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Penasquito gold mine, Zacatecas Mexico. WorldView-2 satellite photo, February 2010.

Mapping Mine Sites

BY GERRY **MITCHELL, P.GEO**

Advances in imaging satellites and data processing technology are now enabling cost effective mine site monitoring and volumetric measurement from space. Mining pit, ore stockpile, leach pad, waste dump and tailings beach surface differences are being mapped to within 20cm. A number of mine sites are using this technology for annual and semiannual volume reconciliations. In the oil sands mines of northern Alberta this technology is being applied monthly and weekly.

There are now five commercial satellites in orbit with the capacity to map mine site surface elevation differences of 20cm. These are the WorldView-1, WorldView-2 and GeoEye-1 satellites owned by the US company Digital Globe and the Pleiades 1A and 1B owned by the French government. The Pleiades commercial satellite data is distributed by the European company ASTRIUM.

The original and still the primary markets for the high resolution satellite data are government defense and security programs. Commercial applications have been emerging over the past few years. The first cost effective engineering applications were for regional and scoping studies. With the improvement in satellite mapping accuracy and resolution engineering design and construction applications began to develop over the past decade. With satellite mine site monitoring and volumetric measurements we are now seeing the emergence of operational mining engineering applications.

A Canadian company, PhotoSat, based in the international mining center

Center: Penasquito mine pit, February 2010.
Image copyright 2013 DigitalGlobe, Inc.

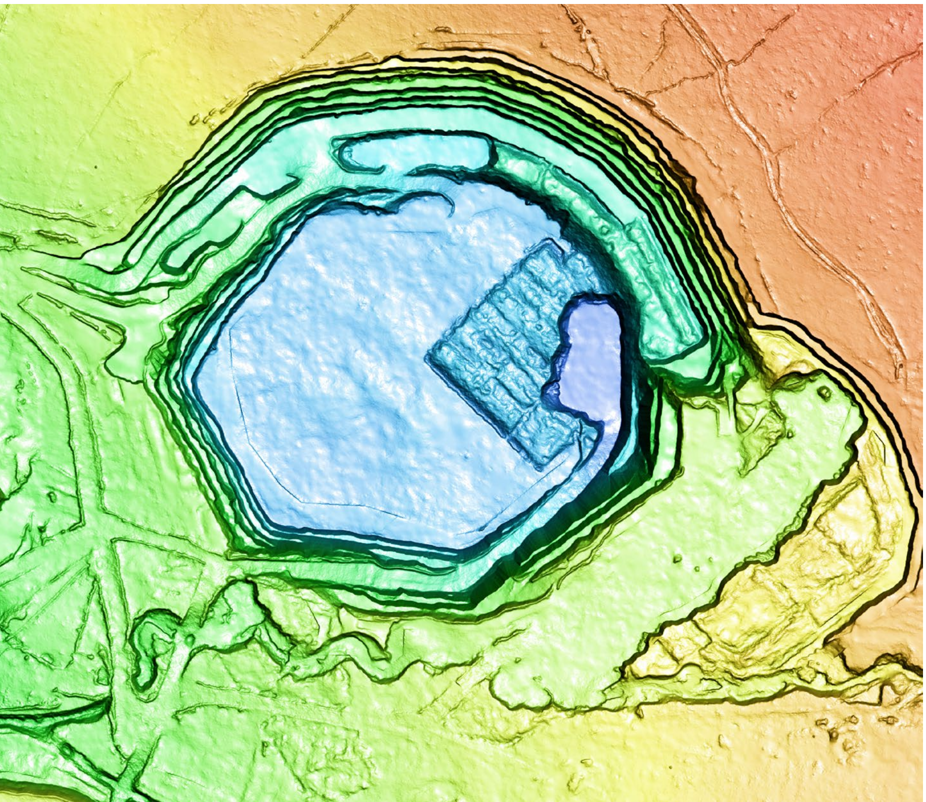
Right: Penasquito mine pit, trucks, shovel and blast hole drill rigs.
Image copyright 2013 DigitalGlobe, Inc.

