Current Research (2013) Newfoundland and Labrador Department of Natural Resources
Geological Survey, Report 13-1, pages 5-33

IDENTIFICATION OF LOCAL MAXIMA IN REGIONAL GEOCHEMICAL DATASETS

S.D. Amor
Geochemistry, Geophysics and Terrain Sciences Section

ABSTRACT

Strong regional (or 'global') geochemical features tend to set the regional threshold too high for the detection of more subtle anomalies. For example, background levels of fluoride in lake water are much lower in southern Labrador than farther north, which results in the non-appearance of an anomalous response to the REE mineralization at Pope's Hill if global threshold values, derived for the whole of Labrador, are applied to the data.

A filtering method has been devised that highlights local maxima in regional datasets, whether local background is high or low. Processing the fluoride data in this way shows that Pope's Hill is indeed associated with a local maximum. Where background is particularly high, for example in the Flowers River region, filtering the data has the equally desirable effect of drawing attention to local hot-spots, in both fluoride and REE, in what is essentially a large regional anomaly.

Elsewhere in Labrador, filtering the data has revealed the presence of an As dispersion train down-ice from Strange Lake. Dispersion from the Voisey's Bay Ni–Cu–Co deposit is also more clearly indicated in filtered data, although a subtle Ni response in lake sediment had been noted previously.

The filtering of Br data in the lake sediments from Newfoundland results in the appearance of a number of local maxima in the interior of the Island, which are masked in unfiltered data by the dominant effect of coastal lakes and the probable effects of marine incursion.

It is believed that a number of anomalies of potential economic interest may have been overlooked because of the masking effects of variable local background. It is proposed to re-evaluate the regional geochemical datasets from both Labrador and Newfoundland and release the results in 2013.

INTRODUCTION

In this paper, some commonly used methods of anomaly identification are reviewed. The percentile method is described in detail, and demonstrated on lake sediment and water analyses from Labrador. An adaptation of the percentile method is proposed and its implementation described in the identification of local maxima, which were not apparent from consideration of the unfiltered data, primarily in Labrador, and one example from Newfoundland. Some of these local maxima have been described in a previous release (including a fluoride anomaly west of Pope's Hill, and the Ni dispersion pattern associated with the Voisey's Bay deposit; Amor, 2012) and another forms a component of a previously known anomaly that has not been described previously (arsenic in the dispersion train associated with the Strange Lake deposit).

METHODS OF ANOMALY DEFINITION

Interpretation of regional geochemical data for mineral-exploration purposes requires a definition of what constitutes an anomalous value of an economic or pathfinder element; *i.e.*, what is the 'threshold', or upper limit of background variation, above which a geochemical analysis is considered to be deserving of further attention. In the very common absence of information gleaned from a geochemical orientation survey, or of many years of local experience, a threshold (or, possibly, a series of thresholds) must be derived internally from the dataset itself.

A POPULAR BUT OUTDATED APPROACH

An early approach to the identification of 'anomalous' geochemical values consisted of establishing the threshold as being equal to the arithmetic mean, plus two standard deviations (m + 2s). It is not known by whom this method was first suggested, but it appears to have become well-established by the time it was described by Hawkes and Webb (1962, page 27). If data are normally distributed and unimodal, this threshold corresponds approximately to the 97.5 percentile and it is believed that this was the motivation behind the method, since before the ready availability of computers the calculation of the mean and standard deviation for a large dataset, although still tedious, was easier (typically, through the use of tally sheets) than the extraction of even one percentile value. Unfortunately, lack of familiarity with statistics, particularly the latter's limitations, led to the m + 2s parameter being accorded a significance, both statistical and geochemical, that was far greater than originally intended. Also, the conditions of normality and unimodality are rarely satisfied in the frequency distributions of geochemical variables, so the relation of this statistic to the percentiles of the distribution is, in practice, unpredictable. This situation was lamented eloquently by Garrett (1989) but the practice continues.

IDENTIFICATION OF SUBPOPULATIONS

Other internally derived methods of deriving threshold values, and identifying samples deserving of follow-up, look for discontinuities in an element's frequency distribution. The subpopulation whose median is highest is, intuitively, most likely to be associated with mineralization (or possibly contamination), although this does not necessarily follow.

The use of probability graph paper, in which the cumulative frequency graph of a normal distribution plots as a straight line, to identify unimodal normally (or lognormally) distributed subpopulations of a geochemical dataset was described by Tennant and White (1959) and Lepeltier (1969), and refined by Sinclair (1974) before being implemented as a computer program by Stanley (1987). The method is effective for a limited number of geochemical variables, but becomes time-consuming when applied to a typical, contemporary multi-element dataset, even when computerized. This is because for each element it is necessary to experiment with an appropriate number of cutpoints, and the subpopulations they define, until the recombination of the latter matches the original frequency most closely.

Jenks' Optimization (Slocum *et al.*, 2009) is an option for subdividing a numerical dataset into a specified number of subsets, such that the variation within the subsets is minimized. The method is available as an option in current releases of ArcGIS® and is implemented very quickly even for very large datasets. However, the number of subdivisions must be specified by the user; although the program provides a default number, this is not data-dependent. Therefore, considerable experimentation must, in theory, be carried out, on an element-by-element basis, to arrive at an appropriate model. Once again, in a typical multi-element dataset this becomes a tedious process, although meaningful results can often be achieved by fixing this number, typically at 5 or 6, for every variable. The Jenks algorithm, and the data subdivisions that it creates, also appear to be susceptible to whether the data are linear, or subjected to a logarithmic or square-root transformation.

Finally, if the goal consists of the identification of indications of mineralization in large regional datasets, both the above population-splitting methods suffer from the inherent disadvantage that such indications are inevitably a statistical rarity. Therefore, they may not exert sufficient influence to be isolated as a subpopulation that is distinguishable in geochemical maps.

PERCENTILES REVISITED

The original, and plausible, intention of establishing thresholds based on percentiles of an element's frequency distribution has become easier to implement with the universal availability of hardware and software to process the data. MS-Excel®, for example, offers the option of calculating a user-specified percentile of a dataset, which is very rapid, or converting every value in the dataset to a percentile value. The latter is more time-consuming; the calculation of percentiles for every parameter in the lake database for Labrador, not including the analyses added recently (McConnell and Finch, 2012) requires approximately one hour of processing time with an Intel® i5 2.50 GHz processor, 4 GB of RAM and 64-bit operating system. Nevertheless, it has advantages in rapid map production and the principle assumes increased importance when filtering is implemented (*see* below).

The selection of samples whose values exceed the 97.5 percentile is analogous to the use of the mean plus two standard deviations (m + 2s). However, unlike the m + 2s method it is not susceptible to polymodal or skewed distributions, or distributions that are severely truncated (or censored) by the lower analytical detection limit, provided that at least 2.5% of the values exceed it. This latter situation is rather common in geochemical datasets, particularly for scarce elements that may be of great economic interest.

Of course, every geochemical population will have an upper 2.5%, even if none of the samples that comprise it are related to the presence of mineralization. At the same time, samples whose composition reflects the presence of mineralization will probably make up more than 2.5% of a set of samples collected from an area that is particularly well mineralized. Therefore, the areal distribution of such samples is critical; if the samples returning values that exceed the 97.5 percentile are concentrated into a limited number of discrete clusters, it is likely that they are related to mineralization, contamination, or at least, to a rocktype that is enriched in the element in question. If such samples are widely scattered and separated by samples returning lower values, the likelihood of their being of economic (or possibly environmental) interest is much less.

ONE THRESHOLD OR MORE?

Nevertheless, the excessively rigid application of a threshold, whereby values that exceed it are followed up and all that fall below it, by however marginal an amount, are permanently ignored, seems imprudent. This is particularly true for values that fall just below the threshold, and were collected from closely spatially associated sites. Such clusters of sample points are intuitively of more significance, compared to values falling just above the threshold that were returned for spatially isolated samples. With this in mind, it has proven useful to assign a second category, termed 'elevated' to samples whose values fall between the 90 and 97.5 percentiles. Like the term 'anomalous', which when used in this context does not necessarily imply either statistical or geochemical anomaly, the term 'elevated' does not imply the effects of some enrichment process, and other terms might be preferred by some users. It is quite likely that setting such a broad selection criterion will result in the highlighting of a certain number of samples that are not related to mineralization, particularly at the lower end of the range. However, it is considered unlikely that such samples will form discrete clusters. Furthermore, if the anomaly is false, the elevated values of a pathfinder for one economic element will probably not be accompanied by elevated or anomalous values of other elements' pathfinders.

Whereas point symbols representing the 'anomalous' class are assigned the warmest colour (such as red, or dark brown), or the largest symbol, points in this 'elevated' category are assigned a somewhat 'cooler' colour, such as yellow, green or pale brown, or a symbol of medium size. Points whose values fall below the 90 percentile are all assigned the coolest colour (grey, pale yellow) or smallest size. Such themes provide a rapid visual impression of zones of concentration.

Examples of the implementation of the percentile method described above, and of a modification thereof, form the core topic of this paper.

A dataset comprising percentile values can be processed cartographically very rapidly because the two threshold values separating the three data classes (background, elevated and anomalous) are always the same: 90 and 97.5. The legend for a geochemical map whose cutpoints are based on percentiles should, nevertheless, specify those cutpoints in the original units rather than percentiles.

APPLICATION OF PERCENTILES TO THE LABRADOR LAKE DATASET

Plots of four geochemical parameters, using the anomaly identification method described above, in which elevated and anomalous values are highlighted, are shown for the whole of Labrador in Figures 1–4.

ARSENIC IN LAKE SEDIMENT (As1)

Arsenic constitutes a useful pathfinder element for most types of gold deposits. Its distribution (Figure 1) shows extensive zones of anomalous and elevated samples over rocks of the Labrador Trough, in the west, and of somewhat weaker enrichment over the Central Mineral Belt (Greene, 1974). Other than weakly defined features on the northern and southern Labrador coasts, there are very few other features that would attract the attention of an exploration company.

FLUORIDE IN LAKE WATER (Fw9)

The distribution of fluoride in water (Figure 2) confirms this parameter's usefulness as a pathfinder for rare-earth elements (REE), with well-defined anomalies associated with known REE occurrences, and in some cases the latter's glacial dispersion trains, at Strange Lake, Flowers River, Ytterby 3 and Two Tom Lake. Over rocks of the Grenville Province in the south, including the Pope's Hill occurrence west of Goose Bay, which has no anomalous signature, fluoride values are generally much lower.

Figure 2 includes a section line passing through Strange Lake, Ytterby 3, Two Tom Lake and Pope's Hill. A profile of the lake-water fluoride values along this line is discussed below.

CESIUM IN LAKE SEDIMENT (Cs1)

Cesium values (Cs1; Figure 3) show extremely strong enrichment over rocks of the Labrador Trough, particularly north of latitude 54º15'N. They appear to define a halo around West MicMac Lake (west of Postville), with less strongly enriched values over the Central Mineral Belt, the Québec-Labrador border north of Strange Lake, and on the Labrador coast at the extreme north and south of the area of coverage. A few other 'hot spots' of restricted size are also present.

