Diakow, 2006; McDowell and Giroux, 2013). The blue box outlines the study area and boundaries of the block model shown in Figures 4 to 10.

3.2. Data compilation, assessment and preparation for modelling

Compilation of all data into 3D modelling software required reformatting the original data into the GOCAD 3D format. Gold Reach Resources Ltd. provided all the digital datasets, which were also used for the resource estimate modelling of the Ootsa porphyry deposits as documented in a National Instrument (NI) 43-101 report by McDowell and Giroux (2013). All quality assessment and quality control (QA/QC) protocols regarding datasets are included in that report. The following datasets were provided by Gold Reach Resources Ltd and used in the modelling: 1) drillhole data; 2) property geology maps; 3) LiDAR and orthophotographs; 4) Bedrock exposure data (points and curves) and location of mineralized zones. Drillhole datasets include assay, collar, lithology, soil geochemistry (not from drilling, but added to the file as accessory data), and survey data (Table 1). Data tables were reformatted for importation into the GOCAD 3D modelling software.

Two geology maps were used to build the 3D model. The first

Table 1. Drillhole datasets provided by Gold Reach Resources Ltd.

Collar	HoleID, X, Y, Z, Length_of_hole
Deviation (Survey)	HoleID, Depth, Azimuth, Dip
Geology	HoleID, From, To, Geology_unit
Property	HoleID, From, To, Property 1, Property 2

was a simplified 1: 50,000 scale geology map of the Ootsa Lake property compiled by Gold Reach Resources Ltd. The second was a regional 1:150,000 scale map of the Ootsa Lake property, also compiled by Gold Reach Resources Ltd., that provided claim boundaries, geology and topographic data.

3.2.1. LiDAR and orthophotographs

A topographic surface was created using 131 LiDAR point sets (called a 'PointSets' in GOCAD). Initial importation of the LiDAR data into GOCAD was difficult because it was too dense for the modelling software to process and manipulate. The area surveyed by Eagle Mapping in 2012 included 103 km^2 and the density of the survey was 7 points per square metre. These data were filtered to decrease point density from 8 million points to 250,000 points to create a single digital surface model (DSM) for the entire property. Finally, a 15,000 x 98,000 pixel orthophotograph mosaic with 1 m resolution of the Ootsa Lake area was imported into GOCAD and draped over the DSM.

3.2.2. Exposed bedrock data and mineralized zones

Included in the drilling database was a spreadsheet containing 35 X, Y, Z coordinates for point locations of exposed bedrock in the project area. These points were incorporated into the 3D model. Exposed bedrock was also represented by curves through digitization of exposures identified on the mosaic orthophotograph. Included with the property geology maps were GIS data including six polygons representing mineralized zones on the Ootsa property. These mineralized zones were imported into GOCAD to aid in geological interpretation.

4. 3D model build

4.1. Creation of surfaces and networks

The first step in building the model was the creation of an area of interest (AOI), which GOCAD uses to identify the area to be modelled. The AOI in the Ootsa project was based on the spatial extent of LiDAR, orthophotograph coverage, drillholes and exposed bedrock locations. A DSM surface was subsequently created from 131 LiDAR point sets and a mosaic orthophotograph at 1 m resolution was then draped over the topographic surface and bedrock exposures were digitized (curves) from the image (Fig. 4). The bedrock surface (typically covered under drift) was generated by creating drillhole 'markers' that populated a GOCAD points set. Markers represent bedrock-drift contacts in the drillholes. This points set was used subsequently to create the bedrock surface with the AOI curve acting as the constraining boundary (Fig. 5). Drillholes used to model the bedrock surface (green) are shown as red lines in Figure 5. Finally, a simplified property geology map was draped over the DSM and surface fault traces digitized. The fault curves were used to build a 'fault network' in GOCAD to the depth of the AOI assuming a vertical dip of 90 degrees (e.g., McDowell and Giroux, 2013). The depth of the AOI varies depending upon the depth of the bedrock surface at a particular location. The faults were used to aid geological interpretation of the block model (Fig. 6).

4.2. Block model

In GOCAD, a voxet (a regular 3D grid with constant cell sizes) was used to define the extent, depth, scale, and resolution of the 3D block model. The voxet cells in our model had X, Y, and Z axes of variable length to allow for flexibility in the model and resolution. The model was constructed using the NAD83 Zone 9N coordinate system to be consistent with data from Gold Reach Resources Ltd. The block modelling process involved adding the DSM surface and the bedrock surface to the voxet, building the voxet, and assigning rock-units (just 'drift' in our model) to the resulting volume of drift (Fig. 7). Essentially, the block model is a 3D isopach map of drift thickness.

