AER/AGS Special Report 115

Till and Stream Sediment Sampling to Support the Evaluation of Critical Mineral Potential in Alberta

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Appendix A – Till and stream sediment analytical results

The appendix is in the accompanying folder entitled 'Appendix A', located in the download zip file.

Appendix B – Till and stream sediment analytical certificates

The appendix is in the accompanying folder entitled 'Appendix B', located in the download zip file.

Appendix C – Surficial geology field observations

The appendix is in the accompanying folder entitled 'Appendix C', located in the download zip file.

Foreword

The Alberta Geological Survey (AGS) outsourced a till and stream sediment sampling program in southwestern, northwestern, and north-central Alberta to provide a better understanding of the province's critical mineral potential. This project delivers information useful in the exploration of critical mineral potential in Alberta through geochemical and grain-size analyses, and indicator-mineral identification in areas where data gaps exist. All planning, logistics, fieldwork execution, sample collection, submission of samples for geochemical and textural analysis, data compilation, and reporting was completed by Palmer, with oversight and approval by the Alberta Energy Regulator and the AGS.

Three areas of interest were identified for till and stream sediment sampling. Till sampling included collecting 358 samples for geochemical and textural analyses and 150 samples for mineralogical analysis. Sampling of stream sediment included 398 samples for geochemical analysis and 360 samples for mineralogical analysis. This publication includes all sampling site descriptions, and geochemical and grain-size analyses results. Approximately 60% of the mineralogical samples collected have been analyzed for indicator minerals and these results are reported in this publication. The results of the analysis of the remaining mineralogical samples (approximately 40%) will be reported in subsequent publications. Analysis and interpretation of reported results will continue in future years to outline prospective areas for critical minerals within Alberta.

This work was completed under the Mineral Grant provided by the Government of Alberta dated June 22, 2021.

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Final Report

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1. Introduction

Alberta is well known for its oil and gas resources, but it also has significant potential for metallic and industrial minerals such as lithium, uranium, nickel, and rare earth elements (Table 1). With increasing worldwide demand for metals and critical minerals, Alberta is poised to be at the forefront of global mineral exploration and development. The Government of Alberta has outlined a Minerals Strategy and Action Plan to take full advantage of this opportunity. A critical objective of this plan is to inform future regulatory decisions regarding mineral applications and unlock critical information to encourage and guide industry operations. It will also support non-industry stakeholders with their understanding of minerals and how development might impact them.

Table 1. Common uses for minerals found in Alberta (source: https://www.alberta.ca/minerals-strategy-and-action-plan.aspx)

Mineral	Common uses
Cobalt	Used in rechargeable batteries and superalloys
Diamonds	Used in manufacturing and jewelry
Iron	Used in steel production, food storage cans, automobiles and heavy machinery
Lithium	Used primarily for lithium-ion batteries, lubricants and pharmaceuticals
Magnesium	Used in furnace linings and steel and ceramics manufacture
Nickel	Used in magnets, rechargeable batteries, steel and superalloys
Potash	Primarily used in fertilizer
Rare earth elements (REE)	Primarily used in wind turbines, clean technologies, batteries and electronics
Titanium	Used in metal alloys and pigments
Uranium	Primarily used for nuclear fuel
Vanadium	Primarily used for catalyst and alloy production and for energy storage
Zirconium	Used in high-temperature ceramics
Zinc	Used in steel plating, alloys, paints, rubber, cosmetics and pharmaceuticals

Alberta Energy Regulator (AER), in association with the Alberta Geological Survey (AGS), has initiated a Mineral Mapping Program (Alberta Energy, 2021). As part of this program, AER and AGS recognize that high-quality and comparable regional-scale geochemical and mineralogical data form an important foundation for successful mineral exploration and are integral to attracting exploration investment to the province. To provide these critical data, AER and AGS have initiated new regional till and stream sediment sampling surveys in three areas of interest (AOIs) (Figure 1): the foothills of the Rocky Mountains (AOI-1); an area surrounding High Level (AOI-2); and an area between Fort McMurray and Lesser Slave Lake (AOI-3). These areas were chosen because of their prospective geology and limited available geochemical and mineralogical data to identify regional exploration targets.

