Gravity surveying and processing in difficult terrain: Greens Creek Mine, Alaska

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Summary

I performed a gravity survey on Admiralty Island in Southeastern Alaska looking for massive sulfides. The survey was conducted for Kennecott Minerals Greens Creek Mining Company to map any possible extension of the present works to the south and on three exploration targets in areas of geologic interest. Admiralty Island is characterized by very steep topography, muskeg, and poor topographic information. Despite these obstacles, good quality data were achieved by careful data acquisition and processing. The data confirmed the extension of the mined ore body at depth and provided valuable information for exploration drilling.

Introduction

The Greens Creek Mine is located in the Alexander terrane consisting of Paleozoic and Mesozoic rocks. This terrane has been subjected to multiple folding and faulting events and has been metamorphosed to the lower greenschist facies. The underground mine produces ore from a zinc, silver, and lead rich massive sulfide deposit. The ore lies along the contact of phyllite and argillite units. It is currently disputed whether the ore body is a volcanogenic, sedimentary exhalative (sedex), or replacement type deposit. The mine funds a surface exploration program to look for additional massive sulfides of the same type in the vicinity of the mine.

The surface exploration has consisted of a well integrated plan of geologic mapping, geochemical sampling, geophysical mapping, and drilling. Geophysical methods have included airborne magnetic and EM, CSAMT, TEM, ground magnetic, and gravity surveying. This paper will only discuss the gravity surveying and processing.

Gravity Survey

I conducted gravity surveys in August 1998 on four grids near the mine. The grids are called ARP, Lower Zinc, Bruin, and Upper Big Sore (Figure 1). Figure 1 also indicates the location of the base camp at the Cannery and the Mine Portal. The northern most extension of the ore zone occurs approximately 450 meters south of the portal opening. The ARP, Lower Zinc, and Bruin grids are exploration grids designed to test targets generated by geologic mapping. The Upper Big Sore grid was designed to map any possible extensions of the ore body to the south.

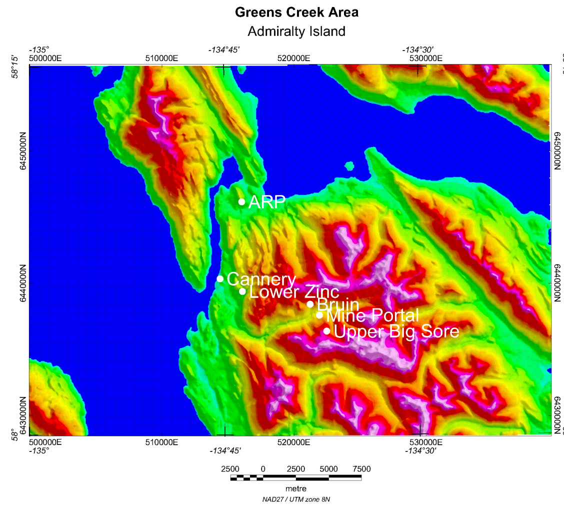

Fig. 1. Greens Creek Mine area shaded topographic map with survey grid locations.

Survey conditions were difficult. The topography in Figure 1 ranges from 0 (blue at sea level) to 1150 meters (pink). Topography was very steep with many of the grid lines climbing slopes in excess of 30°. Trees on the island grow to heights in excess of 50 meters and diameters in excess of 3 meters. Deadfall from the trees litters the ground forming a thick carpet of spongy humus and occasional tree trunks that must be climbed over. The tree roots in the spongy soil caused instrument noise when the wind blew. On flat areas of the island, muskeg is the dominant ground cover and made instrument leveling difficult.

These survey conditions required extra care collecting data. Despite its weight, I selected the Sintrex CG-3 Autograv because of its resistance to moisture. In areas of unstable ground such as in humus or muskeg areas, numerous readings were taken and stacked to improve accuracy. I made notes of slope at each survey station using a hand held inclinometer. Readings were taken perpendicular to the survey lines and in cases of very irregular topography, breaks in slope were noted perpendicular to and along survey lines. In all cases, I estimated the topography out 30 meters from the survey station. I repeated from one to three survey stations per day to protect against instrument tares and drift. I did not return to the base station during the day, but rather relied upon post processing to accurately calculate drift and tide corrections.