4.3. Confidence map

A confidence map was made in GOCAD by creating a new attribute on the DSM. The term 'confidence' is defined as the averaged 'misfit' between the thickness of drift estimated at a particular location in the block model, and the distance of that location to its nearest bedrock 'control points' represented by drillhole 'markers' and surface exposures of bedrock. In other words, the bedrock-drift contact in a drillhole has zero misfit (perfect confidence) with confidence decreasing in the estimate of drift thickness with increasing distance from the bedrock control points (Fig. 8).

5. Results

The 3D depth-to-bedrock GOCAD model indicates that the known mineral deposits (i.e., West Seel, East Seel, Ox, and Damascus) in the Ootsa Lake area are overlain by shallow drift with significant geochemical anomalies (Fig. 9). We have only shown Cu in Figure 9, but other elements (i.e., Au, Mo) show similar behaviour to Cu with respect to anomalies and mineral deposits. Thin drift probably contains a significant component of local bedrock, and where the bedrock is mineralized, geochemical anomalies will develop in the drift. However, no attempt has been made to determine the location of up-ice sources of geochemical anomalies that cannot be ascribed to zones of known mineralization because ice-flow directions in the Ootsa Lake area are complicated by a reversal in ice-flow during the Late Wisconsinan glacial maximum (Ferbey, 2010). Nevertheless, the occurrence of geochemical anomalies directly overlying or partially covering the 4 mineral deposits is suggestive of limited glacial transport of till in the Ootsa Lake area by the latest glacial event, although it may also reflect the interplay between displacements of mineralized till by the ice-flow reversal (Ferbey, 2010).

Figure 9 reveals that the thickness of drift commonly changes dramatically across faults. Similarly, geochemical anomalies and mineralized zones abruptly disappear or show greatly diminished intensity where a fault is crossed. This behavior is especially apparent at the East Seel deposit, which is bounded by the East fault and North fault. The opposite sides of the Damascus and Ox faults also display very large changes in estimated thicknesses of drift. These abrupt increases in drift