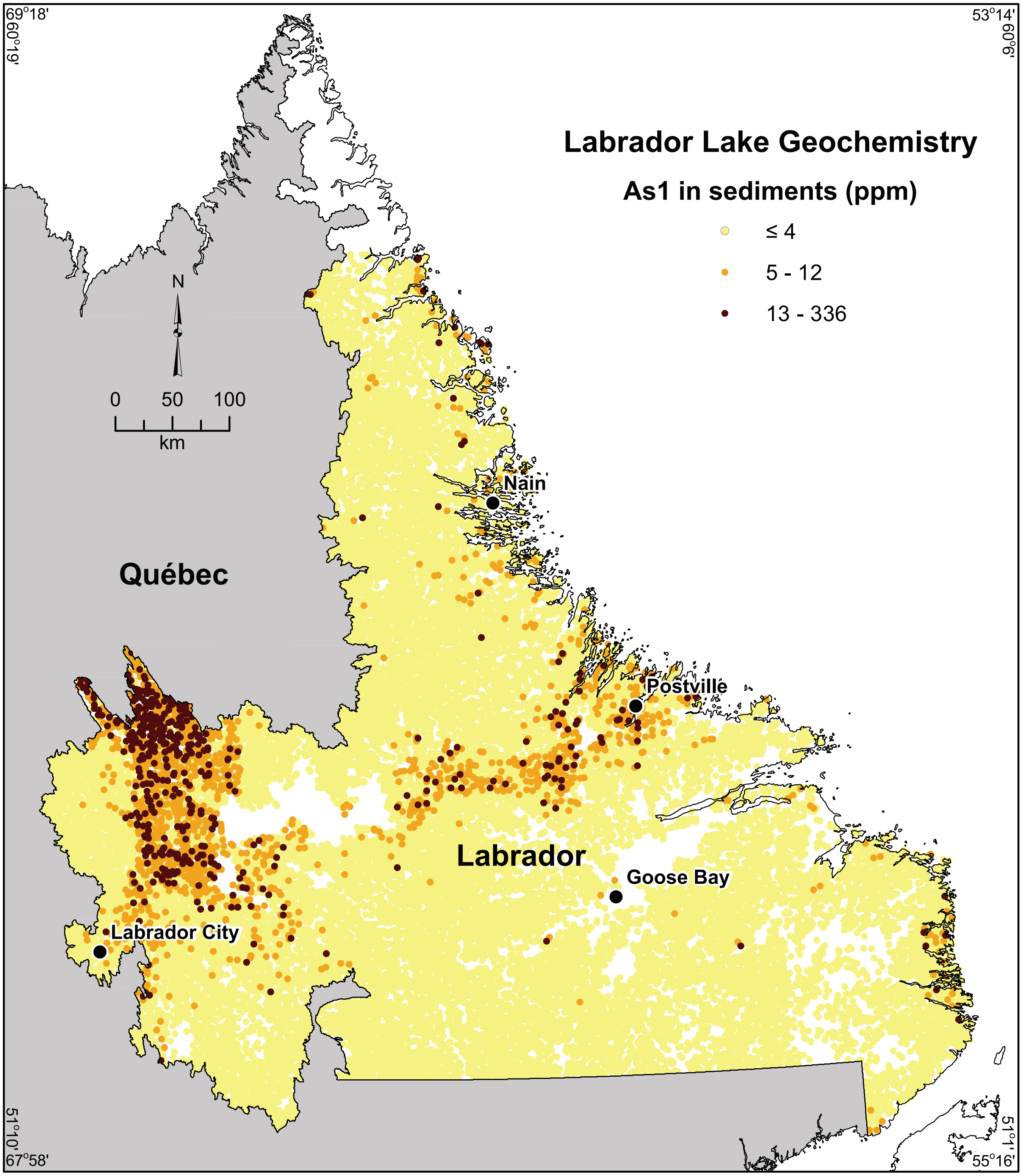

Figure 1. *Distribution of arsenic (As1) in lake sediments, Labrador.*

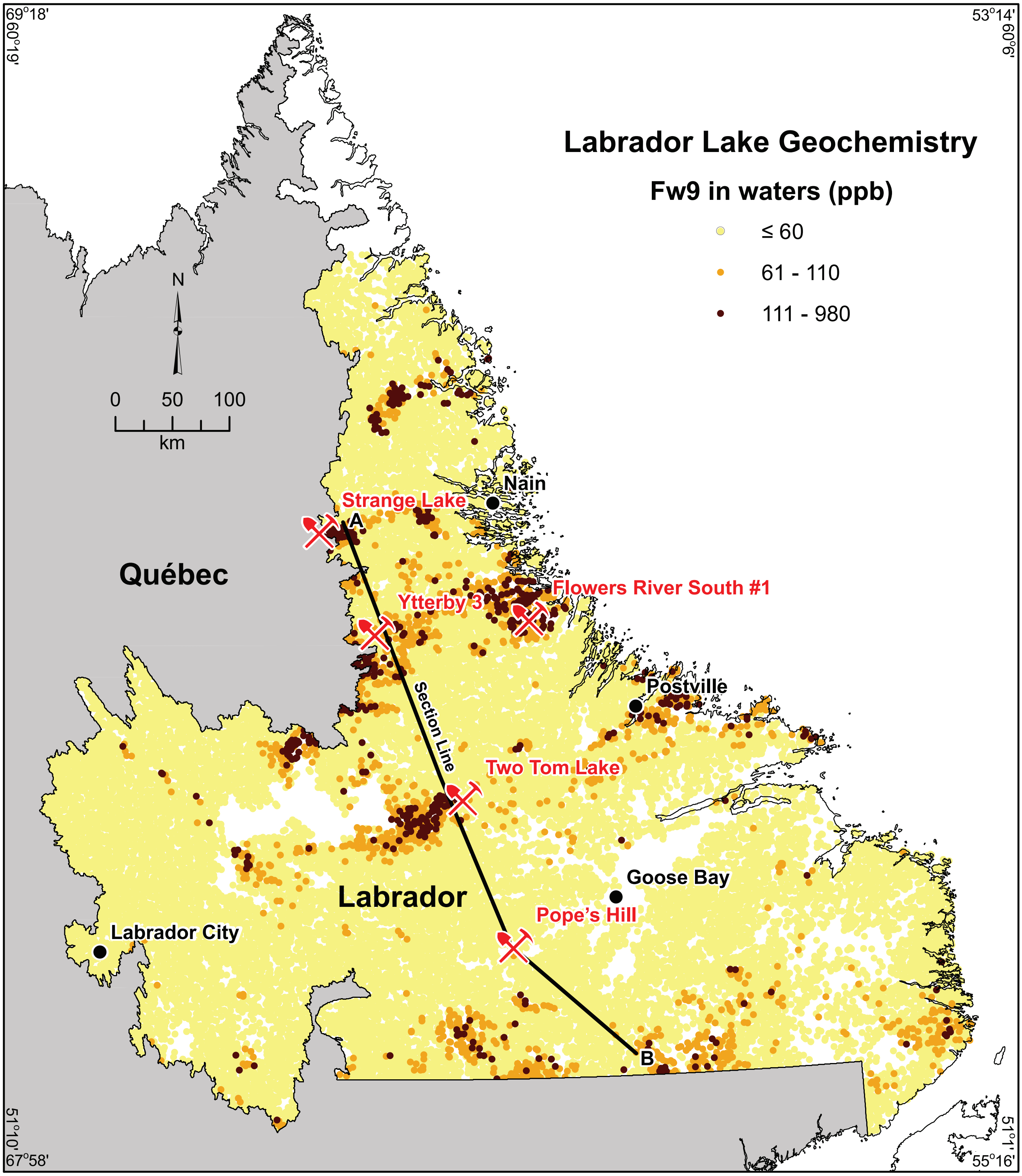

Figure 2. *Distribution of fluoride (Fw9) in lake waters, Labrador. A profile of Fw9 values along the section line is shown in Figure 5.*

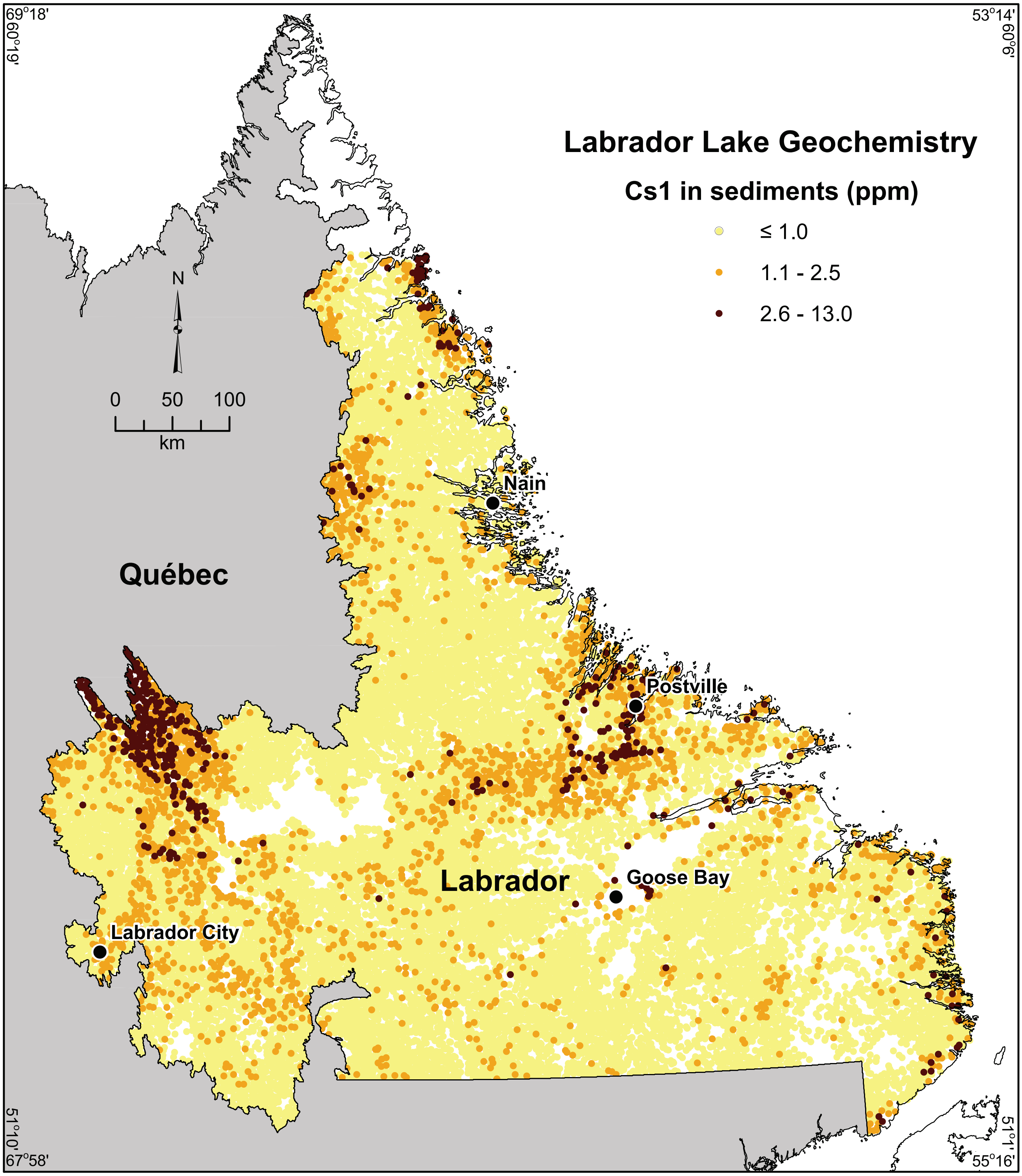

Figure 3. *Distribution of cesium (Cs1) in lake sediments, Labrador.*

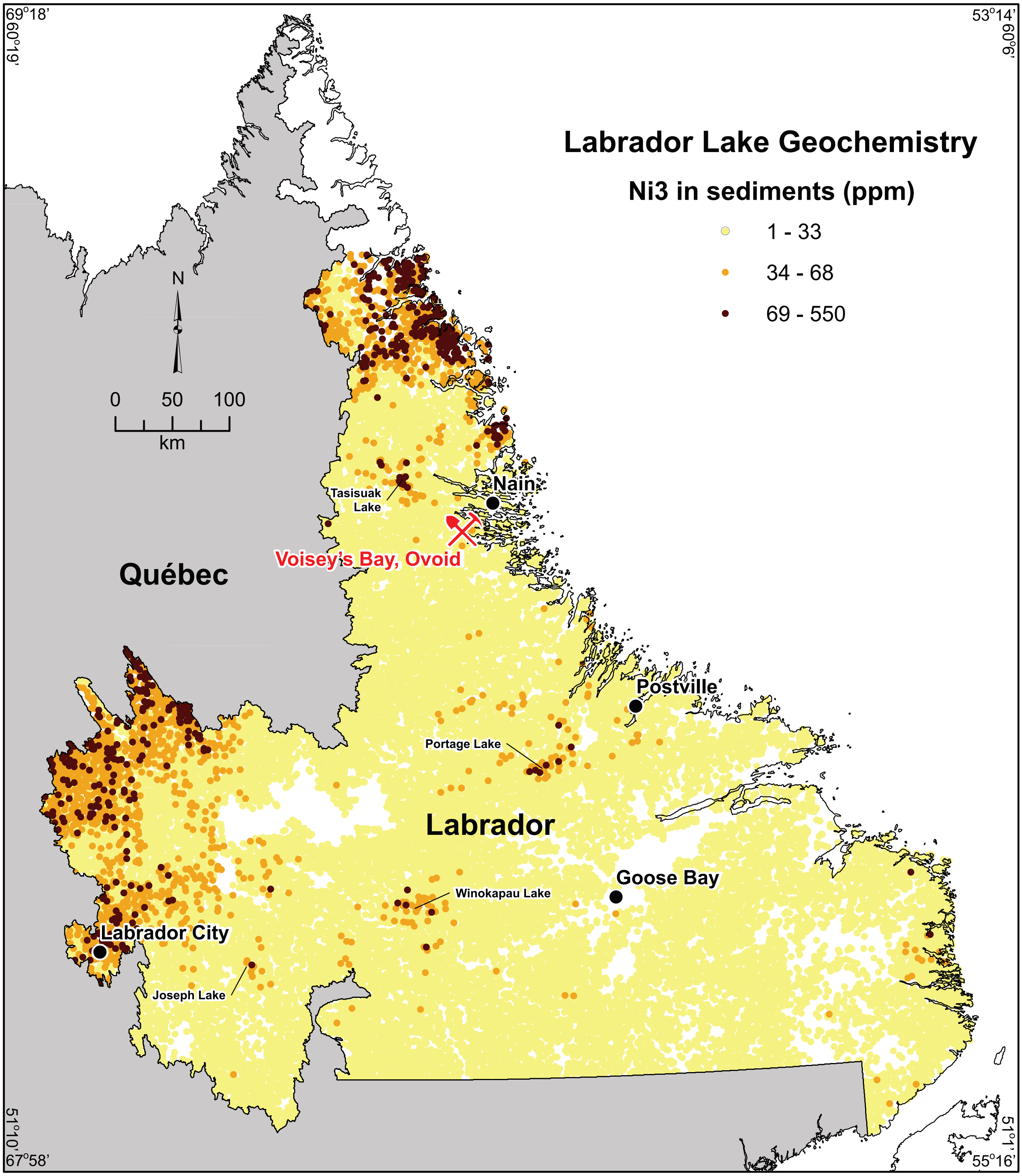

Figure 4. *Distribution of nickel (Ni3) in lake sediments, Labrador.*

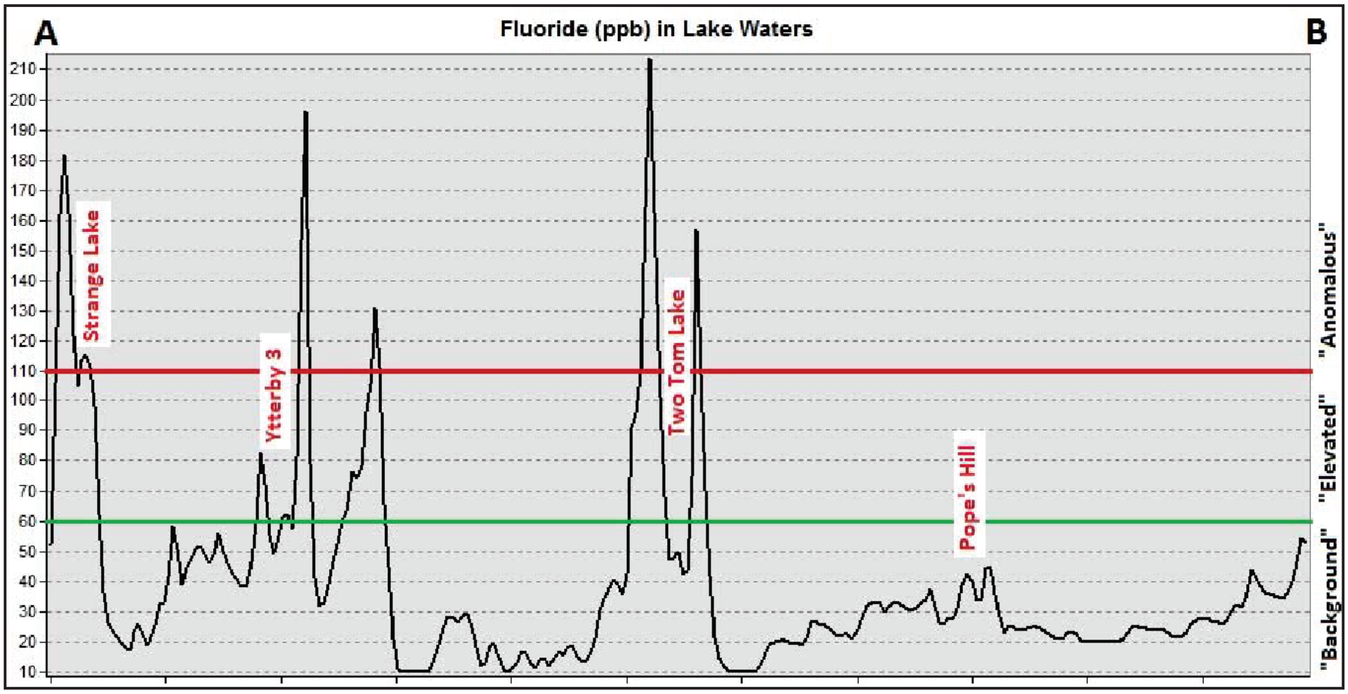

Figure 5. *Profile of fluoride in lake water (Fw9) along section line (*see *Figure 2; line A–B).*

