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An ArcMap Tool for Conducting Fry Analysis of Mapped Point Features

Abstract:

Mineral and petroleum explorationists commonly look for indications of regional trends in occurrences portrayed as points on maps, and use that knowledge in seeking new deposits. Commonly, however, the distribution of representative point features does not display a visually apparent geologically controlled spatial organization. In some circumstances, however, obscure trends that might have value for improving exploration success, can be identified within point-object distributions by a process of spatial point data manipulation referred to as Fry analysis (Carranza, 2009). Fry analysis was conceived as a means of investigating the strain ellipsoid for deformed rocks (Fry 1979; and Hanna and Fry 1979). More recently (Vearncombe and Vearncombe 1999; Vearncombe and Vearncombe 2001; Stubley 2004; and Carranza 2009) have published examples of using Fry plots and polar histograms to analyze point maps of mineral occurrence locations in order to infer geologic controls that may have influenced the spatial placement of the deposits on a regional-, mineral district-, or mineral deposit-scale.

The ArcMap™ Fry analysis script tools described in this tutorial are based on the point manipulation algorithm described by Fry (1979) Hanna and Fry (1979) and Carranza (2009).

Documentation

Introduction:

In this tutorial the data analyzed (Table 1 and Fig. 1) comprise the point locations of mapped mineral occurrences, mines, and prospects extracted from Alaska Resource Data Files (Freeman and Schafer 1999; Freeman and Schafer 2001). Geologic elements used in Figures and referenced in the text are extracted from the Geologic map of Newberry, et al. (1996). All the input data have been compiled, as esri® ArcGis® .shp files, using the esri® Alaska Albers, NAD 1983 equal area conic projection.

Shapefile	Features
GilmoreOccurrences.shp	27 Gilmore Dome mineral occurrences of all types
GilmoreProducers.shp	6 Gilmore Dome sites having recorded production
ClearyOccurrences.shp	146 Cleary Summit mineral occurrences of all types
ClearyProducers_alb83.shp	51 Cleary Summit sites having recorded production
EsterOccurrences.shp	59 Ester Dome mineral occurrences of all types
EsterProducers.shp	33 Ester Dome sites having recorded production
FairbanksGranitoidRocks.shp	48 Fairbanks district granitoid intrusives of all sizes
FairbanksGranCentroids.shp	48 Fairbanks district granitoid intrusive centroids
FairbanksProducers.shp	94 Fairbanks district producing mines and prospects
FairbanksFaultsVeins.shp	Fairbanks mining district faults and veins

Table 1. Fry analysis tutorial exercise shapefiles located in the ***SourceData*** folder in the Fry analysis tool tutorial directory.

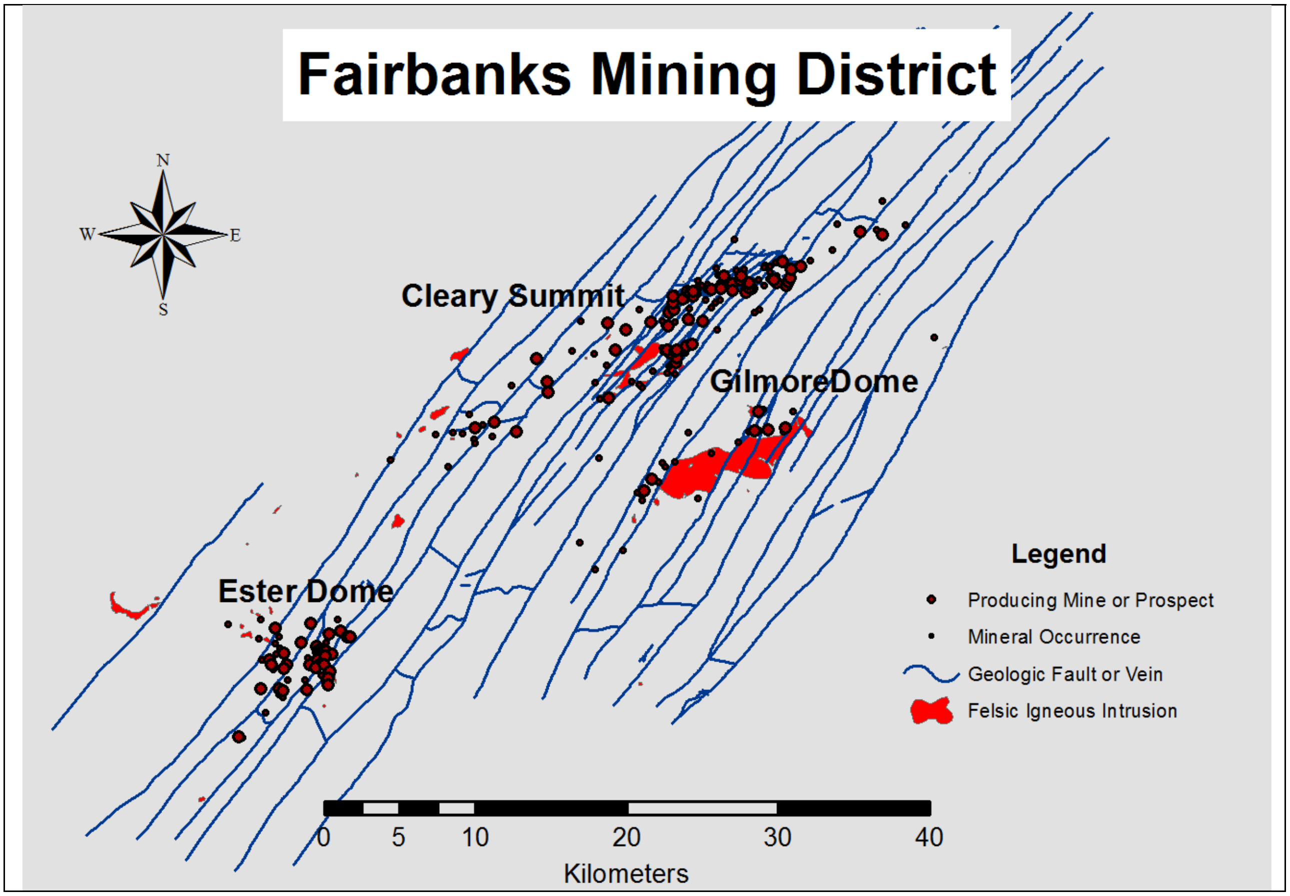

Figure 1. Map of point-objects (mineral occurrences, and producing mines or prospects) and geo-objects (district-scale faults, veins, and felsic igneous intrusions) in the Fairbanks Mining District, Alaska. Modified from, Newberry, et al. (1996).

The Fry Analysis tool implements an algorithm that:

1. Identifies the median center of a set of point-objects,
2. Selects the point-object closest to the median center of the INITIAL point-object data set as the index position for the Fry translation process,
3. Sequentially calculates the offset between the index position and each of the other points in the point-object set, adjusts the original X and Y coordinates of all points in the original point set by an amount equal to the calculated offset, and compiles the adjusted coordinates of each point in a .csv file. This process is repeated n times (where n = the number of original points) to generate a table of $(n^2 - n) + 1$ records of translated X, Y coordinates.
4. The coordinates in the .csv table are used to create a shapefile that is equivalent to a manually constructed Fry plot as described by Carranza (2009) and Hanna and Fry (1979).

The manual procedure for constructing a Fry plot is illustrated in Figure 6.5 in Carranza (2009).

The process has been similarly explained by Fry (1979), Hanna and Fry (1979) and is outlined below.

> Consider an original set of points displayed on a map having N - S index lines. Over this original map place a transparent overlay sheet having a central origin created by pair of N - S and E - W axes. Place the axes intersection on top of one of the original mapped points in

such a way that the N - S axis of the overlay is parallel to the index lines of the original map. Copy each original mapped point to the overlay sheet as it is now positioned. Move the axes intersection to each of the other original mapped points and copy the original points to the overlay sheet each time the overlay sheet is translated. When the overlay - copy process has been completed for every original map point, the overlay sheet will have accumulated (n^2 - n) points. The copied points accumulated on the overlay sheet constitutes a manually generated Fry plot.

If there are systematic point alignment trends in the original positions of the mapped points, they will be enhanced by the Fry translation procedure. Enhanced trends are made more visually apparent by obliquely viewing a plot of all the translated Fry points (Fig. 2).

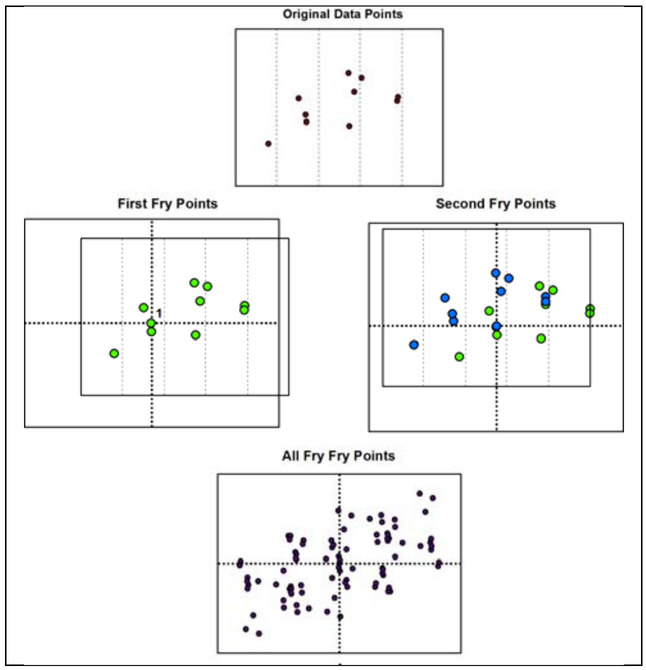

Figure 2. Manual manipulations used in generating a Fry plot from n original data points.