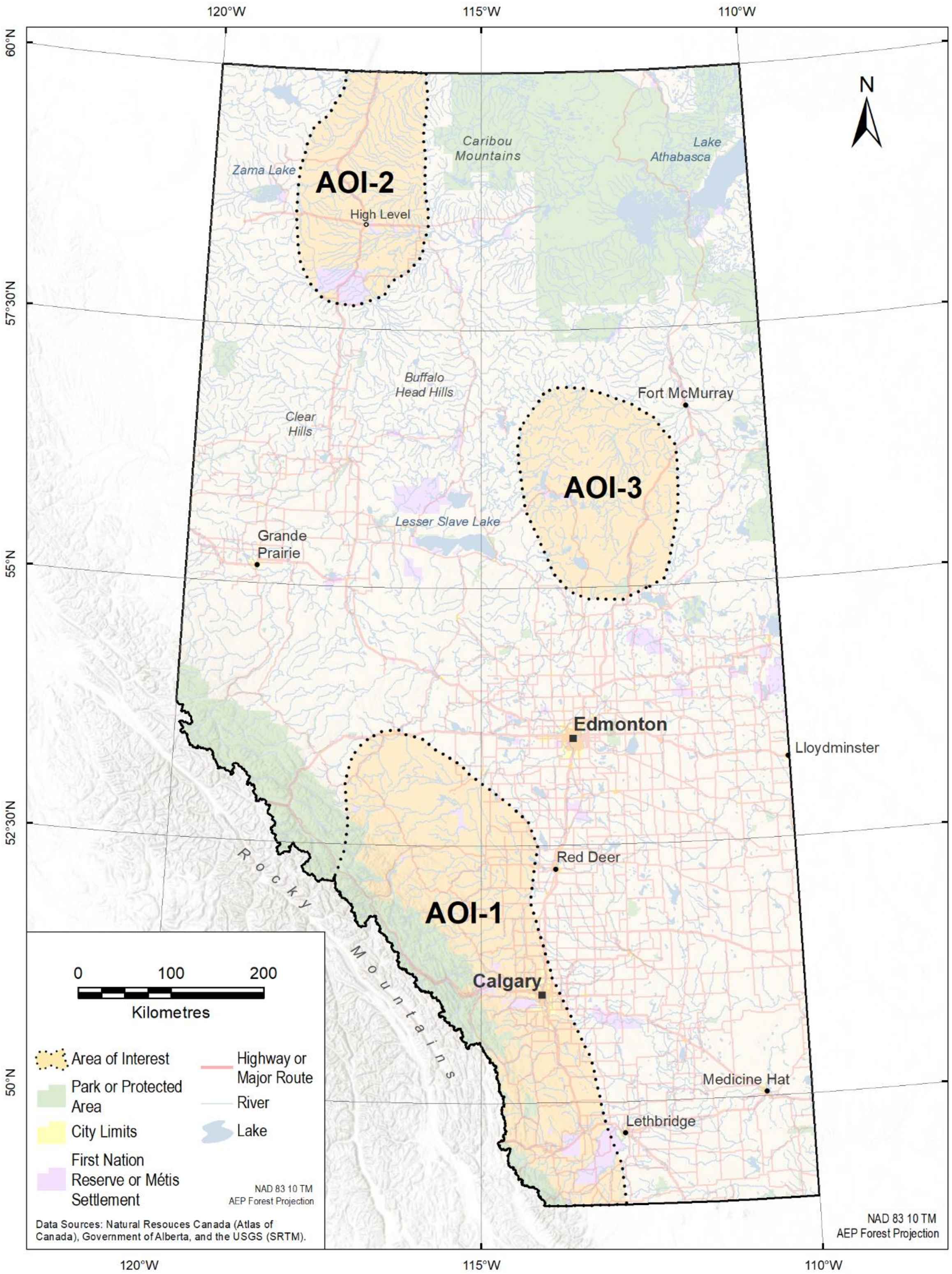


Figure 1. The three areas of interest (AOIs) comprising the survey area. AOI-1 is in southwestern Alberta and encompasses part of the Rocky Mountain Foothills and extends east into the plains region. AOI-2 is in northern Alberta and encompasses the town of High Level. AOI-3 is in central Alberta between Fort McMurray and Lesser Slave Lake.

Palmer was contracted by AER and AGS to conduct the till and stream sediment sampling program. The sampling program had three main objectives:

- to systematically sample till throughout the three AOIs for geochemical and mineralogical analysis;
- to systematically sample stream sediment throughout parts of the three AOIs for geochemical and mineralogical analysis; and
- to gather field-based observations of the properties and genesis of Quaternary sedimentary deposits that will be used for the correlation of units and remote sensing data elsewhere in the province.

The ambitious program extended over 142,000 km^2, reaching the northern and southern borders of the province (Figure 1). Till and stream sediment are optimal sampling materials for these types of regional geochemical and mineralogical surveys because they have a predictable relationship with bedrock and can provide insight into bedrock composition over large areas.

A field survey to acquire samples was mostly completed over a five-week period from September to October 2022. This was followed by a 10-day pilot program completed in January 2023, which was designed to determine how new drilling technology can be used to improve data coverage where standard sampling approaches are ineffective. The sampling survey was conducted to standards established by the AGS and Geological Survey of Canada (GSC), and resulted in high-quality field and analytical results that are consistent with, and comparable to, the existing provincial geochemical and mineralogical database. Together, these data can be used to identify prospective regions and focus mineral exploration efforts.

