# Modelling and Analysis of the Earthquake Zones of British Columbia Using Three-Dimensional Mining Software

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## 1. ABSTRACT

The use of three-dimensional software for modelling earthquake patterns can greatly enhance an individual's ability to determine earthquake locations, the location of tectonic plates, general trending of tectonic movement, and possible associated volcanic activity. MICROMINE, a software package that captures, manages and interprets critical mining and exploration data, can also perform very similar analyses on earthquake patterns and trends.

With a third dimension aspect, earthquake trending does not have to be confined to simple map analysis. Physical structures are capable of being displayed and analyzed, and aspects of the features not readily seen in the 2D environment become more apparent. With the ability to add extra data relevant to the tectonic forces at work, a larger understanding of the geology of British Columbia is also possible.

## 2. INTRODUCTION

The greatest potential for earthquake activity in Canada is in the province of British Columbia. General trending and modelling of the tectonic plates is possible using earthquake patterns that have been accumulated over several years, providing clues as to where major shifts are occurring. A pattern of the generally accepted shape of the tectonic plates can be viewed over several years of seismic study, and with the use of three-dimensional software, spatial relationships between the quakes can be seen.

Three-dimensional software also allows numerous statistical calculations to be made based on the intensity of the earthquakes and their general direction or trend. Most of the data acquired for this case study can be downloaded free of charge from a range of Internet sources. The earthquake data collected was based on the latitude and longitude, depth, and magnitude of the earthquakes. The boundary file outlining the extent of British Columbia was the result of combining the hydrologic and lithologic maps to make a single boundary.

## 3. DATA COMPILATION

The data was compiled using several readings gathered by Natural Resources Canada. Natural Resources Canada provides daily updates of detected earthquakes in the Western Canadian region (including British Columbia, Alberta, Yukon Territories, Alaska and the Pacific and Arctic Oceans) on a one month, one year, and five year basis. Geographic locations are in latitude and longitude, which can be converted to Universal Transverse Mercator (UTM) using MICROMINE. For this case study, data was initially collected from 1 July 2007 to 1 July 2008. The data was later amended to include data from 20 November 2003 to 1 July 2008.

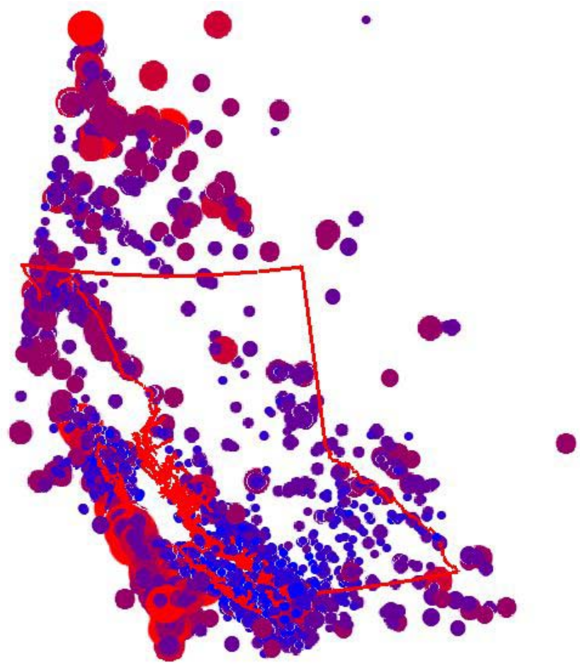

*Figure 1:* A constructed view of the combined features of British Columbia's boundary and the earthquake hypocentres of earthquakes from November 2003 to July 2008. Earthquakes are displayed based on greater magnitude (blue and small to red and large). Image constructed by MICROMINE.

Earthquakes are recorded based on their depths and magnitudes. Magnitude types are also recorded for either the Local or Richter Magnitude (ML), or Moment Magnitude (Mw). The Moment Magnitude Scale was adopted in the 1970s as a successor to the more commonly known Richter Scale. It has a very similar logarithmic structure, although it makes adjustments for quakes over 7.0. Because none of the quakes studied in this case go beyond 7.0, we can use either scale knowing that the value will be similar.

