Kriging Geostatistical Analyses of Down Hole Geochemical Data From the Round Top F-REE-Be-U Deposit, West Texas

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Objective

Kriging geostatistical analyses were applied to a set of rhyolite geochemical data in order to determine if a lateral trend in fluorine concentration could be extrapolated across several elevation horizons within the Round Top laccolith. Several types of rhyolite have been identified at Round Top and it has been suggested that trace element, Rare Earth Element, and fluorine enrichment may vary as a factor or rhyolite type. To determine the variation of trace elemental concentration as a factor of rhyolite type, the geostatistical technique of kriging was applied to discrete elevation horizons within the rhyolite laccolith. This technique is utilized within exploration and production-mining operations as a means to model the potential concentration variations of ore deposits and as a way to economically in-fill drill hole data. Ideally, the prediction model produced through kriging would need to be ground truthed through subsequent drill hole data in order to check the quality of the prediction analyses. This is not possible with the current data set used for this model, as the company is no longer operational in the region.

Kriging is defined as "…a spatially-based estimator of spatial variables (GIS Fundamentals p. 415, 2005)." It is similar to other interpolation methods, such as Inverse Distance Weighting (IDW), in that it uses a weighted average based on distance to calculate values in unsampled regions. Kriging is more precise then these other methods in that it "…uses the minimum variance method to calculate the weights, rather then applying some arbitrary and perhaps more imprecise weighting scheme as with IDW (GIS Fundamentals p. 418, 2005)." This method "…use(s) the control point [known sample point value] as a sample to find optimum values of the weights for the data values included in the interpolation at each unknown location (Geographic Information Analysis p. 266, 2003)." Within the Geospatial Analyst extension, there are a number of options for types of kriging analyses. For this analysis, the basic method of 'Ordinary Prediction Kriging' was chosen as a means to gain knowledge and experience in using the statistical tool. Although kriging does not produce predictions of specific concentrations for an area, it does produce a visual estimate map of calculated values, the Kriging Prediction Map.

The data points analyzed for this report are sourced from the Round Top laccolith, which is part of the Sierra Blanca peaks, a series of five peraluminous laccoliths, located in the Trans-Pecos Magmatic Field of west Texas (figure 1).

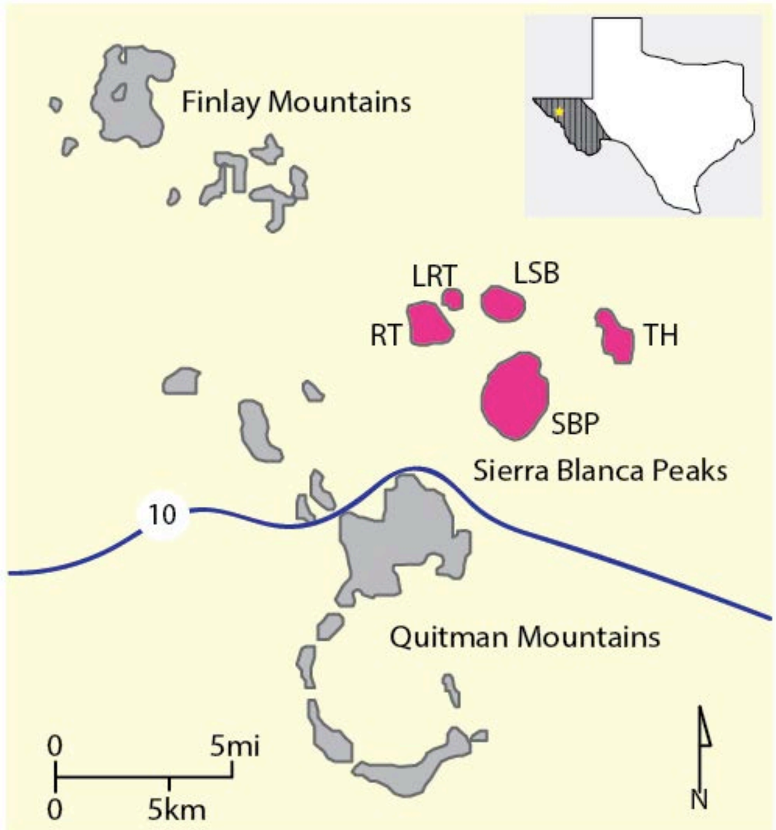

Figure 1: Round Top (RT) laccolith is part of the Sierra Blanca peaks located northwest of the town of Sierra Blanca, Hudspeth County west Texas. Modified from Rubin et al., 1987.

Methods

Data Collection

Geochemical data containing trace element, Rare Earth Element, and fluorine concentrations relative to drill hole depth were obtained from samples collected through reverse circulation drilling, and span drilling conducted by the by the Texas Rare Earth Resources Incorporation 2006 to 2012, and the Cyprus Company during the 1980s.

GIS data gathered for this project include an ASTER DEM and ortho imagery, and were collected from the Texas Natural Resources Information System webpage (www.tnris.org) and the United State Department of Agriculture Geospatial Gateway webpage (http://datagateway.nrcs.usda.gov/). The Digital Elevation Model (DEM) data is a 10-meter resolution Raster and was collected by selecting the Round Top area within the USDA Geospatial Gateway portal, and requesting the National Elevation Dataset 10 Meter, 4 maps 28.648 MS (UTM to NAD83) in FTP format. Additionally, an aerial othro image of the region was utilized and which was initially collected by the

National Agriculture Imagery Program (NAIP) in 2010 with 1-meter ground sample distance through the TNRIS webpage.

Preliminary data distillation

Geochemical data was received from the company within a series of excel tables. In order to use for the geostatistical analyses, data was combined into one master file. The ‘from’ intervals were subtracted from the drill hole collar elevations to produce a true elevation. The true elevation was then utilized to establish the interval brackets for the elevation horizons to be used for the kriging process. Data was sorted based on the true elevation into 10 horizons, consisting of 100-foot increments.

ArcGIS Processing

1. *Creating a personal geodatabase and importing base layers*

Creating personal geodatabase

A personal geodatabase was created within the :R-drive through ArcCatalog10 by File>New>Personal Geodatabase>(GIS_Project.mdb) (figure 2). Within ArcCatalog10, metadata information was then added to the files to be used by highlighting the intended file>Description tab>edit. Information such as the collection date, agency, resolution, and projection was added to the description of each of the files.

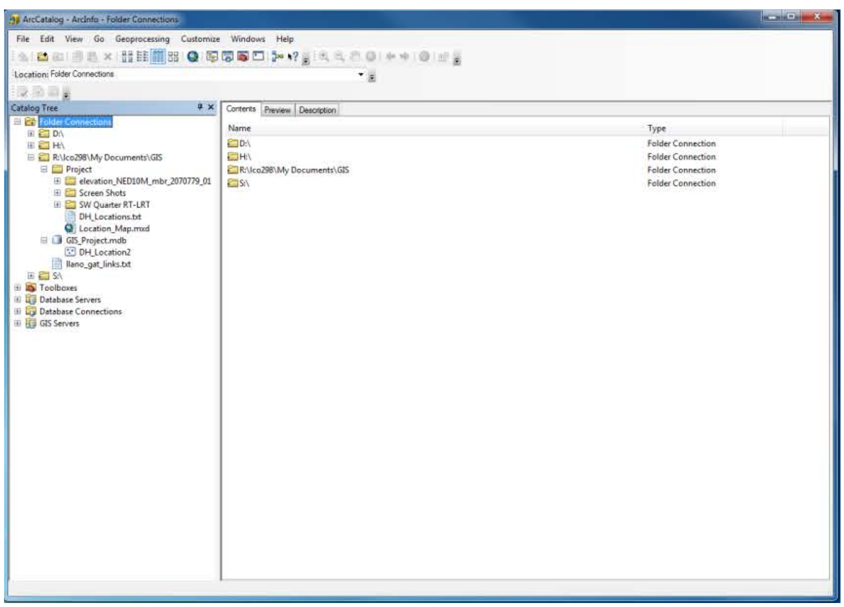

Figure 2: Creating personal geodatabase and adding metadata within ArcCatalog10.

Loading drill hole locations and base aerial photo layer

Within ArcMap10 a blank map was chosen, the drill hole locations were added as a layer by File>Add Data>Add XY Data. The Input File was chosen>(DH_Locations.txt), and the X, Y fields were chosen to match the column headings for the X, Y, fields within the text file. The coordinate system was chosen (NAD83 State Plane Texas Central FIPS 4203 Feet) along with the geographic coordinate system (GSC North America 1983) (figure 3). This geochemical spatial reference information is atypical to most State Plane data, in that this data is using the NAD83 false easting with the NAD27 datum. This is most likely due to when the operator was setting the GPS receiver parameters, they chose Texas Central State Plane, but kept the GPS default of WGS84/NAD83 for the datum. Note: even though the data is not in the conventional format, this is okay because WGS84 and NAD83 are the same within the continental United States. This produced a DH_Locations.txt Events layer (figure 4). The Events layers was then converted to a feature class by right clicking>Data>Export Data with the new export file names (DH_Locations2) and saved in the personal geodatabase (figure 5).