Survey stations were spaced at 100 feet intervals. Lines were separated by 400 feet on the Bruin and Upper Big Sore grids and by 800 feet on the ARP and Lower Zinc grids. Horizontal positions were controlled using a differential GPS receiver and vertical positions were surveyed in using a standard level. Reasonable vertical control with the GPS was impossible because of the dense tree canopy. Accuracy of the horizontal position was estimated at 2 to 3 meters and vertical at 0.0 to 0.1 meters. The entire gravity survey required 24 days to complete and I averaged 28 stations per day. Thirty-five repeat measurements were made on various stations and all were repeatable to within 0.05 mGal.

Gravity Processing

Simple Bouguer values were calculated at night and were completed before leaving camp. All standard corrections were applied. Terrain corrections were much more difficult and required an additional 30 days to complete. Terrain corrections were difficult because of the inaccuracies of the topographic maps and because of the steep topography at survey stations. To improve the accuracies of the digital elevation models (DEMs) near the mine, Greens Creek commissioned an airborne elevation survey years prior during the mine planning phase.

While the airborne survey was an improvement over the USGS DEMs, it still contained large errors. This occurs because the elevation is estimated by measuring the return time of a radar beam being bounced back from the earth and compared with the elevation of the plane. If there are trees present, the beam will be bounced back by the canopy. When the survey company processes the data, the personnel add a correction factor for the height of the trees. For Admiralty Island these values are in error because the extreme tree height and canopy density. The airborne elevation data were compared to the ground elevation survey and found to routinely differ by more than 6 meters. Using the Bouguer slab formula, an error in elevation of 6 meters produces a gravity error of 0.67 mGal.

To provide the maximum accuracy in terrain corrections with the data available, I divided the terrain correction procedure into three zones: Near, Inner, and Outer. The near zone extends from the station out 30 meters, the inner zone extends from 30 meters to the limit of data provided by the airborne topographic data, and the outer zone extends from the inner zone boundary to the limit of the DEM coverage.

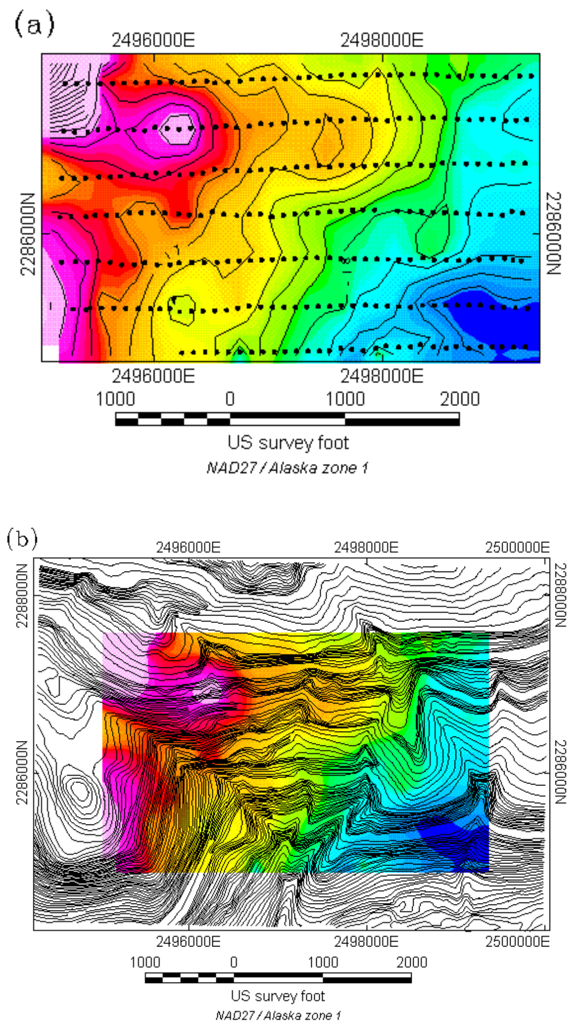

Fig. 2. The Bruin grid CBA with station locations (a) and CBA with hand contoured topography (b). Contour intervals are 0.2 mGal and 10 feet respectively.

