Minnesota Lake Sediment Geochemistry Surveys

Compiled from Mineral Exploration Records and
Mineral Potential Project Files

of the

Minnesota Department of Natural Resources
Lands and Minerals Division
Hibbing, Minnesota

Mineral Potential Project No. 376

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DISCLAIMER

While every reasonable effort has been made to accurately compile the content of the data sets referenced in this report, the Minnesota Department of Natural Resources (MnDNR) makes no claims of accuracy for the compilation, or for the underlying source data. The data compilation is based on historical mineral exploration records and agency reports in the public domain, and held in the Mineral Exploration Archives of MnDNR. Users of the data and this report are encouraged to closely examine the source data to confirm the results contained herein; and to make independent confirmation of data representations before using the compiled information for decision-making or mapping purposes.

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SUMMARY

This compilation of exploration and agency lake sediment geochemistry data for Minnesota began in a rather informal manner as a side project during a routine land use mineral estate evaluation in 2005. At that time, a Minnesota Department of Natural Resources (MnDNR) lake sediment survey for a portion of east-central Minnesota was unavailable in GIS format, so steps were taken to digitally compile and re-symbolize the data set for more convenient mineral potential analysis. That work yielded a striking cluster of +99th percentile and +95th percentile nickel, cobalt and copper metal values in a two-township area between the towns of Deerwood and Aitkin, Minnesota. While the cause of the anomaly is currently unknown, its position between the past-producing mines of the Cuyuna Iron District and delineated sulfur resources of the Glenn area is interesting. Also notable is that the location of the anomaly coincides with a trend of several prominent regional aeromagnetic discontinuities. Bedrock in the Deerwood-Aitkin area, which is covered by glacially-derived surface materials, is generally thought to consist of folded Paleoproterozoic rocks of mixed volcanic and sedimentary origin.

Further compilation and consolidation of the rest of Minnesota's lake sediment geochemistry data may not have occurred thereafter, except that in May of 2007, RGGS Lands and Minerals, LLP, of Houston, Texas donated to the State of Minnesota a large volume of historical mineral exploration documents comprising the U. S. Steel collection. The collection included 110 maps that portrayed lake- and stream-sediment geochemistry survey results for a large portion of east-central and northeastern Minnesota, including the area of the Deerwood-Aitkin anomaly.

For the purposes of contrasting MnDNR's Deerwood-Aitkin lake sediment data with the donated geochemistry maps, a project was undertaken to organize the donated maps and to digitally compile their content. Since the area of the donated survey covers nearly 10,000 square miles and overlaps additional MnDNR geochemistry surveys, the compilation effort was expanded even further to eventually recover all

other public domain lake sediment exploration geochemistry data held in MnDNR's mineral potential project files. A total of 3,540 sample points were recovered from the donated map set, and 2,943 sample points were recovered from MnDNR mineral potential project files. Lake sediment geochemistry data for adjacent portions of Ontario, Canada (6,091 sample points) were also obtained, in digital form, from the Geological Survey of Canada and Ontario Geological Survey.

MnDNR lake sediment geochemistry data and the newly compiled donated data overlap in three locations. In each of these overlap localities the donated data set generally confirms pattern and range of metal concentration values recorded in the MnDNR surveys. In east-central Minnesota, the multi-element cluster of +99th percentile and +95th percentile metal values in the Deerwood-Aitkin area is confirmed. In eastern St. Louis County, in the vicinity of the contact between igneous Duluth Complex and Animikie Basin sedimentary rocks, the pattern and magnitude of metal values is generally complementary between data sets. In the Ely area of northeastern Minnesota, unusually high nickel, cobalt and copper metal values in the MnDNR lake sediment survey results are confirmed by the newly compiled donated data set.

Metal concentration and percentile ranks of the donated data exhibit enough similarity to existing agency data sets that the results of the donated data set might be considered useful for geologic considerations in the 8,700 square miles of survey area that lie beyond the bounds of existing MnDNR surveys. The similarity of results where overlaps occur suggests that the sampling and analysis methodologies used for the donated geochemistry survey may have been substantially similar to those used for the agency surveys. However, reports of methodology and analytical techniques for the donated data set still need to be obtained in order to ensure compatibility of the data sets.

ACKNOWLEDGEMENTS

Jean Matthew did most of the initial digitizing work for the donated and MnDNR lake sediment geochemistry data sets. Rick Ruhanen, Dennis Martin, Jim Sellner, and Marty Vadis of MnDNR, who have been involved in past MnDNR lake sediment geochemical surveys, have provided helpful discussions and recollections. Debra Mayerich at the Hibbing MnDNR office assisted with final formatting of the report. Joe Hudak, formerly with MnDNR assisted with early stages of geo-referencing map images. Constructive input on an earlier draft was provided by Mineral Potential Evaluation Section staff members including Don Elsenheimer, Barry Frey, Heather Arends, Steve Kostka, Hannah Freidrich, and Glenn Melchert. Additional review and comment by David Meineke is greatly appreciated.

Lake Sediment Geochemistry Data in the U.S. Steel Collection

INTRODUCTION

In May of 2007, RGGS Lands and Minerals, LLP, of Houston, Texas donated to the State of Minnesota a suite of maps and records that were amassed by U. S. Steel Corporation over the course of more than a century of mineral exploration in Minnesota. The collection serves to augment existing public domain Mineral Exploration Archive records held at the Minnesota Department of Natural Resources (MnDNR), and provides additional exploration information for locations that were previously only partially detailed in archive records. Approximately one-third of the collection is composed of century-old linen tracings and notebooks from iron exploration in Minnesota's iron mining districts. Another third of the collection contains data from airborne geophysical surveys and associated follow up ground surveys that targeted base metals and uranium in Minnesota. The final segment of the collection contains data from airborne geophysical surveys and ground surveys associated with copper-nickel explorations in the Duluth Complex. Severson and Heine (2008) provide an initial inventory and summary of these donated materials.

Within the base metal and uranium segment of the collection is a suite of geochemical maps from a lake sediment and stream sediment survey project conducted in Minnesota during the period 1977-1979. Recorded on the suite of 110 large maps are sample points and geochemistry results from lake and stream sediment samples collected in an area covering approximately 9,900 square miles in central and northeastern Minnesota (Fig. 1). The project area outlined on the maps is represented by twelve map tiles that touch into two-hundred-and-thirteen 1:24,000 scale (7.5 minute) topographic maps. There are 3,540 sample points recorded on the maps. Sampling density for points recognized as reconnaissance samples is on the order of one sample per 3.22 mi^2 (8.34 km^2).

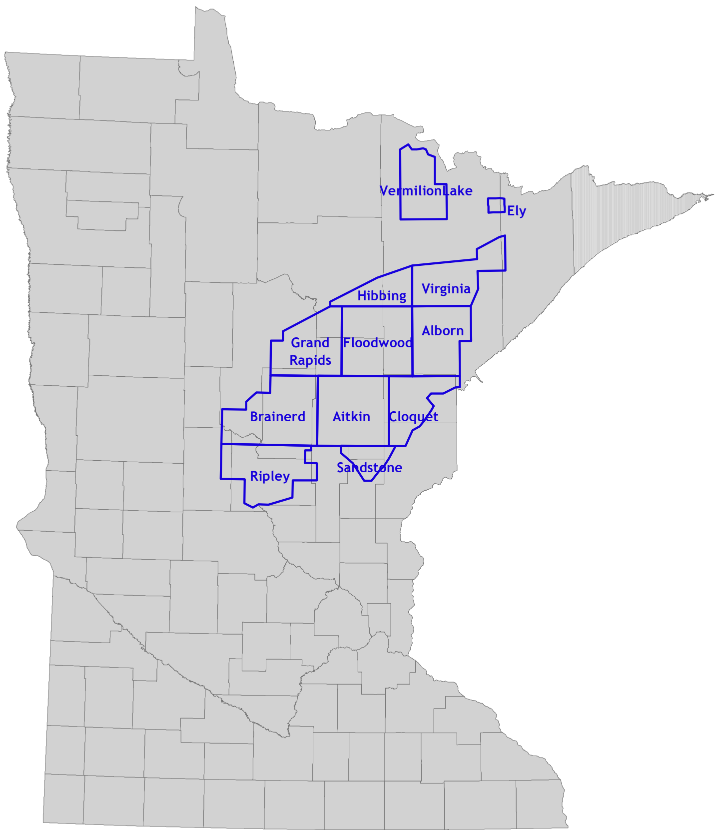

Figure 1. Location and tiling scheme for 1977-1979 geochemical survey maps recovered from the base metal/uranium exploration segment of the RGGS-U.S. Steel Collection.

THE MAP SET

U. S. Steel Corp., as can be surmised from correspondence in the donated collection, acquired this map set from Kerr-McGee Corporation in 1981. Ninety-eight of the 110 donated map sheets are scale 1:62,500 and are captioned "Great Lakes Resources Corporation." Two sheets provide a regional overview at scale 1:250,000 and show project location, project dates, elements-analyzed, and total number of project samples. These regional sheets are captioned "Kerr McGee Corporation." At finer scale, 1:24,000, are ten map sheets that portray detail sampling. For the five Ely detail maps, the style and sample sequence portrayed on the maps matches that of the ninety-eight scale 1:62,500 maps, but the Ely maps do not carry a company name in the caption. The other five fine scale maps in the map set, also at scale 1:24,000, cover detail sampling in the Garrison area. These maps are captioned "Kerr McGee Resources." The Garrison detail area occupies a portion within the SE ¼ of the Brainerd map tile and the NE ¼ of the Ripley map tile and coincides with the footprint of a small airborne magnetic-electromagnetic survey that was flown for Kerr McGee Resources Corporation in Sept-October, 1978. A sheaf of statistical printouts (1978 vintage) also accompanied the geochemical maps.

Kerr McGee Resources Corporation also flew a second small airborne magnetic-electromagnetic survey in 1978 at the Mud Hen area in the E ½ of the Virginia map tile, but detail sample maps for the Mud Hen area have not been found in the collection. Table 1 lists the 1:62,500 scale and 1:24,000 scale map sheets in the overall map set and identifies the subject content of the maps.

Table 1. List of 1977-1979 lake and stream sediment geochemical map sheets recovered from rolled tubes in the RGGS: U. S. Steel Collection. Each map tile has several map sheets. Individual map sheets display posted values for a chemical element, or for sample type. Check marks in Table 1 indicate map sheets found in the map set.

Map Tile	Sample ID/Type	Co Ppm	Ni ppm	Cu ppm	Zn Ppm	Pb ppm	Ag ppm	As ppm	U_3O_8 ppm	Total H.M.	Mo Ppm
Ripley	✓	-	✓	✓	✓	✓	✓	✓	✓	✓	-
Sandstone	✓	-	✓	✓	✓	✓	-	-	✓	-	-
Brainerd	✓	-	✓	✓	✓	✓	✓	✓	✓	✓	-
Aitkin	✓	-	✓	✓	✓	✓	✓	✓	✓	✓	-
Cloquet	✓	-	✓	✓	✓	✓	✓	✓	✓	✓	-
Grand Rapids	✓	-	✓	✓	✓	✓	✓	✓	✓	✓	-
Floodwood	✓	-	✓	✓	✓	✓	✓	✓	✓	✓	-
Alborn	✓	-	✓	✓	✓	✓	✓	✓	✓	✓	-
Hibbing	✓	-	✓	✓	✓	✓	✓	✓	✓	✓	-
Virginia	✓	-	✓	✓	✓	✓	✓	✓	✓	✓	-
Vermilion	✓	-	✓	✓	✓	✓	-	✓	✓	✓	-
Ely detail	✓	✓	✓	✓	-	-	-	✓	-	-	-
Garrison detail	✓	-	-	✓	✓	✓	-	✓	-	-	-

COMPILATION PURPOSE

The donated geochemical maps partly overlap lake sediment geochemical surveys that were conducted by MnDNR in central and northeastern Minnesota. In east-central Minnesota, the donated maps entirely overlap a 1983 MnDNR lake sediment survey (Sellner, 1985). During 2005, as part of a MnDNR mineral potential land use evaluation, the DNR 1983 survey data were reviewed, digitized and re-symbolized. Reworking of the 1983 data highlighted an area of elevated trace metal values in organic-rich lake basin sediments in the Deerwood-Aitkin area. Motivation for compiling the donated maps has been see if the multi-element anomaly recognized in the DNR 1983 data set is also present in the donated lake- and stream-sediment data.

Other goals for this project have been to organize and catalogue the donated maps, determine their extent and character, and to overlay the donated data onto other existing MnDNR surveys. Sample locations and element values posted on the donated maps were compiled into a single GIS-based shapefile. Outcomes expected for the project were: 1) a well-organized set of hardcopy source maps, and 2) a digital data set to represent the content of the fragile donated geochemical maps. The resulting digital data set, compiled from a suite of independently collected lake- and stream-sediment samples might then be used to contrast MnDNR's lake sediment surveys of the same time period. The compiled data set might also contribute to further in-house discussions about whether- and how- to use "anomalies" in metallic mineral potential ratings.

SAMPLES

The donated exploration collection did not include any reports or tabular laboratory results that could be linked to the map-based geochemical data. However, based on the sampling pattern, the sample identification system, the elements analyzed, and the project vintage, some characteristics of the layout and conduct of the project can be ascertained. That said, until detailed project reports of sampling and laboratory methodologies, precision, and accuracy for these data can be located or obtained, the overall usefulness of the data set will remain limited.

Four phases of sampling are recognized based on the sample-identification sequence and geographic distribution of the 3,540 sample points (Fig. 2). A primary regional reconnaissance sampling phase was conducted throughout the project area. Detailed sampling was conducted as follow up around select point anomalies recognized in the reconnaissance phase. Higher-density sampling was conducted in the general Brainerd-Aitkin vicinity. Very detailed sampling was conducted in the Garrison area of the Brainerd tile, and perhaps also in the Mud Hen area of the Virginia tile, within the footprints of airborne geophysical flights (Fig. 2).

Insufficient information is presented on the donated map sheets to determine whether sampling phases were distinct separate events, or overlapped in time. Sample points from the first three sampling phases are found together on the scale 1:62,500 map sheets. Detail samples in the Ely and Garrison areas are on separate 1:24,000 scale maps.

The sequence of sample-identification and the geographic pattern of sample points on the maps indicates that sample identifiers are a two-part label consisting of the initials of the person or team that collected the sample and a sequential number of the order of collection (e.g., samples BI-001, BI-002, BI-003…; FS-001, FS-002, FS-003…). Fourteen unique two-letter codes were extracted from the maps. Table 2 lists these sample sequences recognized during the compilation work.

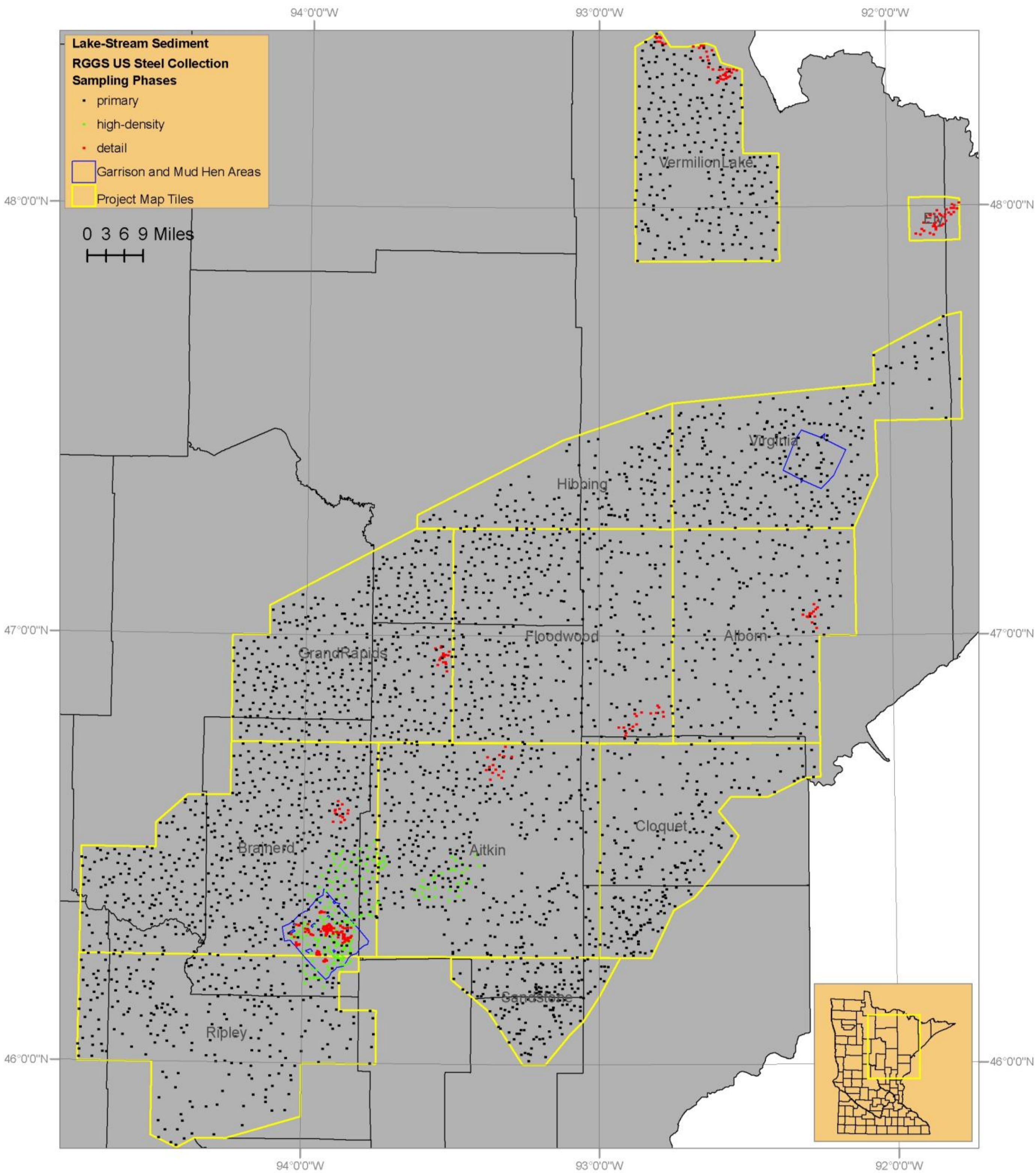

Figure 2. Distribution of sample points by sampling phase (n=3,540). Map tile names added, as well as outlines for Garrison and Mud Hen areas.

Table 2. Sample sequences compiled from donated map sheets.

Sampling Phase	Sequence Code	Sample Numbers Compiled	Notes:
Primary	BI	001-708	708 locations compiled.
Primary	BO	001-373	373 locations compiled.
Primary	FS	001-210	210 locations compiled.
Primary	GV	001-268	268 locations compiled.
Primary	JC	140-274	135 locations compiled.
Primary	HG	001-309	309 locations compiled.
Primary	KU	001-425	425 locations compiled.
Primary	RR	001-211	211 locations compiled.
Primary	SL	001-198	198 locations compiled.
Primary	WC	001-131	131 locations compiled.
Primary	LJ	001-040	40 locations compiled.
Detail	LJ	918-950	33 locations compiled.
Detail	QE	001-011	11 locations compiled.
Detail	RO	569-622	54 locations compiled.
Detail	RO	849-900	52 locations compiled.
Primary	CJ	001-049	48 locations compiled. 002 missing.
Detail	CJ	050-115	66 locations compiled.
Detail	CJ	116-135	Missing. Mud Hen Locality?
Detail	CJ	136-148	13 locations compiled.
Detail	CJ	149-152	Missing. Alborn/Floodwood Locality?
Detail	CJ	153-200	48 locations compiled.
High Density	CJ	201-272	71 locations compiled. 232 missing.
Detail	CJ	273-285	13 locations compiled.
High Density	CJ	286-408	123 locations compiled.
			3,540 samples compiled.