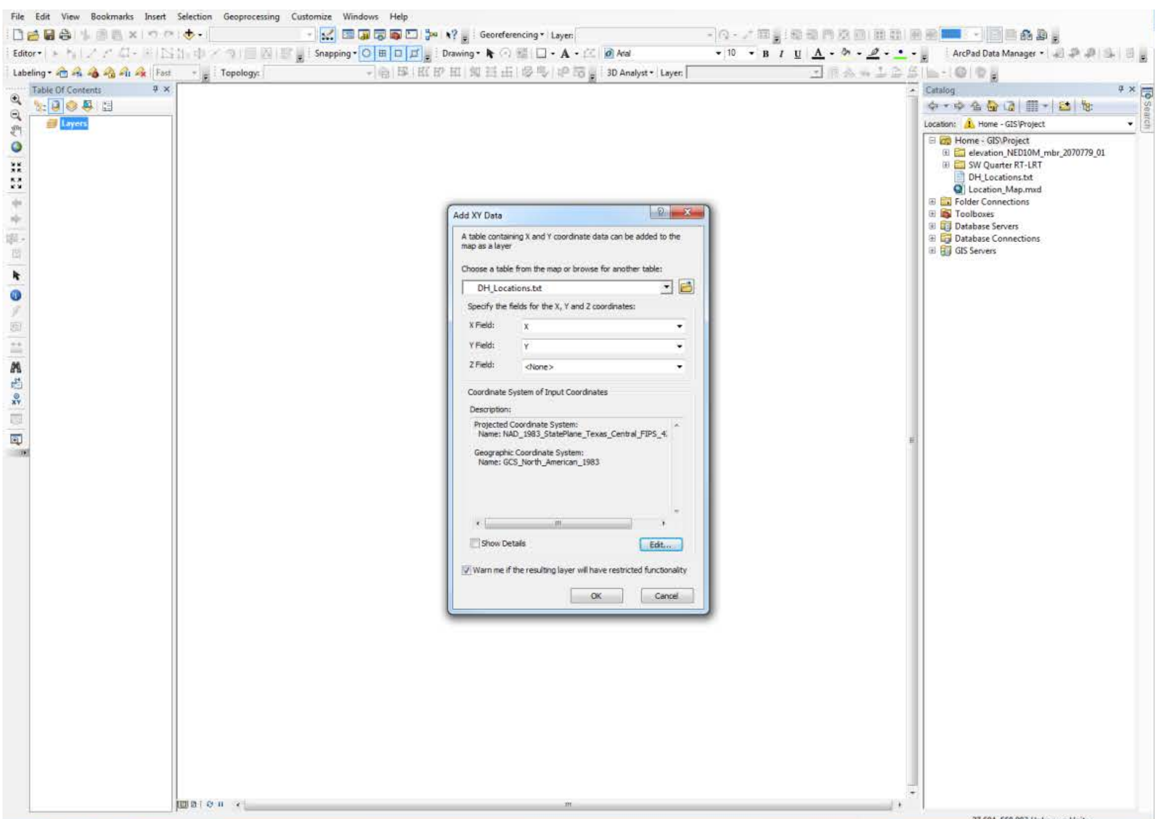

Figure 3: Importing DH_Locations.txt file into ArcMap and setting the coordinate system.

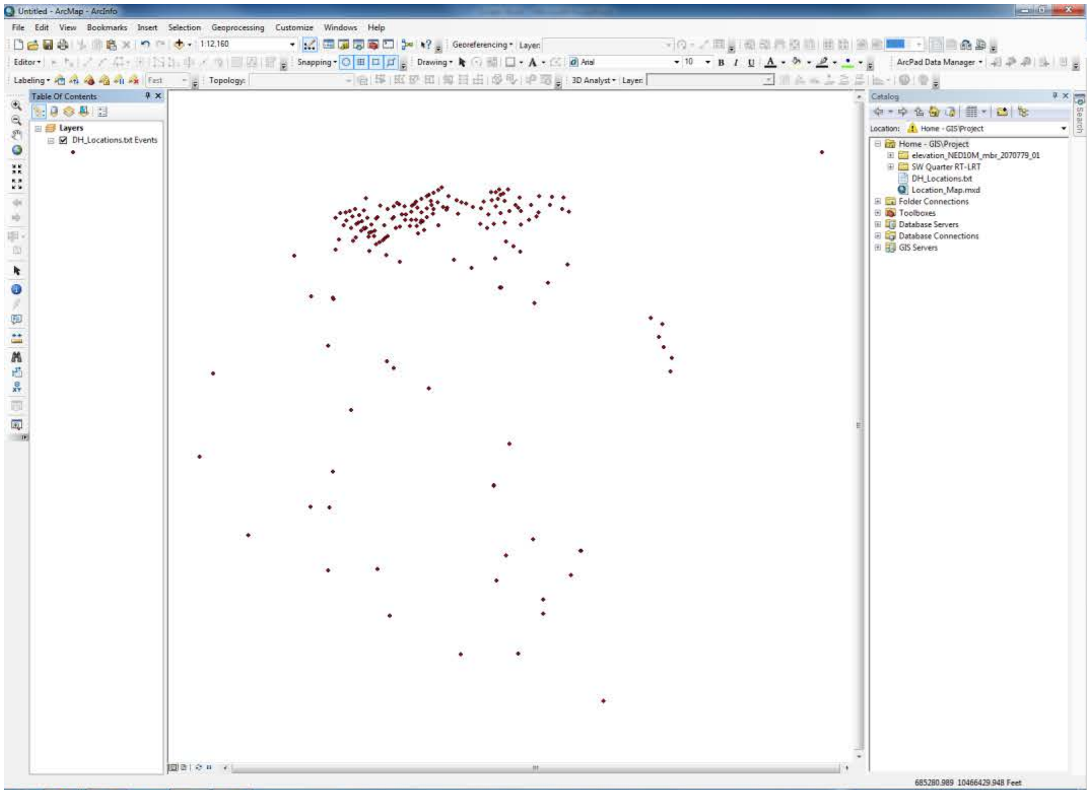

Figure 4: The projected DH_Location2_Events layer.

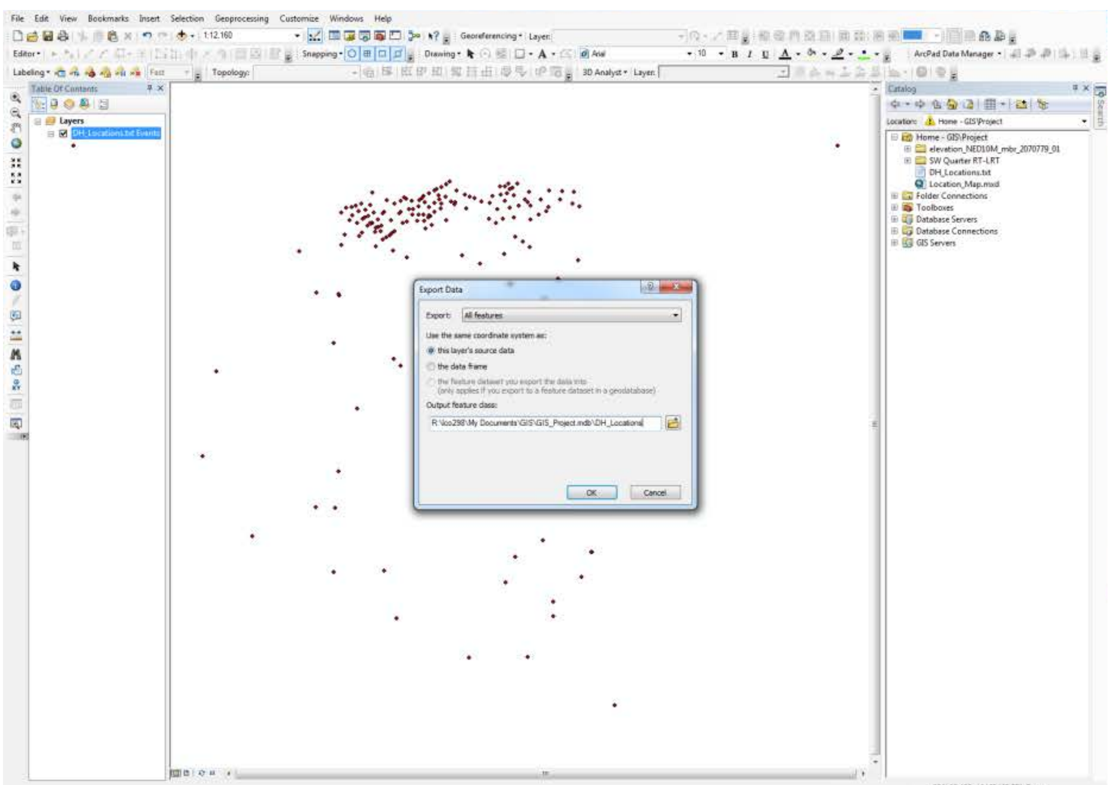

Figure 5: Converting the Events layer to a feature class within the personal geodatabase.

The National Agriculture Imagery Program (NAIP) aerial ortho imagery obtained form the Texas National Recourses System base map was added to the Table of Contents (TOC) by Add Data>(naip10_1m_3105_45_3_20100829.jp2), and selecting all bands (figure 6). The projection of this layer is based on the previously added (DH_Locations2) layer, so no additional projection transformations were necessary for this new layer.