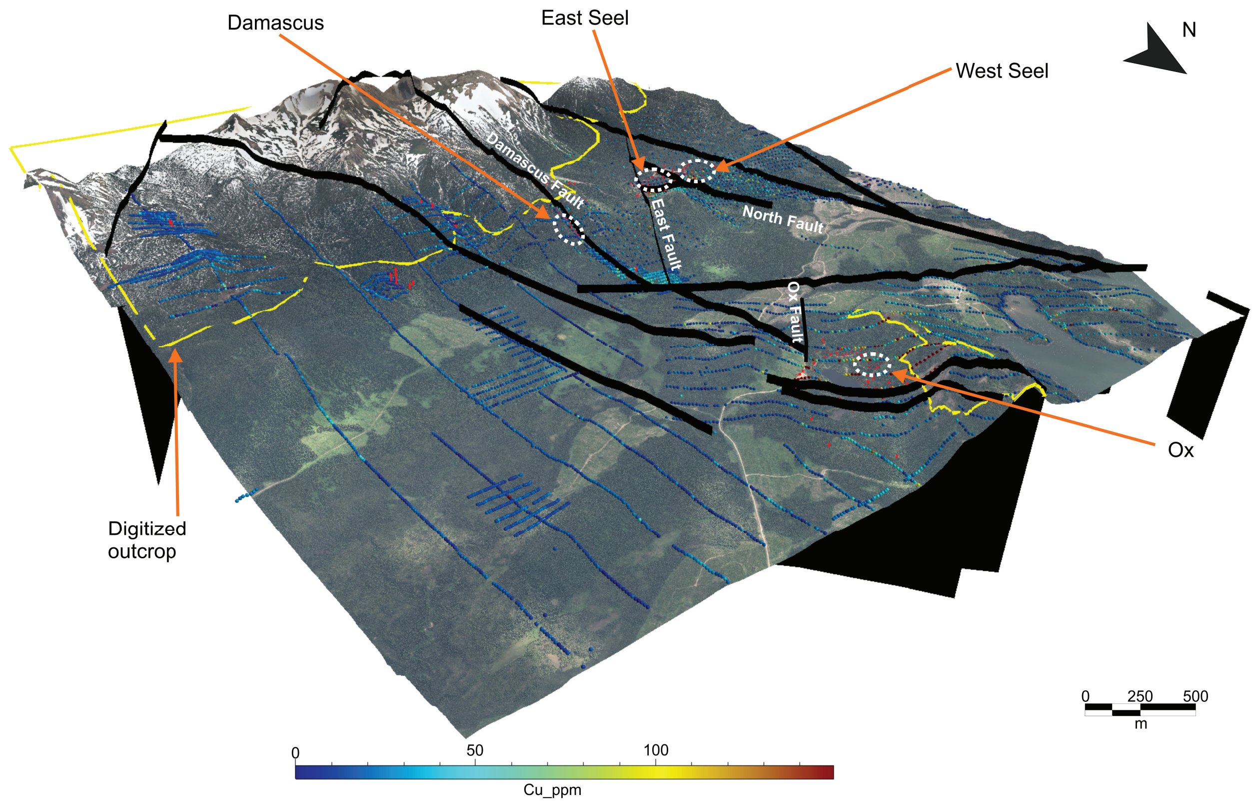

Fig. 4. Digital Surface Model (DSM) created from LiDAR data and a mosaic orthophotograph draped over the topographic surface. Also shown are mineral deposits (surface projection outlined by dotted white circles), faults (black lines), and Cu (ppm) in soils from gridded surveys (colour scale in ppm Cu at the bottom of the figure). The yellow lines enclose areas of digitized bedrock.

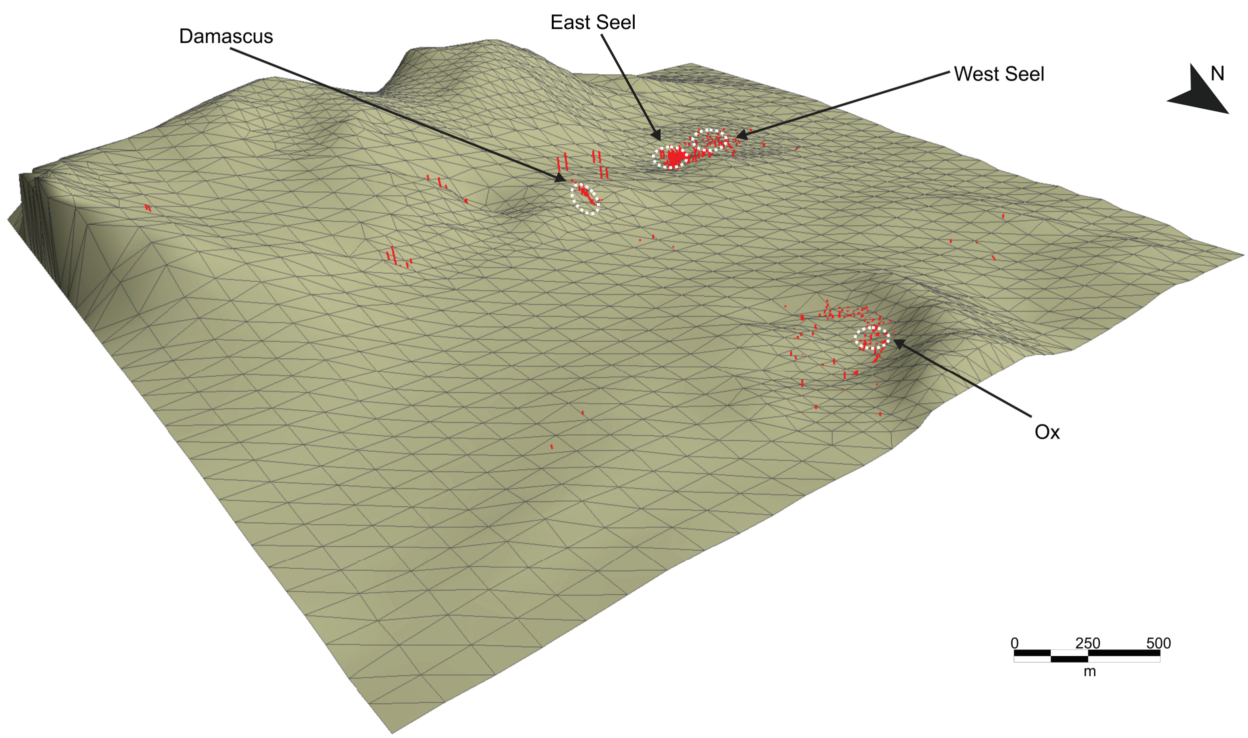

Fig. 5. Bedrock surface (green) modelled using bedrock control points, which comprise digitized bedrock exposures and bedrock-drift contacts (markers) in diamond drillholes (red lines). Also shown are mineral deposits (surface projection outlined by dotted white circles). The 3D view of the block model is the same as in Figure 4.

