4. Regional Surficial Geochemistry

W.A. Spirito and C.W. Jefferson

4.1. Introduction and Background

4.1.1. History of geochemical studies in Nahanni region

Over the years there have been several geochemical investigations in the Nahanni region. Company reports from Northwestern Explorations Ltd. (now Kenneco Explorations (Canada) Ltd.) indicate that during 1953 a reconnaissance of the area was under taken by the Geological Survey of Canada who reported unofficially that favourable lead-zinc-copper mineralization occurred. Northwestern carried out a prospecting program during 1954 which covered 600 sq. mi. of the Upper Flat River area and which discovered 4 showings, 2 of which are noted below.

The Buster showing was mapped and sampled in 1955. Assay results indicated a credible prospect that would have received further investigation if more readily accessible. However, overall low-grade value of mineralization combined with the scattered condition of the deposits limited their interest. (Barr, 1955).

Copper mineralization was discovered in 1954 on the Axel Nos. 1-18 mineral claims. During 1955 the deposit was mapped and sampled. Diamond drilling took place in 1956 to test the lateral extensions of known mineralization. Assay data from the drilling program were not of sufficient interest to continue deeper drilling (Barr, 1956).

Between 1969-1971, the Geological Survey of Canada sampled Cretaceous granitoid rocks to determine if bedrock geochemistry could be used as a tool for mineral reconnaissance and to establish the geochemical relationships of these rocks to known mineral occurrences (Garrett, 1973;1992).

In 1975, Cominco carried out trenching and soil sampling in the Glacier Lake area (95L/3) which provided poor results. Detailed prospecting and mapping was completed in 95L/1 and 95L/8 but no further work was recommended.

In 1981 Kennco carried out a stream sediment geochemical survey in parts of NTS 95C and 95D. No other information was available in the file.

As part of the Nahanni Integrated Multidisciplinary Pilot Project (NIMPP), stream sediment geochemical surveys were done in the Nahanni map area (105I) by the Geological Survey of Canada (Goodfellow, 1982).

In 1982 and 1983 Esso Minerals Canada conducted a rock and stream sediment sampling program in the Flat River area (NTS 95E/2) to look for tungsten and precious and base metal deposits. Individual Au, Ag, Zn and W anomalies found in the heavy mineral separates of the stream sediments are isolated. The remaining samples had only background amounts of the metals. No further work was recommended (Lenters, 1984).

The Selena Creek area, south of the Flat River in NWT (about 160 km NE of Watson Lake,YT) was thought to have the potential for Carlin-style gold mineralization, but most of the work in this area has been related to placer gold. In 1984, prospector Eric Scholtes discovered placer gold in Selena Creek, and prior to this, regional mapping by the Geological Survey of Canada was the only exploration done in this area (Richards, 1989).

In August of 1989, Sirius Resource Corporation and Verdstone Gold Corporation announced significant gold values in alluvium and later that month staked 17,000 more acres of potential gold bearing alluvium (Sirius Resource Corporation, Press Release August 3 & 24, 1989). The report by Richards (1989) concluded that Selena Creek and surrounding areas had the potential for being a significant new region of mineral exploration for both placer and lode deposits. Richards (1989) recommended extensive sampling to determine the extent and reserves of the placer deposit and more staking of adjacent areas. In a November 1989 press release, Sirius Resource Corporation announced that preliminary results of a reconnaissance bulk testing program showed significant fine gold consistently throughout the gravels in Selena Creek. The company indicated that these favourable results meant that an accelerated fill-in and bedrock bulk sampling program would proceed in early spring 1990 which would ultimately lead to a production decision.

At Prairie Creek (about 90 km NW of Nahanni Butte) mineralization (Pb-Ag-Zn) was first discovered in 1928 but only limited work was conducted on the property until 1966 when Cadillac Explorations Ltd acquired the property. During 1966-1969, they explored mineralized zones. Between 1970 and 1982, underground development, bulk sampling and surface drilling was carried out to various degrees by several companies. In May 1982, the mine was about ready to go into production, but when world silver prices fell, Cadillac Explorations Ltd. filed for bankruptcy (http://canadianzinc.com/prairie/history.shtml).

In 1991 Conwest Exploration Company Limited acquired the property and granted an option to San Andreas (in 1999 renamed to Canadian Zinc Corporation) who completed four years of surface diamond drill exploration which greatly expanded the pre-existing resource. In 1999, CZC staked the areas adjacent to the existing property. In these newly staked areas, diamond drilling and geochemical sampling has discovered a new vein showing and indicated Zn anomalies over parts of the Whittaker Formation. (Prairie Creek Project, Canadian Zinc Corporation Information Memorandum). The long term plan of CZC is to bring the Prairie Creek Mine into production.

Environment Canada completed a study on protecting the aquatic quality of Nahanni National Park Reserve (Halliwell and Catto, 1990). They reported on baseline water, sediment and fish tissue quality data that were collected during 1988-1991 and during a 1992-1997 follow-up program. Part of this study documented the overall metal-rich nature of the entire South Nahanni River watershed.

4.1.2. Principles of Stream Sediment Sampling

Many mineral deposits have been discovered because of anomalies in the geological environment. For over 50 years geochemical surveys have been used on a routine basis by industry and government as a reconnaissance tool for exploration. Stream sediment surveys became popular in the 1960's when several studies established that the technique was effective and economical (e.g. Hawkes and Webb, 1962; McCartney and McLeod, 1965). Surveys are used to delineate areas that are anomalously high in metals, possibly reflecting the presence of undiscovered economic mineral deposits. Indicator or pathfinder elements are relatively mobile and occur in close association with the element or commodity being sought. They are commonly distributed over a larger area or can be detected more easily by analytical methods. Patterns of dispersion/dispersal, combined with more detailed sampling, can result in the discovery of a deposit by leading investigators back to the source of the anomaly. A simple example is lode gold deposits being found by tracing placer gold deposits back to their bedrock sources.

Metallogenic models have been developed based on metal associations and geological environments of known mineral deposits. Knowledge of geochemical signatures and pathfinder element-deposit associations (e.g. Levinson, 1974) can assist the interpretation of stream sediment geochemistry. Single element anomalies are compiled for each drainage basin to determine element associations that could indicate known deposit types. However, anomalous element associations must not be ruled out if they have no known relationship to a type or style of mineralization as they could reflect a new deposit type or a new formational environment for a known deposit type.

If properly collected, stream sediments represent the aggregate of material in the drainage basin upstream from the sample site. It follows that samples from streams draining a mineralized basin will contain a higher proportion of indicator and ore elements than streams draining an unmineralized basin. As noted in the Introduction (Section 2), use of surficial geochemistry as a factor for inferring mineral potential involves uncertainty (as does every scientific inventory of natural areas). Only a small proportion of geochemical anomalies is ever traced back to high grade mineral showings, and only a small proportion of showings is ever developed into mines. Nevertheless, it is a chain of investigation such as this, covering and re-covering many large areas across Canada (with very little to no environmental impact in their geochemical and prospecting phases), that have unlocked Canada's mineral wealth and will continue to do so because of the optimism and determination of our explorers.

In addition to the uncertainty related to the odds of successful exploration, there are also complications to consider when interpreting the data collected in an area that has experienced multiple glaciations from different directions. In the Laurentide domain, the locally derived material is mixed with a relatively homogenous blend of tills derived from the Canadian Shield from the northeast, thereby diluting and suppressing local geochemical signatures. In addition, glaciolacustrine lakes occupied river valleys and blanketed local areas with varved clays, further diluting or hiding sources of anomalous material. At the peak of glaciation in Ragged Ranges, the direction of ice flow would have been determined by the slope of the top of the ice surface, not necessarily the present day valley configurations, so that in some places ice and the entrained debris (with geochemical mineral tracers) could have flowed "up-hill".

Ongoing weathering and water flow influence hydromorphic transport of anomalous elements. Many minerals, especially sulphides, are unstable in the present weathering environment. Oxidation and other chemical reactions cause these unstable minerals to break down and disperse in solution. These solutions can move in streams or through shallow to deep groundwater until they are ultimately flushed out of the basin or trapped locally by precipitation, as documented in Chapter 5 (Hydrogeology). Elements released by weathering are also commonly adsorbed onto clay-sized particles, which are then transported throughout the drainage basin. Depending on their chemical mobility, which is related to factors such as adsorption and pH, indicator and ore elements may be dispersed for considerable distances.

The metal content of stream sediments is also affected by clastic processes in addition to hydromorphic transport. In areas of pronounced mechanical weathering, such as glaciated and/or mountainous regions (e.g. Ragged Ranges area)), ore minerals may be dispersed as discrete detrital grains. Higher percentages of these grains will be found in the stream sediments as the source is approached. Typical 'heavy' minerals (e.g. galena, gold) have a high specific gravity and concentrate in the heavy mineral fraction of stream sediments.

<u>Stream silts</u> represent the fine grained (0.05 to 0.002mm) product of weathering, transport and sorting of rocks throughout the stream basin. By choosing the fine grain size, homogenization is maximized and therefore representativeness is increased, and the nugget effect decreased. Silt samples maximize detection of hydromorphically transported and adsorbed elements, however physically transported elements are still captured. The analytical methods used by some surveys for stream silts involve partial chemical extractions rather than complete solution (Hall, 1991), further enhancing the hydromorphic component. In this study, analysis by instrumental neutron activation (INAA) reports the geochemical composition of the complete sample. Details of silt sampling methods are provided by the National Geochemical Reconnaissance Program of GSC (Friske and Hornbrook, 1991; Friske et al., 2001).

<u>Heavy mineral concentrates (HMCs)</u>are mechanically and chemically concentrated detrital minerals (derived from the physical and chemical breakdown of rocks) that have a specific gravity higher than some standard, commonly 2.85. During sample preparation, several techniques can be used to enhance the geochemical signature of components derived from mineral deposits by separating the preferred component of the sample for analysis. These include partial extractions (chemical methods, commonly used for silts) and physical

methods such as floating the light minerals away in heavy liquids, centrifuging and shaker tables (Stewart, 1986). The physical techniques are commonly used to prepare HMCs, which have several advantages over standard silt geochemistry:

1. Anomalies remain detectable in drainage sediments despite dilution by lighter minerals, such as in the Laurentide Glacial Zone. (The intensity of an anomaly can be reduced by dilution with non-mineralized sediment). To emphasize mechanically dispersed anomalies, workers concentrated the heavy mineral fraction from the rest of the sample before analysis (e.g. Garrett, 1971).

2. Concentration levels are commonly higher than in standard silts. Therefore:
   a) analytical precision improves with concentration
   b) the large sample that is necessary for adequate heavy mineral yield increases the chance of a representative sample; this is important when exploring for elements dispersed as resistate and heavy minerals such as gold, tungsten, tin, which commonly create a hit-and-miss, nugget effect.

3. Mineralogical examination can indicate deposit type (Stendal and Theobald, 1994).

Disadvantages of heavy mineral geochemistry include:

1. Field methods, such as panning, are time consuming, have greater potential to introduce operator bias, and large samples are commonly required to yield enough concentrate for study. Together these factors lead to greater cost.

2. The technique is less well suited to exploration for deposits with fine initial particle size (Stendal and Theobald, 1994.

3. Laboratory sample preparation is time consuming and expensive (heavy liquids are a health hazard; concentrating tables require skilled operators).

On balance, the success of studies that have added heavy mineral geochemistry to the standard silt analyses indicates that heavy minerals are a viable medium for exploration (e.g. Friske, 1986; Ballantyne, 1991).

Many factors control the distribution of light and heavy minerals in streams. The mineral composition of a stream depends on the type, abundance and size of minerals in the source rock.. It is also related to the way the source rocks are weathered, the mechanical wear and chemical breakdown of the minerals during transport. The rate of transportation of different minerals and different sizes of the same mineral is also an important factor (Rittenhouse, 1943). Anomalous metals may be distributed among several size and density fractions, so a single size fraction may not represent the entire heavy mineral suite (Rittenhouse, 1943). Many authors have suggested that heavy minerals reside in the sand size fraction but some studies on both sand and silt-sized heavy minerals suggest that the modal grain size of heavy minerals commonly lies in the silt fraction (Blatt et al., 1980).

In this study, HMCs were extracted from stream silts in addition to pebbly sands, in order to increase confidence in this resource assessment, as well as to enhance exploration and resource assessment technology under an NWT Mineral Development Agreement. Jefferson and Paré (1991) have shown that the silt fraction from samples in the Liard Range/Ram Plateau area contains more gold grains from more sample locations than the coarser pebbly sands, and is therefore more sensitive for detecting a distant provenance of gold, at least in the eastern Nahanni River study areas. Conventional stream sediment geochemical programs utilizing the < 177 µm fraction and a heavy mineral concentrate (HMC) of the sand fraction have been successfully used for resource evaluation and reconnaissance mineral exploration.

Assessing the concentration of fine gold present in stream sediment is important because: (1) where fine gold constitutes a major part of the total gold present, the importance of an anomaly would be greatly underestimated if based only on the coarse gold detected; (2)

where the bedrock source of the gold is a fine-grained disseminated deposit, such as the Carlin Trend in Nevada (Knutsen et al. 1991), a gold occurrence may be missed altogether; (3) fine gold (<100 μm) accounts for up to 90% of several placer deposits in British Columbia (Day and Fletcher 1986), Yukon (Ballantyne 1987 pers. comm.), Alaska, and the Soviet Union (Wang and Poling 1983). Nichol and Shelp (1987) recognized that the majority of the gold in tills is in the <125 μm fraction. Many fluvial placers in areas of glaciated terrains are derived from till and other glaciogenic sediments adjacent to and underlying the stream. When these glaciogenic sediments have a large fine-grained component, much of the gold found may be fine-grained; (4) the fine fractions of alluvial sediments provide less variable results and therefore more reliable data (Saxby and Fletcher 1986). Assessing gold in silt size material should therefore increase the accuracy of this resource evaluation and improve the chances of indicating fine- grained disseminated deposits.

Detecting gold in a standard whole silt sample using conventional geochemical techniques is, however, problematic because the detection limit for gold is commonly too high and because small quantities of gold are diluted by light minerals. Also, only a small quantity (10-20 g split as compared with 2-4 kg for silt HMC) of silt is analyzed thereby reducing the chance of striking gold. Finally, concentrations of rare earth elements in heavy minerals such monazite, zircon, and allanite can screen some elements and raise the detection limit in neutron activation analysis. These factors apply particularly to the Canadian Cordillera where heavy mineral concentrations are often low and where high energy stream environments may inhibit the formation of hydromorphic dispersion halos such as in New Brunswick (Friske 1986).

Therefore HMCs are required to properly assess gold potential. Additional factors reasons for collecting HMCs from silts as well as from pebbly sands are:

(1) Based on the above considerations, logistics facilitated collection of bulk silt samples in the course of collecting the larger sand samples for this resource assessment.

(2) Because alluvial silt is transported further than sand, the catchment area represented by silt HMCs may be larger and therefore require a lower sample density.

(3) The sampling medium from which HMCs are most often recovered is coarse sand from areas of the stream where any fine particles of economic minerals have been removed by high current velocity and deposited with sediment having similar hydraulic equivalence. In contrast, for this study, silt samples represent lower energy environments of the stream, thus representing another dimension of the catchment basin and sediment transport dynamics.

(4) Geochemical values from fine-grained HMCs are much less erratic than those from coarser grained sediments. Saxby and Fletcher (1987) have shown that in the case of tungsten, results show much better reproducibility.

(5) Silt heavy mineral concentrates should have the well known advantages of sand HMCs in overcoming heterogeneity and detection limits (Harris 1982). Spirito et al. (1988) found that gold anomalies in sand HMCs are very localized in the study areas, and this possible nugget factor required testing.

(6) Silt HMCs are likely to be more effective than sand HMCs in detecting fine gold (possible indicator of fine-grained disseminated gold deposits, because: (i) only coarse sand and gravel from the stream bed are sampled for traditional sand HMCs; and (ii) separation and recovery of HMCs (including gold) using gravity separation methods are incomplete for samples with wide grain-size range.

4.2. Sample Collection, Preparation and Analysis

4.2.1. Sample collection for the Nahanni mineral resource assessment

Four main types of geochemical sample media were collected by the resource assessment team for geochemical analysis: approximately 285 stream silts and 285 pebbly sands (Spirito et al., 1988; Spirito, 1992), 124 spring and surface waters (Hamilton et al., 1988; Hamilton, 1990) and 63 rocks. Seven till and varved clay samples were also collected for comparison with the stream sediments. This section deals with the stream sediment samples.

The stream sediments were collected during the latter parts of three summers when water levels were relatively low (Spirito et al., 1988). During a 1985 orientation survey, sediments were collected from 120 streams to test sampling procedures (best sampling medium, size fraction to be analyzed, method of analysis), to identify potential problems (effects of topography and drainage, effects of glaciation, contamination, presence of organic material) and to determine the geochemical signatures of mineralized areas. In 1986, a regional reconnaissance survey was initiated to sample major drainage basins in the study regions. Using techniques tested in 1985, 284 streams were sampled. In 1987, anomalous streams were re-sampled and samples from previously untested, associated tributaries were taken, for an additional total of 84. In addition to the follow-up work, which was based on results from 1985 and 1986, samples were collected at sites to fill in gaps where time had not permitted collection the previous summer.

Sample location maps are shown in Figures 4.1a and 4.1b. All but two of the geographic features provided on these maps are named on existing topographic maps. Two creeks were informally named here because of their unique character, and because of the geochemical anomalies located in their catchment basins. “Wretched Creek”, a tributary of Tetcela River draining the east side of Ram Plateau, was named because of the need to refer to its placer gold anomalies (samples 86HJPW237,239, 87JPW065,066). This creek has characteristics that any stream sampler would appreciate - heavy tree cover, narrow and steep canyon walls - very difficult for both foot traverse and helicopter access. “Brophy Creek” was named because it also yielded anomalous gold results (samples 86JPW077, 87JPW005A,B) as well as being a challenging target for stream sediment sampling. It has a very high gradient and its stream bed is dominated by boulders, with very little medium to fine-grained sediment as bars or overbank deposits that would yield sand or silt samples. John Brophy, the Mackenzie Mountains District Geologist from DIAND who participated in the 1986 program, used this creek to demonstrate that sampling success could be attained given sufficient enthusiasm, energy and athletic prowess.

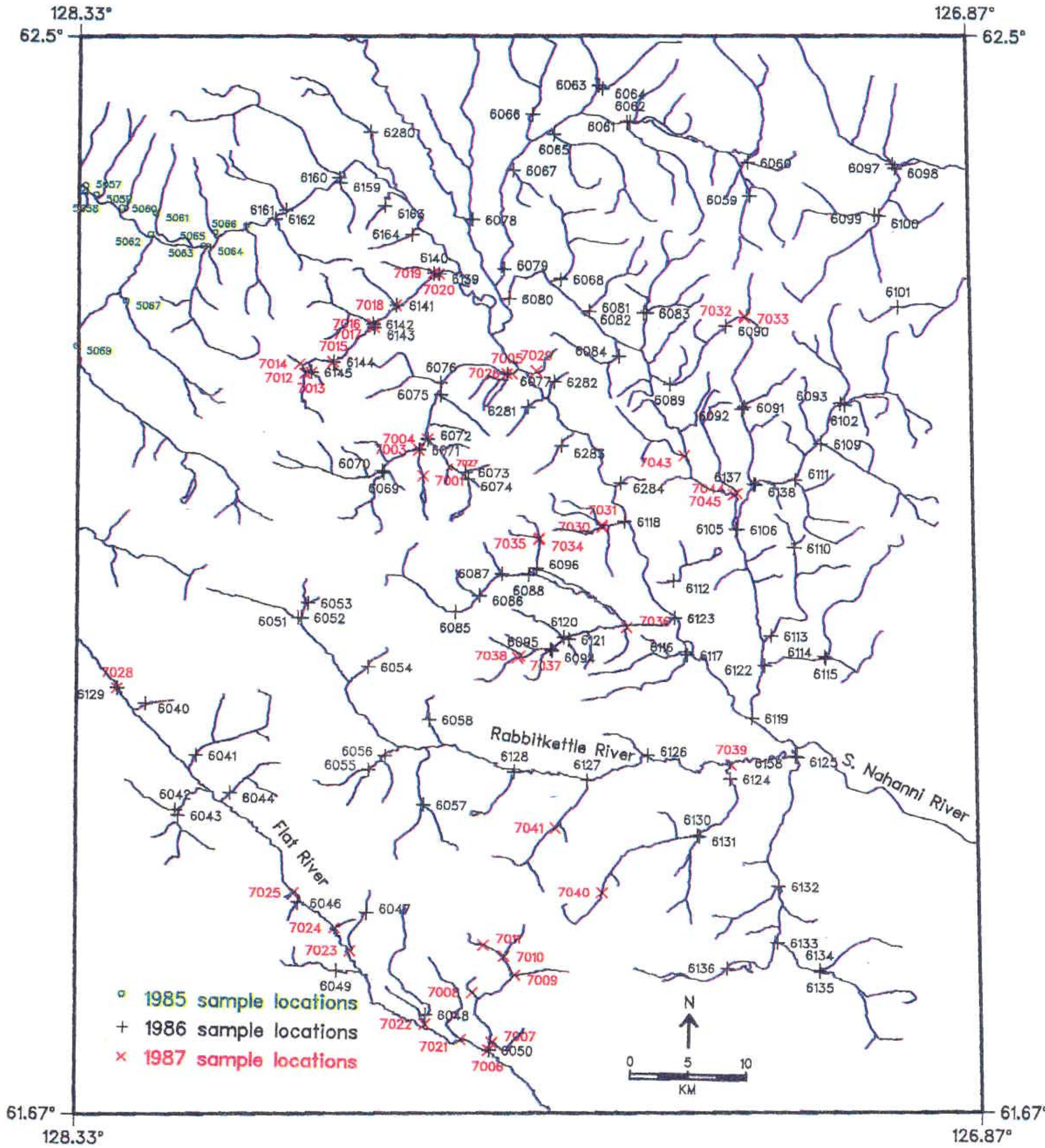

Figure 4.1a: Sample Location Map, Ragged Ranges Study Area

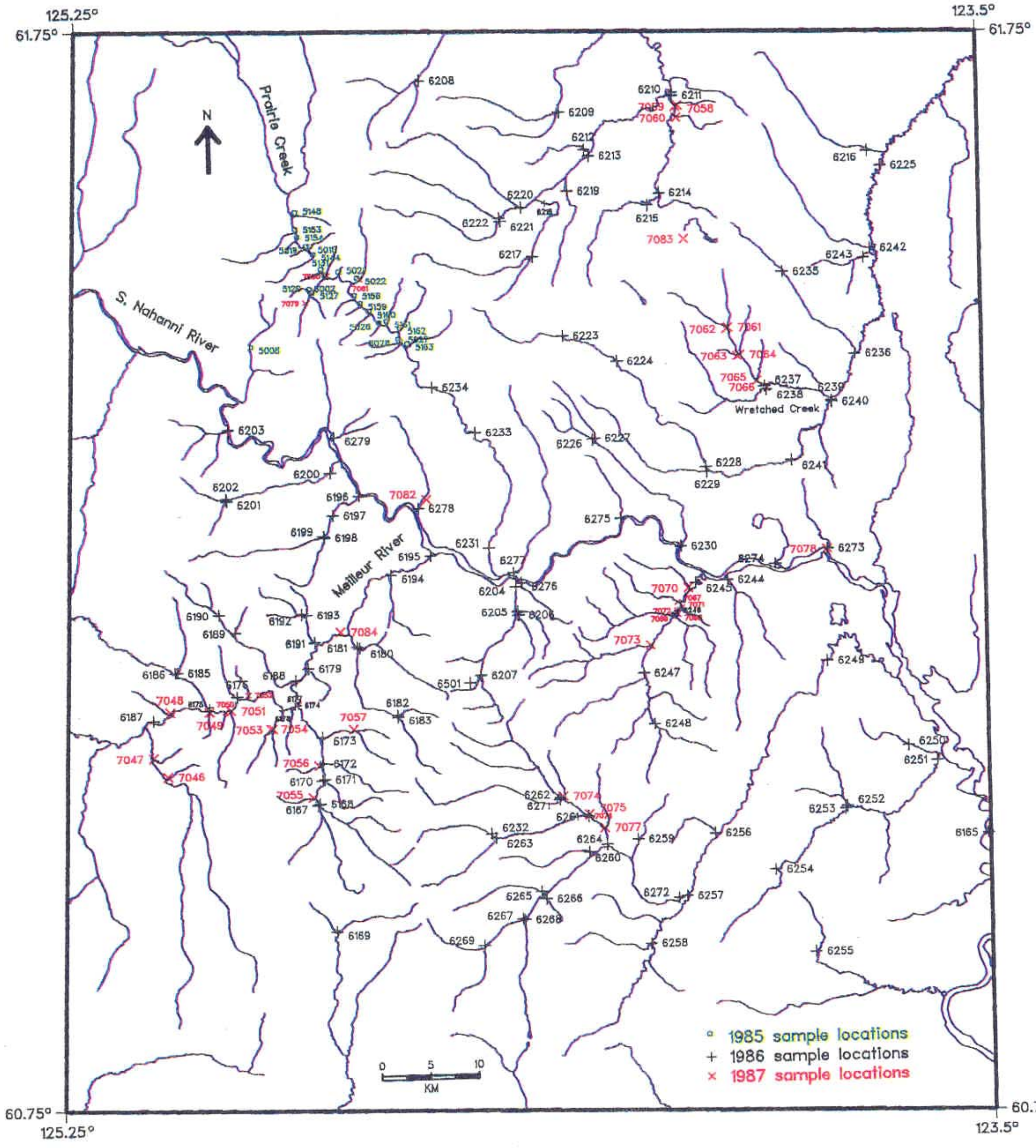

Figure 4.1b: Sample Location Map, Nahanni Karst Study Area

In Ragged Ranges study area, an orientation survey was conducted in an area extending from Lened, where skarn tungsten deposits are associated with Cretaceous plutons, to Vulcan, a shale-hosted Zn-Pb showing which is similar to deposits at Howards Pass (Fig. 2.1). The orientation areas also contain precious metal-bearing veins and stratabound carbonate-hosted Pb-Zn. The results from the Lened to Vulcan area overlap and are similar to those in the Nahanni map sheet (105I) resulting from a National Geochemical Reconnaissance (NGR) survey (Goodfellow ,1982).

In Nahanni Karst - Tlogotsho Plateau, the orientation survey was conducted around the Prairie Creek (Cadillac Mine) Ag-Pb-Zn vein

(Fig. 1.1). Occurrences of vein-hosted precious metals and Mississippi Valley type Zn-Pb are also found in this study region. The results confirmed anomalous lead and zinc, and included some sporadic high gold concentrations for Prairie Creek, verifying that the sampling method is applicable in these terrains.

In the 1986 regional reconnaissance survey, one sample was taken for approximately every 20 km^2. The sites were chosen to uniformly sample the drainage and bedrock. Primary, secondary and some tertiary streams were sampled in 1986. Sediments from smaller drainages were collected in the follow-up year, 1987. Very large streams such as South Nahanni River, Flat River, Rabbitkettle River and Broken Skull River in Ragged Ranges, and Meilleur River and South Nahanni River in Nahanni Karst-Tlogotsho Plateau were sampled at their mouths where possible, to obtain background samples which represent entire drainage basins. Dilution of geochemical signatures is a factor in considering the results of these samples: the larger the stream being sampled, the larger the mineralization must be to have a significant effect on the trace element content of the sediments (Levinson, 1974). Streams draining into these rivers are considered first order or primary in this study.

In Ragged Ranges, four large river valleys and their tributaries were investigated: Flat River, Rabbitkettle River, South Nahanni River and Broken Skull River (Figure 4.1a).

The main rivers investigated in Nahanni Karst-Tlogotsho Plateau include: Meilleur River, South Nahanni River, Prairie Creek, Sundog Creek and Clausen Creek (Figure 4.1b).

At each site, stream silt and pebbly sand, (from which heavy minerals were concentrated), were both collected to test which medium is more suitable for exploration of various elements in the Northern Cordillera. Except for about 5% of the streams, both silts and pebbly sands were collected. Some high gradient streams with high rates of flow have a paucity of silt-sized sediment and in rare cases, even the coarser material (<1 cm) was difficult to collect. Other meandering, low gradient streams, such as those found near Nahanni Butte are composed entirely of silt-size material. Dry streams were sampled when necessary: a very large sample (20 kg) of gravel material (<2 cm) was collected and then sieved and panned at the next stream or at base camp.

At all sample sites, the pH and temperature of the stream water were measured using a pH meter (accurate to 0.1 pH units) and a hand thermometer (accurate to 0.1° C). The pH meter was recalibrated twice a day using solutions of known pH. When the battery was dead, a pH range was determined using pH paper. Some streams have no temperature recorded because the thermometer was not working.

Additional information recorded for each site includes: water colour and depth, sediment colour and amount of organic matter present, bank material, stream rate of flow, gradient, width and degree of braiding, possible contamination (if sampling near a mine, a culvert, or in a burn area, for example) and lithology of stream boulders. Recording the presence or absence of granitic and greenstone boulders from the Canadian Shield was useful in determining the extent of Laurentide Ice, with import to the origin of fine placer gold.

<u>Collection of silts for silt and HMC analysis</u> - silt was collected for silt geochemistry as well as for extraction of fine-grained HMCs for neutron activation analysis, as explained above. Small teflon scoops were used at any spot in the stream where fine material was concentrated, such as thin films on point bars, fresh overbank deposits in mossy areas that trap silt, and close to the stream bank in protected areas, such as near boulders, where finer material could settle. Approximately 4 kg of silt were taken at each site and packaged wet in 2 litre plastic bags. The samples were shipped in steel pails to 601 Booth Street where they were air dried. Small splits were taken by cone-and-quarter method for laboratory analysis. We were unable to collect any significant volume of silt from some high-gradient, silt-poor streams in Ragged Ranges. In these cases, extra-large pebbly sand samples were taken and laboratory sieving provided small aliquots from some that could be analysed as silt.

This silt-sampling method differs from that of the NGR Program (Friske & Hornbrook, 1991) in that samples were not dried in the field, the individual samples were much larger (3-4 times larger than conventional stream silts samples) and the detail of sampled tributaries was less consistent. The lesser detail was decided by the financial and human resources available for field work, and the decision to combine silts with heavy mineral sampling. Large silt samples were taken in case analytical resources permitted their further processing for HMCs, after the representative silt aliquot had been removed from each sample (see section 4.2.2).

Collection of pebbly sands for HMC analysis was mainly at the downstream ends of longitudinal and point bars where heavy minerals tend to accumulate. Heavy mineral lags, where the stream had naturally concentrated the heavy minerals, were also sampled if they existed. Where possible, samples for a site were combined from several different bars and different places on the bar, including vertical profiles of dissected bars.

The HMC sampling technique was meant to involve minimum field operator bias on the type of sample collected, and standardize processing under controlled laboratory conditions. The material was collected with a teflon scoop and passed through a 1 cm sieve into a standard gold pan (Fig. 4.2). The remaining sediment was gently agitated and culled to remove clay and organic matter, and to reduce the amount of coarser material (> 4 mm) without loss of heavy minerals. The partially concentrated sample was placed into a 2 litre plastic bag and the process was repeated until approximately 8 kg were collected (2 bags). Samples with a high water content were left to settle and then the excess water was drained off. Samples were not dried until they reached the laboratory.

In the 1985 orientation surveys, 2-3 kg of sample were collected, which yielded only 0.5 to 4.0 g of HMC in the laboratory, so minimum 8 kg samples were taken in subsequent years. Samples from carbonate terrains yielded considerably less heavy mineral concentrate than those from shale or granitic terrains.

Figure 4.2. Sieving Pebbly Sand Samples for Heavy Mineral Concentrates

If no coarse material was available for the pebbly sand sample, 8-12 kg of silt was taken in order to maximize the likelihood of obtaining useful HMCs, as well as to obtain the standard silt analysis. This most commonly was required in meandering streams located close to Nahanni Butte, in direct contrast to the lack of silt in some high-gradient cobbly streams in Ragged Ranges noted above.

Collection of bulk samples – both bulk silt and bulk pebbly sand for HMCs were collected on the Flat River, upstream from Tungsten, N.W.T., and on the Nahanni River, upstream from Nahanni Butte. Two 5 gallon pails each of wet silt and pebbly sand were collected at both sites to be used as sample duplicates. The collection methods for each sample type were the same as those described above.

4.2.2. Sample preparation in the laboratory

Preparation of the silt samples began with air drying. Hardened samples were broken up with a mortar and pestle. Using a stainless steel sieve, each sample was screened to -80 mesh (<180μm) and the oversize material (+80 mesh) was stored in plastic bags. One 16 dram vial of -80 mesh silt was powdered for geochemical analysis, another vial was reserved for storage and the balance was used to recover

HMCs. The analytical results for silts are listed in Appendix 3.1.

Preparation of HMCs from silt samples in 1990 involved 211 of the reserve 4-kg silt samples (Jefferson and Paré, 1991). The rationale for analyzing HMCs from silts is provided above. In the case of gravity separation, and the shaker table in particular, density, size and shape affect the separation. Because the hydraulic equivalence of small heavy mineral grains is the same as larger, lighter grains, fine gold may be transported on the deck with the coarser lighter minerals if the feed has too large a grain-size range. This problem also applies to spiral wheels, centrifugal separators, spiral columns, and elutriation tubes. Most stream sediment HMC processing (including the HMC from pebbly sands described below) is of sediments which have an upper size range of 850 to 2000 µm. In order to limit the effects described above, the silt samples used for this study were sieved to <180 µm (-80 mesh) using stainless steel sieves (as noted above), resulting in a much narrower size range and better hydraulic equivalence.

Before sieving, samples were soaked in a solution of water and tetrasodium pyrophosphate (TSPP) for 24 hours. Proper disaggregation and wetting is particularly important when treating clay-rich tills or fine-grained fluvial sediments (see Appendix 3.2). It ensures the disaggregation of all flocs and the liberation of mineral grains, including gold, from adhering clay particles. If a sample is not properly disaggregated before sieving, lumps of fine-grained material containing heavy minerals, including gold, will end up in the coarse (non-table fraction). Furthermore, if heavy mineral grains are adhered to clay, their mass may be decreased to the point that they are included with the lights when tabled or panned. Tetrasodium pyrophosphate also acts as a wetting agent and insures that no dry heavy mineral grains are affected by water tension and floated away with the lights on the table.

A Diester laboratory model shaker table was used to prepare the HMCs. The original intention was to use a Wilfley, laboratory model shaker table with a one piece, molded fibre-glass deck with a black "hard-gel" surface. The Wilfley would have been preferable to the Diester because it is easy to clean between samples and provides the best technology to insure against cross contamination of samples. The black surface of the custom-made Wilfley deck permits observation and immediate recuperation of gold grains as small as 50 µm at the table. Such gold is nearly impossible to observe on the stock beige or aquamarine decks normally supplied by Humphrey's Processing Company of Colorado, and by Wilfley Holman, U.K. The custom deck could not, however, be used for the Nahanni silt samples because the smooth deck reduces the width of the heavy mineral "band" which appears on the table during processing. In many of the Nahanni samples heavy mineral abundance is very low, making its recuperation from the table difficult. After a series of trials it was judged more prudent to use the Diester table rather than the Wilfley.

The wet, disaggregated silt samples were passed on the Deister table once and the resultant table concentrate (~>3.1 s.g.) was passed on the Deister table three more times in order to provide the purest possible concentrate. Visible gold grains were collected by the table operator and reserved in glass vials. The >5.5 s.g. fraction was also recuperated by the table operator, examined under a microscope for fine gold, and returned to the table concentrate.

Because of the unconventional sediment size (<177 µm as compared to <850 µm), test samples were run for the first two days in order to determine the optimum setting for the many table adjustments that influence the separation of heavy minerals and gold. The most important adjustments were:

1) rate of feed to the deck;
2) amount of water introduced with feed;
3) distribution pattern and stream velocity of water supplied to create water film over deck;
4) shaker dynamics such as length, elevation and number of strokes per minute;
5) tilt of deck;

Shaker table tailings (table lights) were recuperated using a two-container overflow system to minimize loss of fine-grained sediment. The light minerals (<3.3 s.g.) were air dried at <500ºC in 10 L paper bags and then transferred to ziplock bags. The heavy mineral concentrates (~3.3 s.g.) from the table were dried using fans at room temperature to avoid the oxidation of sulphides that might have been accelerated by heat. Magnetic minerals were removed using a permanent magnet, weighed, and stored in vials.

Methylene iodide was used to calculate the effectiveness of the table separation technique and to produce >3.3 s.g. samples on which heavy minerals could be identified and counted under the microscope. The procedure used was that of the sedimentology labs of the Terrain Sciences Division, Geological Survey of Canada (Paré, 1982). Methylene iodide separation of 100 g splits from the light fraction of ten silt samples was also performed, in order to determine the proportion of heavy minerals remaining in the light fraction.

Methylene iodide HMCs were coned and quartered to produce a 0.25g split for reference purposes and a <0.05 g split for a permanent grain mount. The grains were evenly distributed over a thin layer of Araldite 504 on a 1x2" glass slide and finished with a cover slip.

Heavy minerals were counted on 104 slides (½ were HMCs from sands, ½ HMCs from silts). A Zeiss stereoscopic microscope in tandem with a petrographic microscope was used to count 300 grains in each slide. Data were entered through a computer keyboard using software developed by Consorminex Inc. The system is preferable to conventional point counters because it allows a greater number of mineral classifications to be used, allows the operator to see entries while counting, and records the data on floppy disks. Ten sand HMCs, processed in 1987, were previously counted in this way.

The resultant point counts allow statistical comparison of mineral distributions between silt and sand HMCs at 50 sites representing a wide range of provenance. The ten counts already reported in Spirito et al. (1988) show significant differences related to provenance.