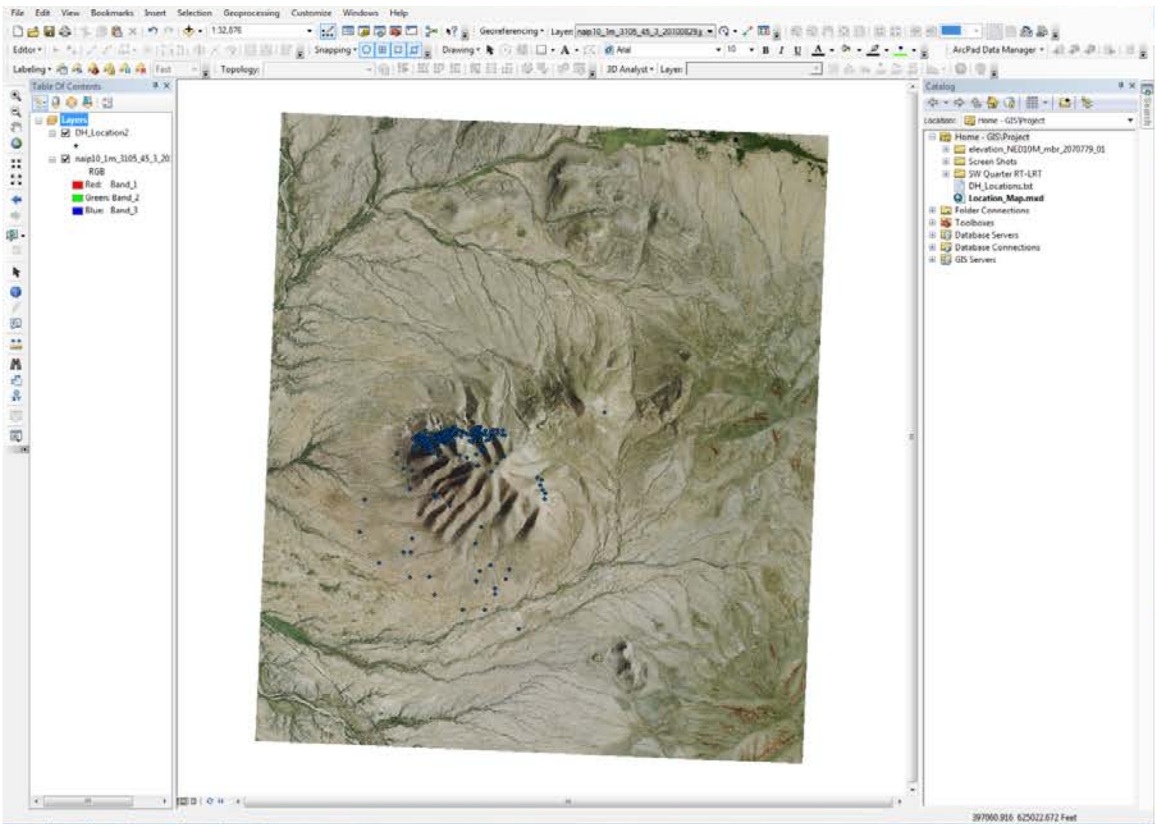

Figure 6: Importing the naip10_1m_3105_45_3_20100829.jp2 aerial ortho base map collected from TNRIS and produced by the National Agriculture Imagery Program.

In order to view the drill hole locations and labels more clearly, the symbology was changed by right clicking the DH_Locations2 layer in the TOC>Layer Properties> Symbology> and choosing a new symbol and color. The drill hole identification labels were added by right clicking the (DH_Location2) in the Table of Contents>Layer Properties>Label tab>checking the ‘Label all the features in this layer’> and changing the ‘Label Field’ to ‘ID’ (figure 7).

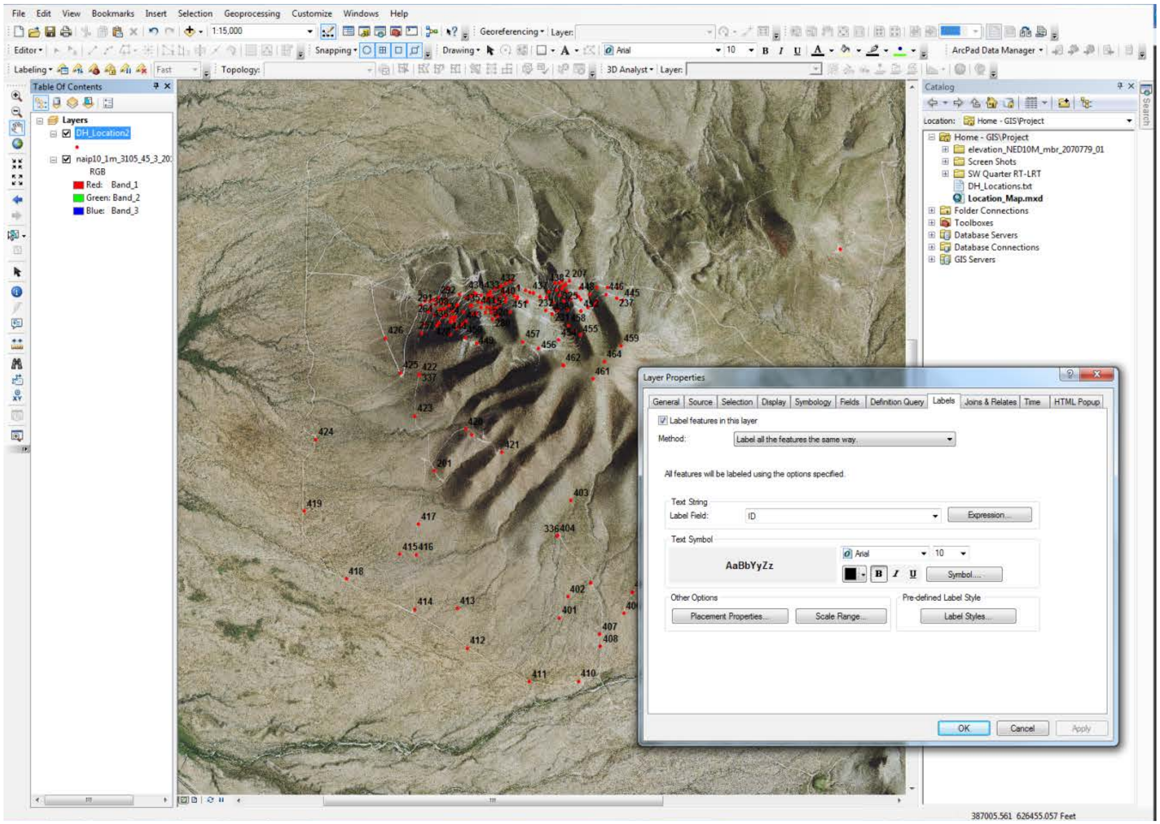

Figure 7: Adding the identification labels to the drill hole locations.

Loading ASTER DEM data and clipping

The DEM data (dem_10m_3105.prj) was loaded to the current map by Add Data>(dem_10m_3105.pjc). A transformation had to be preformed to convert the current projection of the DEM from GCS_North_America_1983 to GCS_North_America_1927 using a NAD_1927_To_NAD_1983_NADCON transformation in order to have the drill hole data and the DEM match (figure 8). The DEM was then clipped to the current aerial photo (naip10_1m_3105_45_3_20100829.jp2) using the Clip (Data Management) Tool within the System Toolboxes. The Input Raster was chosen (dem_10m_3105)>the Output Extent was chosen (naip10_1m_3105_45_3_20100829.jp2)>the output clip was saved to the personal geodatabase (dem_10m_3105_Clip2)> and the original DEM was removed from the TOC (figure 9).

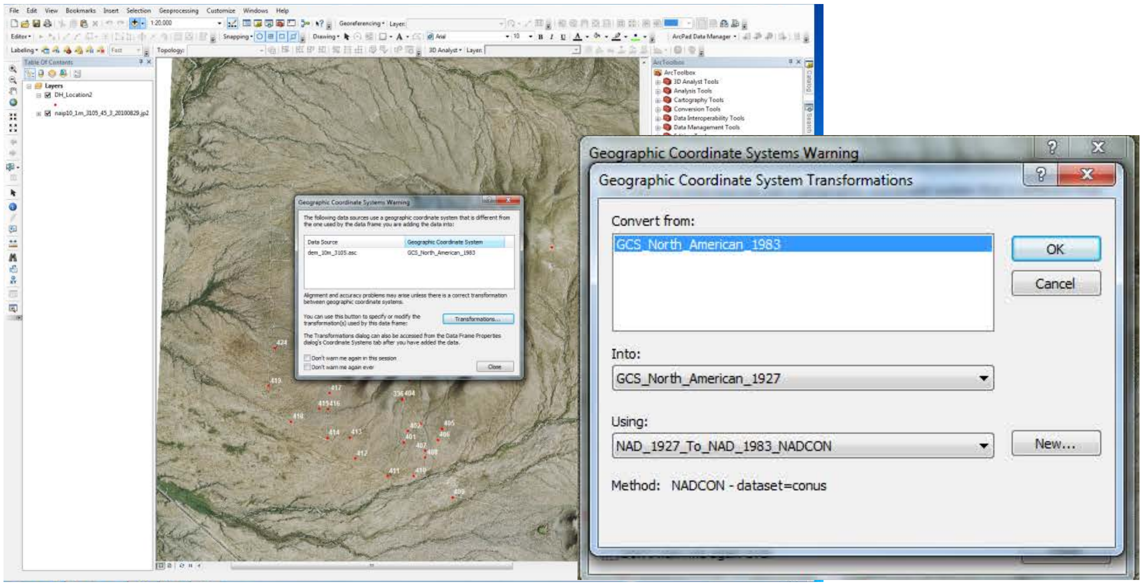

Figure 8: Loading the DEM data layer, and preforming the transformation from GCS_North_America_1983 to GCS_North_America_1927 using the NAD_1927_To_NAD_1983_NADCON transformation.