SAMPLE VARIETY

Of the 3,540 sample points compiled from the maps, 87% (n=3,056) are from the primary regional reconnaissance; 2,189 of them are symbolized as lake samples, and 867 are symbolized as stream samples. Secondary high-density sampling accounts for 5% of points (n=194); 185 lake samples plus 9 stream samples. Detail samples taken at seven sites, excluding the Ely and Garrison areas, account for 3% of points (n=112); 89 lake samples plus 23 stream samples. Ely area detail sampling entails 1% of points (n=39); 28 lake samples plus 11 stream samples. Lastly, 139 sample points (4% of total) are represented from the Garrison detail area, consisting of 44 stream samples plus 95 samples of unknown type/analysis.

SEQUENCE GAPS

There are four gaps in the sample-identification sequence that cannot, at present, be reconciled from the source maps. The four gaps are found in the "CJ" sampling sequence (see Table 2). There is insufficient information on the maps themselves to determine whether these sequence gaps represent unmapped data or inconsistent sample labeling. If the missing sample identifiers are found to be actual samples, their locations would likely be as follows: Sample number CJ-002 would most likely be a reconnaissance sample located southeast of the city of Brainerd; sample number CJ-232 would most likely be a high-density sample from the Glenn area or eastern part of the Brainerd tile.

Sample numbers CJ-116 thru CJ-135 would most likely be detail samples. If these "missing" sample numbers reflect unmapped data, the geographic progression of the sampling sequence across the project area suggests that these 20 sample points might have been from the Mud Hen area of the Virginia tile, where the highest uranium value in the entire project area was recorded, and where a small airborne geophysical survey was flown.

The last sample sequence gap is for four sample numbers, CJ-149 thru CJ-152. Based on the sample sequence and map distribution, these would most likely turn out, if they reflect unmapped data, to be detail samples associated with the Alborn or Floodwood map tiles.

MAP ERRORS

In a few instances, duplicate sample identifiers were discovered in the sample numbering sequence on the maps. These are interpreted to reflect posting mistakes on the source maps; they consist of typographical errors in a letter code or sequence number. These typographical errors on the source maps were able to be corrected in the digital data set because, upon examination of the sequence of sample identifiers on the maps, a mis-lettered or mis-numbered point in the sequence was clearly distinguished, and in the digital compilation a corresponding sequence gap was found that was typographically very similar to the duplicated ID.

Another variety of map error is present at two map locations, where errant values were posted onto the source maps. At one location, in the Vermilion map tile, a suite of fifteen sample points constrained an unusual looking copper anomaly. Closer examination of the digitized values on the Vermilion map tile show that the "copper anomaly" consisted of fifteen sample points in which the zinc and copper values are identical. Since zinc values in the project area usually have higher values than same sample copper results, and since the artifact "anomaly" presented itself on the copper map sheet, it is reasonable to conclude that the "copper" values for these 15 samples are in fact zinc values mistakenly plotted on the copper map. On the zinc map, the 15 values match well with surrounding values. Based on this recognition, the fifteen errant values on the copper map sheet were replaced in the digital compilation with the value of "–1" indicating no data, since no alternative source of valid copper values was available. This affected samples BI-588, BI-589, BI-594 thru BI-600, BI-612 thru BI-614, BI-626, BI-684, and BI-685.

The second instance of apparently mis-plotted values occurs on the Garrison detail maps. In this case, several zinc values from the reconnaissance source maps were mistakenly plotted as lead (Pb) values on a detail scale 1:24,000 map sheet, involving samples SL-180 thru SL-185. The translation of the higher value zinc results onto the lead detail map sheet resulted in artifact "lead (Pb)" anomalies on the detail map sheet. To show this error on the source maps, MnDNR staff made pencil notations on the detail maps noting each of these mis-plotted values. The Garrison area detail map set also contains seven instances where nickel values from regional reconnaissance samples were mistakenly plotted onto the zinc detail map sheet, involving samples SL-178, SL-180 thru SL-185. Pencil notations were added to the detail zinc source map for each of these mis-plotted values.

Some of the map sheets contain element values posted as “zero”. Without further information on what these “zero” values actually represent, the only thing that can be done with the values is to carry them forward into the digital data set. Other sample points on some maps carried no posted value and there was no supplemental explanation on the map sheet. For these instances a value of “-1”, for “no data”, was recorded as the digital attribute. For cases where values on maps were posted as falling below threshold, for instance “<2”, the threshold value “2” was recorded as the value in the digital attribute.

DIGITIZING METHODOLOGY

In order to digitize the sample points and element values from the 108 data maps, the sample location map sheet for each map tile was scanned and then geo-referenced to UTM zone 15 projection, NAD83 datum using ESRI ArcMap software. Sample points on the geo-referenced images were then digitized onscreen into an Arcview shapefile using the geo-referenced image as a backdrop. Sample identifiers for each sample point were then entered as shapefile attributes using the onscreen display as the source.

Proofing of the digitizing work and the data entry entailed the efforts of a second person, to examine the digitized points and sample ID’s onscreen against the geo-referenced sample-location image. Once digitizing and proofing of individual map tiles was complete, the Arcview shapefiles from the individual tiles were merged together to make a master shapefile. Sample identifiers of the master file were then examined to find occurrences of duplicate or missing sample numbers. Proofing corrections were made to correct typographical entry errors, double-digitized points, or to add sample points that were missed during digitizing.

Digitized sample point locations were not adjusted to better match geo-referenced 1:24,000 topographic maps. While the sampling sequence pattern indicates that 1:24,000 topographic maps were the basis for field collection and marking of sample locations, it was felt that additional manual adjustment of the digitized points to "match" the 1:24,000 scale digital topographic maps would introduce unwarranted bias to the sample locations. Considering the sampling density of the survey, additional minor adjustments to sample point locations would not significantly change or "improve" the geochemical patterns seen in the regional reconnaissance, high density, or detail sample suites. For users wishing to examine the data at a detail scale, comparison of the digital sample point shapefile to 1:24,000 topographic map (DRG) images should be made, in order to better understand what kind of location error may be present for data points that have been digitized from reduced scale 1:62,500 maps.

After sample locations had been digitized, attributed with a sample identifier, and proofed in the master file, then element values posted on each subsequent map sheet were entered as attributes of the sample points. Proofing of the element values was conducted in a manner similar to that used for sample identifiers, by examining digitized values against the sample location map image, and using a second person to compare the digital postings to the original map sheets.

DATA SET

Figure 3 shows the location of the 3,540 sample points recovered from the donated maps and color codes them by sample type. In the Garrison detail area, source maps used a circle symbol to plot 95 sample points that were neither lake sediment points nor stream sediment points, but perhaps soil sample points. The sample type for the circle symbol is unexplained on the source maps.

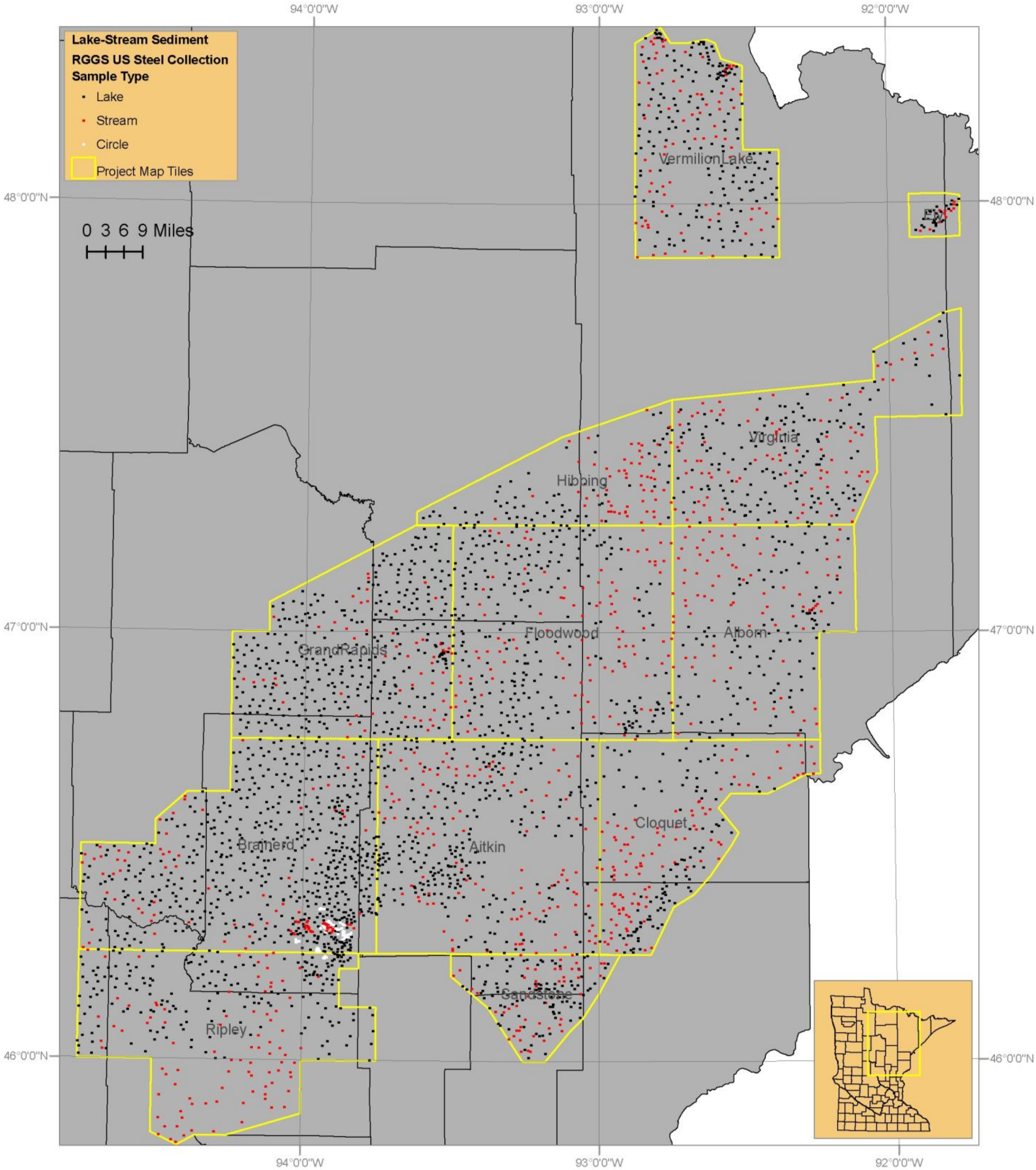

Figure 3. Sample media represented in the survey area. Circle type indicates sample points recovered from the Garrison detail sample map, but sample type and results for the circle symbols are not defined on the maps.

In order to symbolize new plots of the digitized data, percentiles were calculated for the overall data set and for subsets such as lake sediment versus stream sediment samples, or reconnaissance versus detail samples. For symbolizing the maps in this report, values were calculated for each element for the following: maximum value, 99.75th, 99.5th 99th, 98th, 97th, 96th, 95th, 90th, 85th, 80th, 75th, 50th, and 25th percentiles, and minimum value. Data values were then plotted as proportionally sized symbols using the percentiles from the suite of reconnaissance samples. As part of this symbolizing activity, data were also examined by highlighting the sample values sequentially onscreen for each metal, from highest value to lowest in order to see how data values cluster by location and at what threshold additionally highlighted sample values become noisy background.

STATISTICAL PRINTOUTS

A sheaf of statistical printouts from the reconnaissance sampling phase of the project accompanied the source maps. The printouts, dated 8-17-1978, list correlation coefficients, cumulative instances, percentiles in standard and logarithmic form, and listings of sample values that exceed element thresholds of mean-plus-2-standard-deviations. Table 3 recreates a summary table from the statistical printouts that lists the distribution of sample types for the reconnaissance sampling phase.

Table 3. Statistical summary table of reconnaissance phase sampling, copied from source statistical printouts dated 8-17-1978.

	Sand	Silt	Organic Silt	Organic	Vegetation	B-horizon	Row Total
Lake	51	99	161	1658	157	0	2126
Stream	130	228	183	159	214	1	915
Soil	0	0	0	1	3	0	4
Col Total	181	327	344	1818	374	1	3045

Number of missing observations = 7

These counts on the statistical printouts are slightly different than the compiled digital results, which found 3,056 primary samples symbolized as 2,189 lake samples and 867 as stream samples. The discrepancy between the statistical printout and the digitally compiled points might be accounted for as lake samples that were mistakenly plotted with the stream symbol, or that the statistical printouts were made prior to full validation of the data. The discrepancy of 3,056 points digitized versus 3,052 on the printout is unaccounted for.

Most anomalous values listed on the statistical printouts are also posted on the maps, but not in all cases. Table 4 lists twenty-two instances where the statistical printout value for a sample did not match the value posted on the map.

Table 4. Element value discrepancies between map values and statistical printout values. Shaded values have been posted on the digital data set.

Sample	Element	Printout Value	Map Value	Map Tile, location
BI-434	Ni	-	36	Hibbing (SW), SE of Marble
KU-007	Ni	-	40	Virginia (NW), E of Kinney
KU-142	Ni	-	64	Floodwood (NE), SE of Silica
KU-251	Ni	-	60	Virginia (NE), at Seven Beaver Lake
HG-010	Ag	-	0.2	Brainerd (NE), E of Emily
JC-151	Ni	51	14	Cloquet (SE), E of Barnum
KU-369	Ni	180	18	Floodwood (NW), W of Goodland
BO-277	Ni	130	4	Grand Rapids (NC), NE of Remer
KU-261	Cu	43	4	Virginia (NE), near Duluth complex
KU-315	Cu	73	19	Virginia (NC), near Virginia horn
BI-375	Zn	219	19	Floodwood (NW), SE of Pokegama lake
BI-391	Zn	222	22	Floodwood (WC), E of Hill City
BO-277	Pb	60	7	Grand Rapids (NC), NE of Remer
KU-273	Pb	77	7	Virginia (NE), SE of Aurora
KU-324	Ag	2.0	0.2	Virginia (NW), N of Iron Junction
KU-417	Ag	1.4	0.4	Floodwood (NW), W of Swan River
BO-277	Ag	2.0	0.2	Grand Rapids (NC), NE of Remer
CJ-047	Ag	0.9	<0.2	Ripley (SE), near Pierz
CJ-048	Ag	0.9	<0.2	Ripley (SE), near Pierz
CJ-049	Ag	0.9	<0.2	Ripley (SE), near Pierz
SL-196	As	53	15	Brainerd (SE), NW of Edson
HG-117	U_3O_8	8.0	0.8	Aitkin (SW), just NE of Lake Mille Lacs

In seventeen of the twenty-two instances, the plotted map value was lower than the printout value. In the other five cases, element values that met the statistical printout threshold condition of mean-plus-2-standard-deviations were found on the map, but not listed on the printouts.

While these discrepant values amount to less than 0.1% of the total posted values, it is important that they be noted, as in Table 4, because the discrepancies involve values that are almost all +98th percentile in the reconnaissance phase data. For fourteen of the seventeen discrepant values, the higher printout value has been used for the digital data set so that the entirety of listed anomaly values can be seen. This either adds some single point anomalies to the plots, or reinforces already existing clusters of elevated values. One instance needs specific caution. Sample BO-277 reports values that fall in the +99th percentile on the statistical printouts for nickel, lead, and silver (130, 60, and 2.0 ppm respectively). Without adding the BO-277 statistical printout values to the digital map there is a single point nickel anomaly northeast of Remer. Adding the BO-277 printout values to the digital data set makes for a two-point anomaly, on a magnetic feature that could be interpreted to be a fault-bounded intrusion.

The three discrepant silver values for CJ-047, CJ-048 and CJ-049 were left as originally posted on the map because the printout values look like artifacts; that is, three consecutive sample identifiers having the identical anomalous silver value in an area where no other silver values reach detection limits.

Figures 4 thru 12 show percentile plots of the digitized data set symbolized by reconnaissance phase percentiles of the donated data set. The plots emphasize +90 percentile aspects of the nickel, copper, zinc, lead, silver, arsenic, uranium as U_3O_8, total heavy metals, and cobalt values, and use a color shaded-relief background image (illumination from the east). For overview purposes there are four general categories of symbols used in the plots: Dark Grey for +99th percentile; shades of Red for +95th percentile; shades of Blue for +75th percentile, and small black dots for -75th percentile. Each of these categories is additionally subdivided by shading or symbol size for detailed viewing. Small white dots indicate "nodata"

Figure 13 offers an aeromagnetic perspective of the project area. Figures 14 thru 16 contain paired-element plots of Cu-Ni, Cu-Pb and As-Ag, respectively.

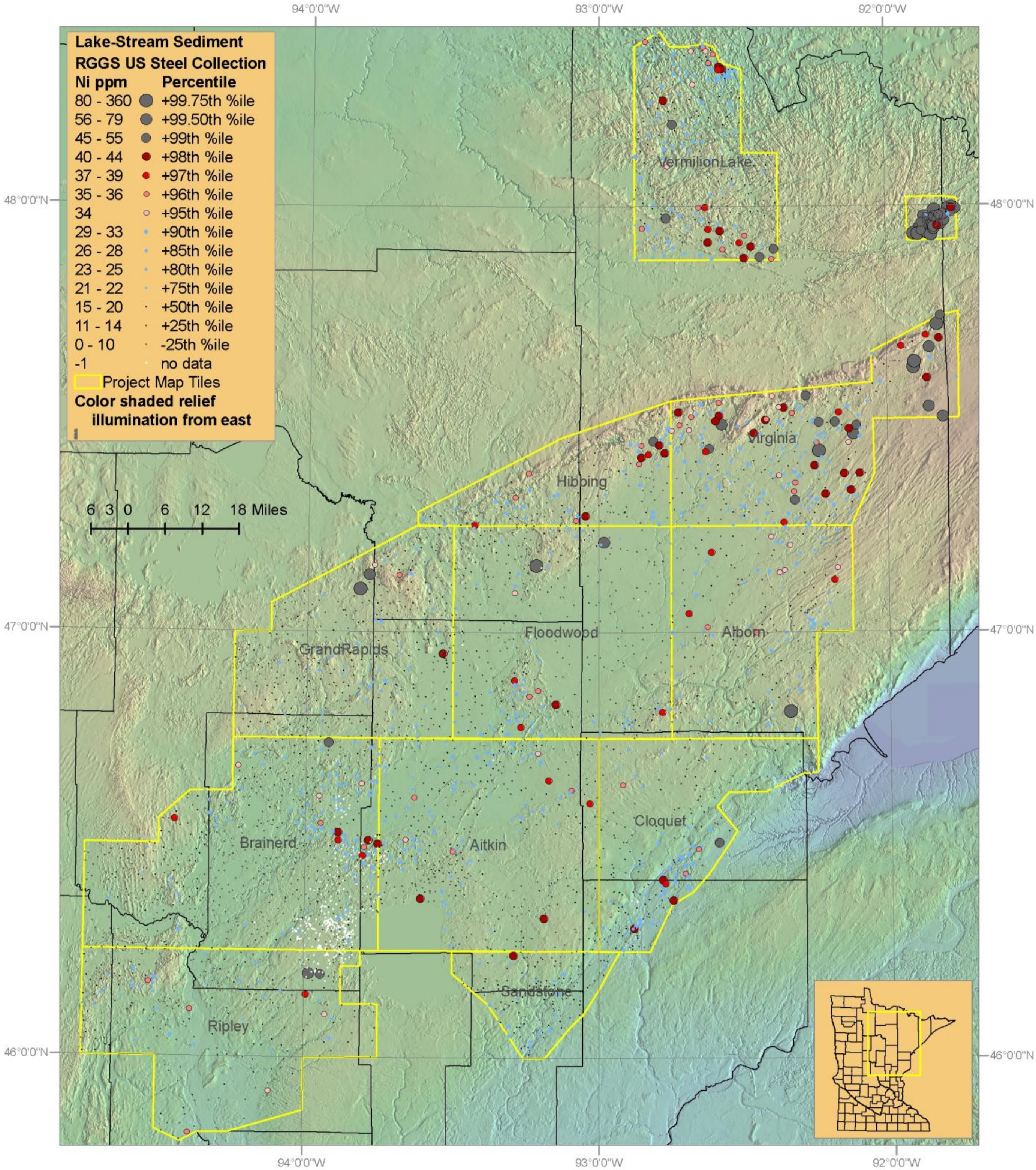

Figure 4. Nickel values (in ppm) in the donated data set for lake and stream sample points, by percentile.