NICKEL IN LAKE SEDIMENT (Ni3)

The principal impressions of Labrador (Figure 4) are of anomalous and elevated Ni3 values over the Labrador Trough, both north of Wabush and south of Schefferville, although the latter feature also extends westward over rocks of the Superior Province. A very strong and extensive anomaly is also present in the extreme north of the sampled area, overlying Unit APtgn of the Nain Province (Eo-Paleoarchean orthogneiss, amphibolite and mafic granulite), containing numerous slivers of paragneiss, amphibolite and mafic granulite (Wardle *et al*., 1997). The Ni response over the remainder of Labrador is essentially flat, with the exception of Tasisuak Lake (NTS map area 14D/10), northwest of Voisey's Bay in the north, Portage Lake southwest of Postville (NTS 13K/06, 13K/07, 13K/10 and 13K/11), and north of Winokapau Lake (NTS 13E/07) and east of Joseph Lake (NTS 23A/14) in the west. The response to the Ni deposits at Voisey's Bay is not apparent when the data are displayed in this way.

LOCAL *vs.* REGIONAL THRESHOLDS

A recurring pattern in the regional data for Labrador, which the above examples illustrate, is that the strong responses to certain features have the effect of drawing attention away from local maxima in areas of lower background. The response of various elements (including Cs1 and Ni3, as shown here) to rocks of the Labrador Trough, and of fluoride to the dispersion train from Strange Lake, are examples of strong regional geochemical features that 'set the bar' (or bars) very high for the rest of the sampled area, where background may be lower but local maxima may be present. In the case of fluoride, the influence of such strong features in northern Labrador is such that the use of thresholds based on percentiles of data for all of Labrador, on which the anomalies in the north exert a very strong influence, results in the fluoride values from large areas of southern Labrador, including the area of REE mineralization at Pope's Hill, being classed as background (the response of this latter area will be examined further). Similar effects are noted for As and Ni.

If the fluoride data are viewed in section (Figure 5), along a line connecting Strange Lake, Pope's Hill and Labrador's southern border (Figure 2) it is apparent there is a local fluoride maximum at Pope's Hill; however, it does not reach either of the two thresholds (90 and 97.5 percentile) for Labrador.

Although section plots are very effective in locating local maxima in this way, it is not practical to construct and interpret multiple geochemical section lines of this type. There is, therefore, a requirement to create geochemical maps whereby the data are filtered in such a way that such local maxima are highlighted. The remainder of this paper describes the development and implementation of such a method.

THE FILTERING ALGORITHM

Since the method of conversion to percentiles, despite the limitations pointed out above, is reasonably effective in the identification of anomalies in regional geochemical datasets, it was used as a starting point in assessing the degree of anomaly for each sample with respect to its neighbours, rather than the entire Labrador dataset. Drawing a circle around each sample, and defining those neighbours as the samples that fall within a certain radius of it, has an intuitive appeal and the algorithm for treating the samples in this way is readily programmed, although it is computer-intensive and has not been integrated into a GIS application.

By a method analogous to the assignment of a percentile value to a sample with respect to the entire dataset (*see* above), the value of the sample at the centre of the circle just defined is assigned a percentile value with respect only to the samples that fall within the circle. This permits the emphasis of local maxima and reduces the effects of strong, spatially extensive anomalies elsewhere.

A utility Fortran program has been written to create filtered geochemical data. The input file consists of UTM coordinates and geochemical variables, in tab-delimited format. Essentially the program executes the following steps:

1. The data are read and stored in a 2-dimensional array.
2. The user specifies the geochemical variable to be processed.
3. The program selects the first search radius (currently set at 20 km).
4. The first sample is selected. The coordinates of this sample form the centre of the search circle.
5. The Euclidean distance from the centre of the search circle, to every other sample point in the dataset, is calculated. If a sample location's distance from the centre of the search circle is less than the search radius, the sample qualifies as a 'neighbour' and the value of the geochemical variable is added to an array.
6. When all distances have been calculated, the values in the array created in Step 5 are sorted, and the value of the sample at the centre of the circle is ranked in this array.
7. The rank is converted to a percentile, and the percentile is assigned to the sample selected in Step 4.
8. The next sample is selected and Steps 5–7 are repeated.
9. When Steps 4–7 have been completed, the program selects the next search radius and Steps 4–8 are repeated.
10. When data for all of the search radii (20 to 100 km) have been compiled, the data are written to an output file in tab-delimited format and the program terminates.

With the aid of a spreadsheet application, the output data can be converted into a form compatible with a GIS application. As the data are expressed as percentiles, they can be readily identified and symbolized as 'anomalous', 'elevated' and 'background' in the same way as if the global 90 and 97.5 percentile were being used. It is not, however, realistic to represent them in compositional units in the legend, because the relationship between composition and percentile varies with each sample.

EFFECTS OF VARYING SEARCH RADIUS

EFFECT OF SEARCH RADIUS ON NUMBER OF SAMPLES

Assuming that the same sampling density is sustained over the entire area of coverage, the number of samples falling within a search circle is proportional to that circle's radius. In practice, there is always a shortfall between theoretical and actual mean (or median) number of samples in the search circle. This shortfall increases with increasing radius, because search circles that cross the boundary of the sampled area, which become more numerous as the search radius is increased, will be partly empty. The observed relationship between search radius and median total of enclosed samples for Labrador (where the sample density is 1 per 15 km^2) and Newfoundland (1 per 7 km^2) are shown in Figures 6a and b.

EFFECT OF SEARCH RADIUS ON PATTERN COHERENCE

Figure 7 demonstrates the way in which the distribution patterns for one geochemical variable, *e.g.*, nickel in Labrador lake sediments, change as the search radius is increased. The progression is typical of that displayed by most elements, with low search radii resulting in an essentially random scattering of points representing 'anomalous' and 'elevated' values. The latter tend to coalesce gradually into coherent clusters as the search radius increases, although this is to some extent data-dependent. Although each element would not be expected to show exactly the same characteristics in this regard, a search radius of 75 km seems to be suitable for most of them; this corresponds to a median of about 1000 "neighbours" in each search circle, for the Labrador lake dataset. As will be shown later, the corresponding radius for Newfoundland, where the sample density is higher, is different.

EXAMPLES FROM LABRADOR

Four geochemical features from Labrador, as defined

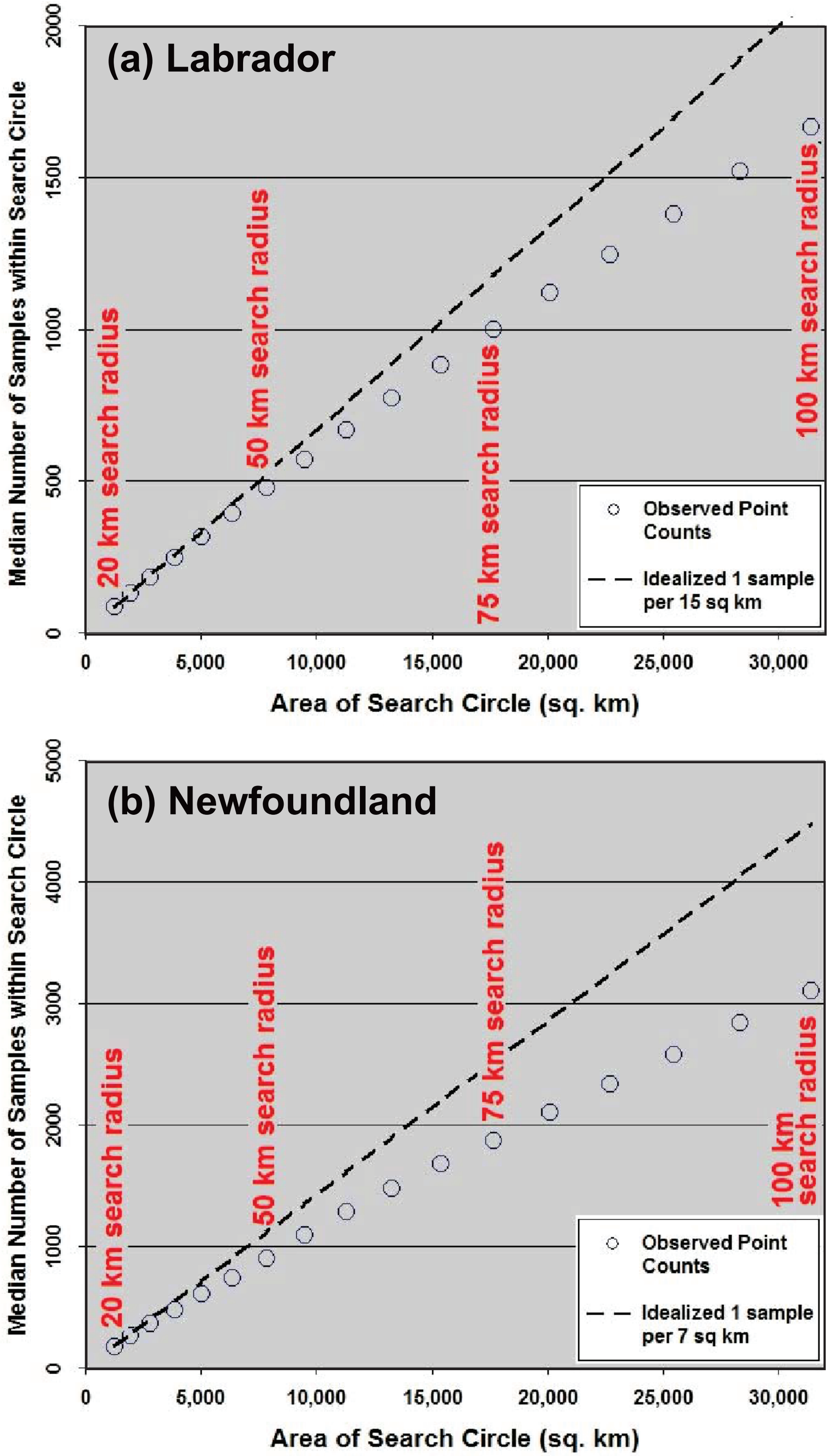

Figure 6. *Relationship between search radius and median total of enclosed samples;(a) Labrador (b) Newfoundland.*

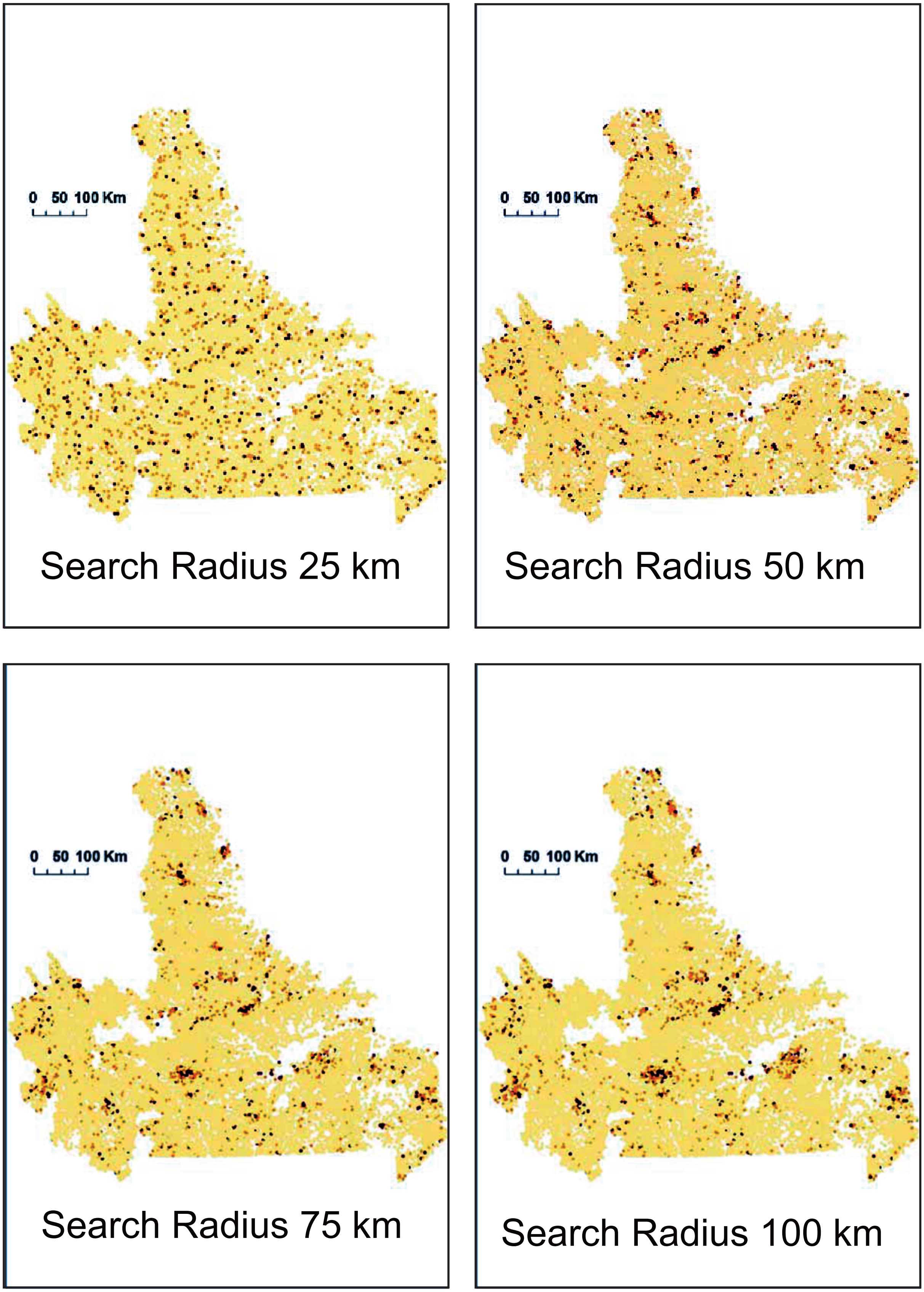

Figure 7. *Variation of distribution pattern of nickel in lake sediment (Ni3), Labrador. Search radius individually indicated.*

by the application of the filtering algorithm, are described below. Three of these (Lower Churchill, Flowers River and Voisey's Bay) were described previously (Amor, 2012) and one consists of a dispersion pattern in an accessory element from a known REE occurrence (Strange Lake).