The inclinometer data and the two nearest survey stations' elevations provided the near zone terrain information. These data were processed using the sloping wedge algorithm (Barrows and Fett, 1991). The user records the elevations along spokes radiating from each station then the algorithm fits sloping wedges using the elevation data and integrates over the wedges to calculate the terrain correction. I used four spokes for each station: two defined by the neighboring station elevations and two defined by the inclinometer data.

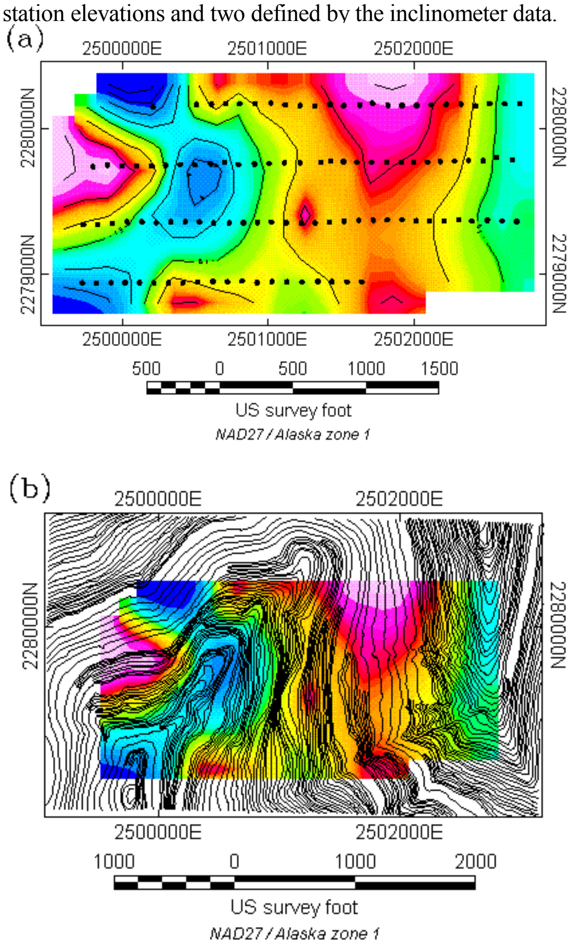

Fig. 3. The Upper Big Sore grid CBA with station locations (a) and CBA with hand contoured topography (b). Contour intervals are 0.2 mGal and 10 feet respectively.

The inner zone correction was the most difficult because it required extensive modification of the elevation data. To minimize topographic inaccuracies near the survey stations, I recontoured the airborne data to honor the ground survey elevations and then digitized these contour lines. The recontoured area was then windowed out of the airborne data and the hand contoured values entered. This combined data set was then gridded at 30 meter intervals and formatted for import into a public domain algorithm written by Allan Cogbill (Cogbill, 1990). This code requires data formatted in USGS UTM DEM form. It uses a combination of continuously differentiable surfaces and numerical integration to model the terrain using the DEM values. This creates a smooth surface that more closely approximates true topography than simple parallelepipeds.

The outer zone correction used the USGS DEM data. The highest resolution DEM data for this area are digitized at 2 arc second by 3 arc second (2” X 3”) intervals. Normally I used Donald Plouff’s (Plouff, 1966) code for processing latitude-longitude formatted DEMs. Unfortunately his code requires the data be digitized at the same spacing (i.e. 3” X 3”). Therefore the data were gridded at 60 meter intervals and formatted for input into Cogbill’s code. Outer zone corrections were only carried out to distances between 8.0 and 15.0 km because I did not extend terrain corrections beyond the boundaries of the island.

To guard against any systematic errors, I calculated terrain corrections for three points in steep terrain by hand. The three values agreed to within 0.1 mGal of the values calculated using the computer code. The average terrain corrections for the different grids and zones are as follows.

Zone	*ARP*	*L Zinc*	*Bruin*	*U B Sore*
Near	0.06	0.06	0.13	0.11
Inner	1.06	3.20	6.93	4.26
Outer	1.17	2.27	3.73	4.85

Table 1. Average values of the terrain corrections (in mGal) for the four grids and the three terrain zones.