Additional information that can be extracted from the Fry plot includes the frequency of Fry point-pair azimuths calculated between Fry point-pairs that occur within a specified distances of one another. The Fry analysis tool allows the user to specify a limiting point-pair search radius and creates a polar histogram that summarizes the frequency of point-pair azimuths for all pair combinations that occur within that search radius as it is sequentially applied to each point in the Fry plot. If all the point-pairs of all the Fry Points are included in the search radius (the default setting of the tool), 100 mapped points, for example, will yield (10,000 - 100) = 9900 Fry points and (9900^2 -9900) i.e., 98, 000,100 point-pair azimuths. In this tutorial, If the search radius of the Fry analysis tool is set to encompass all Fry points, a set of 51 original mapped points (the number producing mines and prospects on Cleary Summit in the Fairbanks mining district, Alaska) will generate 6,499,950 Fry point-pair azimuths and requires between 4 -5 minutes to process. Processing time escalates rapidly for input point data sets larger than 50 points.

Two versions of the Fry analysis tool are included in this tutorial. Both will run in either the ArcMap™ "foreground" or "background" Python processing environment. They are identified by the appropriate inclusion of "foreground" or "background" in their name label. The foreground version of the tool processes data faster, but is limited to processing 75 input data points due to the algorithm used. The background version of the Fry Analysis tool does not have this constraint, but processes data at a slower rate, and because of the sheer number of calculations in larger data sets, is more conveniently run in the ArcMap™ background.

The first three exercises in this tutorial are meant to be implemented using the foreground version of the Fry analysis tool. **Exercsie_4** uses the background Fry Analysis tool to generate a regional Fry point-pair azimuth frequency polar histogram that summarizes the azimuth frequencies for all possible pair combination between Fry points derived from pas producing mines and prospects in the Fairbanks mining district (76,431,306 azimuths). The maximum number of original data points that can be processed with the background version of the Fry Analysis tool has not been determined.

Installing the Fry Analysis tool:

The current Fry Analysis tools require the esri® ArcMap™ Spatial Statistics extension and ArcMap™ functions in ArcGis® Desktop v. 10.1 and 10.2. The Python script for the Fry Analysis tool was written with Python version 2.7x which is included with ArcGis® v. 10.x site package. The Fry Analysis tools were developed on a desktop computer having a 64-bit Windows 7© operating system.

This tutorial utilizes the file structure and files contained in the ***FryAnalysisTutorial*** folder (***Fry Analysis Toolbox***, ***Documentation, Exercises,*** and ***SourceData***)**.**

Installing the ***Fry Analysis.tbx*** and other tutorial data files is accomplished by implementing the workflow outlined below:

- From the disk or download file provided, copy the ***FryAnalysisTutoria***l folder and subfolders to any disk drive location that can be accessed by ArcMap™. The ***FryAnalysisTutorial*** folder contains subfolders named:
  - ***Documentation***
  - ***Exercises***
    - ***Exercise_1***
    - ***Exercise_2***
    - ***Exercise_3***
    - ***Exercise_4***
  - ***Fry Analysis Toolbox***
  - ***Source Data***

  These folders can be given different user-preferred names, if desired.

- Link the Python script, "*FryAnalysis_foreground,"* found in the ***Fry Analysis Toolbox*** folder to the Fry Analysis (foreground) tool. This is accomplished in ArcMap™ by:

1. Right-Clicking the 'Fry Analysis (foreground)' tool in the ***Fry Analysis.tbx,***
2. Select "Properties" from the drop-down menu > select the "Source" tab in the properties dialog window> browse to the ***Fry Analysis Toolbox*** subfolder, and select the *FryAnalysis_foreground.py* script file to enter it in the browse-Open-"File name:" parameter window,
3. Left -click the "Open" button at the bottom of the browse-window to enter the selected script file in the "Script File:" parameter window of the script tool's Fry Analysis (foreground) >Properties> Source-tab dialog.
4. Check the "Run Python script in process" button on the Source tab.
5. Select the "General" tab of the Fry Analysis (foreground) tool's Properties dialog window, and make sure that "Store relative path names" (instead of absolute paths)" is checked, and that "Always run in foreground" is checked. Left-click "OK" to close the script tool's Properties dialog window.

The Fry Analysis (background) tool is installed in a similar fashion except that in step 2, above, the FryAnalysis _background.py script file is selected; and in step 5 above, make sure the "Always run in foreground" option button on the "General" tab is not checked.

Tutorial Exercises:

Four tutorial exercises are provided to illustrate how to use of the Fry Analysis tool to generate Fry plots and polar histograms mapped points representing mineral occurrences in the Fairbanks mining district, Alaska. The objective of the exercises is to determine whether there are obscure systematic deposit location alignment trends captured by the mapped deposit locations. If present, such alignment trends perhaps can be associated with a geologic process that causally affected the spatial distribution of the mapped deposit locations. The same analysis could be applied to point-locations representative of oil wells, centroids of igneous intrusives, geologic structural domes, or any feature locations that can appropriately be represented on a map as points.

For this tutorial, the shapefiles listed in Table 1 are provided in the "***SourceData***" subfolder of the "***FryAnalysisTutorial*"** folder. The Fry Analysis (foreground) tool is found in the ***FryAnalysisTutorial > Fry Analysis Toolbox > Fry Analysis.tbx*** ArcGis® toolbox The Fry Analysis tool is a "script" tool and will be displayed as such when it appears in the ArcMap™ Catalog window.

Exercise_1: Gilmore Dome

Set the ArcMap™ session Environment Workspace to : **<drive>:\<Path>\ *FryAnalysisTutorial***

In the ArcMap™ Catalog window, browse to the *GilmoreOccurrences.shp* file and drag it into the ArcMap data frame. Note that there is a pronounce overall NE - SW trend to the Gilmore mineral occurrence location point data set (Fig. 3). Can you discern other systematic trends in the spatial distribution of the data point locations as displayed in the data frame?

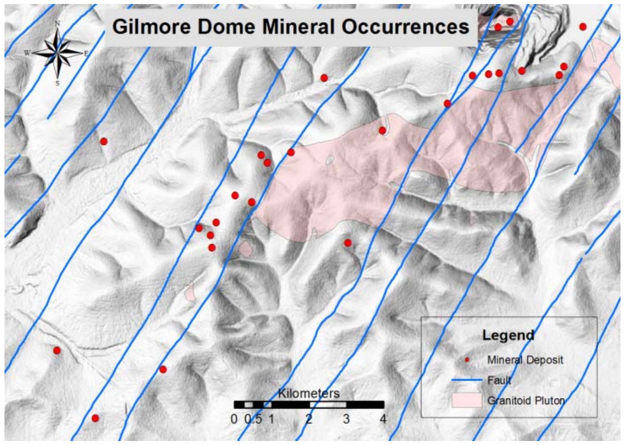

Figure 3. Spatial distribution of mineral occurrences in the Gilmore Dome area, Alaska.

Double-click the Fry Analysis (foreground) tool to open it. The following dialog window will appear (Fig. 4). The window prompts for two required and one optional user-specified parameters.

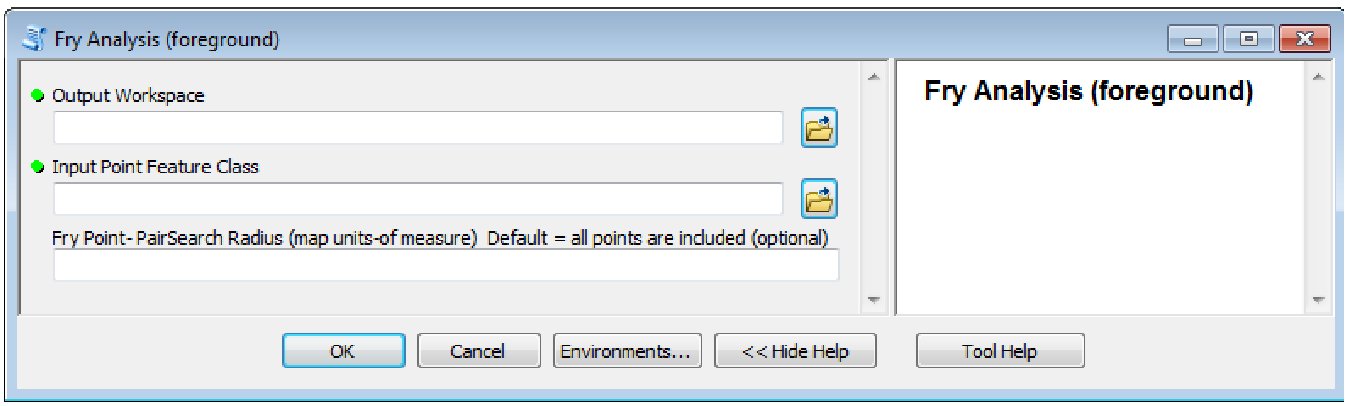

Figure 4. Fry Analysis (foreground) tool input parameter dialog interface window.

- <u>Output Workspace:</u> The Fry Analysis tool generates several generic output files. The output of the tool will be placed in the folder specified in the Output Workspace parameter window. It is convenient to keep these files together so that they can be consulted in order to evaluate the tools output. For this tutorial, in the Output Workspace Parameter window; browse to: **<drive>:\<Path>\ *FryAnalysisTutorial**Exercise_1,*** and click "Add".

- <u>Input Point Feature Class:</u> For this tutorial, the input point feature classes are located in the ***SourceData*** subfolder of the **<drive>:\<Path>\ *FryAnalysisTutorial*** folder. In the Input Point Feature Class parameter window, browse to the ***SourceData*** folder and select the *GilmoreOccurrences.shp* file to enter it in the browse "Name:" parameter window, click "Add" to enter the file name to the Input Point Feature Class parameter window of the Fry Analysis tool.

- Fry Point-Pair Search Radius: The Fry Point-Pair Search Radius is an optional parameter that controls how far the Fry Analysis tool will search around each Fry point to locate other points to pair with when computing the azimuth of point-pair alignments. The default for this parameter is to allow each point in the Fry plot to pair with every other point in the Fry plot. Accepting the default results in a polar histogram of point-pair azimuths that reflects the overall regional alignment trend of the entire Fry plot point set. Because (N^2 - N) azimuths (where N = the number of all Fry points) are calculated when the tool is used in default mode, it will require significant time to generate a polar histogram for a large number of Input Point features. For **Exercise_1**, accept the default setting of the Fry Analysis tool and leave the "Fry Point-Pair Search Radius" parameter window blank.