LOWER CHURCHILL

The Pope's Hill prospect (MODS number 013F/04/Ree001), approximately 55 km southwest of Happy Valley-Goose Bay (NTS map areas 13F/03 and 13F/04) consists of REE mineralization hosted in a peralkaline, syenitic unit of the late Paleoproterozoic (Silver Spruce Resources website). It is accompanied by two further indications: Pope's Hill T1 (MODS number 013F/03/Ree001) and Pope's Hill T2 (013F/03/Ree002). The Fig River South indication (MODS number 013E/03/Ree001) is hosted in a fault zone in siliceous biotite-, muscovite-, and sericite-bearing quartzofeldspathic paragneiss (the Disappointment Lake Gneiss) about 100 km west of Pope's Hill (Thomas, 1993).

If the criteria for elevated and anomalous values of fluoride, derived for Labrador, are applied to the lake-water data in the area (Figure 8), just one elevated value at the Pope's Hill REE occurrence, and three elevated values at the Fig River South occurrence to the west, are indicated, although as described above, there is a local maximum in the vicinity of Pope's Hill that does not surpass the global thresholds either for elevated or anomalous samples (and, therefore, does not appear on this map). By contrast, fluoride values whose rank and percentile are only assessed with respect to their neighbours (Figure 9) indicate clusters of elevated and anomalous values in the vicinity of both the Pope's Hill and Fig River South occurrences. In both cases, the anomalies are disposed to the east, northeast or southeast of the occurrences: a pattern consistent with ice-movement directions indicated by striations. Furthermore, there is another cluster of mostly elevated values about 30 km northwest of Pope's Hill, disposed to the east of a linear, north-striking intrusion (Unit P_3gr) in NTS map areas 13E/01 and 13E/08, composed of migmatitic gneiss, possibly derived from granite or granodiorite, and intruded by coarsely crystalline pegmatite dykes (Thomas *et al*., 2000). There is no response to the same intrusion in REE, or related elements such as Mo or Be, in either raw or filtered lake-sediment values. However, the response to Pope's Hill and Fig River South in these elements is also weak.

STRANGE LAKE

The dispersion train from the Strange Lake rare-earth-element (REE)–rare metal (RM) deposit has been well documented in terms of the response in lake sediments and other media to the REE and RM themselves, as well as certain other elements including Be and Pb in sediment, and fluoride in water (McConnell and Batterson, 1987). The previously documented response to at least one chalcophile element (Pb) is interesting, because the filtering of the As1 data in this study reveals a dispersion pattern in this element that is not apparent if 'global' criteria are applied to the Labrador data (Figures 1, 10 and 11).

FLOWERS RIVER

The documented mineral occurrences at Flowers River occur within a large, approximately circular regional anomaly of REE in lake sediments and fluoride in lake water, nearly 100 km in diameter (Figure 2). Therefore, in contrast to the situation at Pope's Hill, where REE and fluoride background are very low, background here is very high. The effect of applying the filtering algorithm to these data is to set an extremely high local threshold, so that only the highest values within the regional anomaly are indicated. This is also a desirable outcome, because it is unlikely that the large REE and fluoride anomaly is representative of an equally large zone of REE mineralization.

Figures 12–15 show the filtered and unfiltered values of fluoride in lake water (Fw9) and ytterbium in lake sediment (Yb1) in the Flowers River region; the patterns indicated by the two parameters are not identical, with a local fluoride maximum disposed directly over an area of known REE mineralization on NTS map area 13N/11 (Figure 14), and a corresponding feature defined by Yb1 about 20 km to the west (Figure 15).

VOISEY'S BAY

As has already been widely observed, the response in lake sediments to the Ni–Cu–Co mineralization at Voisey's Bay is not strong, and no anomaly is indicated when the analyses are classed by global Ni3 percentiles (Figures 4, 16). Filtered Ni3 values indicate that what is probably a Ni dispersion train, defined by a local maximum, is indeed present to the east of the zones of mineralization (Figure 17). Whereas a search radius of 75 km has been applied to most of the geochemical parameters from Labrador, a stronger response to the Voisey's Bay mineralization is obtained for Ni values that are ranked in search circles of 60 km radius. It is likely that the 75 km generalization, although convenient as a first pass, could be refined for other elements also.

The usefulness of the filtering process described here, at least in the case of Ni3 data, remains questionable when much larger and stronger features are present elsewhere in the same region, and not associated with known mineraliza-

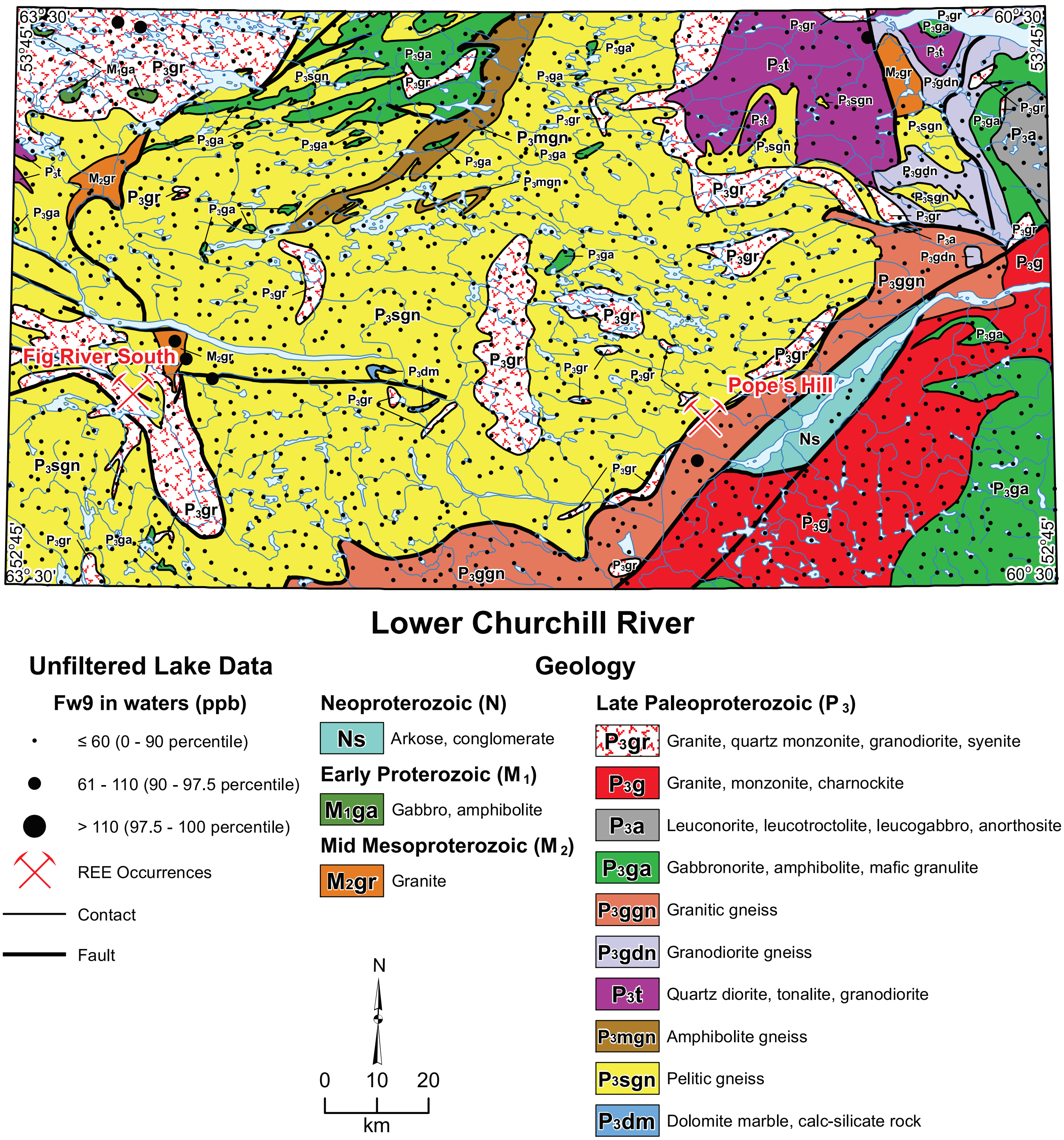

Figure 8. *Distribution of unfiltered (raw) fluoride in water (Fw9) in the lower Churchill River valley.*

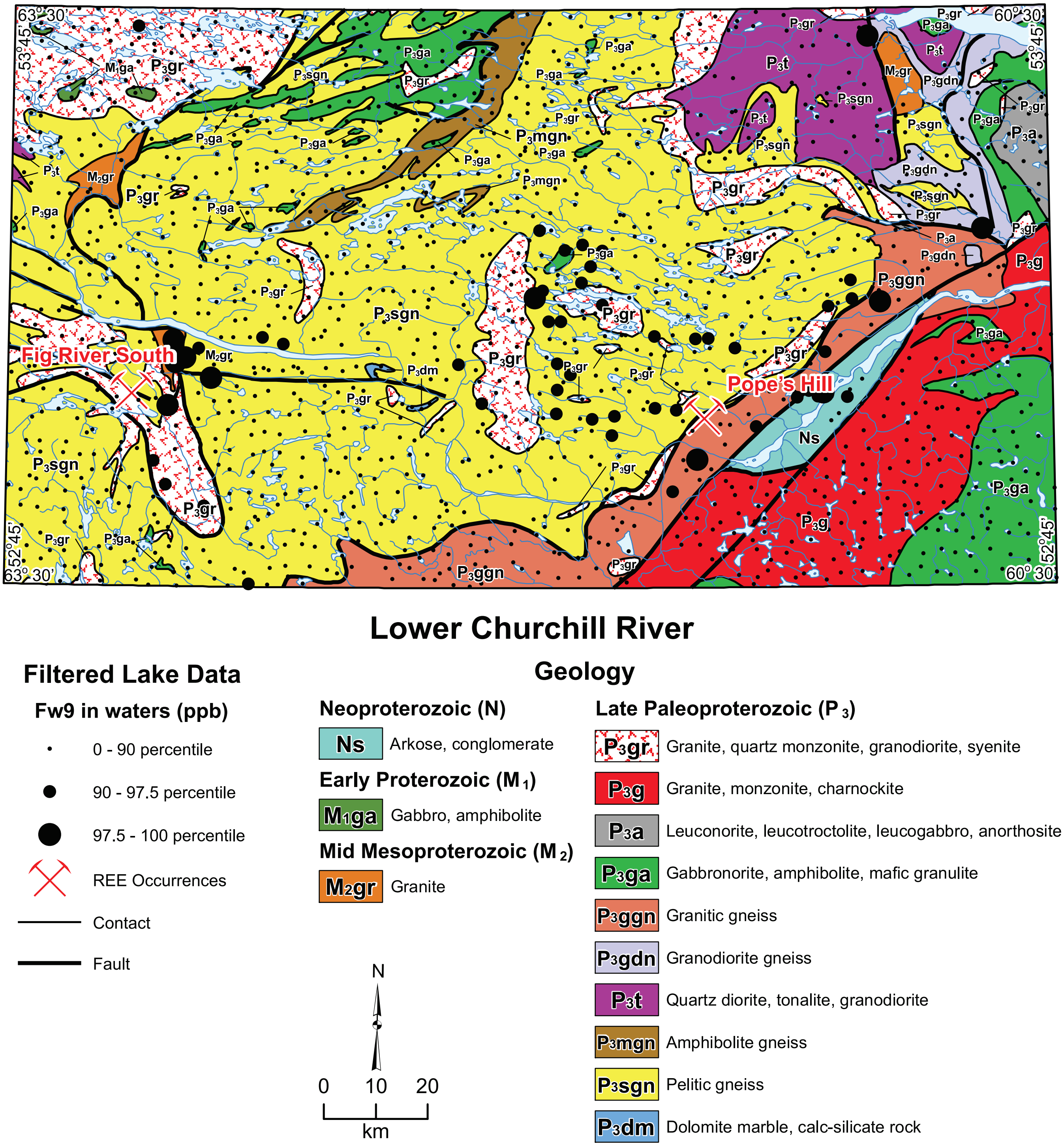

Figure 9. *Distribution of filtered fluoride in water (Fw9) in the lower Churchill River valley. Search radius 75 km.*