From Space

of Vancouver, has invented new data processing algorithms that produce mine surface elevation maps accurate to 30 cm and elevation difference maps accurate to 20 cm. When technology developed for processing topographic mapping from airborne photography is applied to the satellite photos the resulting mapping is generally only accurate to between 2 m to 3 m in elevation. This accuracy was not sufficient for PhotoSat's mining engineering customers for design and operational applications so the company investigated other technologies that could provide better accuracy from the satellite photos.

PhotoSat found that by applying technology developed in the oil industry for the processing of oil exploration seismic exploration data to the mapping of topographic surfaces from satellite photos they could achieve mapping accuracies of between 20cm and 30cm in elevation. Digital processing of oil exploration seismic data began in the 1960's and has been the subject of billions of dollars of research and development investment ever since. The seismic processing field includes many sophisticated tools for image matching, signal enhancement and noise attenuation that, to PhotoSat's knowledge, have never before been applied to topographic mapping from satellite photos. This is a classic case of the transfer of technology between different technical fields resulting in a significant technical breakthrough.

PhotoSat's processing technology is being developed by a team of Geophysicists with experience in oil exploration seismic processing and satellite remote sensing and a Physicist with experience in machine vision. PhotoSat's satellite topographic data processors are graduates of Astronomy, Astrophysics and Physics. The Astronomers and



Penasquito mine pit satellite elevation image January 31, 2010. The satellite mapping is accurate to approximately 25cm in elevation.

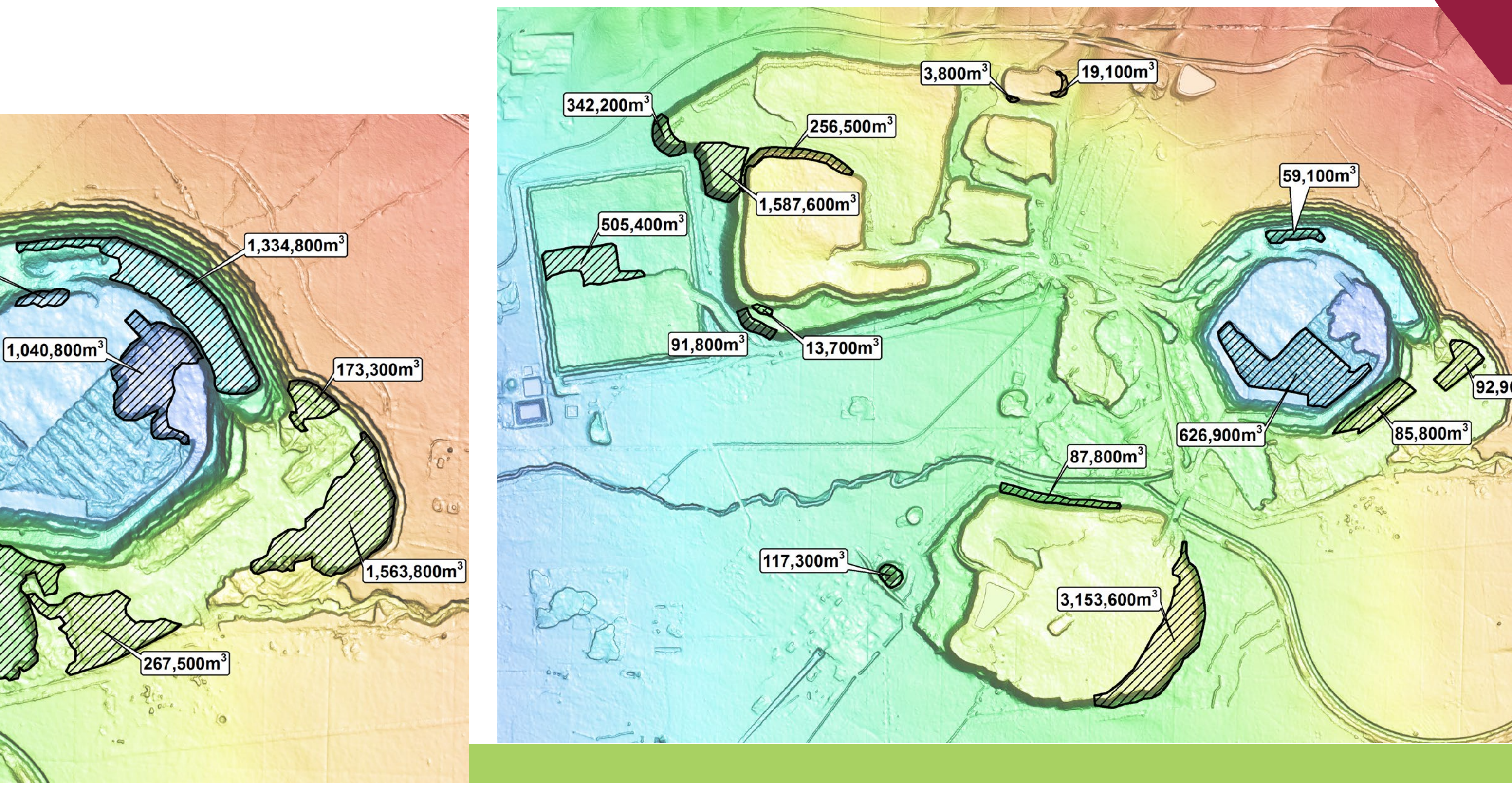
Penasquito mine site satellite elevation image February 27, 2010. The volumes of material removed from the pit and ore stockpiles between January 31 and February 27 are labeled. The accuracy of the measured elevation differences between the mapping dates is approximately 20cm.