When all suggested parameter entries have been made, select 'OK' to launch the Fry Analysis tool.

All results generated by the Distance Distribution Analysis tool will be sent to the file folder named 'Exercise***_1' that*** was entered in the Output Workspace: parameter window of the Fry Analysis tool dialog window. After running the tool, it may be necessary to 'Refresh' the chosen Output Workspace in the ArcMap™ catalog window in order to make the polar histogram image icon appear in the lower ArcMap™ Catalog window (Right-click the ***Exercise_1*** subfolder and Select "Refresh").

The Fry Analysis tool generates 9 files:

Output File	Content
Gilmoreoccurrences_Copy.shp	Copy of original input .shp file
Gilmoreoccurrences_Copy.csv	XY coordinates of input point features
Gilmoreoccurrences_MedianCenter.shp	Median center point of input point set
PoinyXY.lyr	Intermediate layer of translated points
Polar_Histogram.png	**Polar Histogram of Fry point-pair azimuths**
TranslatedPoints.csv	.csv file of intermediate translated points
UniqueTranslatedPointAngles.dbf	.dbf file of esri® point-pair angles
UniqueTranslatedPoints.shp	.shp file of Fry Plot
UniqueTranslatedPoints.csv	**.csv file of Fry point-pair azimuths**

Table 2. Output files generated by each use of the Fry Analysis (foreground) tool.

Repetitive use of the tool with the same output workspace will overwrite all existing files having the same file names (except the *Polar_Histogram.png* file will not be overwritten if it is active in the ArcMap™ Table of Contents).

The *UniqueTranslatedPoints.shp* file and the *Polar_Histogram.png* image file are the final analytical output of each iteration of the Fry Analysis tool. The *UniqueTranslatedPoints.shp* file is the "Fry plot" generated from the Input Point Feature Class. In practice, one often uses the tool iteratively with a sequence of Point-Pair Search Radius values in order to look for local alignment trends in the Fry points derived from the original data. The polar histogram for each iteration can be preserved by uniquely renaming it in the output ArcMap™ catalog window prior to running a subsequent iteration of the tool. The Fry plot (*UniqueTranslatedPoints.shp*) remains the same for all iterations regardless of the point-pair search radius.

Open the attribute table of the *GilmoreOccurrences.shp* file and note that there are 27 recorded point locations. Open the *UniqueTranslatedPointAngles.dbf* file to see how many azimuths will be calculated. Note that the *UniqueTranslatedPointAngles* are not point-pair azimuths but are esri® Cartesian coordinate angles, where 0° corresponds to the positive Cartesian X-axis.

In the ***Exercise_1*** file folder locate the *UniqueTranslatedPoints.shp* file and drag it into the ArcMap™ data frame. This shapefile contains Fry translations of the original point features input to the Fry Analysis tool, and thus displays a "Fry plot" of the original point locations. Open the *UniqueTranslatedPoints.shp* file attribute table and note the plot of Fry points has 703 recorded point locations. The algorithm used in the Fry Analysis tool will generate $(n^2 - n) + 1$ unique Fry points (where n = the number of original point features).

In the attribute table of the *UniqueTranslatedPoints.shp* file, select the first record. Note that the corresponding selected point in the ArcMap™ data frame is at the center of the Fry plot and (by turning off the *UniqueTranslatedPoints.shp* file in the data frame) you will see that record corresponds to a record in the *GilmoreOccrrences_Copy.s*hp file that is at, or closest to, the median center of the original point-object data set. The median center point of the input data is recorded in the *GilmoreoccurencesMedianCenter.shp* file. Add that file to the data frame and zoom in to see both the first selected record and the median center point. Does the first record in the *UniqueTranslatedPoints.shp* belong to the Fry point that is closest to the median center of the Gilmore occurrences input data point set?

Locate the *Gilmoreoccurrences_MedianCenter.shp* file in the ***Exercise_***1 folder and drag it into the ArcMap™ data frame. This shapefile contains one point feature that is the median center of the original point data set. Note that the original *GilmoreOccrrences_Copy.s*hp file data point that is spatially closest to the median center of the original input point data set is the one that that corresponds to the first record of the *UniqueTranslatedPoints.shp* file that provides the center point for the Fry plot. The Fry Analysis tool positions the center of the Fry plot on the original data point that is closest to the median center location of the input data points (Fig. 5).

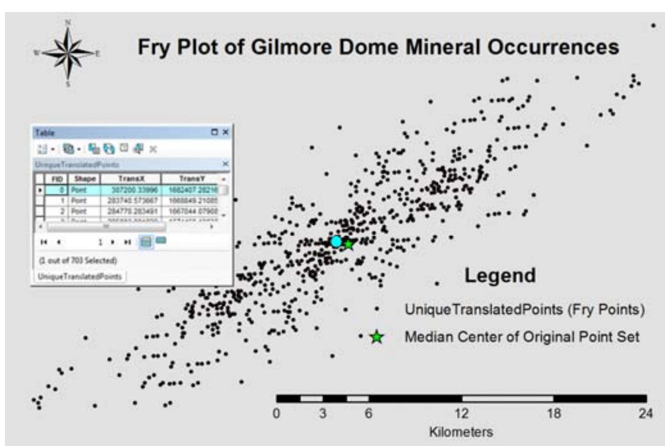

Figure 5. Fry plot of Gilmore Dome mineral occurrences showing the median center position of the original mineral occurrence locations (star) and the center point of the Fry plot linked to the location of the original data point closest to the median center (blue dot) of all original data points. The center point of the Fry plot corresponds to the first record of the *UniqueTranslatedPoints.shp* file.

Note that the overall trend of the Fry point locations is a visually enhanced verification of the NE - SW trend observed in the spatial distribution of the original input *GilmoreOccrrences_Copy.s*hp point data. Can you discern any other systematic trends in the Fry plot data points? If you have access to a printer, reduce the size of the point symbols in the plot of the *UniqueTranslatedPoints.shp* file data to (1) and print it. By looking obliquely at the plot and slowly rotating it in a horizontal plane, at least one other point alignment trend will be clearly visible. You also may be able to see that trend by viewing the computer screen from various oblique angles. (There is a noticeable alignment of Fry points in a series of rows having an 80° - 90° trend.) You also may pick out other, less well defined, point trends in the Fry plot.

The 80° - 90° trend of Fry points indicates that, for the Gilmore Dome mineral occurrences, there is some process that has imposed a systematic local constraint on the spatial distribution of the known mineral occurrence locations. The cause of that constraint may be known and thus confirm the validity of the information conveyed by the Fry plot, or the cause may be unknown; in which case the Fry plot suggests that field investigations designed to identify the cause of the trend observed might result in identifying additional geologic parameters useful for discovering unknown mineralization.

Locate the image icon "*Polar_Histogram.png"* contained in the ***Exercise_1*** folder, and drag it into the ArcMap™ data frame. Left-click "OK" on the 'Unknown Spatial Reference" dialog box that opens in the data frame (Fig. 6). Right-click the *Polar_Histogram.png* file in the ArcMap™ Table of Contents, and left-click "Zoom To Layer" in the drop-down menu. A polar histogram will appear in the data frame (fig. 7).

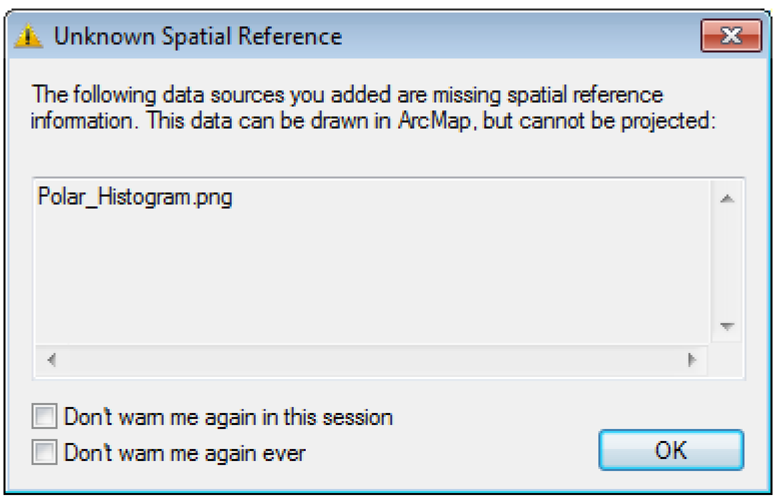

Figure 6. Unknown Spatial Reference dialog box for the Polar_Histogram.png

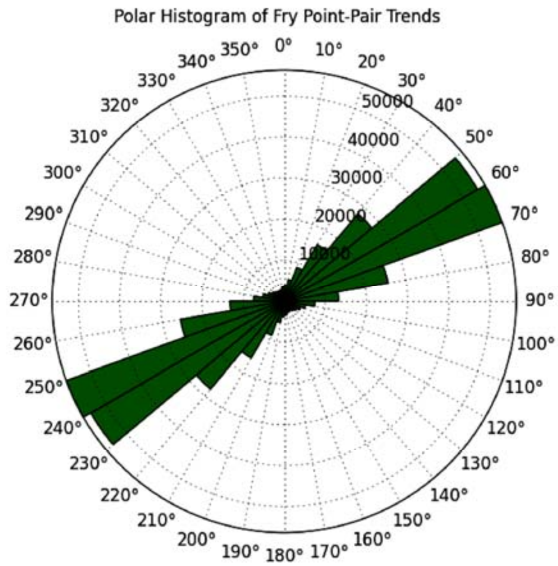

Figure 7. Polar histogram of azimuths calculated for all possible point-pairs in the Fry plot of Figure 5.