This report provides the survey and analytical methods and resulting field and analytical data from the sampling survey. Summaries of selected data are included in this report. Analytical results are provided as digital files in Appendices A; lab certificates and reports are provided in Appendix B; and observations about the surficial geology that were not captured in the sample site descriptions are provided in Appendix C.

1.1 Regional Bedrock Geology

The bedrock geology of Alberta includes metamorphic rocks of the Canadian Shield, sedimentary rocks of the Western Canada Sedimentary Basin (WCSB) and uplifted metasedimentary rocks forming the Rocky Mountains (Walker *et al.*, 2012; Earle, 2019).

Precambrian Canadian Shield bedrock is found in northeastern Alberta, where it is exposed north and south of Lake Athabasca, and extends northward into the Northwest Territories (Hamilton *et al.,* 1998). These highly metamorphosed rocks include feldspar-granitoid rocks, granitic gneiss, and metasedimentary rocks such as quartzite, amphibolite, phyllite, and schist formed during the Archaean period (Hamilton *et al.,* 1998). Younger Proterozoic rocks of low metamorphic grade include volcanic, granitoid, mylonitic marine sandstone, non-marine sandstone, siltstone, minor tuff and marine pyroclastic rocks (Hamilton *et al.,* 1998; Walker *et al.,* 2012).

The Rocky Mountains include the Middle Proterozoic Purcell Supergroup, Late Proterozoic Windermere Group, and other more recent formations (Mossop and Shetsen, 1994; Earle, 2019). The Purcell Supergroup consists of unmetamorphosed limestone, dolomite, quartzite, argillite, shale, siltstone, and basalt (Hamilton *et al.,* 1998). The Windermere group comprises conglomerate, sandstone, shale, and minor carbonates (Mossop and Shetsen, 1994; Earle, 2019); these units are exposed throughout the western portion of the Rocky Mountains within Alberta.

Sedimentary rocks of Paleozoic age formed in the WCSB in some northern parts of Alberta when an inland sea developed over Alberta during the Ordovician to Carboniferous periods (Walker *et al.,* 2012; Earle, 2019). Fifteen major formations were deposited at this time, largely consisting of limestone and dolomite, and including minor sandstone, argillite, evaporite, and shale (Hamilton *et al.,* 1998; Walker *et al.,* 2012; Earle, 2019). Devonian rocks west of Lake Athabasca extend northward across the Northwest Territories border, westward almost as far as the Caribou Mountains, and southward to the Firebag River. Bedrock transitions to Cretaceous sediments to the south and west of these areas (Hamilton *et al.,* 1998).

Across the remainder of the province, sediments that lithified into sandstone, siltstone, mudstone, and coal were deposited in river deltas and floodplains that existed during the Cretaceous to Paleocene periods (Hamilton *et al.*, 1998; Walker *et al*., 2012; Earle, 2019). These relatively flat-lying rocks form most of the bedrock in Alberta (Hamilton *et al.*, 1998; Earle, 2019). Alberta's oil and gas reserves formed in the Cretaceous inland sea, and its abundant dinosaur fossils are found in the terrestrial deposits of this period (Earle, 2019).

More recent sedimentary rocks formed during the Cenozoic period in fluvial and deltaic environments that persisted within the WCSB (Hamilton *et al.*, 1998; Walker *et al.*, 2012; Earle, 2019). They include sandstone, mudstone, minor chert, limestone, coal, tuff, and conglomerate (Hamilton *et al.*, 1998). Fossil beds are also common in these rocks (Earle, 2019). Cenozoic rocks are found adjacent to the Rocky Mountains in southern and central Alberta.

A detailed synthesis of Alberta's bedrock geology is available in the Atlas of the Western Canada Sedimentary Basin (Mossop and Shetsen, 1994).

1.2 Regional Quaternary Geology

Alberta experienced multiple glaciations during the Quaternary Period. The most recent, Late Wisconsin, glaciation reached its maximum extent approximately 22,000 years ago, and is thought to be responsible for most modern-day landforms and surficial deposits (Mix *et al*., 2001; Dyke *et al.*, 2002). Quaternary deposits are extensive across much of Alberta, with sediment packages that range in thickness from less than 1 m to 445 m, the thickest of which are in the northern and eastern regions of the province (Atkinson and Lyster, 2010). The genesis and composition of surficial materials vary across the province, with till being the most dominant material. This is advantageous for mineral exploration because the subglacial facies of till are commonly a first derivative of bedrock (Shilts, 1993), predictably transported in the direction of ice flow, and provide a larger anomaly than the original bedrock source (Levson, 2001). Deglaciation initiated approximately 14,500 years ago (Dyke, 2004), resulting in the deposition of ablation till and glaciolacustrine material throughout different regions of Alberta. These deglacial sediments typically occur at surface and, due to their passive mode of deposition, likely overlie subglacial till in many areas. Modern deposits are less common; however, stream erosion and sedimentation have remobilized many glacial sediments and the streams have locally incised through the surficial sediment package to bedrock.