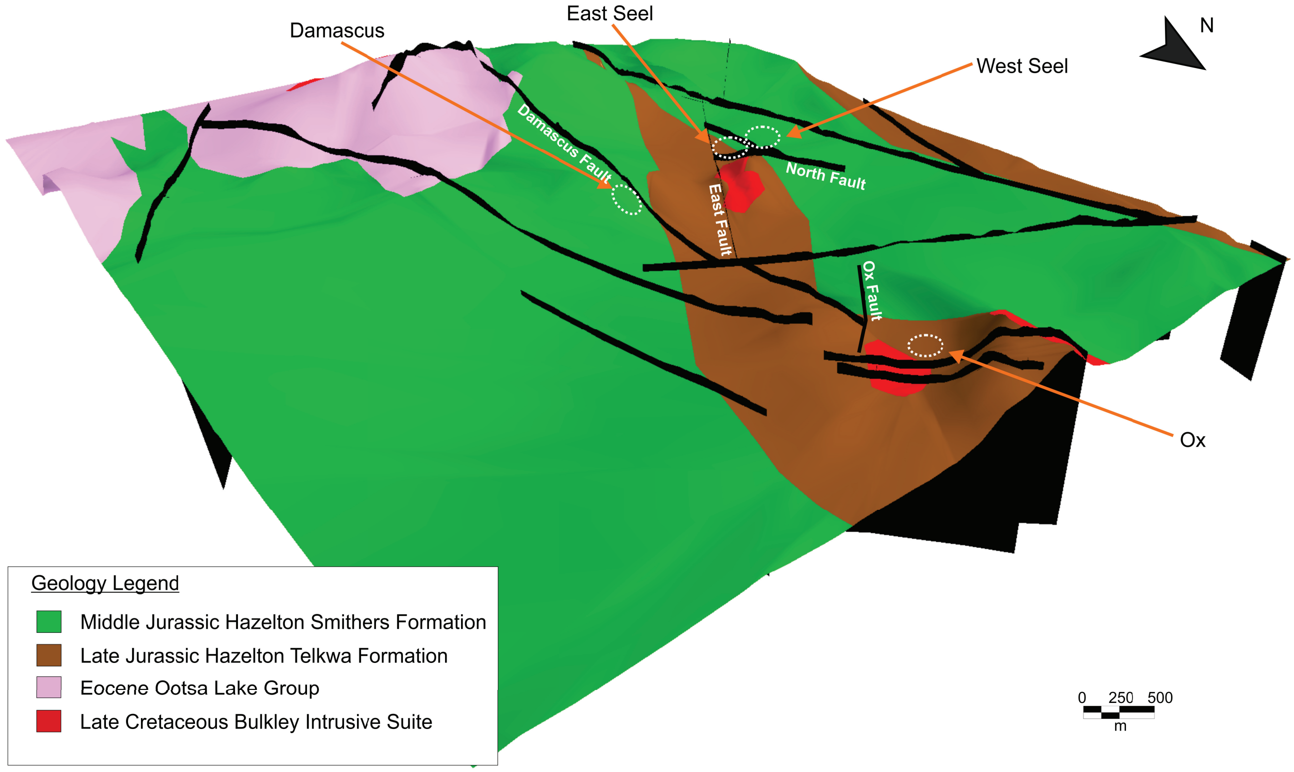

Fig. 6. Faults and local geology draped over the Digital Surface Model (DSM). Geology from the 1;150,000 scale map of Diakow (2006) modified by Gold Reach Resources Ltd. Also shown are mineral deposits (surface projection outlined by dotted white circles). The 3D view of the block model is the same as in Figure 4.