Gold or other economic minerals in silt HMCs have been concentrated by up to 2 orders of magnitude from samples that averaged 2.5 kg. Gold grains observed during tabling were removed as they went over the edge of the deck.. A special temporary sample of the >5.5 s.g. fraction of HMCs was also taken during tabling. Any gold too small to see at the table, but large enough to observe with a binocular microscope, is often collected with the >5.5 s.g. fraction. This >5.5 s.g. temporary sample was examined under the microscope for gold grains, and any found were removed and stored in glass vials together with those removed earlier. The remainder of the >5.5 s.g. fraction was merged with the >3.3 s.g. fraction for INAA analysis.

In cases where initial tabling of the <177 µm fractions yielded relatively large gold grains, these samples were resieved at 250 µm in order to extract larger gold grains if present. For some of these samples this procedure proved profitable. These same samples were then resieved at <850 µm for the same reasons.

Concentrate from samples which contained gold grains from several of the Nahanni samples were further concentrated using a South American batea (gold pan). This permitted the recovery of gold grains as small as 10 µm. The South American bateas used by Consorminex are 40 cm diam. spun steel conical pans which are 12 cm deep. The action of these pans is based on the principles of resistance of denser grains to centrifugal force, water film flow, frictional drag, dilation of the sediment bed and differential movement. Properly used the South American gold pan incorporates the action of the shaker table and super-panner. For fine-grained sediments, there is also a minimal chance of loss of very fine gold or heavies as these grains immediately work their way down to the bottom tip of the pan and away from exposure to the water-air interface where water tension can result in heavy minerals being lost to the lights. In order to recuperate gold grains, the samples were panned till only 2-5 g of heavy mineral concentrate remained. This concentrate was then removed using a pipette and examined under a binocular microscope for gold grains.

Gold grains were examined under the microscope; their dimensions, morphology, texture, and Cailleux roundness index were recorded (Appendix 3.2). A 35 mm colour slide photograph was taken of the gold fraction of each sample. Gold grains were stored in microfossil holders.

Concentrates were sent to Bondar and Clegg Ltd., Ottawa for direct irradiation/neutron activation analysis (INAA). Gold (at detection limit 5 ppb) plus 33 (Sb,As,Ba,Br,Cd,Ce,Cs,Cr, Co,Eu,Hf,Ir,Fe,La,Lu,Mo,Ni,Ru,Sa,Sc,Se,Ag,Na ,Ta,Te,Tb,Th,Sn,W,U,Y, Zn,Zr) elements were analyzed. The analytical results for HMCs from silts are listed in Appendix 3.2 (Table A-3.2(vi) but were not included in the statistical analysis, although visual comparison of results indicated compatibility with previous analyses, and selected results for gold only are shown in Table 4.7.

Preparation of HMCs from pebbly sands was first tested with the 1985 samples. These were air dried and weighed at the Geological Survey of Canada. The <841µm to >63 µm fraction (-20 to +250 mesh) was separated and passed through methylene iodide (MI; s.g. = 3.28) to concentrate the heavy minerals, and then washed with acetone. Initial sample weights of 2-3 kg yielded only 0.5-4 g of concentrate, with the lesser amounts being derived from sediments from carbonate terrains. It was therefore decided to collect larger samples in 1986 and 1987.

In 1986 and 1987, the cost of heavy liquid separation would have exceeded available resources for the large size and number of heavy mineral samples. There was also a concern about the health hazards inherent in the use of heavy liquids. Therefore, it was decided to use only hydraulic separation techniques. After being air dried and weighed at Consorminex, Ltd., the samples were wet sieved from <841µm to >63µm (-20 mesh to +250 mesh). The >841µm fraction was stored for reference and the <63µm fraction was discarded. The remaining fraction was sieved to remove the >250 µm (+60 mesh) fraction and then passed three times on a Deister concentrating table, which separated the heavy minerals from most of the light ones (Stewart, 1986).

During the tabling by Consorminex, visible gold grains were observed when they reached the upper riffles of the black deck, collected separately as they washed off the end of the deck, and then catalogued. Both the heavy and light fractions were air dried, weighed and stored in plastic vials. Initial dry weights of 8-12 kg yielded 10-30 g of HMC in most samples. The magnetic fraction was removed from all HMCs using an auto magnet and then weighed. The magnetic fraction consists mostly of magnetite but also minerals with magnetite inclusions, polymineralic grains with magnetite and hematite or ilmenite with magnetite lamellae. Pyrrhotite, when present also occurs in the magnetic fraction as do steel shavings.

Samples used for point counting of individual heavy mineral species were further processed using MI to ensure an extremely clean separation. The bulk of this processing was done by Consorminex Inc., although approximately half of the 1986 samples processed using MI were done by the author and T.J. Pilgrim at the Geological Survey of Canada. Many of the details of the methodology provided above for the HMCs from silt samples are applicable to HMCs derived from pebbly sands.

The HMCs were sent for geochemical analysis without further preparation, unless the yield was greater than 10 g, the suggested weight for Neutron Activation analyses. One or more 10 g portions were split from the larger HMC's using the cone-and-quarter method to produce unbiased duplicate samples. The analytical results are listed in Appendix 3.3.

Preparation of bulk samples for each sample type followed the same procedures as outlined above. A portion of each bulk silt sample was dried and screened to -180 µm (-80 mesh) and then powdered to ensure homogeneity. These powdered samples were used as internal quality control reference samples in laboratory analysis.

The pebbly sand bulk samples were prepared in the same manner as the routine pebbly sand samples (described above), and then split into 10 g portions using a cone and quarter method. Of the Flat River sample, 4.6 kg (sieved, dry weight) yielded 38.95 g of HMC; of the Nahanni River sample 23 kg (sieved, dry weight) yielded 156 g of HMC. Analytical results are reported in Appendix 3.4.

4.2.3. Analytical Methods

Different analytical laboratories and methods were used to determine the compositions of each type of stream sediment sample. The methods remained consistent for each sample type between years with the exception of extra silt analyses by ICP-ES on the 1987 samples. A list of methods used for each sample type are listed in Appendix 3.5.

Precision and accuracy must be estimated in order to validate interpretations for resource estimation or exploration decisions. Precision is the ability to reproduce and repeat the same analytical result. It is more useful if accuracy, the approach to the true content, is also obtained (Levinson, 1974). In geochemical exploration, patterns which reflect variations in the abundance of indicator elements are examined to identify target areas. In this situation the relative amount of an element is more important than the absolute amount, as long as the variability sought is measurably greater than variability introduced during sample collection and analysis (Fletcher, 1981).

Splits from the bulk samples were inserted into the analytical sequences for each type of medium, every 7 to 10 samples, to monitor precision. The limited yield of heavy mineral concentrate from the Flat River area required that splits from some of the largest routine samples had to be used as blind duplicates in addition to those from the bulk samples. Pairs of samples were also taken at several sites to be used as field duplicates.

Accuracy was checked by inserting lake and stream sediment standards used in National Geochemical Reconnaissance (NGR) studies at the Geological Survey of Canada (Lynch, 1990). The analytical results from the NGR standards are listed in Appendix 3.4. Nine samples from 1986 were re-analyzed, and field duplicates of 18 additional sites were taken at exactly the same locations in 1987 to further check reproducibility.

The risk of contamination is always present in geochemical surveys and must be considered when interpreting results. Erratic results that do not fit geochemical patterns or relate to bedrock may be readily identified as suspect. In other cases, contamination may produce believable but artificial anomalies which are not as easily detected. Therefore, it is important that at all stages of the geochemical survey (collecting, analyzing and interpreting), one must be aware of the possible presence of contamination and how to avoid it.

In Ragged Ranges, the few known sources of contamination were avoided where possible and noted where impossible to avoid. The most significant source is the Canada Tungsten Mine on the Flat River. The original tailings pond broke and distributed tailings downstream along the Flat River. Rusty river banks reflect acid mine tailings that were incorporated into the stream sediments and subsequently oxidized. Geochemical survey of stream waters by Halliwell (1998) at the mouth of Flat River shows that the Flat River waters are stabilized but still metalliferous, as is much of the surface water draining the Nahanni watershed. As shown by Hamilton (1990 and Chapter 5 of this Open File), many of the spring waters that feed the surface drainage are also metalliferous.

Samples for this study were taken upstream from the Cantung Mine and on tributaries leading into the Flat River. Drill prospects on these tributaries were noted, as well as the presence of fuel sites and machinery throughout the study area. Streams in relatively recent burn areas were sampled north of the Nahanni River where it bends, at the junction of the Nahanni and Broken Skull Rivers and northeast of Glacier Lake. Streams near metal-rich, hot and cold springs were sampled for comparison with water analyses; streams near moose ponds were only sampled if necessary, but could usually be avoided.

In Nahanni Karst, the Prairie Creek (formerly Cadillac) Mine and trenched showings are major sources of metals in sediments of the Prairie Creek drainage basin. Samples were taken downstream from the mine to calibrate its effect on the geochemical results. Streams were sampled upstream from tracked vehicle roads near the headwaters of the Jackfish River in Tlogotsho Range. An old burn area was noted north of the Meilleur River and streams from a more recent burn were sampled in Ram Creek drainage basin. Old road construction camps were seen on unsampled tributaries of Sundog Creek, near the karst terrain.

In both study areas, samplers wore no jewellery when collecting the stream sediments. Contamination from agriculture and human habitation is not a factor in these remote regions.

Treatment of gold grains required great care because of their small size and tendency to fly into the air due to electrostatic charges. The gold flakes separated out during the tabling process were systematically described (Appendix 3.2) and subsequently weighed by J.C. Bisson at the Geological Survey using a Perkin-Elmer ultramicrobalance, with AD-6 autobalance. It is accurate to +/- 0.0005 mg on samples weighing < 2 mg, and to +/- 0.001 mg on samples weighing up to 20 mg. These weights were combined with the ppb abundances obtained by Neutron Activation analyses on the concentrate from which the gold was removed (Spirito et al., 1988).

The flakes recovered were optically examined for evidence of artificial origin and individually photographed with a 35 mm camera attached to a microscope. The gold flakes were also viewed under a scanning electron microscope (SEM; Figures 4.3a and 4.3b).

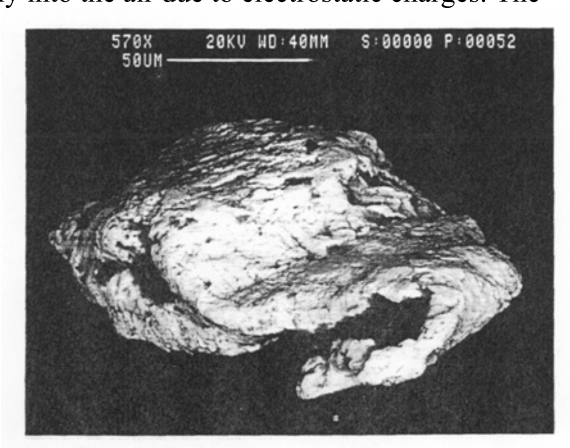

Figure 4.3a: Gold Grain from Brophy Creek, Ragged Ranges

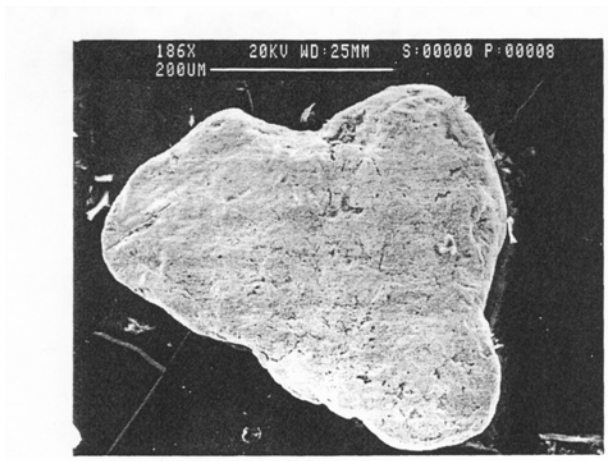

Figure 4.3b: Gold Grain from Wretched Creek, Nahanni Karst

Slides of heavy minerals were made from the tabled concentrates using the method outlined in Paré (1982). The slide was mounted on a stereoscopic microscope equipped with an automatic counter at Consorminex. Equally spaced transects were made parallel to the slide's long axis, and grains that crossed the transect line were recorded until 300 grains were counted. Initially, 9 samples from the 1987 HMCs that contained gold were counted, but this was later expanded to include 50 more HMC's from 1986 and 1987 pebbly sands, and 50 HMCs from silt (Jefferson and Paré, 1991; Appendix 3.2).

4.3. Statistical Analysis

4.3.1. Statistical methods for Nahanni data

Many of the Nahanni samples analyzed by Neutron Activation have results below variable detection limits. In some cases due to interference from other elements (especially radioactive elements) the detection limits are high and variable (e.g. HMC W data, Appendix

3.3), but this does not necessarily imply that the element is present in high or low amounts.

Because resource assessments commonly involve imperfect data (Scoates et al., 1986), but require that a certain degree of confidence be placed in those data, a method that uses all available information without requiring subjective removal or arbitrary substitution of censored data is needed. The Maximum Likelihood (ML) method (e.g. Chung and Spirito, 1989) is used here to analyze the Nahanni data, some of which are censored. It takes into account all available data, including those less than the detection limit and therefore defines the distribution of elements and allows more confidence to placed in the results.

4.3.2. Geochemical data below detection limit

Statistical analysis of geochemical data can be hindered by censored data i.e. analytical values below the detection limit. Commonly, substitution methods are used where a certain percentage of the value (e.g. 0.5, 0.66) is substituted for the "less than" value. For example, if a sample has an analytical gold value of <5 ppb, the gold value would be set to 3 ppb (5 x 0.66). If small portions of the data are censored, substitution probably has a minimal effect on the results and therefore the interpretations. However, substituting where a higher proportion of data are censored can result in false values (see Chung and Spirito, 1989; Appendix 3.6), which can mimic geochemical anomalies. If the detection limits vary or are high, the problem is compounded.

Ideally such imperfect data should be deleted or ignored, or if practical, sites should be re-sampled and re-analyzed to obtain better primary data. If re-sampling is not feasible, a visual scan of the data can eliminate those values with high detection limits or those elements with a high proportion of censored data which should not be included in the statistical analyses. However, the choice of data removal is subjective and the decision of a cut-off point (i.e. how high a detection limit is too high) is difficult to make. Removal of a large proportion of censored data may also bias the statistical results.

An alternative technique that can be applied to an entire set of censored geochemical data is known as the method of Maximum Likelihood (ML) Estimation (Chung, 1990) which is discussed below.

4.3.3. Maximum likelihood estimation (MLE)

The concept of ML estimation is one of the most popular estimation procedures in statistics (e.g. Bickel and Doksum, 1977). However its application in the geosciences is relatively recent and is still not widely used. If the data are complete (no values below detection limit) and normally distributed, the maximum likelihood estimators (MLEs) of the population mean and variance are the same as the sample mean and variance; that is, the MLEs are the sample mean and variance of the data set and can be derived using any standard statistical package. If the data set contains values below the detection limit, the sample mean and variance (which estimate the population mean and variance respectively) are not possible to determine unless the censored data are removed or substituted, which, as discussed in Chung and Spirito (1989), is not always a good solution. However, ML estimation procedures can still be applied to the censored data without any substitution to estimate the population mean and variance. Using this technique, the estimates of the population mean and variance are known as Maximum Likelihood Estimators (MLEs). Table 4.1 shows that the ML technique can be applied to both censored and uncensored data.

Table 4.1. Data Types to Which ML Estimation Can Be Applied

Data Type Under Normality	Sample Mean and Variance*	ML Estimator of Mean & Variance
Complete/Uncensored Data	x s^2 - from any statistical package	same
Incomplete/Censored Data	cannot calculate without substitution	- can be calculated - can be tested using confidence bands

* which estimate the population mean and variance respectively

How are MLEs derived? Several iterative algorithms have been used to obtain MLEs, including the scoring method (Rao, 1975), the EM-algorithm (Dempster et al., 1977) and the conjugate gradients method (Stoer and Bulirsch, 1980) as discussed in Chung and Spirito (1989). By using one of these iterative procedures the ML estimates for mean and variance can be derived. The starting point for the iterations is a data set that has been made complete by substituting some percentage for the censored values. The precise starting point is arbitrary because the final MLEs will always be the same. The only difference is that there will be more (or less) iterations if a certain percentage for the censored value is substituted instead of another. The sample mean and variance result from estimating a distribution of the entire data set based upon the known distribution of the uncensored data. The ML methods recognize that samples with high detection limits provide little information about the distribution and therefore have almost no influence on the estimators (Chung and Spirito, 1989). As is the case in all statistical calculations, if the normality assumption is violated the MLEs are meaningless.

Suppose that a sample has relatively high detection limit and therefore the value cannot be observed. For example, W in sample #7039 is less than a detection limit of 4900 ppm. This sample contains almost no information (only that the value is between 0 and 4900 ppm) and it should be removed from any further analysis. The next question is how high must the detection limit be before the sample is disregarded. This question is particularly relevant if the substitution method is used. A value of 2940 ppm (0.6x4900 ppm) substituted for <4900 ppm will distort the estimators. However, if the ML estimators are used, then it can be shown that this kind of sample has almost no effect on the estimators. The reason is that in maximizing the log-likelihood function (see Appendix 3.6), this sample (<4900 ppm) will not have any influence on the ML estimators. This is illustrated in Table 4.2 where the presence or absence of four samples with high detection limits has very little effect on the ML estimator whereas it has a noticeable effect on the substitution method means. The table also illustrates the difference that results from substituting arbitrary values (0.4 up to 0.8) for the undetected data. It should also be noted that because the means and standard deviations are log values they cannot be applied to the data set directly. This is discussed further in Section 4.3.6.

Table 4.2. Calculation of Mean and Standard Deviation Using MLE and Substitution

W in HMC	μ	μ*	σ	σ*
MLE	1.13	1.13	3.37	3.39
SUB (0.4)	2.25	2.19	2.16	2.22
SUB (0.5)	2.41	2.31	2.13	2.16
SUB (0.6)	2.57	2.42	2.12	2.10
SUB (0.7)	2.73	2.54	2.13	2.05
SUB (0.8)	2.89	2.66	2.15	2.01

* estimates with <3600, <3400, <3600, <2900 removed

Chung and Spirito (1989) compared the ML and Substitution methods; they analyzed the data for each extension area first as a group and then by rock type. Calculating statistics on samples of similar rock type necessarily means that the population size is smaller but avoids combining samples that may be geochemically very different. Because only three elements (Zn, W and Au) were being studied, the smaller population size was not a problem. However, in this larger study of 16 elements, the small population was a problem. Therefore, each study area was evaluated first without considering rock type (Section 4.3.3.2) and second by removing the effect of rock type (Section 4.3.8).

Maximum likelihood (ML) estimation of Nahanni data was employed by Spirito (1998) instead of the substitution method, using a technique based on the scoring method outlined in Rao (1975). Because the ML programs for statistical treatment of censored data (Chung and Spirito, 1989) do not use commercially available software, a wide variety of statistical analyses are not yet available. New applications are currently being developed for correlation analysis (Chung, 1992). In this study, the ML method was used to estimate mean and standard deviation as well as for regression analysis.

4.3.4. Elements Used in Statistical Analysis

In the Nahanni data, more than a dozen elements yielded a high proportion of INNA analytical values below variable detection limits. Because re-sampling and re-analysis was not possible, analytical results for the following elements were visually inspected but not statistically analyzed because they provided no statistically useful information: Br, Cs, Eu, Na, Ir, Rb, Se, Sn, Te, Yb, Zr. Some elements yielded a small proportion of values below the detection limit but were also eliminated from this study to make the number of calculations and maps more manageable: Fe, La, Lu, Sc, Sm, Ta, Tb, and U. The following elements were statistically studied: W, Au, Zn, Sb, As, Ba, Cr, Co, Mo, Th, Hf, Ce, Ni (Cu, Pb, Cd silts only). Underlined elements are those with a high proportion of undetected values. Au and W were chosen despite their high proportions of undetected values because they are apparently anomalous in some streams, they illustrate the usefulness of the Maximum Likelihood method and they have direct implications on the resource assessment of the study areas.

4.3.5. Tests for Normality

There are many tests for normality that can be used if the data set is complete, the preferred being the Anderson-Darling test (Stephens, 1974). If the data are censored, there is no simple, reliable test. Most geochemical stream sediment data have a "skewed" or lognormal distribution (e.g. Bonham-Carter et al., 1987). A log transformation can be applied to achieve a normal distribution, which is symmetric and therefore easier to understand. The normal distribution is completely described by two parameters: the mean, μ (location parameter) and the variance, σ^2 (scale or shape parameter).

4.3.6. How sample mean and standard deviation can be used

Appendix 3.7 illustrates the input required for and the output produced by the program used to calculate the sample mean and variance for the elements listed in Section 4.3.4. The geochemical data were grouped by area (Ragged Ranges and Nahanni Karst/Tlogotsho Plateau) and medium (heavy minerals and silt) but not by rock type, which means that there were four large groups of data. A general rule of thumb is to take the number of geochemical elements to be used in a statistical analysis and multiply by 3. The result is the minimum number of samples that are required before doing statistical analysis. If the Nahanni samples were further divided by rock type, the sample would have been too small because the number of elements in the heavy mineral and silt analyses is 13 and 16 respectively. So for the first step, rock type was not considered. Rock type and its effect on the geochemical maps are discussed in Section 4.3.8.

The estimates of the population mean and standard deviation are calculated for both the substitution method (using the initial values the user specified; shown at Step 0 in Appendix 3.7) and the ML method (shown at the final step). If the logarithmic transformation of the data was requested, as is the case for the Nahanni data, these values are in log form and cannot be applied to the original data set directly. To estimate the mean and standard deviation of the original data, taking the exponential (antilog) of the values is not adequate. An additional adjustment must be made (see Aitchison and Brown, 1966) but the estimators no longer represent the data as well as they did in the log-transformed environment. This is because for normal distributions, the mode (MO), median (M) and mean (μ) of a variable X are all equal to the expected value of X, E(X) (e.g. Bickel and Doksum, 1977). This is not true of lognormal data.

Suppose X is a variable from a lognormal distribution. It follows that the logarithm of X is normally distributed with mean μ and variance σ^2:

(1) $\log(X) \sim N(\mu,\sigma^2)$

It can also be shown that the distribution of X can be characterized by two parameters known as α and β^2, which are the "mean" and "variance" respectively. This is denoted by:

(2) $X \sim LN(\alpha,\beta^2)$

where α and β^2 are defined by the following equations:

(3) $$\alpha = e^{(2\mu+\frac{1}{2}\sigma^2)}$$
$$\beta^2 = [e^{(2\mu+\sigma^2)}][e^{\sigma^2} - 1]$$

Equation (3) also illustrates the relationship between α and β^2 (the parameters that characterize a LN distribution) and μ and σ^2 (the parameters that characterize a normal distribution).

The parameters α and β^2 cannot be calculated directly because the data set is always only a sample of the entire population. Therefore estimates of these mean and variance parameters must be determined. In the case of the LN distribution, possible estimates of these parameters (denoted by $\underline{\hat{\alpha}}$ and $\underline{\hat{\beta}}^2$) can be obtained by using the ML estimates of μ and σ ($\hat{\mu}$ and s, which were derived in the log-transformed environment) and Equation (3):

(4) $$\underline{\hat{\alpha}} = \exp\left(\hat{\mu} + \tfrac{1}{2}s^2\right)$$

and $$\underline{\hat{\beta}}^2 = [\exp(\underline{\hat{\mu}} + s^2)][\exp(s^2) - 1]$$

where exp is the exponential. These are not "good estimators" (Aitchison and Brown, 1966). Aitchison and Brown (1966) suggested that the expected value of a good estimator should be its true value. For example, if $\hat{\Theta}$ is a good estimator of Θ, then we expect that Equation (5) is true:

(5) $E(\hat{\Theta}) = \Theta$

However, it can also be shown (Aitchison and Brown, 1966) that

(6) $E(\underline{\hat{\alpha}}) \neq \alpha$

Good estimators of α and β^2 are given in Aitchison and Brown (1966, p.45) and are listed in Appendix 3.8.

4.3.7. Calculation of percentile values to classify the original data

Because the relationships among means and variances in the original and transformed environment are not simple or obvious, the method of quantiles and percentiles was used (Aitchison and Brown, 1966) to relate the estimators derived in the transformed environment (Section 4.3.6) to the original data set. In this procedure, the estimated values are used to calculate percentiles which can be applied to the original data set. The basic formula is:

(7) percentile = 100 * [exp ((cv * s) + $\hat{\mu}$)]

where:
- cv = critical value for the percentile
- s = ML estimator of population standard deviation
  - = sample standard deviation
- $\hat{\mu}$ = ML estimator of population mean
  - = sample mean
- exp = take the exponential

The critical values can be obtained from Standard Normal Distribution tables which are found at the back of many statistics books (e.g. Bickel and Doksum, 1977). The critical values for percentiles applied to the Nahanni data are listed in Table 4.3.

Table 4.3. Critical Values to Calculate Percentiles

Percentile	cv=Critical Value
98	2.055
95	1.645
90	1.280
80	0.840
70	0.520
60	0.250

Using Equation (7) and Table 4.3, the 98th and 70th percentiles are defined by:

$$P_{98} = 100 * \exp\left[(2.055 * s) + \hat{\mu}\right]$$
$$P_{70} = 100 * \exp\left[(0.52 * s) + \hat{\mu}\right]$$

The values of $\hat{\mu}$ and s that were estimated by the ML program (Appendix 3.7) for each element can be used to calculate all percentile values for that element, only the critical value must be changed. The antilog (exponential) is taken so that the percentile can be applied to the non-transformed data set. The percentile value is taken from the lognormal curve and the corresponding point on the normal curve is read off. It is possible to do this because in taking a log transformation, the order of the data has not changed, only the scaling between values has changed. As a result, a 1:1 relationship between normal and lognormal distributions still exists. Table 4.4 illustrates the quantities which remain the same in the log-transformed and non-transformed environments.

Table 4.4. Statistical Elements Which Remain Unchanged/Change in Log-transformed and Non-transformed Environments

Antilog of Log-Transformed	is	Value in Non-transformed Environment
Median	=	Median
Percentile	=	Percentile
Mean	≠	Mean
Variance	≠	Variance

Using the critical values outlined in Table 4.3, each element now has a set of values which represent the break points between percentile classes. This classification scheme, based on percentiles, can be applied to the original data. Analytical values which fall into the 80th percentile category or higher are considered of interest.

To assess the mineral potential of the South Nahanni River area, the technique of catchment basin analysis was applied to the HMC and silt data. It is based on a method used by Bonham-Carter and Goodfellow (1984) to distinguish background from anomalous samples, further developed by Bonham-Carter et al. (1987). An area of influence called a catchment basin is assigned to each sample and encompasses the region drained by the stream (Fig. 4.4). It is assumed that samples from mineralized catchment basins contain higher proportions of metals than samples from streams draining unmineralized basins. Each sample is locally affected by several factors such as the presence of organic matter which may cause variations in metal content that are unrelated to bedrock mineral content (Bonham-Carter and Goodfellow, 1984). In addition, the proportions of rock types present and the degree of glacial transport contribute to the geochemical signature of the stream sediments and make each basin unique in terms of its background value.

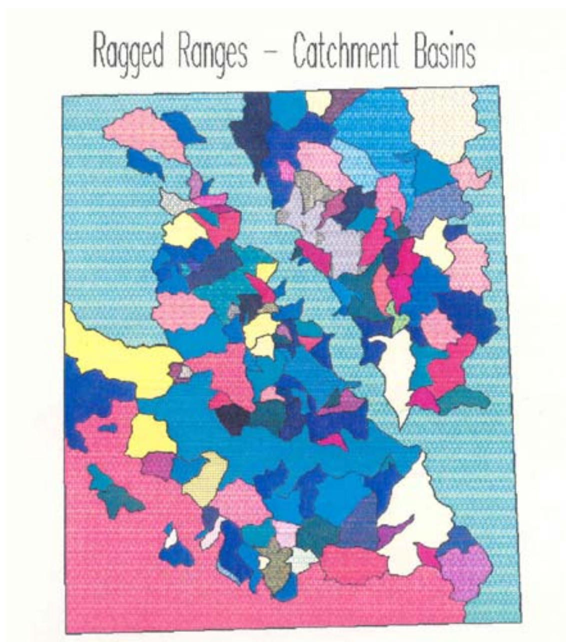

Figure 4.4: Catchment basins for Ragged Ranges

The concept of regional versus local background is important because it influences how anomalous samples are identified. Some workers (e.g. Garrett, 1991) have characterized regional background by first removing "mineralized" samples from the data set used to calculate background. Because the style and location of mineralized zones are mostly unknown in geochemical surveys, removing samples introduces a bias into the population distribution model. In the case of discrete catchment areas underlain by varying rock types, the concentration of geochemical elements in the stream sediments will vary within the catchment basin as lithology changes. In this case, using all of the data to determine local background values for each sample is more applicable. In addition, the choice of a cut-off point between anomalous and non-anomalous populations would be arbitrary. Including all samples avoids this decision (e.g. Ellwood et al., 1985).

Using the percentile values determined by the MLE technique for each element, the catchment basin for each sample was coloured in shades of red and blue, for higher and lower percentiles respectively. As a first approach, the data were plotted without correcting for lithology underlying the basin (e.g. Fig. 4.5a and 4.6a).

As a comparison of statistical methods, Au, W and Cr HMC data from Ragged Ranges were plotted using the substitution method (Figs. 4.6a, 4.8a and 4.10a) as well as MLE (Figs. 4.5a, 4.7a, and 4.9a). Figures 4.5a and 4.6a show the raw data for Au by the MLE and substitution methods respectively. The substituted catchment basin map shows 10 basins in the 98th percentile (bright red) above a critical value of 160 ppb, whereas the raw MLE map (Figure 4.5a) has only 3 samples above a critical value of 617 ppb. The critical value for the 98th percentile is increased from 160 ppb in the raw substituted map to 617 ppb in the raw ML map meaning that fewer samples are in that category. This indicates that the ML method is more discriminating. Regression analysis was used to create the predicted maps (all the Figure b's; e.g. Au MLE Predicted; Fig. 4.5b) and is explained in Section 4.3.11 below.

Figures 4.7a and 4.8a illustrate the results of MLE and substitution methods for W HMC data. The critical value for the 98th percentile has increased from 2834 ppm in the raw substituted map to 6124 ppm in the raw MLE map, so that 2 basins instead of 7 fall into the 98th percentile. Cr in HMC for MLE and substitution is shown in Figure 4.9a and 4.10a. The increase in the 98th percentile critical value from 522 to 1205 reduces the number of basins in that category from 8 to 1. In both cases, the MLE maps are more discriminating.

The raw MLE maps also provide more information about the nature of the original analytical data. The raw substituted maps give no indication about the number of basins that have samples with analytical values below detection limit whereas the ML maps have a category for undetected data. It is evident that the catchment basin maps can become variably misleading if automatic substitution with a certain percentage of the detection limit is used. For example, the raw substituted W map (Figure 4.8a) shows basins with analytical values that are actually undetected as falling into the 95th percentile. The MLE generated classifications provide a greater degree of confidence than those obtained by substitution. This is especially true for Au and W which are considered end member cases (high proportion of undetected values) but which illustrate the difference well.