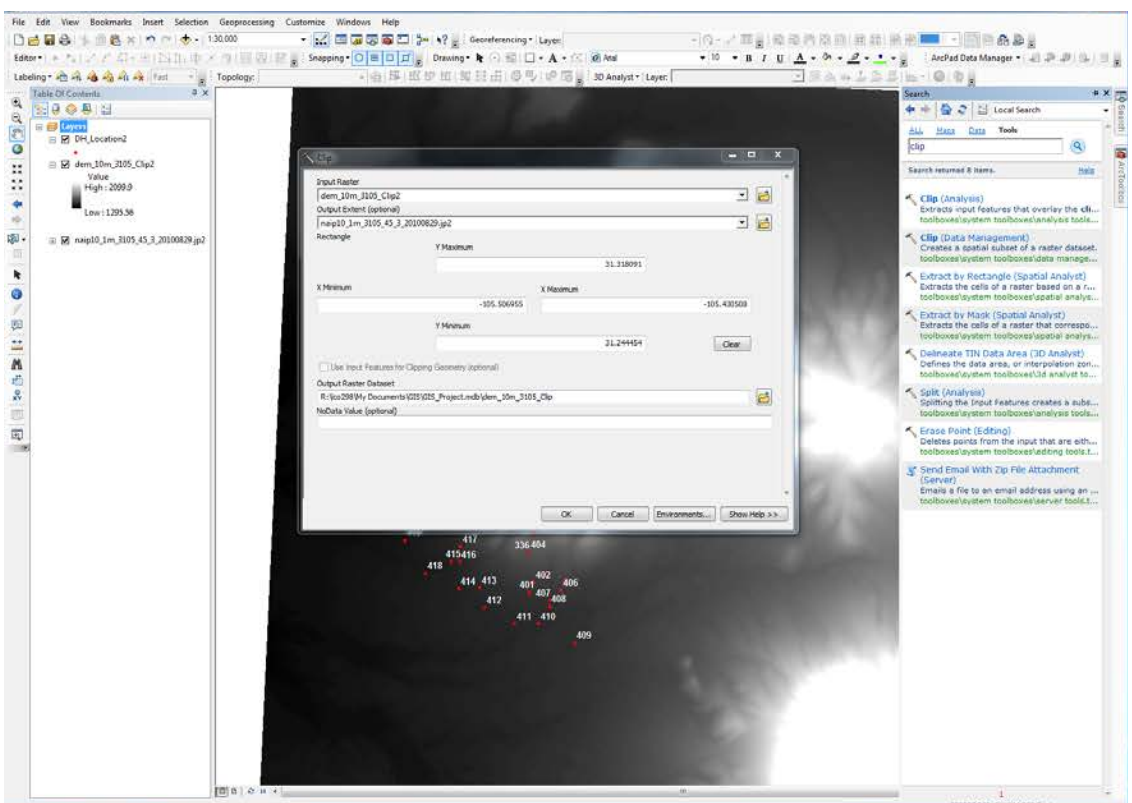

Figure 9: Clipping DEM layer to the aerial ortho layer and creating the clipped DEM layer (dem_10m_3105_Clip2).

The downloaded DEM data is in meters, which posed a challenge since all of the geochemical data is in feet. To convert the DEM layer from metric to imperial units, the Raster Calculator (Spatial Analyst) was used by searching within the ArcGIS Toolbox, ‘calculator’. The input equation was entered as (“dem_10m_3015_Clip2”*3.28084)>and the output file (M_Ft) was saved in the personal geodatabase. The new raster loaded automatically into the TOC, and the original clipped DEM layer (dem_10m_3105_Clip2) was removed (figure 10). Note: the smoothing and contouring process was completed once prior to the conversion from meters to feet, where this issue was originally recognized. It was then completed once more subsequent to the DEM conversion to feet, to ensure all information was in the same units.

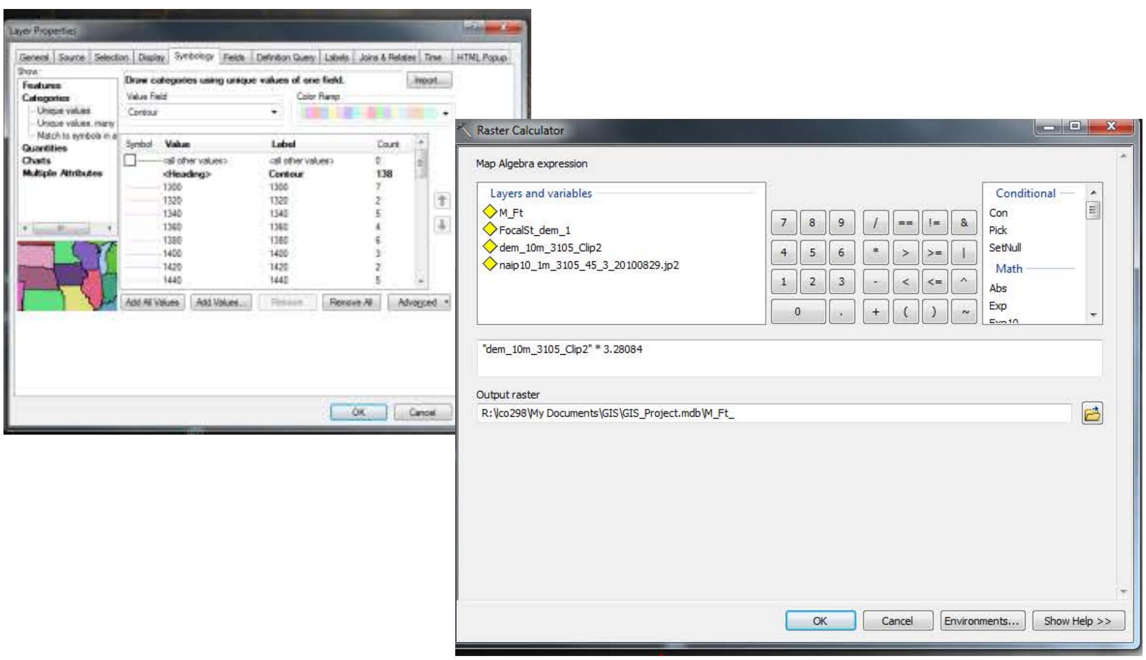

Figure 10: The contouring process was preformed before the DEM had been converted to imperial units (left screenshot), which brought to light the conversion issue. The clipped DEM was converted from meters to feet using the Raster Calculator (right screenshot).

2. Map enhancement

Creating contour lines

To create a set of contour lines for the Round Top DEM, a smoothed DEM was first created using the Focal Neighborhood tool within the Spatial Analyst Toolset. The Spatial Analyst extension was activated>within the ArcToolbox Spatial Analyst

Tools>Neighborhood>Focal Statistics. The Input Raster was chosen (dem_10m_3105_Clip2)>the Output Raster was chosen (FocalSt_dem_1) and saved within the personal geodatabase>the Neighborhood was changed to 'Circle,' and the Radius was changed to (2)>all other options were left to the default options. The smoothed DEM was automatically loaded into the current TOC (figure 11). The smoothed DEM layer showed no visible difference between the original DEM therefore the original was chosen to preform the contouring process in order to preserve as much detail as possible. The smoothed DEM was then removed from the TOC (figure 12).

To create the contour lines using the DEM data, ArcToolbox>Spatial Analyst Tools>Surface>Contour>the Input Raster was chosen (M_Ft)>the Output Raster was chosen to be (Contour_M_Ft1)>the contour interval was chosen to be 20>and the new file was saved within the personal geodatabase>the new layer was loaded into the current TOC (figure 13).