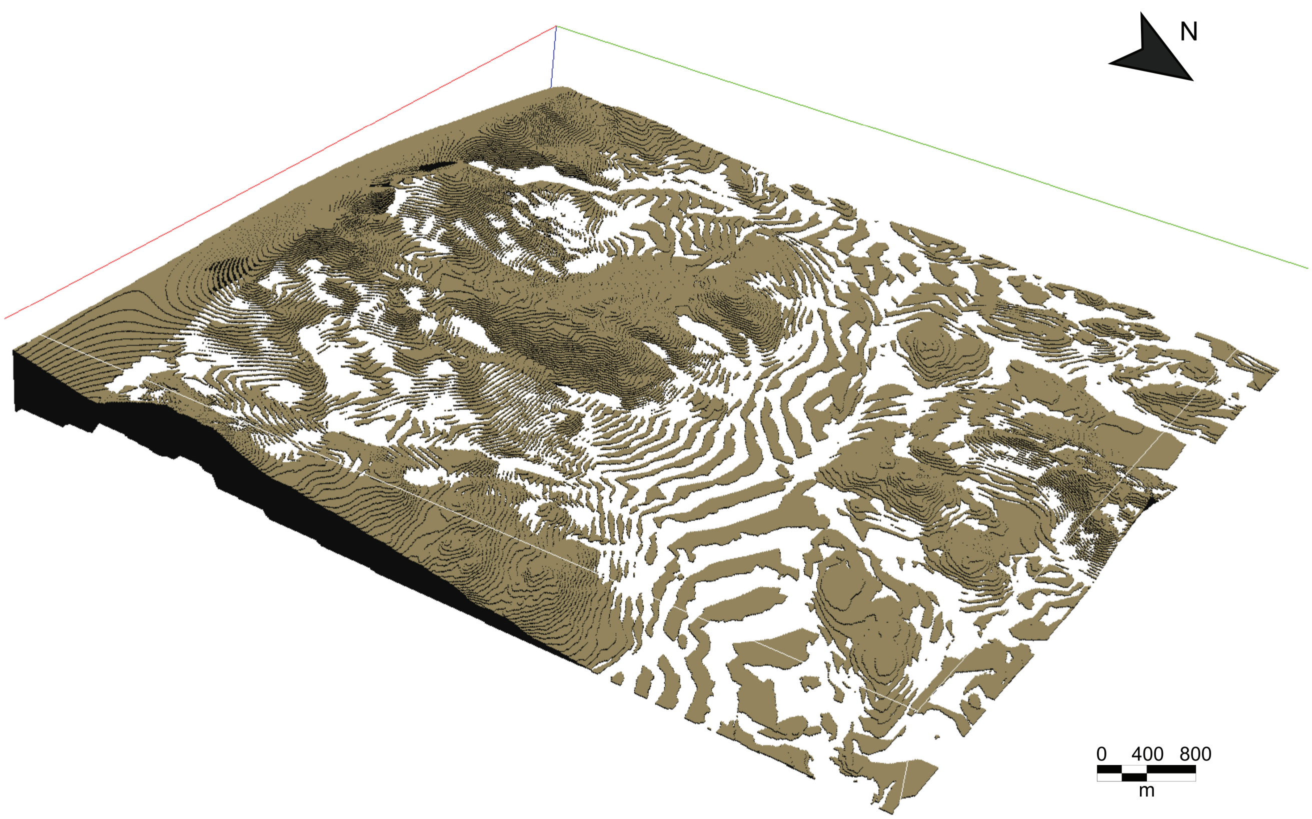

Fig. 7. Block model of drift volume (isopach map) for the Ootsa Lake property. Contour intervals are 10 m. Brown is the volume of drift. White represents areas of no drift. Top of the volume is the surface topography. Base of the volume is the bedrock surface. The 3D view of the block model is the same as in Figure 4.