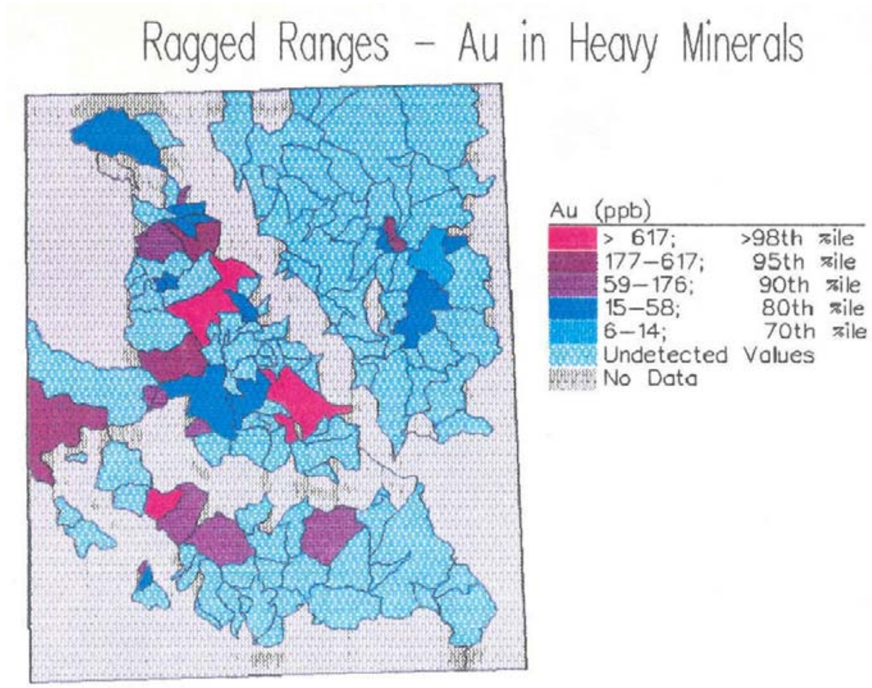

Figure 4.5a: Ragged Ranges, Au in HMC using MLE – Raw Data

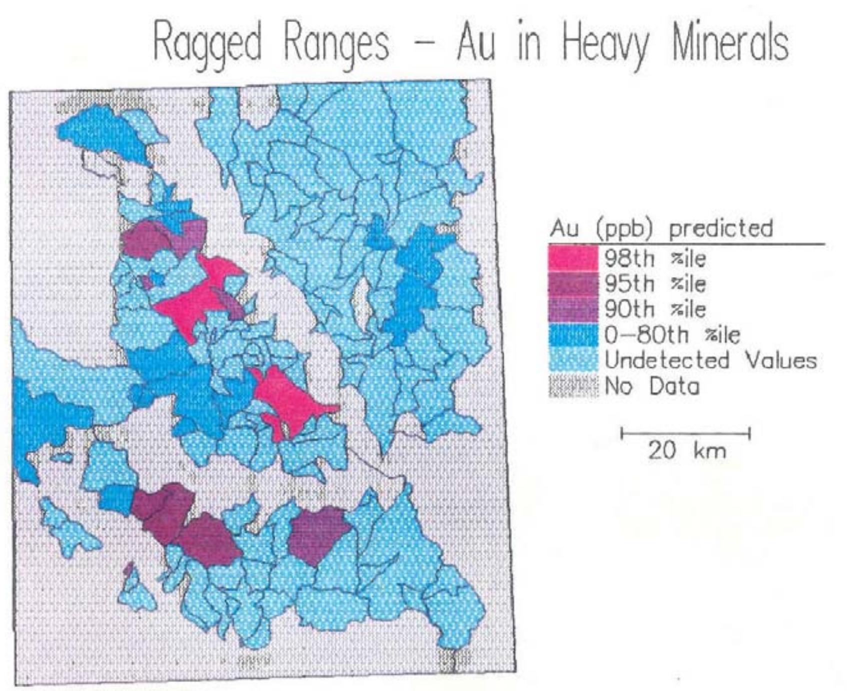

Figure 4.5b: Ragged Ranges, Au in HMC using MLE – Predicted Data

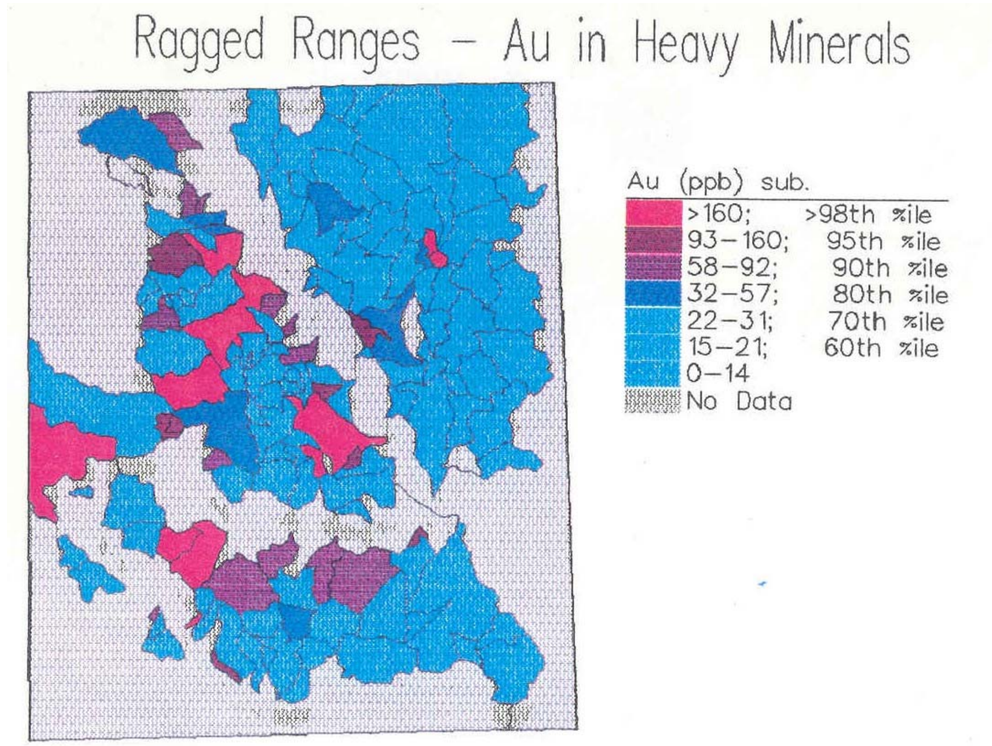

Figure 4.6a: Ragged Ranges, Au in HMC using SUB – Raw Data

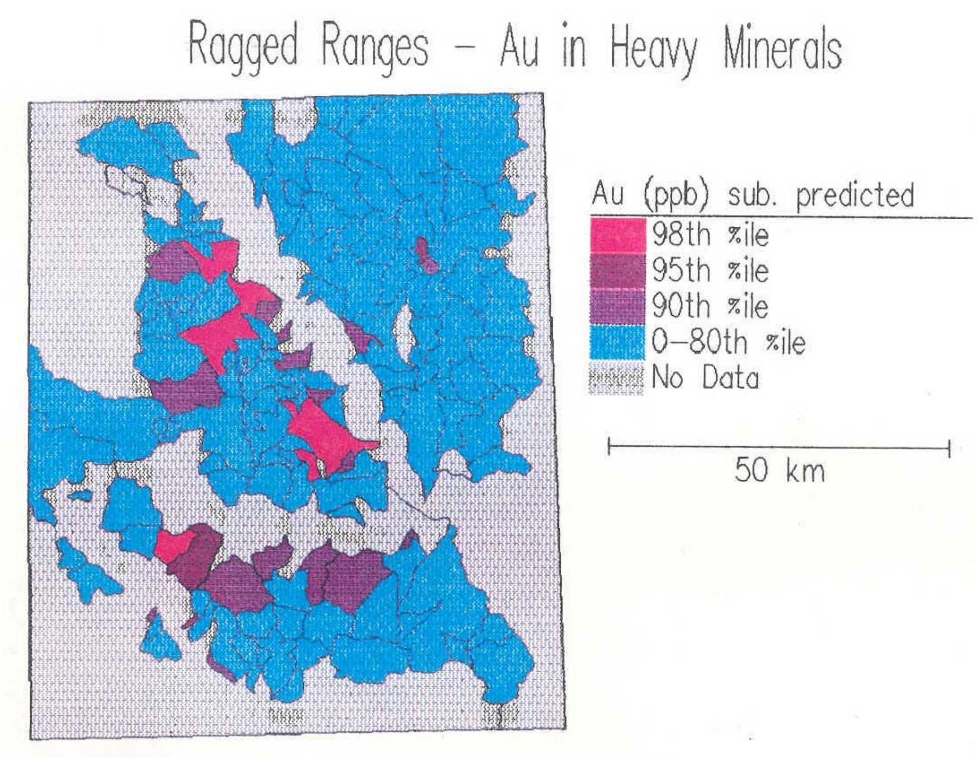

Figure 4.6b: Ragged Ranges, Au in HMC using SUB – Predicted Data

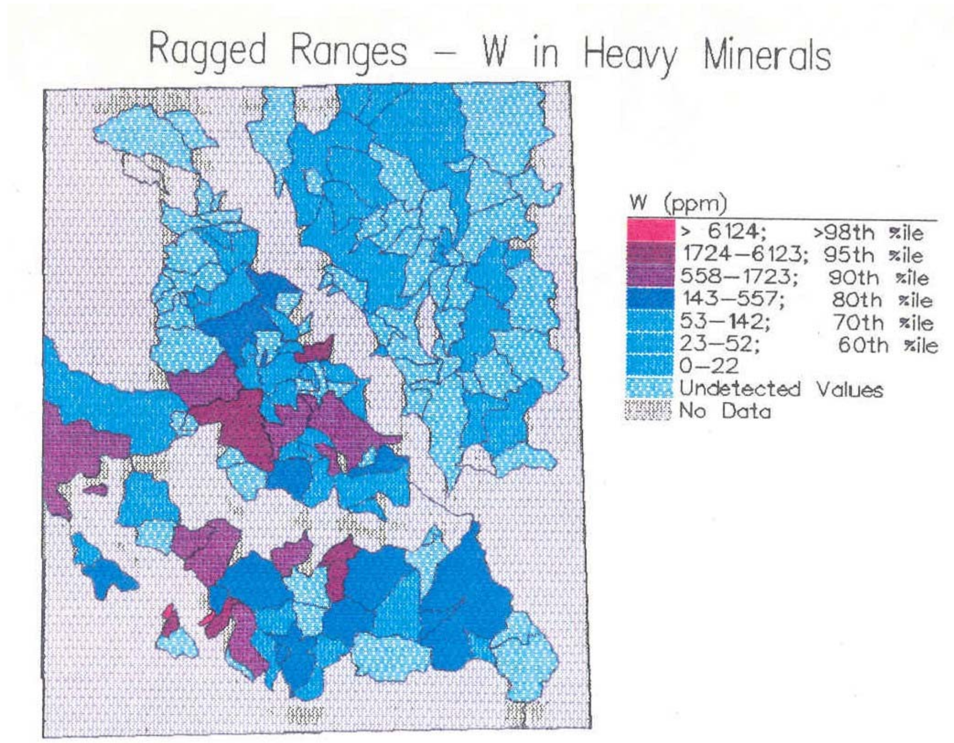

Figure 4.7a: Ragged Ranges, W in HMC using MLE – Raw Data

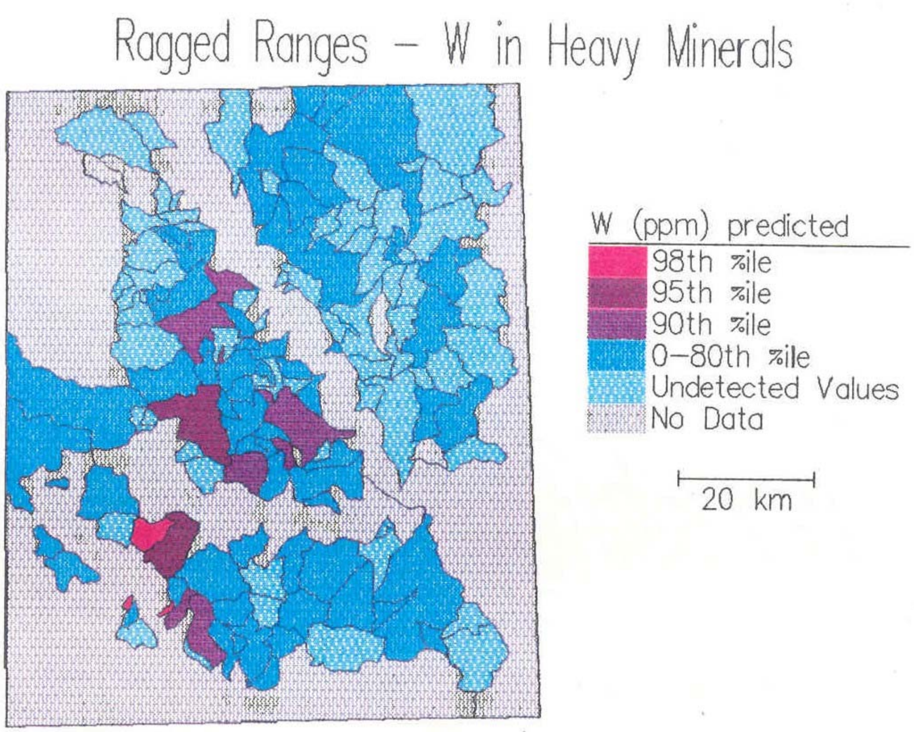

Figure 4.7b: Ragged Ranges, W in HMC using MLE – Predicted Data

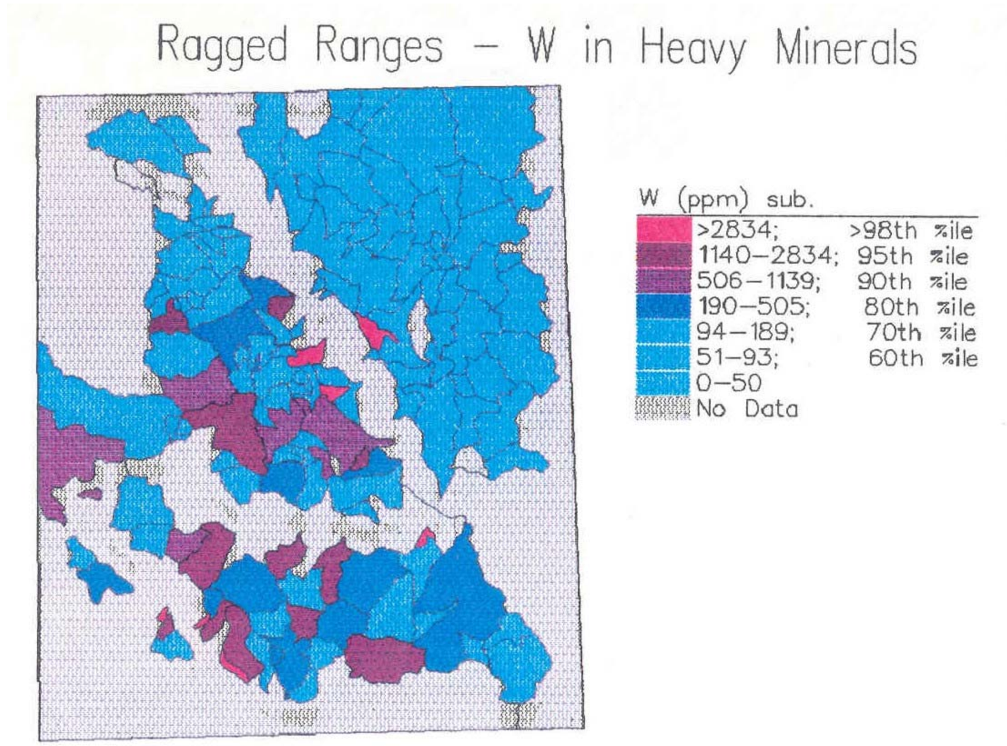

Figure 4.8a: Ragged Ranges, W in HMC using SUB – Raw Data

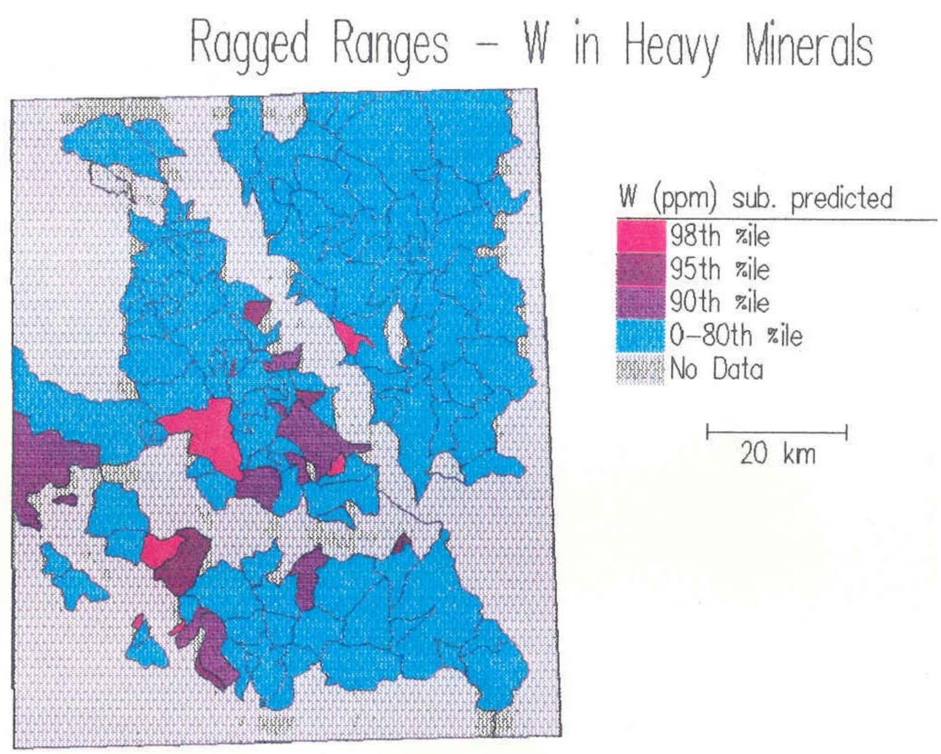

Figure 4.8b: Ragged Ranges, W in HMC using SUB – Predicted Data

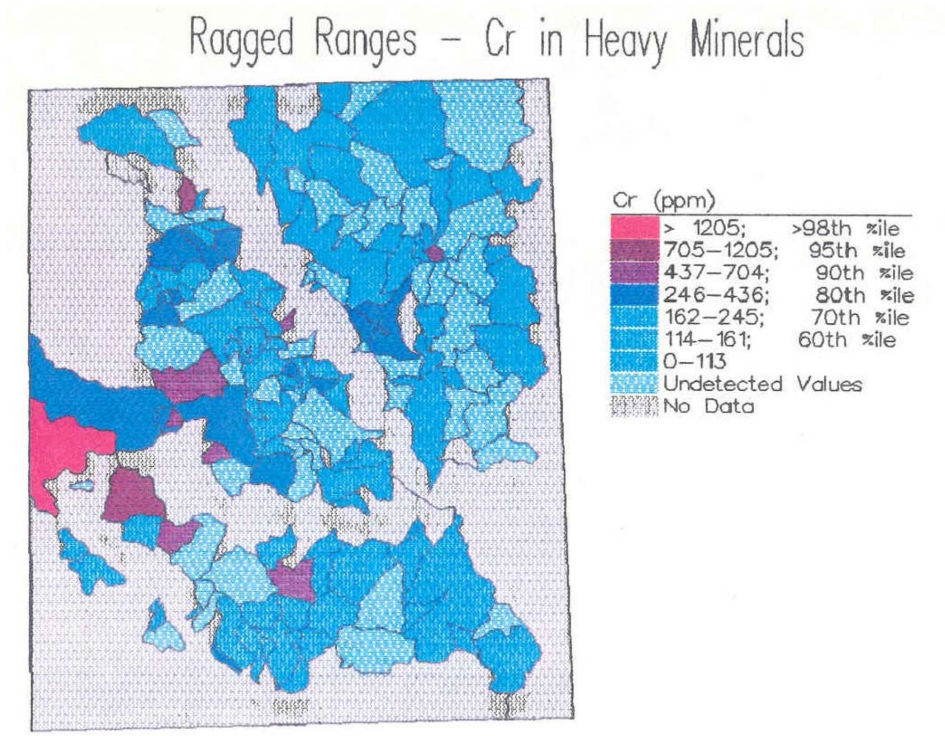

Figure 4.9a: Ragged Ranges, Cr in HMC using MLE – Raw Data

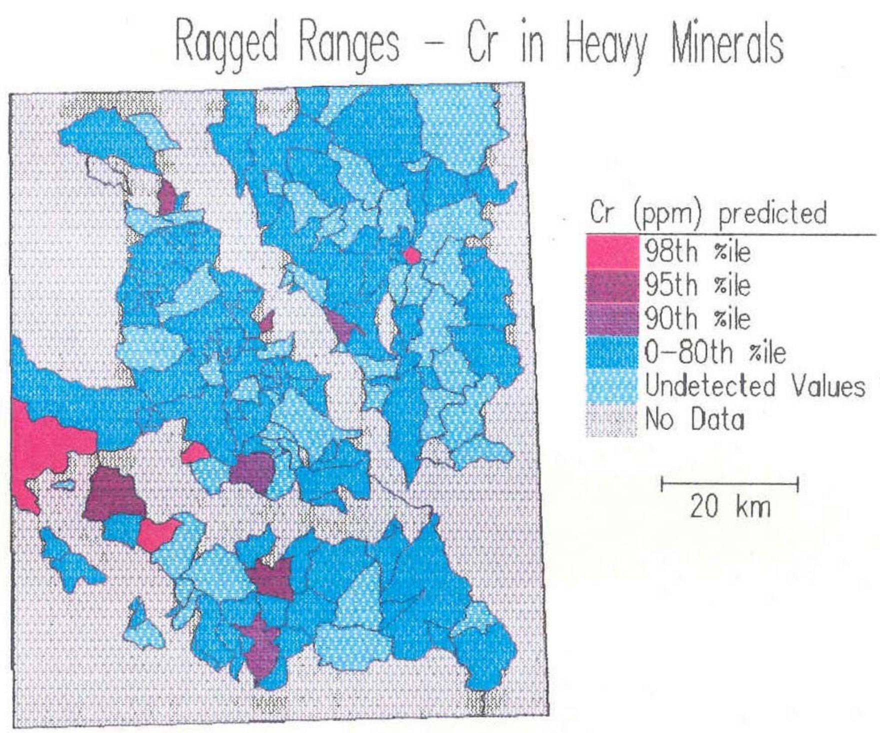

Figure 4.9b: Ragged Ranges, Cr in HMC using MLE – Predicted Data

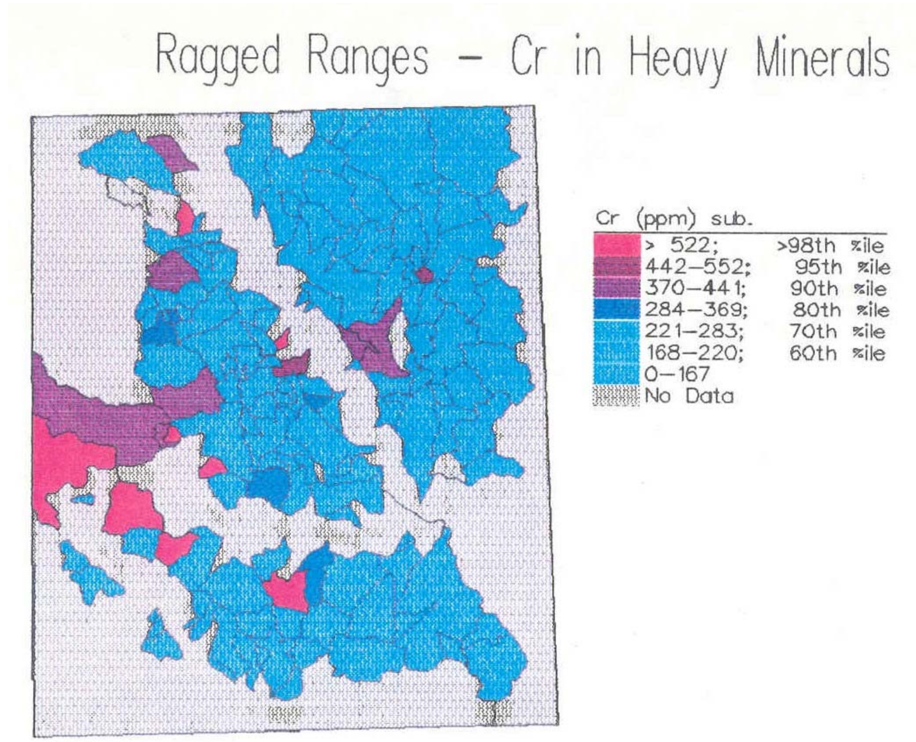

Figure 4.10a: Ragged Ranges, Cr in HMC using SUB – Raw Data

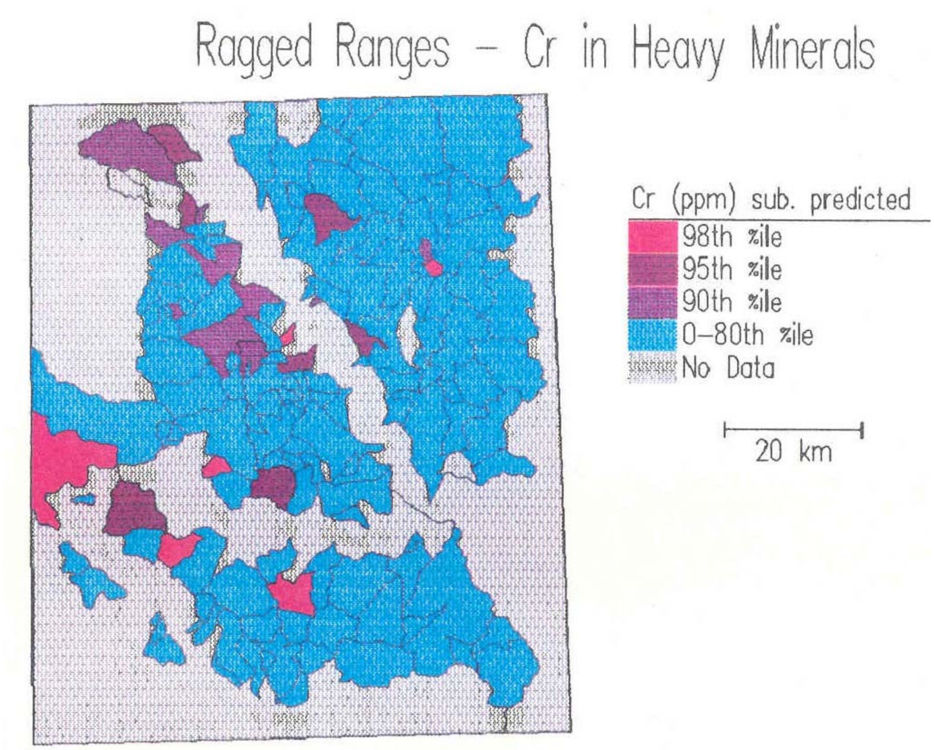

Figure 4.10b: Ragged Ranges, Cr in HMC using SUB – Predicted Data

4.3.8. Regression analysis

Sections 4.3.3.-4.3.7 illustrated how the ML technique is more discriminating and therefore improves upon the substitution method for statistical analysis and for plotting the geochemical data. The next step is to consider the possibility of further improvement by evaluating the effect of rock type on the geochemistry. To remove the masking or enhancing effect of bedrock on the chemistry, multiple regressions are performed.

To estimate the regression parameters for this study, two methods were used. The first was an extension of the ML technique which requires no substitution. As a comparison, ordinary least squares (OLS) regression was also performed for a few elements. This method minimizes the sum of the squares of the difference between an observation and its expected value. For OLS, the undetected data were substituted with 0.66 of their detection limits. Although the regression considers the effect of rock type on the chemistry, the data had to be changed before they could be used.

A linear first-order regression model was used to represent the concentration of geochemical elements in the stream sediment samples. The following is based on models used by other workers (e.g. Dahlberg, 1969; Rose et al, 1970; Bonham-Carter and Goodfellow, 1984 & 1986) and can be used to predict background values for each rock type (Section 4.5) and to identify possible geochemical anomalies in the stream sediment samples:

(1) $Y_i = ß_0 + \Sigma\, ß_j X_{ij} + \varepsilon_i$

where:

Y_i = observed value of a geochemical element at sample site i in catchment basin i

X_{ij} = area of rock type j (predictor) at sample site i in catchment basin i

$ß_j$ = coefficients of the predictor variable; $ß_0$ is a constant

ε_i = an error or residual term which measures the amount which any individual Y falls off the regression line

In this model the rock types underlying each catchment basin are considered the independent variable (X). The chemical composition of a sample taken at site i (Y) is the dependent (response) variable. The regression constant $ß_0$ and the regression parameters $ß_j$ (j = 1..m) are unknown, as is the error term ε which is difficult to determine because it changes for every value of Y. However, $ß_0$ and $ß_j$ are fixed and can be estimated by using a form of Equation (1):

(2) $\hat{y}_i = b_0 + \Sigma\, b_j X_{ij}$

where b_0 and b_j are the estimates of $ß_0$ and $ß_j$ respectively. Once these parameters are known, they can be used to determine $\hat{y}_i$.

For example, it is assumed that the stream waters draining catchment basin i are composed of a dissolved load and a clastic load whose chemical compositions reflect the areal proportions of rock j in catchment basin i (X_{ij}) and the mineralogical makeup of the underlying bedrock. To predict the concentration of a given geochemical element at a sample site i (corresponding to basin i), which is underlain by (potentially) several rock types whose areas are denoted by X_j (j = 1..m), the following prediction model, taken from Equation (2) above can be used:

(3) $\hat{y}_i = b_0 + \Sigma\, b_j X_{ij}$ i = 1..n

where:

$\hat{y}_i$ = the predicted value of a geochemical element at sample site i in catchment basin i.

X_{ij} = the areal percentage of rock type j at sample site i.

b_j = coefficients for each rock type j; to be estimated by the regression; b_0 is a constant.

n = the number of sample sites/catchment basins.

m = the number of rock types.

There is a set of regression coefficients for each geochemical element to be predicted. Each b_j can be considered the average element content for the corresponding rock unit j. The total contribution from rock unit j can be thought of as the product of the average element concentration and the area of rock unit j underlying catchment basin i (i.e. b_j*X_{ij}). An estimate of the total concentration $\hat{y}_i$ at site i can be thought of as the sum of all the b_j*X_{ij} for every rock type found in that catchment basin (Ellwood et al., 1985). This model assumes that the concentration at site i is the result of adding all the contributions from each rock type j underlying basin i. Equation (3), which predicts $\hat{y}_i$ can be solved by using the least squares method to minimize:

(4) $$\Sigma(Y_i - \hat{y}_i)^2 = \Sigma e^2$$

This quantity is known as the square of the sum of the residuals. A residual is the difference between the predicted value of an element at sample site i and the observed value at that site. Residuals can be positive or negative. Positive residuals (the observed value for an element is greater than the predicted value) may indicate geochemical anomalies because the element content is higher than expected. This is the result of removing the effect of high background which can enhance geochemical anomalies. However, the positive residuals could also be caused by other factors including pH, variable erosion rates and hydrologic factors (Bonham-Carter and Goodfellow, 1984) but at least they highlight areas of interest which may warrant further study. Negative residuals (observed value is less than predicted) may also be important because the absence of an element can be geologically significant.

Application to Nahanni stream sediment geochemical data - the regression analysis used the model in equation (1) but was not accomplished with a standard statistical package, except to compare the effect of substituting data on the regression. To perform regressions with censored data, another MLE program (Chung, 1990) was used. The geochemical data (in MLE form, described in Appendix 3.7) were merged with the areal proportions of each rock type under each basin, generated by SPANS (discussed in Section 4.4). The regression calculates the regression constant (b_0), regression coefficients for each rock type (b_j) and the standard deviation (s). The b_j values are the average amount of the element present in each rock type j underlying catchment basin i. These values are used in Equation (3) to calculate the predicted value of an element ($\hat{y}_i$) based upon the geochemical composition of the sample and areal proportion of geologic units present in the drainage basin from which the sample was taken.

After carrying out OLS regressions, Bonham-Carter and Goodfellow (1984, 1986) subtracted the calculated predicted value from the original observed value to produce a residual value which, if positive represented an area of interest because once the effect of bedrock was removed, the value was greater than expected. These residual values were converted to percentiles and then plotted and compared to the original map.

In the case of the Nahanni data it is not always possible to calculate these residuals because a considerable number of element values are variably censored (i.e. not really observed). Therefore, another way of representing the effect of removing the influence of bedrock had to be determined.

The regression coefficients were used to calculate the expected mean value (μ) of an element in each basin based on the areal percentage of each rock type underlying it. Using a form of Equation (3), the expected mean value (μ) of an element is defined by:

(5) $$E(X) = a_0 + a_1R_{i1} + ...+ a_9R_{i9} = \mu_x$$

where a_j are the coefficients of regression for rock type j (j=1..9) and R_{ij} is the percentage of rock j in basin i.

The mean (μ_x) value determined from (5) and the standard deviation calculated in the ML regression procedure were used to calculate percentiles (Equation (7) section 4.3.7 above) for each basin and each element. These new percentile values (for 98th, 95th, 90th, 80th) which were derived after the effect of bedrock has been removed were used to classify the original observed values. That is, the analytical value for each element in each basin was compared to the corresponding percentile values generated by the regression and then classified.

Extra classes were made for cases where the observation is undetected or no data exist, to preserve the character of the original data. Appendix 3.9 discusses the input and output from the regression program and the new classification for the observed (analytical) values.

The newly classified values were used to produce a new set of mineral potential maps, here labelled MLE-predicted and Sub-predicted. These maps differ from the raw data maps in that the effect of bedrock has been removed. Figure 4.5a and b of Au in HMC Ragged Ranges show the raw data and predicted data (effect of rock type removed by regression) respectively. The first thing to note about the predicted map is that there are no discrete values for the percentile breaks as there are in the raw data map. The reason is that the 98th critical value, for example, changes for each basin, based upon the areal percentage of underlying rock types so that no one critical value applies to all basins. The two basins along the Nahanni River in Figure 4.5a remain in the 98th percentile even after the effect of rock type has been removed, suggesting that the anomalies are not due to high background for that basin. In the same manner that residuals were used by Bonham-Carter and Goodfellow (1984, 1986), the new classification scheme can highlight areas of interest and subdue basins with high background due to rock type.

To evaluate the effect of substituting data before regression analysis, substitution and ML regression analyses were done for W, Au and Cr in HMC from Ragged Ranges. These elements were chosen because they are of interest and because they represent a range of data which are below detection limit.

In the case of the substitution regression for Au, W and Cr (Figure 4.6b, 4.8b and 4.10b respectively), the most noticeable fact is that there is no indication of how many basins have analytical values below the detection limit because the "less than" values have been substituted. However, although the data have been made complete by substitution, and residual values can be calculated in a manner similar to Bonham-Carter and Goodfellow (1984, 1986), the method of percentiles was applied instead. These substituted regression maps (sub. predicted on the legend) have a classification scheme similar to that described for the ML maps (no regression) in that each basin has its own background value so that there are no discrete values for percentile breaks on the legend. This facilitates comparison with the ML regression maps (Figure 4.5b, 4.7b, 4.9b). Even though the effect of rock type has been removed in both cases, the substituted regression maps show more basins falling in the 98th percentile category than do the ML regression maps. In the Cr maps (Figures 4.9b and 4.10b), the ML regression map (predicted on the legend) shows subdued Cr values along the South Nahanni River when compared with the substituted regression map. Some of these basins actually have undetected analytical values, so that substituting for these values changes the distribution of the data significantly enough that the mineral potential map is highlighting target zones that probably do not exist.

It has been shown that the ML technique is more effective whether or not regression analysis is applied. A comparison of raw data (without substitution) and predicted (based on ML regression) data indicates that the effect of rock type on the stream sediment geochemistry is an important factor to consider. Removing the effect of rock type further refines the model after the initial ML analysis is complete. Basins that still fall in the 98th percentile even after the effect of rock type has been removed, are considered important because the anomaly does not seem to be related to high background in the underlying bedrock. For example, Figures 4.5a and b, show Au in HMC for raw and predicted data respectively. Of three basins originally in the 98th percentile, two remain in that category after the regression, and one drops down to the 95th percentile. In the same manner that potential anomalies are enhanced, false anomalies are subdued. Two small basins in the 95th percentile category north of the Nahanni River, are subdued to the 0-80th percentile category after the regression. This suggests that the background value for gold is higher in these basins. The fact that a large number of basins contain gold analytical values below the detection limit is not a factor because these data remain in an "Undetected" class and do not affect the interpretations.

Another example of subduing a "false" anomaly is Hf in silts in the NK/TP region. Figure 4.11a shows a plot of the raw data (percentiles calculated using MLE). A target zone is highlighted in the Mattson Creek area, whereas the rest of the study region shows background Hf values. The predicted map (Figure 4.11b) shows the distribution of Hf after the effect of rock type has been removed and the Mattson Creek area is completely subdued. The Hf anomaly and other rare-earth abundances in Mattson Creek can be correlated with zircon-monazite concentrations normal for mature sandstones, the bedrock in the Mattson area. The Hf MLE-predicted map also shows that some basins in Wretched Creek have been upgraded to the 90th, 95th or 98th percentile category.

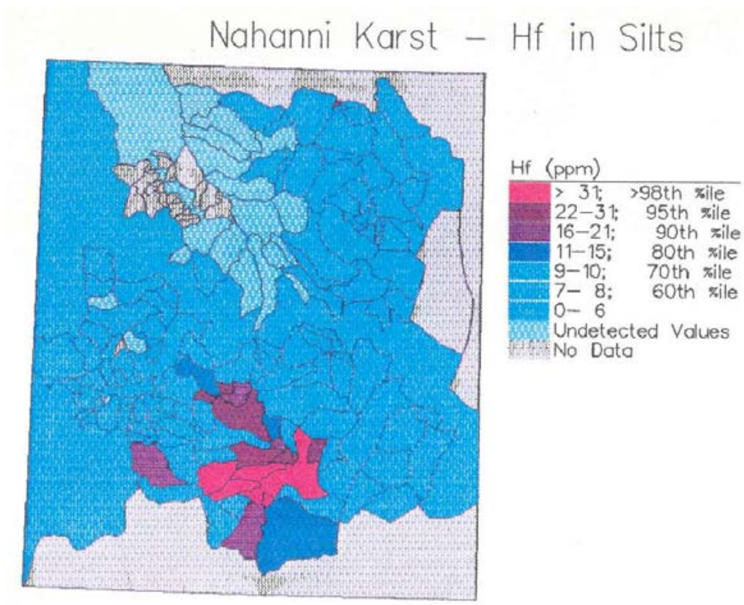

Figure 4.11a: Nahanni Karst, Hf in silt using MLE – Raw Data

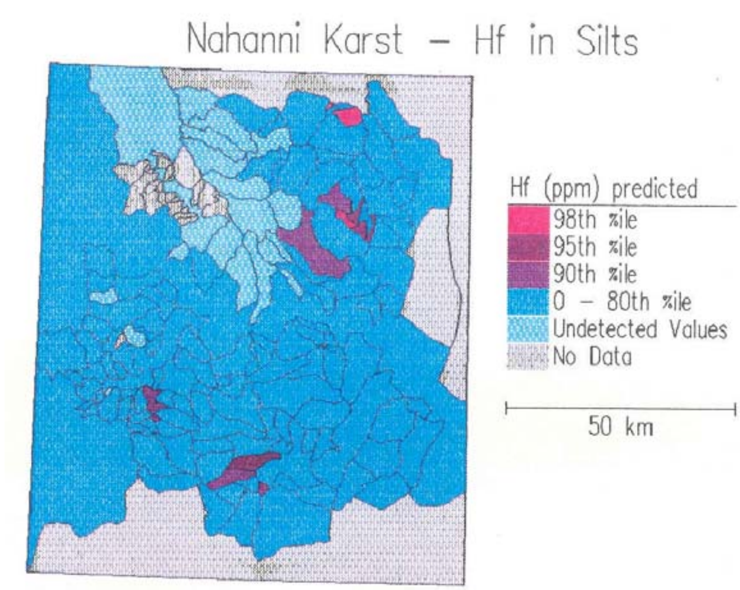

Figure 4.11b: Nahanni Karst, Hf in silt using MLE – Predicted Data

The significance of regression results depends upon the validity of the assumptions made: that the data are from a normal population and are related to the areal proportions of the bedrock underlying each basin. In addition, the regression has not removed the effect of glacial transport or other chemical and physical processes in the secondary environment. The effects of mineralization, if any, in the basin are also still contained in the residual.

In the case of the Ragged Ranges, it was assumed that the geochemical results are related to the seven rock types present in the area (1,2,3,4,5,8,9). In Nahanni Karst - Tlogotsho Plateau, six rock types (3,4,5,6,7,9) were assumed to affect the chemistry. When regressions were performed on the NK-TP heavy mineral data, the program overflowed. The iterations diverged instead of converging to a solution, suggesting that the model may be incorrect. Rock types were removed one at a time and in groups to determine the combination that explained that most variation. When all rock types but the Quaternary (Rock 9) were considered, the regression converged.

The above regression results are compatible with different styles of glaciation in the two areas. The NK-TP area was affected by continental glaciers, most recently by the Laurentide Ice Sheet during the Wisconsinan, and therefore has received material from many and distal sources. The geochemical analytical results are generally not statistically related to the glacial deposits suggesting that the geochemical anomalies are locally controlled, either by bedrock or structure. As will be discussed in Section 4.5.5., this may or may not mean bedrock sources for the anomalous elements. For example placer gold may be concentrated by fluvial reworking of relatively uniform glacial material in favourable topographic sites created by intersecting faults. In RR, the Quaternary element is more directly correlated to the trace element geochemical results. The Ragged Ranges has been glaciated by local alpine ice tongues that have been feeding locally derived material to the stream sediments. This explains why the surficial trace element geochemistry is related to both bedrock geology and surficial deposits.

Predicted background values for 100% of each rock type in each catchment basin are based on the underlying rock units which occur in varying proportions and combinations. The process of determining the expected elemental value for a basin based on its underlying rock types can be taken a step farther to calculate the predicted value for a basin underlain by 100% of any particular lithology. If it is assumed that average element concentrations within a rock unit do not vary regionally (although they most likely do to some degree) there are several ways to determine the background signature of each lithology. The first would be to sample each lithology enough times to obtain an adequate representation of the geochemical signature. The second would be to use the analytical data from the stream sediment samples and to average the element concentrations obtained from streams that drain a single lithology. The third method would be to use the data provided by the regression.

To determine background using the first method, more sampling would be required which is financially and logistically not feasible. The problem with the second method is that not enough samples draining a single lithology exist to carry out a proper statistical analysis. In this case, the third method is the most efficient because most of the work has already been done.

For RR, the regression took into account rock types 1,2,3,4,5,8, and 9. Using Equation (5), and assuming basin i is underlain by rock types 3, 4 and 9, the equation to predict the expected value for element x in basin i is:

$$(6) \qquad \mu_x = a_0 + a_3R_{i3} + a_4R_{i4} + a_9R_{i9}$$

Each basin i (e.g. i=1..138 for Ragged Ranges HMCs) has a similar equation to predict the concentration of each element based on the areal proportions of rock types underlying the basin. As will be seen in section 4.4.2, the regression program produces values for the regression coefficients a_j (j=1,2,3,4,5,8,9 for RR) and estimates the variance. This information can be used to calculate the expected value for 100% of a rock type. The basic equation is:

(7) $\hat{\mu}_x = a_0 + a_j R_j$

where: $\hat{\mu}_x$ = expected value of element x
$j = 1,2,3,4,5,8,9$ (rock types for RR)
R_j = area of rock $j = 1$

The area of rock j is always 1 (or 100%) because the element concentration is being predicted for each rock type separately. Basin numbers are irrelevant because the element concentration of a theoretical basin is being predicted. Therefore to predict the expected value of gold in a basin underlain by 100% of a rock type, the equations shown in Table 4.5 would be used:

Table 4.5. Equations Used to Calculate Predicted Values for 100% of a Particular Rock Type

Rock Type	Predicted Au
1	$a_0 + a_1(1)$
2	$a_0 + a_2(1)$
8	$a_0 + a_8(1)$

and so on for each rock type. The only parameter that changes each time is the regression parameter a_j.