Astrophysicists understand telescope and camera optics and do a significant amount of image processing as part of their degree programs. They have the math and physics to understand the sophisticated processing algorithms and know how to adjust the processing parameters to enhance signal and attenuate noise to produce high quality topographic mapping.

Mine site satellite topographic mapping is produced from pairs of satellite photos taken approximately one minute apart. As the satellite approaches the mine site from the north, at an altitude of over 700 km, the entire satellite swings to focus its telescope on the mine site and takes the first photo. Travelling at 7 km per second, approximately one minute later, the satellite swings to focus the telescope on the mine site to take the second photo, making a stereo pair of photos with a stereo convergence angle of approximately 30 degrees. The ground elevations are calculated from the relative locations of the same ground features on the two photos. The apparent location of the features on each of the photos varies with the elevation of the features. This phenomenon is called the parallax effect.

The pointing of the satellite telescope is controlled by the forces created by variations in the electric current flowing in coils of wire in the satellite, moving at 7 km per second through the earth's magnetic field. The position, orientation and speed of the satellite is so precisely controlled and measured that the resulting topographic maps are usually accurate to 2 m without any ground survey control. By matching the resulting satellite mapping to a single ground survey point the satellite mapping is accurate to 30 cm in elevation for up to 10 km in all directions from that ground survey point.

The satellite mine site maps are instantaneous snapshots of the



Penasquito mine site elevation image, February 27, 2010. The volumes of material added to the waste dumps, ore stock piles and leach pad between January 31 and February 27 are labeled. The volume increases in the mine pit are volume expansion due to blast heave.

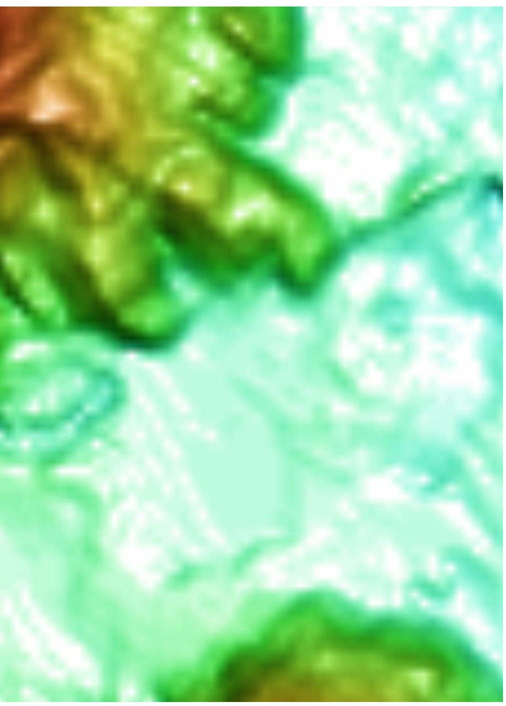
elevation surfaces of the entire mine site. This can be a significant advantage over conventional mine surveying where different areas of the mine site must be surveyed at different times. With ground surveying, unless there is a mine stoppage when the entire site can be surveyed with no ongoing volume changes, there is never a snapshot for a volume balances for the entire mine site. Another advantage of the satellite mapping is for the mapping of areas that may be difficult or impossible for the mine survey crew to safely access such as areas of active mining, dumping and tailings disposal and water saturated zones.