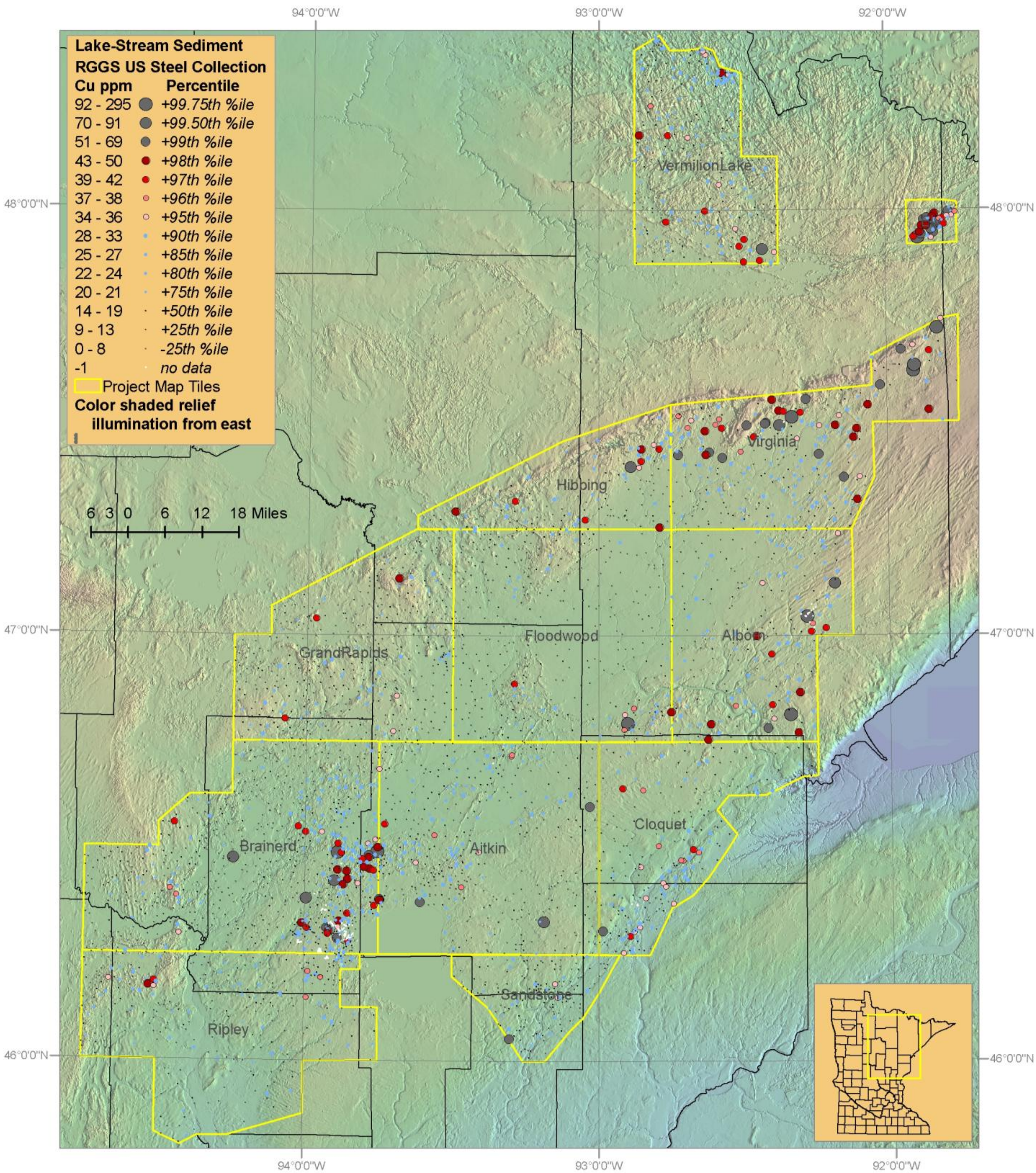

Figure 5. Copper values (in ppm) in the donated data set for lake and stream sample points, by percentile.

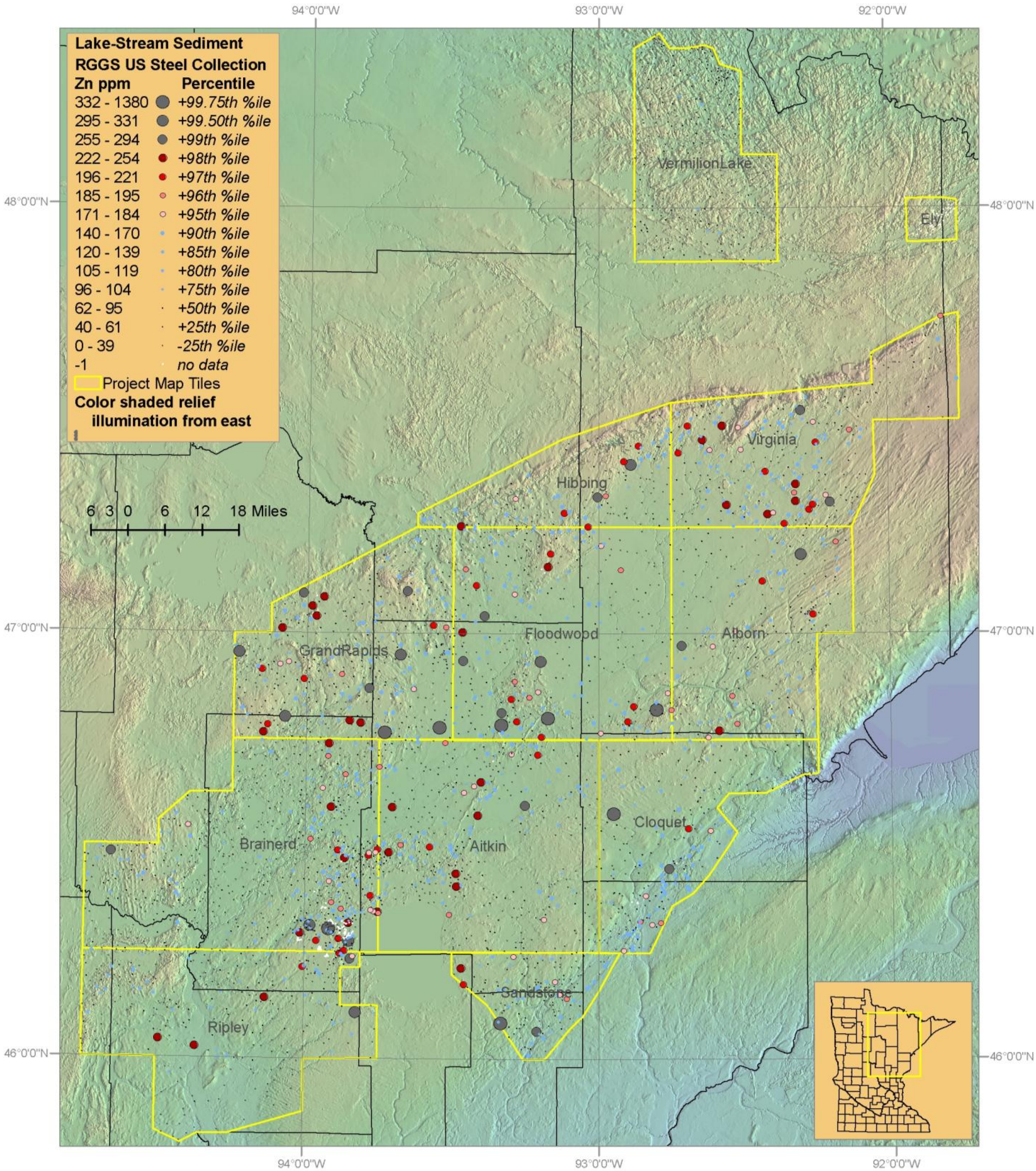

Figure 6. Zinc values (in ppm) in the donated data set for lake and stream sample points, by percentile.

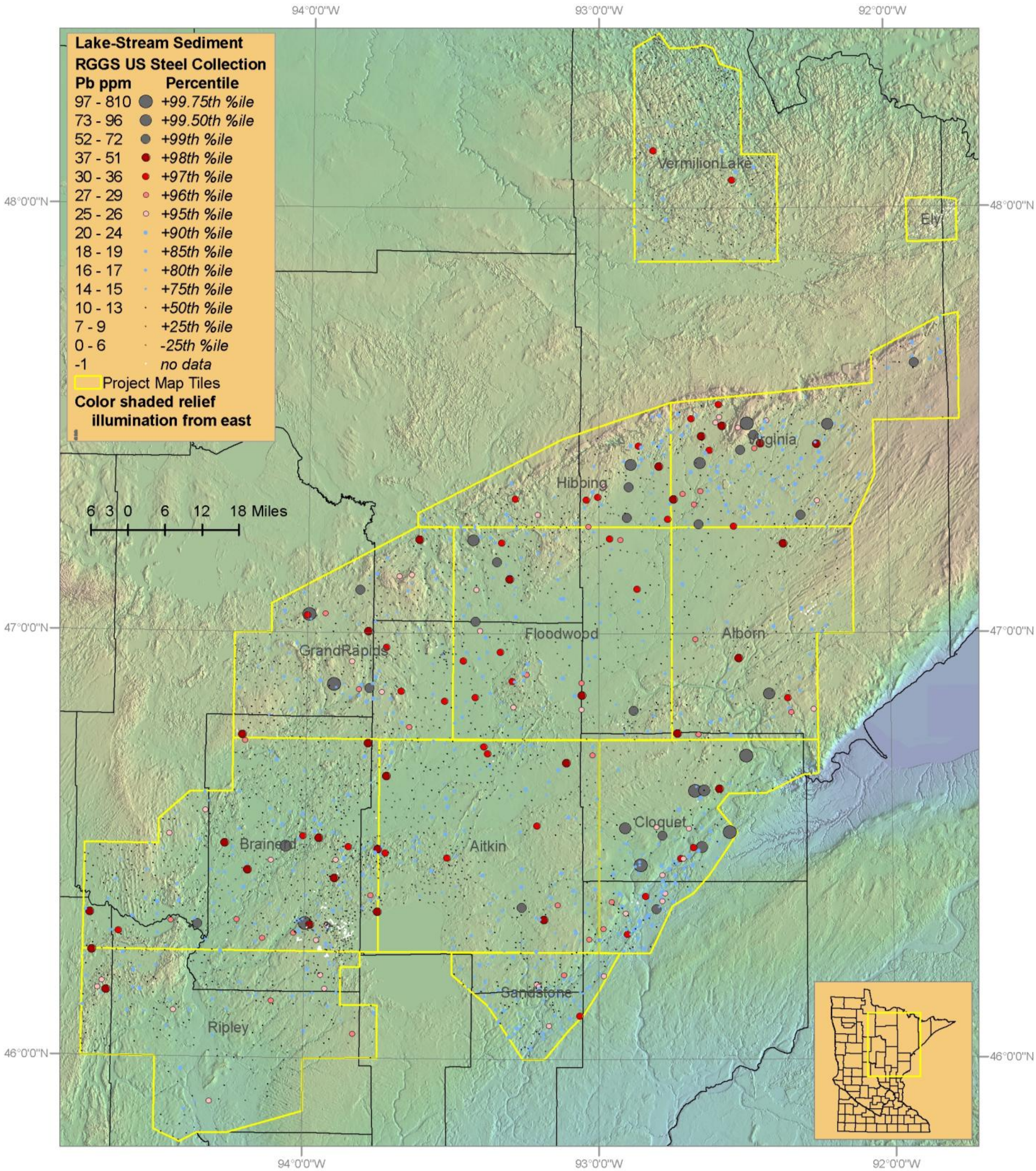

Figure 7. Lead values (in ppm) in the donated data set for lake and stream sample points, by percentile.

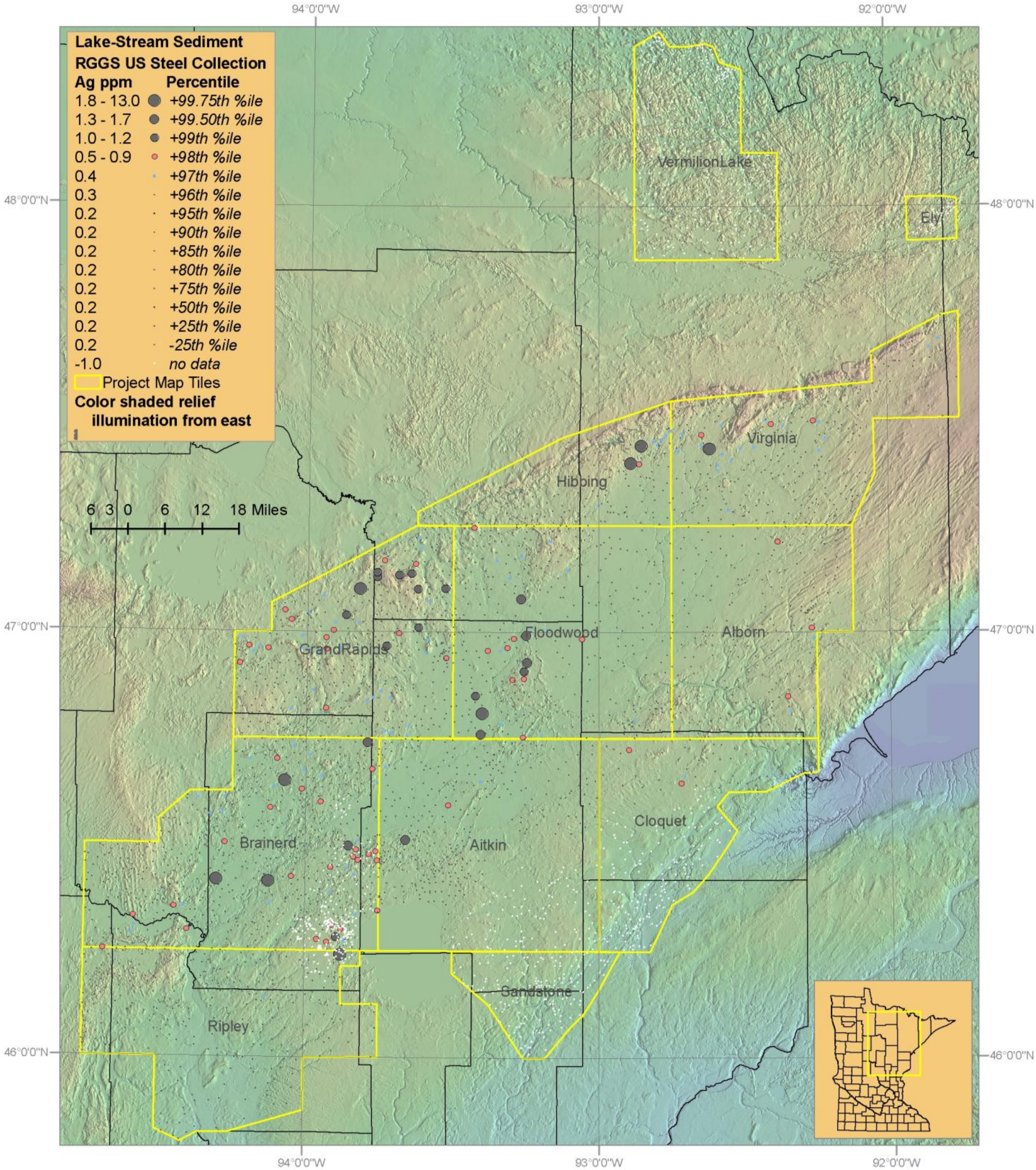

Figure 8. Silver values (in ppm) in the donated data set for lake and stream sample points, by percentile.

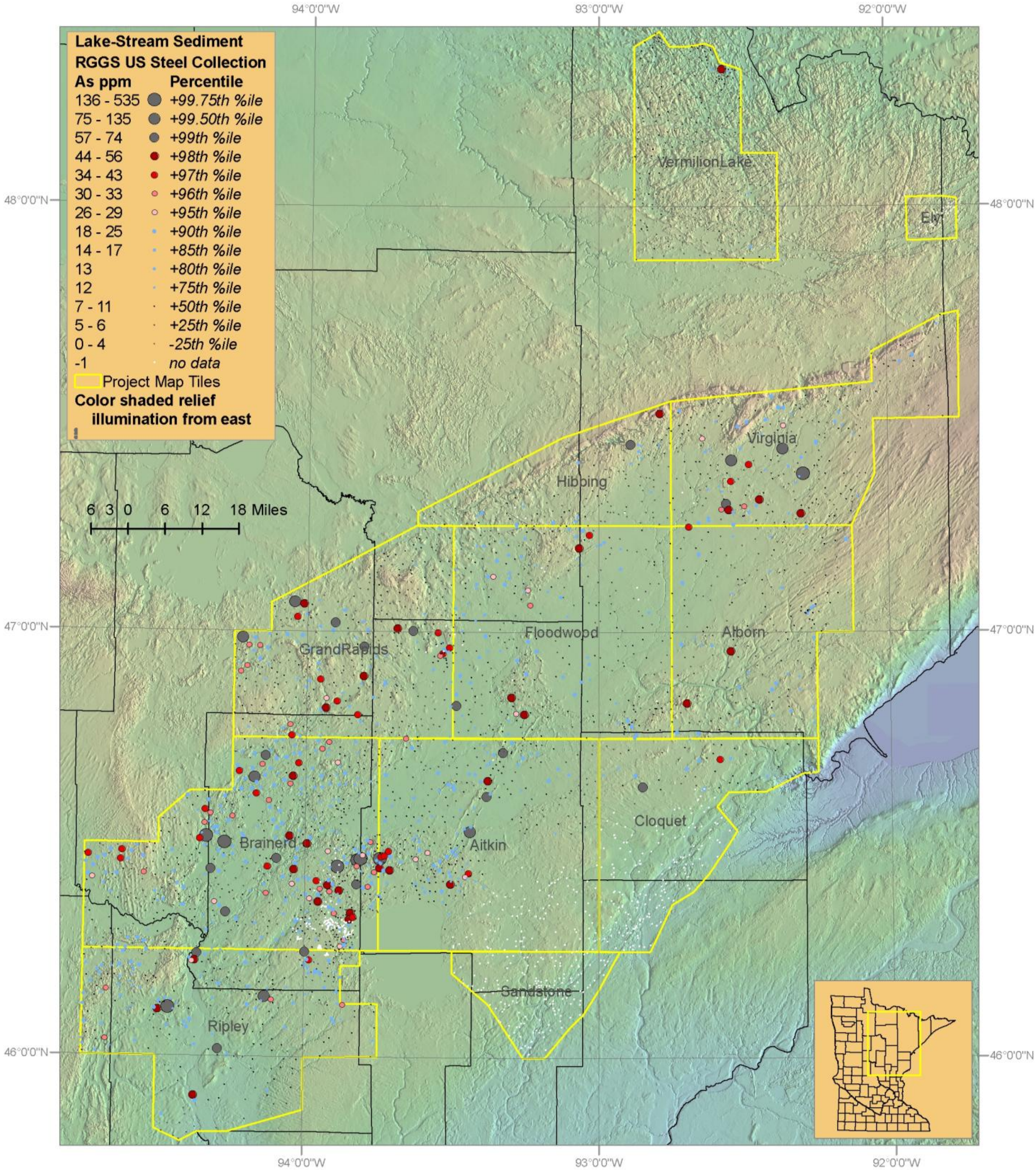

Figure 9. Arsenic values (in ppm) in the donated data set for lake and stream sample points, by percentile.