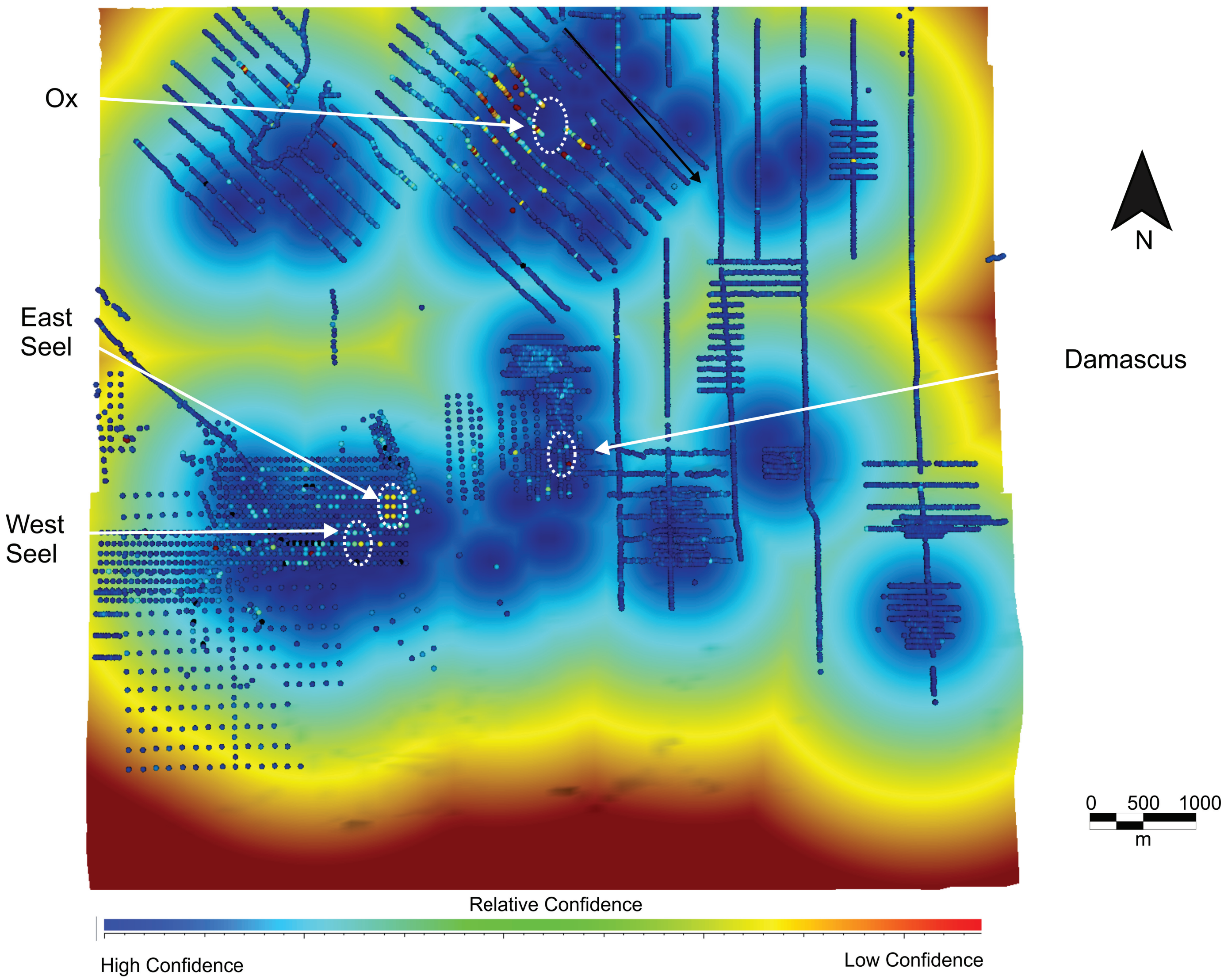

Fig. 8. Shaded confidence map based on the distance of the drift thickness estimate location from bedrock control points. Areas of relatively high confidence are represented by cold colours (blue) that grade to warmer colours (red - danger) in areas of lower confidence. Also shown are mineral deposits (surface projection outlined by dotted white circles), and Cu (ppm) in soils from gridded surveys (colour scale is the same as in Figure 4). The view of the study area is outlined in Figure 3, and is the same as the top of the GOCAD block diagrams shown in Figures 4 to 7.

thicknesses, decreases in intensity of geochemical anomalies, and disappearances of mineralized zones upon crossing a known fault suggest that thick sections of drift fill down-dropped fault blocks, which may contain mineralized stratigraphy. Such areas may be considered good exploration opportunities. The adjacent horsts with shallow drift and geochemical anomalies may indicate mineralized bedrock, potentially near the surface. These targets are easily tested by drilling and follow-up soil sampling (Fig. 9). The depth-to-bedrock map also may be used to identify previously undocumented faults where abrupt changes in drift thickness define a strong linear feature with significant strike length.

6. Limitations of the 3D GOCAD block model

This 3D depth-to-bedrock GOCAD modelling approach is not recommended for areas of rugged topography with highly variable bedrock elevations because depths of drift can be significantly overestimated. This occurs due to interpolation between topographic surfaces at high elevation and bedrock surfaces with control points at relatively low elevations. The model works best in areas with relatively flat topography such as occur on the Interior Plateaus (e.g., Nechako and Chilcotin) of British Columbia.

A confidence map (Fig. 8) and drillhole location data such as shown on Figure 5 should be used in conjunction with the 3D depth-to-bedrock GOCAD model because it assigns a degree of reliability to the modelled drift estimates. This knowledge can be used to further rank exploration targets. For example, some caution might be advised to drilling a potential exploration target located in an area of shallow drift, but having very poor confidence in the thickness estimate.