Like in much of Alberta, extensive subglacial till deposits are found throughout AOI-1, with ablation till commonly occurring in the east part of the AOI (Fenton *et al.*, 2013) (Figure 2). Orientations of streamlined landforms indicate that the Laurentide Ice Sheet flowed southward to southwestward into this region, while the Cordilleran Ice Sheet advanced eastward from the Rocky Mountains (Holme *et al.*, 2002; Atkinson *et al.*, 2014, Atkinson and Utting, 2021). The coalescence of these ice sheets created a dynamic environment resulting in numerous different ice flow directions within the AOI (Figure 2). During deglaciation, the Laurentide Ice Sheet retreated northward and eastward, and the Cordilleran Ice Sheet retreated westward (Holme *et al.,* 2002; Atkinson and Utting*.,* 2021). Glacial lakes developed in many low-lying areas at this time, and fine-grained glaciolacustrine sediments were deposited within them. These deposits are most common in the plains portion of AOI-1, and they were incised by glacial meltwater channels that deposited glaciofluvial material after the lakes drained (Holme *et al*., 2002; Fenton *et al.*, 2013).

In northern Alberta, AOI-2 was mainly affected by southwestward flow of the Laurentide Ice sheet, with regions near the centre of the AOI affected by westward and northwestward flow (Atkinson *et al.,* 2014; Fenton *et al.,* 2003). The ice sheet crossed the entirety of AOI-2 and deposited extensive till deposits in the eastern Caribou Mountains area and in the southwest portion of the AOI (Fenton *et al.,* 2013) (Figure 3). It is likely that much of the remaining portion of AOI-2 also has till within the Quaternary stratigraphic package; however, much of this till was buried under glaciolacustrine material deposited in large glacial lakes impounded by the northward and eastward ice margins during glacial retreat (Fenton *et al*., 2013) (Figure 3). Glaciofluvial material comprises a small portion of the surficial deposits and is commonly associated with glacial meltwater channels in lowlands, such as the one encompassing Hay River that flows through the central region of AOI-2. Glaciofluvial deposits can also be found in till-dominated uplands, such as the Caribou Mountains and the Buffalo Head Hills that border the AOI on its east and southeast sides (Fenton *et al.*, 2013) (Figure 3). Eolian deposits are commonly associated with the glaciolacustrine and glaciofluvial deposits, including in the southeastern parts of AOI-2, where the Peace River and its abundant glaciofluvial deposits are located (Fenton *et al*., 2013; Wolfe *et al.*, 2004). These eolian landforms were most active between the period of ice retreat and the development of vegetation (Wolfe *et al.,* 2004).

AOI-3, in the central region of Alberta, was also covered by the Laurentide Ice Sheet. It flowed dominantly in a southward to southwestward direction and deposited till throughout the region (Atkinson *et al.,* 2014; Atkinson and Utting*.,* 2021; Fenton *et al.*, 2003). A number of streamlined landforms were mapped with a southward to southeastward orientation. It is unknown if these represent advance- or retreat-phase conditions, but they should be considered when interpreting sediment transport vectors. Subglacial till is particularly abundant along the east and southwest borders of AOI-3, while thick accumulations of ablation till formed during deglaciation in its southwestern portion (Figure 4). Glaciolacustrine and glaciofluvial materials were also deposited during deglaciation. Glaciofluvial deposits are common in low-lying areas within glacial meltwater channels, such as along the Athabasca River (Fenton *et al.,* 2013). Glaciolacustrine deposits appear to increase in abundance in a northward direction and are likely present under the organic deposits throughout the middle of the AOI (Figure 4). Eolian deposits are less common than in AOI-2 but can be found associated with glaciofluvial deposits adjacent to the Athabasca River (Figure 4).

Postglacial Holocene deposits are present throughout all three AOIs, with organic deposits present in low-lying areas, particularly within the northern part of AOI-2 and the central part of AOI-3. Colluvial deposits comprise a small proportion of the plains but are commonly found on the slopes of river valleys, such as along the Athabasca River in AOI-3; however, colluvium dominates the surficial deposits of the more mountainous western half of AOI-1 (Fenton *et al.,* 2013). The remaining surficial deposits consist of localized fluvial and lacustrine deposits.