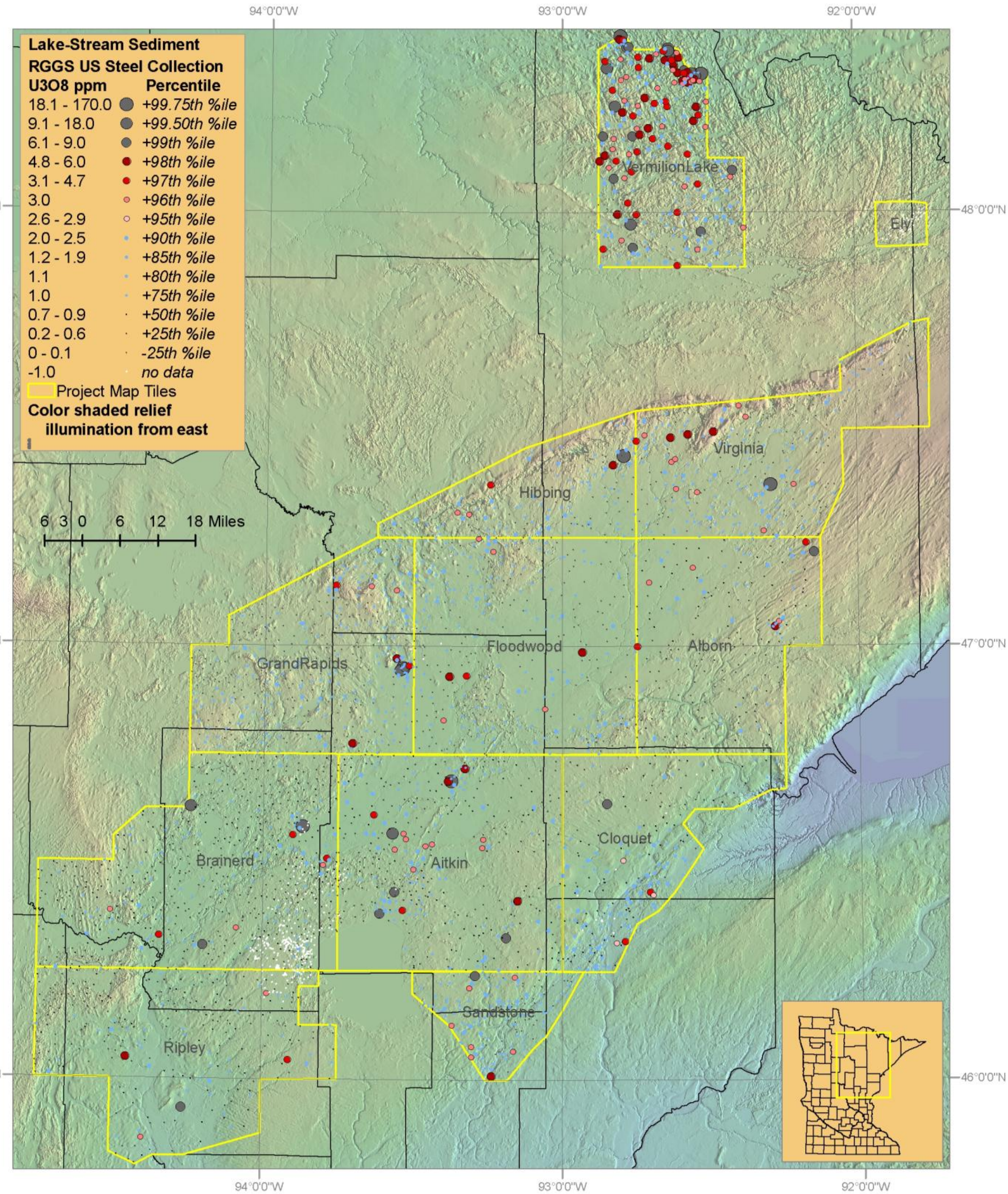

Figure 10. Uranium values (U_3O_8 in ppm) in the donated data set for lake and stream sample points, by percentile.

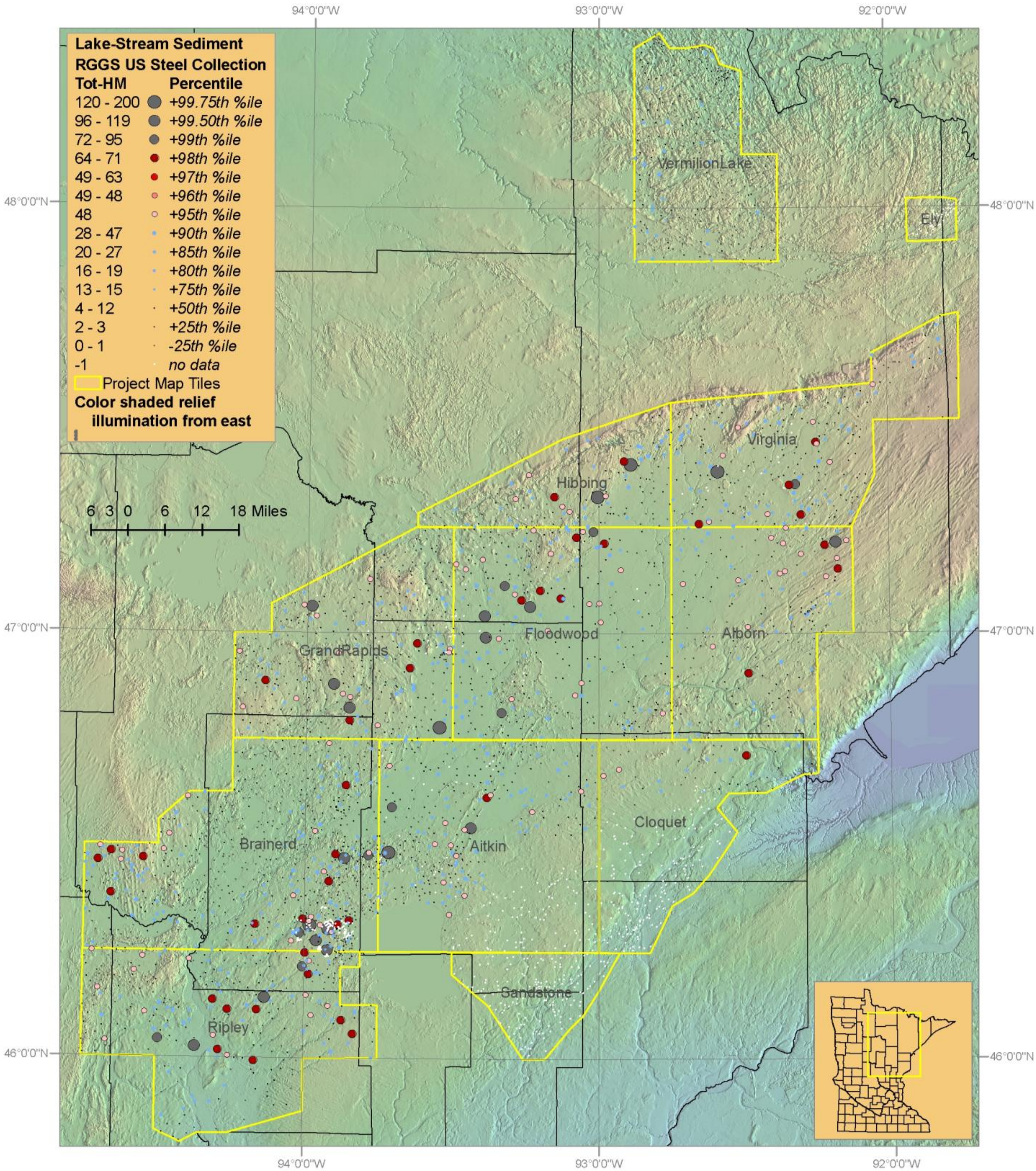

Figure 11. Total Heavy Metals (in ppm) in the donated data set for lake and stream sample points, by percentile.

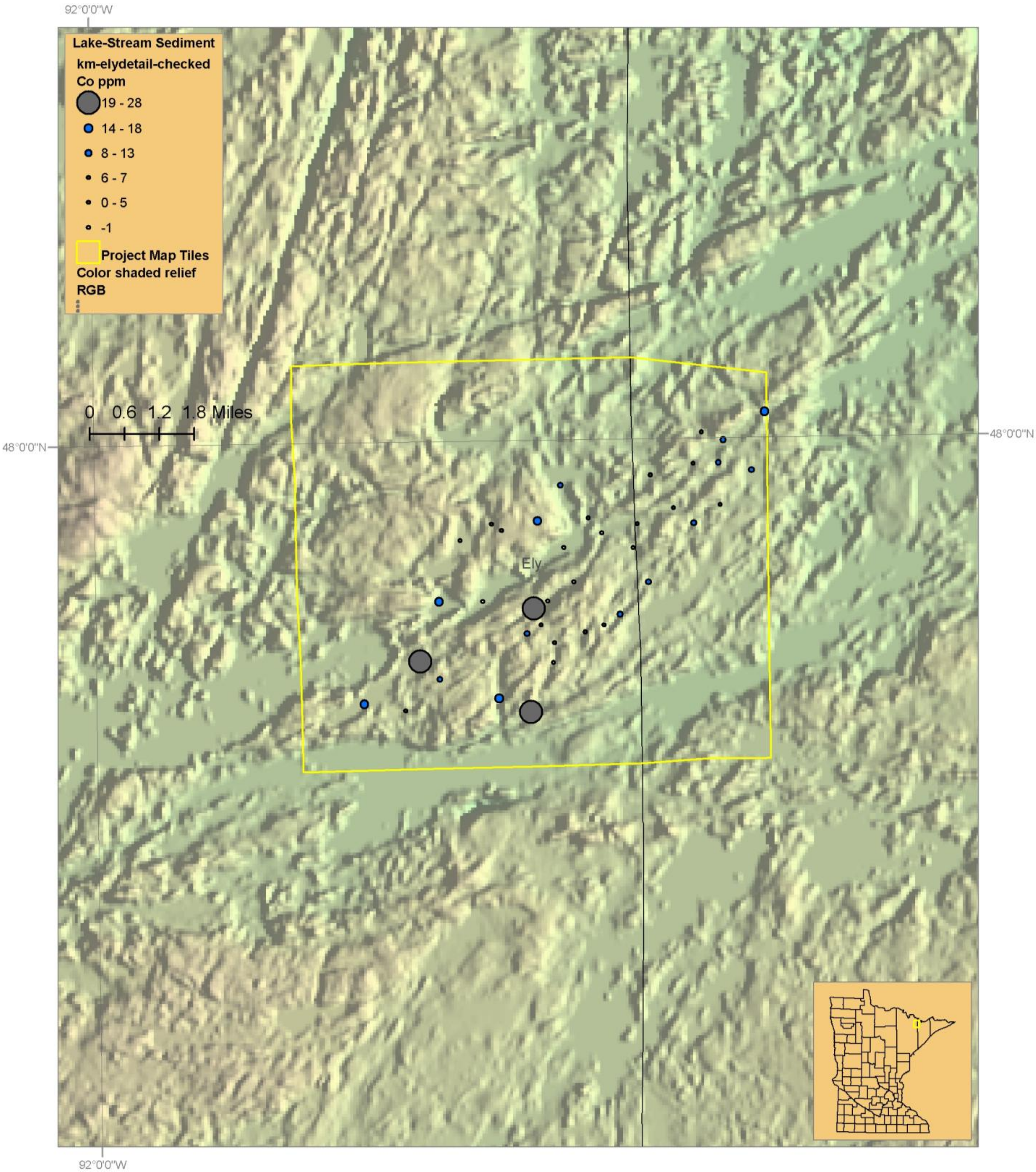

Figure 12. Cobalt values (in ppm) in the donated data set for lake and stream sample points, by percentile. The Ely map tile is the only area of the project that contained a map of Cobalt values.

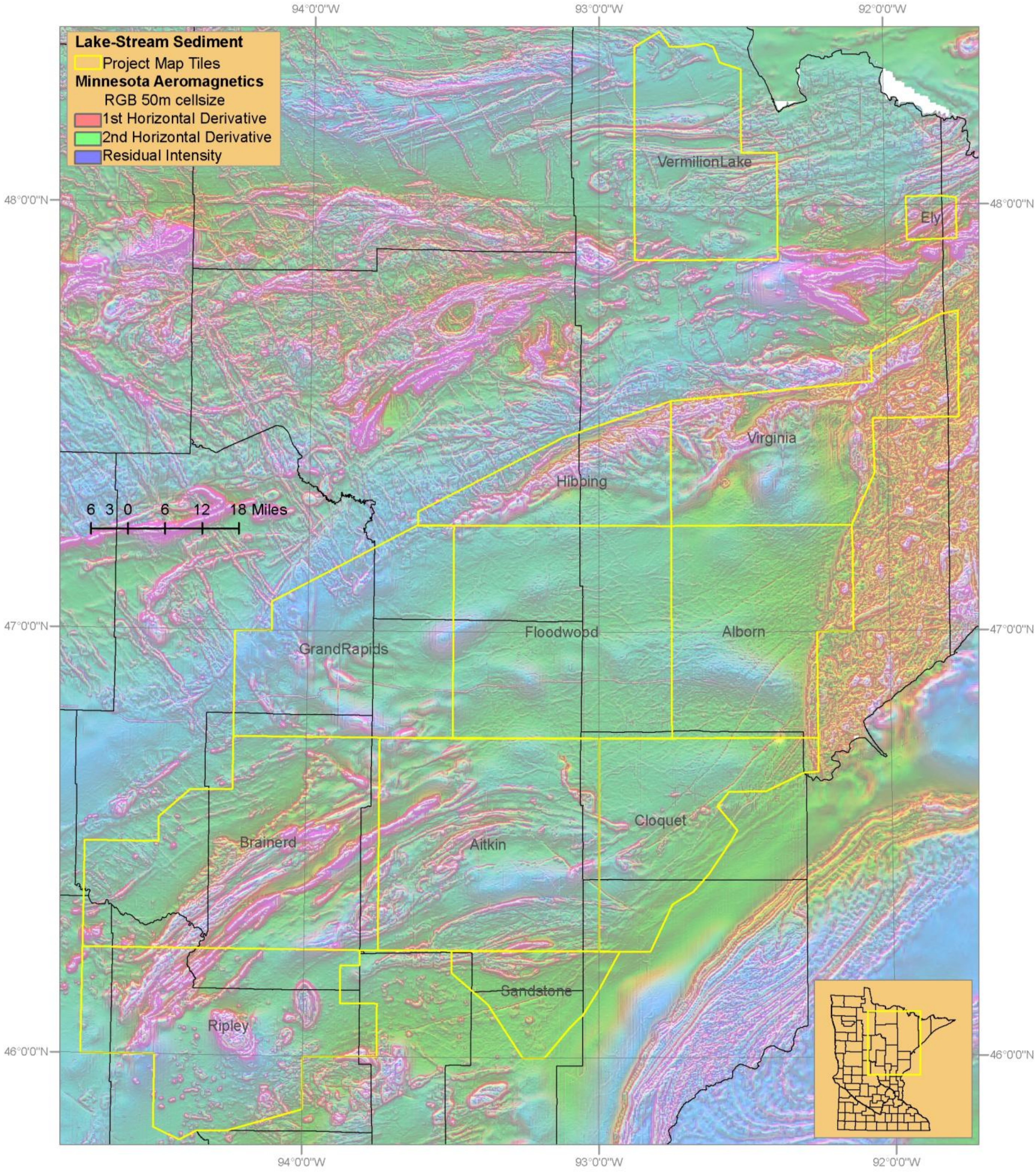

Figure 13. Map tiles superimposed on image of Minnesota aeromagnetic data(1st and 2nd Horizontal derivatives and residual intensity as RGB).

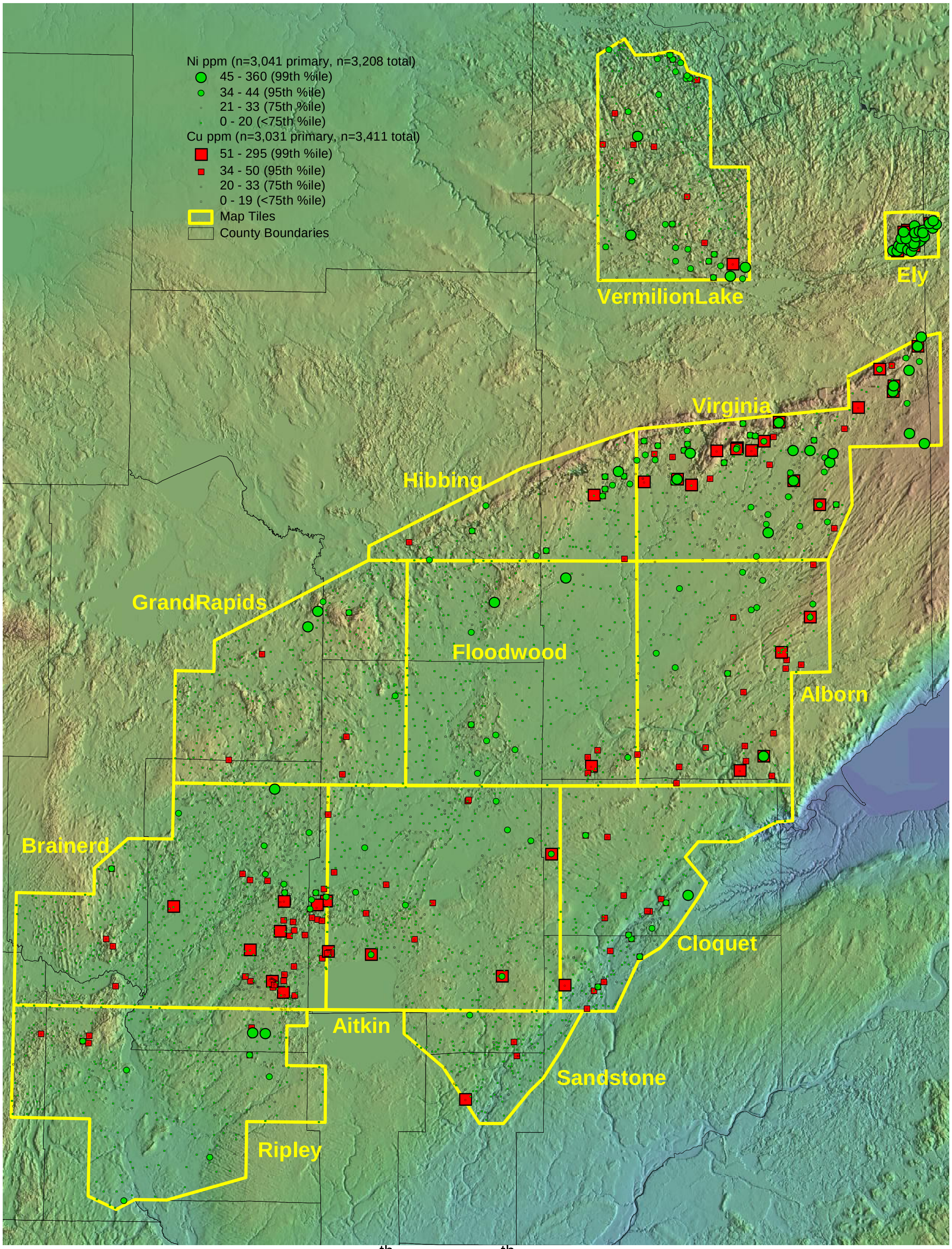

Figure 14. Location of +99th and +95th percentile values for copper and nickel in the donated data set.