The focus, or *hypocentre* of the earthquakes have in many cases been generalized for depth, particularly in regards to earthquakes that occur in the ocean, where determination of the actual depth cannot be made. The depths have the added effect of making certain structures such as tectonic plates more apparent. While the plates themselves are not what we are detecting, the quakes at their margins are what we are observing. We are generally not concerned with finding high magnitudes, as they are considered statistical outliers to an overall pattern.

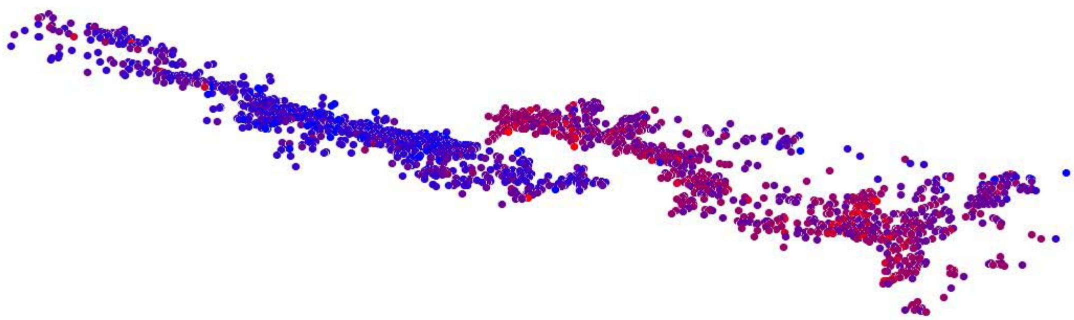

*Figure 2:* Hypocentres of the Queen Charlotte Transform Fault (left) and Explorer Plate (right). Blue colours indicate lower magnitudes, red indicate higher ones. While the depths of these plates are approximates, they show a distinct pattern for different depths of the two features. Vertical exaggeration of 5x. Image constructed in MICROMINE.

The data was copied and pasted directly from the Natural Resources Canada website and placed in a text file. With a small amount of editing for column space, the text file can be imported into MICROMINE into its own data format. Consideration for the different categories, or *fields*, must be made to decide how much of the data to include. Data amendments, such as the conversion of the depth to a negative value and the conversion of kilometres to metres, were made to allow for the correct display in a three-dimensional setting.

Because the coordinates are in units of degrees, it was necessary to convert the data to display the data accurately. Finding the depths of the earthquakes in relation to the layout of British Columbia provides a better understanding of certain events happening underground. MICROMINE has a Transform Grid command that allows the conversion of geographic coordinates to UTM and vice versa. The data points were converted based on Zone 9, as it is the area that British Columbia primarily occupies.

Other data was sourced for free from various Internet sites. Wikipedia lists British Columbia's major volcanoes and their coordinates. With a similar data file they can be created and imported into MICROMINE as per the earthquakes. The line or *string* file was created by merging several geological maps into the one. The strings representing geological units were then deleted, leaving only the coastline. A second file for hydrology, which gave a less detailed representation of the coastline, was used to fill in the areas where the coastline was not shown on the geological map.