Satellite mapping has a significant advantage over airborne surveying for mine sites in remote locations. For the satellites, all areas of the world are easily in range. For remote locations airborne mapping surveys require aircraft mobilization and standby charges for the aircraft and crew in times of poor weather. For mine site surveys in remote locations the aircraft mobilization costs alone often exceed the total cost of satellite mapping of the mine site. Then there is the issue of permits to fly the airborne mapping survey. In some political jurisdictions permits are required from multiple government agencies to fly airborne surveys. This airborne survey permitting process can take up to 18 months and delay an entire engineering project that is relying on airborne mapping data for construction design. Satellite mapping requires absolutely no in country permits or presence so it is not subject to bureaucratic delays.

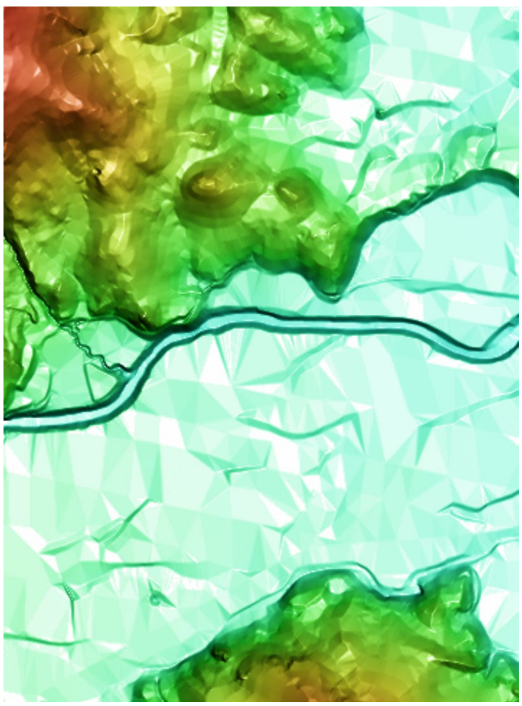
With the global access provided by the satellites, companies with mining operations in various parts of the world can use a consistent mapping process for all of their mine sites. PhotoSat's early satellite mine site mapping projects were for Canadian mining companies with mine sites in remote areas of the world where there was no other feasible mine site mapping option. As these companies became confident with the accuracy and consistency of PhotoSat's satellite mine site mapping for their remote projects they began to employ the technology on their mine sites closer to home. Many of these remote projects were partnerships between Canadian mining companies and mining companies based in other parts of the world. After being introduced to satellite mine site mapping by their Canadian partners many of these companies began using the technology on their own projects, spreading the use of satellite mine site mapping throughout the world. PhotoSat has now carried out satellite mine site mapping on over 300 global projects, mapping some of them multiple times.

On a typical mine site mapping project of a few tens of square kilometers, PhotoSat only actually requires a single ground survey control point to achieve 30 cm satellite topographic mapping accuracy. PhotoSat always requests a minimum of 3 photo-recognizable ground survey points on a project to ensure that there is a consistent match between the ground survey data and the satellite photos. As the relative horizontal accuracy of the satellite photos is in the order of 10 cm in 10 km, any inconsistency in the horizontal survey coordinates of more than 1 m is easy to detect. On larger projects approximately one ground survey control point is required for each 200 km2 of satellite topographic mapping.