Because the data were log-transformed, one single background value that can be applied to the original data could not be calculated. A single background value is not always useful anyway because there are numerous ways to calculate it (which is the "correct" way ?) and because regional and local background values can vary. For these reasons, several percentile values were generated and these reflect the expected values of the element over a range.

The predicted concentrations for elements based on data from heavy mineral concentrates and silts for RR and NK/TP are listed in Appendix 3.10. If the results for RR and NK/TP are compared, it is not expected that the predicted values for Au in heavy minerals for rock type 3, for example, would be the same. This is because the lithology divisions are very broad, being based on time and environment of formation. Therefore rock type 3 for RR is not exactly the same with respect to proportion or lithology as rock type 3 for NK/TP.

4.4. Spatial Analysis

4.4.1. Geographic Information Systems (GIS)

The link between remote sensing, ground truth and cartography has been made possible by Geographic Information Systems (GIS) (Burrough, 1987). The GIS provides a framework for integration and analysis of large data sets representing many different kinds of information.. It allows for collecting, storing, retrieving, transforming and displaying of spatial data. GIS can also handle the non-graphic (i.e. stored in a database) attributes of the information and the way these elements are linked together, as well as being able to relate objects to a geographic frame of reference. Computer graphics are an important part of a complete GIS, but because data in a GIS can be manipulated interactively, it is possible to produce a range of models to represent the concept being analyzed, an important part of the decision making process.

The GIS software package used for the Nahanni resource assessment is called SPANS (SPatial ANalysis System) and was developed by TYDAC Technologies in Ottawa (PCI Geomatics in Toronto currently owns the software). It is a geographic information system that is used for digitizing, storing, analyzing, integrating and displaying spatial data. SPANS uses a "quad-tree" or variable pixel size system for storing and processing images. This means that it can store large areas of a common theme as one pixel, so that not as much memory is required.

SPANS was chosen by the Geomathematics Section of the GSC because of its ability to accept user-defined modelling equations. This feature allows the geologist to generate equations to predict the likelihood of a mineral deposit based on the layers of information in the system: lithology, geochemistry, known mineral occurrences and structure, for example. SPANS weakness lies in how it produces output. At the time the maps in this report were produced, the output was based on a "screen-dump" which means that final images are produced at the resolution of the screen (1024x1280) on which they are displayed and could not take advantage of other file formats and higher resolution colour printers.

4.4.2. Catchment Basin Analysis

Within SPANS, the Ragged Ranges and Nahanni Karst/Tlogotsho Plateau (NK/TP) areas were treated separately because they are geographically and geologically distinct.

Ragged Ranges extension area is located between 61°15' N and 62°30' N latitude and between 126°55' W and 128°20' W longitude in NTS Zone 09. A 1:125,000 stable base of topography and drainage was used for digitizing. Sample locations were manually transferred to the stable base. Using the highest topographic contours around the stream, catchment basins for each sample site were drawn by hand onto an overlay registered to the stable base. Geologic units were digitized from another overlay registered to the original stable base. Catchment basins, geologic units, folds, faults, streams, sample locations, existing park boundary and study area boundary were digitized. A total of 145 basins from 1986 and 1987 were modelled using 13 elements for heavy mineral concentrates and 16 elements for silts. Later, the 1:50,000 catchment basins from the 1985 orientation project were added to the stable base if they fell within the study area.

Three catchment basin types were documented in Ragged Ranges study area:

1. High gradient, rugged drainage basins where boulder-size material is common and there is a paucity of silt to granule-size sediment (e.g. Brophy Creek).

2. Moderate gradient streams with well developed longitudinal and point bars from which heavy mineral samples are readily obtained (e.g. tributaries of Broken Skull River).

3. Broad U-shaped valleys flanked by thick accumulations of alluvium and till (e.g. Nahanni River, Flat River).

The NK/TP extension area is located between 60°51' N and 61°45' N latitude and between 123°15' W and 125°15' W longitude in NTS Zone 10. Catchment basins and geology were plotted on a 1:125,000 stable base with four reference points and digitized. Sample locations, streams, folds, faults, the existing park boundary and the study area boundary were also digitized (Fig 4.12). Extra attributes including the latitude/longitude of mineral showings and spring locations were appended to the chemistry file so that they could be displayed on the geology map. In Prairie Creek, basins sampled at 1:50,000 in 1985 were digitized and appear more clustered than the rest of the basins (Fig. 4.13). In all, 172 basins were modelled using 13 elements for heavy mineral concentrates and 16 elements for silts.

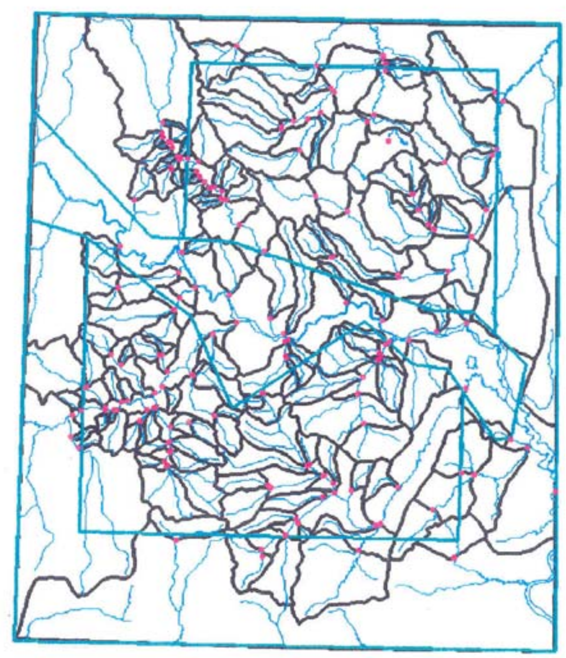

Figure 4.12: Digitized elements: streams, catchment basins, park boundary, study area and sample locations for Nahanni Karst/Tlogotsho Plateau.

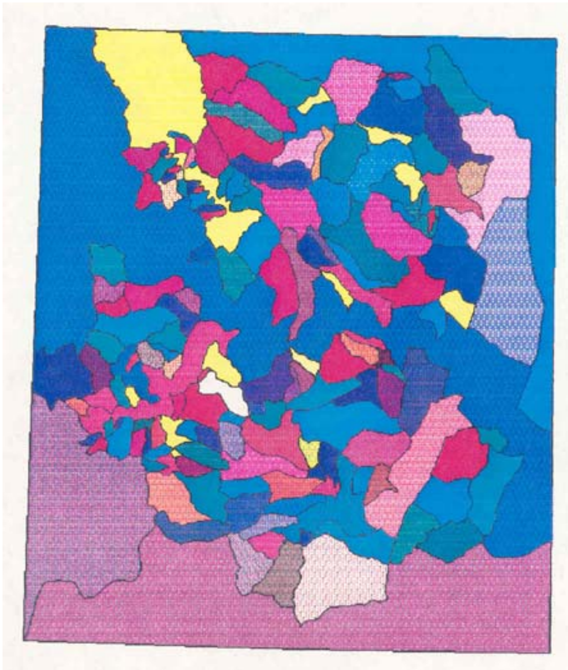

Figure 4.13: Catchment basin map for Nahanni Karst/Tlogotsho Plateau

Nahanni Karst and Tlogotsho Plateau study areas comprise four catchment basin types:

1. Low-gradient, meandering streams, where coarse material is non-existent and silt is abundant (e.g. Mattson Creek and Fishtrap Creek).

2. Broad U-shaped valleys flanked by thick accumulations of alluvium and till (e.g. Nahanni River and Jackfish River).

3. Braided streams that grade downward into meandering streams and dissect broad plateaux (e.g. Ram Creek and Clausen Creek).

4. Moderate- to low-gradient streams that cut through active karst terrain (e.g. Wretched Creek and tributaries to Sundog Creek).

The catchment basin map (Fig. 4.4, 4.13) is the most important map for representing the geochemistry at each sample site. The map is related to an attribute file or look-up table by assigning a unique number (i.e. from 1....145 in Ragged Ranges) to each basin. This unique number is also placed in the attribute file along with the field sample number and the geochemical attributes for each site.

The first step required to create the geochemical anomaly maps is to create a classification scheme in SPANS for each element according to the values generated using the MLE technique (described in section 4.3). In addition to the 98th, 95th, 90th, 80th, 70th and 60th percentiles, classes were also provided for samples with no data or with data below detection limit. The modelling module in SPANS was used to link together the catchment basin map, the attribute file containing the geochemical information and the dictionary files containing the classification scheme. For each element, and using the catchment basin polygon map as a base, SPANS colours each basin according to the class into which the element value falls to produce the geochemical anomaly maps. These maps do not take into account the effect of rock type on the chemistry.

4.4.3. Removing the Effect of Rock Type

The first step in removing the masking or enhancing effect of bedrock on the sample, involves a SPANS area analysis to determine the areal percentage of each rock type underlying each catchment basin. The catchment basin and geology maps are superimposed and SPANS calculates the areal percentage of each of the 9 rock types in each catchment basin. Before the areal values are used in the regression analysis, a single-map area analysis should be done on the geology map to check the area results for each rock type. If the results are the same as those from the two-map area analysis, the areas can be merged into the attribute table containing the chemistry for each sample. Multiple regression analysis (described in section 4.3.8) was used to estimate the local background for each element at every site based upon the areal proportions of each rock type underlying the basin. The regression technique estimates a mean value for a given element in every basin, which can be used to generate a background classification unique to each basin. The observed value for each basin is compared with the expected value produced by the regression analysis; that is, each basin is now classified on its own set of percentiles calculated from the basin's expected value. These new values are coded and used in SPANS to plot new geochemical anomaly maps that now take into account the effect of bedrock on chemistry.

4.5. Gold Results

4.5.1.HMCs from silt samples

The HMCs from silt samples confirmed gold anomalies which had been identified using gravel HMCs, and indicated 6 new highly anomalous placer gold localities: Jackfish River, Windy Creek in Liard Range, a small tributary to Nahanni River at the south end of Nahanni Karst, and 3 tributaries in Ram Plateau (See details in section 4.5.3). The INAA results are in Appendix 3.2 (Table A-3.2(vi)) but have not been analysed statistically or plotted here. Visual inspection also shows that zinc values from silt HMCs parallel those from sieved-gravel HMCs.

4.5.2. Placer gold from pebbly sand samples

The grains range in size from 100 µm to 800 µm. The number of grains from each location is shown in Table 4.6 and their distribution is outlined in Figure 4.14. This table compares anomalous gold analyses from coarse sand heavy mineral concentrates (HMC): physical weight of grains weighed by Perkins-Elmer ultramicrobalance vs. gold determined by neutron activation on pulverized sample after gold flakes removed. The calculated Au HMC (ppb) combines weights of gold flakes with the ppb of gold determined by neutron activation of the remaining HMC.

Table 4.6. Analyses of gold grains found in heavy mineral concentrates made from pebbly sands.

Sampl e#	Locality	Gross[1] Weight (g)	Weight of HMC (g)[2]	# Au Flakes[3]	Weight Au Flakes(m g)	INAA (ppb)[4]	Calc.[5] Au HMC(ppb)
RAGGED RANGES, SELWYN BASIN SHALES AND MESOZOIC INTRUSIONS							
6077	"Brophy Creek" (informal name)	5250	15.05	1 (3)	0.2062	<35	~13,700
7005A		8550	26.10	2	0.0403	616	~2,150
7005B				0		320	"
NAHANNI KARST - TLOGOTSHO PLATEAU, DEVONIAN SHALES ON CARBONATES							
6237	"Wretched Creek" (informal name)	9700	33.16	33	2.447	3260	~77,000
7066A		10575	34.45	17	1.4270	1070	~43,000
7066B				0		2350	"
7065A	Tributary to 6237	10400	20.10	2	0.0955	320	~5,000
7065B				0		<25	"
6246	Clausen Creek two tributaries	10900	48.22	2 (3)	0.0744	<5	~1,500
7070		9675	18.90	1	0.0284	<24	~1,500
6165A	Splits of Nahanni River Bulk Sample	23125	155.9	2	0.0226	<14	~145
6165B				0		<110	"
6165C				0		<97	"
6273	Yohin River at north end of Yohin Ridge	12050	22.14	1 (2)	0.3	<5	13,000
7078A		11900	18.95	1 (2)	0.5876	<20	~31,000
7078B				0		<21	"

[1] weight of rough-sieved heavy mineral concentrate bulk sample taken from sandy stream gravels.
[2] weight of heavy mineral concentrate (HMC) made from bulk sample on Deister concentrating table
[3] Number in ( ) is original number of gold grains recorded as taken from Deister table. Only the smaller numbers of grains were recorded as being weighed and used for calculations. Loss of gold flakes was observed during weighing of sample 6273 as one or more grains of gold flew off equipment because of

static charges. Other discrepancies are inferred to have a similar cause.
[4] determined by neutron activation on sample from which gold flakes had been removed.
[5] calculated ppb: [(ppb by INAA) + (10^6 weight of gold flakes (mg))] / weight of HMC (g).

The grains exhibit classic placer shapes and textures. The majority are equant, with smooth outlines appearing like flat flakes. The surfaces are commonly spongy or porous with some of the edges being folded over. The grains are pure Au with only traces of Ag. Figure 4.3a is a grain from Brophy Creek in Ragged Ranges which has been beaten and folded over during transport in the stream. Figure 4.3b is a typical grain from Wretched Creek showing a smooth edged, flat flake with a fairly porous surface.

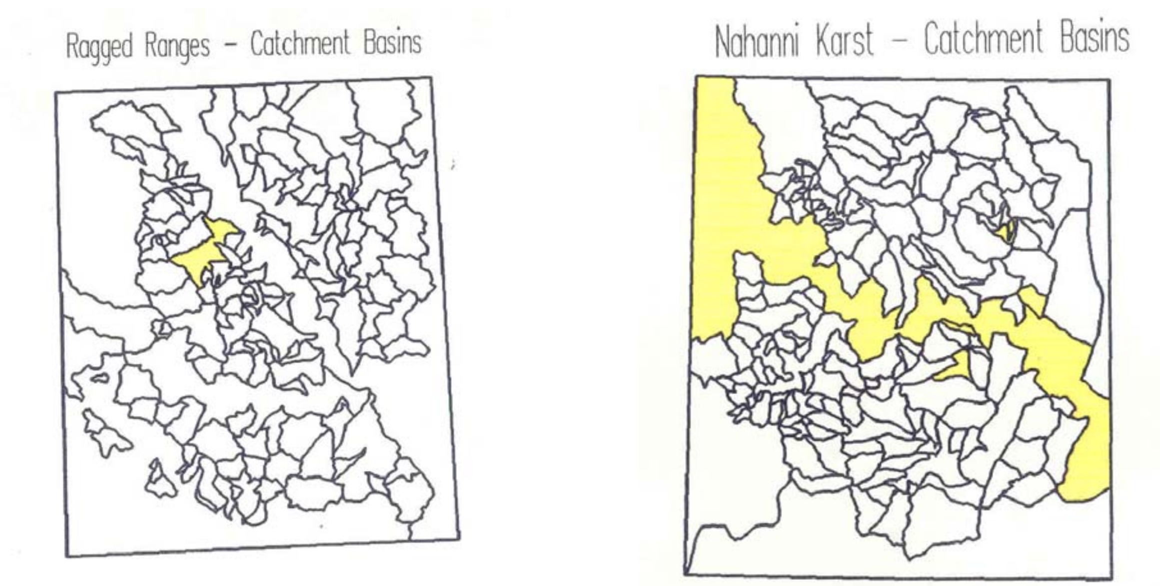

Figure 4.14: Location of Gold Flakes from HMCs in Ragged Ranges and Nahanni Karst

4.5.3. Placer Gold from Silts

As noted above the HMCs from silt samples confirmed gold anomalies which had been identified using gravel HMCs, and indicated 6 new highly anomalous placer gold localities: Jackfish River, Windy Creek in Liard Range, a small tributary to Nahanni River at the south end of Nahanni Karst, and 3 tributaries in Ram Plateau (Figure 4.15, Table 4.7). All but one of these new localities are aligned north-south on a trend that appears to be independent of the distribution of glacial deposits, although the action of terminal moraine processes cannot be discounted. Each locality coincides with an intersection of northerly and northwesterly trending faults.

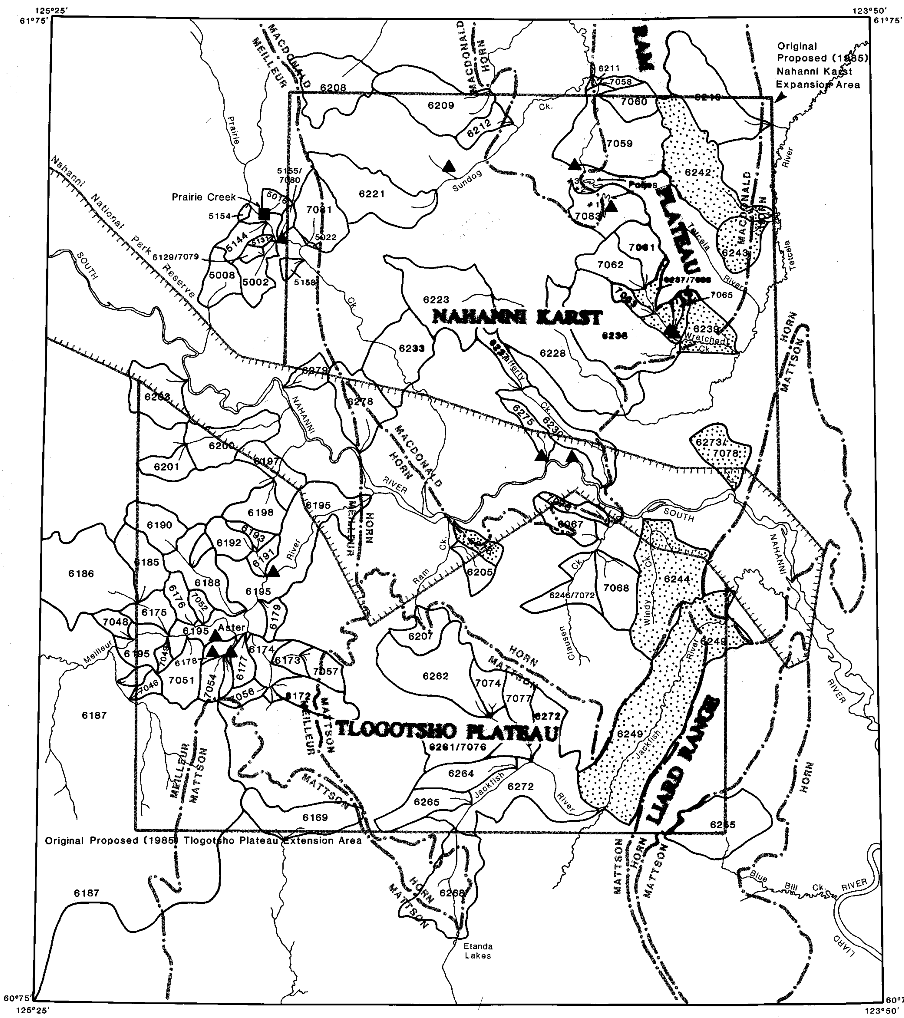

Figure 4.15. Locations of catchment basins (numbered polygons outlined by solid lines) which are anomalous in one or more elements in the eastern part of the South Nahanni River resource assessment region. Dotted polygons are those which yielded anomalous amounts of placer gold (Table 4.7) in heavy mineral concentrates made from stream sediment samples. Faint background lines and text outline the Nahanni National Park Reserve, earlier proposed park extensions, and various geological domains: HORN = Devonian and younger shales, MACDONALD = platformal carbonates, MATTSON = Mesozoic sandstones; MEILLEUR = Ordovician to Devonian shales of Selwyn Basin (domains are explained in Chapter 3)

Table 4.7. Comparison of gold from silt heavy mineral concentrates with gold from standard silt samples and from sieved-gravel HMCs, eastern Nahanni Karst (Ram Plateau) and northeastern Tlogotsho Plateau (northern Liard Range).

Location	Sample Number	Silt (g)	Silt HMC (g)	Au flakes		Silt HMC	Net ppb Au in 3 media		
				#	(mg)	Au (ppb)[1]	Silt-HMC[2]	Silt	Gravel-HMC[2]
Wretched #1	6237	2575	27.00	1	0.0409	360	1,875	<5	77,000
Wretched #2	6239	2100	20.75	2	0.0411	<5	1,981	<5	<5
Tetcela #1	6242	2000	14.25	7	0.4741	180	33,450	<5	22
Tetcela #2	6243	1800	24.05	6	0.0528*	<5	2,195*	<5	<11
Windy Creek	6244	2775	20.80	17	0.1641*	330	8,219*	<5	<5
Jackfish	6249	2100	27.95	11	0.1785	705	7,091	<5	7
N. Yohin R.	6273	2275	16.90	0	0.0	<5	<5	<5	31,000*
Ram Creek	6276	3300	13.35	3	0.3328	<5	24,929	<5	<5
Wretched	7065	2550	11.80	0	0.0	<16	<16	<5	4,750*
Wretched	7066	3025	11.25	0	0.0	N/A	N/A	<5	41,400*

* = minimum value, because one or more grains of gold were lost before weighing
Silt HMC = heavy mineral concentrate made on Deister concentrating table from silt.
Silt = 30 g split of whole standard silt from stream.
Gravel HMC = heavy mineral concentrate made on table from <850 um split of gravel.
[1] = determined by neutron activation sample from which gold flakes have been removed.
[2] = calculated: [ppb by NAA] + 10 [weight of gold flakes (mg) / weight of silt HMC (g)].

In Table 4.7, the net ppb Au in silt HMCs and sieved-gravel HMCs is a calculated value from Table 4.6 which combines weights of separated gold flakes with the ppbs of gold determined by neutron activation on the remaining HMC (method in Table 4.6). Gold in standard silt samples ("silt") was determined by neutron activation alone.

4.5.4 Heavy Mineral Point Counts

The methodology of HMC preparation and point counting are documented in Appendix 3.5.3. A total of 211 HMCs were prepared from the silt samples. With 26 standards and duplicates, the silt HMCs were analyzed by neutron activation for gold and 33 other elements. A total of 53 silt HMCs and 53 previous gravel HMCs were further concentrated using methylene iodide (3.3 s.g.), mounted and analyzed using a 30-class mineral point-counting program. Results of gold grain descriptions and mineral point counts of these 106 HMCs from representative streams, are provided in Appendix 3.2. INAA analyses of HMCs from gravelly sands are included in Appendix 3.3 for comparison. INAA analyses of HMCs from silts, made directly from the Wilfley Table as part of sample preparation for point counting, are not included in the appendices but are available in paper copy from the first author. As noted above, INAA results from stream silts corroborate those from gravelly sands, and here we note that HMC point counts are also compatible with the INAA results.

Similarly, point counts of duplicate HMCs of the same categories, as well as HMCs from silts compared to HMCs from gravelly sands taken from the same sites, are all compatible. The presence of relatively abundant heavy mineral categories in a given silt sample is generally paralleled by those mineral categories in the HMCs from gravelly sand at the same sample site, although the absolute amounts may differ by a factor of 2 or more. In the case of rare heavy minerals, where only one or a few grains were counted in a given category, that mineral type is commonly absent in the other sample type. In some cases the mineral type is present in the silt HMC but not the gravelly sand HMC; in other cases the converse is true. Statistical analysis was not attempted, just visual inspections. The following discussion thus treats the total results without regard to sample type, but focuses more on the spatial distribution of heavy mineral types gleaned from the combined results of all analyses.

Table 4.8 lists samples that were the focus of comparison; Fig. A-3.2(i) in Appendix 3.2 illustrates typical heavy mineral suites as various localities. Streams draining Ragged Ranges have heavy mineral assemblages that reflect the local rock types, with a predominance of barite, goethite and pyrite coming from metalliferous basinal shales of Road River Group and overlying Earn Group. Anomalies of barium, lead, zinc, silver, vanadium correspond to these heavy minerals. Goethite and other minor iron oxide minerals tend to adsorb elements such as zinc and silver, thus enhancing their geochemical signature as determined by AA and INAA analyses.

Table 4.8. Samples for which HMCs and INAA analyses from bulk silts vs sand & gravel were compared. A histogram comparing point counts from selected streams (H) is shown in Appendix 3.2. (Fig. A-3.2(i)).

Sample[1]	Description	H
6176	Meilleur R. background	Y
6179	Meilleur R. anom As, Ba, Ce, Co, Cr, Cu, (Mo, Pb), Sb, Zn	
6216	not anomalous E. Nahanni Karst (northernmost)	
6236	not anomalous Tetcela R	
6237/7066	Au in silt & gravel Wretched Creek (6248 on graph)	Y
6238	no Au in silt or gravel trib entering Wretched	
6239	Au in silt not gravel E. Nah Karst (Wretched Ck)	
6242	Au in silt not gravel E. Nah Karst	
6243	Au in silt not gravel E. Nah Karst	
6244	Au in silt not gravel Windy Creek	
6249	Au in silt not gravel Jackfish River	
6261 / 7076	Jackfish R. Trib minor Au in gravel	Y
6273 / 7078	Au in gravel not silt N Yohin Ridge	Y
7004	Brophy Creek, Tributary from Mount Sir James O'Brien, anomalous in Pb, Zn, etc	
7005	Brophy Creek, Au in gravels	Y
7006	Flat River Trib anom Zn etc. (6050)	Y
7021	Flat R. Trib background	
7025	Flat R. Tributary anomalous in gravel but not silt, in W, Ba, etc	
7051	Meilleur River anomalous Mo, Ni, W	Y
7052	Meilleur River anomalous As, Ba, Ce, (Co), (Cr), Cu, Mo, Ni, Sb, Th, Zn	
7061	Upper Wretched Ck no fine Au	Y
7070	Au in gravel not silt trib to Clausen Creek	Y
7079 or 5002 / 5B07	High Au Prairie Creek	Y
6113	tributary draining Mawer anom Zn, Pb etc	

Streams draining the eastern area have heavy mineral suites that still contain elements of the local rock types, but are dominated by garnet, and zircon, with minor but common amphiboles, rutile, monazite and ilmenite. These minerals are characteristic of Canadian shield provenance and corroborate the glacial history set out by Ford (1976) and Duk-Rodkin and Lemmen (1992) of a strong Laurentide influence on the eastern Nahanni River area. In addition however, the high zircon and elevated monazite content of the Jackfish River sample may reflect detrital minerals being recycled from the Mattson Formation. The zircon and monazite would account for the high Rare Earth Element signatures of geochemical analyses of stream sediment samples from this area.

Minor almandine-pyrope garnets (but not kimberlitic pyropes) and rare chrome diopsides were noted in streams from the eastern areas, commensurate with the shield derivation of these reworked stream gravels from glacial tills. These were not analysed by microprobe. The heavy mineral suite lacks other indicator minerals (such as those found by Fipke et al, 1995) farther north along the mountain front, nevertheless it is possible that, with large samples and abundant more thorough analyses, more of the kimberlite suite might be found. This would not however indicate diamonds in the Nahanni region, but would simply further reflect the shield provenance of the tills and alluvium reworked from there.

4.5.5. Sources of Gold

Jefferson and Paré (1991) observed that the most anomalous of the new-found placer gold localities are located on the eastern sides of the Nahanni Karst and Tlogotsho Plateau study areas, forming a sporadic north-south trend that appears to be independent of the distribution of Quaternary glacial deposits. From south to north these are on Jackfish River (6249), Windy Creek (6244), and western tributaries to Tetcela River (6239, 6737/7066, 7065, 6243 and 6242). For example, sample 6238 (non-auriferous) from a tributary entering Wretched Creek very close to sample 6237 (highly auriferous), and other streams such as the Tetcela River and Sample 6216 along the same belt have yielded no gold despite having very similar rock fragment and heavy mineral compositions (see Appendix 3.2., Table A-3.2(iii)).

A series of samples taken from tributaries entering Nahanni River also yielded one to three colours which were reproduced by resampling. Many of these are thought to be contributed by the Nahanni River system and are of uncertain significance, except for basin 7070 (a tributary of Clausen Creek not influenced by the Nahanni) and 6273/7078 (may be part of the north-south-aligned anomalies) The maximum abundance of gold in any of the north-south aligned anomalous occurrences is about one tenth of grades in the Selena Creek property that is located in Ragged Ranges to the west (see description of the Selena Creek property in Chapter 6).

Each highly auriferous locality in the Wretched Creek trend coincides with an intersection of northerly and northwesterly trending minor faults or fractures. It was first thought likely that the fine gold is thus related to a bedrock lode gold source, such as the carbonate hosted Carlin deposit type (e.g. Knutsen et al. 1991). A Carlin-like source has been suggested for the gold at Selena Creek in Ragged Ranges (Richards, 1989; Rowan, 1989), which has other attributes more favourable for the Carlin association, such as nearby granitoid intrusions and a variety of associated elements like silver, arsenic, mercury, tin and copper. Silt samples from the same sites as the Wretched Creek type of gold occurrences have none of the Selena Creek accessory element anomalies, nor zinc, molybdenum or tellurium that are typical of lode gold deposits that are part of an epithermal or mesothermal lode source which could conceivably be found in Devonian carbonates (i.e. carbonate replacement (manto) deposits or sediment-hosted micron gold deposits as summarized by Poulsen et al., 1999). There is no evidence of proximal intrusions or alteration that might be related to such an intrusion in Nahanni Karst or Tlogotsho Plateau.

A second hypothesis is that the gold was locally derived from tetrahedrite-bearing sulphide veins such as at Tetrahedrite Creek in Yukon (Grapes and Hajek, 1982), at Prairie Creek (see description of Prairie Creek in Chapter 6) and at Nahanni Butte (Showing AC SE2 in 95G/3, Appendix 1). Fault-control of the putative lode gold sources is suggested by the coincidental spatial association of major linear features trending 145º directly through or close to each of the placer gold occurrences. Some have been mapped as faults, for example those along Wretched Creek and that cutting across Jackfish River, thence along a tributary to Windy Creek. Other valleys in the Ram Plateau area of Nahanni Karst are also clearly linear. Morrow (pers. comm., 1989) and Cook (1977) have presented evidence for Devonian movement on faults of this orientation in other parts of the study area, and several were clearly reactivated during the Laramide deformation that created Mackenzie Mountains. Some of these faults may still be active (Wetmiller et al., 1988). Again however, the lack of accessory trace elements discounts this as a significant source of gold.

A third and most likely hypothesis is that the provenance of this placer gold is distant – for example from lode gold occurrences in the Archean Slave Province in the vicinity of Yellowknife. This hypothesis is supported by the monomineralic (gold only) and far-travelled appearance of the gold flakes, and from the known glacial flow directions of the Laurentide ice sheet (Rutter, 1981, 1984). As noted in Section 3.1.9. (Quaternary), garnets and granite pebbles in the host stream gravels are of Canadian Shield parentage. Even if a nearby lode source provided the gold, its refolded flaked shapes, and multiple scratches (e.g. Fig 4.3a) clearly indicate extensive transport and placer processes (multiple pounding and abrasion) in gold concentration. No crystal shapes are preserved so that there is no direct evidence of whether the gold was physically or chemically transported to the stream environment.

The distal placer hypothesis is analogous to one of the greatest mineral discovery stories in Canadian exploration history. The recently discovered diamond indicator minerals at Blackwater Lake (some 300 km north of Nahanni Butte on the east side of Mackenzie River) are located in glacial tills at about the same position along the mountain front, but farther north. Those indicator minerals were traced eastward by Chuck Fipke and Stu Blusson to discover the Ekati diamond mine in the Slave Province (Fipke et al., 1995). This hypothesis does not indicate high gold potential in the Nahanni Karst and Tlogotsho Plateau areas, except as a possible source of entertainment for tourists. The sporadic distribution of the gold anomalies can be explained by local sorting and winnowing of the glacial deposits in hydraulically favourable sites to produce the anomalous accumulations of fine placer native gold.

4.6 Discussion of surficial geochemistry results

Catchment basin maps were produced for 16 silt elements and 13 HMC elements in both study areas, making the number of mineral potential maps approximately 60. To summarize this information, anomalous elements for each basin were compiled and grouped to represent various deposit types (Eckstrand, 1984; updated by Eckstrand et al., 1995) and are shown in Table 4.9:

Table 4.9: Element Associations and Inferred Deposit Types

Inferred Deposit Type	Associated Elements	Notes
Precious metal rich base-metal skarn	As-Au-Ce-Co-Cr-Cu-Hf	Ce-Hf-Th are granite related
Skarn W	Mo-Ni-Pb-Sb-Th-W-Zn	also associated with As-Au-Ce-Co-Cr-Cu-Hf
Sedex Zn-Pb-Ag or Ni-Zn	Ba-Cd-Cr-Cu-Mo-Ni-Pb V-Sb-Zn	Mo-Ni-Zn: sub-type represented by the Nick deposit type (Hulbert et al., 1990)
Precious metal vein	As-Au-Cu-Sb	may be related to skarn/replacement or porphyry systems
Granite / sandstone	Ce-Hf-Th	HMC dominated by zircon and monazite from granites in Ragged Ranges, sandstone in Tlogotsho Plateau
Sandstone copper	Co-Cu-Mo	Tlogotsho Plateau only

High potential for a deposit is inferred if three or more elements are anomalous in the basin and mineral occurrences are present in the area. Basins anomalous in three or more elements indicative of a deposit type are considered to have moderate to high potential for that deposit. Moderate to low potential is inferred for basins anomalous in two or less of the elements associated with a deposit type.

Sandstones and granitic plutons contribute high proportions of zircon and monazite (mature heavy mineral assemblage) which contain the rare earth elements Ce-Hf-Th. These elements therefore do not in themselves indicate prospective terrain, except in Ragged Ranges where they may be associated with rare-element pegmatites such as the CALI/Little Nahanni Pegmtite or O'Grady pegmatites in Ragged Ranges. In these instances, there are valuable mineral species such as tourmaline, spodumene and gem elbaite suitable for specimen collecting (see Resource Assessment chapter).

4.6.1. Mineral Potential from Geochemistry - Ragged Ranges

The stream sediment survey indicates mineral potential in much of the Ragged Ranges study area. Approximately 80% of the basins are anomalous in at least one element association. The Flat River valley, where the Cantung deposit is located has high potential for skarn tungsten deposits (Figs. 4.16b aus, 4.17b ash, 4.18b cus, 4.19b moh, 4.20b nih; Note: for all figures in this chapter, only "b" will be referred to because it is the MLE-predicted regression map. The raw data for each element are shown in "a" for comparison only; each figure listed is followed by a short-form representing the element and medium shown in that figure; i.e. aus for gold in silt). The following elements are most likely related to the skarn process: Au-As-Co-Cr-Cu-Mo-Ni-Pb-Sb-W-Zn. Pb and Zn may also be derived from a sedex deposit predating the skarn. Ce (Fig. 4.21b ceh) is granite related. As-Au-Co-Sb are anomalous around Vampire Peaks, Mount Appler, Mount Sir James MacBrien, SW of Hole-in-the-Wall Creek, near Dolf Mountain and near the Mawer showing as well as in known skarn areas. Plutons throughout the rest of the area have low mineral potential but moderate-to-high potential for tungsten (Fig. 4.22b ws) and moderate potential for silver-copper-lead-zinc skarns is indicated for areas surrounding the plutons.