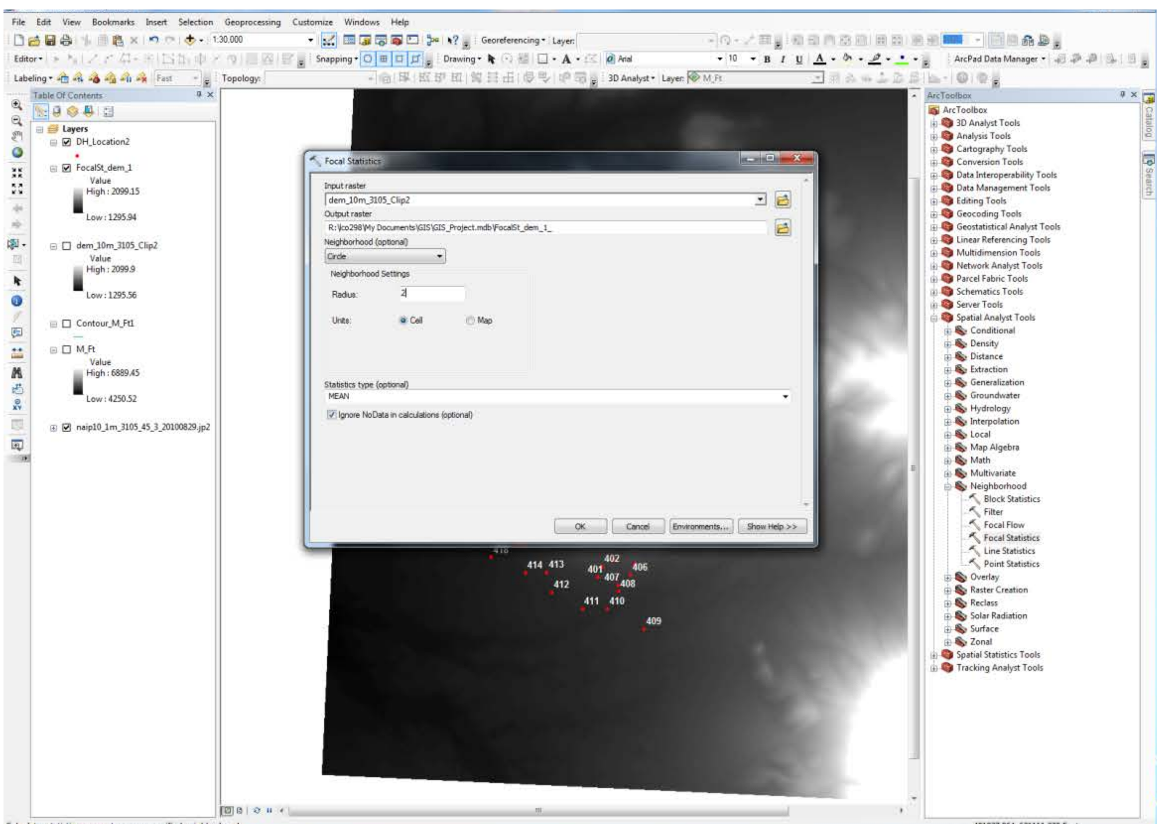

Figure 11: Creating a smoothed grid DEM using the Focal Statistics tool within the Spatial Analyst Toolset.

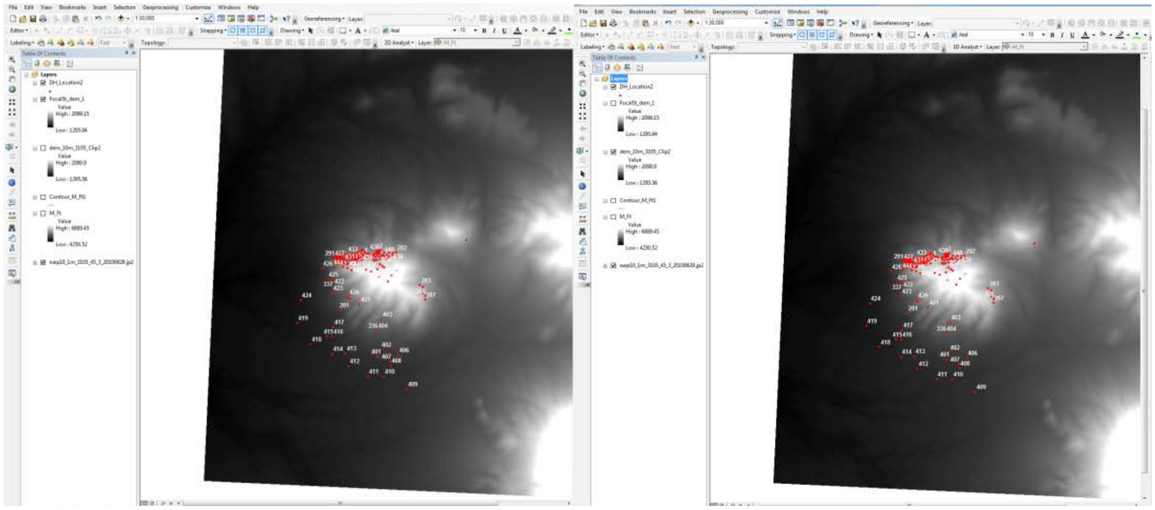

Figure 12: Smoothed DEM layer (left screenshot) versus original DEM (right screenshot). Note, there is no visible difference between the two DEM layers, therefore the original DEM was chosen to proceed in the contouring process in order to preserve as much detail as possible.

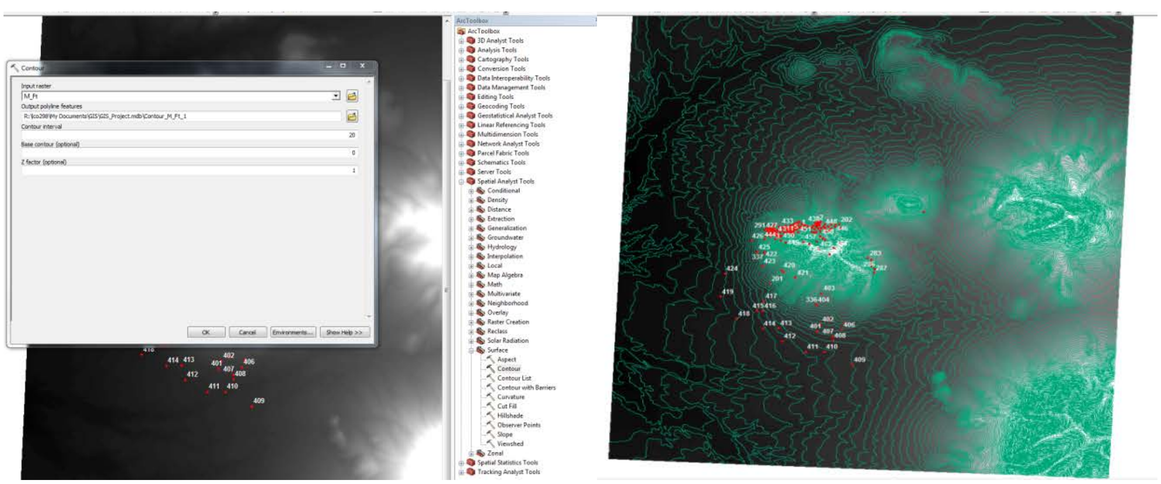

Figure 13: Making contour lines in feet using the Surface Spatial Analyst Tool (left screenshot). The completed contour lines layer (right screenshot).

The contour layer (Contour_M_Ft1) was then joined with the premade contour interval table (contsel.dfb) provided by www.esri.com/news/arcuser/0506/spring2006.html in order to be able create index contour lines. Using the instructions provided by the 'Creating Cool Contours Modeling Glacial Terrain with ArcGIS (Price, 2006),' article the table was added to the layers by Add Data>(cont-sel.dfb)>and joined to the existing contour layer by right clicking the (Contour_M_Ft) layer>Joins and Relates>Joins. 'Contour' was then chosen as the field in this layer that the join will be based on>(cont_sel) was chosen as the table to join to this layer>and ELEV_BASE was chosen as the field in the table to base the join on (figure 14).

Once joined, extra sets of contour lines were filtered out by right clicking (Contour_M_Ft1) layer>Properties>Definition Query tab>Query Builder. The expression (Cont_Sel.ELEV_020=1) was entered and applied (figure 15).