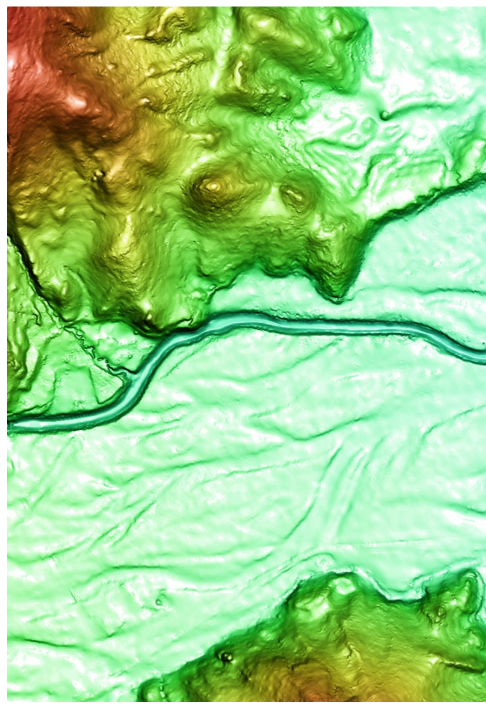
The relationship between ground surveying and satellite topographic mapping has had an interesting evolution over the past ten years. Ten years ago ground surveying was considered to be absolutely accurate compared to satellite topographic mapping. Satellite maps produced in the early 2000's were always adjusted to perfectly match all of the ground survey points. Beginning about five years ago, as the geometric quality of the new generation of satellite topographic mapping became



Space Imaging 2004 elevation image from a 20m topographic grid produced from stereo IKONOS satellite photos. The accuracy is between 5 and 10 meters of elevation.



PhotoSat 2004 elevation image from a 5m topographic grid produced by PhotoSat from the same stereo IKONOS satellite photos. This elevation data was produced by conventional photogrammetric stereo satellite mapping. The accuracy is 2 meters in elevation.



PhotoSat 2013 elevation image from a 2m topographic grid produced by PhotoSat from the same stereo IKONOS satellite photos. The elevation data was produced by PhotoSat's new "Geophysical" stereo satellite mapping system. The accuracy is 50 centimeters in elevation.

The locations of over 400 global stereo satellite mapping projects produced by PhotoSat since 2004. 80% of these are mining projects.

established, many of PhotoSat's customers started using the satellite mapping to check the accuracy and consistency of their survey data. Mismatches of more than 1 m between the ground survey coordinates and the satellite topographic mapping were almost always determined by resurveying to have been caused by survey errors. PhotoSat has over fifty documented cases where the satellite mapping identified ground survey errors where the ground survey was confirmed to be wrong by subsequent surveying.

Over the past few years, on a number remote mine sites when there was not time or budget to mobilize a survey crew to check and resurvey points that did not match the satellite mapping, mining companies began using the satellite mapping coordinates instead of the ground survey coordinates when there was disagreement between the ground surveying and satellite mapping. Recently, on a number of projects, mining companies have had local crews clearly mark ground features, such as drill hole collars, that were then located on the satellite mapping to within 25 cm in X, Y & Z, entirely eliminating the ground surveying of these features. So over ten years the relationship between ground surveying and satellite topographic mapping has evolved from the ground surveying being the unequivocal "true location" of all ground features to today where, on some mining projects, ground surveying of some features has been entirely eliminated by satellite topographic mapping. MC

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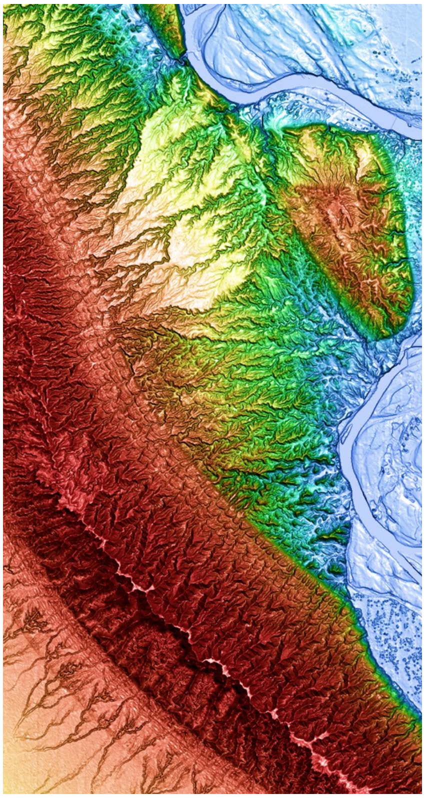

Satellite topographic image of a mountain range and the Tigris River in Northern Iraq.