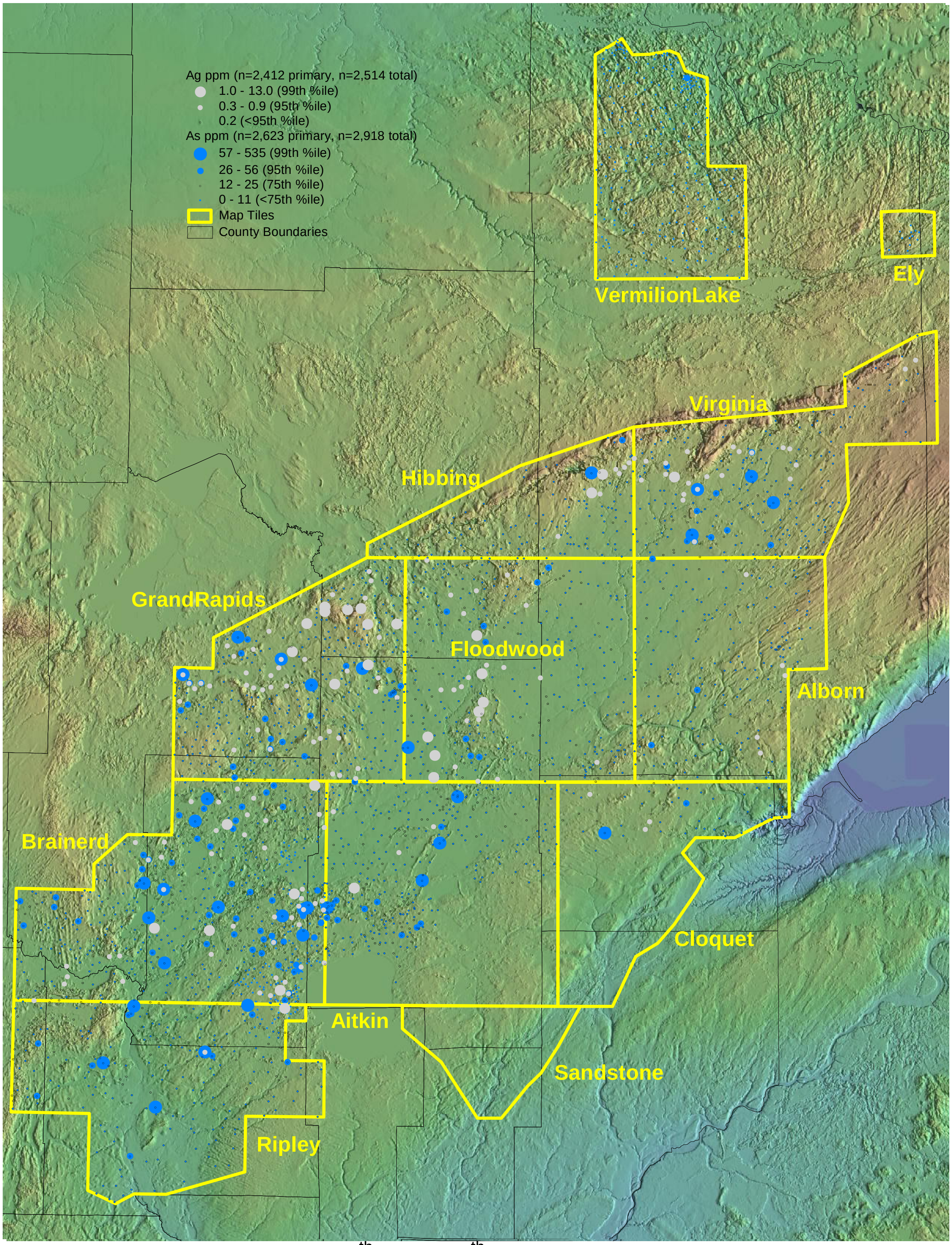

Figure 15. Location of +99th and +95th percentile values for copper and lead in the donated data set.

Figure 16. Location of +99th and +95th percentile values for arsenic and silver in the donated data set.

DETAIL AND HIGH DENSITY SAMPLES

As previously described, the sample-identifier sequence and the geographic distribution of sample-identifiers indicate that a detail sampling phase took place at nine (perhaps ten) localities, each locality following up on point anomalies detected in the reconnaissance phase (see Fig 2). High-density sampling took place at two areas in the Brainerd-Aitkin map tiles. Table 5 lists these detail and high-density localities, assigns names to them, and identifies the reconnaissance values that likely prompted follow up detail sampling.

Table 5. Detail and high-density sample locations in the U.S. Steel collection geochemistry maps.

Location	Map Tile(s)	Type of Samples	No. of Samples	Likely Anomaly
Ash River Campground	Vermilion	Detail	8	32 ppm U_3O_8
Johnson Lake	Vermilion	Detail	30	34 ppm U_3O_8
Willow River Pool	Grand Rapids	Detail	17	25 ppm U_3O_8
West Island Lake	Alborn	Detail	13	5 ppm U_3O_8
Headquarters Lake	Floodwood	Detail	16	392 ppm Zn, 105 ppm Cu
North Aitkin	Aitkin	Detail	15	20 ppm U_3O_8
Dean Brook	Brainerd	Detail	13	19 ppm U_3O_8
Ely	Ely	Detail	39	360 ppm Ni, 84 ppm Cu
Glenn	Aitkin	High Density	31	249 ppm Zn?
Brainerd SE	Brainerd Aitkin Ripley	High Density	163	multi-element area
Garrison	Brainerd Aitkin	Detail	139	multi-element area
Mud Hen Lake/Creek	Virginia	Detail?	20?	170 ppm U_3O_8

Seven of these locations focus on elevated uranium values detected in the reconnaissance sampling. The other five locations appear to follow up on elevated base metal values detected in the reconnaissance sampling. At the time these samples were collected (1977-78), active exploration for uranium and base metals was taking place in Minnesota.

Nickel-copper base metal mineralization appears to be the target of the Ely area detail samples, possibly following up on 1974-75 and 1976 MnDNR lake sediment surveys of the area (Meineke, et. al., 1976, 1977a).

Base metals also appear to be the interest of high-density sampling, detailed sampling and an airborne survey in the Garrison area. High-density sampling in the Glenn vicinity could conceivably have been for orientation purposes given the known presence there of a twenty-six million ton iron pyrite-phyrrotite historical resource that was delineated during a sulfur exploration program in the early 1950's (Hanna Collection, MnDNR Mineral Exploration Archive files).

GENERAL OBSERVATIONS ON THE DONATED DATA SET

While the digital data set compiled from the donated map suite provides an interesting geochemical perspective on this part of Minnesota, it should be viewed with some caution. Since an exploration report was not found for the donated data set, there is not a clear understanding of sample collection methodology, sample site selection criteria, sampling tools used, sample containers, sample drying procedures, sample preparation and dissolution procedures, nor analysis or quality control procedures, or statements of precision and accuracy. Kerr-McGee's Uranium exploration data and databases were transferred to a spinoff company, Tronox Worldwide, LLC in 1989, and its data, consisting of 300 containers of exploration information were subsequently acquired by Uranium Energy Corp. in 2008 (See March 12, 2008 news release by Uranium Energy Corp.). It is possible that additional pieces of the Minnesota project might be found in this collection or in files that remain with Tronox. With these limitations in mind, the following general observations are made regarding the donated data set:

Nickel

Nickel (Figs. 4 and 14, n=3,041) displays clustering of 99th percentile values in an area of known mineralization along the base of the igneous Duluth Complex, at the east edge of the Virginia map tile. The elevated nickel values appear to extend southwestwards from the Duluth Complex into the Animikie basin, in a direction generally matching what would be expected from glacial dispersion activities.

For the entire 9,900 square mile project area, the highest nickel values are reported from the Ely area where a tight cluster of highly elevated nickel values, ranging up to 360 ppm Ni, is displayed in the vicinity of Hobo Lake, Little Long Lake, Camp Lake, Picketts Lake, Low Lake, High Lake and Bass Lake. The Ely detail values confirm similar results from earlier MnDNR lake sediment surveys conducted in 1974-1975 and 1976. In this area, ultramafic flows and sills are recognized in the Newton Lake Formation (Peterson and Jirsa, 1999).

Clustered nickel values in the +95th percentile occur west of the Virginia Horn in the Virginia (NW ¼) and Hibbing (NE ¼) map tiles; also in the southeastern part of the Vermilion map tile in the Frazer Bay – Niles Bay area of Lake Vermilion; in the Moose Lake-Barnum area of the Cloquet map tile; and in eastern Crow Wing County in the Deerwood-Aitkin area (Brainerd and Aitkin map tiles). Smaller groupings of +95th percentile values are also found in a glacial outwash area overlying part of the Animikie basin in the vicinity of Big Sandy Lake; also in a ground moraine area near the Aitkin-Carlton County boundary; and near Johnson Lake in the Vermilion (NE ¼) map tile. One and two point +99th percentile values were compiled near Munger in Solway Township in the Alborn (SE ¼) map tile; also in the Goodland delta overlying the Animikie basin in the north half of the Floodwood map tile; southwest of Pine Center in the Ripley (NE ¼) map tile; and northeast of Remer in the Grand Rapids map tile.

Nickel values were not found to be posted on source maps for the high-density sample points in the Brainerd (E ½) map tile, nor for detail (circle symbol, soil?) samples in the Garrison area.

Cobalt

The only source map for cobalt values covers the Ely detail area. Cobalt values there range from 2 to 28 ppm Co (Fig. 12, n=28), generally confirming the results from earlier MnDNR lake sediment surveys in the Ely area which reported cobalt values up to 34 ppm Co.

Copper

Copper values were successfully compiled for the entire project area (Figs. 5, 14 and 15, n=3,031). Copper values in the +99th percentile form clusters at several localities that have already been mentioned under the Nickel heading, that is, in the Ely detail area; in the southeastern Vermilion map tile; in the Virginia map tile covering the basal portion of the Duluth Complex and thence down-ice southwestwards over the Animikie basin; in the vicinity of the Virginia Horn in the Virginia (NW ¼) and Hibbing (NE ¼) map tiles; in the eastern Brainerd map tile; and in portions of the Alborn and Cloquet map tiles. An additional area in the Floodwood (SE ¼) map tile also displays a grouping of elevated copper values. Copper values in the overall project area range from zero to 295 ppm Cu, with values greater than 50 ppm Cu falling in the +99th percentile. Copper values greater than 100 ppm Cu were compiled in the Ely (Newton Lake Formation) area, in the Basal Duluth Complex area, in the eastern Brainerd map tile, and in the Alborn map tile area. Clustered copper values in the eastern Brainerd area and the Virginia Horn are generally collaborated by high percentile copper lake sediment values in a MnDNR lake sediment survey in the eastern Brainerd area, and perhaps by a report of sphalerite (zinc) bearing boulders in a mining (overburden) stockpile west of the Virginia Horn, respectively.

Zinc

Zinc values in the +99th percentile and in the +95th percentile are scattered across much of the project area without much pattern, but seem to be uniformly lower in the Vermilion map tile (Fig. 6, n=3,039). There is perhaps, visually, some correlation of higher values being more often found in areas of topographic relief. The area from Hibbing to the west side of the Virginia Horn displays several elevated zinc, lead, silver, copper and nickel values. In same this area, a 1938 MnDNR annual operations report noted mineralized boulders in the Wheeling mine overburden stockpile north of Parkville. The report (Walle, 1938) described the following:

> *"During a visit at the Wheeling surface stockpile our research engineer, Mr. Aho, was attracted by the presence of mineral particles in some of the boulders. Samples from these boulders were brought back to Hibbing and tests made by various methods: microscopical examination and qualitative determination. The quantity of sphalerite was such in the material that a ground sample was examined by the Chemical Section. It was found to contain: Zinc: 5.24% and Iron: 3.50%. A flotation test was made on the same material and a concentrate obtained containing zinc: 37% and iron 11%."*

A more recently-conducted cooperative statewide glacial till reconnaissance by the Minnesota Geological Survey and Western Mining Corp. (Thorleifson, et al., 2007) also yielded till samples with elevated chemical and mineral values in the area. For instance, MGS-WMC sample R-10, collected near Kinney reports values in the +95th percentile for Zn and Cu, and +98th percentile for Ni, Fe, Cr, Al and Sn, as well as mineral counts in the +95th to +99th percentiles for olivine, orthopyroxene, goethite, hematite; and for pebble counts of mafic intrusive - high grade metamorphic, iron formation, and quartzite.

A source map of zinc values was not found for the Ely detail area, and zinc values were not posted on source maps for the Garrison detail (circle) sample points. While zinc values in the overall project area range from zero to 1,380 ppm Zn, only four the project samples exceed a value of 400 ppm Zn, and only one sample exceeds a value of 1,000 ppm Zn.

Lead

Lead (Pb) values in the +99th and +95th percentile cluster near- and down-ice from the Virginia Horn in the Hibbing and Virginia map tiles, and also in the Cloquet map tile where the highest lead values in the project area were compiled in the Park Lake - Moose Lake area (Figs. 7 and 15, n=3,040). Two of the sample values in the Moose Lake-Park Lake vicinity exceed 500 ppm Pb, and seven total samples exceed 100 ppm Pb.

Lead values were omitted from source maps for some Garrison detail (circle) sample points, and a source map of lead values was not found for the Ely detail area.

Silver

Most compiled values for silver fall below indicated detection limits of 0.2 ppm Ag (Figs. 5 and 16). Only one sample, in the Ripley (NE ¼) map tile exceeds a value of 10 ppm Ag, and only three samples exceed 2 ppm Ag (north of the Brainerd airport, and east of Hibbing). Sixteen total samples exceed 1.0 ppm Ag, and only 171 compiled samples exceed the detection limit of 0.2 ppm Ag. Most +90th percentile silver values are found in the west half of the project area with an additional grouping of +90th percentile values also found in the vicinity of the Virginia Horn (Fig 16). The higher silver values in the west half of the project area and Virginia Horn area are perhaps associated with St. Louis sub-lobe glacial sediments. Silver, arsenic and Total Heavy Metals plots show some similarity in this regard.

Silver values maps were not found for the Vermilion, Ely and Sandstone map tiles. On the Aitkin and Cloquet map tiles silver values were listed as “NA” for significant portions of the tiles. Silver values were not posted on source maps for high-density Brainerd area sample points, nor for the Garrison detail (circle) samples.

Arsenic

Arsenic values generally cluster in the same areas as described for silver, that is, in the west half of the project area and in the Virginia Horn area (Figs. 9 and 16). Arsenic values in the Vermilion map tile are relatively low. A predominance of +90th percentile arsenic values in the west half of the project area and south of the Virginia Horn might reflect St. Louis sub-lobe glacial sediments, for which entrained shales of the Winnipeg lowlands may be a plausible source. Martin, et al (1991) found arsenic useful in north-central Minnesota for distinguishing till packages derived from northeast versus northwest sources, with higher arsenic values generally being associated with northwestern-derived (Winnipeg lowland) sources. Arsenic values in the project area range from zero to 535 ppm As, ten total samples exceed 100 ppm As, three samples exceed 200 ppm As. Several of the +99th and +95th percentile arsenic values appear to cluster in the eastern part of the Brainerd map tile.

Arsenic values are not reported for portions of the Aitkin and Cloquet map tiles (posted as "NA"), and a source map of arsenic values was not recovered for the Sandstone map tile. Arsenic values are also not posted for detail samples in the Garrison area (circle sample points) and Ely detail area.

*U_3O_8 (Conversion factor: 1.1792 * U ppm = U_3O_8 ppm)*

Almost 99.5 percent of the data set values for U_3O_8 range from "zero" to 9 ppm U_3O_8. Only 16 samples of the 3,024 compiled values exceed 10 ppm, half of them located in the Vermilion map tile (Fig. 10). A large percentage of +98th percentile values also plot in the Vermilion map tile. Most of the Vermilion map tile is underlain by metasedimentary/gneissic/granitic rocks of the Quetico Subprovince terrane, and the values reported on the maps match a trend of elevated values found in the same subprovince terrane as it trends into adjacent Ontario (see data from Friske, et al, 1981). Detail sampling in the Vermilion map tile confirmed the reconnaissance phase findings but did not result in values higher than 34 ppm U_3O_8. A single point anomaly of 170 ppm, the highest in the project area, was posted in the Animikie basin portion of the Virginia (E ½) map tile. A small airborne geophysical flight (Mud Hen area) was subsequently flown in the vicinity of this anomaly, but no follow up work or detail sample maps have been identified in the donated data collection.

U_3O_8 values for high-density sampling in the Garrison area are not posted on the source maps, nor are values for sampling in the Ely detail area. A large population of 1.0 ppm U_3O_8 values seems to reflect differences in drafting U_3O_8 values onto some of the map tiles. On some map tiles the smallest value drafted was "<1.0". On other map tiles, values down to 0.1 ppm U_3O_8 were posted.

Total Heavy Metals

"Cold-extracted" total heavy metal values (THM, Fig. 11) are broadly low in the Vermilion map tile, and were not analyzed in the southeastern part of the project area in the Sandstone tile and parts of the Aitkin and Cloquet map tiles, nor in the Ely or Garrison area detail sampling. THM values range from "zero" to 200, with only 7 samples exceeding a value of 100 out of 2,575 compiled values. Higher THM values are scattered through the higher relief portions of the project area, but without a distinct pattern. One might speculate that more of the higher values are found in the western half of the project area, perhaps corresponding to St. Louis sub-lobe glacial sediments.

Elevation-Relief

As a gross generalization (but excluding the Vermilion and Ely map tiles where much bedrock relief occurs), lake sediment samples from the low and relatively flat areas of glacial lake bottoms in the project area seem to have lower metal values;

lake sediment samples from areas of uplands, outwash and morainal areas seem to have higher metal values.

Other Available Lake Sediment Geochemistry Data Sets from Agency Projects

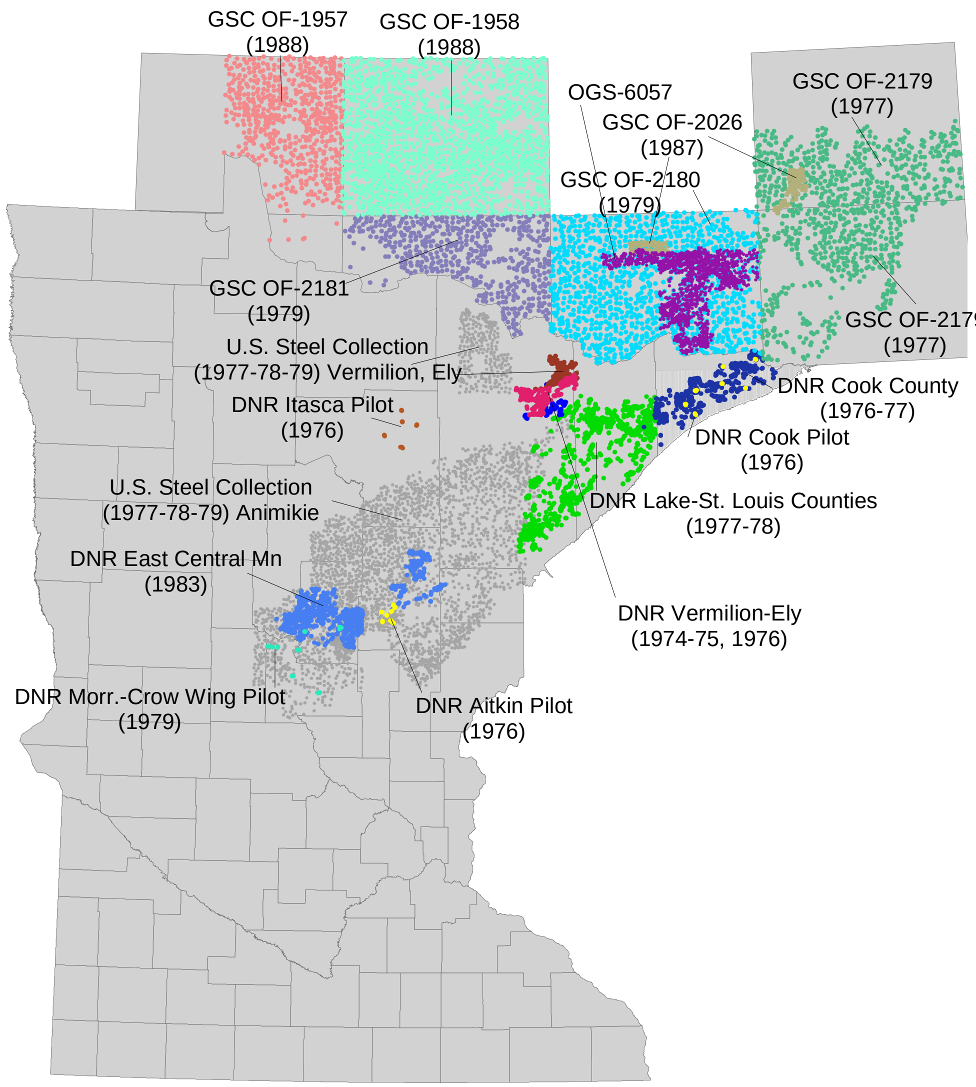

Figure 17. Overview of public domain organic-rich lake sediment geochemistry data sets for Minnesota and a portion of adjacent Ontario.