For simplicity, I will refer to simple Bouguer anomalies with terrain corrections as complete Bouguer anomalies (CBA) even though the corrections are only carried out a few kilometers.

Results

For brevity, I will only discuss the results from two of the survey grids: Bruin and Upper Big Sore. Figure 2 shows the CBA (a) and the CBA with hand contoured topography (b) for the Bruin grid. The contour interval for the gravity data is 0.2 mGal and station locations are indicated by black dots. Two stations were deleted because the CBA values were obviously in error. The contour interval for the topographic map is 10 feet and in areas of steep relief only every fifth contour was digitized. The data exhibit a gradient from east to west and some strong anomalies are present on the western edge. These anomalies are probably artifacts caused by a lack of topographic control beyond the surveyed lines. Otherwise there are no features of interest.

Figure 3 shows the CBA with station locations (a) and the CBA with hand contoured topography (b) for the Upper Big Sore Grid. The contour intervals are 0.2 mGal and 10 feet respectively. Three stations were deleted because the CBA values were obviously in error. The CBA map is dominated by a large low amplitude gravity high extending from the north to the south. A strong anomaly is also present on the western edge of the grid but this response is probably caused by lack of topographic control in an area of steep relief. The north-south trending anomaly generally corresponds with the southern extension of the ore zone.

I modeled the northern most line (Line 3800N) of the Upper Big Sore grid using a Talwani 2½D model (Talwani, 1973 and Webring, M., 1985) assuming the ore zone was the source of the anomaly (Figure 4). The model is shown in three panels. The bottom panel is a cross section of the line showing the station locations (yellow triangles) on the topography, the host rock (gray), and the modeled ore zone (orange). The middle panel shows the observed CBA values (gray dots), model curve (gray line), and relative difference (orange line). Finally the top panel shows a plan slice indicating the strike length of the modeled ore zone. This plan slice occurs at the elevation indicated by the orange line in the bottom panel. The ore zone and host rock are modeled with densities of 4.1 g/cm^3 and 2.67 g/cm^3 respectively. The ore body is modeled at a depth below surface of approximately 300 to 400 feet. Its depth and size generally agree with the known location and dimensions of unmined ore. However, the ore zone dips to the west rather than east.

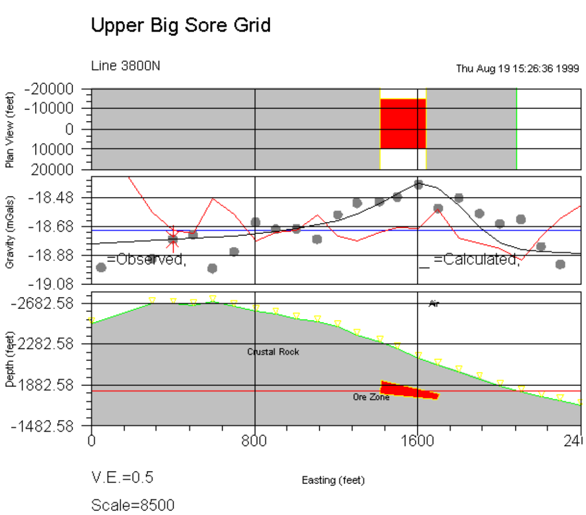

Fig. 4. 2½D Talwani gravity model of observed CBA data. Ore zone is indicated by orange, host rock by gray. All observed stations are in gray and modeled curve is in gray.

Conclusions

Good quality data were obtained at the Greens Creek Mine area despite steep topography, poor DEMs, and poor ground conditions. With the exceptions of the ends of the grid lines, I estimate the accuracy of the data to be within 0.2 mGal. Careful field acquisition techniques and thorough processing for terrain corrections achieved this success. While this process was time consuming, considering the cost of helicopter supported surveying, the time was justified. The survey indicated the extension of the known ore zone at great depth and indicated a lack of targets on the other three exploration grids. The lack of anomalies on the other grids means it is unlikely a sulfide large enough to be economic exists within 300 feet of the surface.

Acknowledgements

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