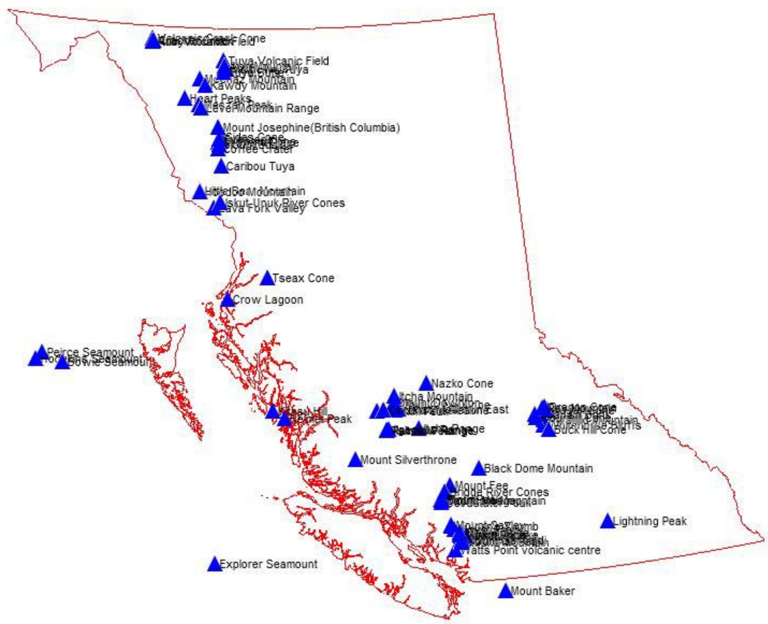


*Figure 3:* Major volcanoes of British Columbia. Source of locations courtesy of Wikipedia, displayed in MICROMINE.

## 4. APPLICATION OF THE DATA

The data was set in a points file and filtered using the coordinates 138 degrees west to 106 degrees west, almost covering British Columbia. The initial data set of one year determined the earthquake activity within British Columbia, although it didn't provide a thorough account of tectonic activities. A second data set was gathered for a period of just under five years.

The initial view of the data confirms that most earthquake activity occurs off the coast of British Columbia in the vicinity of Vancouver Island and the Queen Charlotte Islands. There is also a major fault zone located near the British Columbia/Alaska border where a subducting plate is pushing its way under the continent known as the Yakutat Collision Zone. There is also a phenomenon known as the Richardson Mountains Seismicity, which is a right-lateral strike-slip fault. Minor earthquakes can be found within British Columbia close to the coast which coincides with the Cascade Mountains, a chain of mountains and volcanoes that extend south from British Columbia right down to Northern California.

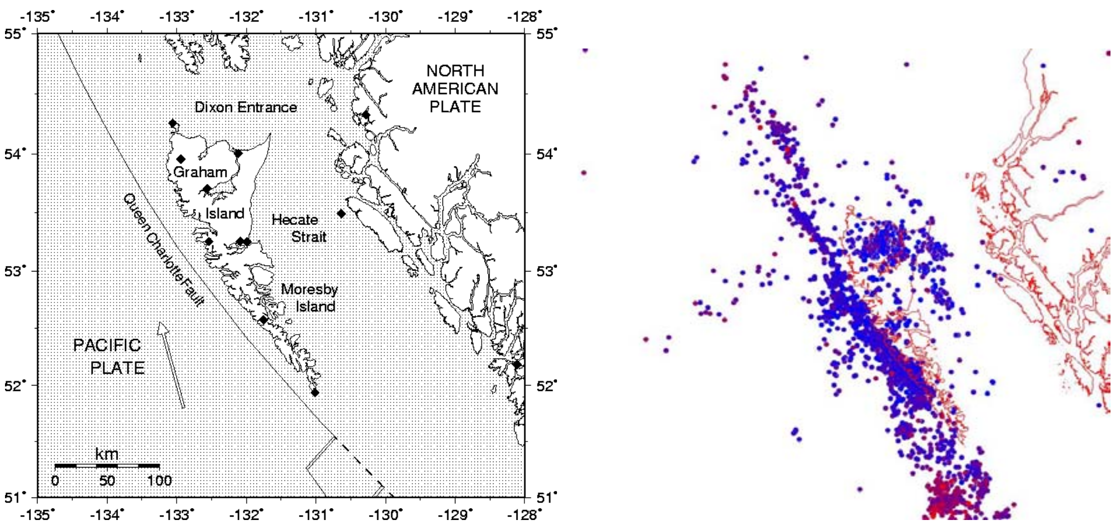


*Figure 4:* Comparison of agreed location of Queen Charlotte Transform Fault (left); earthquake pattern along mapped Queen Charlotte Islands in MICROMINE (right). Image of Queen Charlotte Islands courtesy of University of Victoria's School of Earth and Ocean Science.