OVERVIEW

Several public agency lake sediment geochemistry surveys have been conducted in and near Minnesota, in areas proximal to the donated data set described previously in this report (Fig 17). In the ten year period beginning in 1974, eleven reconnaissance surveys of organic-rich lake basin sediments and stream sediments were undertaken in northern and east-central Minnesota in an effort to better identify and classify areas of bedrock having potential to host nonferrous metallic mineral resources.

MnDNR undertook these organic-rich lake basin sediment surveys in Minnesota over the course of five funding periods, with the last project report published in 1985. During that ten-year time period, MnDNR reported results for eleven lake sediment and seven peat-humus-soil-till geochemical projects that were conducted at pilot scale, regional reconnaissance scale, or detailed follow-up scale (see references by Meineke and others, Vadis and others, and Sellner).

MnDNR built its organic-rich lake basin studies on the basis of techniques developed over the previous decade by the Geological Survey of Canada (GSC) and the geological surveys of the Canadian provinces. GSC, in cooperation with the provinces, developed public domain sample collection, preparation and analysis techniques, and undertook research to promote a greater understanding of the distribution of metals in lake sediments. GSC's first regional scale reconnaissance survey from the province of Newfoundland was released in 1973 (Coker, et al, 1979). GSC in cooperation with the Ontario Geological Survey collected organic-rich lake sediment samples from 1 x 2 degree map areas adjacent to Minnesota in 1977 (Hornbrook and others, 1978) and 1979 (Hornbrook and others, 1980) (Fig.

17), and re-analyzed archived samples in 1989 (Friske and others 1990, 1991). GSC conducted detailed sampling in the Lac des Iles, Crooked Pine Lake-Atikokan, Marathon and Beardmore-Jellicoe areas of Ontario in 1987 to determine the feasibility of using lake-bottom sediments for precious metals prospecting (Friske, et al, 1990). Areas north and east of Minnesota's Northwest Angle were evaluated in 1988 (Hornbrook and Friske, 1989). A high-density lake sediment survey was conducted by the Ontario Geological Survey, in 1999, in an area adjacent to Minnesota, stretching north to the Shebandowan area (Jackson, 2001). GSC has also published compilations of multiple combined data sets (Coker and Ellwood, 1981, Friske et al, 1997, 1998), and published interpretations of reconnaissance data (Friske, 1985).

During this same time period the mineral exploration community also used organic-rich lake basin sampling techniques to conduct lake sediment sampling activities in Minnesota. At least one large lake- and stream-sediment mineral exploration survey, described in the previous section of this report, was conducted in 1977-1979, centered on the Paleoproterozoic rocks of the Animikie foreland basin and Penokean fold and thrust belt of east-central Minnesota. Selected portions of the Archean Quetico Metasedimentary Subprovince, the Archean Vermilion greenstone belt (Wawa Subprovince) and the Mesoproterozoic Duluth Complex of northern Minnesota were also sampled during the project. Other industry geochemical projects housed in MnDNR's mineral exploration archives (mostly soil surveys), and particularly covering parts of the Duluth Complex area, are yet to be compiled.

LAKE SEDIMENTS

Each of these surveys, whether sponsored by government, industry, or university, had a common underlying purpose: to detect watersheds containing subtly elevated levels of trace metals. While a host of natural and cultural causes can influence overall watershed-to-watershed trace metal variations, the principal factor of interest that motivated these surveys was the possibility of detecting variation due to base metal or uranium dispersion from enriched/mineralized bedrock, or from glacial debris carrying entrained pieces of enriched/mineralized bedrock. Much work and research activity during this time period was given over to identifying trace metal accumulators in the natural environment that might scavenge enough metal from natural waters to allow detection by analytical techniques of the day. The concept of "geochemical prospecting" benefited greatly from increased understanding of how and where trace metals disperse or accumulate in the natural environment, and from better understanding of source-to-sink ideas, that is, how trace metals cycle through the natural environment from "source" to "sink".

Lake-basin sediment was seen as a natural trace metal accumulator, and because of its widespread occurrence and relatively easy sampling access in lakes across much of Canada, it was viewed as a favorable sample media upon which to base regional geochemical surveys. Lake sediments can be classified as 1) organic gels, often referred to as *gyttja*, which are found in lake basins (*profundal basins*) away from sources of coarse organic debris and coarse inorganic sediments, 2) organic sediments comprised of mixtures of organic debris, organic gels and inorganic silts and clays, or 3) inorganic sediments consisting of boulder to sand sized, and silt and clay materials lacking organic material (Coker, et al., 1979). The gyttja material is viewed as more representative of the overall composition of the surrounding watershed than the more locally variable coarse organic and inorganic debris.

The basin centre organic gels comprising the gyttja are thought to accumulate trace metals from water through the scavenging activity of algal and plankton blooms (Coker, et al., 1979). As succeeding generations of algae and plankton moult or die, the organic remains (containing the trace metals they have scavenged), eventually settle and accumulate at the lake bottom. Trace metals are also thought to accumulate in lake-bottom organic gels through direct complexing or absorption mechanisms. Occasionally, direct precipitation of metal oxides from lake water occurs, with subsequent settling and accumulation of the material as lake-bottom sediments. Friske (1991) prvides a practical description of lake sediment sampling practices and procedures, and Cook and McConnell (2001) provide a good review of the context and uses of lake sediment data in mineral exploration in Canada.

MnDNR COMPILATION WORK

After efforts had been undertaken to digitally compile 3,540 lake and stream sediment samples from the RGGS-U.S. Steel collection, and upon recognizing that the donated data set partly overlaps MnDNR lake sediment survey data along the Animikie Basin – Duluth Complex margin, it was decided that the same procedures used to digitally compile the donated map set could be used to compile Minnesota's existing lake sediment survey projects. A total of 2,943 lake sediment geochemical sample localities were recovered from eleven Minnesota DNR projects, covering approximately 4,000 square miles of northeastern and east-central Minnesota.

Lake sediment geochemical data from adjacent Ontario, Canada is already compiled and available through the internet in the form of digital downloads from GSC's web site at http://gdr.nrcan.gc.ca/geochem_ngr/index_e.php. These data provide an additional 4,706 samples in the vicinity of Minnesota's northern border. The Ontario Geological Survey has also published a high density lake sediment survey from the Shebandowan area (Jackson, 2001) which is available through the Ontario Geological Survey's web site at the address: http://www.geologyontario.mndm.gov.on.ca/mndmaccess/mndm_dir.asp?type=pub&id=MRD076, adding another 1,385 sample results, for a grand total of 13,024 samples potentially available for evaluation in and adjacent to Minnesota. Specific projects, numbers of samples and types of samples analyzed are summarized in Table 6. Appendix A summarizes the distribution of samples, analyzed metal values and percentiles for the major components of Minnesota, RGGS-US Steel Collection, and nearby Ontario surveys.

The purpose of recovering all of these public domain lake sediment sample data from the Minnesota surveys, even beyond the area of overlap with the donated data set, has been to bring Minnesota's sizeable lake sediment sampling and analytical investment into the digital geography realm, so that the results can be used in support of classification and mineral management of public-trust lands.

Table 6. Public domain data sets for Minnesota and adjacent areas of Ontario.

Project Name	No. Samples	Sample Pattern	Collection Year	Sample Media	Reference
DNR Verm.-Ely	270	Reconnaissance	1974-75	Lake	Project 73-3
DNR Verm.-Ely North	184	Reconnaissance	1976	Lake	Project 134
DNR Verm.-Ely South	92	Reconnaissance	1976	Lake	Project 135
DNR Verm.-Ely-U	50	Pilot	1976	Lake	Project 148
DNR Itasca County	15	Pilot	1976	Lake	Project 71-3
DNR Aitkin County	16	Pilot	1976	Lake	Project 117
DNR Cook County	20	Pilot	1976	Lake	Project 138
DNR NW Kooch. Cty	-	Pilot	1976	Stream/Soil	Project 36-7
DNR Skeleton Lake	13	Detail	1977	Stream	Project 107
DNR Birch Lake Peat	11	Pilot	1977	Peat	Project 108-1
DNR Birch B-Soil	22	Pilot	1977	B-Soil	Project 108-2
DNR Birch A-Soil	7	Pilot	1977	A-Soil	Project 108-3
DNR Filson Creek	30	Pilot	1977	Stream	Project 109
DNR Cook County	608	Reconnaissance	1976-77	Lake	Project 138-2
DNR Lake-St. Louis	1087	Reconnaissance	1978-79	Lake	Project 171
DNR Morrison-Crow	20	Pilot	1979	Lake	Project 152
DNR Geodrilling	-	Detail	1980	Lake/Strm	Project 201
DNR East Central Mn	618	Reconnaissance	1983	Lake	Project 236
Animikie-Vermilion	3056	Reconnaissance	1977-78	Lake/Stream	U.S. Steel Col
Animikie-Vermilion	194	High-density	1977-78	Lake/Stream	U.S. Steel Col
Animikie-Vermilion	112	Detail	1977-78	Lake/Stream	U.S. Steel Col
Ely	39	Detail	1977-78	Lake/Stream	U.S. Steel Col
Garrison	139	Detail	1979	Lake/Stream	U.S. Steel Col
Mud Hen	20?	Detail	1979?	Lake/Stream	U.S. Steel Col
GSC OF-2179 *	922	Reconnaissance	1977	Lake	GSC OF-2179
GSC OF-2180	1131	Reconnaissance	1979	Lake	GSC OF-2080
GSC OF-2181	510	Reconnaissance	1979	Lake	GSC OF-2081
GSC OF-2026 *	299	Detail	1987	Lake	GSC OF-2026
GSC OF-1957	590	Reconnaissance	1988	Lake	GSC OF-1957
GSC OF-1958	1365	Reconnaissance	1988	Lake	GSC OF-1958
OGS Shebandowan	1385	High-density	1999	Lake/Water	OGS OF-6057

*Samples west of UTM easting 870,000 used for these purposes.

DISCUSSION

Compiled MnDNR lake sediment geochemistry surveys and compiled donated data overlap in three places: a) East-central Minnesota, b) the Animikie Basin–Duluth Complex margin, and c) north of the town of Ely.

EAST-CENTRAL MINNESOTA (Deerwood-Aitkin Anomaly)

The donated data set overlaps a 1983 MnDNR lake sediment survey (Sellner, 1985) from East-central Minnesota. Figure 18 depicts Copper, Nickel, Cobalt, and Zinc values for the 1983 survey, using symbol sizes proportional to percentile value, and +99th percentile and +95th percentile symbols colored.

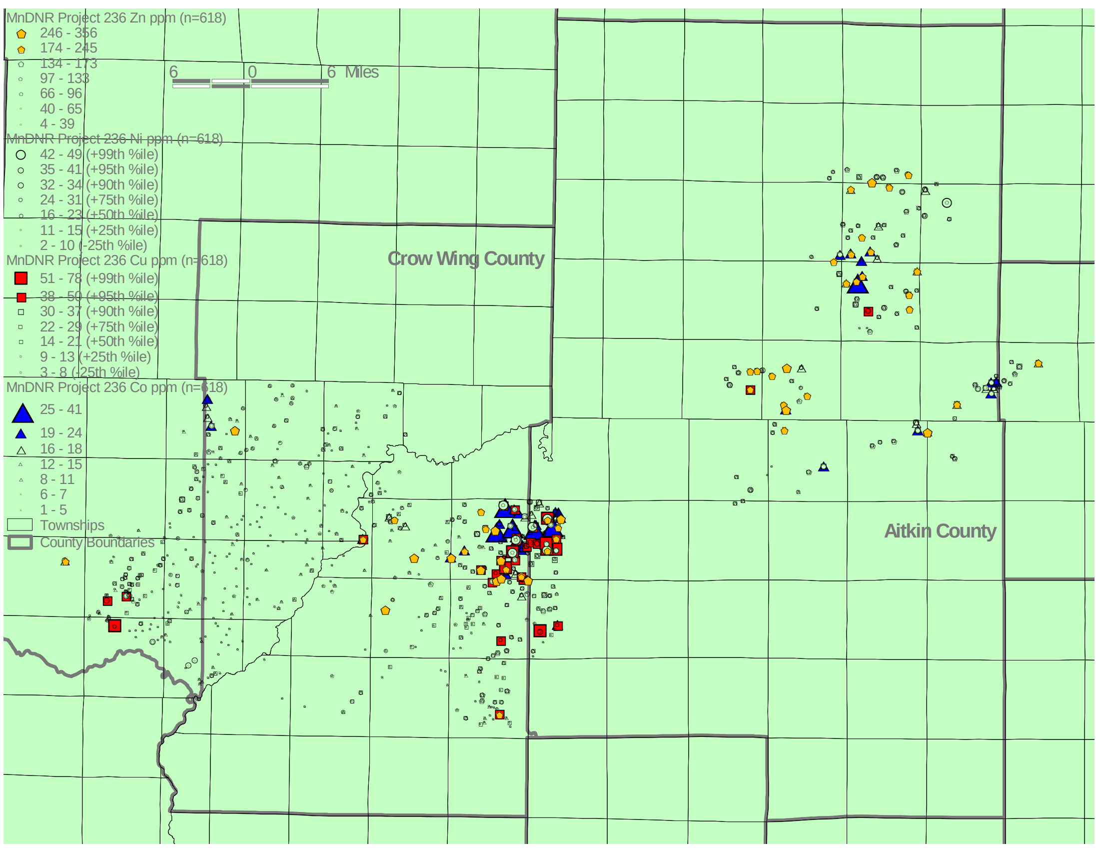

Figure 18. MnDNR lake sediment data for Co, Cu, Ni and Zn in east-central Minnesota. Township boundaries shown for general reference and scale.

In the central part of Figure 18, a prominent anomaly consisting of a cluster of +99th and +95th percentile zinc, copper, nickel and cobalt values can be seen in a two township area straddling the Aitkin County – Crow Wing County boundary. The anomaly appears to be closed to the south and west, but no MnDNR data is available for the area immediately north and east of the elevated values. Scattered +95th percentile values located further northeast of the anomaly, in northern Aitkin County, are from the Big Sandy Lake vicinity. A small anomaly, at the east side of Aitkin County, lies in the vicinity of a peridotite-bearing intrusion that is currently being explored for copper-nickel mineralization near Tamarack, MN.

Figure 19 shows percentile values for copper from the 1983 MnDNR survey (as red squares) overlain by percentile values for copper from the RGGS-U. S. Steel donated data set (as gray or red circles) and using a colored shaded-relief elevation background. While the donated set has much more comprehensive coverage, the dozen or so clustered +95th and +99th percentile copper values for the donated data set show much the same anomaly location and pattern as first noted in the MnDNR data. The metal concentration values for the two data sets, in percentile rank, are also quite similar.

A large, flat plain composed of former glacial Lake Aitkin lake bottom lies just north of the clustered copper values from the two data sets. It is not clear from the data whether the anomaly terminates south of the lake plain or is masked by cover of glacial lake bottom sediments.

In a manner similar to Figure 19, Figures 20 and 21 depict nickel and zinc metal value percentiles for the two data sets. Cobalt was not analyzed in the donated data set in this area, so comparison of the two data sets for cobalt metal values are not possible at this locality. A broader aeromagnetic perspective on the area can be found by referring back to Figure 13, which illustrates the regional aeromagnetic pattern beyond the Deerwood-Aitkin anomaly. In figure 13 the Deerwood-Aitkin anomaly area lies along the eastern edge of the Brainerd map tile, directly east of the word "Brainerd".

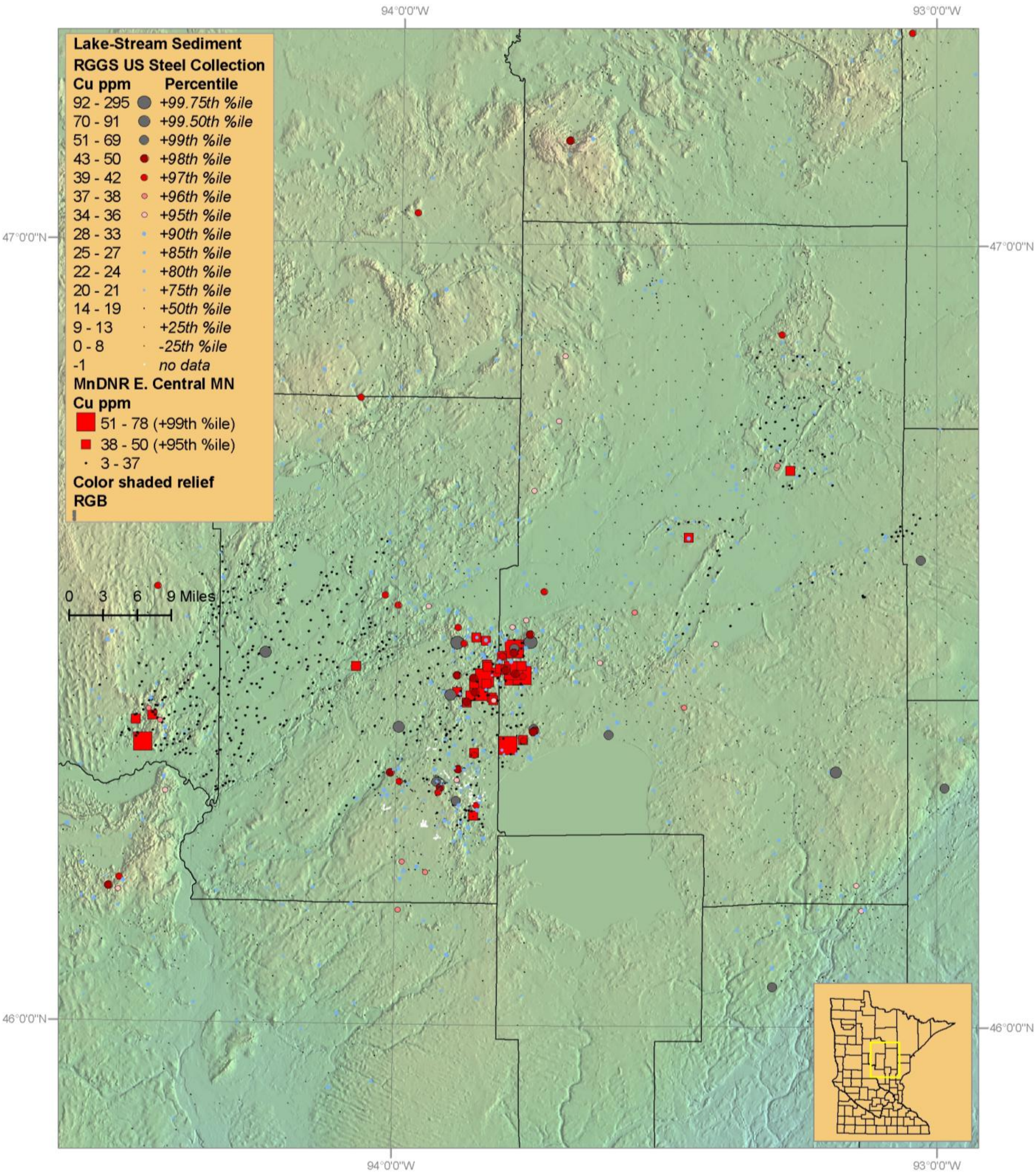

Figure 19. Copper values (in ppm) for lake sediments from MnDNR project 236, overlain by copper values (in ppm) from lake and stream sediment data from RGGS- US Steel Collection.