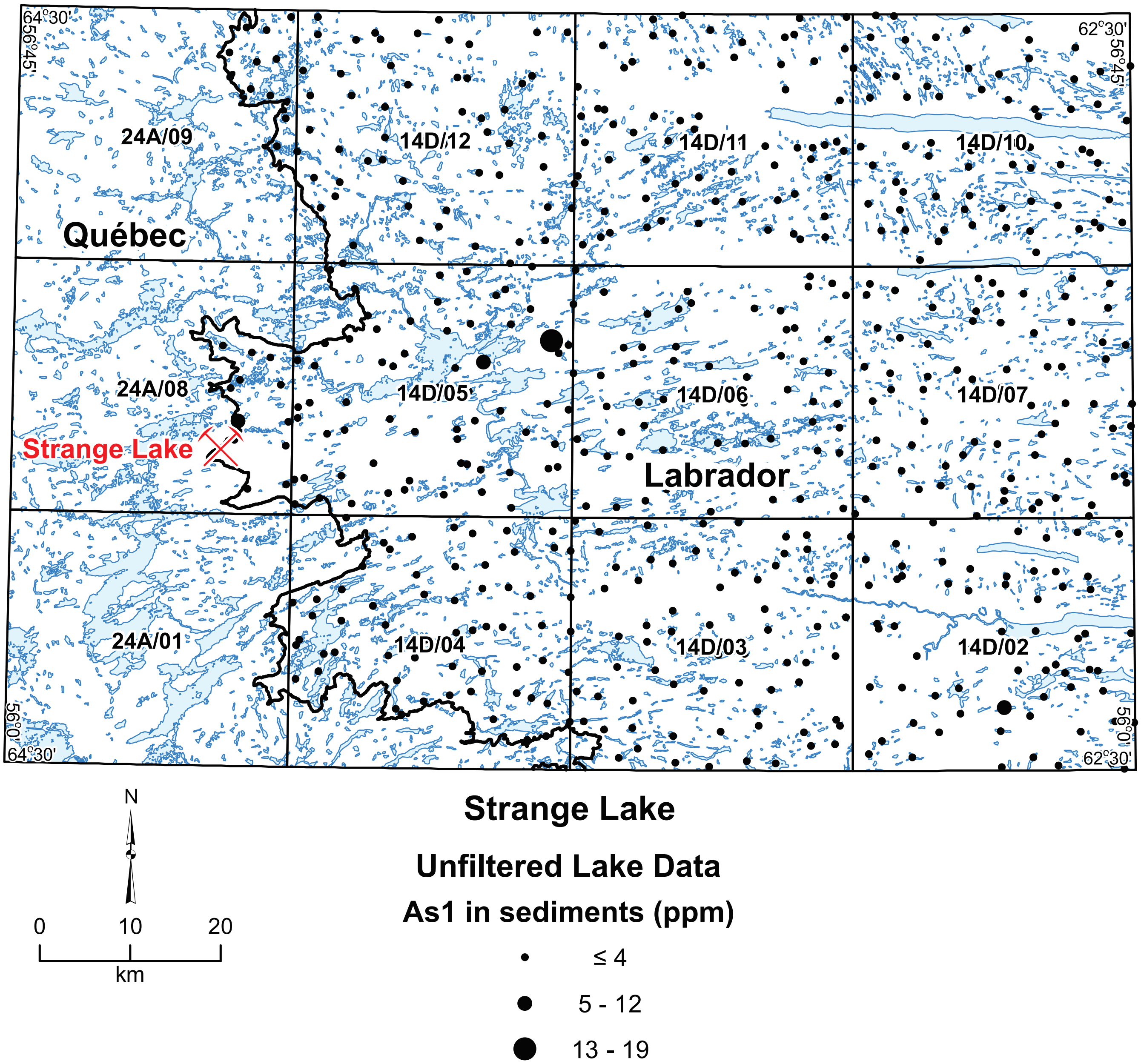

Figure 10. *Distribution of unfiltered arsenic in lake sediment (As1), Strange Lake area.*

tion. Specifically, in the northwestern and southwestern quadrants of NTS map area 14D/10, intensive exploration, including diamond drilling, has taken place, and only trace amounts of mineralization discovered.

EXAMPLES FROM NEWFOUNDLAND

Based on examination of the resulting plots, and coherence of the patterns generated for most elements, the optimal search radius for the more densely collected samples on the Island appears to be about 45 km. Possibly not coincidentally, this radius corresponds to approximately 1000 samples in each search circle; the same number of 'neighbours' contained within the 75-km-search radius in Labrador. The optimal radius is, however, likely to vary slightly from element to element depending on various characteristics of the latter's dispersion in the primary and secondary environments.

Figures 18 and 19 show the distribution of anomalous and elevated values of Br1 over Newfoundland. Bromine has limited economic significance, and was selected for demonstration purposes only. The unfiltered results plotted using global thresholds (Figure 18) are dominated by high values in lakes near the coast, with the result that no local maxima are apparent in the interior of the Island. That such

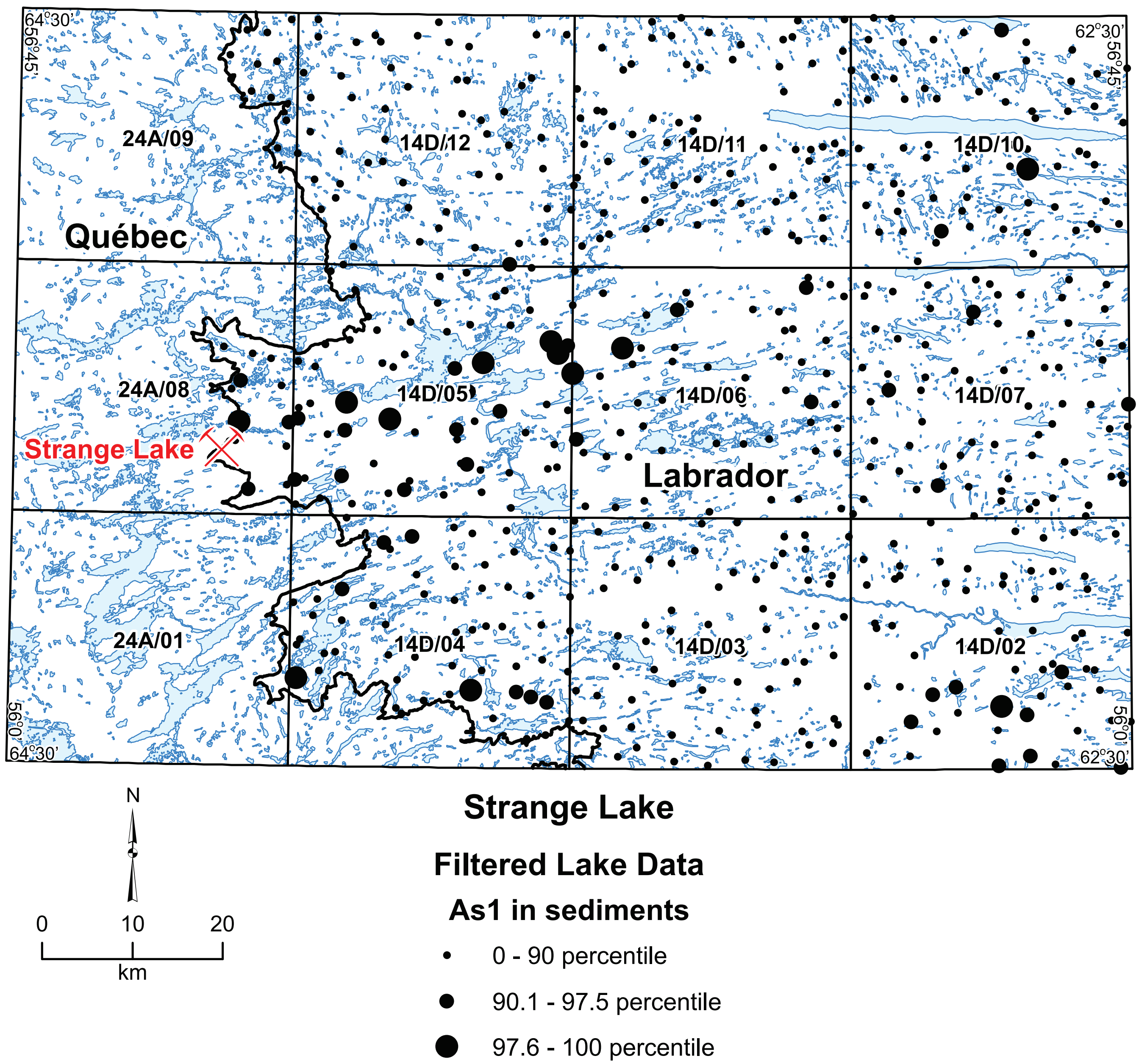

Figure 11. *Distribution of filtered arsenic in lake sediment (As1), Strange Lake area. Search radius 75 km.*

maxima do in fact exist is apparent when the data are filtered (Figure 19), although the strongest coastal anomalies are still discernible.

Detailed maps of the distribution of Br1 in the interior of the Island are shown in Figures 20 (unfiltered values) and 21 (filtered values). Local Br1 maxima are apparent astride Red Indian Lake (NTS map areas 12A/10 and 11), to the northwest of Meelpaeg Lake (NTS map area 12A/07) and in the southeast corner of NTS map area 12A/16 and southwest corner of NTS map area 02D/13. The cause of these local maxima is unknown; the underlying geology is different in each case, and there is no corroborative evidence of marine incursion that might have given rise to them.

DISCUSSION

MANDATE

Whereas values in the lower ranges may be of interest for other reasons (and in the case of certain parameters, such as pH in waters and LOI in sediments, may have relevance in the screening of false anomalies), the primary motivation for the current study is to identify 'top end' geochemical val-

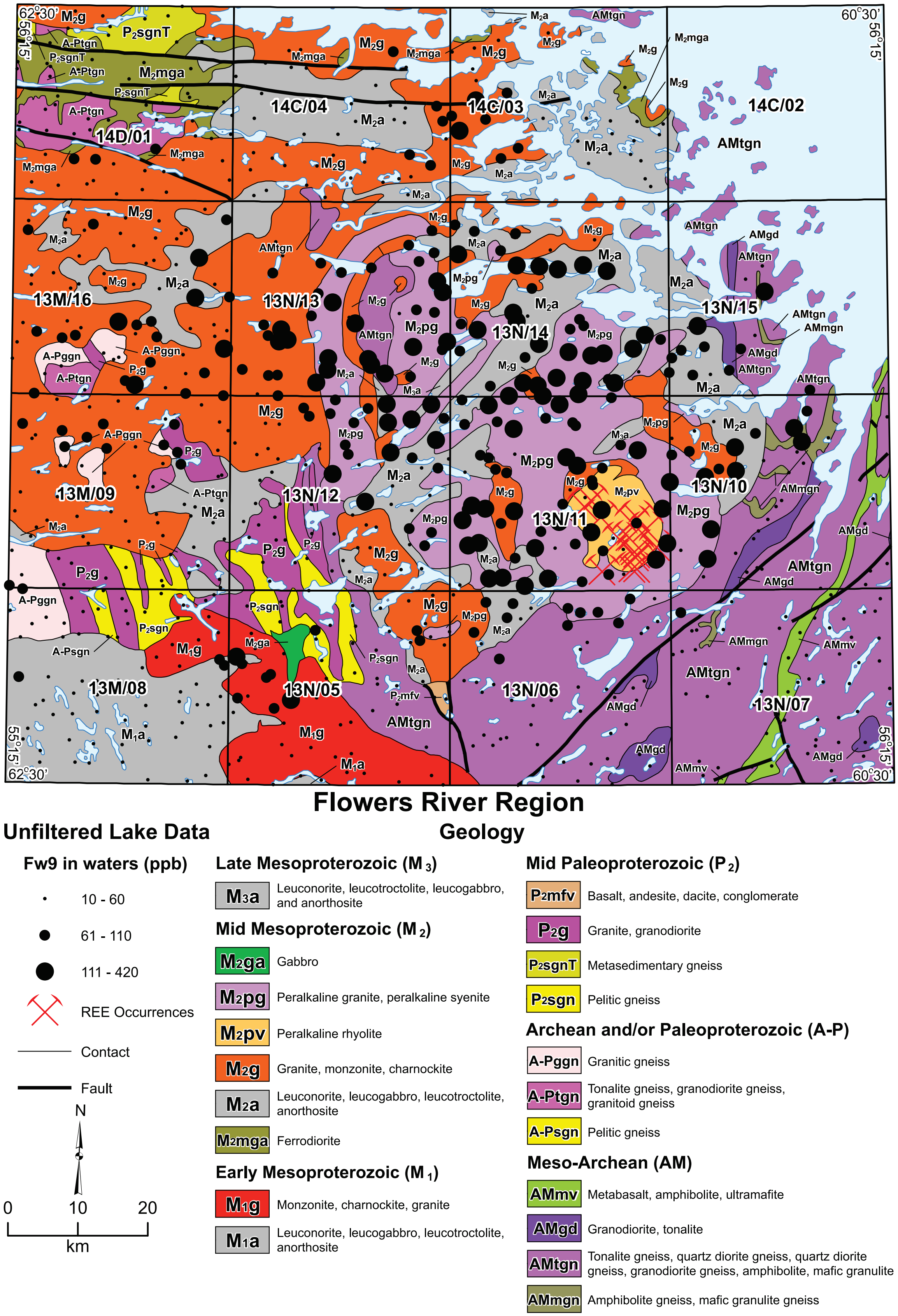

Figure 12. *Distribution of unfiltered (raw) fluoride in water (Fw9) in Flowers River region.*