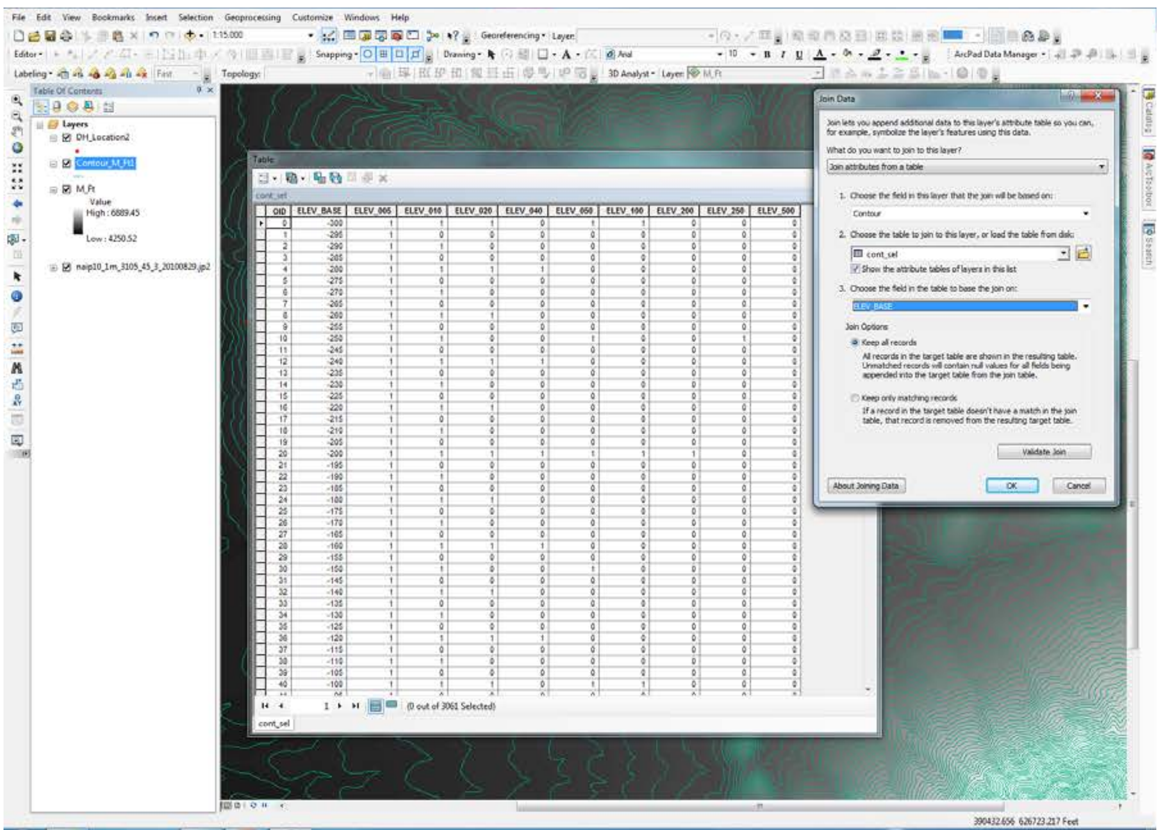

Figure 14: Joining the contour interval table (cont_sel.dfb) to the contour layer (Contour_M_Ft1).

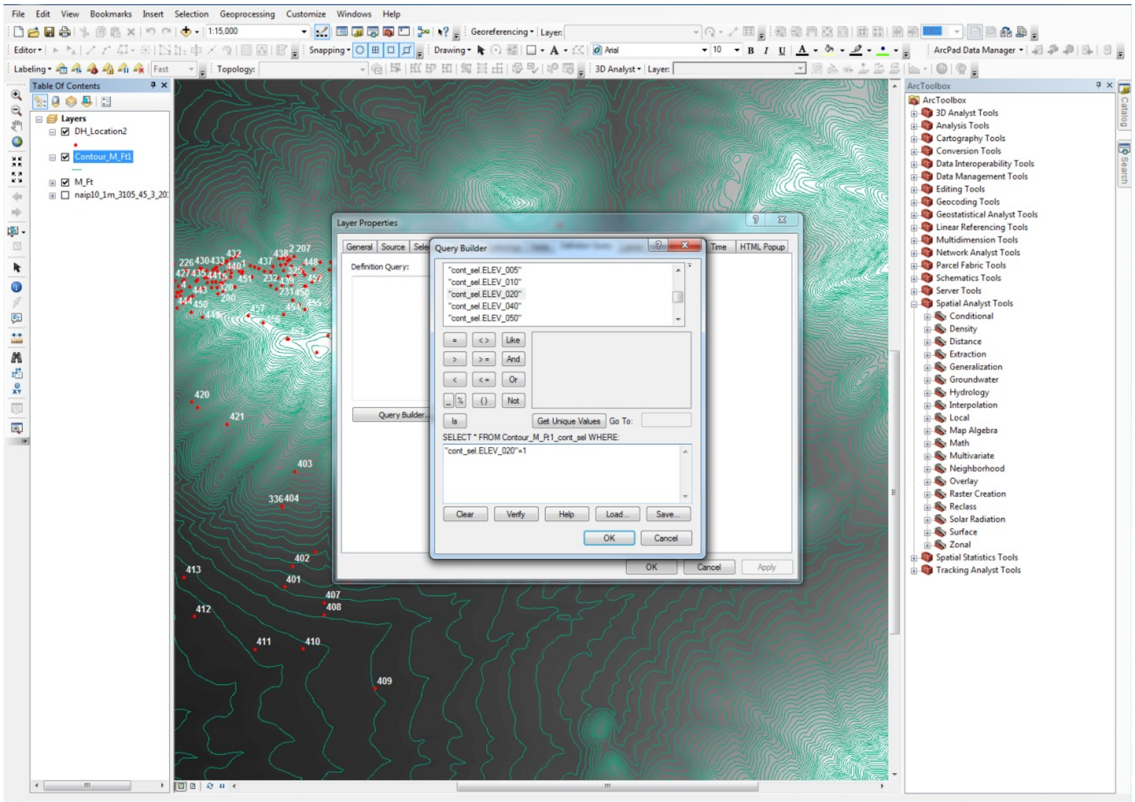

Figure 15: Using the Query Builder tool to filter contour lines not in 20-foot increments.

The index and intermediate contour lines were created by using the same tabular join that was used in the previous step with the (cont_sel.dfb) file, by opening the Properties screen for the (Contour_M_Ft1) layer>Symbology tab>Categories>Unique Value> 'cont.sel.ELEV_100' was chosen for the index contour value>Add All Values>right click '0' and selected reverse ordering. To define the symbology of the new index and intermediate contour lines, dark brown was selected as the color for both and the weight of the line was changed to 1.2 for the index contours and the 0.6 for the intermediate lines (figure 16).

The index contour lines were then labeled by, right clicking (Contour_M_Ft1) layer>Labels tab>checking the 'Label features in this layer>defining the Method as 'Define classes of features and label each class differently'. A new Label field was added by clicking 'Add'> Class Name: 'index'. The intervals to be labeled were chosen by clicking SQL Query>and filling in the expression "Contour_M_Ft1.Contour=4300 OR Contour_M_Ft1.Contour=4400 …" for all values of an even 100 foot increment (figure 17).

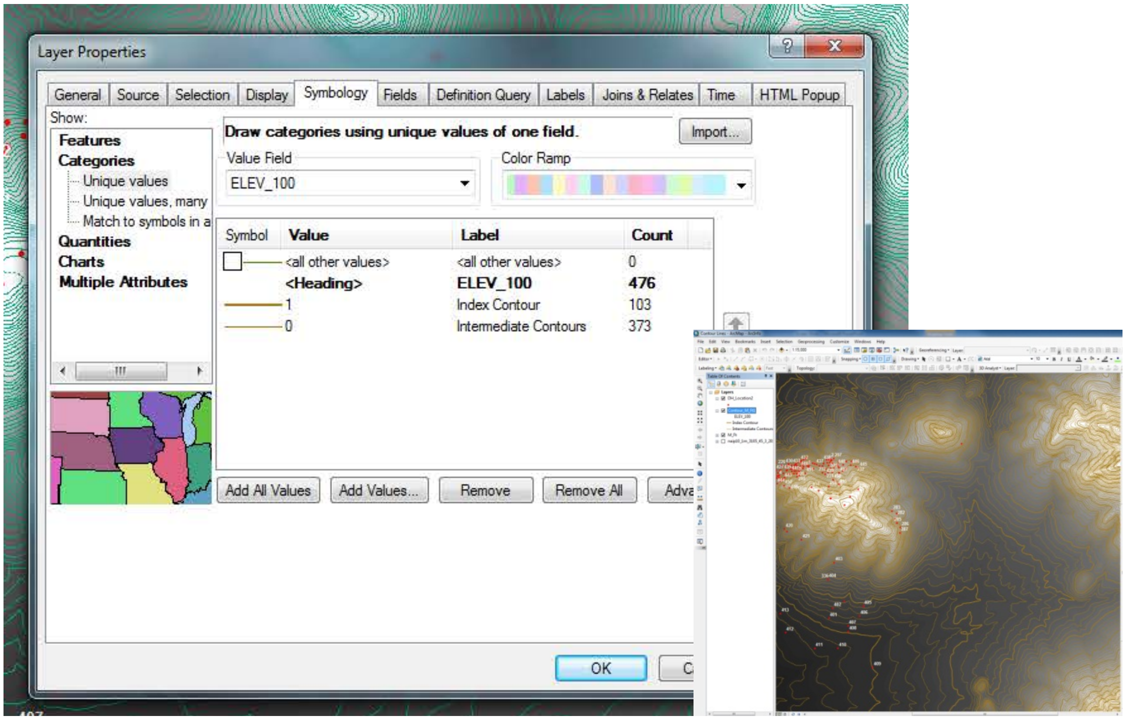

Figure 16: Setting the symbology for the index and intermediate contour lines (left screenshot). The applied symbology for the contour layer (right screenshot).