Note that the polar histogram that results from the tool's default search radius represents all possible point-pair azimuths for every Fry point in the Fry plot, and therefore displays a "regional" summary of point-pair azimuths. In general, such a plot of all possible point-pair azimuths will emphasize the overall trend of the entire Fry point data set. In this case the overall trend of the Fry points in the Fry plot varies between 50-70°. This overall trend is clearly discernible in the NE - SW elliptical map pattern of Fry points (Fig. 5). The internal Fry point alignment trends observed by oblique viewing of the Fry plot, however, are not clearly identified in the default regional polar histogram of Fry point-pair azimuth frequencies.

Use the Fry Analysis tool to reprocess the Gilmore Dome *GilmoreOccrrences.shp* file, but this time enter a value of 300 in the tool's <u>Fry Point-Pair Search Radius:</u> parameter window. This value will cause the tool to compute only azimuths between Fry point-pairs that are within 300 meters of one another. Thus, the polar histogram will present a display of "local" trends within the Gilmore Dome Fry plot (Fig. 5). Be aware that reprocessing the data set and sending the output to the same folder as previously used will cause all the previous output stored there to be overwritten, and that a new polar histogram image cannot be generated and stored there if the previous one is still in the ArcMap™ Table of Contents. If you want to preserve the current polar histogram, rename it in the ArcMap™ Catalog window (*GilmoreDomeRegPolHist.png*, for example).

Add the reprocessed *UniqueTranslatedPoints.shp* Fry points and the new local (300 m search radius) polar histogram to the data frame. Note the primary 80-90° point-pair azimuth trend displayed by the local polar histogram (Fig. 8). This corresponds to the most clearly discernible Fry point alignment within the Fry plot point set (Fig. 5). By obliquely viewing the Fry point plot, can you discern the other two next most prominent Fry point alignments indicated on the local polar histogram?

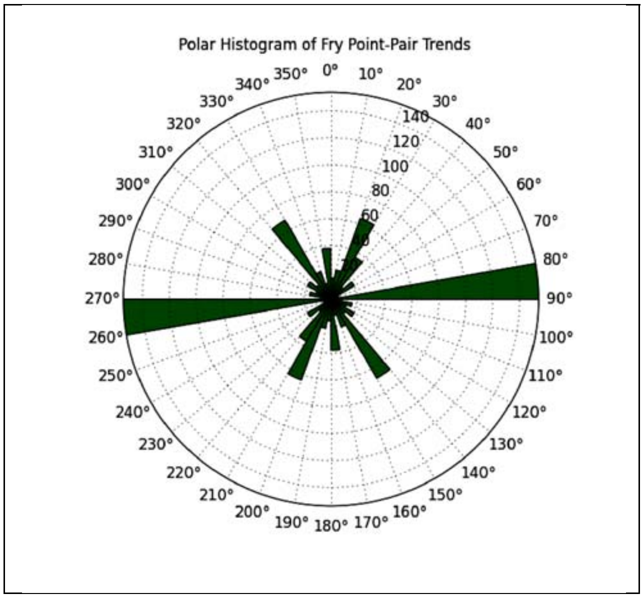

Figure 8. Polar histogram of azimuths measured between Gilmore Dome mineral occurrence Fry point-pairs within 300 m of each other.

Consider the Gilmore Dome mineral occurrence Fry Plot (Fig. 5), its regional polar histogram (Fig. 7), and the geologic map displayed in Figures 1 and 3. From the geologic map, It is apparent that the overall distribution of Gilmore Dome mineral occurrences are aligned along an approximate azimuth trend of about 60°; and this is reflected in the Fry plot and regional polar histogram. It also is apparent that many of the Gilmore Dome mineral occurrences are spatially close to the somewhat linear northern contact of the Gilmore Dome intrusive rocks. The Gilmore Dome deposits are genetically classified as skarns, therefore, in general, this observed spatial association is consistent with known geology. In detail, however, the dominant local trend in the Fry plot deviates by about 10° from the general trend of Gilmore Dome's northern intrusive contact. This suggests that there is an additional factor influencing the spatial distribution of mineral occurrences on Gilmore dome. As will be seen in Exercises 2 and 3 of this tutorial, the pronounced 80-90° trend seen in the local polar histogram of mineral occurrences near Gilmore Dome, can also be observed in the spatial distribution of deposits on Cleary Summit, and Ester Dome.

The 20-30° trend seen in the polar histogram of Gilmore Dome local Fry point-pairs closely conforms to the bearing of the pervasive NE high-angle faults mapped throughout the Fairbanks mining district (Fig. 1) and suggests that those faults may have exerted some influence on the spatial distribution Gilmore Dome mineral occurrences. The 320-330° point-pair alignment trend may reflect the influence of a major low angle mineralized shear system that has been observed in the Fort Knox mine pit, (Quandt, et al., 2008).

Exercise_2: Cleary Summit

The Cleary Summit group of mineral occurrences are included within a 38 km long NE trending band approximately centered on Cleary Summit (Fig. 1). There are 146 recorded mineral occurrences in this set of mineralized properties. The 51 occurrences compiled in *ClearyProducers_alb83.shp* file found in the ***SourceData*** folder, are mines or prospects within this zone that have some amount of recorded mineral production.

Use the same workflow that was followed **Exercise_1 for** creating Fry plots and polar histograms of Fry point-pair azimuths, to generate the same kind of information for the Cleary Summit producing mineral deposit locations. Set the Output Workspace: parameter to: ***FryAnalysis > Exercise_2***. In the Input Point Feature Class; parameter window, browse to the *ClearyProducers_alb83.shp* file in the ***FryAnalysis > SourceData*** folder and "Add" it to the parameter window. Leave the Fry Point-Pair Search Radius: parameter window empty. The Fry Analysis tool will require about 4-6 minutes to complete the processing for all 51 deposit locations.

When the Fry Analysis tool completes the data point processing, drag the *UniqueTranslatedPoints.shp* file (Fry plot) into the ArcMap™ data frame and open the attribute table. How many Fry points have been generated? Does this number equal $(n^2 - n) +1$, where n = the number of original points? (Answer = 2551)

The default setting of the Fry Analysis tool should calculate, and generate a record for $(N^2 - N)$ point-pair azimuths, where N = the number of Fry points. Calculate the number of expected point pair azimuths that the tool needs to calculate to make a polar histogram of Fry point-pair azimuths for the original 51 mineral deposit locations on Cleary Summit. (Answer = 6,505,050)

All the Fry point-pair ANGLES calculated by the Fry Analysis tool are compiled in the *UniqueTranslatedPointAngles.dbf* table found in the **Exercise_2** folder. Drag the *UniqueTranslatedPointAngles. dbf* file into the ArcMap™ data frame, Right-click its icon in the ArcMap™ Table of Contents and select "Open" to view the table's records. How many records are in the *UniqueTranslatedPointAngles.dbf* table? (Answer = 6,505,050)

Examine the Fry plot created by displaying the point features of *UniqueTranslatedPoints.shp* in the ArcMap™ data frame (Fig. 9). By decreasing the size of the point symbols to (1), varying the scale of the map display, and viewing the plot at various oblique angles, you should be able to discern several internal point alignments within the overall set of Fry points.

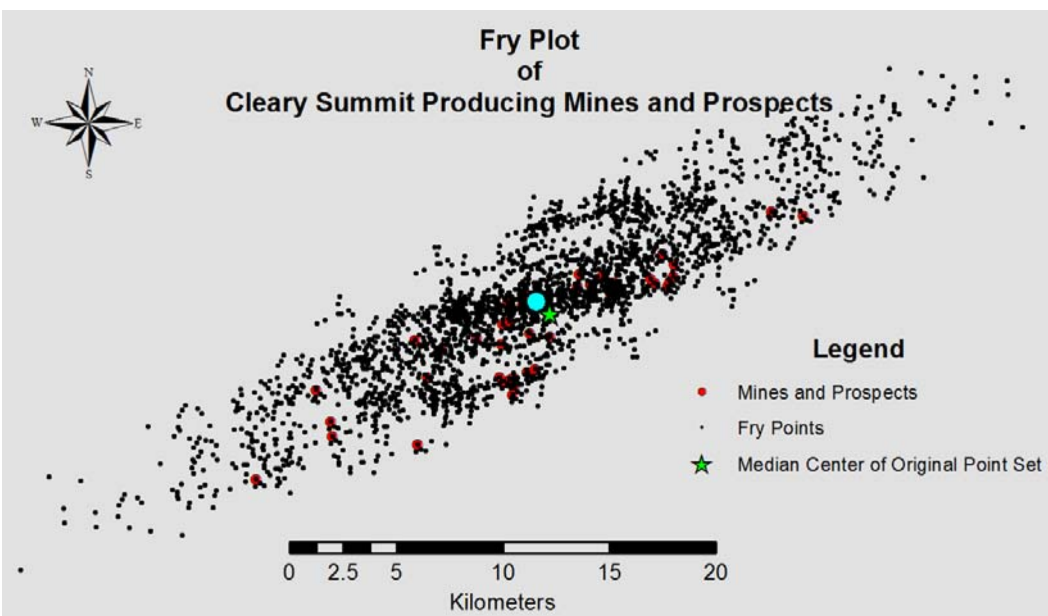

Figure 9. Fry plot generated from the recorded point locations of 51 mines and prospects approximately spanning Cleary Summit

Click and drag the *Polar_Histogram.png* image file (Cleary Summit polar histogram of regional point-pair azimuths) into the ArcMap™ data frame. Right-click the image file and Select; "Zoom to Layer" (Fig. 10). What point-pair trends are emphasized in the polar histogram? Does the regional polar histogram (azimuths for all possible point pairs) identify the point-pair trends that you discerned by closely examining the Fry plot from various oblique angles and various map scales? What information does the regional polar histogram convey?