The oceanic quakes coincide with many of the models of the Juan de Fuca Plate and the Explorer Plate, two minor tectonic plates that are subducting underneath the North American continental plate. The Explorer Plate's "panhandle" shape is unmistakably apparent based on the seismic data, while the Juan de Fuca Plate can be seen subducting under the major continental plate. Although the plate itself is not "seen", the earthquakes detected show a very distinctive sloping pattern that accurately represents the pattern of subducting. By using the 3D aspect, a much accurate view of the subducting plate can be witnessed.

Much of the earthquake data can be directly attributed to volcanic activity rather than tectonic movement. Several hotspots, which are places where magma is pushing its way upwards to the surface, are apparent. Places underneath the Nazko Cone and the area surrounding Vancouver have vertical occurrences of quakes, suggesting the vertical movement of magmatic pipe chambers.

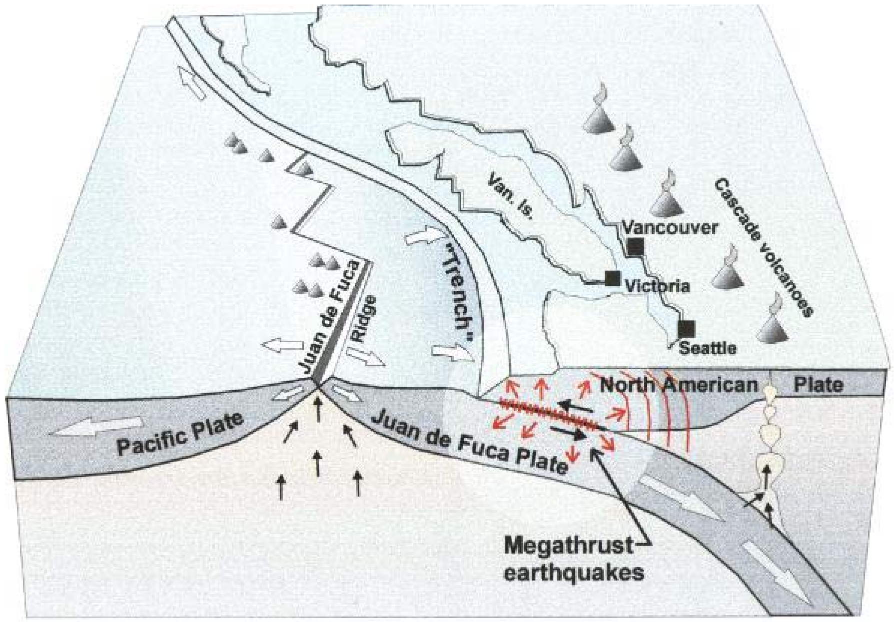


*Figure 5:* Megathrusting earthquakes produced from the subduction of the Juan de Fuca Plate underneath British Columbia and Washington State. Photo courtesy of the Natural Resources of Canada website.

In the case of the Nazko Cone, it is interesting to note that prior to 2007 the amount of earthquakes in the vicinity were virtually non-existent. From 2007 there was a tremendous amount of activity. It is documented that on 10 October 2007, there were a series of earthquakes that were generally a 1 on the Richter Scale, but went as high as 3.9. Since this date, the Nazko Cone has been a focus of interest by the Geological Survey of Canada. While the clustering of earthquakes can indicate danger zones from the surface, the ability to model them in three dimensions allows us to study the structure of such occurrences.