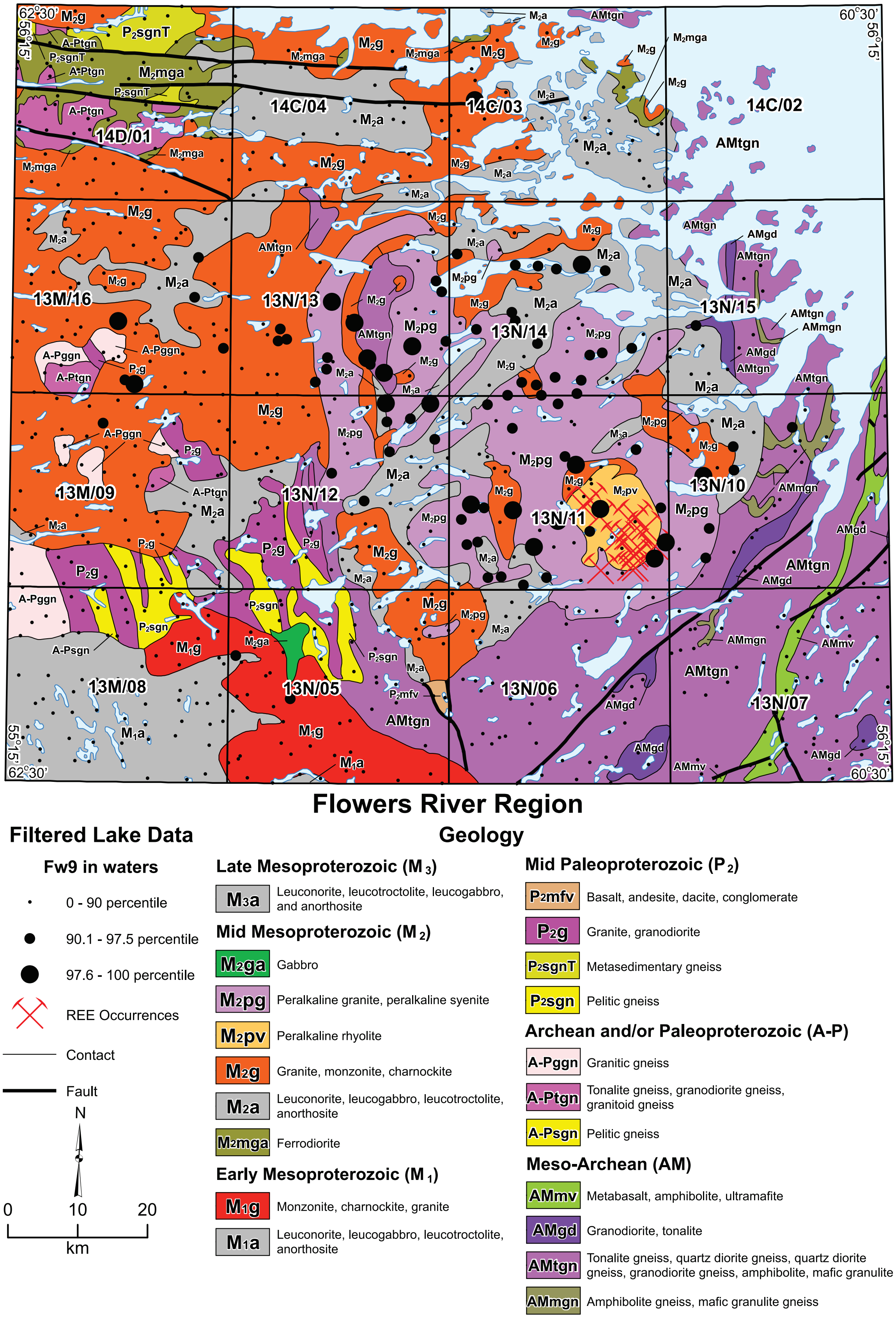

Figure 13. *Distribution of filtered fluoride in water (Fw9) in Flowers River region. Search radius 75 km.*

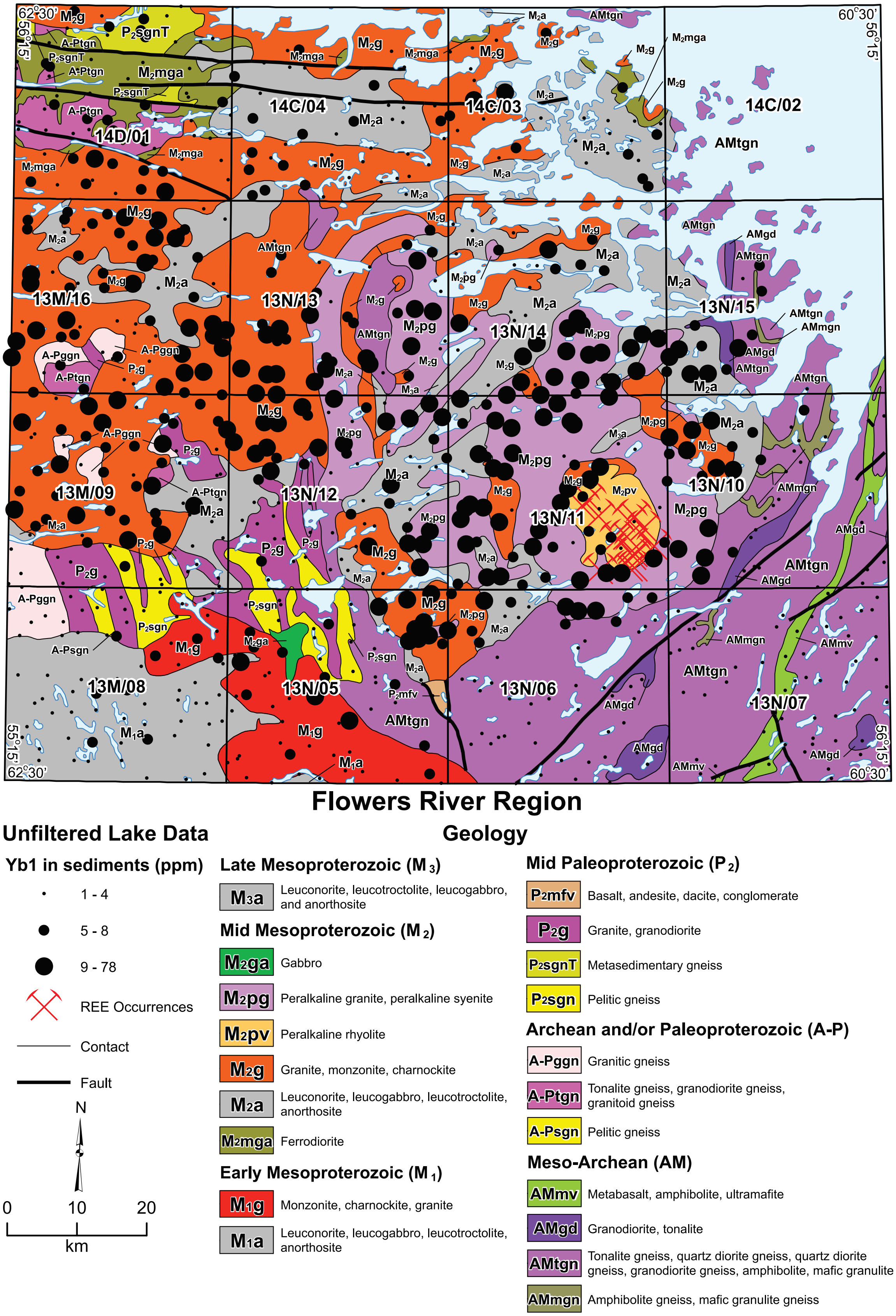

Figure 14. *Distribution of unfiltered (raw) ytterbium in lake sediment (Yb1) in Flowers River region.*

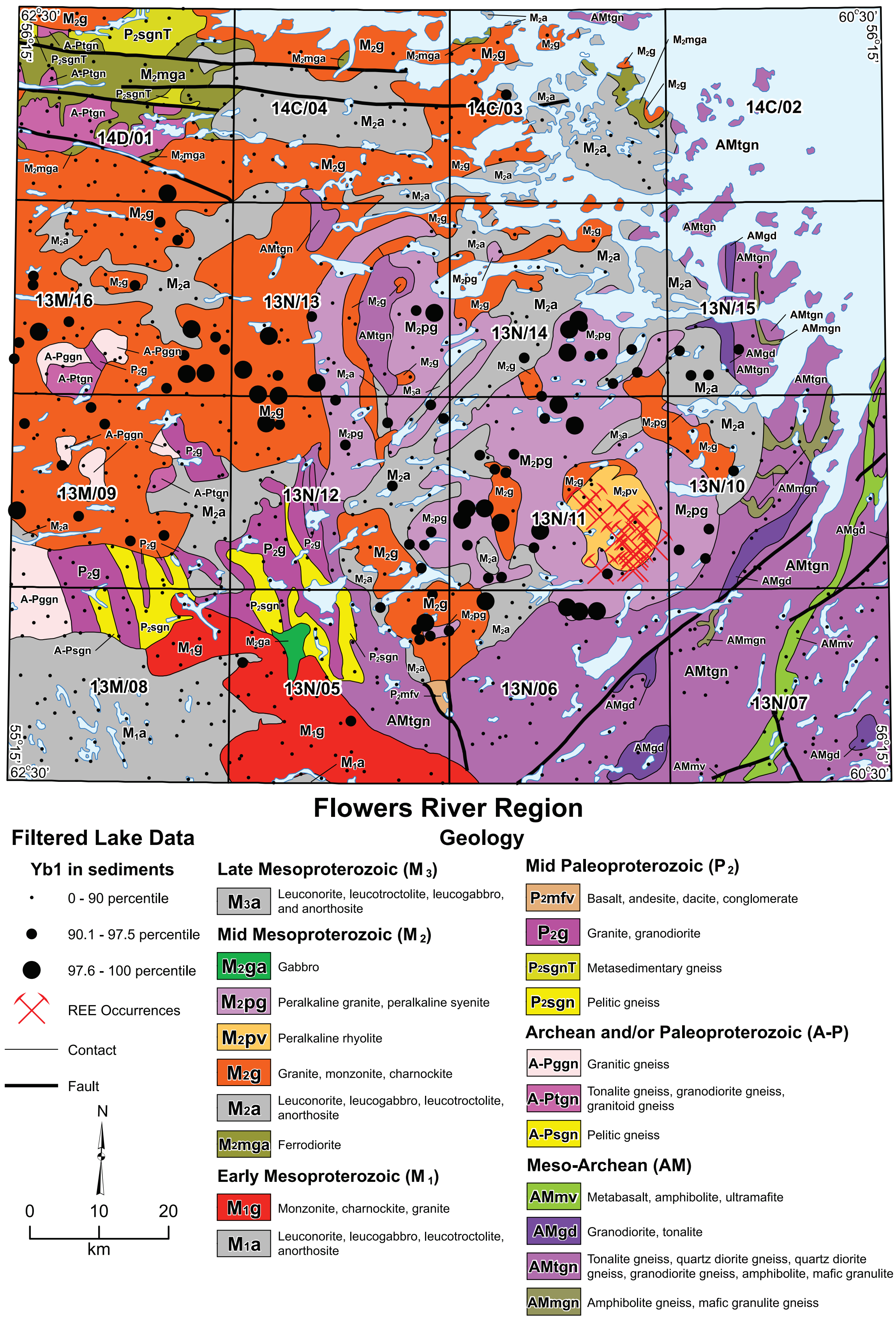

Figure 15. *Distribution of filtered ytterbium in lake sediment (Yb1) in Flowers River region.*

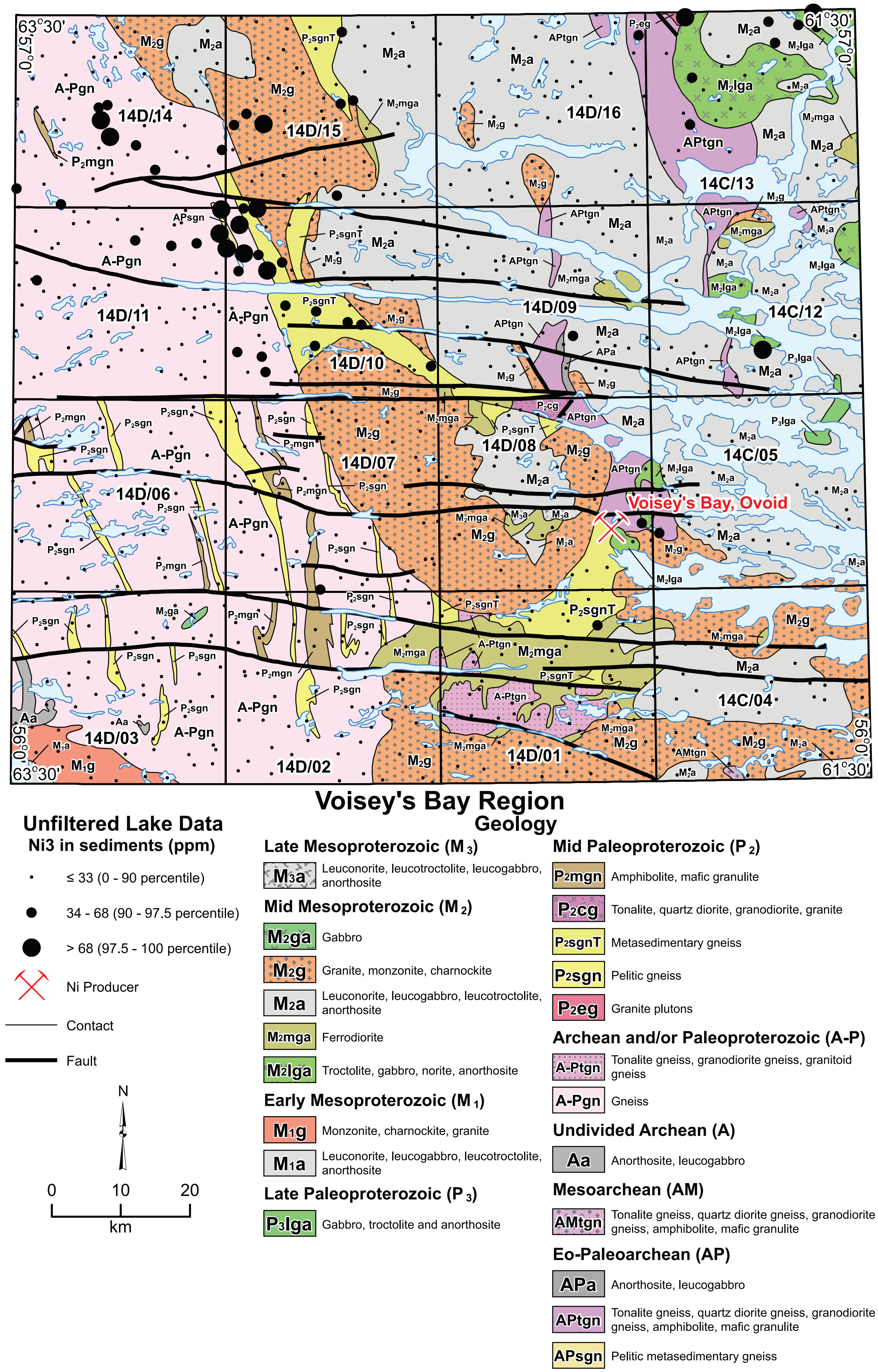

Figure 16. *Distribution of unfiltered (raw) nickel in lake sediment (Ni3) in Voisey's Bay region.*