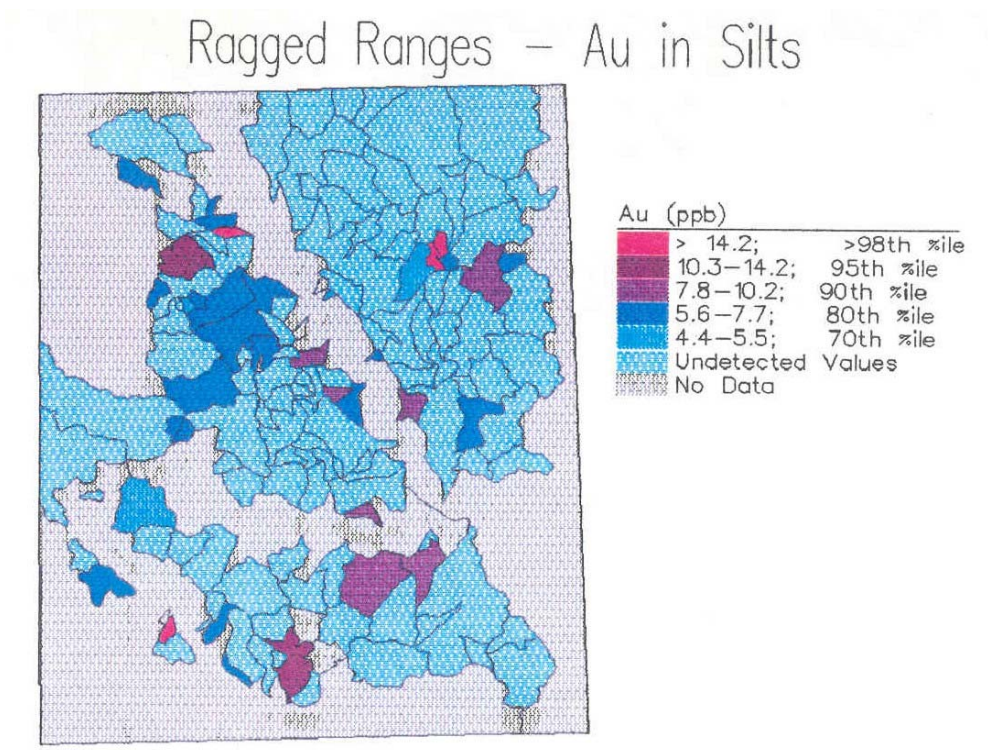

Figure 4.16a: Ragged Ranges, Au in silt using MLE – Raw Data

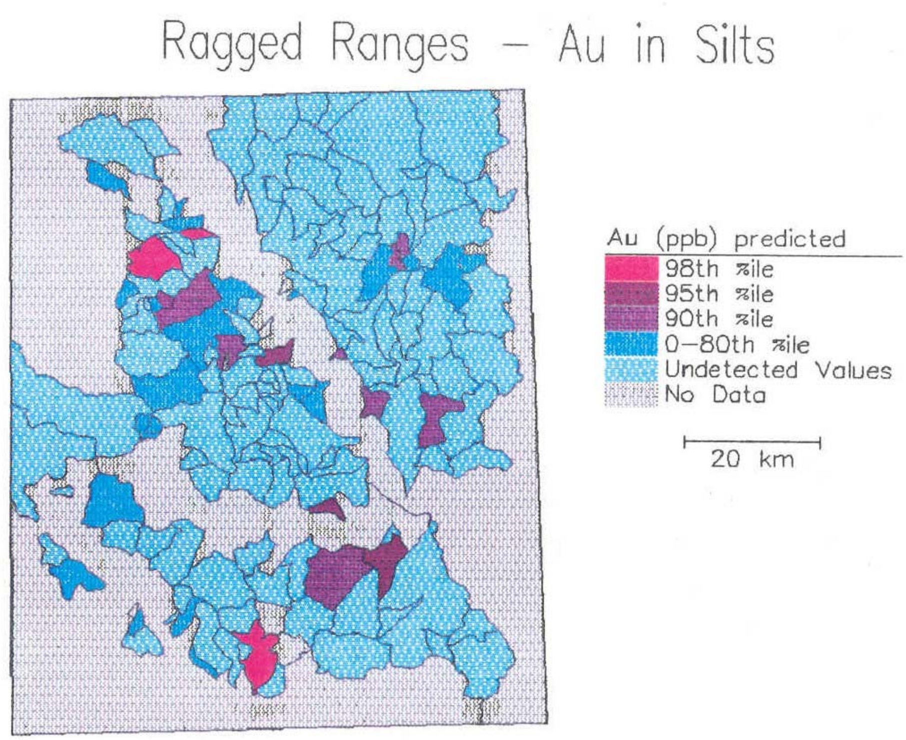

Figure 4.16b: Ragged Ranges, Au in silt using MLE – Predicted Data

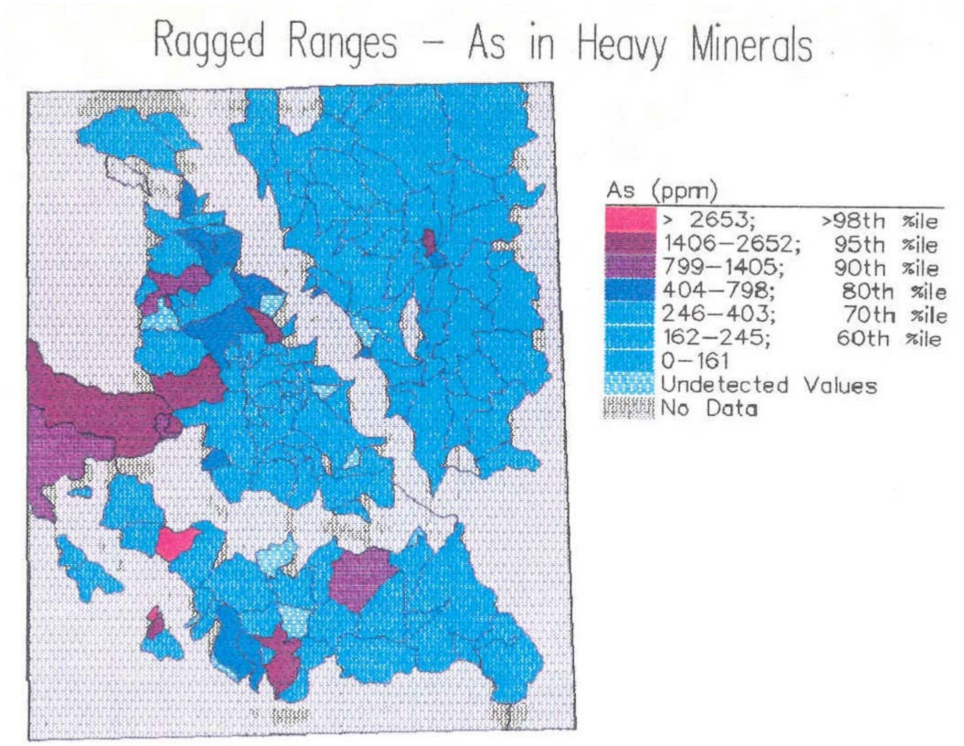

Figure 4.17a: Ragged Ranges, As in HMC using MLE – Raw Data

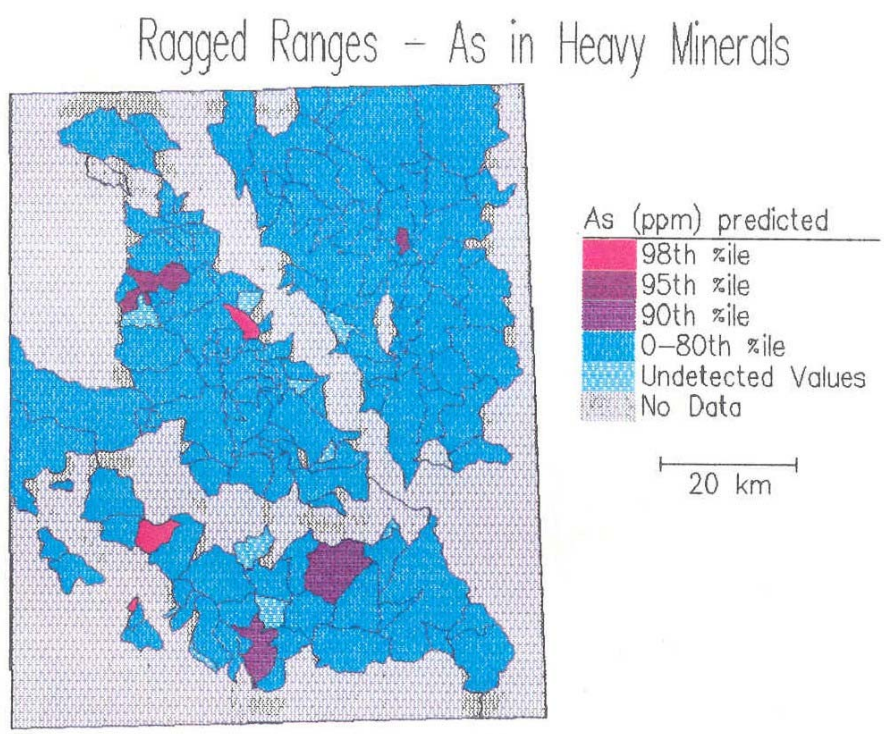

Figure 4.17b: Ragged Ranges, As in HMC using MLE – Predicted Data

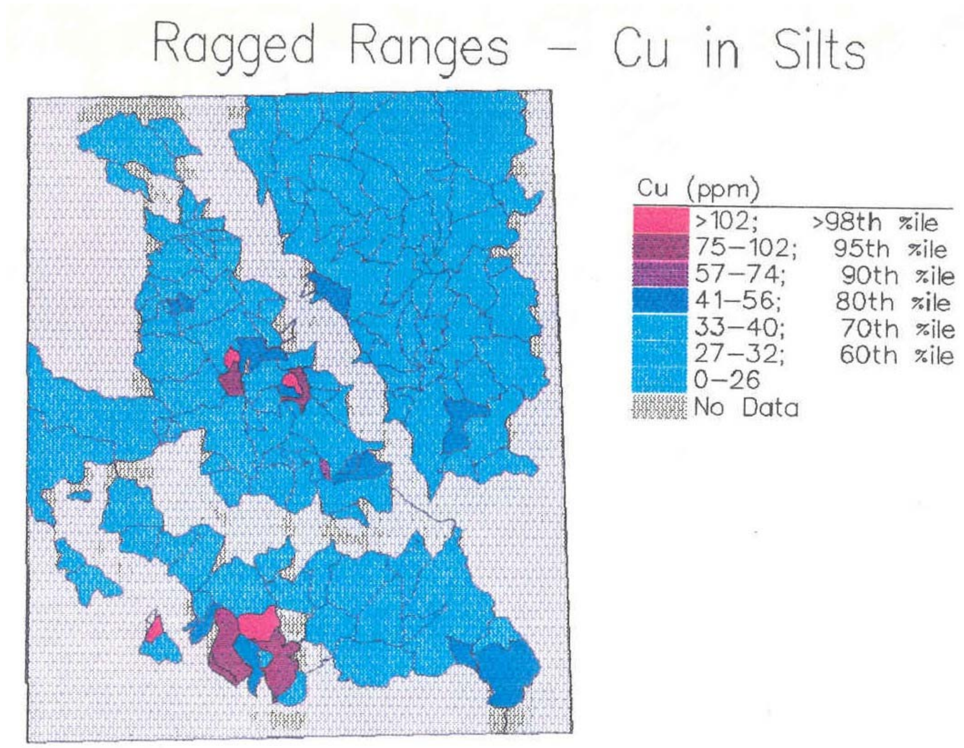

Figure 4.18a: Ragged Ranges, Cu in silt using MLE – Raw Data

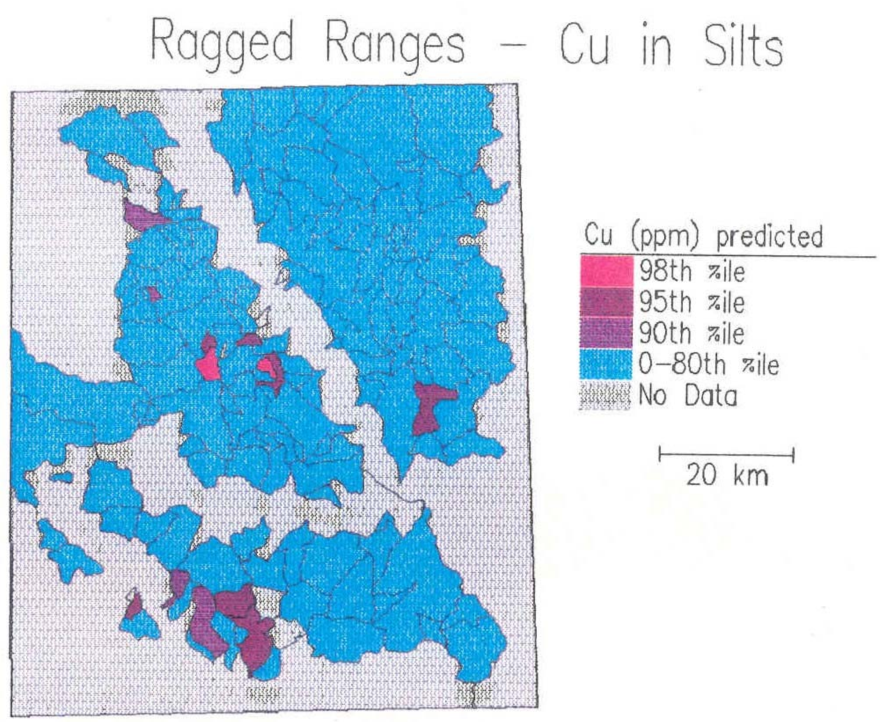

Figure 4.18b: Ragged Ranges, Cu in silt using MLE – Predicted Data

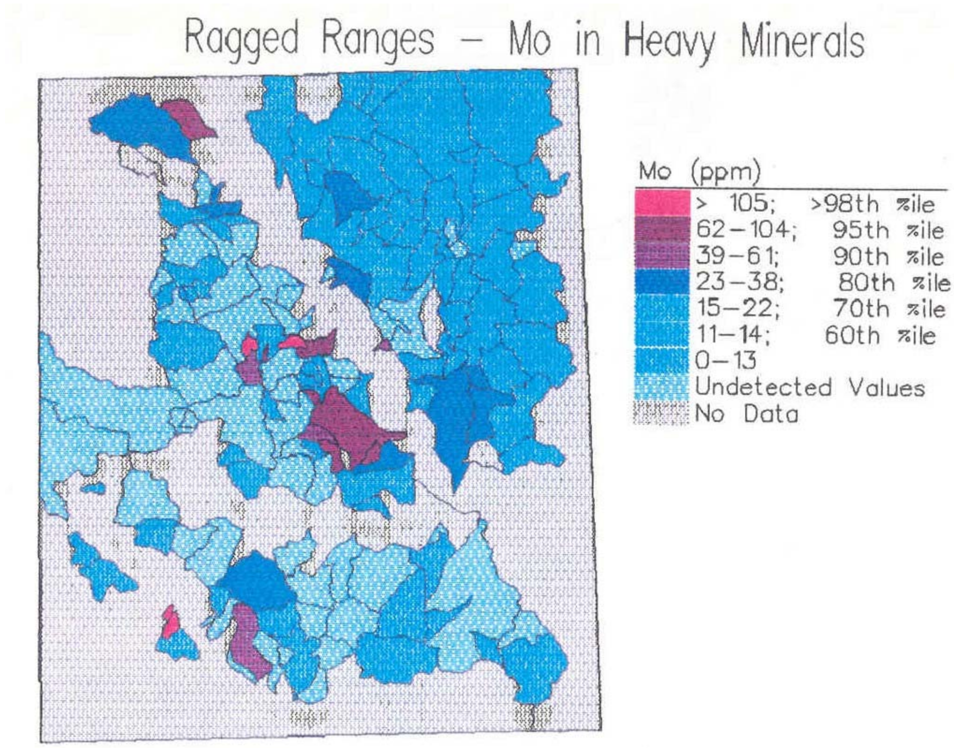

Figure 4.19a: Ragged Ranges, Mo in HMC using MLE – Raw Data

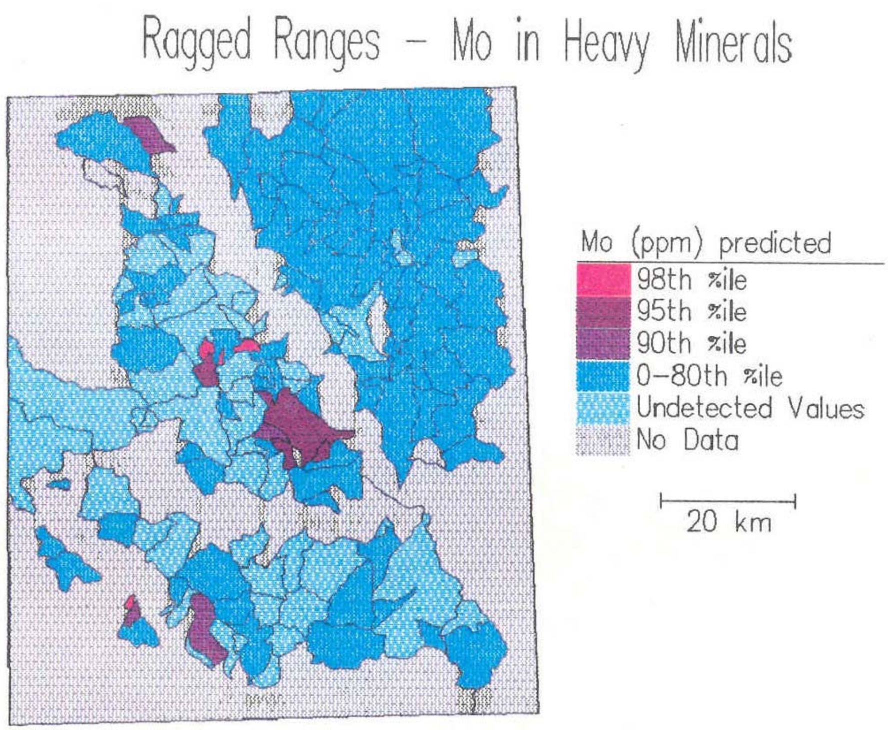

Figure 4.19b: Ragged Ranges, Mo in HMC using MLE – Predicted Data

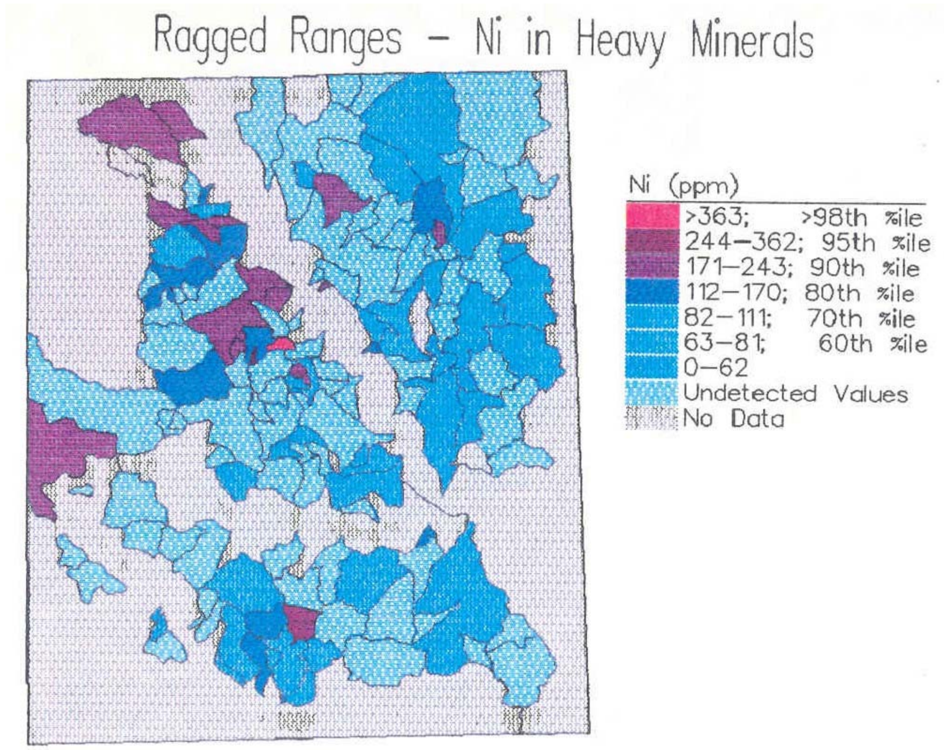

Figure 4.20a: Ragged Ranges, Ni in HMC using MLE – Raw Data

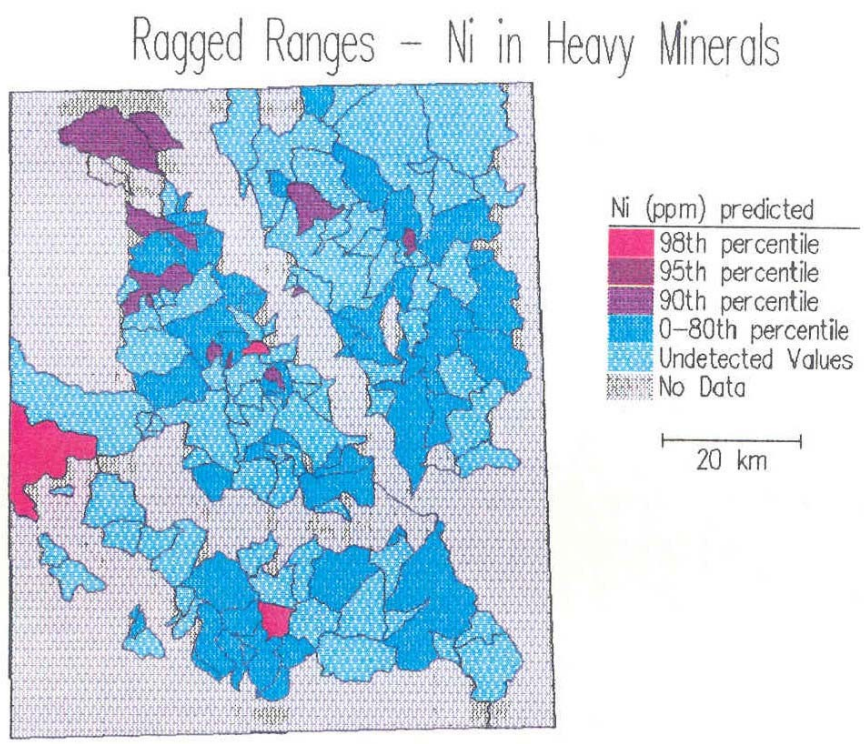

Figure 4.20b: Ragged Ranges, Ni in HMC using MLE – Predicted Data

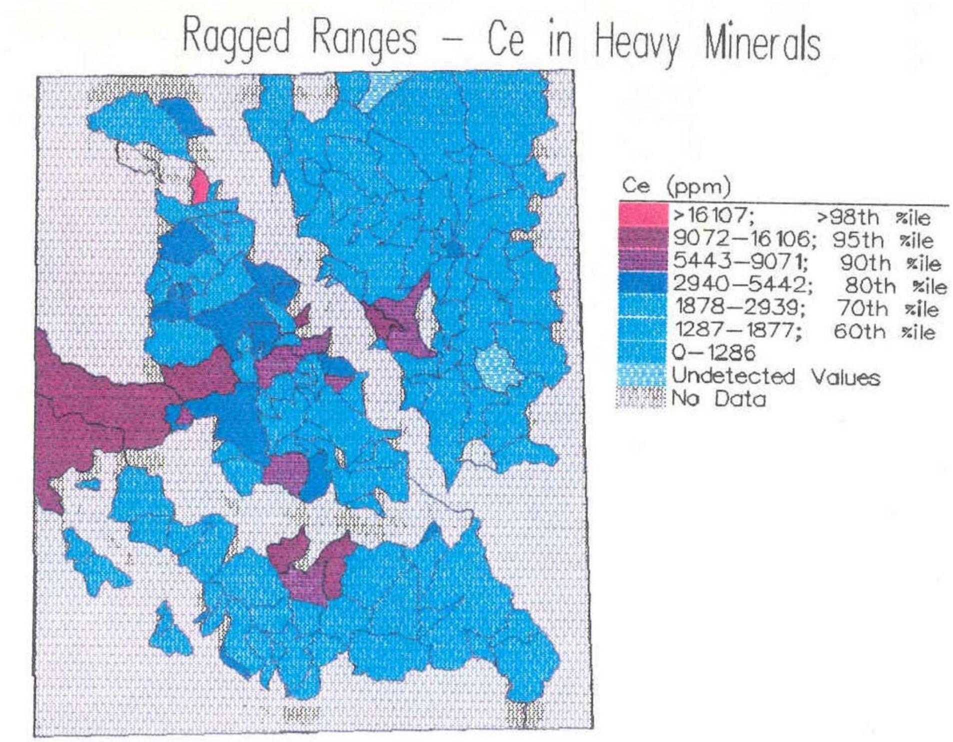

Figure 4.21a: Ragged Ranges, Ce in HMC using MLE – Raw Data

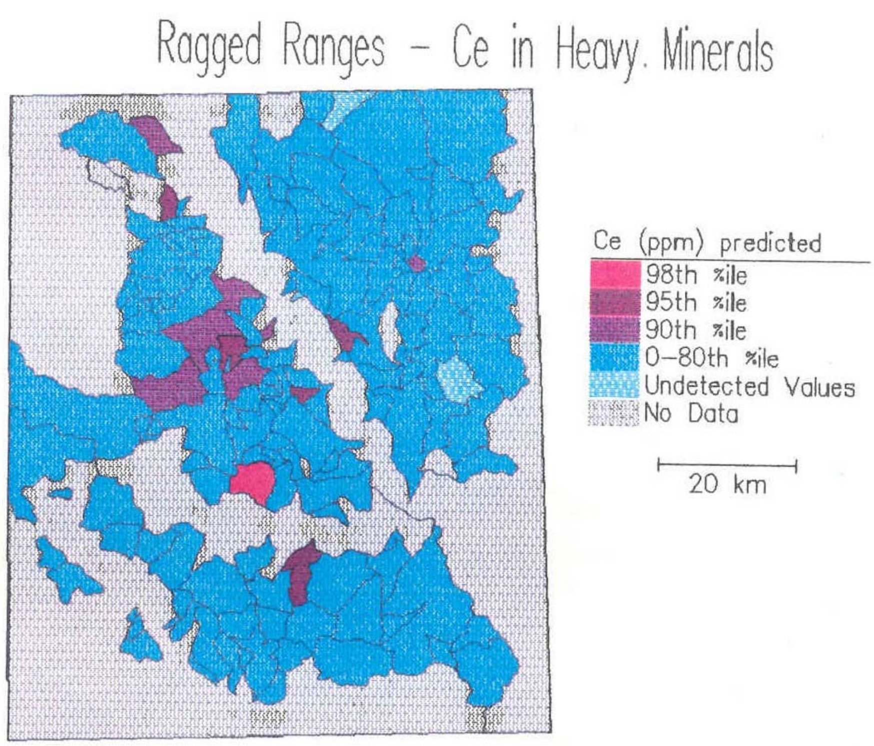

Figure 4.21b: Ragged Ranges, Ce in HMC using MLE – Predicted Data

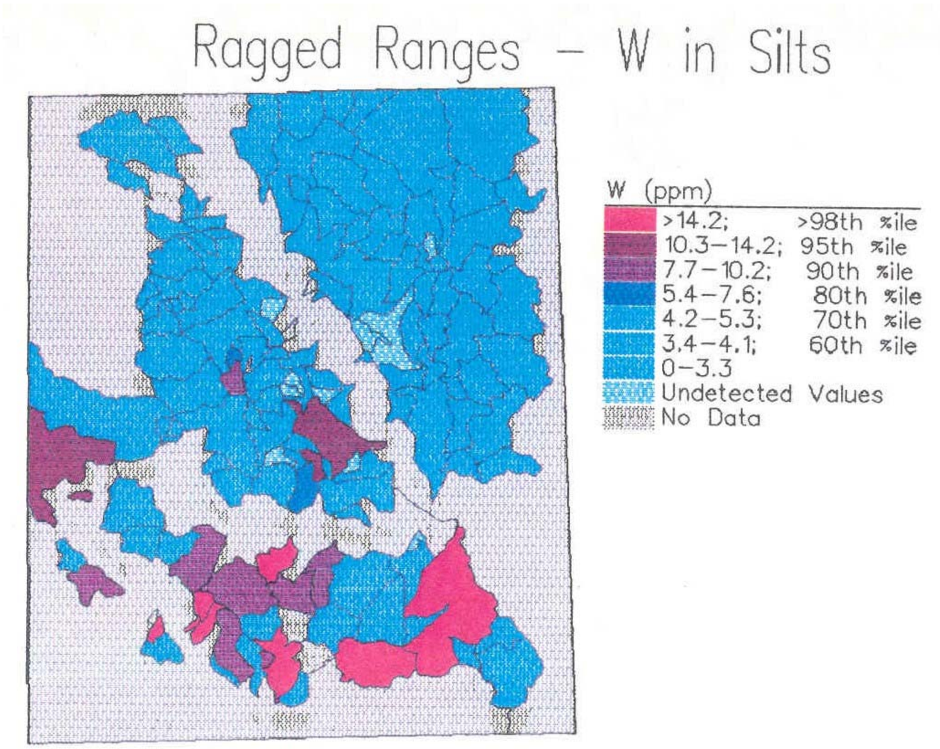

Figure 4.22a: Ragged Ranges, W in silt using MLE – Raw Data

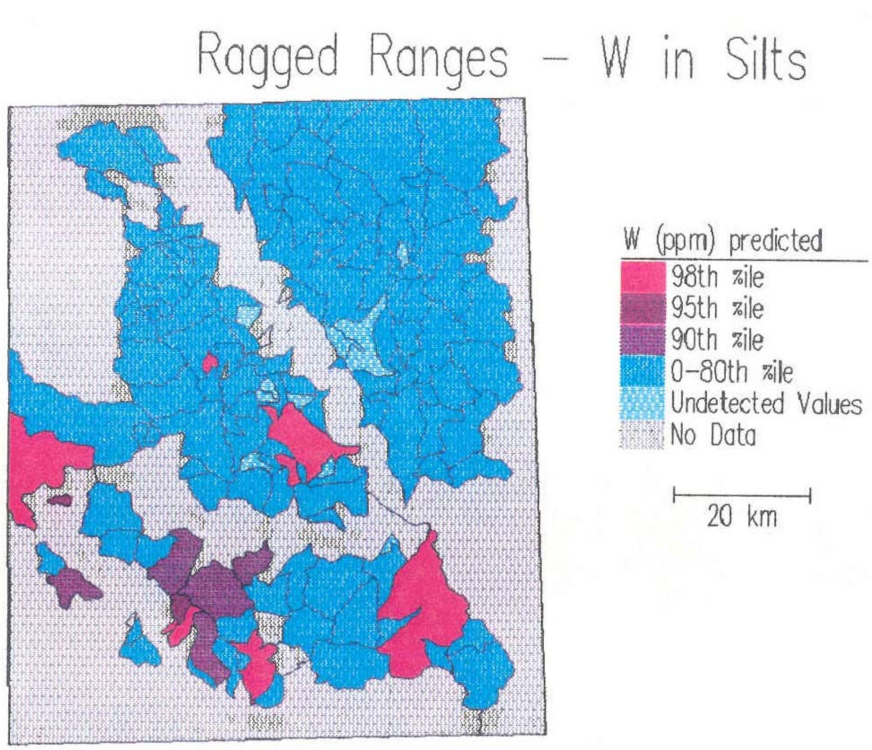

Figure 4.22b: Ragged Ranges, W in silt using MLE – Predicted Data

Mineral occurrences and stream geochemistry (Ba-Cd-Cr-Cu-Mo-Ni-Pb-Sb-Zn) indicate moderate to high potential for stratabound zinc-lead deposits north of the Nahanni River (Figs. 4.23cds, 4.24b nis, 4.25b pbs,4.26b zns, 4.27b znh). Almost all of the elements are anomalous in the creek draining the Mawer showing. This zinc-lead showing is found in the carbonate rocks of the Sunblood Formation, associated with dolomite, characteristic of the Mississippi Valley (MVT) deposit type (Sangster 1995). The Ni-Mo association with zinc is similar to the sedex sub-type recently recognized in the Yukon at the Nick deposit (Hulbert et al., 1990).