Given the sometimes sporadic nature of the hypocentres, it can be difficult to create a plane that will accurately reflect the points and represent a tectonic plate. MICROMINE is able to construct a *wireframe* or a series of triangles representing a surface using points, but the results are not always a smooth representation. Joining a wireframe by using several “best fit” strings that coincide with the location of the hypocentre points can create a plane that accurately shows a subduction zone. The points showing the oceanic plates are approximate numbers and are all set to a single elevation, allowing wireframes to be easily constructed.

## 5. CALCULATION OF DATA

The data is a series of points that exist in a three-dimensional space and have a unique value, much like the values associated with any resource estimation mineralogical survey. We can treat earthquakes in a parallel manner, showing a “trend” in their behaviour similar to one that might appear in an orebody.

MICROMINE is able to calculate a *block model* which is a three-dimensional form of gridding. Like a grid shows surface trends in a two-dimensional plane, block models show similar trends in the calculated values for assay values or geochemistry. The magnitudes of earthquakes can be calculated in a similar manner to determine their directional trend, known as *anisotropy,* within the values. Anisotropy is expected with the shifting of continental plates which are meant to have a directional flow that is determined by the different methods of calculations available.

Calculations using the *inverse distance weighting* method will suffice for many anisotropic studies. This method calculates and populates the blocks with the scattered values of the individual hypocentres. While this method has the advantage of expediency, it does not account for outlying earthquakes that cause a "bulls-eye" effect, adding values to earthquake hypocentres that should otherwise be excluded. A calculation method known as *Kriging* can be implemented when bias needs to be removed from certain calculations. The principal calculation used is *Ordinary Kriging*, which assumes an unknown constant trend.

Data is treated similarly to the type you might find in a mineralogical survey, where a cut-off value needs to be applied. While the occurrence of larger earthquakes is an interesting phenomenon, the larger magnitude values they produce unduly influence the statistical values of the norm, skewing the values and trends. Analyzing the distribution of the earthquakes reveals a mild kurtosis (skew) towards the smaller values. It is therefore necessary to calculate a cut-off value of 3.6 for magnitude. While the larger values will be excluded as a result, the trade-off is that an unbiased examination of the overall plate trending will occur.

The results of the IDW block model reveal a general trending direction that would be expected given the transform fault and the mainly NW-SE orientation of the tectonic belts of British Columbia. The search ellipsoid used to determine the block model was set at a radius of 15,000m and has no set orientation, with a minimum of two points to restrict single outlying points from getting separate blocks. Many solitary blocks can still be found, which can create a bias for outlying earthquakes that would otherwise have no bearing on the general trend.

Studying the Kriging pattern of earthquakes not only has a bearing on the removal of outliers and overall bias, but can also be used to set specific drifting trends for areas known to be unique components of the overall tectonic area. For example, The Juan de Fuca Subduction Plate can be subset due to its unique points and have its own trend separate from the entire earthquake file. Much like trying to find the grade anisotropy with assay or geochemical values, in this case, we are attempting to find the occurrence of earthquake patterns showing their anisotropy, which should illustrate their axis of movement.

Analysis of the hypocentres is to be performed using *semi-variograms*, or graphical displays of the data designed to determine statistical correlation. When a correlation of the hypocentres is found, the trend indicates where the tectonic plates are moving. The factor of *ranges* becomes relevant at this point, as earthquakes with in increasing amount of distance from each other appear to have little or no correlation with one another. Once the earthquakes arrive at a *partial sill* they can be treated as unrelated.

Attempting to find a correlation between the points can be done as an overall procedure, although due to the spatial and magnitude differences, it is more sensible to subset the differing zones to determine their trending patterns. Dip-slip and strike-slip zones have differing trends, and if the two zones appear, MICROMINE will make it obvious where they occur. The magnitudes and depths of earthquakes associated with the Explorer Plate have differing values from those seen in the Juan de Fuca subducting plate, so performing differing Kriging calculations may be the better option. Orebodies can be broken into different domains with similar methods of subsetting. Despite their relative proximity, they will be treated independently for the analysis. It is interesting to note that once the earthquakes have been zoned into regions, a readjustment must be made to the statistical cut-off. The magnitude values for the Explorer Plate are notoriously high, and the cut-off must be readjusted to reflect the values accurately.