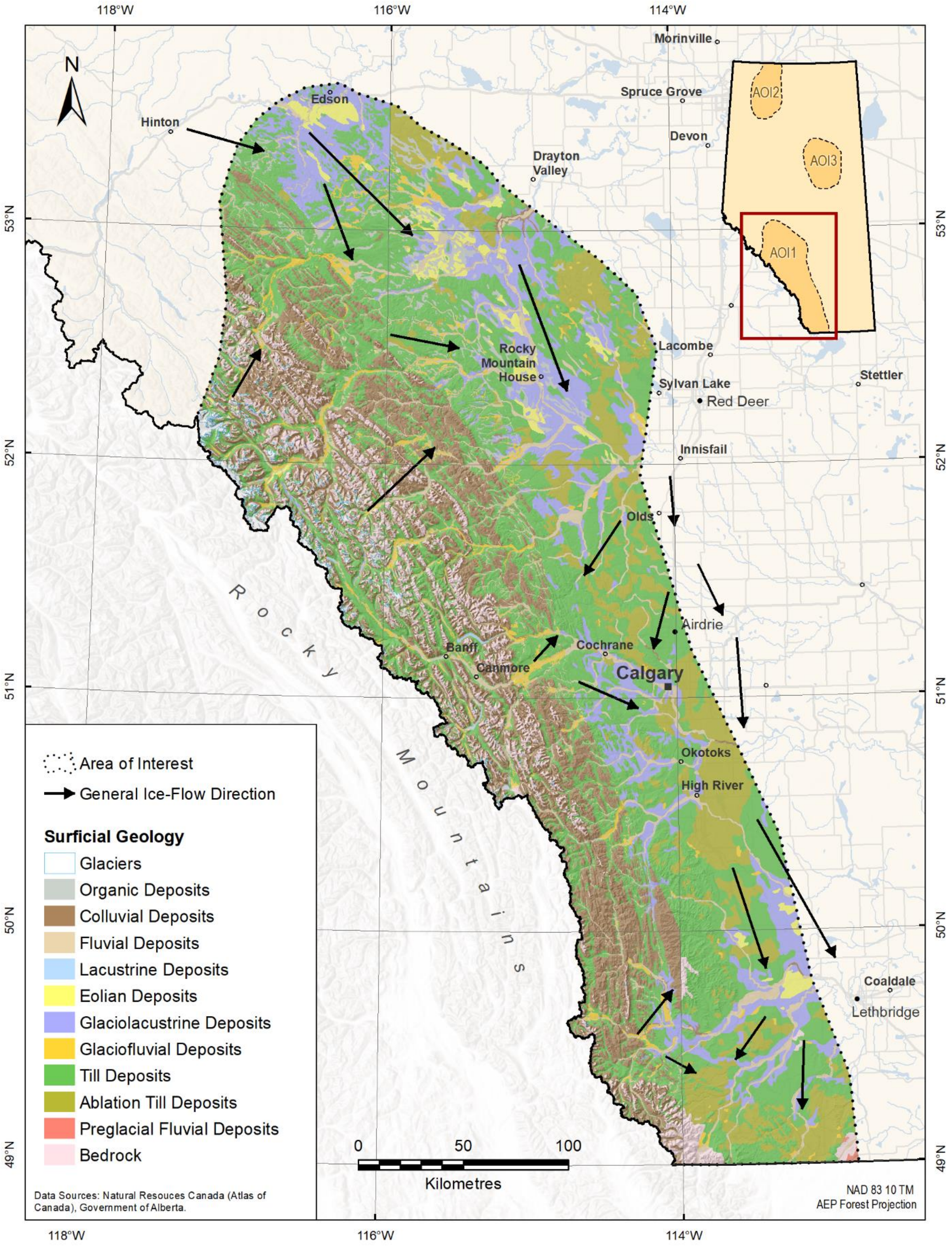


Figure 2. Generalized surficial geology and dominant ice flow directions in AOI-1 (https://open.alberta.ca/opendata/gda-dig_2014_0022).