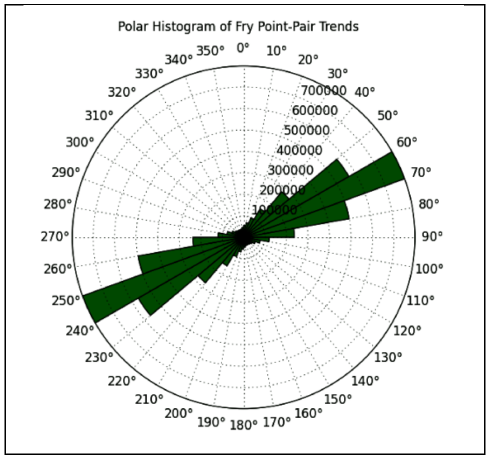

Figure 10. Polar histogram of all point-pair azimuths calculated from the Fry plot of Cleary Summit mine and prospect locations.

Rename the *Polar_Histogram.png* file as *ClearyRegionalPolHist.png*. Rename the *UniqueTranslatedPoints.shp file as ClearyRegionalFryPlot.shp.* Rerun the Fry Analysis tool with the following input parameters: Output Workspace: set to: ***FryAnalysis > Exercise_2***; ***Input*** Point Feature Class: parameter set to: *ClearyProducers_alb83.shp* file; Fry Point-Pair Search Radius: parameter set to: 250. Because a small local search radius limit has been imposed on the Fry analysis tool, processing will be completed in a few seconds.

Right-click ***the Exercise_2*** subfolder and Select "Refresh." Select the *UniqueTranslatedPoints.shp* file, and the *Polar_histogram.png* image file and drag them into the ArcMap™ data frame.

Compare the Fry plot generated by the Fry Analysis tool when the tool has a Fry plot point-pair search radius restriction of 250 meters vs. the Fry plot generated when there was no such restriction (*ClearyRegionalFryPlot.shp*). You will see that they are exactly the same because the Fry Analysis tool always generates a Fry plot from all the input data points regardless of the search radius used.

Compare the polar histogram of azimuths generated with a Fry point-pair search radius restriction of 250 meters (*Polar_Histogram.png*) vs. the polar histogram of azimuths generated when there was no such restriction (*ClearyRegionalPolHist.png*). You will see (Fig. 11 a., b.) that there is a major difference in appearance. The search radius restriction limits the spatial domain from which each Fry point may select other Fry points when calculating point-pair azimuths. This has the effect of filtering out region-scale point alignment trends and emphasizing systematic point-pair alignments that occur locally within the overall comprehensive Fry point data set.

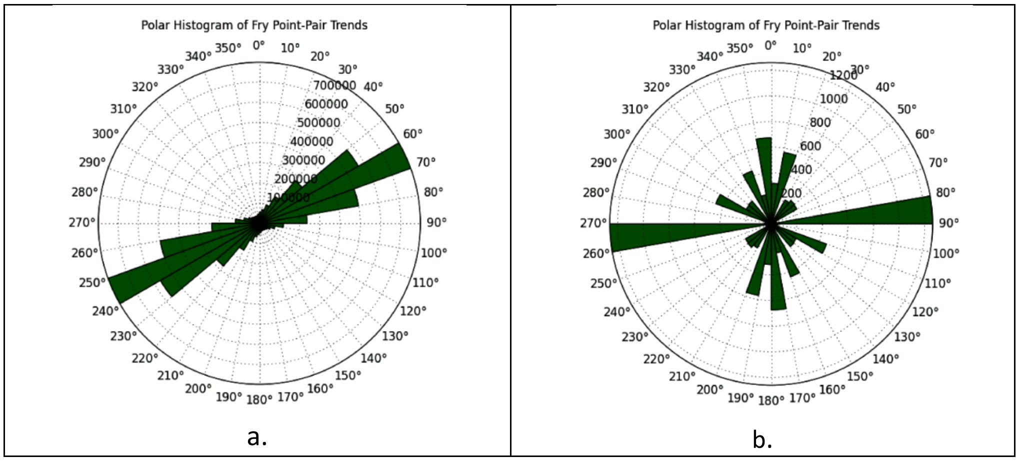

Figure 11. Comparison of the regional polar histogram of Fry point-pair alignments (a.) vs. the polar histogram of Fry point-pair alignment azimuths that occur within a 250 meter search radius of each point in the Cleary Summit mines prospects Fry plot (b.).

Re-examine the Fry plot of Cleary Summit producing mines and prospects generated by the Fry Analysis tool. Reduce the point symbol size to (1). Vary the map scale and examine the plot as you try to visually discern point alignment trends within the plot. You will probably be able to identify at least 3 distinct trends in addition to the single overall elongate NE trending axis of the composite Fry plot point set. Some trends become most apparent at small scale, while others are not revealed clearly until the scale is increased.

The most prevalent point-pair trend in the Fry plot (Fig. 12) is a systematic closely spaced Fry point alignment trending 80-90°. This trend is clearly captured by the polar histogram constructed from data acquired using a 250 meter search radius (Fig 11 b.). Other discernible point trends in the Fry plot are much less organized, but are persistently reflected in polar histograms constructed using search radii ranging from 150 - 350 meters.

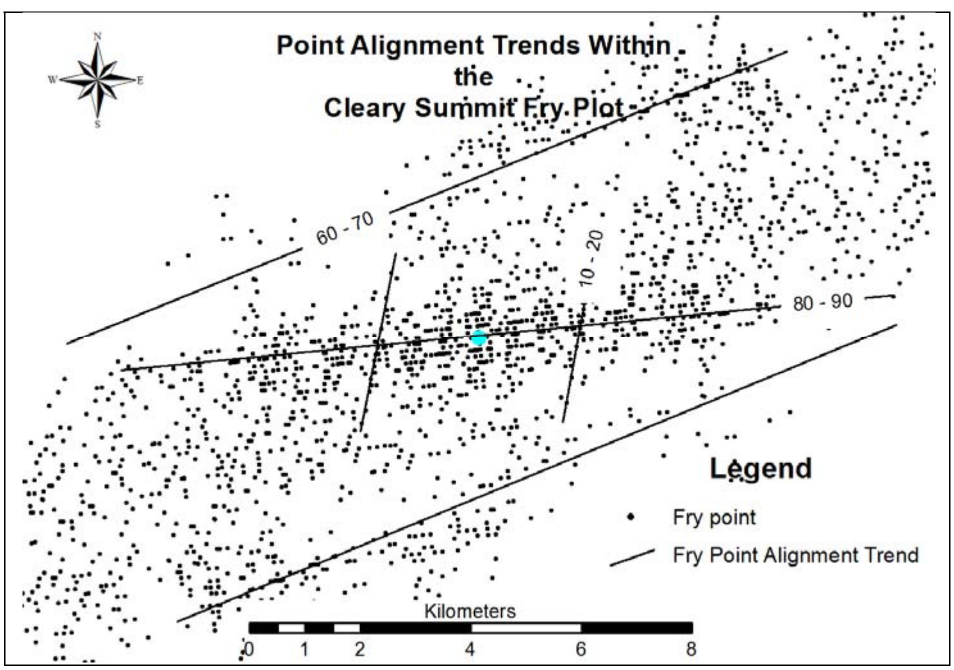

Figure 12. Fry point alignment trends present within the Fry plot of Cleary Summit mine and prospect locations (80 - 90°, 60 - 70°, and 10 - 20°) Center of Fry plot (blue dot).

The preceding two sets of Fairbanks mining district mineral occurrence groups, Gilmore Dome and Cleary Summit, have some similar spatial location attributes (Fig. 13 a. - d.).

- The original locations recorded for deposits in each group are spatially distributed in patterns that have SE-NE trends that are enhanced in their respective Fry plots (Figures 5 and 9).
- Polar histograms of regional point-pair azimuths for both deposit groups reflect similar dominant 50-70° orientations for the overall group patterns (Figures 7 and 10),
- Polar histograms of local point-pair azimuths for both deposit groups reflect similar dominant 80-90° Fry point-pair azimuth alignments (Figures 13 c. and d.).

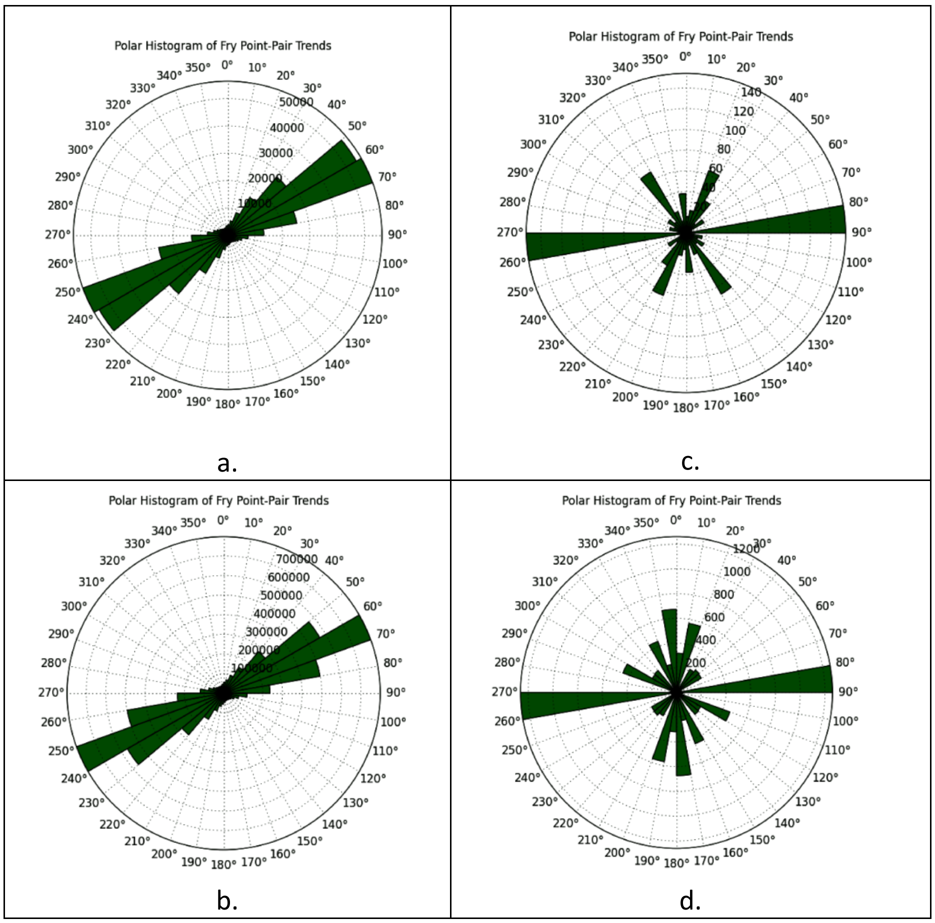

Figure 13. Polar histograms of Fry points associated with mineral deposits located in the Gilmore Dome and Cleary Summit areas of the Fairbanks mining district, Alaska. a. = regional Fry point-pair azimuths for Gilmore Dome deposits, b. = regional Fry point-pair azimuths for Cleary Summit deposits, c. = local Fry point-pair azimuths for Gilmore Dome deposits, and d. = local Fry point-pair azimuths for Cleary Summit deposits.