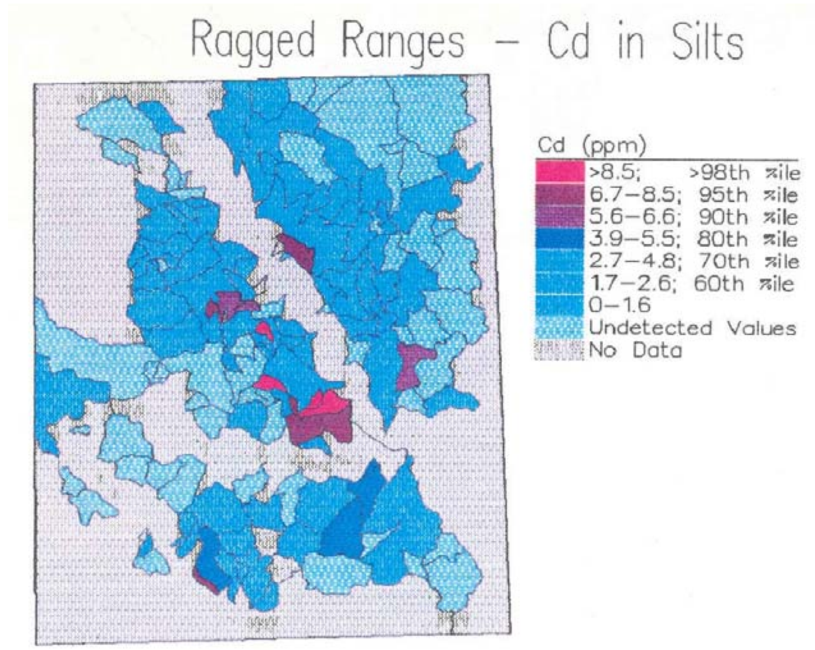

Figure 4.23a: Ragged Ranges, Cd in silt using MLE – Raw Data

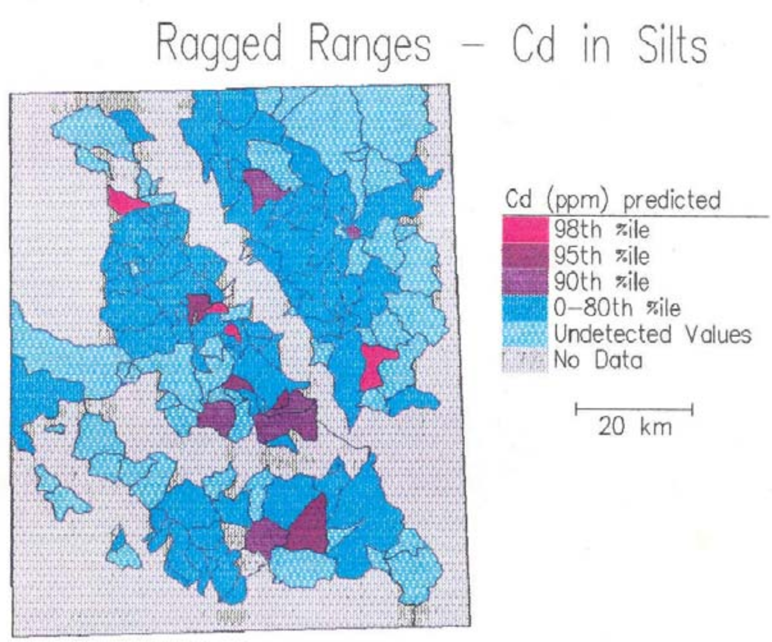

Figure 4.23b: Ragged Ranges, Cd in silt using MLE – Predicted Data

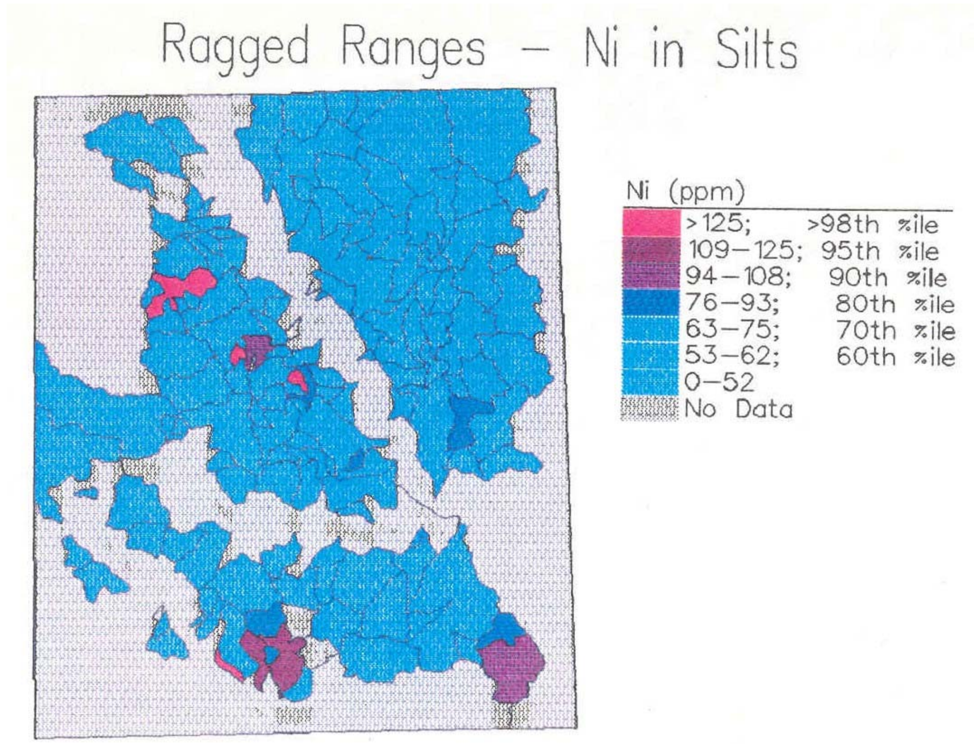

Figure 4.24a: Ragged Ranges, Ni in silt using MLE – Raw Data

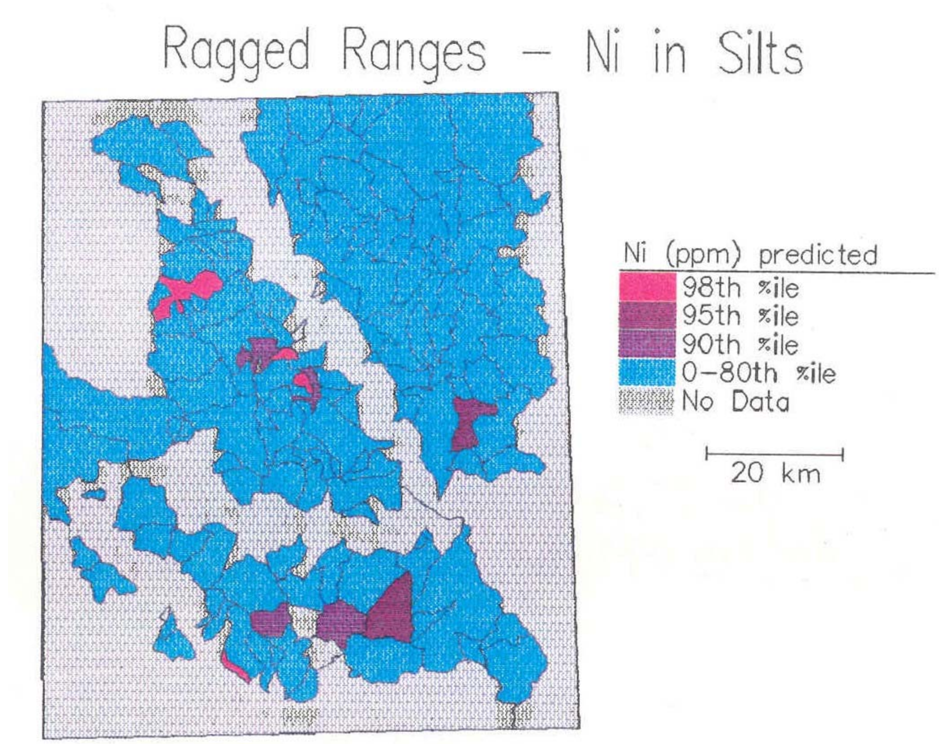

Figure 4.24b: Ragged Ranges, Ni in silt using MLE – Predicted Data

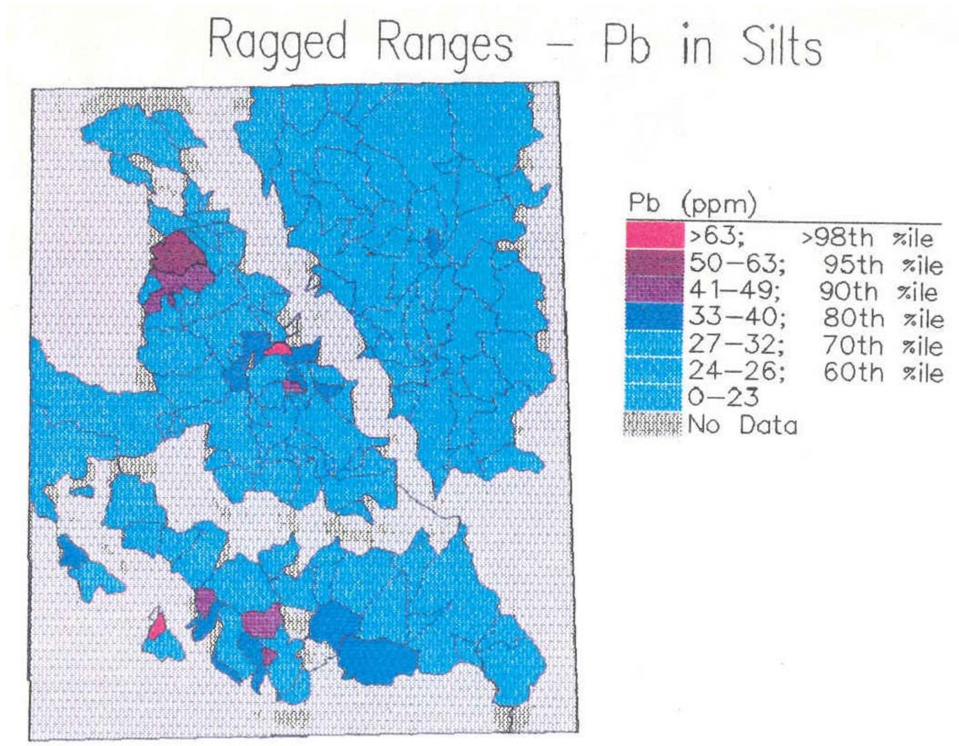

Figure 4.25a: Ragged Ranges, Pb in silt using MLE – Raw Data

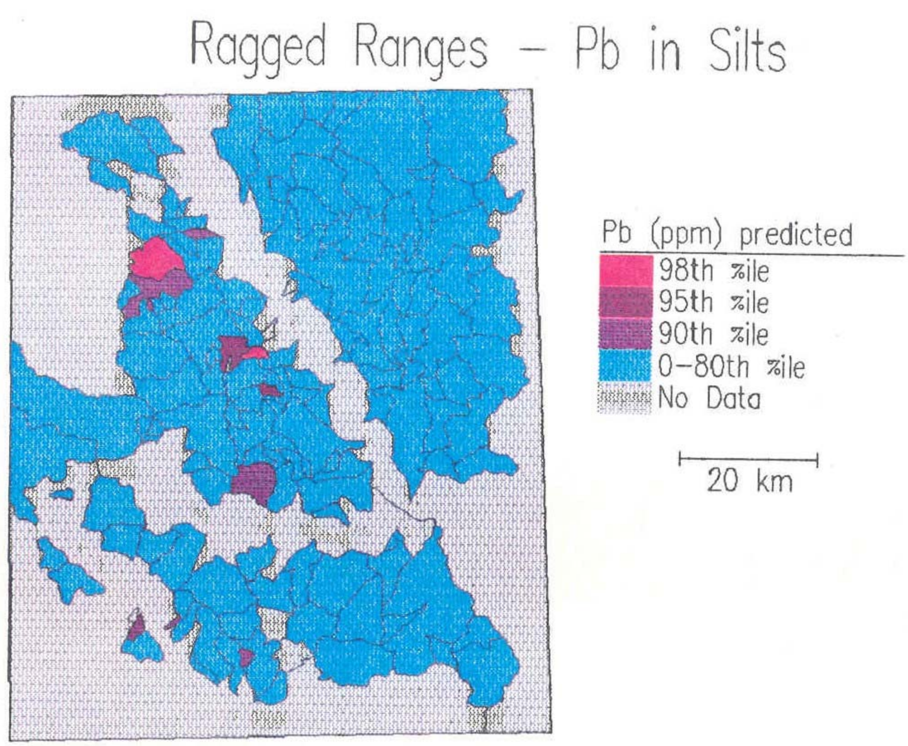

Figure 4.25b: Ragged Ranges, Pb in silt using MLE – Predicted Data

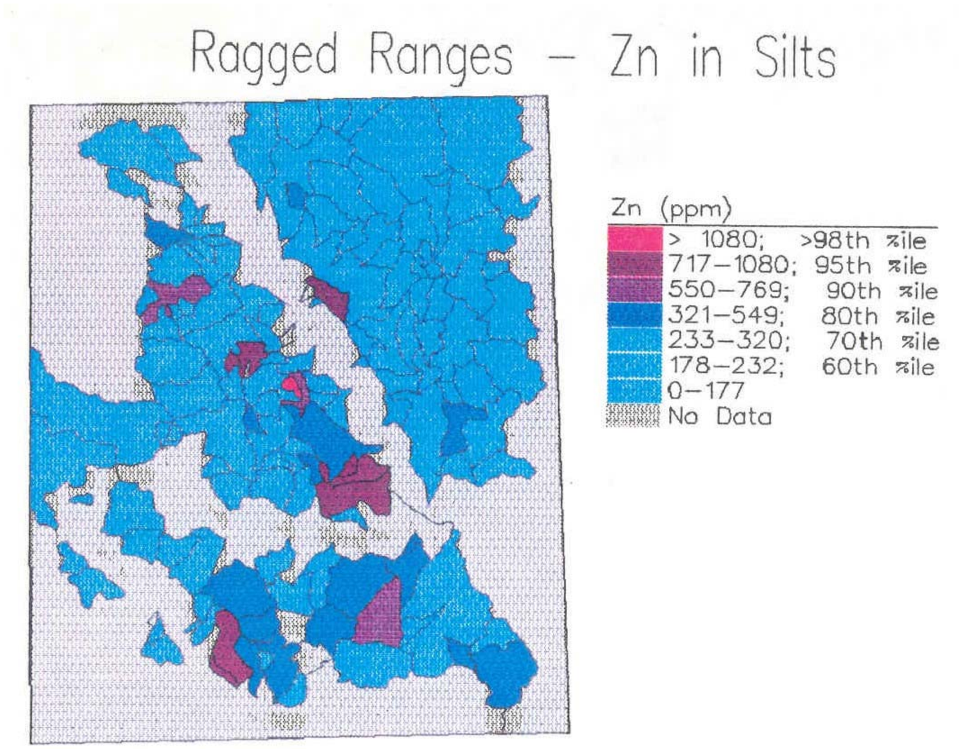

Figure 4.26a: Ragged Ranges, Zn in silt using MLE – Raw Data

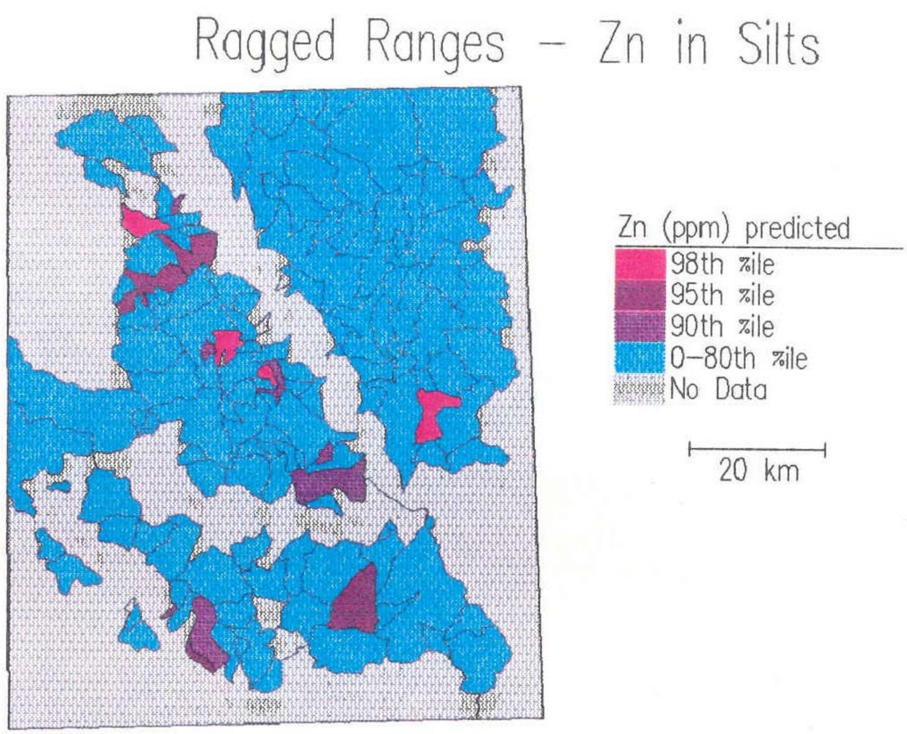

Figure 4.26b: Ragged Ranges, Zn in silt using MLE – Predicted Data

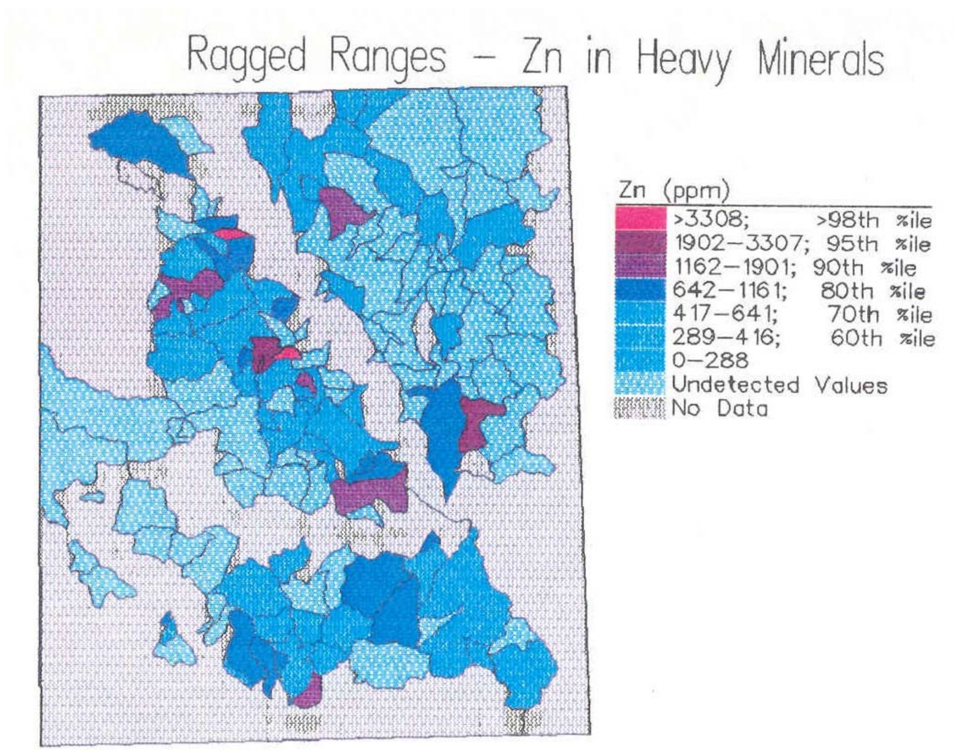

Figure 4.27a: Ragged Ranges, Zn in HMC using MLE – Raw Data

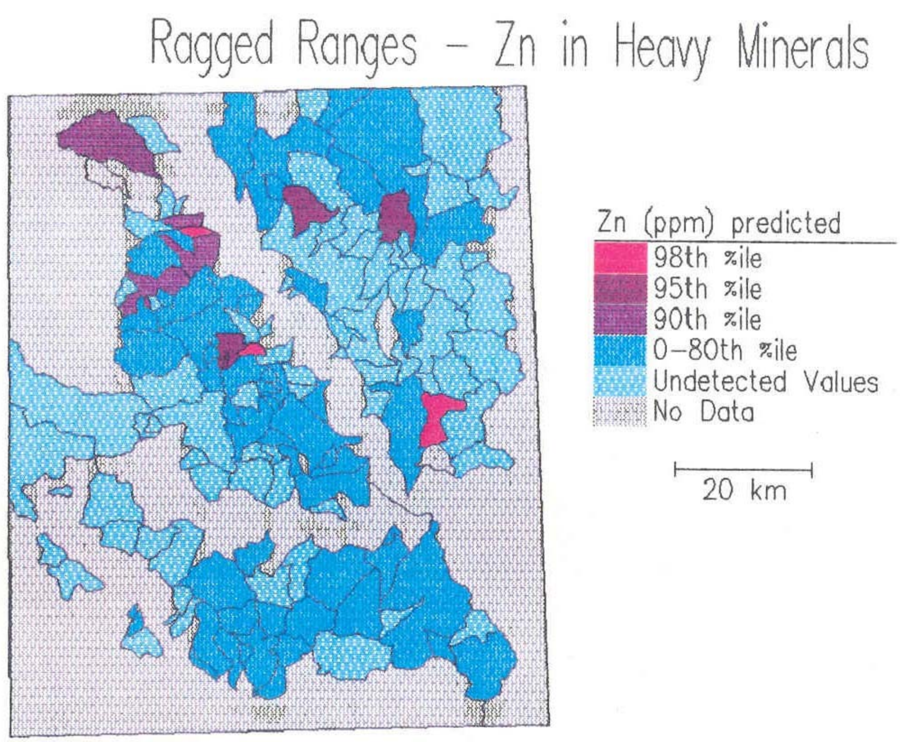

Figure 4.27b: Ragged Ranges, Zn in HMC using MLE – Predicted Data

4.6.2. Mineral Potential from geochemistry - Nahanni Karst / Tlogotsho Plateau

The stream sediment survey identified three areas of interest. The first is the known Prairie Creek lead-silver-zinc vein. The element association of Au-Cu-Pb-Sb-Zn is characteristic of the Prairie Creek vein system and is inferred to represent vein systems which are spatially related to intersecting fault zones and lineaments (Jefferson et al., in prep.). Figure 4.28b and Figure 4.29b show mineral potential maps for Zn and Sb in HMC respectively which highlight Prairie Creek. Figure 4.30b of Pb in silts shows high values in that region as well. High potential for this type of mineralization is located in a zone south of Nahanni River, trending in the same northerly direction as the Cadillac Mine occurrence.

A second area in the Meilleur River valley exhibits a multi-element (Zn-Co-Ba-Ni-Cr-Cu-Cd) association in HMC and silts (Figs. 4.31b zns, 4.32b cos, 4.33b coh, 4.34b bas, 4.35b nih, 4.36b crh, 4.37b cus, 4.38b cds) indicating the potential for stratiform sediment-hosted zinc-lead deposits as well as stratabound deposits similar to the Mawer in Ragged Ranges. This is supported by Zn-Cd-Ni-Co-Cu-U anomalies in water samples from hot and cold springs (Hamilton, 1990) which are similar to spring waters found near the Howards Pass deposit. These geochemical associations could also be related to the Prairie Creek vein system because the Meilleur River valley falls on the same lineament as Prairie Creek.