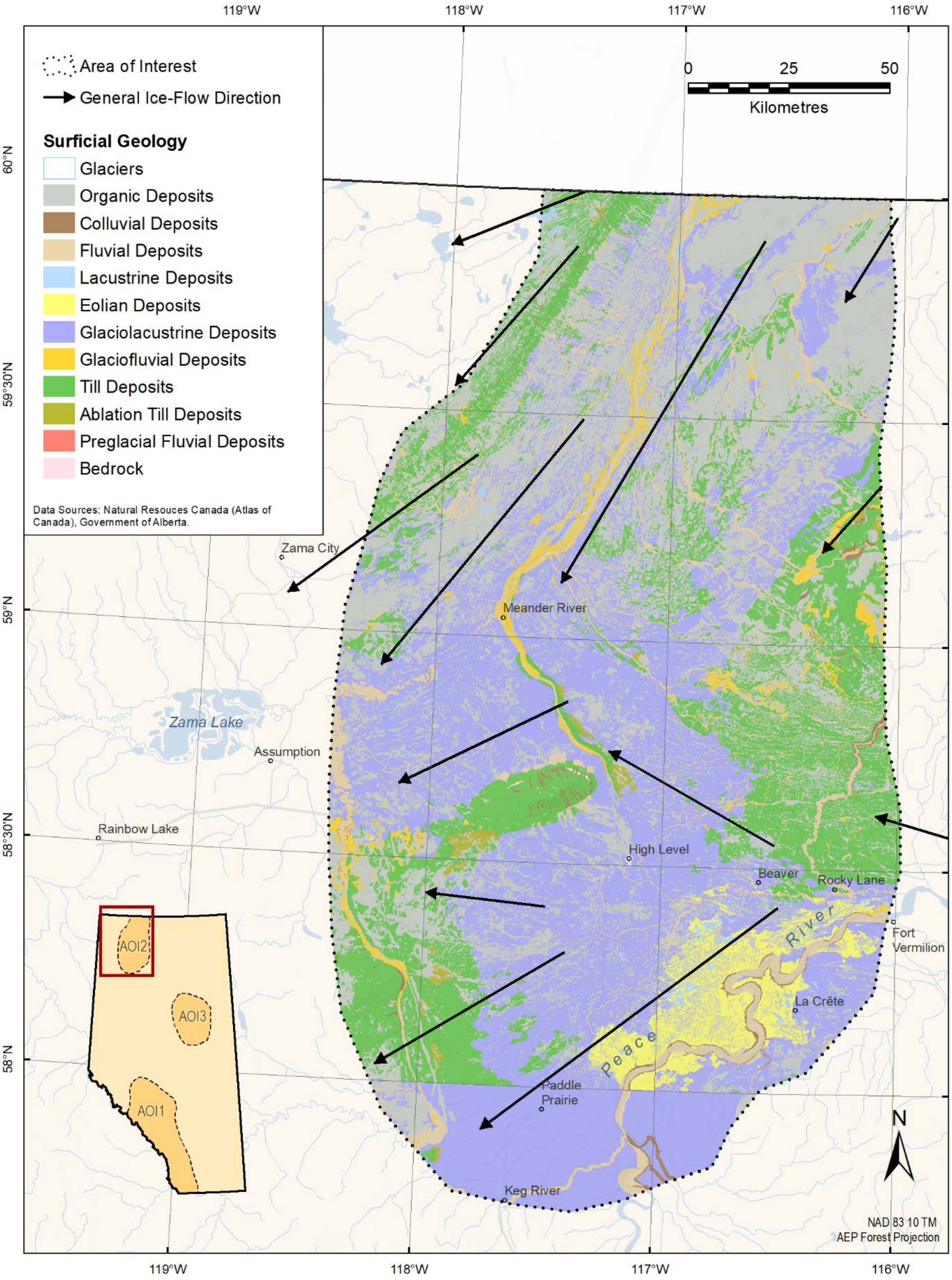
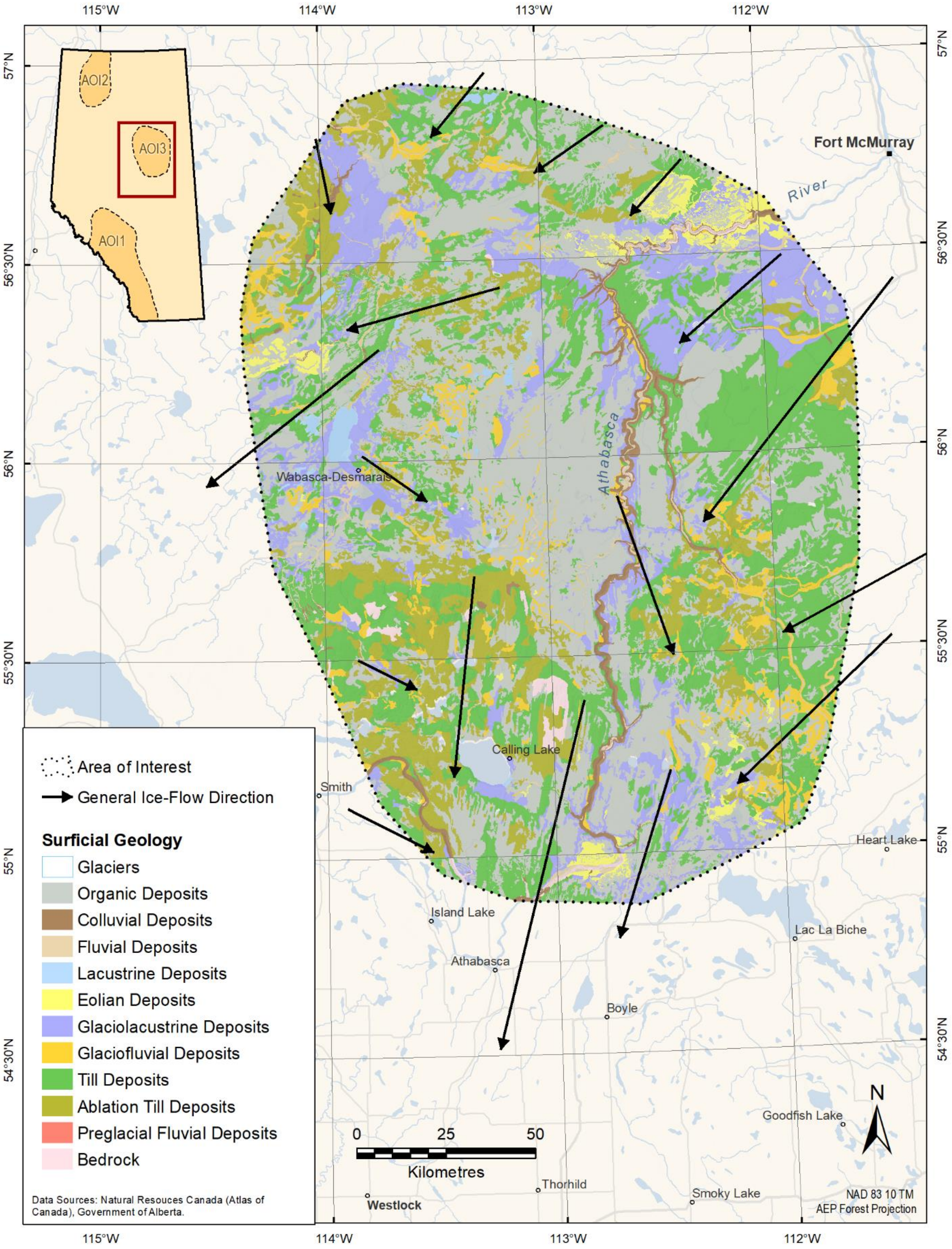