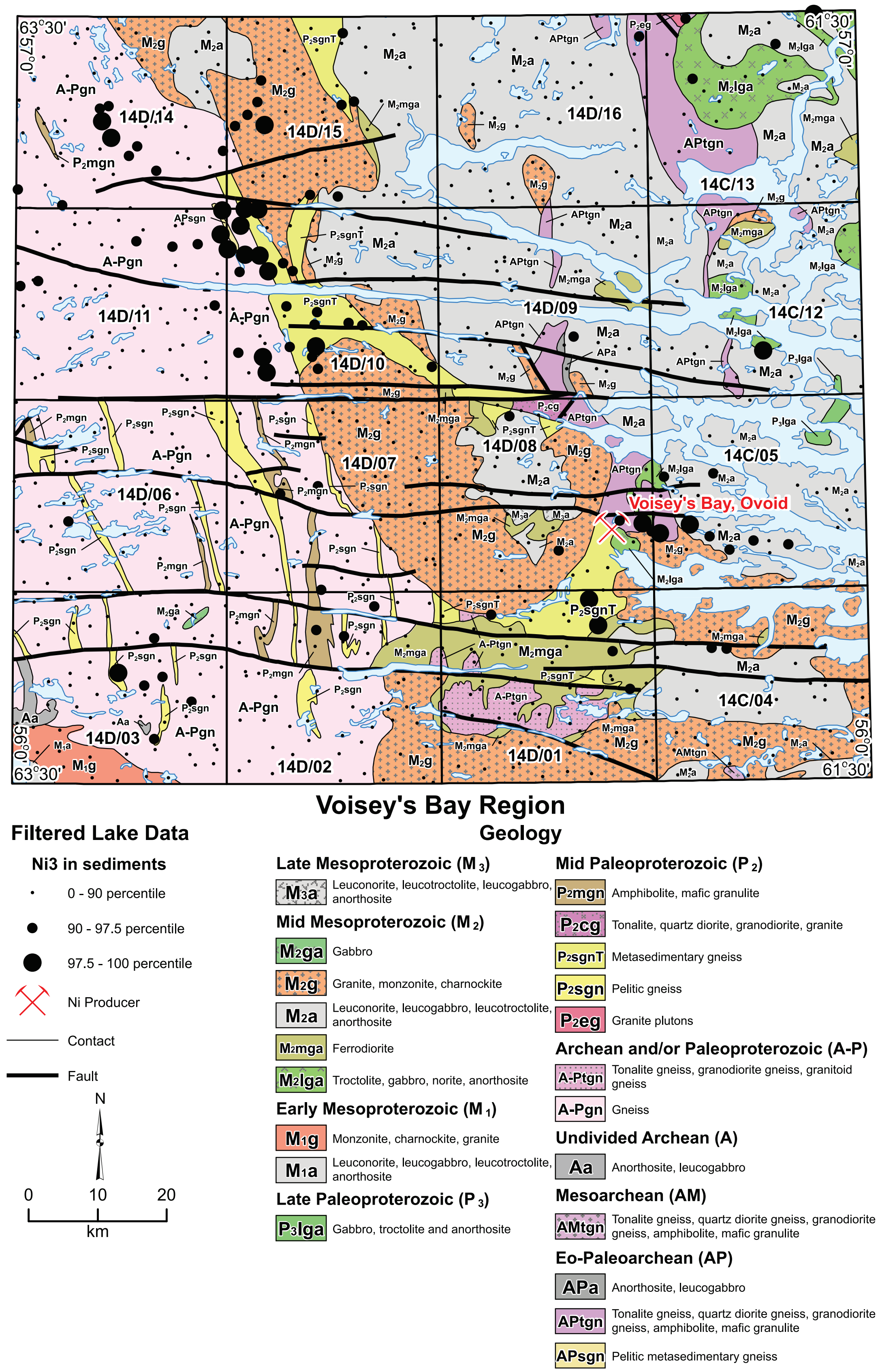

Figure 17. *Distribution of filtered (raw) nickel in lake sediment (Ni3) in Voisey's Bay region.*

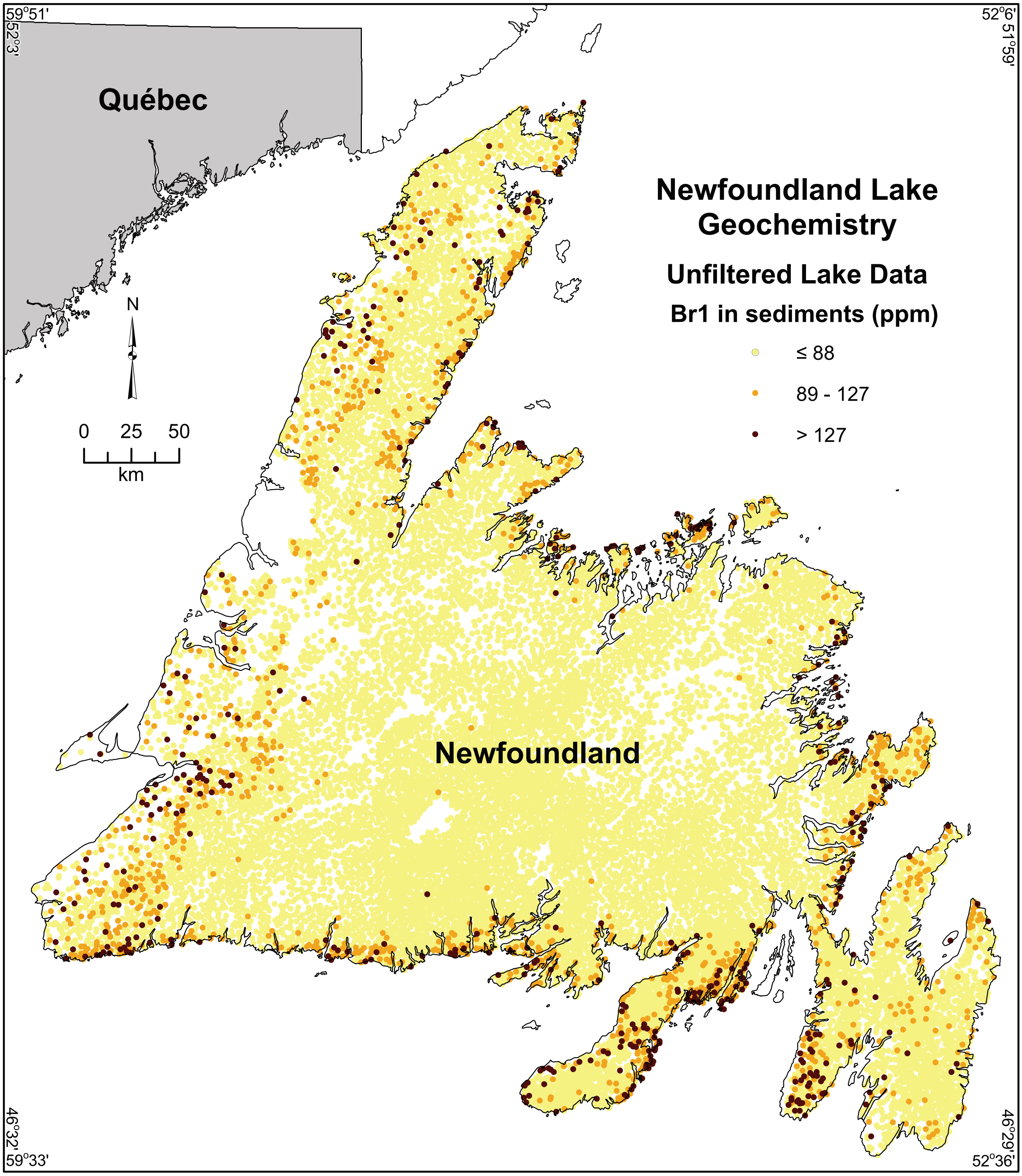

Figure 18. *Distribution of unfiltered (raw) bromine in lake sediment (Br1), Newfoundland.*

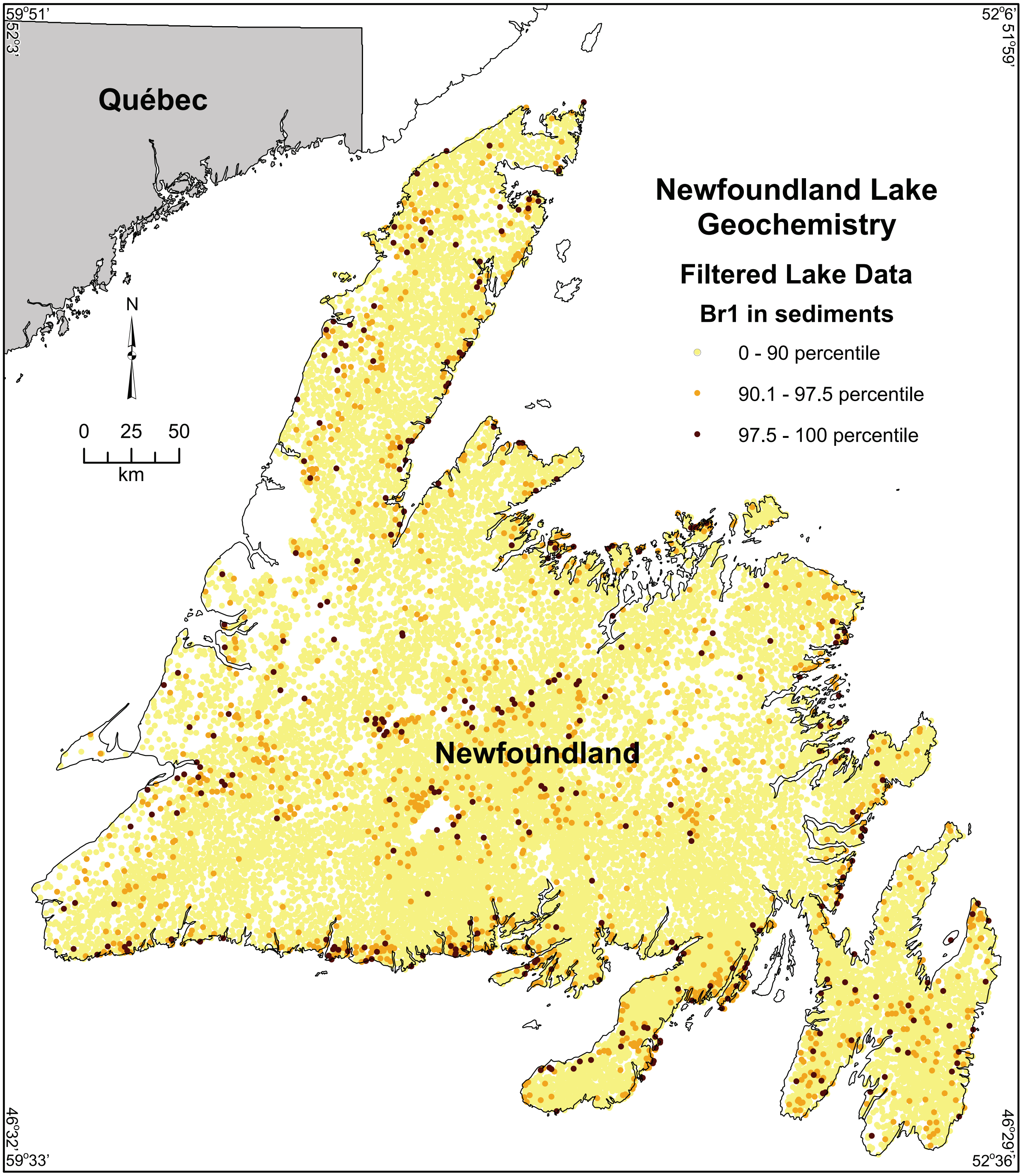

Figure 19. *Distribution of filtered bromine in lake sediment (Br1), Newfoundland. Search radius 45 km.*

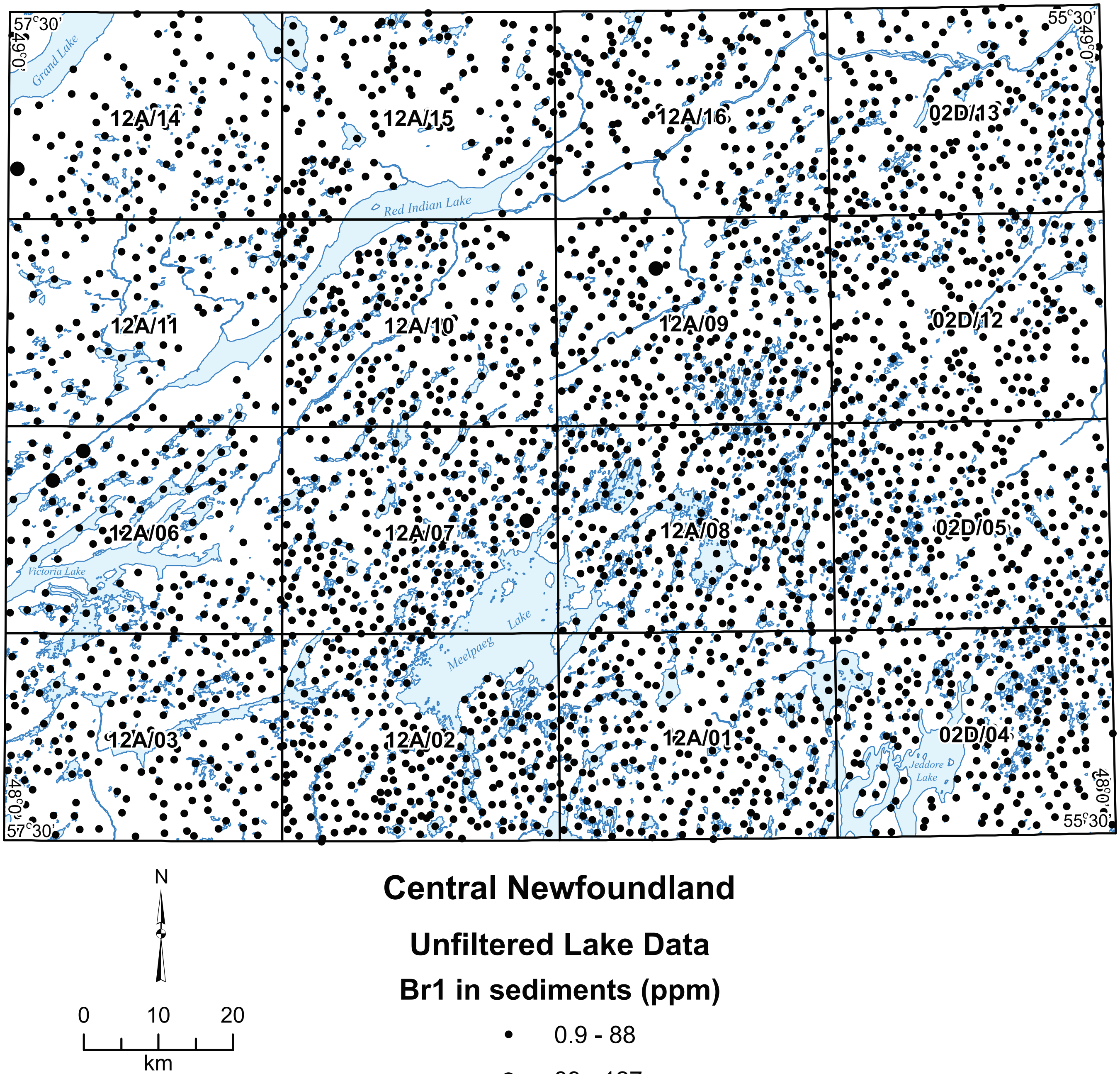

Figure 20. *Distribution of unfiltered (raw) bromine in lake sediment (Br1), central Newfoundland.*

ues that suggest the presence of potentially economic mineralization. This need dilutes one of the proposed advantages of population-splitting techniques using probability paper (or its digital equivalent), or Jenks' Optimization, whereby equal or greater emphasis may be given to subpopulations with lower median values, at the expense of values that are potentially of interest to the prospecting community.