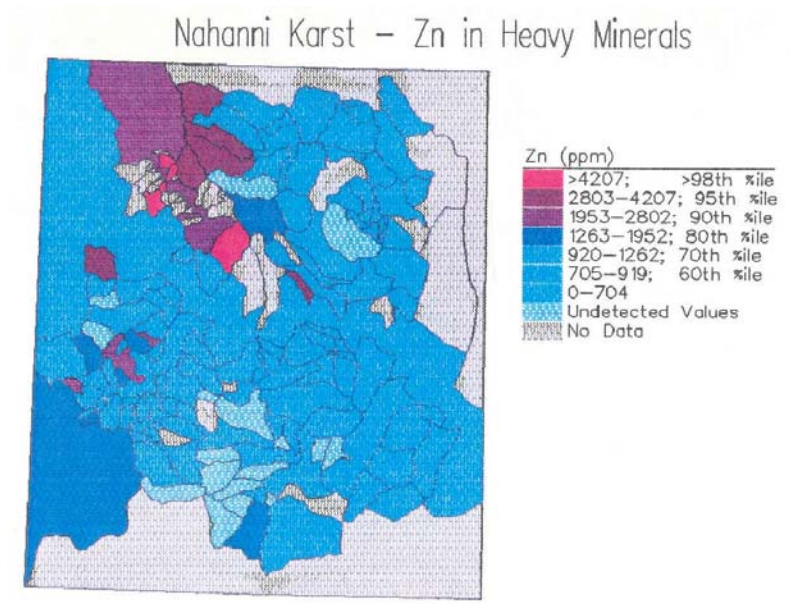

Figure 4.28a: NK/TP, Zn in HMC using MLE – Raw Data

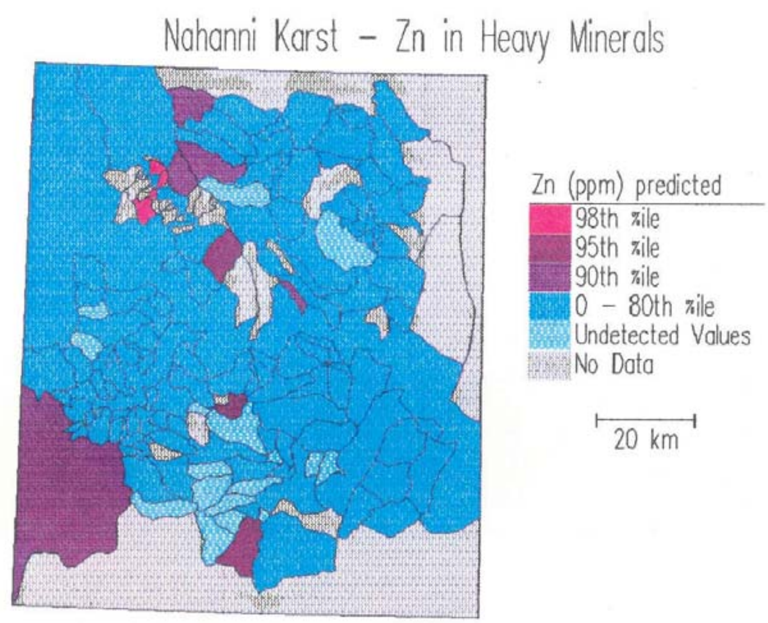

Figure 4.28b: NK/TP, Zn in HMC using MLE – Predicted Data

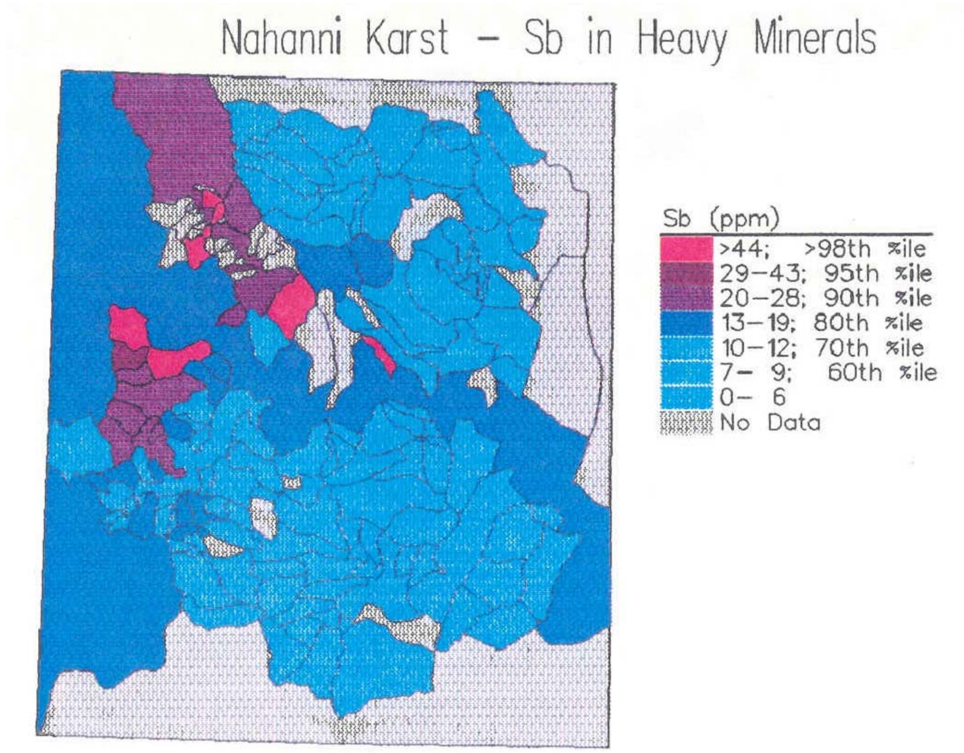

Figure 4.29a: NK/TP, Sb in HMC using MLE – Raw Data

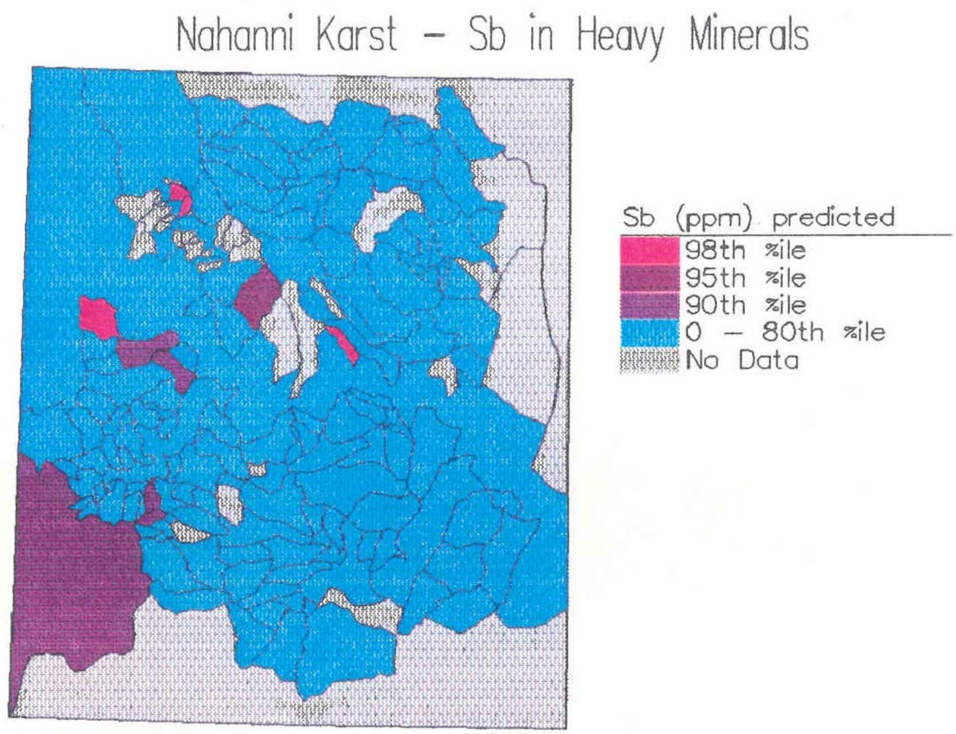

Figure 4.29b: NK/TP, Sb in HMC using MLE – Predicted Data

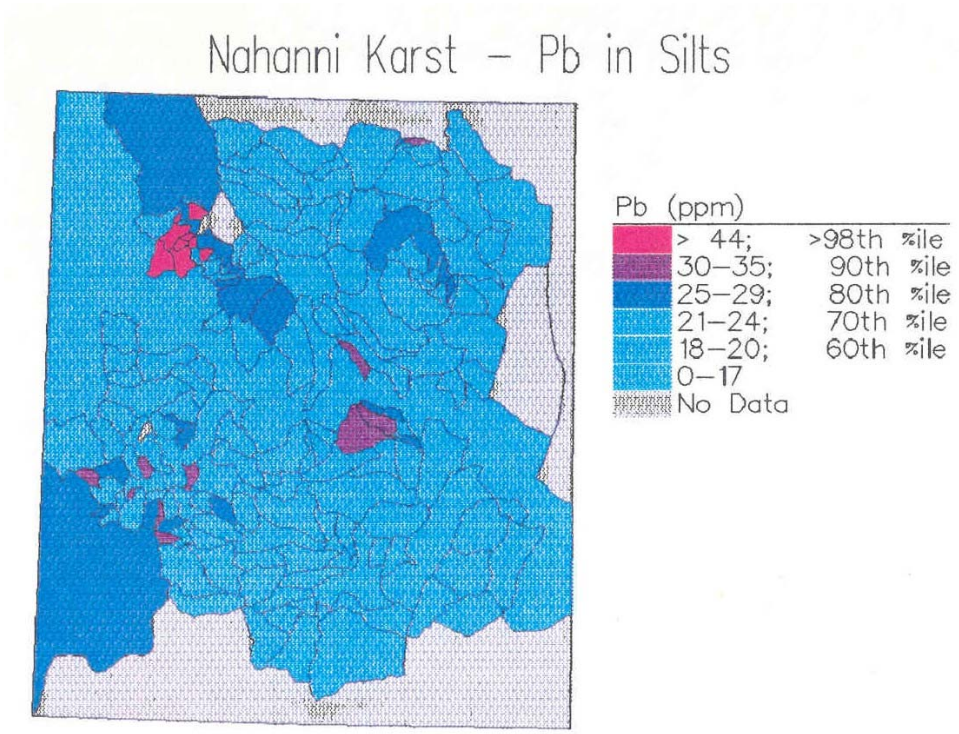

Figure 4.30a: NK/TP, Pb in silt using MLE – Raw Data

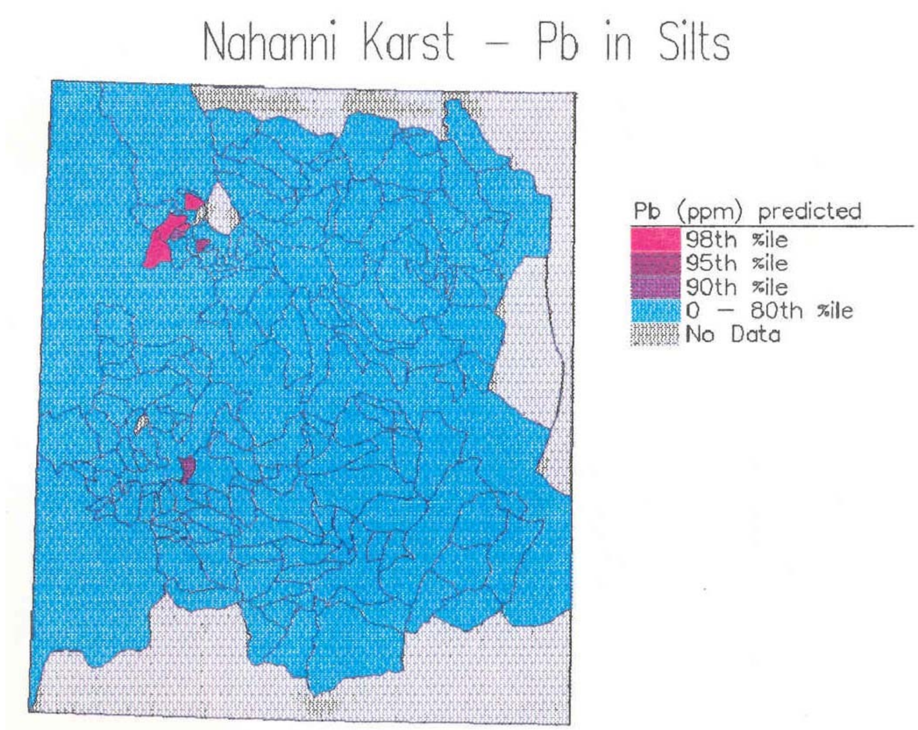

Figure 4.30b: NK/TP, Pb in silt using MLE – Predicted Data

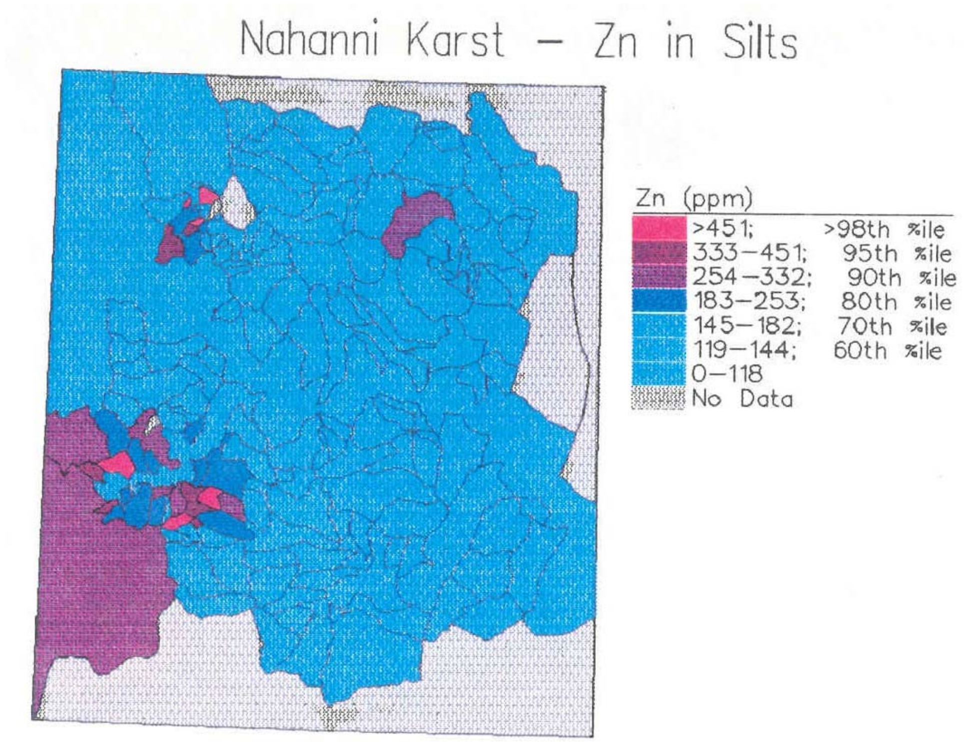

Figure 4.31a: NK/TP, Zn in silt using MLE – Raw Data

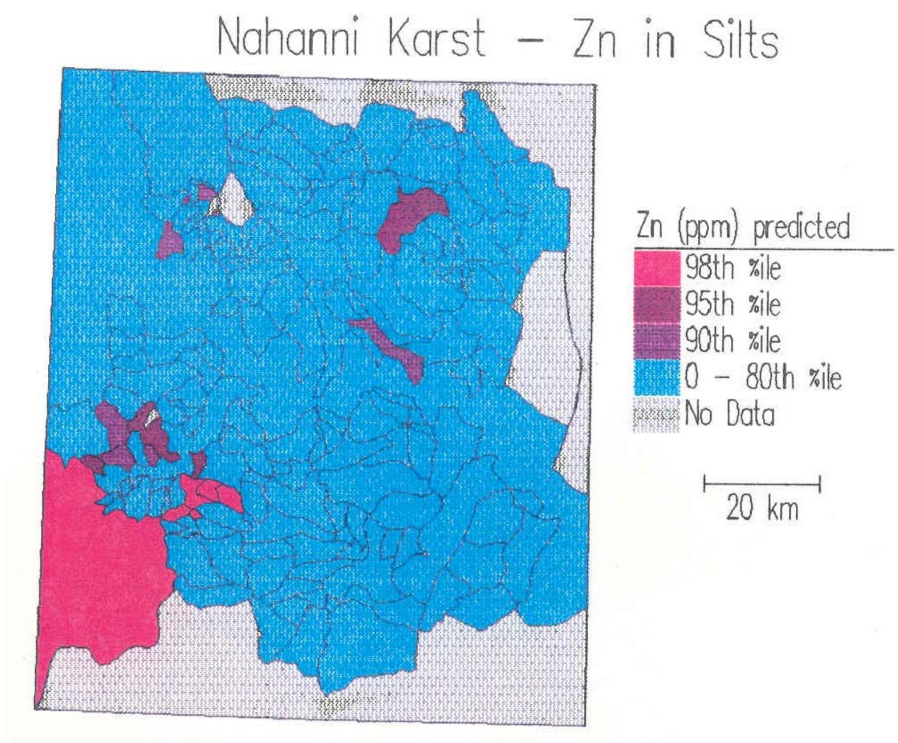

Figure 4.31b: NK/TP, Zn in silt using MLE – Predicted Data

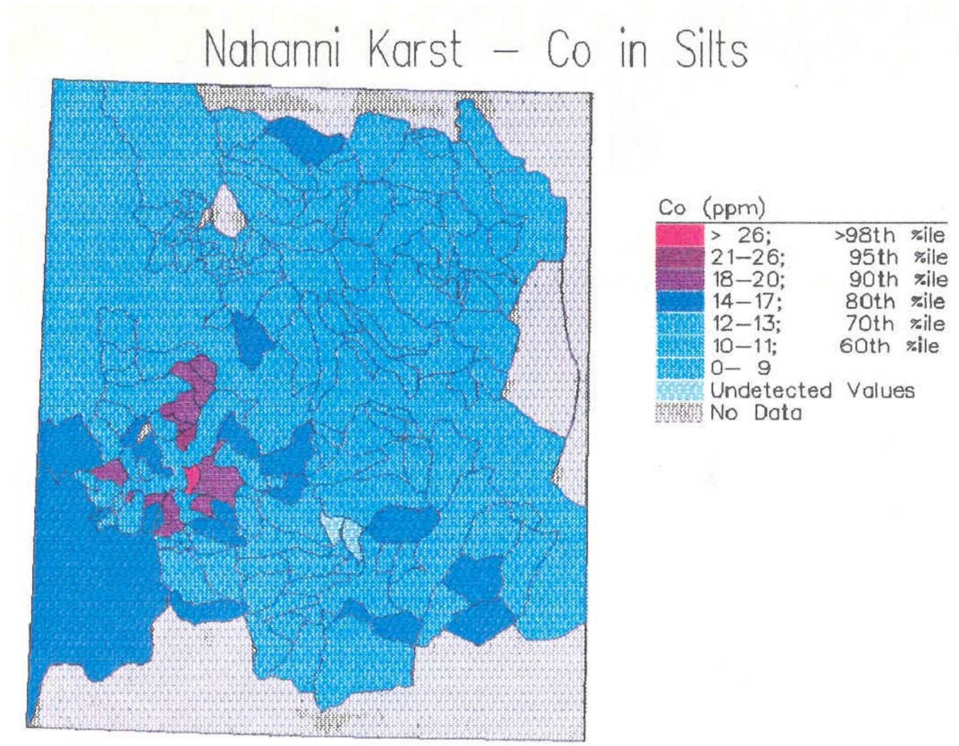

Figure 4.32a: NK/TP, Co in silt using MLE – Raw Data

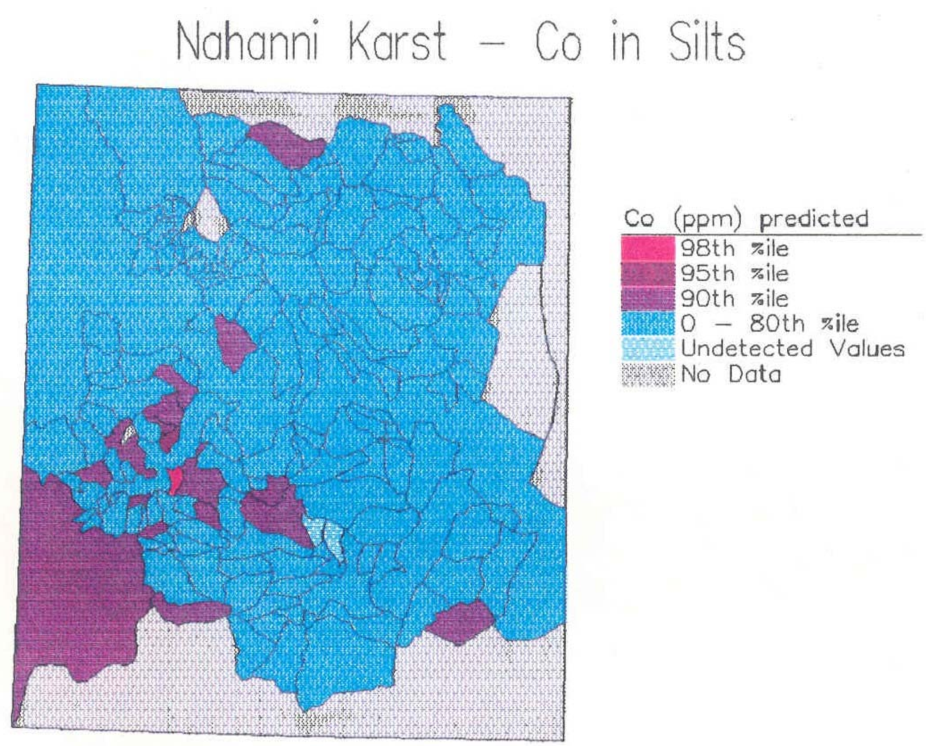

Figure 4.32b: NK/TP, Co in silt using MLE – Predicted Data

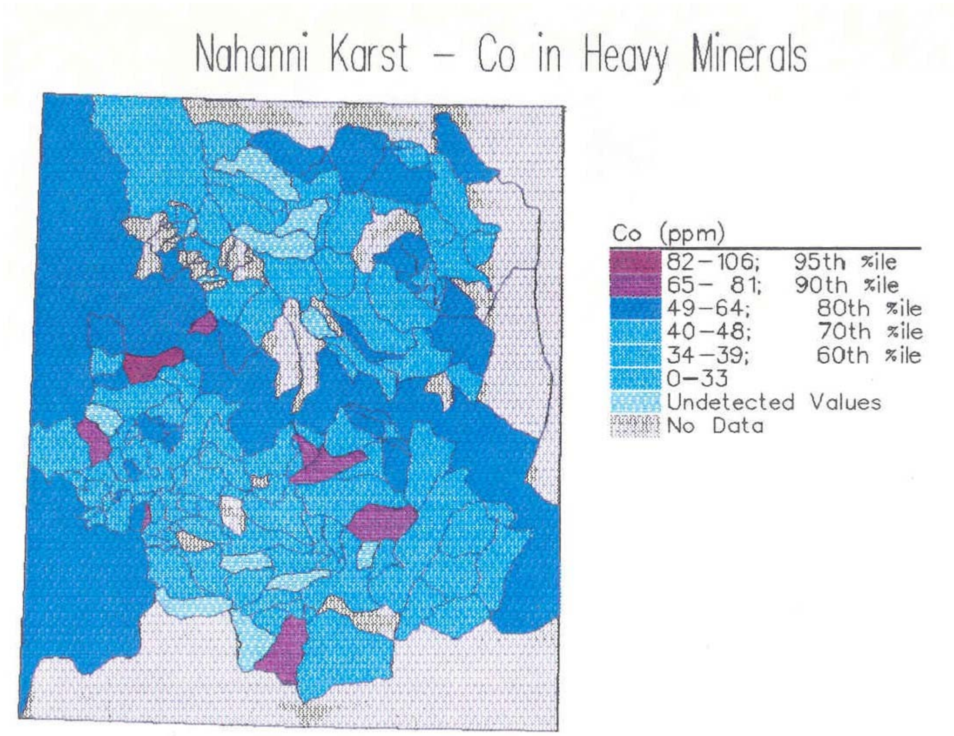

Figure 4.33a: NK/TP, Co in HMC using MLE – Raw Data

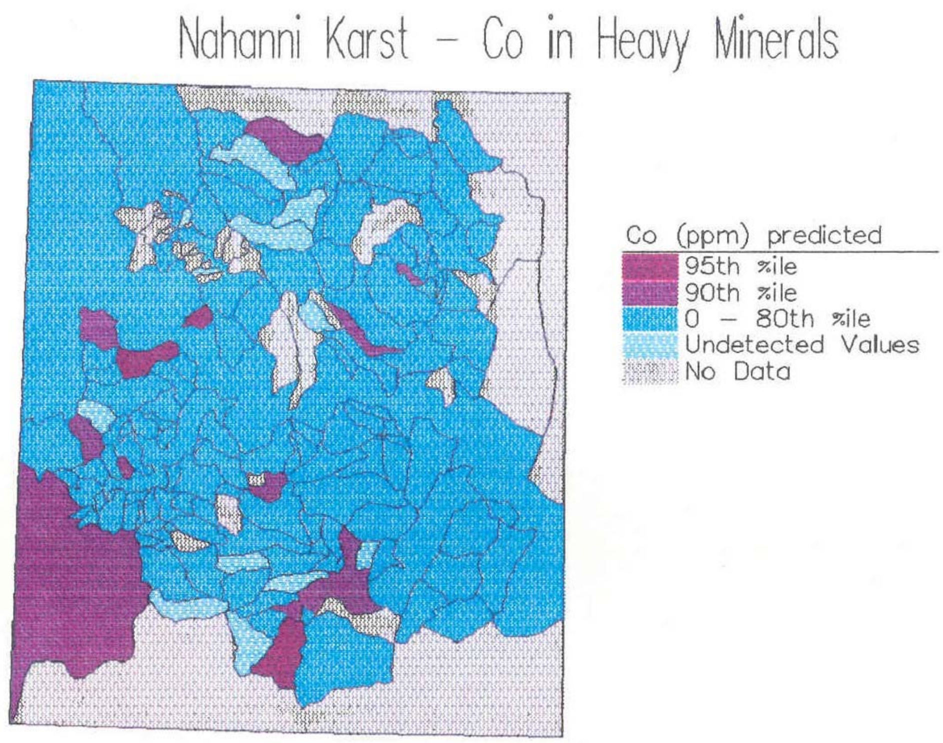

Figure 4.33b: NK/TP, Co in HMC using MLE – Predicted Data

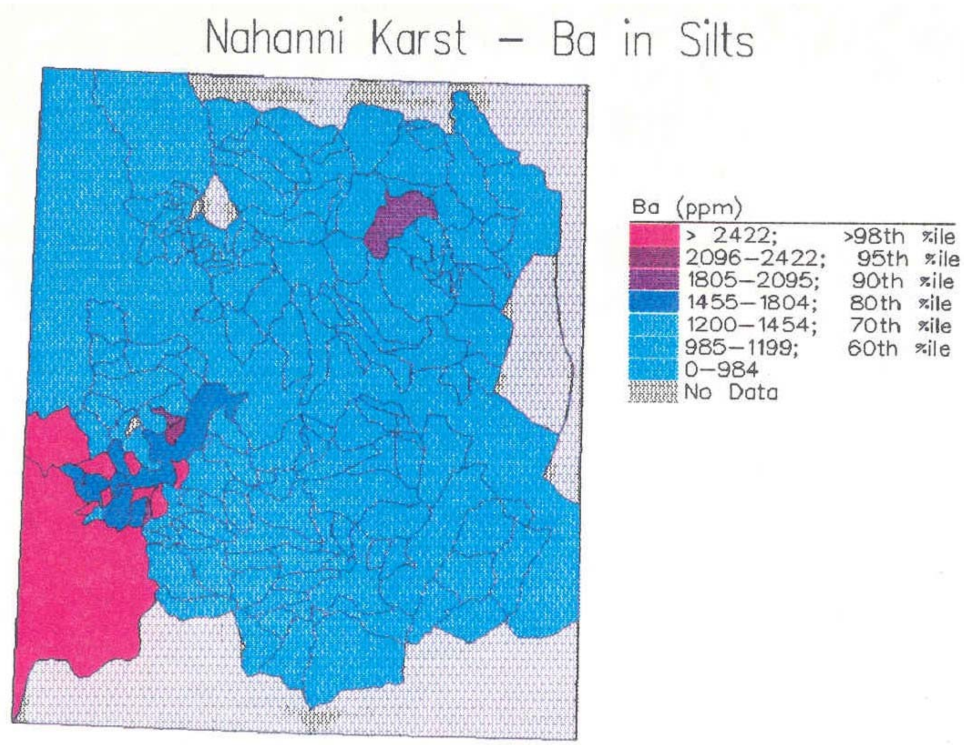

Figure 4.34a: NK/TP, Ba in silt using MLE – Raw Data

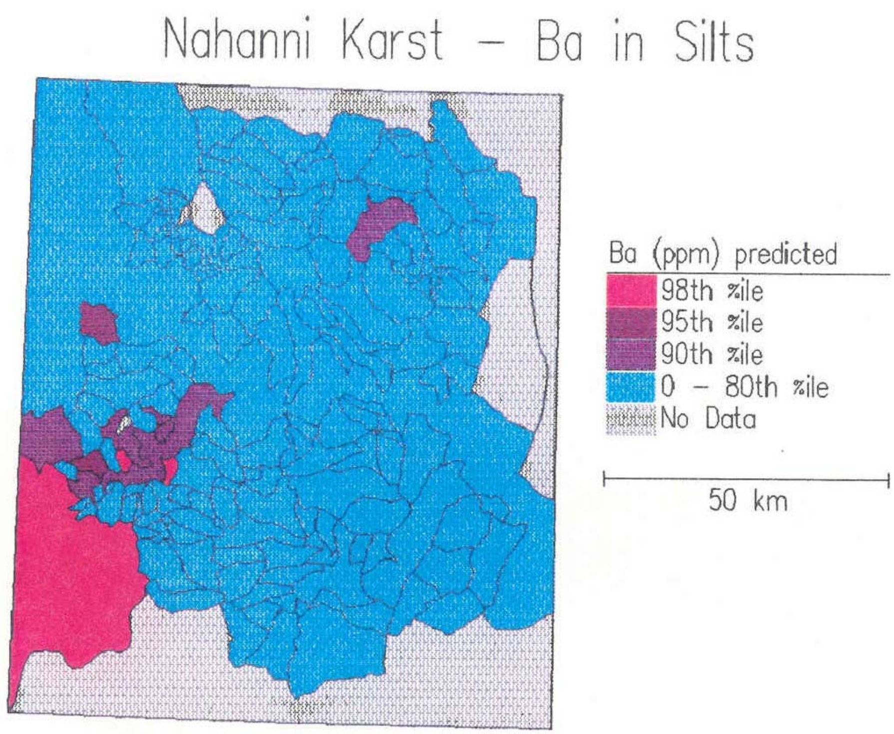

Figure 4.34b: NK/TP, Ba in silt using MLE – Predicted Data

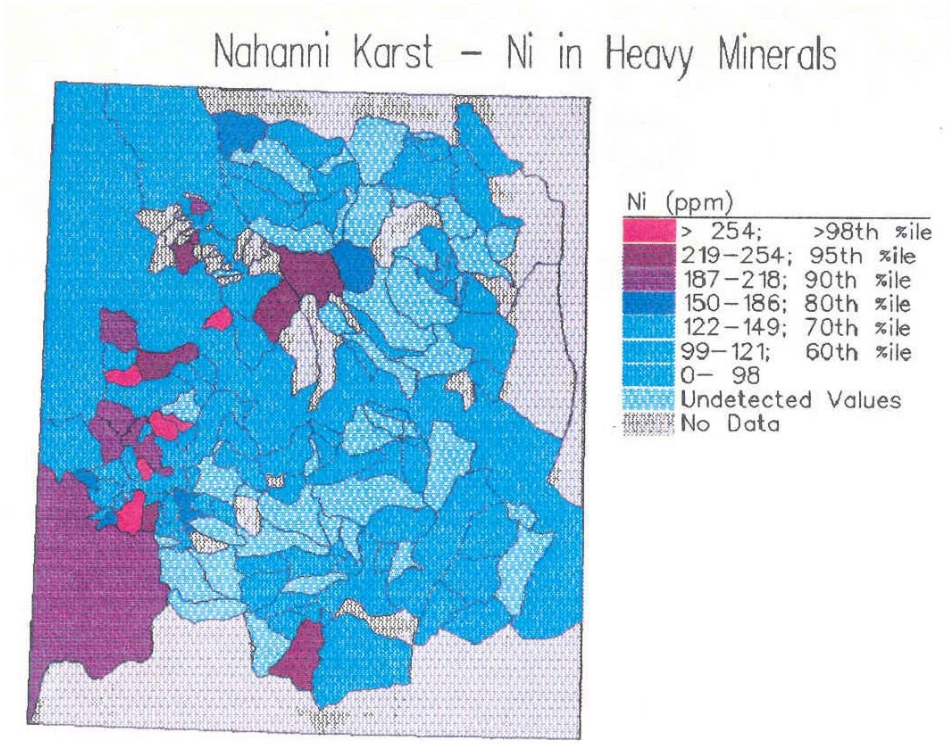

Figure 4.35a: NK/TP,Ni in HMC using MLE – Raw Data

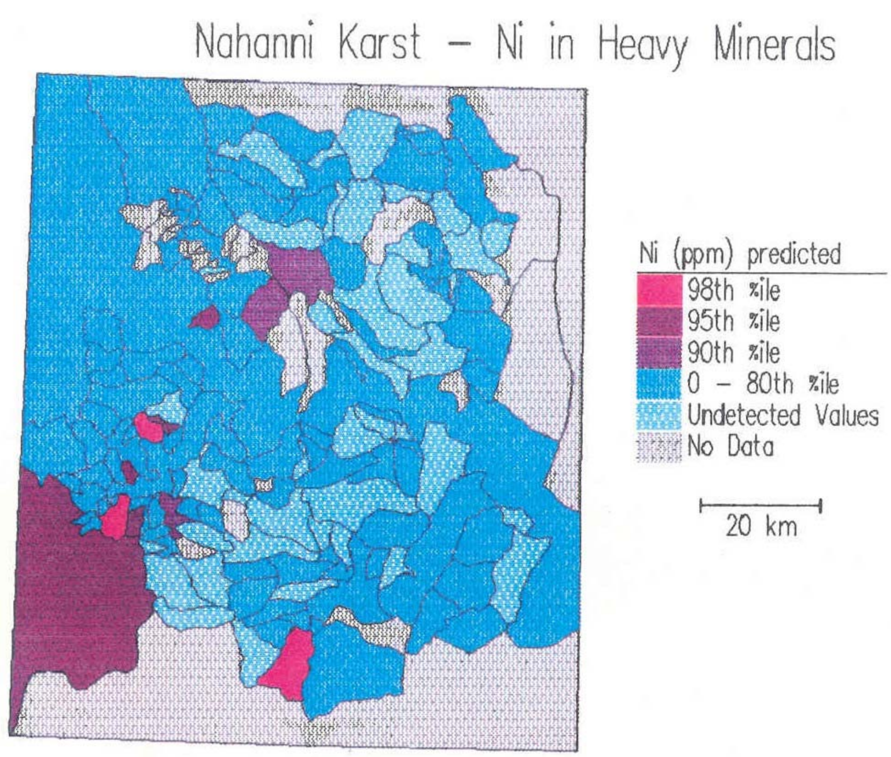

Figure 4.35b: NK/TP, Ni in HMC using MLE – Predicted Data

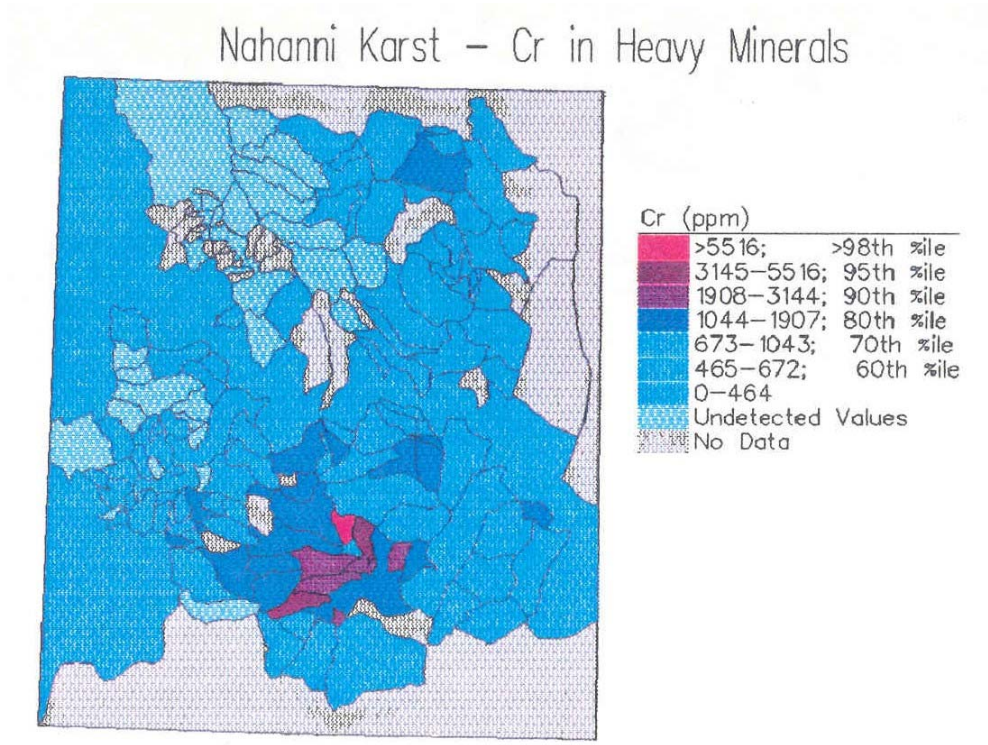

Figure 4.36a: NK/TP, Cr in HMC using MLE – Raw Data

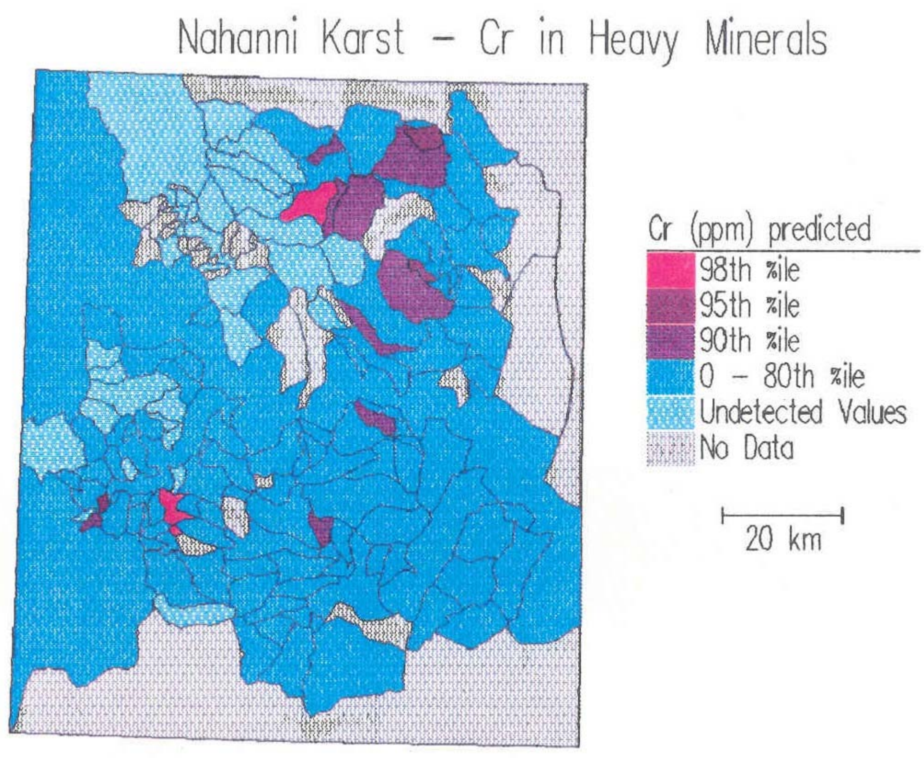

Figure 4.36b: NK/TP, Cr in HMC using MLE – Predicted Data

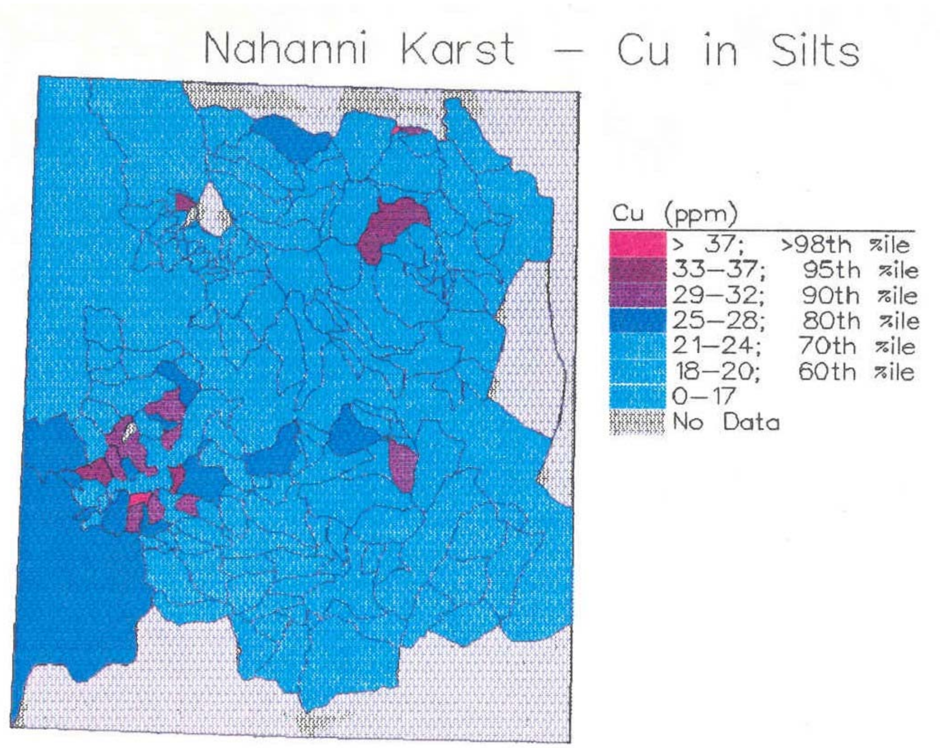

Figure 4.37a: NK/TP, Cu in silt using MLE – Raw Data

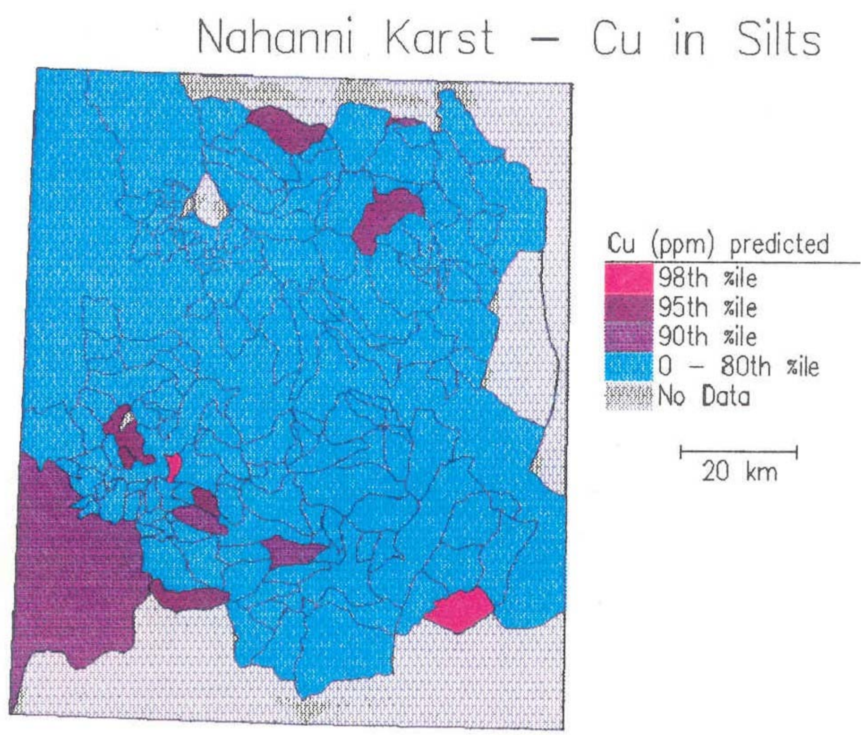

Figure 4.37b: NK/TP, Cu in silt using MLE – Predicted Data

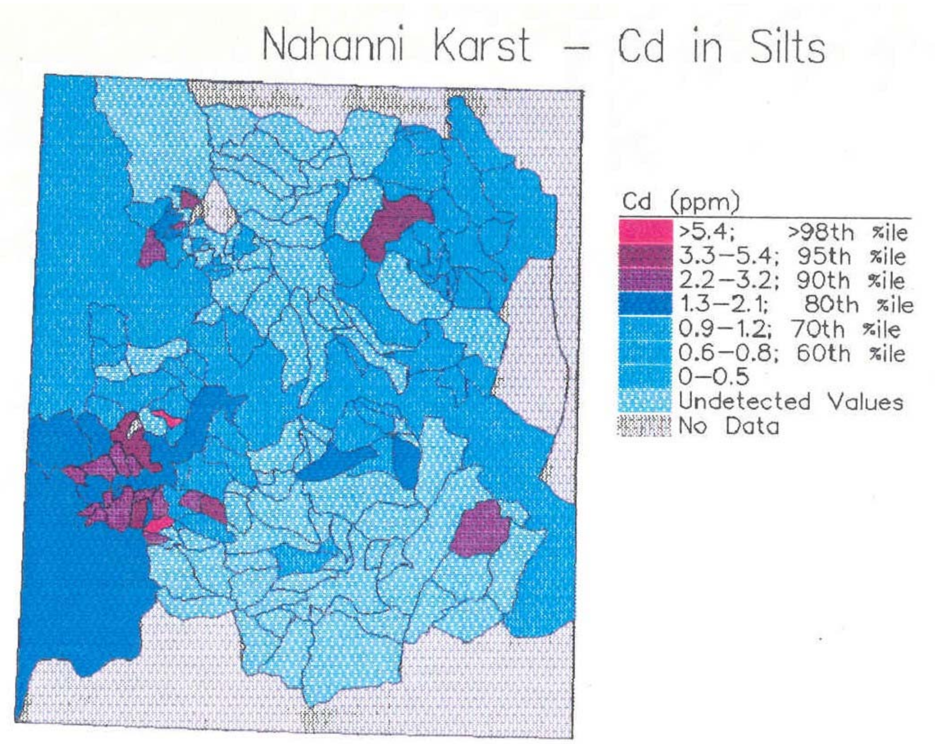

Figure 4.38a: NK/TP, Cd in silt using MLE – Raw Data

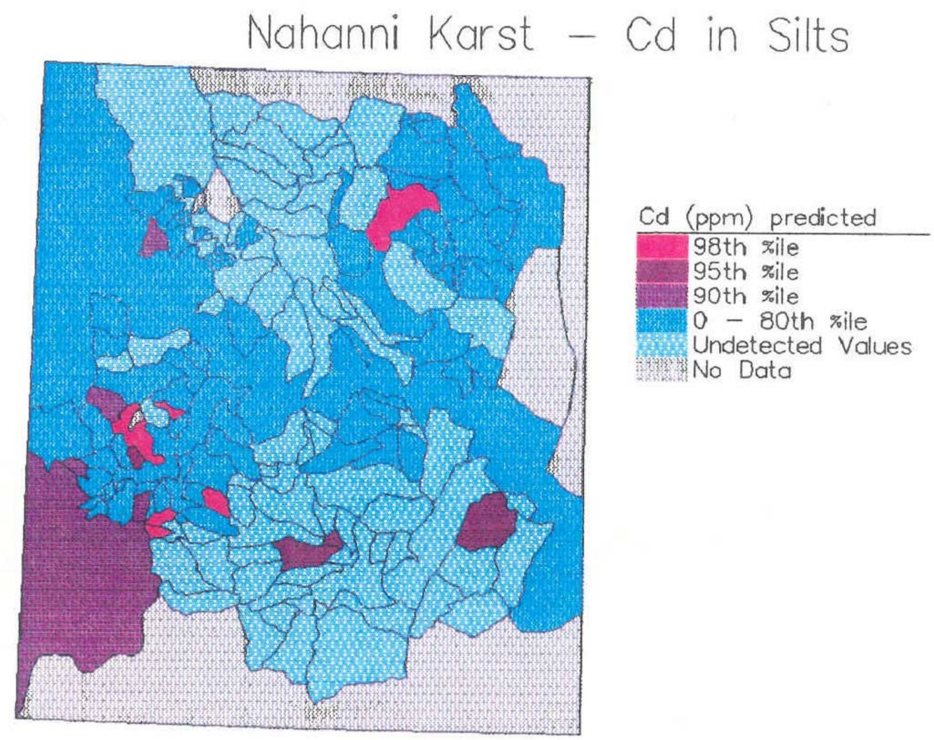

Figure 4.38b: NK/TP, Cd in silt using MLE – Predicted Data

Finally, a new placer gold anomaly in heavy mineral concentrates at Wretched Creek was identified (Figure 4.39b). This was confirmed by later analysis of heavy minerals from silts and expanded to include a 100 km north-trending belt of discontinuous placer gold occurrences from Mattson to Tetcela Rivers (Jefferson and Paré, 1991). The chemistry is statistically unrelated to Quaternary deposits. We originally considered that this means the geochemical anomalies are locally controlled by lode bedrock sources and/or structure. However, the gold anomalies are not related to other elements in that no other element is anomalous and associated with gold. The only common factor seems to be that all the streams are associated with intersecting N and NW trending faults which could be structural traps for placer gold (Jefferson and Paré, 1991). Based on a discussion of several hypotheses above (Section 4.5.5) distal glacial transport from a Canadian Shield source is favoured, and these occurrences are recommended only as of interest to tourists who would like to practice their gold panning skills.

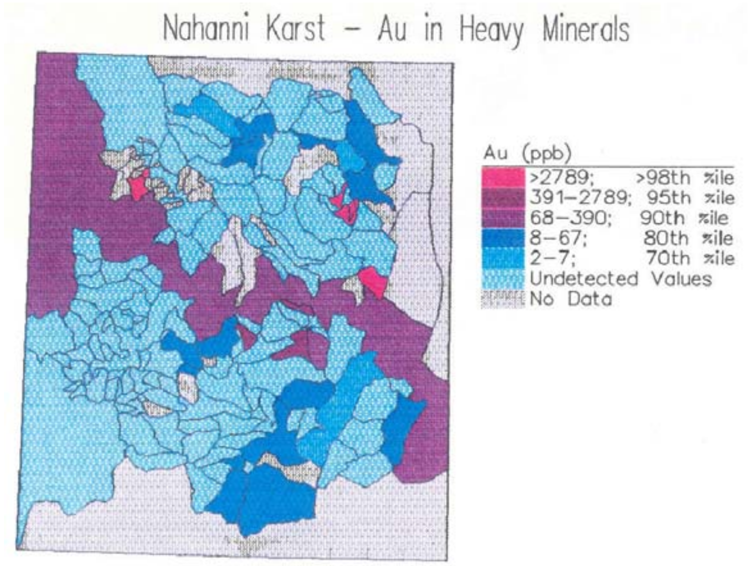

Figure 4.39a: NK/TP, Au in HMC using MLE – Raw Data

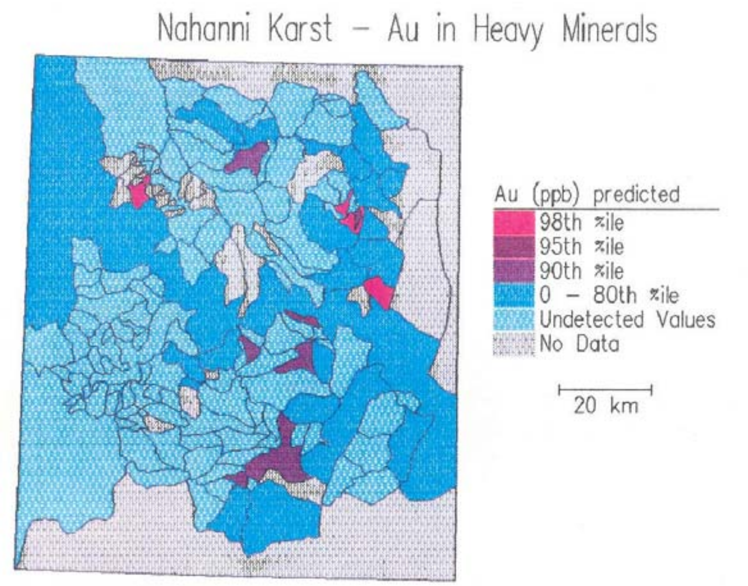

Figure 4.39b: NK/TP, Au in HMC using MLE – Predicted Data

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*4.7 Conclusions from stream sediment geochemistry studies in Nahanni reg*ion

4.7.1. Stream silts vs. heavy mineral concentrates

Stream sediment sampling is useful for highlighting geochemical anomalies in the South Nahanni River area. However, the design and execution of the sampling program as well as the analytical technique all affect whether or not the survey will be able to detect mineralization. Orientation surveys are a valuable way to test the sampling technique and the volume of sediment needed in a particular terrain. Reconnaissance surveys of large regions such as the Nahanni expansion areas, are a good way of covering large areas and highlighting mineralized targets. More localized follow-up surveys are required to check results and to trace anomalies to their source. For example, 1987 follow-up work in Wretched Creek confirmed gold in HMC (from pebbly sands) anomalies but more ground work is needed to discover its origin. Jefferson and Paré (1991) did further studies on HMCs from silts which confirmed and expanded the anomalies but also indicated that more work needs to be done on bedrock.

Traditionally, stream silts have been the medium most commonly sought by explorationists because they are easier and less expensive to collect. In the Meilleur River area, stream silts highlighted zinc anomalies which could be hydromorphically dispersed, as well as a variety of elements which are typically transported in detrital minerals (e.g. barium).

Heavy mineral concentrates are an important addition to the Nahanni sampling program because they are better able to detect mechanically dispersed elements, such as gold and tungsten. These resistate and/or heavy minerals are relatively insoluble and are therefore more stable in the secondary environment. The HMCs also mimicked the silts to a large extent. Based on visual comparison of results, the shaker table methods with targeted heavy liquid separations were effective in producting HMCs from both gravelly sand and silts from streams. A Wilfley type table with black deck separates most >50 micron free gold. Most remaining free gold (including <50 µm) is concentrated in the HMC which is analysed by neutron activation. Neutron activation results provide further confirmation of the free gold results as well as for other elements of exploration significance. For example: W and Au correlate in HMCs; they are associated with Zn near Ag-Pb-Zn veins; but they are not associated with Zn in other regional samples. Other element associations are summarized in Tables 4.10 and 4.11.

A full statistical comparison of analytical results from standard stream silts and HMCs in the Nahanni database is beyond the scope of this study, but should produce interesting results. Such a comparison would benefit from the use of correlation programs for the ML method (Chung, 1993).

Table 4.10. Summary data used to determine anomalous catchment basins (shown in Figure 4.40a), Ragged Ranges Area. Element symbols used in this table are described below. SPANS plots of individual elements in catchment basins are shown in Figures 4.5-4.10 and 4.16-4.27; chemical analyses of stream sediments are listed in Appendix 3.

Catchment basin #	Anomalous elements ordered by decreasing percentiles[1]	Deposit(s) inferred[2] STRONG/weak	General location
5058	*Au Ni (Ba Cr W)	vein + sedex	Mouth Lened Ck.
5062	**Pb *Sb Cd Zn Cr (As Au Th)	SEDEX + vein	Mouth Bologna Ck.
5063	**Pb ***Zn** *Sb *Ni Cd	SEDEX	Vulcan Creek
5064	*Ni Co (Ni Pb)	SEDEX	E of Vulcan
5065	*Pb [Cd] HMC too small	SEDEX	N of Vulcan
5066	(As Ni)	sedex	E of Vulcan
5067	W (As Ni Th Zn)	skarn + granite	S of Vulcan
5069	(As Au Ce Hf Th Zn)	granite/sandst.	Head Bologna Ck.
6040	W	skarn	E of Tungsten
6043	Mo (W)	skarn	Baker showing area
6046	Cu (Cr Pb Mo) [**As W** Au]	SKARN	Baker showing area
6047	*As Sb (Cu W) [Pb]	SKARN + vein	MB Showing
6048	*As Co Cu (Cd **W** Zn Mo)	SKARN + vein	MB Showing
6050/7006	*Au *W Cu (Co As Cr) [Ni]	SKARN	E of MB Showing
6053	[Ce As Cr]	vein?	NE Rabbitkettle R.
6054	*Cr	skarn?	NE Rabbitkettle R.