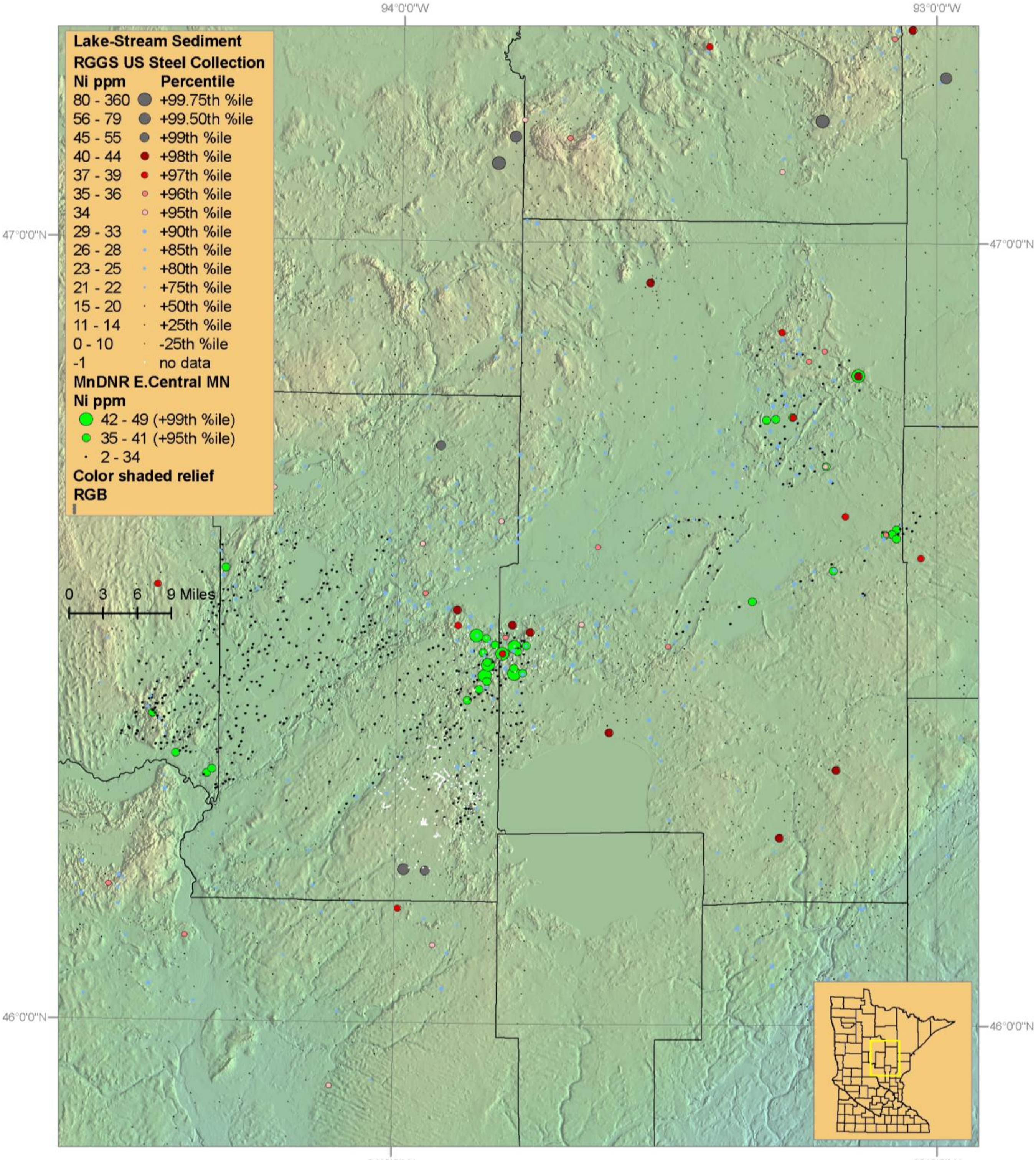

Figure 20. Nickel values in ppm in lake sediments, MnDNR project 236, overlain with nickel values in ppm from lake and stream sediment data from RGGS-US Steel Collection.

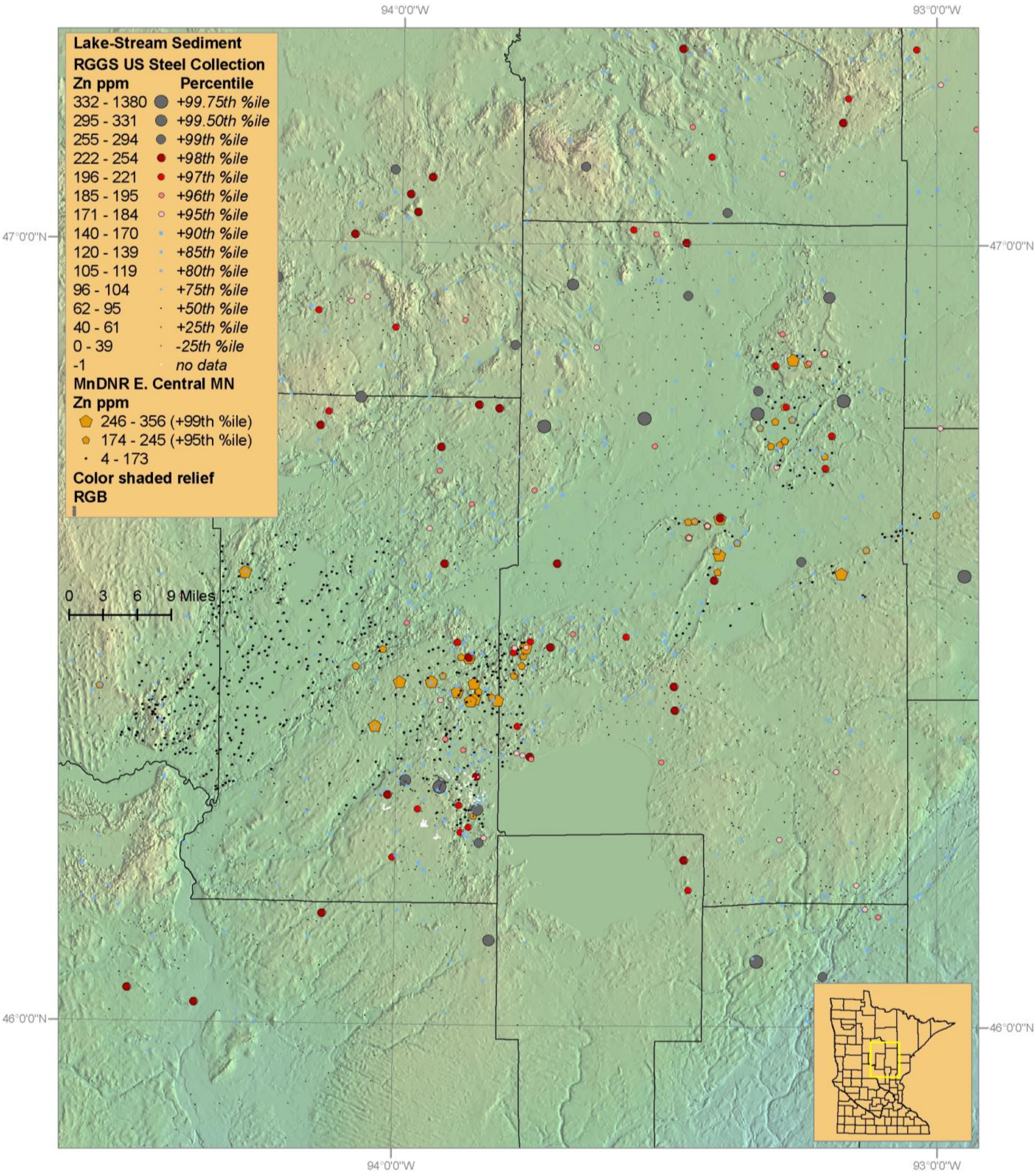

Figure 21. Zinc values in ppm in lake sediments, MnDNR project 236, overlain with zinc values in ppm from lake and stream sediment data from RGGS-US Steel Collection.

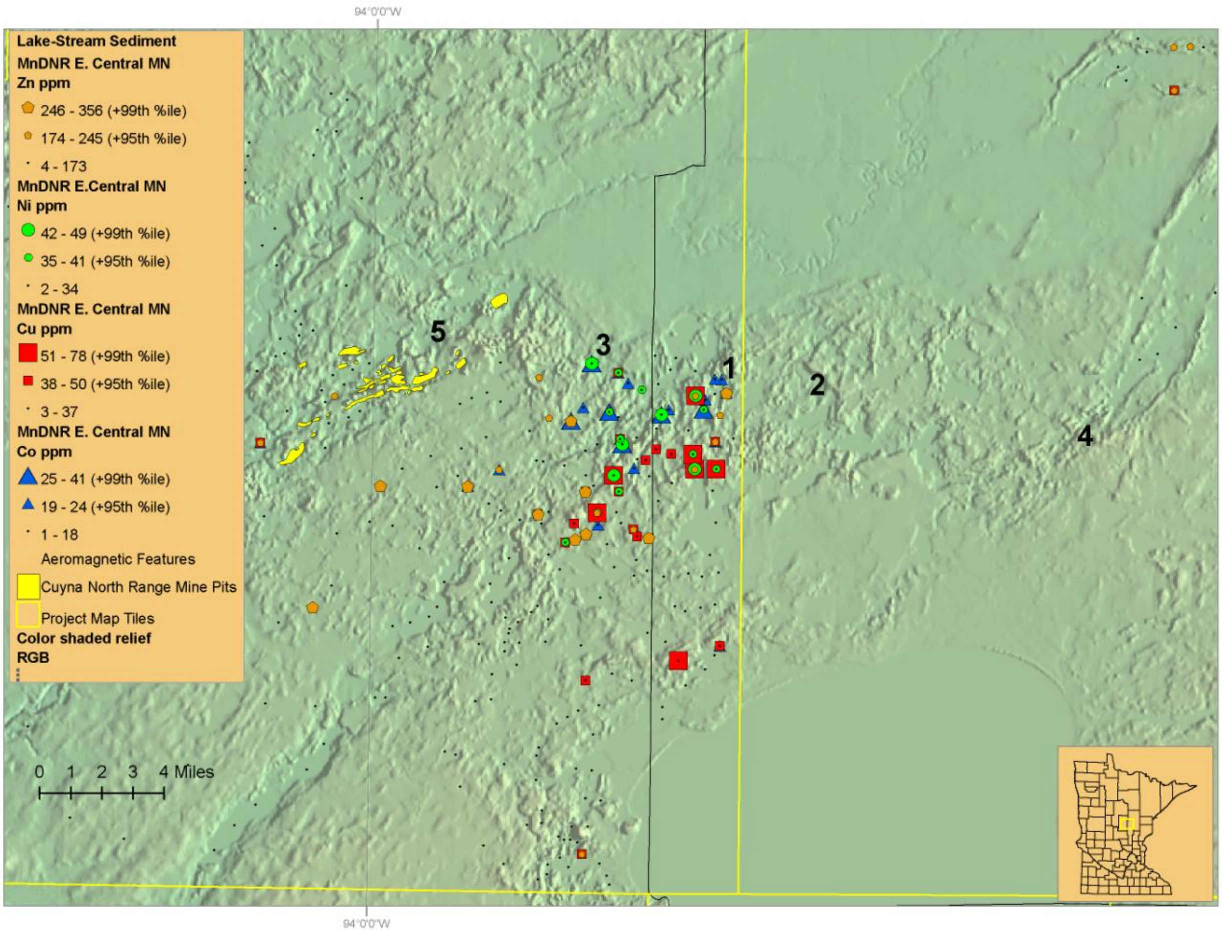

Figure 22. Composite Cu-Ni-Zn-Co lake and stream sediment data covering the Deerwood-Aitkin area. Background image of statewide color shaded relief (illumination from the east). Numbered locations discussed in text.

Figure 22 portrays the multi-element Deerwood-Aitkin anomaly pattern at finer resolution against the local landscape image. For reference, the locations of past-producing natural iron ore pits of the Cuyuna Iron Range are shown in yellow on the figure. The local landscape in the area has been transgressed by glacial advance from at least two directions. Streamlined glacial landscape features and moraines can be seen associated with glacial advance from the northeast (Rainy lobe) and perhaps from the east (Superior lobe). An overprint of young St. Louis Sublobe sediments (from the north-northeast in this vicinity) may also be present as suggested by the general pattern of Arsenic and silver values (for instance, see Fig. 16).

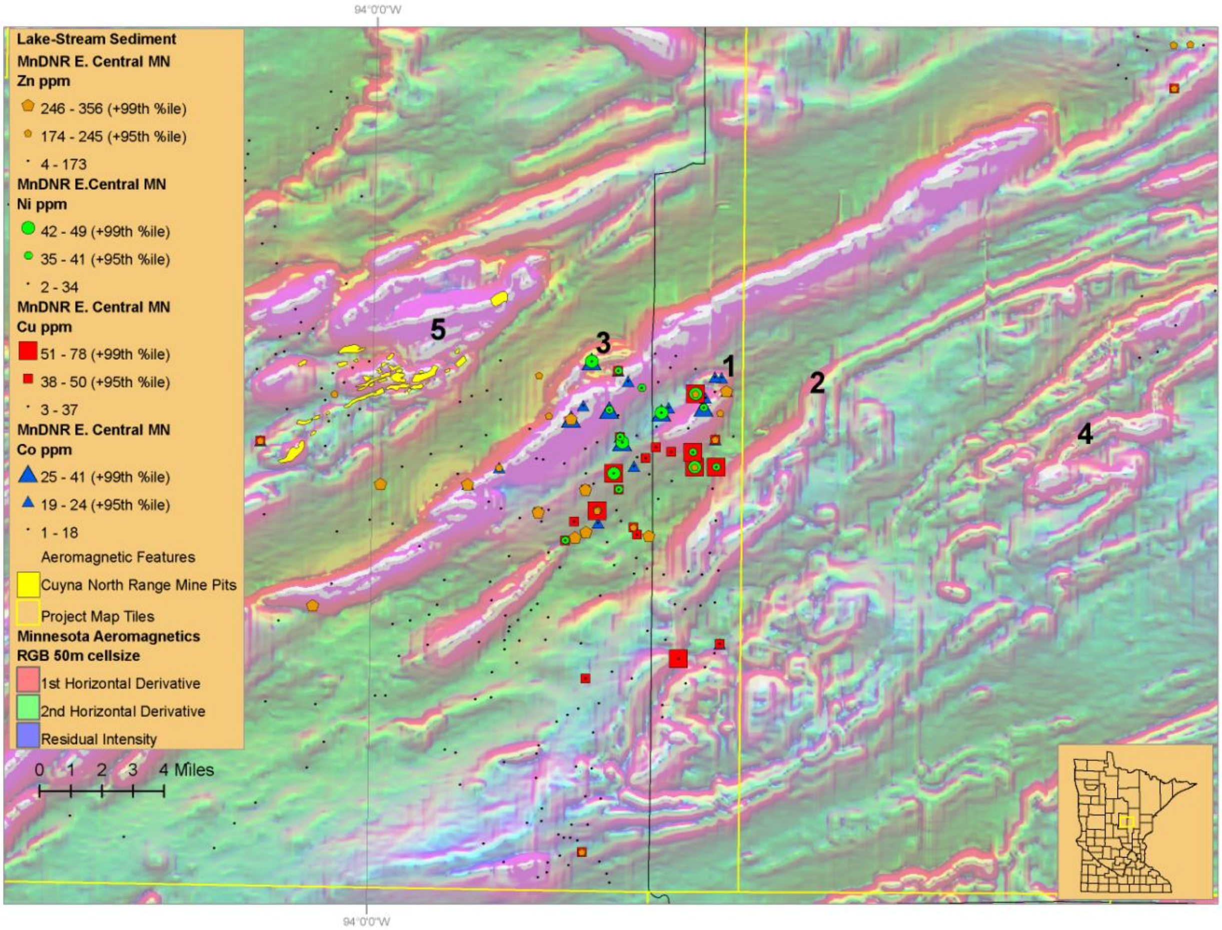

Figure 23. Composite Cu-Ni-Zn-Co lake and stream sediment data covering the Deerwood-Aitkin area. Background image of statewide aeromagnetic data (1st and 2nd horizontal derivatives and residual magnetic intensity as an RGB image). Numbered locations discussed in text.

Figure 23 depicts the same Deerwood-Aitkin anomaly against the local aeromagnetic pattern. Of interest is that the north end of the lake sediment anomaly corresponds to the general location of two rather prominent magnetic-structural discontinuities in the aeromagnetic pattern. In the same vicinity, a series of aligned deflections and discontinuities of aeromagnetic units cuts across the northeasterly (N30E) regional strike of magnetic units in the area, marking a trend that passes through 1) the two prominent magnetic discontinuities in the immediate area of the Deerwood-Aitkin lake sediment anomaly, 2) through a deflection in the Bay Lake iron belt, 3) through iron and manganese-bearing iron prospects, volcanics and intrusives of the South

Cuyuna range, 4) through the Glenn district, and 5) through the most productive part of the Cuyuna North Range. Historic geologic maps of the Portsmouth and other North range mines of the Cuyuna district (Hanna Collection in the Archives) note similar structural trends in local mine features. Interestingly, geophysical interpretation of aeromagnetic and other information in this area by Spector and Associates (1992) concluded that some of these same discontinuities should be investigated further as potential mineral areas.

A 1985 scientific drill hole, AB-27 (Southwick, et al, 1986), drilled at a location 5 miles (8 km) northeast (along regional aeromagnetic strike) of the lake sediment anomaly yielded Cu 5,916 ppm, Zn 323 ppm, As 525 ppm, Mo 108 ppm, Sb 97 ppm, Hg 14.5 ppm, Ag 2.67 ppm and Au 0.032 ppm from a grab sample of quartz-veined graphitic argillite core. A second grab sample of un-veined graphitic argillite from 4 ft further down the drill core also yielded anomalous values including Cu 429 ppm, Zn 227 ppm, As 75 ppm, Mo 65 ppm, Sb 14 ppm, Hg 2.59 ppm, Ag 0.68 ppm, and Au 0.005 ppm.

That nearly all of the +99th and +95th percentile iron and manganese metal values in the MnDNR lake sediment survey data (none available for the donated data set) also lie proximal to this projected zone of discontinuities (Figs. 24 and 25) is also noted. The correspondence of these combined geochemical, geophysical and geological features is unexplained at this time, but makes the area of the Deerwood-Aitkin multi-element lake sediment anomaly interesting from a mineral resources potential viewpoint.

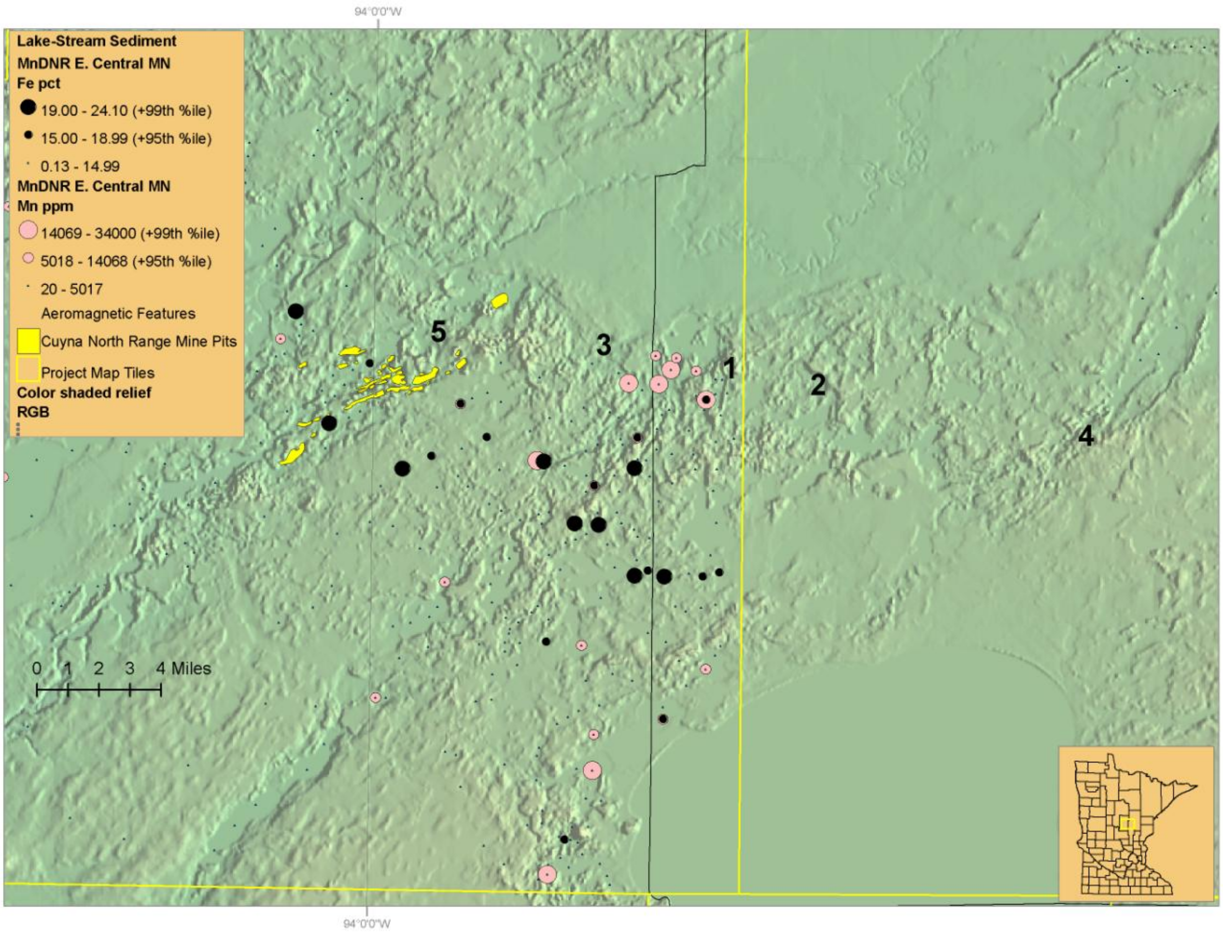

Figure 24. Iron values in percent and manganese values in ppm showing +99th and +95th percentile lake sediment values for MnDNR project 236 area, dem background. Numbered locations discussed in text.