The use of percentiles to draw attention to the highest values addresses this issue and is not subject to the onerous requirement of experimenting with multiple numbers of subpopulations to arrive at a suitable model (or, in practice, many suitable models, one for each geochemical parameter). Whereas local or global maxima thus identified may not be related to mineralization, the same is true of the uppermost class intervals defined by the population-splitting

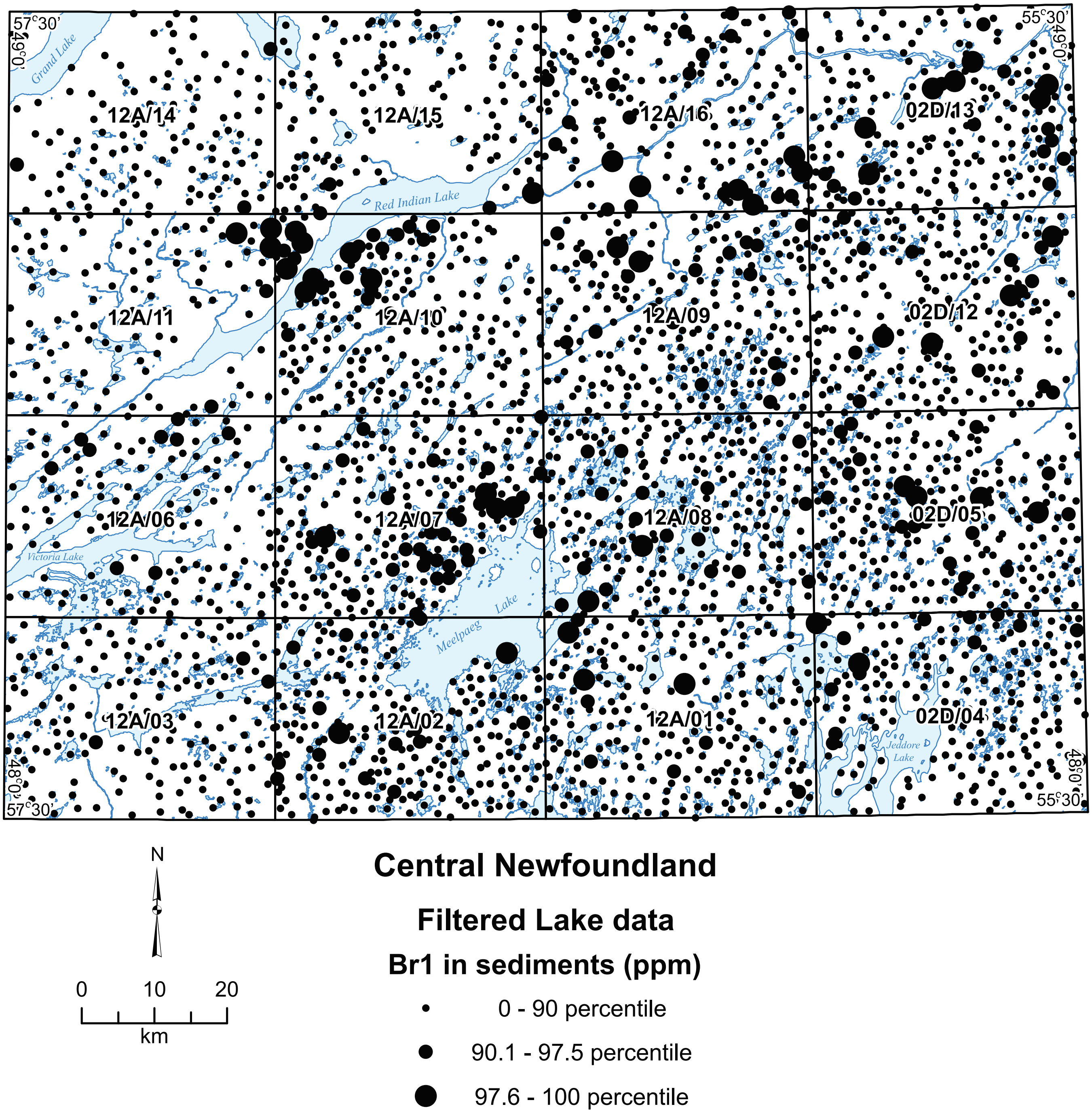

Figure 21. *Distribution of filtered bromine in lake sediment (Br1), central Newfoundland. Search radius 45 km.*

methods even if the latter are capable of detecting the anomalies.

OTHER WAYS OF IDENTIFYING LOCAL MAXIMA

The procedure described here is intended to propose that regional geochemical data be viewed in a different, although systematic, way, without being subjected to complex statistical procedures. That is not to say, however, that the evaluation of geochemical data using local criteria constitutes an entirely new approach. Whenever company or consulting geochemists evaluate their own surficial geochemical data for a mineral property, they will probably derive local thresholds from a set of samples whose geographical extent is constrained by the boundaries of the property. Because the area of sample coverage, and consequently the size of the dataset, is small, there is increased likelihood that ostensibly 'high' values may be unrelated to mineralization.

Plotting data in the form of profiles along section lines achieves the same aim as filtering the data by the method described in this paper; indeed, it probably does it better, because local maxima along the section line can be identified visually without the need to specify an appropriate search radius so that the data can be displayed in plan view. However, for a large dataset the length and orientation of the section lines need to be varied to create an inevitably very large, and potentially almost infinite, number of combinations in order to display all of the features of interest.

Through judicious use of appropriate class intervals and sized symbols, an anomalous Ni dispersion train was identified by Cook and McConnell (2001) down-ice from Voisey's Bay, in the same data on which the current study is based. Like the current study, these authors also identified a number of stronger Ni features that have not proven to be derived from significant mineralization.

OPTIMAL SEARCH RADIUS

Whereas a 75-km-search radius, and the approximately 1000 Labrador lake samples that it encloses (the corresponding figure for the Newfoundland samples is 45 km), has proven to be a useful first approximation for the search radius, the observation that the Ni response down-ice of Voisey's Bay appears stronger when data are ranked using a smaller (60 km radius) circle indicates that the filtering algorithm might be applied with more precision if appropriate search radii were selected for each element in turn. This requires further testing.

ELEMENTS THAT DO NOT BENEFIT FROM FILTERING

Application of a data-filtering algorithm to identify local maxima is justified by the observation that for many elements, strong, extensive responses in one area can set the bar so high that lower, but still locally prominent features elsewhere go unnoticed. There are many such examples, including As, fluoride and Ni in Labrador and Br in Newfoundland, as demonstrated here. However, this regional imbalance in response strength is not universal, and when an element is distributed more evenly over a large area, filtering the data will not result in the identification of local maxima that were not apparent in the unfiltered data. A number of elements, including Co3, Mn3 and Zn3 in Labrador and Ba1, Fe1 and Zn3 in Newfoundland, display this behaviour.

OTHER DATASETS AMENABLE TO THE FILTERING ALGORITHM

In addition to data from Newfoundland and Labrador, extensive regional geochemical databases have been compiled for lake-sediment and water data elsewhere in the Canadian Shield, as part of the Geological Survey of Canada's National Geochemical Reconnaissance (NGR) program. The program includes coverage of much of northern Ontario, Manitoba and Saskatchewan and smaller areas of Alberta, Northwest Territories and Nunavut. Stream-sediment and water data for British Columbia, Yukon Territory and parts of the Maritime Provinces also form a component of this program and the applicability of the filtering algorithm to these data also merits testing. All of the NGR data are available without charge, as are stream- and lake-sediment data from the National Uranium Resource Evaluation (NURE) program in the United States. Lake-sediment data may also be purchased from the Government of Québec.

OTHER FINDINGS

As far as is known, the behaviour of chalcophile elements in the primary environment at Strange Lake and other peralkaline granite–pegmatite REE–RM deposits has not been studied in detail. The Pb signature in the dispersion train from Strange Lake was noted previously (*e.g.*, McConnell and Batterson, 1987). The presence of this element, and that of As as identified in the current study, may have genetic significance as well as environmental implications in the matter of safe tailings disposal.

CONCLUSIONS

Strong regional (or 'global') geochemical features tend to set the regional threshold too high for the detection of subtle anomalies. A filtering method is proposed whereby the content of each sample, for a particular element, is ranked with respect to all of its neighbours, within a specified radius. The rank is converted to a percentile that is then assigned back to the sample. The process is repeated for all of the samples in a regional dataset. The plotting of these locally ranked percentiles has the effect of highlighting local maxima where local background is either low, or high, compared to most of the area covered by the data.

Background levels of fluoride in lake water (Fw9) are much lower in southern Labrador than farther north, where the response to such features as Strange Lake, Flowers River and the Red Wine Mountains dominates the Labrador dataset. Filtering the data enables the identification of a local fluoride maximum associated with the Pope's Hill

REE prospect and several other features in the same area. Where a large regional geochemical anomaly is present, *e.g.*, Yb at Flowers River, filtering the data allows the identification of 'hot-spots' within the larger anomaly. These do not necessarily coincide with known REE occurrences.

Filtered values of Ni in lake sediment define the down-ice Ni signature of the Voisey's Bay Ni–Cu–Co deposits better than their unfiltered counterparts, without the need for detailed fine-tuning of the class intervals for display, although the presence of this signature was already known. However, some stronger anomalies elsewhere in northern Labrador are equally well defined by filtered Ni values (and in some cases, by unfiltered values also) and most of these have already been intensively prospected without conspicuous success.

The response of Br in Newfoundland lake sediments is dominated by the response in coastal areas, presumably due to the residual effects of marine incursion. Filtering these data in the same way results in the appearance of a number of local maxima in the interior of the Island, whose origins are as yet unclear.

Results of the re-examination of the entire Labrador and Newfoundland datasets will be released as a timed-release Open File in 2013.

ACKNOWLEDGMENTS

Pierre Garigue provided guidance with programming. An earlier version of the report was reviewed by Martin Batterson. Thanks are due Neil Stapleton for drafting assistance.

REFERENCES

Amor, S.D.
2012: A filtering technique for identifying local maxima in regional geochemical datasets. Government of Newfoundland and Labrador, Department of Natural Resources, Geological Survey, Open File NFLD/3167.

Cook, S.J. and McConnell, J.W.
2001: Lake sediment geochemical methods in the Canadian Shield, Cordillera and Appalachia. *In* Drift Exploration in Glaciated Terrain. *Edited by* M.B. McCleneghan, P.T. Bobrowsky, G.E.M. Hall and S.J. Cook. Geological Society, London, Special Publication 185, pages 125-149.

Garrett, R.G.
1989: A Cry from the Heart. Explore, Volume 18, pages 18-19.

Greene, B.A.
1974: An outline of the geology of Labrador. Geoscience Canada, Volume 3, pages 36-40.

Hawkes, H.E. and Webb, J.S.
1962: Geochemistry in Mineral Exploration. Harper and Row, 415 pages.

Lepeltier, C.R.
1969: A simplified treatment of geochemical data by graphical representation. Economic Geology, Volume 64, pages 538-550.

McConnell, J.W. and Batterson, M.J.
1987: The Strange Lake Zr–Y–Nb–Be–REE deposit, Labrador: A geochemical profile in till, lake and stream sediment, and water. Journal of Geochemical Exploration, Volume 29, pages 105-127.

McConnell, J.W. and Finch, C.
2012: New ICP-ES geochemical data for regional Labrador lake-sediment and lake-water surveys. Government of Newfoundland and Labrador, Department of Natural Resources, Geological Survey, Open File LAB/1602, 50 pages.

Sinclair, A.J.
1974: Selection of threshold values in geochemical data using probability graphs. Journal of Geochemical Exploration, Volume 3, pages 129-149.

Slocum, T.A., McMaster, R.B., Kessler, F.C. and Howard, H.H.
2009. Thematic Cartography and Geographic Visualization, 3rd Edition. Prentice Hall, 576 pages.

Stanley, C.R.
1987: PROBPLOT: An interactive computer program to fit mixtures of normal (or lognormal) distributions with maximum likelihood procedures. Association of Exploration Geochemists, Special Volume, No. 14, 40 pages.

Tennant, C.B. and White, M.L.
1959: Study of the distribution of some geochemical data. Economic Geology, Volume 54, pages 1281-1290.

Thomas, A
1993: Geology of the Winokapau Lake area, Grenville Province, central Labrador. Geological Survey of Canada, Paper 89-18, 91 pages. [GSB# 013E/0048]

Thomas, A., Blomberg, P., Jackson, V. and Finn, G
2000: Bedrock geology map of the Wilson Lake area

(13E/SE), Labrador. Government of Newfoundland and Labrador, Department of Mines and Energy, Geological Survey, Open File 013E/0061, Map 2000-01. Scale 1:100 000.

Wardle. R.J., Gower, C.F., Ryan, B., Nunn, G.A.G., James, D.T. and Kerr, A.
1997: Digital geological map of Labrador, Version 1.0. Government of Newfoundland and Labrador, Department of Mines and Energy, Geological Survey. Open File LAB/1226.