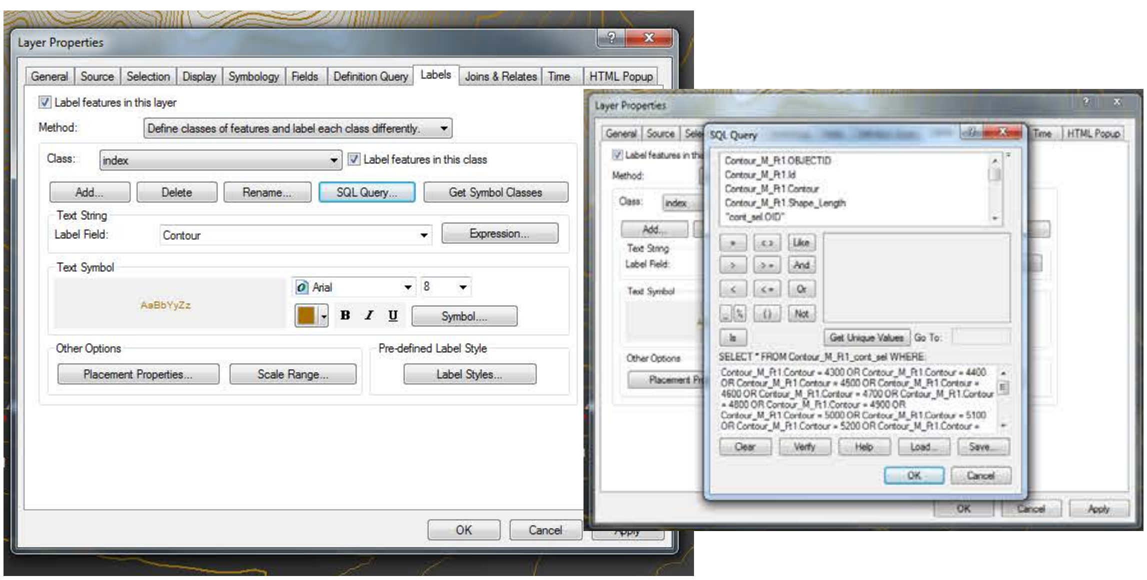

Figure 17: Labeling index contour lines at 100-foot increments through the Labels tab under the layer Properties.

Kriging Spatial Interpolation

HorizonA data was converted from an excel sheet to a text file with data containing the drill hole ID, the X, Y, and Z values of the sample location, and the trace element concentration for fluorine in ppm. This file was then loaded into the existing map by File>Data>Add XY Data>(HorizonA.txt). The fields for X, Y, and Z were chosen to match the text file, and the coordinate system was chosen by Edit>Import>(DH_Location2) since this coordinate system was already been established for this layer (figure 17). Once added to the TOC, this Events layer was converted to a feature class by right clicking the layer in the Table of Contents>Data>Export Data which created the HorizonA feature class (figure 18). Once this new feature class was added to the current map, then the original Event layer was removed. This process was continued for all of the Horizons A-J.

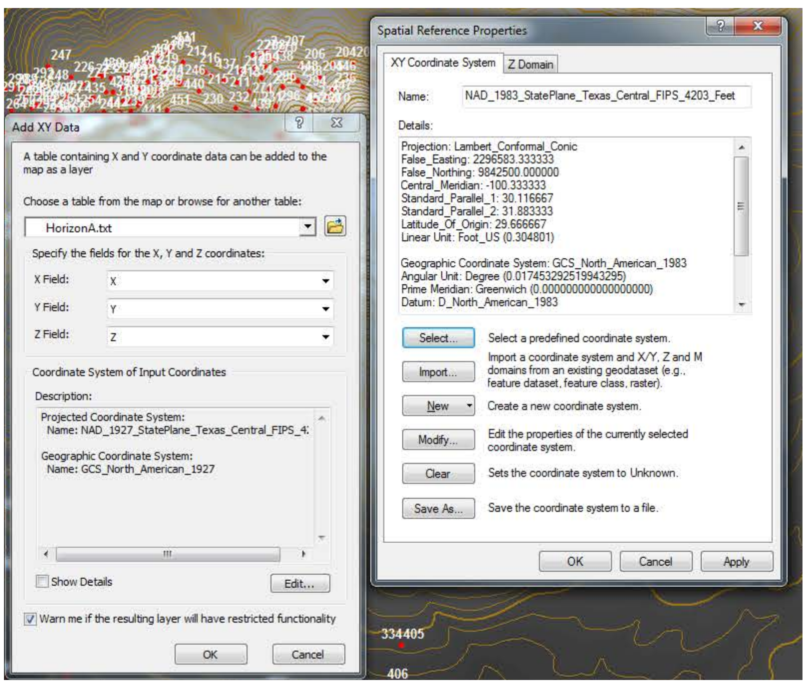

Figure 17: Importing HorizonA.txt into the current map and setting the projection parameters.

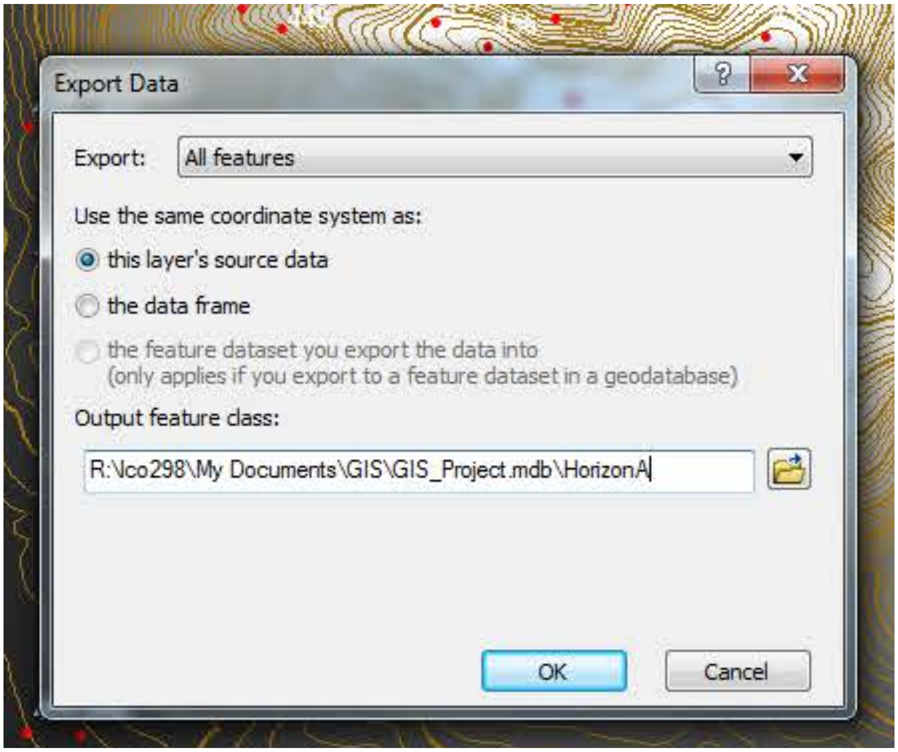

Figure 18: Exporting the Events layer to a feature class for HorizonA.

A kriging prediction map was created for each Horizon, though the general process will be described using only HorizonA. The Geostatistical Analyst was turned on by, Customize>Extensions>and checking the Geostatistical Analyst box. The Geostatistical tool was then displayed by, Customize>Tools>Geostatistical Analyst. From the Geostatistical Analyst toolbar>Geostatistical Wizard>Kriging/Cokriging was chosen under Methods>and under Input Data, the Source Dataset was set to HorizonA and the Data Field to (F)>Next (figure 19a). A window for 'Handling Coincidental Samples' next appears which is in to response to the multiple fluorine values attributed to each drill hole site, since processing is being conducted over 100-foot vertical intervals (figure 19b). The 'Mean' of all the values was chosen as the method to handle coincidental values since a representative suite for each Horizon is trying to be reached. Next, the Kriging Type was selected as Original>Output Type was set to Prediction>and the Transformation Type and Order of Trend Removal for Dataset #1 were left as None>Finish. As I leaned from multiple trial and error attempts, and many hours of research, there is a glitch in this part of the Geostatistical Wizard. At this step, if you press 'Next' (as one would think to do at this point), the system will crash. You must press 'Finish', not 'Next'. This in turn produces a Method Report that lists the statistical information such as; the Nugget size, the Lag size, and the Measurement Error Percent etc. (figure 19c). This report was saved for each Horizon analyses. When 'Ok' is pressed from this screen, the Kriging Prediction Map is automatically loaded into the current TOC.