The common 80-90° local Fry point alignment displayed in the polar histograms for Cleary Summit and Gilmore Dome producing deposits suggest the influence of a common geologic process in both areas.

Exercise_3: Ester Dome

Ester Dome defines the current southwest extent of the Fairbanks mining district (Fig. 1). Unlike the Gilmore Dome and Cleary Summit groups of mineral deposits, the spatial distribution of those associated with Ester Dome do not have a readily apparent preferred orientation (Fig. 14)

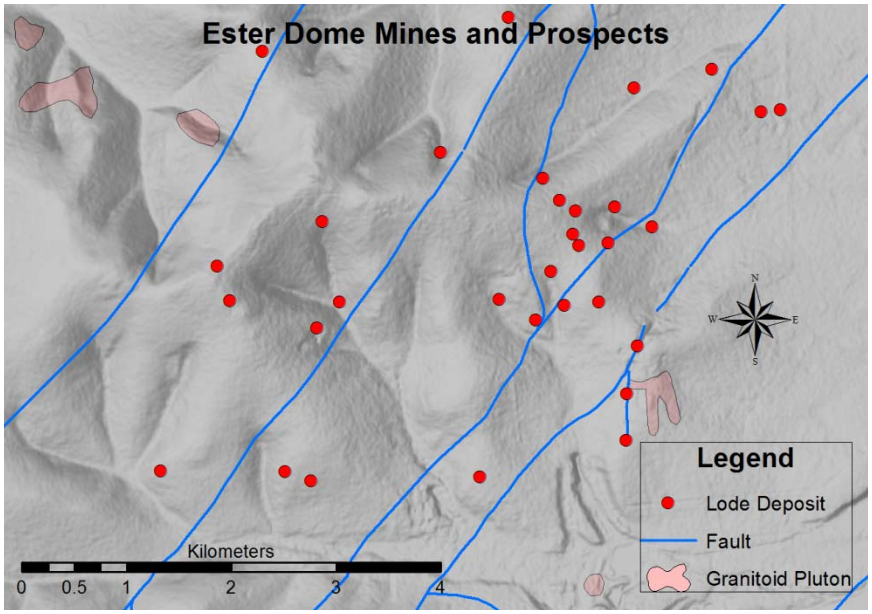

Figure 14. Location of lode mines and prospects located on Ester Dome for which there is recorded production.

Using the *EsterProducers.shp* file found in the ***SourceData*** folder, use the Fry Analysis tool to generate a Fry plot and regional polar histogram of point-pair azimuths for the producing mines and prospects located on Ester Dome. Set the <u>Output Workspace:</u> parameter to the ***Exercise_3*** folder.

The Fry plot of producing mines and prospects in the Ester Dome area and the associated regional polar histogram are displayed in Figure 15. When considered as a whole, the plot of Ester Dome Fry points display a clear SW - NE trend that is reflected in the regional polar histogram as a maximum azimuth frequency between 40-60°. Though more diffuse, this azimuth of this trend is similar to the regional trend in mineral deposit Fry point distributions displayed by the Gilmore Dome and Cleary Summit data (Fig. 13). The Fry plot of Ester Dome mineral deposit location data also displays several discernible local Fry point alignments that are not reflected in the regional polar histogram.

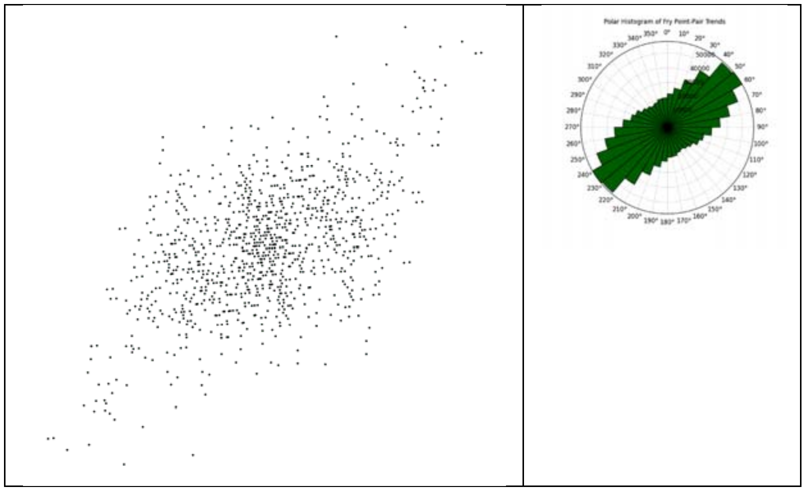

Figure 15. Fry plot and regional polar histogram derived from 33 Ester Dome mine and prospect locations.

Rerun the Fry Analysis tool after renaming the *Polar_Histogram.png* image file: *'EsterProdReg.png,'* to prevent it from being overwritten. Explore a series of polar histograms generated with local search radius values ranging for 600 to 300 meters. Rename each *Polar_Histogram.png* file with an interpretable name so that you can preserve it for comparison. For example, if a search radius of 500 meters is used, you might rename '*Polar_Histogam.png*' as *'EsterProd500m.png,'* before reprocessing the source data. The sequence of polar histograms that emerge from this workflow will document the emergence of several local Fry point-pair alignments that are discernible within the overall Fry plot.

Select a local polar histogram that you believe best displays the internal Fry point alignments that you can discern in the Ester Dome mineral deposit Fry plot. You should be able to see a major 80-90° Fry point alignment (Fig 16 f.) that is identical in orientation to the major local Fry point alignments seen in the Gilmore Dome and Cleary Summit data (Figures 13 b. and d.).

Subordinate local point-pair alignment trends displayed in the polar histograms of local Fry point-pair azimuths generated from the point locations of mineral occurrences throughout the Fairbanks area indicate that there are district wide similarities in the spatial alignment of mineral occurrences within separated clusters of deposits. These common local alignments are not apparent in the primary map of the deposits' locations (Fig. 1). For example, a common 80 - 90° mineral occurrence alignment trend is displayed in polar histograms of local Fry point-pairs constructed for each of the three sub-areas of the district (Fig.14 b, d, and f). Similarly, although the relative frequencies of more subordinate local point-pair alignment trends vary, the azimuths of subordinate alignment trends also have some similarities among the Fairbanks mining district's sub-areas.

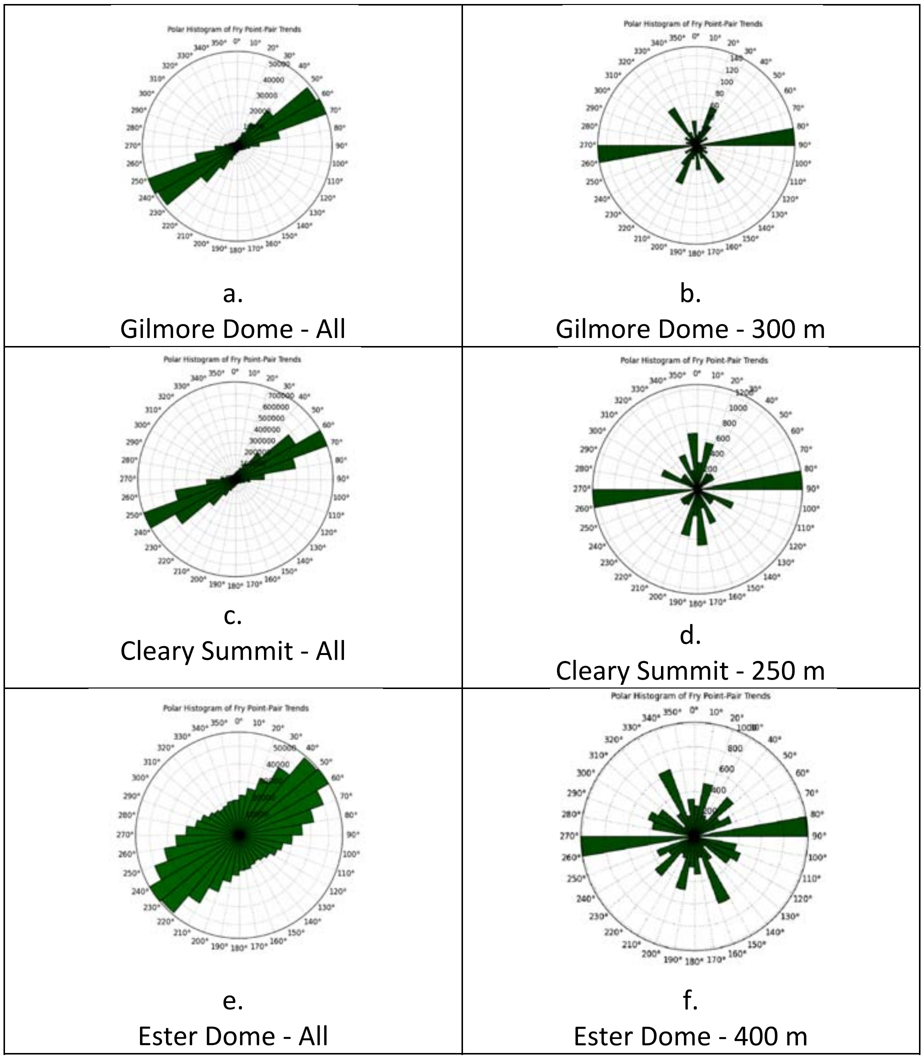

Figure 16. Polar histograms of Fry point-pair alignments generated from mineral deposit groups associated with Gilmore Dome, Cleary Summit, and Ester Dome in the Fairbanks mining district, Alaska. Regional polar histograms of Fry point-pair azimuth frequencies (a., c., e.); Local polar histograms of Fry point-pair azimuth frequencies (b., d., f.)