Figure 3. Generalized surficial geology and dominant ice flow directions in AOI-2 (https://open.alberta.ca/opendata/gda-dig_2014_0022).



Data Sources: Natural Resouces Canada (Atlas of Canada), Government of Alberta.

Figure 4. Generalized surficial geology and dominant ice flow directions in AOI-3 (https://open.alberta.ca/opendata/gda-dig_2014_0022).

1.3 Previous Surveys

Till surveys in Alberta have been conducted at regional scales since the 1950s as coordinated efforts by the AGS and the GSC (Table 2). The standard approach for these surveys includes geochemical and mineralogical analysis. An initial till sampling campaign from 1958-1963 covered approximately 65% of the province, avoiding areas of thick glaciolacustrine cover and rugged terrain along the Rocky Mountains (Bayrock and Pawluk, 1967). Throughout the plains region of Alberta, 474 till samples were collected to determine regional variations in chemical, mineralogical and physical properties of tills. This initial survey was followed by a low-density, interprovincial, prairie-wide till sampling initiative from 1990-1997 with coverage in southern Alberta and lower-density reconnaissance till sampling in northern Alberta (Thorleifson and Garrett, 1993; Bednarski, 1993; Fenton and Pawlowicz, 1998; Pawlowicz, *et. al.,* 1998). These surveys largely focused on assessing the potential for diamondiferous kimberlite or lamproite through till matrix geochemistry and indicator mineral data, and the potential for gold placers and base metal mineralization were also considered (Bednarski, 1993; Fenton and Pawlowicz, 1998).