The subducting Juan de Fuca Plate is interesting to view since plates such as the Explorer Plate and Queen Charlotte Transform Fault are displayed as totally flat. The magnitude of 2.8 was determined to be the optimal cut-off limit. Because of the nature of the subducting plate, it is a more useful study for determining anisotropy than a flatter plate because dips can be determined.

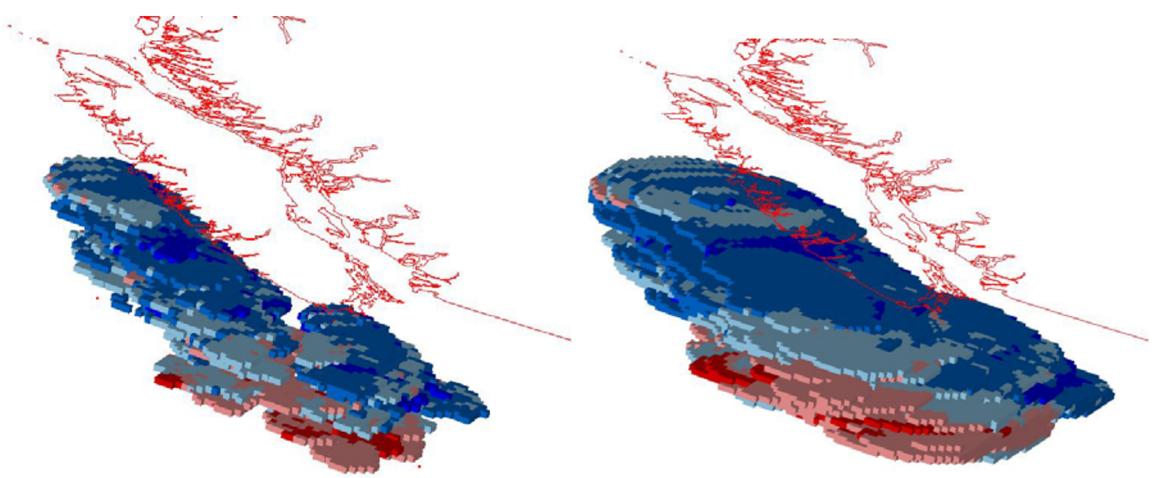

*Figure 6:* Comparison of Kriging for 25,000m search radius (left) and 80,000m radius (right). The colour scheme shows extremely low magnitudes < 0.3 (dark blue) to > 2.8 (dark red). Image constructed in MICROMINE.

The graphics above show how the two Kriging block models demonstrate the analysis of the points for the hypocentres associated with the subducting plate. The first graphic is showing a radius of 25 000 m.

The *search ellipsoid* is only able to analyse and compare the points that fall within that radius to populate the block with a value. The second graphic shows a radius of 80,000 m, which will make a more inclusive block model which extends its boundaries, but will be considered less accurate as an analysis. The pattern of the block model reveals that the earthquakes show a higher magnitude on the bottom of the plate compared to the top.

## 6. CONCLUSION

The application of many three-dimensional occurrences using modelling software can allow for a detailed and realistic view of data. The above case study shows MICROMINE's potential for monitoring volcanism, the ability to map proper tectonic patterns emerging from the resultant earthquake's hypocentres, statistical decomposition and analysis of magnitudes, and the modelling of data into pertinent block models that allow for trend analysis. While MICROMINE is traditionally used as mining software, this case study provides a view of other applications that can utilise different modules.

Earthquakes are a hot topic for areas that are sensitive to earthquake activities. Whilst the public's concern over "the big one" has merit, it does not help us gather an understanding of how and where tectonic plates are shifting. It will be far more useful to the scientific community to find a method for mitigating these catastrophes than knowing the definitive times they will occur.

## RESOURCES

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