Exercise_ 4: Fairbanks Mining District

The previous exercises have used point data sets of less than 75 points, therefore the Fry Analysis (foreground) tool generates a valid polar histogram of Fry point-pair azimuths in a reasonable time without encountering a memory limit. Using the foreground version of the Fry Analysis tool with an initial point data set of more than 75 initial points, however, takes an unacceptably long time for interactive data processing using the default search radius, i.e. all Fry point-pairs included. It also will result in either creating a biased polar histogram or a preemptive termination of the analysis process due to a memory limit error. In spite of the tool's limitation with respect to creating an all points inclusive synoptic polar histogram for Fry points generated from more than 75 initial points, the foreground version of the Fractal Analysis tool is capable of efficiently generating valid local Fry plots and polar histograms for hundreds of initial data points.

If, however, one must generate a synoptic polar histograms for large initial point data sets, a second Fry Analysis tool, Fry Analysis (background), is included in the Fry Analysis toolbox. Creating a synoptic Fry point-pair azimuth frequency polar histogram for a large initial point data set is a time intensive process, and for the algorithms used in the current Fry analysis tools, is most conveniently accomplished as an ArcMap™ background process. The background processing version of the Fry Analysis tool can generate the same Fry plots, as well as regional and local search-radius constrained polar histogram outputs as the Fry Analysis (foreground) tool used in **Exercises_1 - _3**, but uses code that avoids the memory limitations of the Fry Analysis (foreground)tool.

Unless it is absolutely necessary in order to avoid memory size limitations, it is recommended that the Fry Analysis (foreground) tool should be used to conduct iterative local analysis of most Fry plots because it executes faster than the Fry Analysis (background) version. Figure-17 displays a Fry plot and synoptic regional polar histogram for all 94 mineral deposits in the Fairbanks mining district that have recorded mineral production. These outputs were calculated with the Fry Analysis (background) tool, and the data processing took several hours.

The Fry plot of the original data points displays three distinct spatial "corridors" of Fry points. If a synoptic regional polar histogram is not required, this Fry plot can be generated in seconds with either the foreground or background version of the Fry Analysis tool simply by specifying a small (<= 100m) search radius. These Fry point corridors are imaginary in the sense that the majority of Fry points shown do not indicate the location of an actual mineral occurrence. The corridors do, however, provide an enhanced empirical representation of mineralized zones and possible spatial domains that are not readily discernible from a visual consideration of the original data points. Such multiple Fry point corridors are produced when the original data points are spatially distributed in two or more, sometimes obscure, offset zones of occurrence. In this instance, the Fry plot of the historical location data suggest that the deposits are located within two distinct 60 - 40° trending zones having center-lines spaced about 7 km apart.

Because the Fry plot is centered on an actual centrally located deposit, and most of the actual deposit locations lie within two of the Fry point corridors, the Fry plot suggests there are two preferentially mineralized linear zones in the Fairbanks mining district (Cleary Summit, and Ester-Gilmore).

The third, northernmost, Fry point corridor coincides with no known mineral occurrences. Based upon historical data, however, if there is significant mineralization north of the central Fry point corridor, the Fry plot suggest that it will occur in the northern Fry point corridor shown in Figure-17.

The dominant zonal pattern of Fry points displayed on the map is not reflected in the dominant bar of the regional polar histogram of point-pair azimuths (Fig. 17). The dominant 45 - 225° point-pair trend of the polar histogram summarizes the azimuths of Fry point-pairs between the large clusters of deposits on Cleary Summit and Ester Dome, respectively. The alignment azimuth of the corridors of Fry points is reflected in the subordinate second and third order subordinate bars of the polar histogram which summarize the azimuths between the local Fry point-pairs within the corridors.

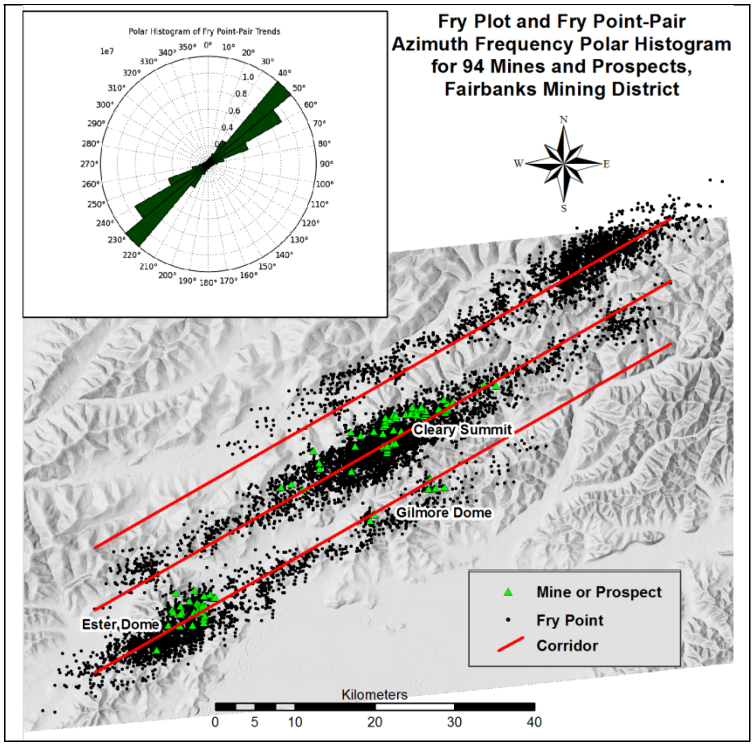

Figure-17. Fry plot and polar histogram generated by a 64-bit version of the Fry Analysis tool.

The Fry Analysis (foreground) tool is used for the remainder of **Exercise_4**.

Recall that the Fry Analysis tool always generates the same Fry plot of the input data regardless of the user-defined search radius. Therefore, one can generate Fry plots of large point-object data sets with either tool by entering a limiting search radius value in the tool's optional Fry Point-Pair Search Radius: parameter window. Because a limiting search radius reduces the number of point-pair combinations that require azimuth calculations and compilation for a polar histogram, the memory limits of 32-bit Python are not often exceeded, and the tool will generate a Fry plot for large numbers of input points without raising a memory error when it generates the local polar histogram. As an example, there are 53,593 Fry points in the Fry plot shown in Figure-18, below. They were generated from 232 recorded locations of known lode mineral occurrences (both those with and without a record of some mineral production) in the Fairbanks mining district. Using a Fry Point-Pair Search Radius: parameter value of 100 m, the Fry Analysis (foreground) tool generated the Fry plot (Fig. 18) in 2 minutes and 17 seconds. A local polar histogram corresponding to a 100 m search radius is not of interest in this instance, and has not been included in the Figure.

To calculate a regional synoptic polar histogram that includes all possible combinations of the Fry points in the Fry plot shown in Figure-18 would require the calculation and compilation of ($(53,593)^2$ - 53, 593) point-pair azimuths (2, 872,156,056 values). The memory requirements of this process, as implemented by the faster Fry Analysis (foreground) tool, exceeds the capacity of the ArcMap™ 32-bit site package. If calculated with the algorithm used in the Fry analysis (background) tool, processing time is estimated to be more than 24 hours, but the process will work to completion.

In practice, one can use the background version of the Fry Analysis tool to create an initial one-time synoptic regional polar histogram of Fry point-pair azimuths for a large input point data set (greater than 75 points) while continuing to work with ArcMap™, and then iteratively use the Fry Analysis (foreground) tool for iterative local analysis using a series of restrictive search radii of interest.