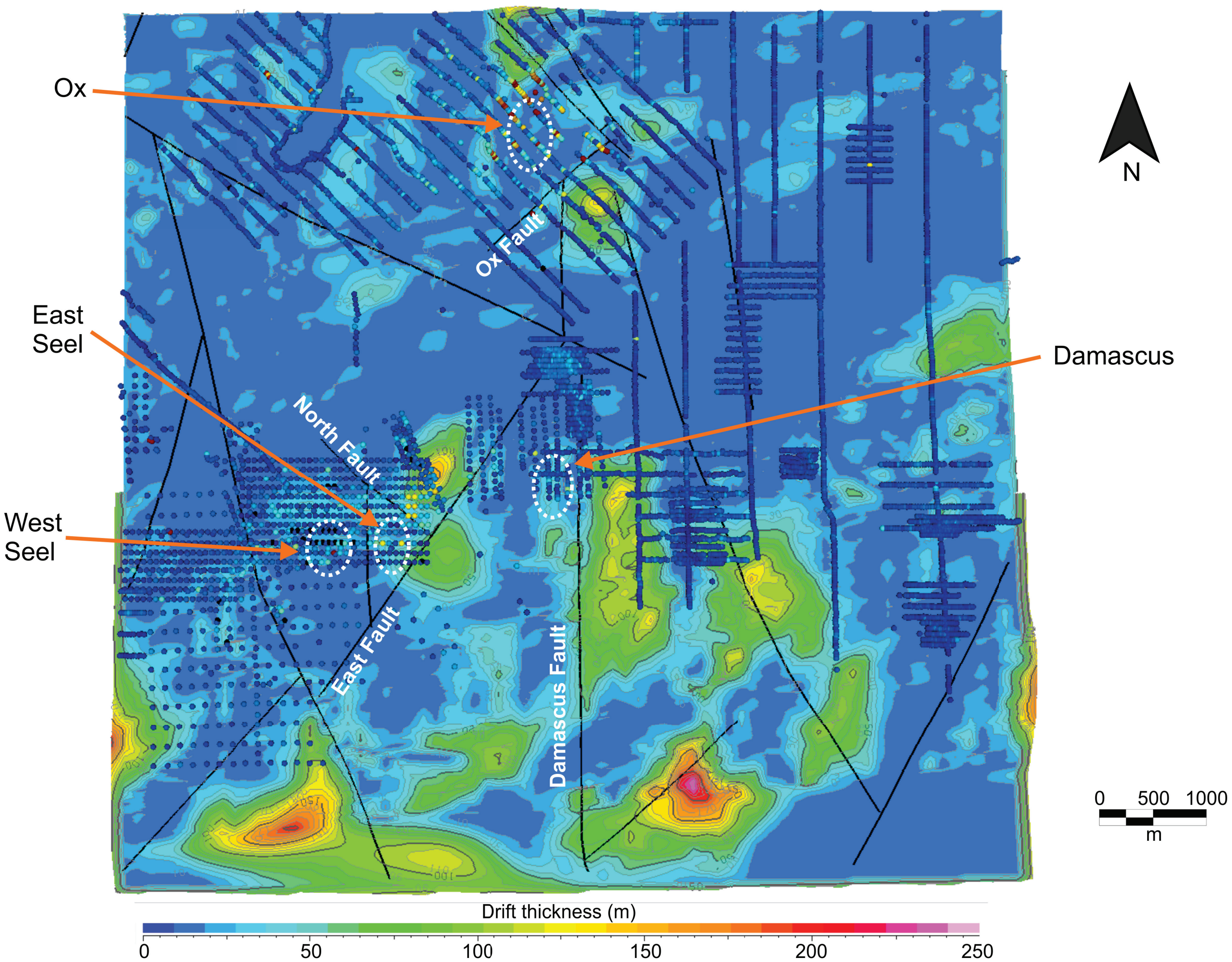

Fig. 9. 3D depth-to-bedrock GOCAD model for the Ootsa Lake project area with contoured thicknesses of drift (10 m intervals), major faults (black lines), locations of mineral deposits (dotted white circles), and Cu (ppm) in soils from gridded surveys (colour scale is the same as in Figure 4). The view of the study area is outlined in Figure 3, and is the same as Figure 8.

7. Conclusions

The 3D GOCAD modelling approach successfully created a depth-to-bedrock model of the Ootsa Lake area using company datasets. Where combined with geophysical data (if available), the depth-to-bedrock model is a useful aid in assessing a property for both new and old targets. Specifically, geochemical anomalies in areas of shallow drift are less technically challenging targets and relatively inexpensive to drill. They may rank quite high if the confidence map indicates a high degree of reliability of the drift thickness estimate and are located near known mineralization. However, areas of thick drift with geochemical anomalies that disappear, or show decreased intensity upon crossing a known fault, may indicate down-dropped fault bocks with mineralized stratigraphy. Abrupt changes in drift thickness that define linear features with considerable strike length may signify previously undocumented faults. In summary, constructing a 3D depth-to-bedrock GOCAD model for an exploration property with significant past and/or ongoing drilling, may provide sufficient digital data to produce an exploration aid at very little cost. It is essentially a data-mining exercise of existing datasets.

Expansion of the Ootsa 3D GOCAD model using data from the Huckleberry Cu-Mo mine to the northwest to build a regional model is possible. However, care will be needed to apply the model only to areas of low topographic relief. Other prospective areas in British Columbia that might benefit from 3D GOCAD modelling include the Woodjam area of south-central British Columbia. This area contains a cluster of large porphyry Cu-Mo-Au deposits in a region with extensive drift and low topographic relief (e.g., del Real et al., 2017). Except for the Southeast Zone porphyry Cu-Mo deposit, all the other porphyry deposits including Deerhorn, Megabuck, Takom and Three Firs (e.g., Vandekerkhove et al., 2014) are buried.