6055	**As** Au Co Cr Sb W	SKARN + vein	NW of MB Showing
6056	**W** Au	SKARN + vein	NW of MB Showing
6057	Au (W) [Ba]	skarn?	N of MB Showing
6058	Ce	granite	NE Rabbitkettle R.
6059	Mo Zn (Co)	sedex + vein	S. of Avalanche L.
6067	(Cd) [Mo]	sedex	Black Wolf Mt.
6068	Zn (Ba Mo Ni)	SEDEX/MVT	Black Wolf Mt.
6069	(Hf) [Hf As]	granite	Mt. Sir James MacBrien
6071/7003	*Mo *W Cd Co Cu (**Ni** Zn)	SKARN +sedex	Mt. Sir James MacBrien
6072/7004	*Ce*Hf*Zn Mo Ni Pb Th (Au Ba Cd Co)	SKARN + SEDEX	Mt. Sir James MacBrien
6073	***Mo** ***Ni** *Pb *Sb **Cu** Cd	SKARN + SEDEX	Mt. Sir James MacBrien
6074	***Th** *Hf **Ce**	granite	Mt. Sir James MacBrien
6075	***As** (Co Au)	VEIN	Mt. Sir James MacBrien
6076	Co Sb (Au)	vein	SE Mount Appler
6077/7705	***Hf** *Au **Th** (**Ce** Cr W)	VEIN + skarn	Mt. Sir James MacBrien
6082	Mo	sedex/vein?	S. of Avalanche L.
6083	Mo	sedex/vein?	S. of Avalanche L.
6084	*Cd [Ba Mo Zn]	sedex	NW of Dolf Mt.
6085	Th W (Hf)	granite/skarn	Mt. Sir James MacBrien
6089	(As)	vein	S. of Avalanche L.
6090	As	vein	S. of Avalanche L.
6092	**Hf**	sandstone	S. of Avalanche L.
6095	Th	granite	Mt. Ida
6096	*Co (Cr Cu Ni Zn)	SEDEX	Mt. Sir James MacBrien
6106	Co	vein?/skarn?	Dolf Mt.
6109	(Co)	vein?	NE of MAWER Showing
6112	Ba (As Au)	vein + sedex	Dolf Mt.
6113	***Zn** *Cr *Sb **Ba** Cd Cu Mo Ni (Au)	MVT/SEDEX+VEIN	MAWER Showing area
6114	(Ba)	sedex	MAWER Showing area
6115	***Ba** (Sb)	sedex	MAWER Showing area
6116	*Cd (Hf) [Sb Zn]	sedex + granite	Mt. Sydney Dobson
6117	Cd (Ba Sb Zn)	sedex	Mt. Sydney Dobson
6120	Co (Ce Sb)	vein?	Mt. Ida
6121	[Ba Sb Zn]	sedex	Mt. Sydney Dobson
6122	(Ba)	sedex	MAWER Showing area
6123	***Th** ***W** *Hf *Au Ce Mo (Ba)	SKARN + sedex	Mouth Brintnell Ck.
6124	Au	vein	Hole-in-the-wall
6125	*Hf *W (Th Co)	SKARN/granite	Hole-in-the-wall
6126	(Au)	vein	Mt. Sydney Dobson
6127	Ce Th (Hf) [**Th** W]	granite	S Rabbitkettle R.
6128	(Hf Th W) [Ce Th Hf]	granite/skarn	S Rabbitkettle R.
6129/7028	W Cr Ni [Ce]	SKARN + sedex	Upstream Tungsten
6130	**As** (**Au** Ba Th Hf)	vein + sedex	Hole-in-the-wall
6131	*Sb Ni Zn (Ba)	SEDEX	Hole-in-the-wall
6133	*Co	skarn?	Hole-in-the-wall
6134	(Co)	skarn?	Hole-in-the-wall
6136	[W]	skarn?	Hole-in-the-wall

6135	*Co	skarn?	Hole-in-the-wall
6139/7020	**Th Zn** Ba (Ce Au)	SEDEX/MVT+vein	Vampire Peaks
6140/7019	*Au Sb Zn (Pb)	VEIN + sedex	Vampire Peaks
6141/7018	(Ba Ni)	sedex	Vampire Peaks
6142/7016	***Au** *Ce *Pb Th (Cr)	VEIN + SEDEX	Mount Appler
6143/7017	***Ni Zn** Co As Sb (Pb)	SEDEX + vein	Mount Appler
6144/7015	Th (Au Ce)	vein	SE Mount Appler
6145/7013	Cr (Cu Au)	vein	SE Mount Appler
6159	Ce Cr (**Hf** Th)	sandstone	Vampire Peaks
6160	(Zn Ni)	sedex	N of Vulcan
6162	*Mo *Zn **Ba** Sb (Cr Cu Hf Ni)	SEDEX+sandst.	Vampire Peaks
6163	Sb (Zn)	sedex + vein	Vampire Peaks
6164	Sb (Zn)	sedex + vein	Vampire Peaks
6280	Mo Sb (Ce Ni)	sedex + vein	N of Vulcan
6282	Co (As)	vein	S. Nahanni R.
6283	[**W**]	skarn?	Mt. Sir James MacBrien
6284	(Au)	vein?/placer?	Dolf Mt.
7001	***Mo** *Cu (Co)	skarn/porphyry	Mt. Sir James MacBrien
7008	(Pb)	skarn+sedex?	E of MB Showing
7011	***Ni** Cu [Pb]	skarn	E of MB Showing
7021	[Co Ni]	skarn?	E of MB Showing
7022	*Ni Co Zn (As Hf) [Cu]	skarn+sedex	MB Showing
7023	***W** Mo [Hf]	SKARN	MB Showing
7024	***Sb *W Th** (As Cu Pb Zn Hf)	SKARN + sedex	W of MB Showing
7025	*As *Mo *W Sb (Au)	SKARN	Baker showing area
7026	Co	skarn?	Mt. Sir James MacBrien
7027	*Mo	porphyry/sedex	Mt. Sir James MacBrien
7030	***Hf** *Th	granite	Mt. Sir James MacBrien
7032	*As (Au Co Ni)	VEIN	S. of Avalanche L.
7033	*As *Cr (Ce Sb Th)	VEIN	S. of Avalanche L.
7034	Cu Cr Ni Zn	SEDEX	Mt. Sir James MacBrien
7035	Pb (As)	SEDEX + vein	Mt. Sir James MacBrien
7036	*Ba (Zn Mo)	sedex	Mt. Sydney Dobson
7037	***Ce *Th** (Pb Cr Hf W)	granite+sedex	Mt. Sydney Dobson
7038	Ce	granite	Mt. Ida
7041	Cr [Th Hf]	skarn?	S Rabbitkettle R.
7043	Ce (Cr)	vein?	Dolf Mt.
7045	(Hf Co)	vein?	Dolf Mt.

7003-7006, 7013, 7015-7020, 7028- duplicates of 6xxx samples (collected in 1986) listed above

[1]**Percentile symbols for anomalous elements in catchment basins**	
****Au**	extremely anomalous
***Au**	>98th percentile in silt + HMC (heavy mineral concentrate) (one may be only >90th percentile)
*Au	>98th percentile in silt only
*Au	>98th percentile in HMC only
Au	>95th percentile in silt + HMC (one may be only >90th percentile)
Au	>95th percentile in silt only
Au	>95th percentile in HMC only
(**Au**)	>90th percentile in silt + HMC
(Au)	>90th percentile in silt only
(Au)	>90th percentile in HMC only
[Au]	selected >80th percentile: >95% in raw data and/or part of a geochemical association

[2]Anomalous element associations in Ragged Ranges area (listed alphabetically), and their inferred relevance to mineral deposit types. Not all of each association is anomalous at any one site.
As-Au-Ce-Co-Cr-Cu-Hf-Mo-Ni-Pb-Sb-Th-W-Zn: SKARN tungsten: granite-associated elements are Ce-Hf-Th; the remaining elements are related to the skarn process. Pb and Zn may also be derived from a sedex deposit predating the skarn. Elements such as As-Au-Co-Sb are anomalous not only in known skarn areas but also around Vampire Peaks, Mount Appler, Mount Sir James MacBrien, SW of Hole-in-the-Wall, south of Avalanche Lake, around Dolf Mountain and near the Mawer Showing. Some of these associations, especially Mo-Cu-Co, suggest a porphyry deposit type.
Ba-Cd-Cr-Cu-Mo-Ni-Pb-Sb-Zn: SEDEX/MVT zinc-lead-silver or nickel-zinc: All of these elements are anomalous in the creek draining the Mawer-Showing. This zinc-lead showing is situated in carbonate rocks of the Sunblood Formation, associated with dolomite and karst-like breccia, characteristic of the Mississippi Valley (MVT) deposit type. The elements (Au-Cr-Cu-Sb) suggest that hydrothermal processes were active here. A number of other small showings and geochemical anomalies in the assessment area suggest that zinc concentrations are regional and stratabound in the upper Sunblood Formation, with local high-grade sites (e.g. 6068, 6072, 6073, 6162) marked by several of the associated hydrothermal elements and two by associated lead (Pb) and cadmium (Cd). Cadmium is useful to corroborate zinc as sedex indicators, which can be concentrated hydromorphically (e.g. Jonasson et al., 1987), and barium (Ba) which constitutes extensive thin beds as well as parts of base-metal deposits. Lead (Pb) is dispersed in detrital form and is a more direct indication of outcropping base-metal sulphides. The Mo-Ni association with zinc suggests the presence of a newly recognized SEDEX deposit sub-type, represented by the Nick in Yukon Territory, which also contains platinum group elements (Hulbert et al., 1990).
As-Au-Cu-Sb: VEIN/SKARN/REPLACEMENT PRECIOUS METALS: No known precious metal veins were tested geochemically in orientation surveys in Ragged Ranges, but this element association is inferred to represent vein systems which are either independent of, or distal parts of, skarn/replacement or porphyry systems.
Ce-Hf-Th: MATURE HEAVY MINERAL CONCENTRATE: Sandstones and granitic rocks contribute high proportions of zircon and monazite which contain the rare earth elements listed. They are not considered to have economic mineral potential, except for possible rare-element pegmatites such as the CALI which may contain mineral species suitable for specimen collecting.

Table 4.11. Summary data used to determine anomalous catchment basins (shown in Figure 4.41a), Nahanni Karst -Tlogotsho Plateau areas. Element symbols used in this table are described below. SPANS plots of individual elements in catchment basins are shown in Figures 4.11 and 4.28-4.39; chemical analyses of stream sediments are listed in Appendix 3.

Catchment basin	Anomalous elements ordered by decreasing percentile[1]	Deposit(s) inferred[2] STRONG / weak	General location
5002	*Zn Au Pb (Zn)	PB ZN AG VEIN	Prairie Creek
5008	*Pb (Ni Zn)	PB ZN AG VEIN	Prairie Creek
5016	*Pb *W **Sb** Cu (Zn)	PB ZN AG VEIN	Prairie Creek
5022	(Zn)	PB ZN AG VEIN	Prairie Creek
5129+7079	Pb	PB ZN AG VEIN	Prairie Creek
5131	*Pb	PB ZN AG VEIN	Prairie Creek
5144	*Pb	PB ZN AG VEIN	Prairie Creek
5154	(Zn)	PB ZN AG VEIN	Prairie Creek
5155+7080	*As *Ba *Zn (Sb)	PB ZN AG VEIN	Prairie Creek
5158	Pb	PB ZN AG VEIN	Prairie Creek
6067	(Cr)	mature HMC	trib. Claussen Ck.
6169	Cu	sandst. Copper	S-central Tlogotsho
6172	(Cu)	sandst. Copper	W Tlogotsho Plateau
6173	Mo Ni Zn	SEDEX/MVT	S trib. Meilleur R.
6174	***Hf** *Cr*Zn (As Ni)	SEDEX/MVT	S trib. Meilleur R.
6175	Ba (Ce Co Zn)	sedex	N trib. Meilleur R.
6176	(Mo)	sedex?	N trib. Meilleur R.
6177	Sb (**Mo**)	sedex/mvt?	S trib. Meilleur R.
6178	Co Cu Mo Sb	sedex + vein?	S trib. Meilleur R.
6179	*As*Ba*Ce*Co*Cr*Cu Sb Zn (Mo Pb)	sedex/mvt	S trib. Meilleur R.
6185	(Zn)	sedex	N trib. Meilleur R.
6186	(Ba Sb)	sedex	N trib. Meilleur R.
6187	**Sb Zn** Ba Mo Ni (**Co** Ce Cu)	SEDEX/MVT	upper Meilleur R.
6188	*As Cu Mo Ni Sb Th Zn (Ba Co Cr)	sedex + vein	N trib. Meilleur R.
6190	Mo (Ce Sb)	sedex?	N trib. Meilleur R.
6191	(Ba Ce Co Cr Mo Sb Th)	SEDEX/MVT	N trib. Meilleur R.
6192	Ni	sedex?	N trib. Meilleur R.
6193	Mo Ni (Ba Ce Co Cr Th)	SEDEX/MVT	N trib. Meilleur R.
6195	(Ba)	sedex/mvt	main Meilleur R.
6197	(Co Mo)	sedex?	NW of Meilleur R.
6198	(Co Cr Cu)	vein?	NW of Meilleur R.
6200	As Co (Hf Sb)	vein	SW of Prairie Ck.
6201	Mo (As)	vein	SW of Prairie Ck.
6203	***Sb** Ba Mo (As Co)	VEIN	SW of Prairie Ck.
6205	Ce As Cu Th (Au Co)	VEIN	E of Ram Creek
6207	Zn (**Co**)	vein?	upper Ram Creek
6208	(Zn)	MVT Pb Zn	NE of Prairie Creek
6209	*Ce *Cr Cu (**Co**)	vein + sandst.	NE of Prairie Creek
6211	*Hf Cu (As)	vein + mature	S trib. Sundog Ck.
6212	(Cr Th)	sandstone	N trib. Sundog Ck.
6216	Th	mature HMC	W trib. Tetcela R.
6221	(Zn)	MVT Pb Zn	NE of Prairie Creek

6223	Ni	mvt/vein?	E of Prairie Creek
6227	As	vein?	Lafferty Creek
6228	(Ce Cr Hf Th)	mature HMC	SW of poljes
6230	Zn + Cu Zn Pb float #6230R	mvt	Lafferty Creek
6233	Zn (Ni Sb)	mvt/vein?	lower Prairie Creek
6237+7066	*Au *Au* Hf (Th) both samples	placer/vein	Wretched Creek
6238	(Cr Th)	mature HMC	southern poljes
6239	*Au*	placer/vein	trib. Wretched Ck.
6242	**Au*	placer/vein	W trib. Tetcela R.
6243	**Au*	placer/vein	W trib. Tetcela R.
6244	**Au*	placer/vein	Windy Creek
6246/7072	Ce (Au 7072 only)	vein?	Classen Creek
6249	**Au* upstream limit unknown	placer/vein	lower Jackfish R.
6255	*Cu (Co)	sandst. Copper	Blue Bill Creek
6261+7076	Cu (Mo)	sandst. Copper	S-central Tlogotsho
6262	(Co Mo)	sandst. Copper	trib. Jackfish R.
6264	Hf	mature HMC	trib. Jackfish R.
6265	(Hf)	mature HMC	trib. Jackfish R.
6268	*Ni Co Zn (As)	SEDEX	Etanda Lakes
6272	(Au Co)	placer/vein?	upper Jackfish R.
6273+7078	Au both samples	placer/vein?	W of Fishtrap Ck.
6275	*Sb (As Zn)	VEIN	W of Lafferty Creek
6276	*Au*	placer/vein	E of Ram Creek
6278	(Co Cr Th Ni)	mvt/sedex?	S of Prairie Creek
6279	Co Mo Ni (Au)	mvt/vein?	S of Prairie Creek
7046	As Hf (Ce Cr)	vein + mature	S trib. Meilleur R.
7048	Zn Th	Sedex	N trib. Meilleur R.
7049	Ce Cr (Hf)	mature HMC	S trib. Meilleur R.
7051	*Ni W (Mo)	SEDEX + vein	S trib. Meilleur R.
7052	***Ce** *As*Ba*Sb*Th **Ni** Cu Mo Zn (Co)	SEDEX/MVT	N trib. Meilleur R.
7054	(Ni)	sedex/mvt?	S trib. Meilleur R.
7056	*Zn *Mo Sb (As Hf Mo)	SEDEX/MVT	S trib. Meilleur R.
7057	Cu Mo Ni Zn	SEDEX + ss	W Tlogotsho Plateau
7058	*Ce *Cr *Ni *Th Cu (As)	VEIN	S trib. Sundog Ck.
7059	(Cr Th)	mature HMC	S trib. Sundog Ck.
7060	***Cr *Hf** *Ni **Th** *Au*	vein + mature	S trib. Sundog Ck.
7061	(Ni)	mvt?	SE of poljes
7062	(Hf)	mature HMC	S of poljes
7063	*Hf *Th Cr Th (Co)	mature HMC	trib. Wretched Ck.
7065	Au	placer/vein	Wretched Creek
7068	(Cu Ni)	vein?	trib. Claussen Ck.
7070	Au	vein	trib. Claussen Ck.
7074	(Cr)	mature HMC?	trib. Jackfish R.
7077	Cr Ni	mature HMC?	trib. Jackfish R.
7081	*Cr Ni (Zn)	Pb Zn Ag vein	Prairie Creek
7083	*As *Cr *Mo *Ni Cu Sb Zn (Ba) no HMC	VEIN + MVT	northern polje

[1]Percentile symbols for anomalous elements in catchment basins	
**Pb	extremely anomalous
*Au	>98th percentile in silt + HMC (heavy mineral concentrate) (one may be only >90th percentile)
*Au	>98th percentile in silt only
<u>*Au</u>	>98th percentile in HMC from gravels
*Au	>98th percentile in HMC from silts
Au	>95th percentile in silt * HMC (one may be only >90th percentile)
Au	>95th percentile in silt only
<u>Au</u>	>95th percentile in HMC only
Au	>95th percentile in HMC from silts
(**Au**)	>90th percentile in silt + HMC
(Au)	>90th percentile in silt only
(<u>Au</u>)	>90th percentile in HMC only
(*Au*)	>90th percentile in HMC from silts
[Au]	selected >80th percentile: >95% in raw data and/or part of a geochemical association

[2]Anomalous element associations in Nahanni Karst/Tlogotsho Plateau area (listed alphabetically), and their inferred relevance to mineral deposit types. Not all of each association is anomalous at any one site.
Ba-Cd-Cr-Cu-Mo-Ni-Pb-Sb-Zn: SEDEX/MVT zinc-lead-silver or nickel-zinc: All of these elements are anomalous in the tributary to Prairie Creek that drains the many showings there; the same suite is strongly represented in Meilleur River and tributaries. The Prairie Creek silver-lead-zinc shows are situated in basinal carbonate rocks of the Whittaker Formation, associated with a high-angle reverse fault and extensive quartz-carbonate veining. The elements (Au-Cr-Cu-Sb) suggest that hydrothermal processes were active here. No showings are recorded for the Meilleur River valley which has subdued topography and extensive cover by till, varved lacustrine clays and forest, but the widespread extent of highly anomalous values suggest that zinc concentrations are regional. The highly metalliferous hot and cold springs also located in and around Prairie Creek and Meilleur River valley are interpreted to represent significant buried deposits, with local high-grade sites (e.g. 5002, 5176, 6179, 6187, 6188, 7052) marked by several of the associated hydrothermal elements. Cadmium is not anomalous in the eastern streams (in contrast to the Ragged Ranges area Table 4.10), however it is anomalous in springs of both Prairie Creek and Meilleur River areas, again serving as Sedex indicators (e.g. Jonasson et al., 1987), and to corroborate barium (Ba) which is anomalous in stream sediments and characteristically is associated with Sedex base-metal deposits. Lead (Pb) is dispersed in detrital form and is a more direct indication of outcropping base-metal sulphides. The molybdenum-nickel (Mo-Ni) association with zinc here as in Ragged Ranges suggests the presence of a newly recognized deposit type, represented by the Nick occurrence in Yukon Territory, which also contains platinum group elements (Hulbert et al.,1990; Hulbert ,1995).
As-Au-Cu-Pb-Sb-Zn: VEIN PRECIOUS METALS: This element association is characteristic of the Prairie Creek vein system, and is inferred to represent vein systems which are spatially related to, intersecting fault zones and lineaments. In many cases gold (Au) is the only anomalous element, and it is present in placer form so that no direct geochemical inference can be made as to the type of vein system.
Ce-Hf-Th: MATURE HMC (Heavy Mineral Concentrate): Sandstones and carbonate rocks contribute high proportions of zircon and monazite which contain the rare earth elements listed. They are not considered to have economic mineral potential in Nahanni Karst -Tlogotsho Plateau area.
CO-Cu-Mo: SANDSTONE COPPER: Small deposits of copper are suggested by this element association in the Mattson sandstones. They are not likely to be large and high grade.

4.7.2. *Statistical techniques*

The Nahanni geochemical data provide a typical example of analytical results using the multi-element Neutron Activation method. The data are far from "perfect" because some elements contain a large number of values below variable, and commonly high detection limits. The method of Maximum Likelihood Estimation allows for statistical analysis of these data without subjective removal or arbitrary substitution. Removing the effect of bedrock underlying the catchment basins further refines the model and provides more discriminating results. The method of percentiles is a suitable alternative to residual analysis and has been extended to determine the predicted background values for 14 elements (in HMC and silt) in each of 9 rock types for RR and NK/TP. These lists (Appendix 3.10) will be useful to explorationists for comparing geochemical data sets of similar environments, even if they do not have access to the statistical programs used here.

4.7.3. *Mineral potential from stream sediment geochemistry*

Figures 4.40a and 4.41a show compilations (after Spirito, 1992) of anomalous basins and element associations for Ragged Ranges (RR) and Nahanni Karst/Tlogotsho Plateau (NK/TP) respectively. Basins anomalous in 3 or more elements are shown. Although single element anomalies are important, it is the association of elements that best identifies mineralization of known deposit types. The element associations are classified into one of: skarn (RR only), vein, sedex, granite/sandstone (granite RR only) and sandstone copper (NK only). Not all basins are anomalous in all elements considered to represent a deposit type. The upper legend on Figures 4.40a and 4.41a represents areas of higher potential than the lower legend, either because the basins are anomalous in more elements or because the elements are more highly anomalous or because they are associated with known mineral showings.

In Ragged Ranges (Fig. 4.40a), the fact that approximately 80% of the basins are anomalous in one element association or another is not unexpected because the Selwyn Basin has long been known as a region of high mineral potential. In addition, the kinds of mineralization identified by the survey are not surprising. Geochemical indicators for skarn tungsten are high in the Flat River valley, south of Cantung mine and in areas north of the river. Strong geochemical signatures for Ag-Cu-Pb-Zn skarns and precious metal veins are also determined north of the Flat River. Moderate to high indicators for stratiform zinc-lead are found north of South Nahanni River, and for stratabound carbonate hosted zinc-lead near the Mawer showing. Figure 4.40b illustrates the sample numbers of the anomalous stream sediment catchment basins shown in Figure 4.40a.

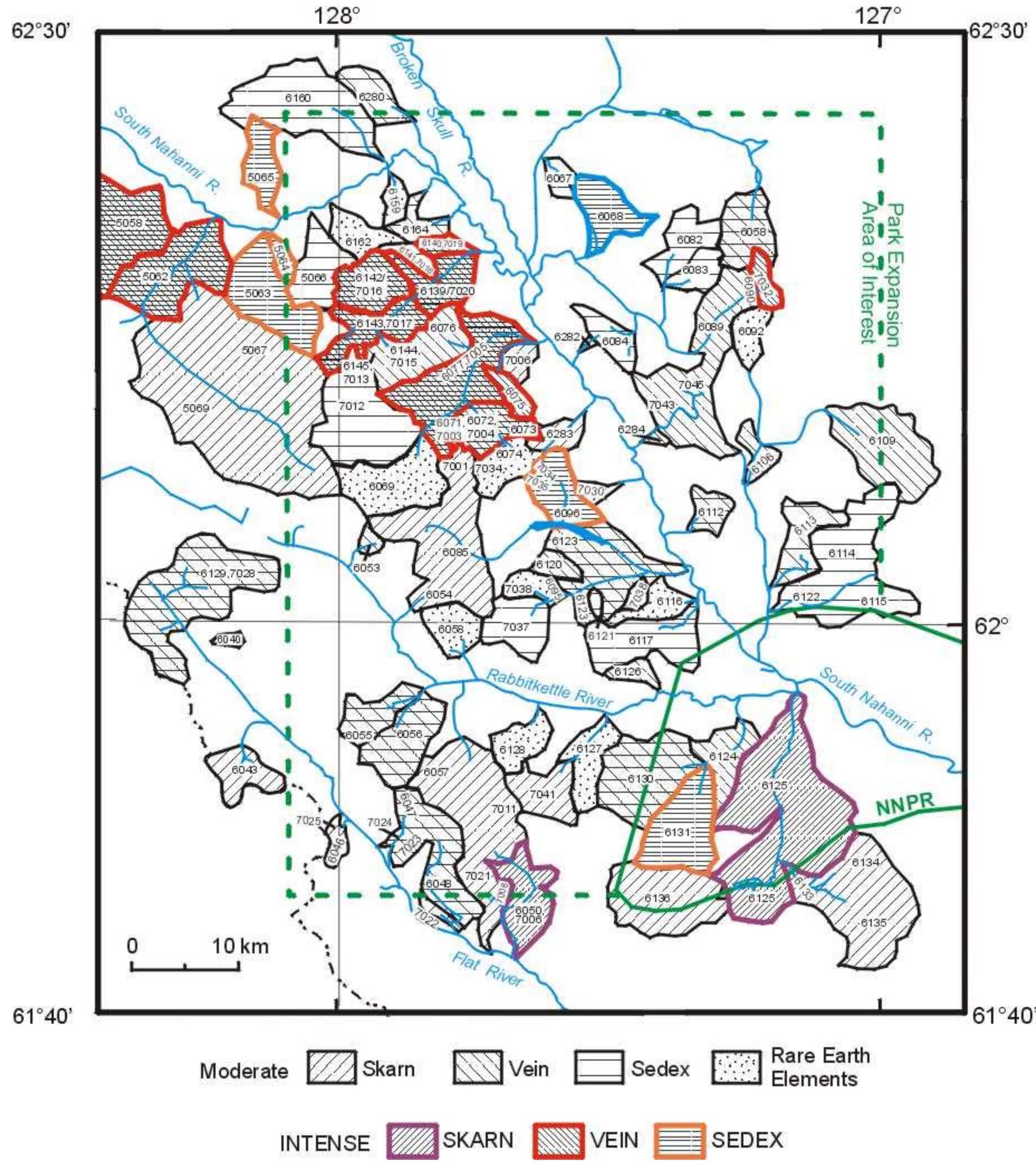

Figure 4.40a: Ragged Ranges Mineral Potential Summary Map

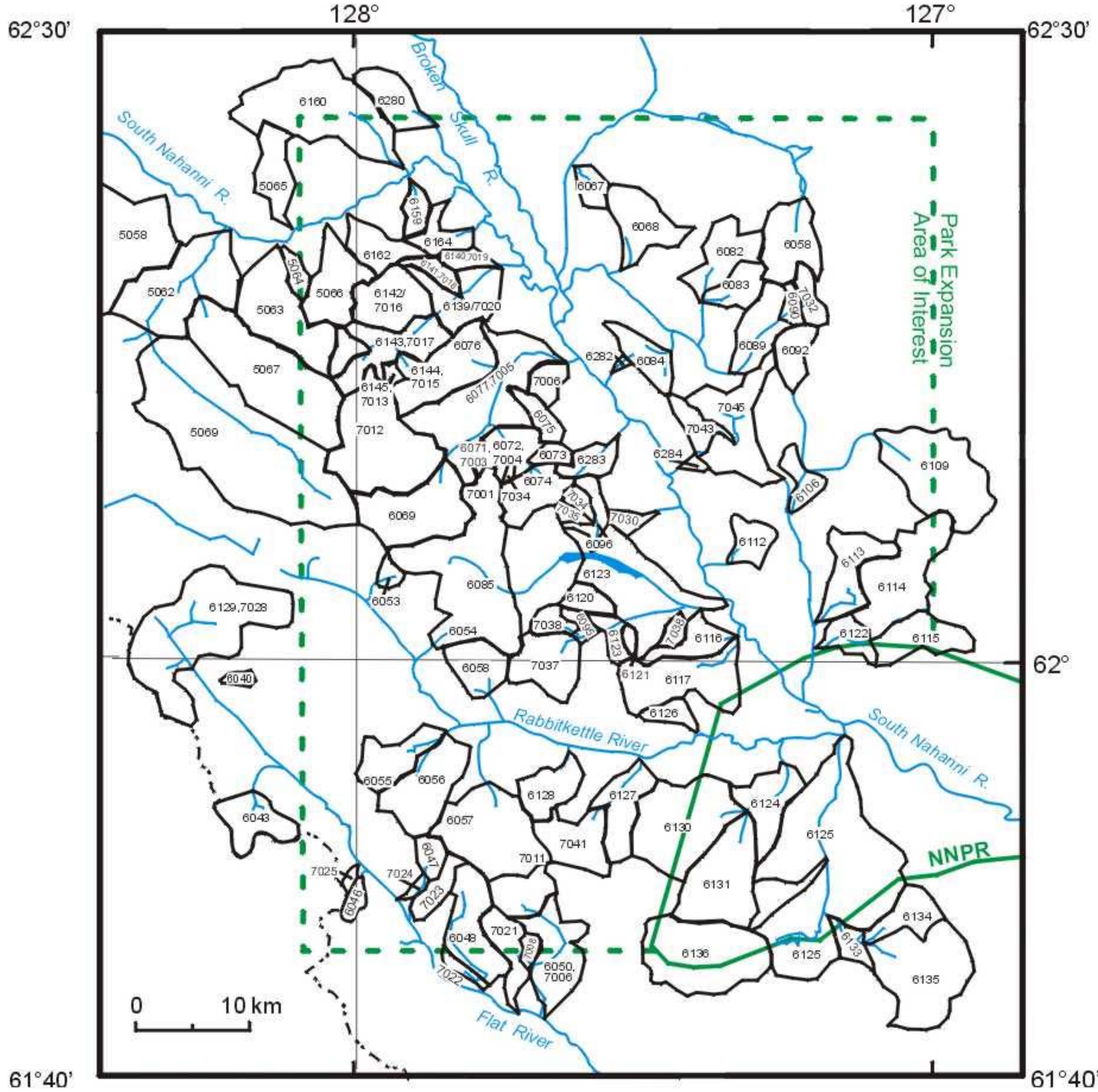

Figure 4.40b: Ragged Ranges Anomalous Basin Sample Numbers

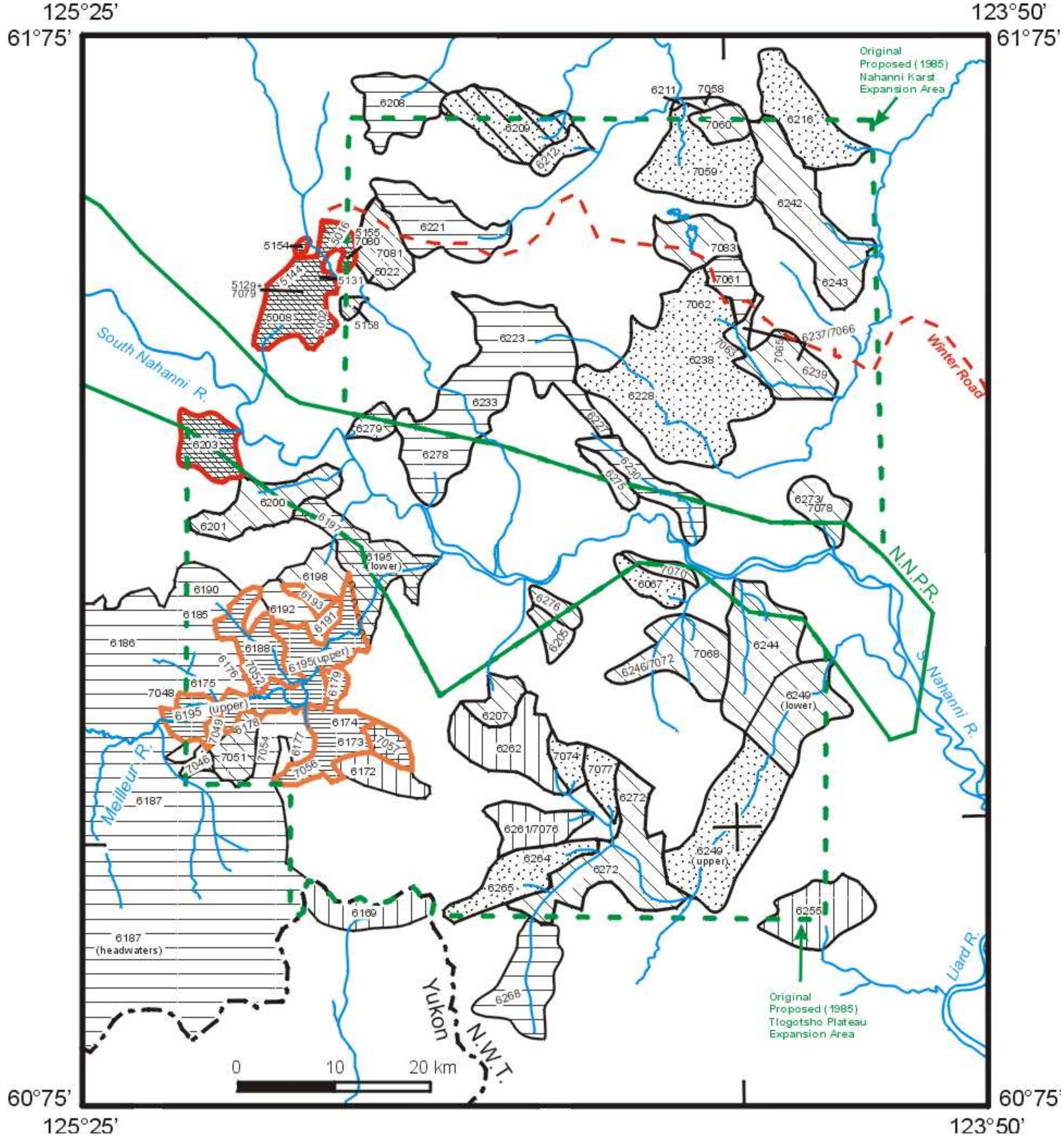

Figure 4.41a: NK/TP Mineral Potential Summary Map (for legend, see Figure 4.40a)

In NK/TP, geochemical indicators for mineral potential are not as widely distributed (Figure 4.41a) as RR, however they are intense and focused in two areas. This is not surprising because of the lithology (no igneous activity, mainly stratabound mineral environments) and the paucity of known occurrences. The two strong foci, both somewhat unexpected, are the north-south trend of placer gold anomalies from Wretched Creek south to Jackfish River, and lead-zinc anomalies in Meilleur River valley.

In the case of gold, various possibilities are discussed above, with the conclusion that the gold is of distal placer origin, not related to any nearby lode deposit(s). This is because the usual spectrum of geochemical indicators for precious vein deposits is lacking (with gold being the only anomalous element in most cases, and being present only in placer form.

The Meilleur River valley is a very different case, with many geochemical indicators of base metal potential as summarized in Table 7.2. These indicators (Zn-Cd-Ni-Co-Cu-U) are valid for both stratiform and stratabound silver-zinc-lead (Sedex and MVT deposit types), as well as for Ag-Pb-Zn veins such as at Prairie Creek.

The Mattson Creek Co-Cu-Mo association may indicate sandstone copper deposits, but they are most likely not very large or high grade. Rare earth abundances in the Mattson valley are not considered to have economic potential because they reflect normal abundance of zircon and monazite in a mature sandstone heavy mineral suite (Blatt et al., 1980). Figure 4.40b illustrates the sample numbers of the anomalous basins shown in Figure 4.41a.

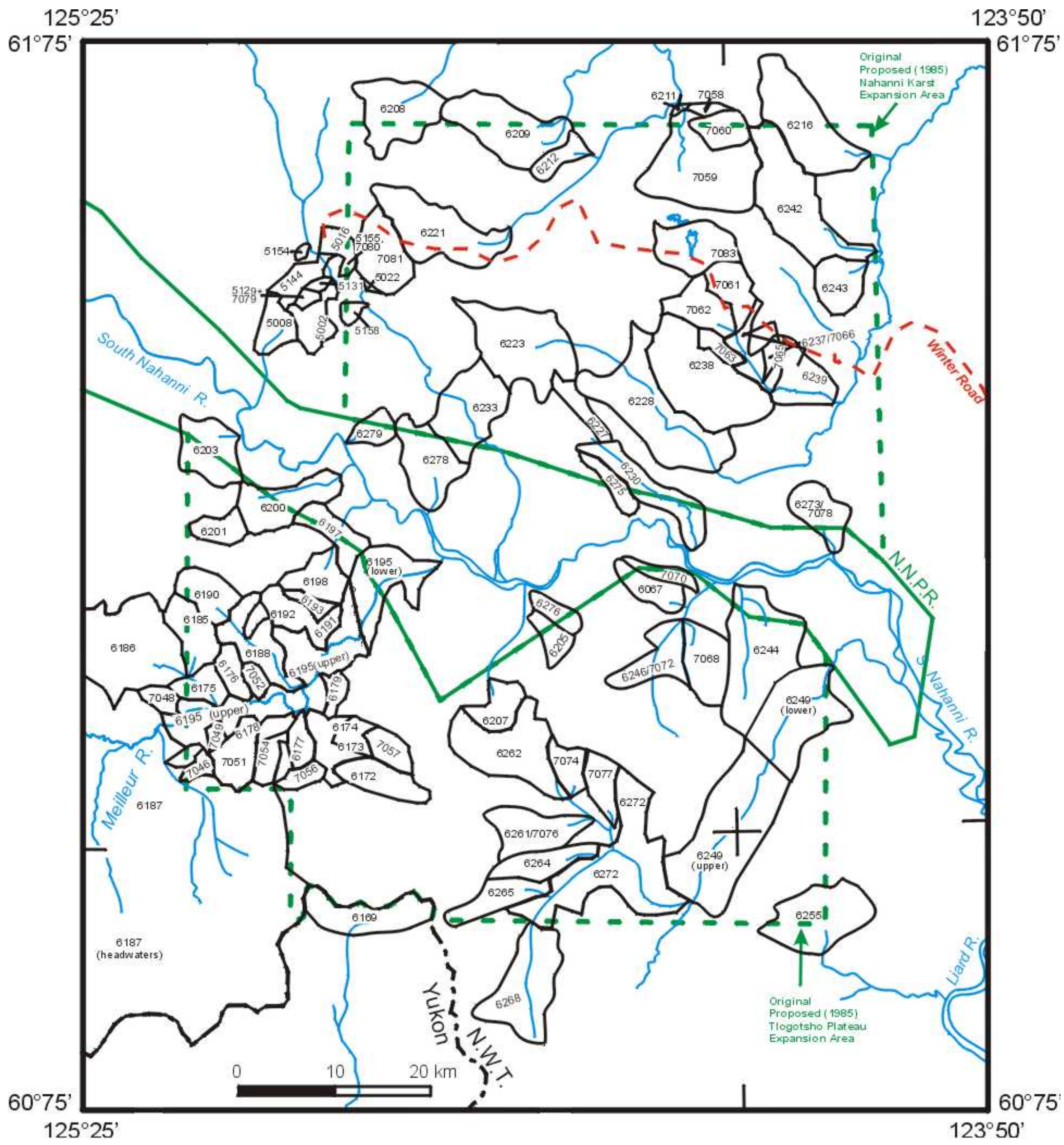

Figure 4.41b: NK/TP Anomalous Basin Sample Numbers