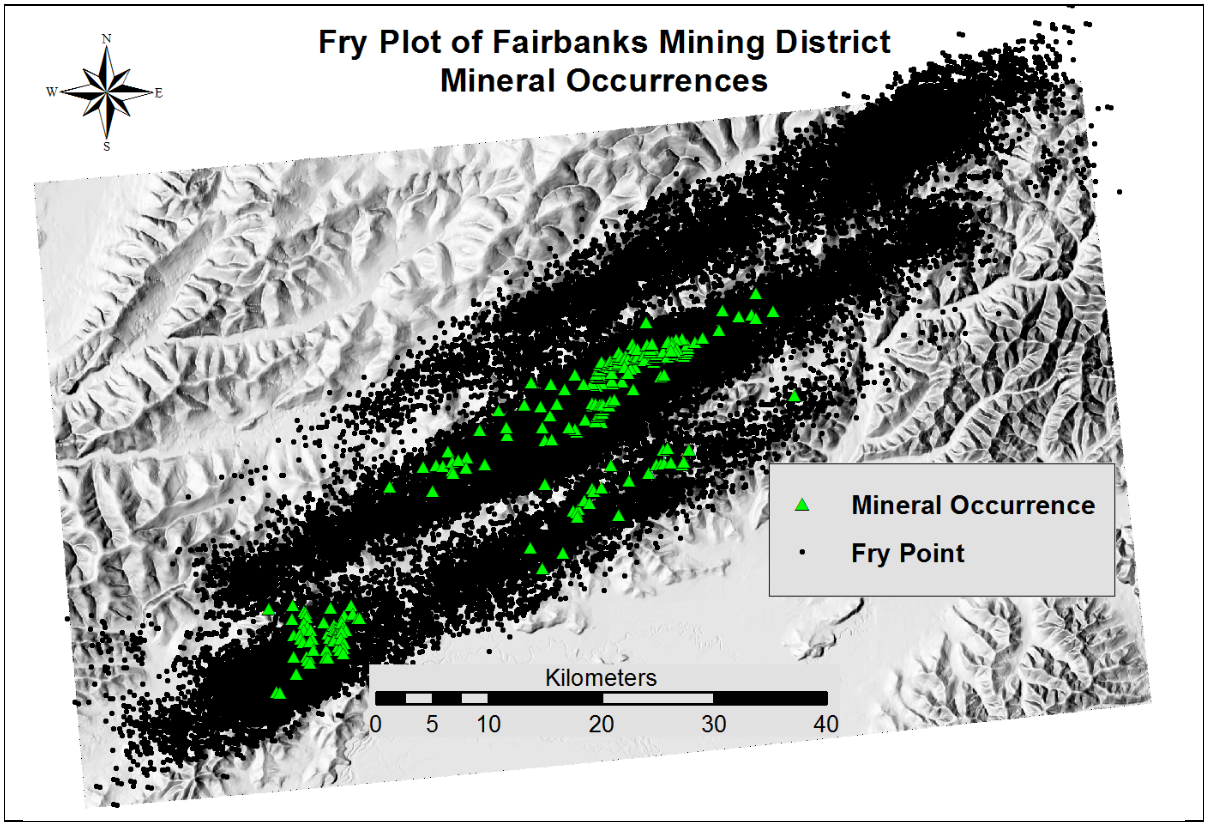

Figure 18. Fry plot of 232 point objects representing the locations of mineral occurrences recorded in the Fairbanks mining district, Alaska

The center lines of the Fry plot corridors generated from 94 Fairbanks mining district mines and prospects having recorded production (Fig. 17) are spaced about 7 km apart. If a search radius of 3.5 km, or less, is specified; the resulting polar histogram of Fry point-pair azimuth frequencies should primarily summarize point-pair alignment trends within, rather than between, Fry point corridors.

Use the Fry Analysis (foreground) tool to create a polar histogram of the Fry point-pair azimuth frequencies for the Fairbanks mining district's producing deposits when a 3500 meter search radius is specified.

The resulting polar histogram, shown in Figure-19 a., was generated in 3minutes and 42 seconds. The histogram summarizes 5,396,082 Fry point-pair azimuths and shows the general trend of the corridors, but virtually no internal local point-pair trend information. To continue the Fry analysis of the data, one can iteratively process the initial data set with a series of shorter search radii.

Generate a series of local Fry point analyses using search radii of 2000 m, 1000 m, and 500 m, and 250 m.

Figure_19 a.-e., shows the polar histograms of the Fry point-pair azimuth frequencies that are produced by the iterative use of the Fry Analysis tool with a series of decreasing search radii. Local Fry point-pair alignment trends begin to emerge when using a search radius of 2000m and become increasingly apparent as the search radius is decreased. The 250 m polar histogram displays virtually all the point-pair alignment trends that were collectively displayed in the local polar histograms for Gilmore Dome, Cleary Summit, and Ester Dome (Fig. 16). This result suggests that if an initial point data set is spatially distributed in separate point clusters, it is advisable

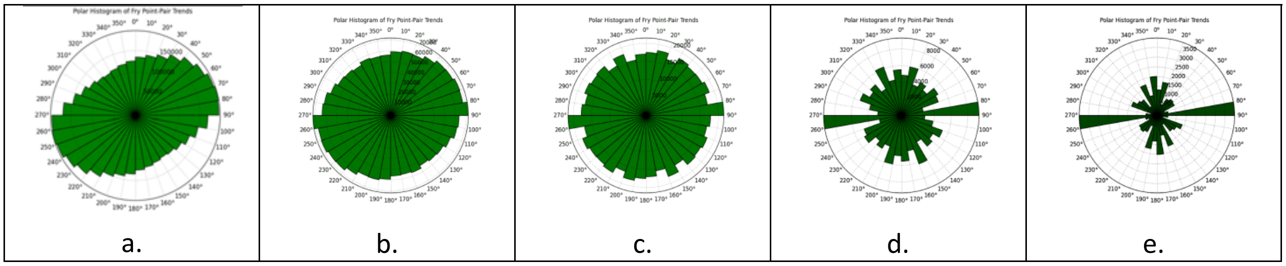

Figure-19. Polar Histograms of Fry point-pair azimuth frequency for search radii of: a. =3500 m, b.= 2000 m, c.=1000 m, d.=500 m, and e. = 250 m

to investigate the local Fry point alignments of individual point clusters as well as the local Fry point alignments of the comprehensive data set. Individual point clusters may have significant unique local Fry point-pair alignments that will be conflated with other local point cluster alignments when processed as part of a comprehensive data set. This characteristic of Fry point analysis is not unlike that of other geologic structural elements that benefit from consideration within local domains.

Discussion of Results:

Persistent Fry point-pair alignments:

The Fry plot point translation algorithm effectively enhances obscure systematic point alignments that exist within the spatial distribution of geographic point-objects. Systematic alignment of data points suggests the influence of some underlying factor or process that constrains what would otherwise be a random positioning of the data points. Systematic point alignment trends may serve as a validation of previously observed controlling phenomena and may support an inference that the same controlling phenomena exist elsewhere in a larger area of interest.

The systematic point-pair alignments within a set of geologic data points may be influenced by a geologic process without being strictly aligned with the physical expression of that process. The pervasive 80 - 90° point-pair alignment trend present in the Fry plot for the Cleary Summit area (Fig. 11), for example, is reasonably inferred to result from constraints imposed by primary orientations of a system of linear mineralized veins or shear systems that have been offset by the system of left-lateral closely spaced NE trending high angle faults that transect the district (Fig. 20). Symbolization of the linear vein mineralization by a simple point-object captures the net effect of offset mineralization but loses the detail of the underlying local vein orientation. The resultant local Fry point-pair polar histogram's azimuth frequency maximum is not coincident with either the mineralized vein orientation or the strike of the offsetting faults, but is constrained by both.

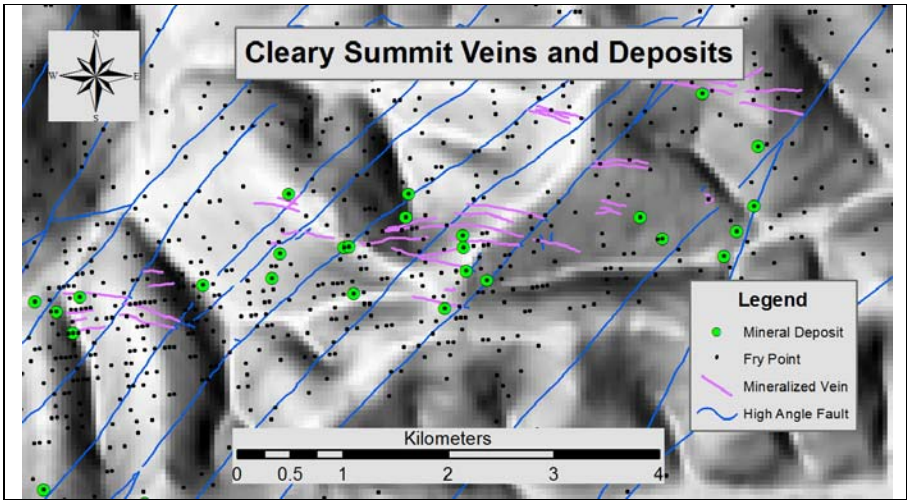

Figure-20. Cleary Summit mineralized veins having strike azimuths of 90 - 100°, mineral deposit locations of record, and left lateral high angle faults. The displayed faults and veins have been extracted from the geologic map of Newberry, et al.(1996).

The same dominant Fry point-pair alignment is seen in the Fry analysis plots and polar histograms generated for the district's Gilmore- and Ester Dome groups of mineral deposits (Fig . 16 b. and f.) In the latter areas, however, a pronounced approximately E - W system of mineralized veins has not been documented on published maps. From a local deposit-scale brown-field mineral exploration perspective, however, knowing that the dominant close inter-deposit alignment trend among mineral deposits of interest is 80 - 90°, rather than the overall regional trend of 60 - 70°, can be useful for guiding future local exploration efforts.

Similarly, other subordinate but persistent Fry point-pair alignments suggest there are additional systematic district-wide geologic constraints that have influenced the location of mineral occurrences in the Fairbanks district. If the alignment trends identified by Fry analysis of deposit locations can be associated with observable geologic features, it may be possible to develop other effective exploration guides.

Fry point corridors:

In one sense Fry point corridors are imaginary. The great majority of the fry points do not represent the actual location of a point-object of interest. The corridors, however, are defined by an algorithm that enhances the expression of possibly obscure, but empirical systematic spatial alignments or concentrations of point data. In the latter sense, Fry point corridors are of interest because they draw attention to possibly meaningful zones of mineralization that would otherwise be overlooked. Additionally, Fry point corridors frequently display a degree of symmetry and regular spacing that also is derived from the original point data's spatial distribution. The implication of this is that there may be a discernible causative process related to the emergent corridor's alignment, spacing, and repetition that is useful for more effective resource exploration.

If the Fry plot has been centered on the original data points, additional spatial and geologic insights may be gained by examining a co-registered display of the original deposit and Fry point data sets. For example Figure-17 is a map of 94 Fairbanks District mines and prospects that have recorded production, co-registered with the Fry plot that was generated from the recorded location points for those deposits. In addition to enhancing the identification of the regional trend of mineral occurrence locations, the display of Fry points reveals Fry point "corridors" (Carranza, 2009) which are constrained by the original location data. In this example, the Fairbanks District historical mineral location data suggest that there are two distinct SW - NE corridors favorable to mineralization spaced about 7 km apart. The third, northernmost, corridor contains no known deposits, and is probably an incidental artifact of the Fry point translation algorithm. However, if there is a plausibility systematic, i.e. consistently spaced, northerly repetition of the underlying geologic process that led to creating the known mineralization on Cleary Summit, the northern Fry corridor provides some guidance on where to focus future attention.

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