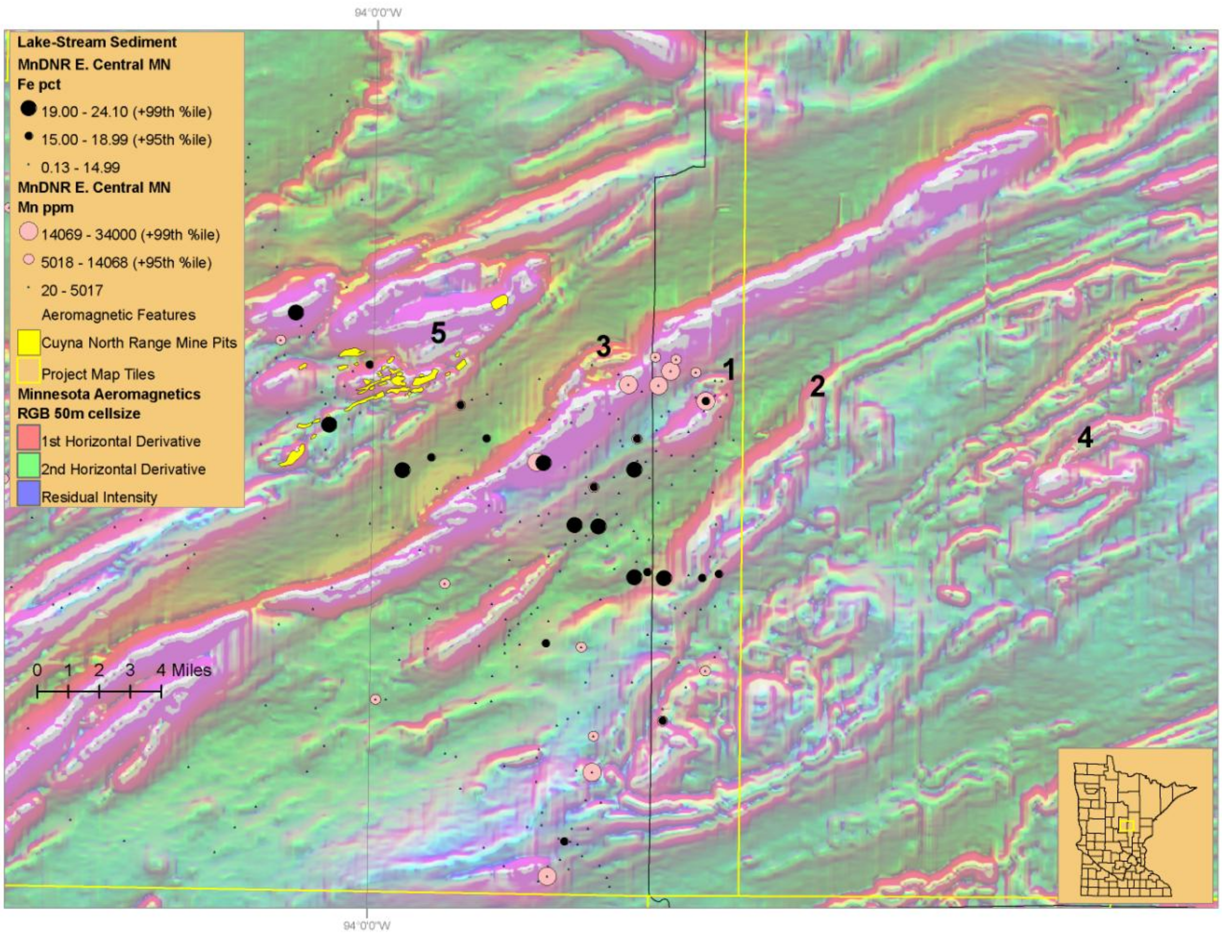

Figure 25. Iron values in percent and manganese values in ppm showing +99th and +95th percentile lake sediment values for MnDNR project 236 area, aeromagnetic background. Numbered locations discussed in text.

EASTERN ST. LOUIS COUNTY

The RGGS - U. S. Steel donated data set overlaps another of MnDNR's lake sediment geochemistry data sets in Eastern St. Louis County. Whereas sampling in the donated data set was mainly over the Paleoproterozoic Animikie Basin, the MnDNR survey (Vadis, et al, 1982) was conducted mainly over Mesoproterozic, rift-related Duluth Complex intrusions and volcanics. Percentile values for the two data sets are quite different and it is suspected that these differences reflect regional background differences caused by a) bedrock of the metasedimentary Animikie basin underlying a large portion of the donated data set area versus volcanic and intrusive bedrock underlying the MnDNR project area, and b) quaternary glacial lake bottom sediments underlying large portions of the donated data set project area versus glacial uplands, primarily till, underlying the area of the MnDNR survey. Where the two data sets overlap, there is generally good correspondence in both pattern and absolute value for element concentrations, for instance Nickel and Copper (Figs. 26 and 27).

ELY AREA

As described earlier in this report (under general observations: nickel), the area of the Newton Lake formation where two MnDNR lake sediment surveys (Meineke et al, 1976, 1977a) and the donated data set overlap is characterized by high metal values for nickel and copper in both data sets (Fig 28). The MnDNR surveys record nickel values up to 280 ppm Ni, copper up to 65 ppm Cu, and cobalt up to 41 ppm Co. The donated data set records nickel values up to 360 ppm Ni, copper up to 130 ppm Cu, and cobalt up to 28 ppm Co.

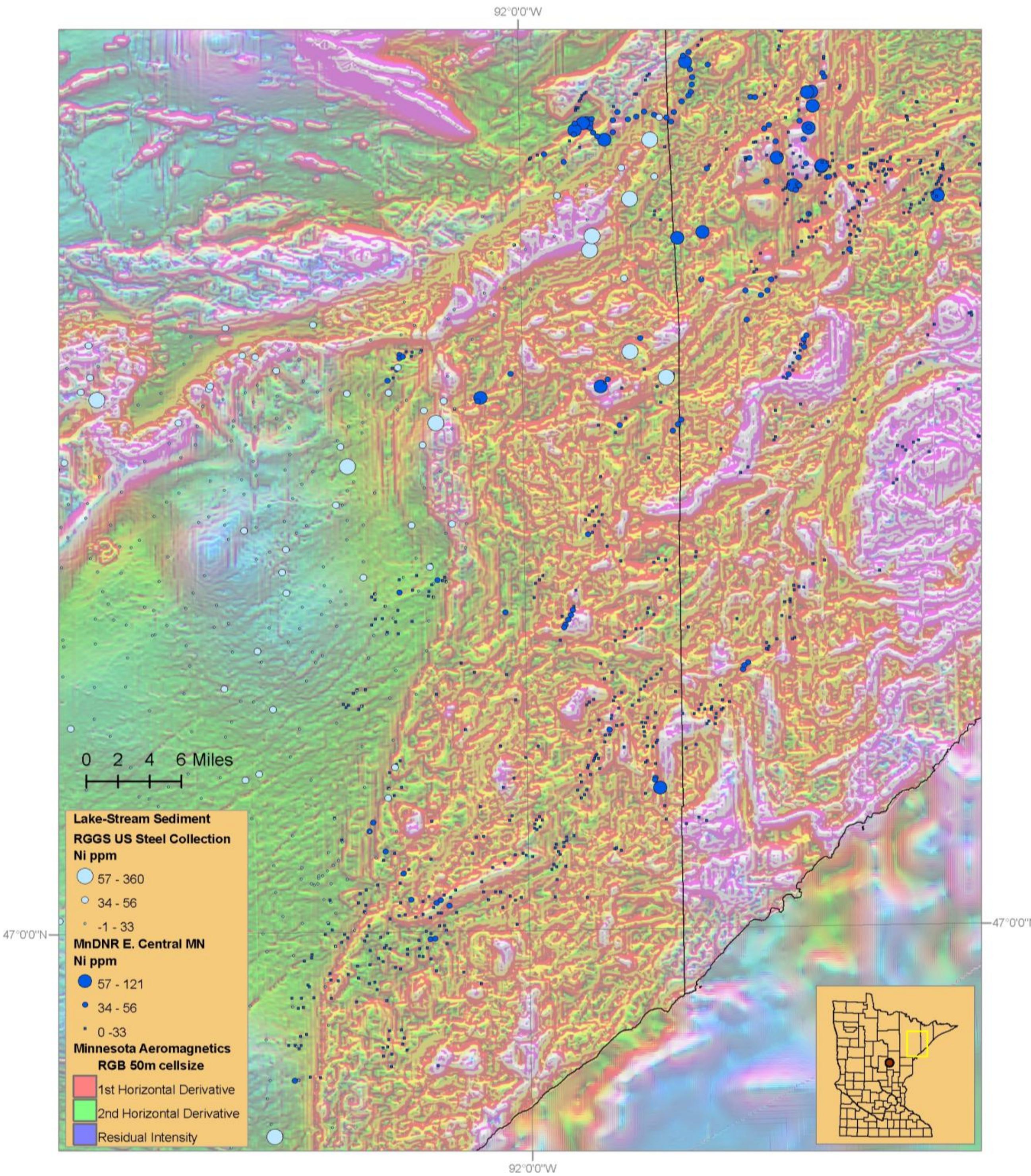

Figure 26. Nickel values from RGGS-US Steel Collection and MnDNR project 171. Aeromagnetic backdrop.

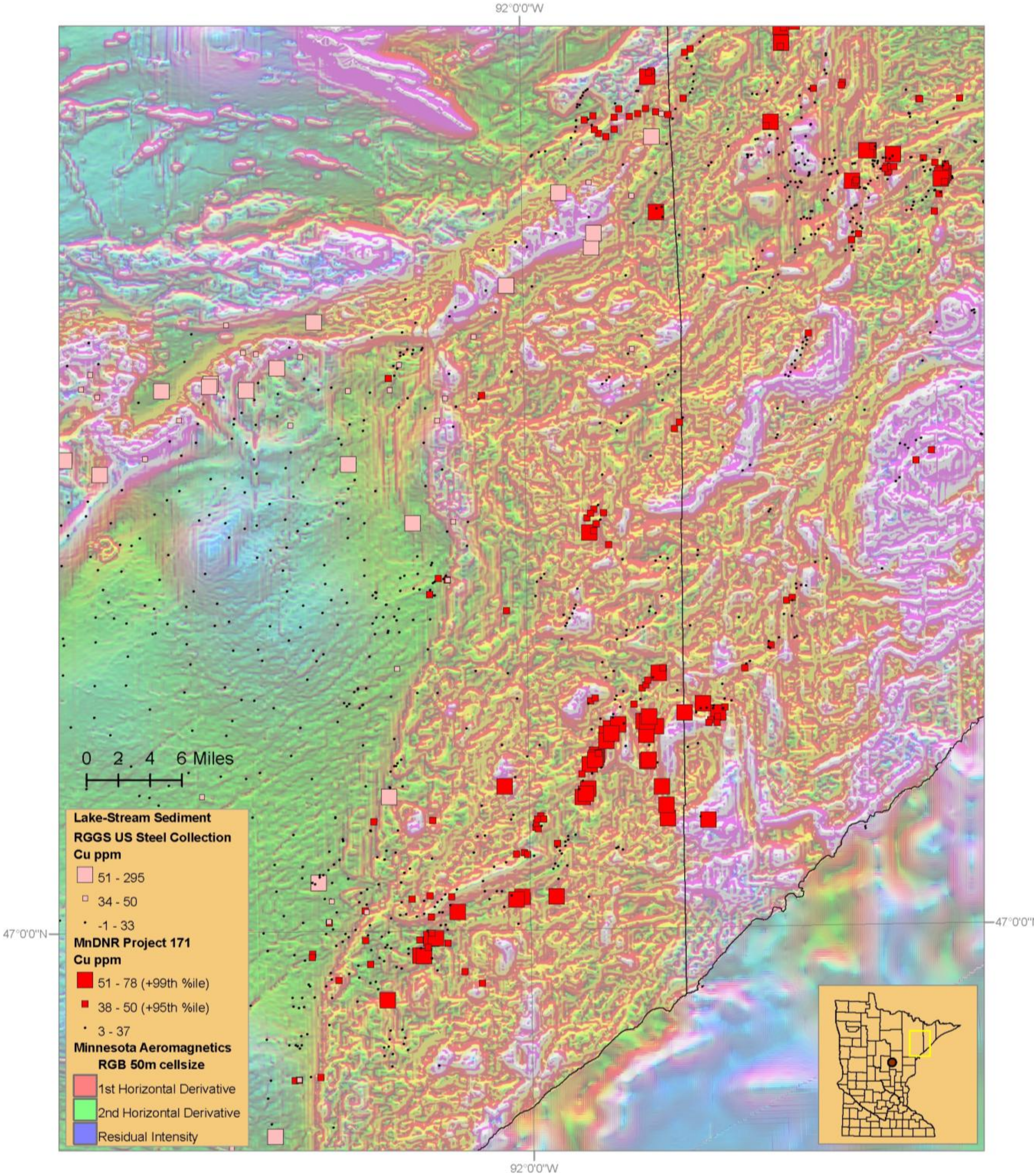

Figure 27. Copper values from RGGS-US Steel Collection and MnDNR project 171. Aeromagnetic backdrop.

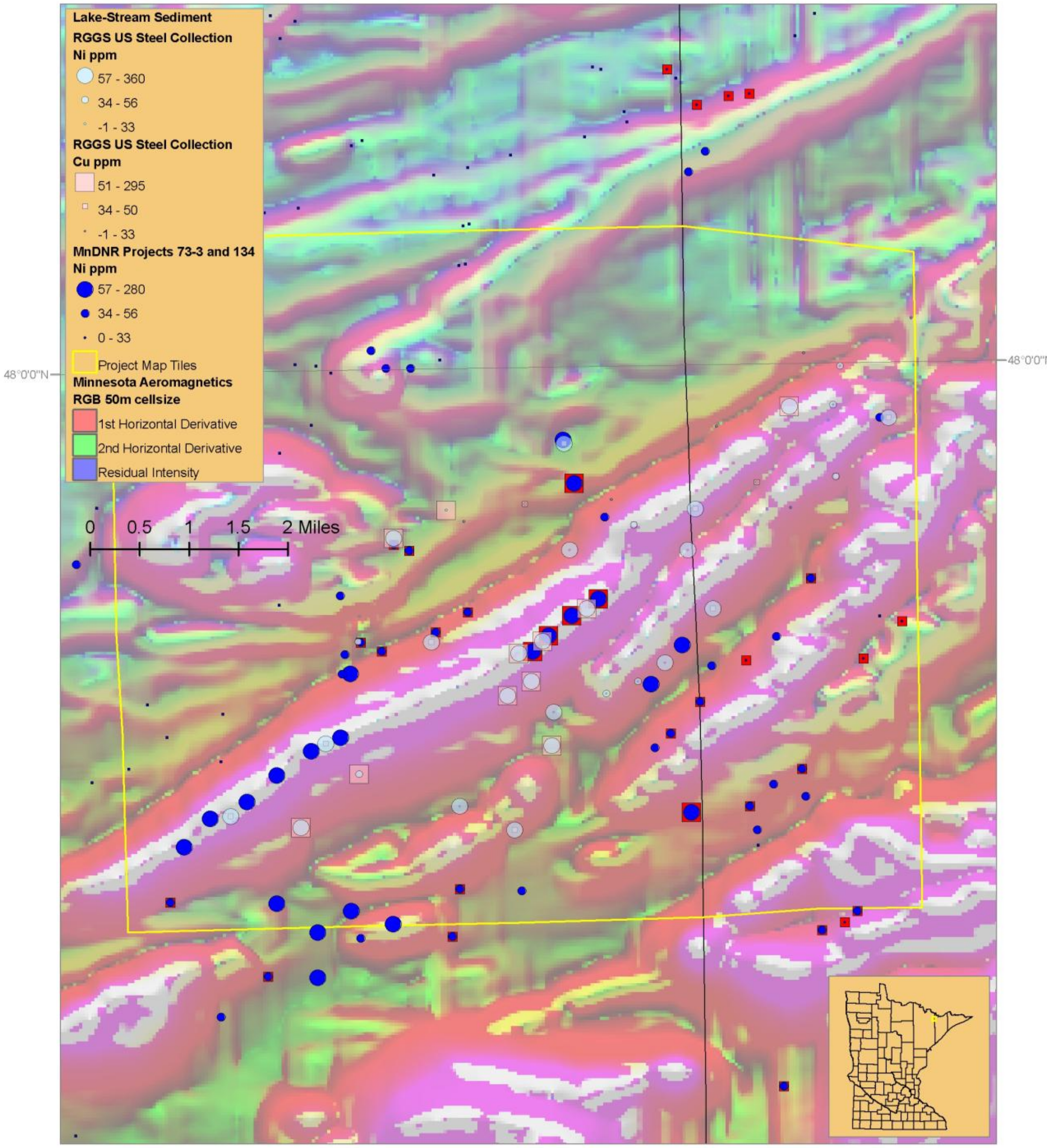

Figure 28. Copper and Nickel values of MnDNR lake sediment surveys and donated data set values in the Ely area.

CONCLUSIONS

Where donated data and MnDNR surveys overlap, correspondence of metal values and patterns lends some credence to the donated data set being compatible with nearby lake sediment data sets, and perhaps useful in the 8,700 square miles of donated data set survey area that lie beyond the bounds of existing MnDNR lake sediment geochemical surveys.

RECOMMENDATIONS

Three recommendations seem reasonable based on the foregoing results:

1. Determine whether the geochemical anomaly present in the Deerwood – Aitkin area can be extended to underlying glacial sediments. If the anomaly can't be confirmed in the underlying sediments, then the possibility is raised that the anomaly may be the product of topographic relief combined with greater ground water flow in areas of higher relief. On the other hand, confirmation of the anomaly in underlying drift raises the possibility that the anomalous values may reflect mineralized material being carried in the glacial drift. If the anomaly can be confirmed in the glacial drift, preferably in till or esker sediments, then some effort might be further entertained to determine a) if the anomaly extends further north but beneath glacial lake-bottom sediments, and b) the stratigraphy of glacial sediment package(s) that carry the anomaly.

2. Evaluate further the nickel-copper anomaly north of Ely.

3. Continue compilation of historic mineral exploration information housed at MnDNRs Mineral Exploration Archives for multi-purpose reuse including classification and mineral management of public trust lands. This kind of work appears to be a cost effective method of obtaining landscape and bedrock information about previously explored portions of Minnesota.

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APPENDICES

Appendix A: Summary of Lake and Stream Sediment Geochemistry Data.