Finally, six potential areas were identified as favourable

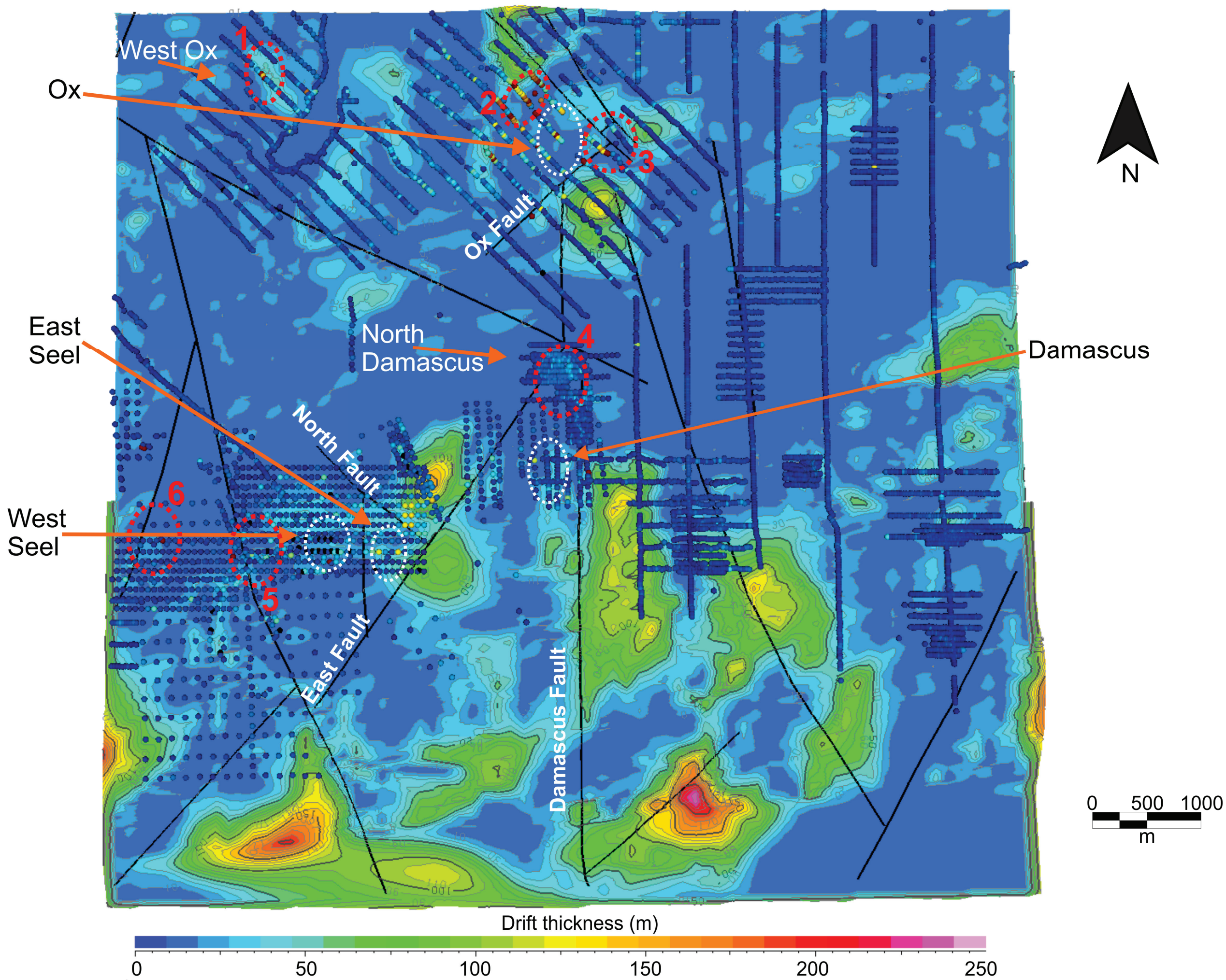

Fig. 10. 3D depth-to-bedrock GOCAD model for the Ootsa Lake project area with potential exploration targets (red circles labelled 1 to 6), contoured thicknesses of drift (10 m intervals), major faults (black lines), locations of mineral deposits (dotted white circles), and Cu (ppm) in soils from gridded surveys (colour scale is the same as in Figure 4). The view of the study area is outlined in Figure 3, and is the same as Figure 9.

targets for future exploration on the Ootsa Lake property (red circles in Fig. 10). For convenience, these selected areas are labelled 1 to 6 on Figure 10. They do not indicate a numerical rank. The selection of these targets was based solely on the data used to build the 3D depth-to-bedrock GOCAD model (i.e., drift thickness, geochemical anomalies, structures and confidence map). These exploration targets were previously identified by Gold Reach Resources Ltd. using soil geochemistry, field mapping, and additional geophysical data (e.g., West Ox and North Damascus). All of these activities are normal components of an advanced exploration project with ongoing regional exploration. We found it encouraging, however, that the 3D GOCAD model also identified these prospective areas and demonstrated that, in the absence of additional data, this simple digital approach has merit as a low-cost method to help evaluate an exploration property.

Acknowledgments

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