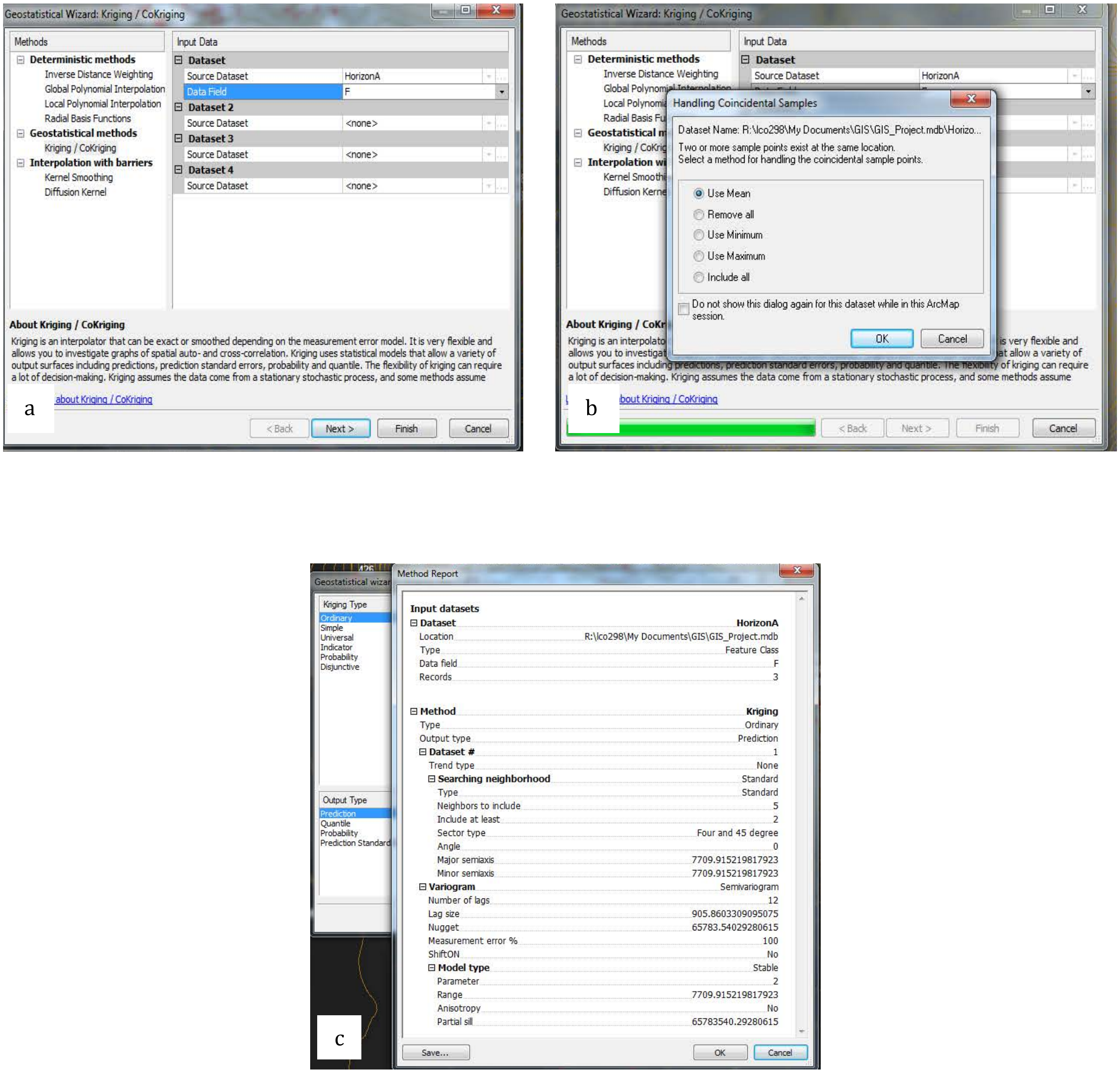

Figure 19: (a) Geostatistical Wizard tool, selecting interpolation type and dataset, (b) Handling Coincidental Samples window, the Mean of samples from the same location was selected, (c) Method Report produced before the Kriging Prediction Map.

To smooth the data further, the method of classification was alerted by right clicking the Krig layer in the TOC>Symbology Tab>Classify>and the Method was changed to Geometric Intervals with 10-20 intervals (depending on the range of fluorine values). Still under the Symbology Tab> the labels were changed to whole numbers so they would display better in the ledged by>clicking Label>Format Labels>and changing the number of decimal places from 9 to 0. The option to change the color ramp for the symbology is also under this tab. Additionally, (and I haven't decided which is best yet), but within this tab you can also change the display of the gradient to a hillshade, contour lines, and/or a grid. The transparency of the Kriging Projection Map was changed to 40% through the Display Tab.

Each Kriging Prediction Map was exported to a raster file by right clicking the layer>Data>Export to Raster>the input file is set automatically to the map of choice>and the Output file name was chosen. The new Rater layer is added automatically to the current TOC, allowing for the same changes listed above to be made to the symbology and labeling.

An unknown error was encountered at this point; the initial ranges of fluorine ppm established in the Kriging Prediction Map legend for some of the Horizons were drastically changed when converting from the Kriging Projection Map to a Raster file. This error has been noted in several Kriging/ArcGIS blogs, but no explanation for this artifact could be found. Additionally, for an unknown reason once the Kriging was performed the drill hole labels and index contour line labels no longer displayed even though all of the settings were correct and the labels displayed properly prior to the kriging process (figure 20).

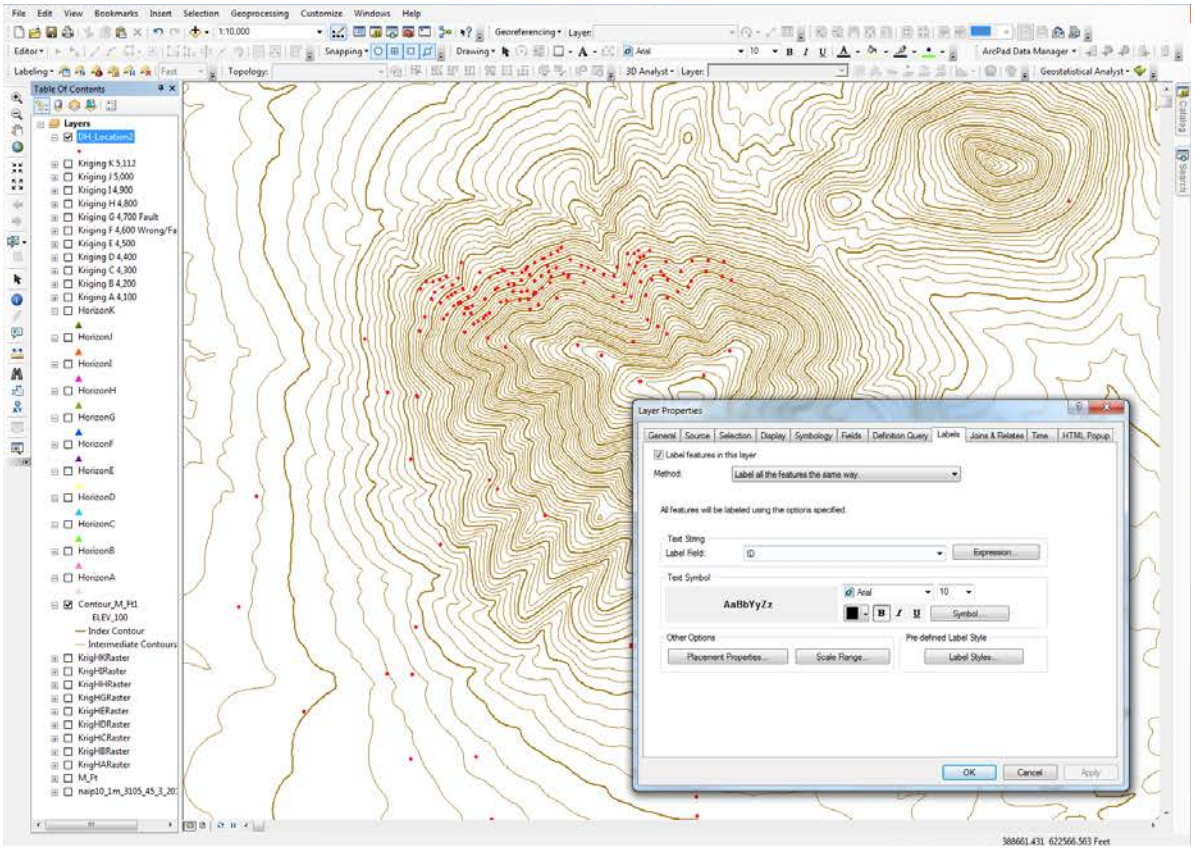

Figure 20: Error artifacts of kriging process where labels for the contour lines and drill holes no longer display even though the settings are correct and they displayed properly before the krig.

Kriging Results and Conclusions

The success of the kriging geostatistical analyses of the down hole geochemical data was mixed. I was able to complete the process and produce working Kriging Prediction Maps and manipulate the various variables associated with creating and displaying the kriging results. Though I was not able to answer the initial question regarding lateral correlation between fluorine concentration and elevation as a means to distinguish the various types of rhyolite that comprise the Round Top laccolith.

Due to propriety reasons, the final results of the kriging and cokriging analyses are not displayed in this report.

I addition to the kriging, an attempt was made to cokrig: a similar geostatistical analysis processes to that kriging except two variables are considered instead of one. A smaller dataset was used for the Cokriging Prediction Map (the suite of drill holes in the 200s), and the two variables considered were the fluorine concentration and the true down hole elevation with all coincidental values located at the same sample point utilized rather then averaged.

In future analyses, I believe the cokriging technique will be a more successful approach rather then breaking the data into arbitrary horizons, as done with the kriging analyses. Additionally, smaller sample sets in close proximity to each other will need to be used rather the data spanning the large portions of the field area, as done with the initial process

Additionally, with future analyses a better understanding of the statistics involved with the kriging/cokriging process will have to be examined in order to determine the quality of the data set and the analyses being preformed. In future endeavors, the accuracy of the analyses will also have to be tested, possibly by withholding a small subset of data and comparing the produced results with the known values.

For propriety reasons, the majority of the results from the kriging/cokriging analyses are not shown in this report.

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Rubin, J.N., Price, J.G., Henry, C.D. and Kppenaal, D.W., 1987, Cryolite-bearing and rare metal-enriched rhyolite, Sierra Blanca Peaks, Hudspeth County, Texas: American Mineralogist, v. 72, no. 1122-1130.