Regional till surveys have since focused on northern Alberta (Bednarski, 1993; Fenton *et al.,* 1996; Fenton and Pawlowicz, 2001, Paulen *et al.,* 2005; Seneshen *et al*., 2005; Fenton *et al*., 2006; Plouffe *et al.,* 2006; Plouffe *et al*., 2008; Prior, 2010; Utting *et al*., 2019; Utting, 2020). These surveys were part of a multi-year, multi-disciplinary study designed to support kimberlite exploration, assess metallic mineral potential, and provide information on Quaternary geology and glacial dispersion patterns. Most of these till surveys focused on sampling with hand tools from opportunistic exposures (*e.g.,* roadcuts, stream cuts, borrow pits). One program in 2002 utilized an auger drill equipped with a 6-inch hollow-stem auger to log the sediment stratigraphy and collect till samples (Fenton *et al.,* 2006) and another analysed till recovered from drill core (Utting, 2020). This approach provides additional 3-dimensional information to better understand the glacial history of the area. Multi-media orientation surveys over five known kimberlites were conducted during 2000 and 2001 (Seneshen *et al*., 2005). These surveys collected aspen bark, willow twigs, spruce needles, A- and B-horizon soils, C-horizon till and peat/subpeat deposits, with the goal of investigating the use of alternative media in kimberlite exploration. From 2002-2010, the AGS completed till sampling in a known kimberlite field near Swan Lake to better understand kimberlite-indicator mineral (KIM) dispersal (Table 2). The objective of this work was to help optimize diamond exploration programs elsewhere in northern Alberta. The results of these previous till surveys have aided in the discovery of new zones of mineral potential. Of particular interest is an area near Zama Lake that is characterized by anomalous concentrations of sphalerite grains discovered during the sampling campaigns in 2003 and 2004 summarized by Plouffe *et al*. (2008).

The first major stream sediment sampling program in Alberta was conducted by the AGS in 1992 and contributed to the discovery of previously unknown metallic mineralization in southern Alberta. Since this program, stream sediment surveys in Alberta have been focused on the northern part of the province, highlighting potential for kimberlites, base metals and other economic minerals. Stream sediment surveys in Alberta have all been carried out as part of the National Geochemical Reconnaissance (NGR) program and contribute to a national geochemical dataset. The Buffalo Head Hills area of Alberta has been a major focus of this work (Friske *et al*., 2003; McCurdy *et al*., 2004; McCurdy *et al.*, 2005), although smaller-scale stream sediment sampling campaigns have also been conducted by the GSC and AGS near Fort McMurray and in the Clear Hills area (Eccles *et al*., 2001; McCurdy *et al.*, 2008).

Table 2. Summary of previous till and stream sediment sampling surveys.

Year(s)	Area covered	Number of samples	Sample media	Reference
1958-1963	Plains region of Alberta	474	C-horizon till	Bayrock and Pawluk, 1967
1993	Canadian prairies, including southern Alberta	816 (includes sample sites outside of Alberta)	C-horizon till	Thorleifson and Garrett, 1993
1992-1994	North of Lake Athabasca, northeastern Alberta	324	C-horizon till	Bednarski, 1993
1990-1996	Emphasis on northern Alberta	160	C-horizon till, includes 30 non-till sediment samples	Fenton and Pawlowicz, 1998
1995-1997	North-central region of Alberta	125	C-horizon till	Pawlowicz *et. al.,* 1998
2000	Wapiti map area, Alberta	92	C-horizon till, includes 11 non-till sediment samples	Fenton and Pawlowicz, 2001
2002	Peace River region, Alberta	19	C-horizon till	Paulen *et al.,* 2005
2000-2001	Northern Alberta	806	aspen bark, willow twigs, spruce needles, A- and B-horizon soils, C-horizon till and peat/subpeat deposits	Seneshen *et al.,* 2005
2002	Buffalo Head Hills, Alberta	155	C-horizon till, stratified non-till sediment samples and bedrock samples	Fenton *et al.,* 2006
2003-2006	Zama Lake area, northwestern Alberta	310	C-horizon till and 20 non-till sediment samples	Plouffe *et al*., 2006; Plouffe *et al.,* 2008
2002-2010	Sawn Lake area of southern Buffalo Head Hills, Alberta	68	C-horizon till and 1 glaciofluvial sediment sample	Prior *et al.,* 2005; Prior, 2017; Prior, 2010
2011-12, 2017	Northern Alberta	68	C-horizon till and 5 glaciofluvial sediment samples	Utting *et al.,* 2019
2020	Fort McMurray region, northeastern Alberta	31	C-horizon till	Utting, 2020
1992	Southern Alberta Rift, southwest Alberta	415	Stream sediment	Williamson *et al.,* 1993
1999	Fort McMurray region, northeastern Alberta	153	Stream sediment	Eccles *et al.,* 2001
2001-2002	Buffalo Head Hills, Alberta	253	Stream sediment	Friske *et al.,* 2003
2003	Northern Buffalo Head Hills, Alberta	95	Stream sediment	McCurdy *et al.,* 2004
2004	Northern and southwestern part of Buffalo Head Hills	122	Stream sediment	McCurdy *et al.,* 2005
2004-2005	Northeastern and southern Clear Hills, Alberta	173	Stream sediment	McCurdy *et al.,* 2008

2. Methods

2.1 Survey Design

Sampling locations for till and stream sediments were determined prior to the field program to help optimize sample distributions and streamline the field program. Sampling was restricted to Crown land, avoiding private property, national and provincial parks, First Nations Reserves and existing mineral exploration leases. Most till samples were planned assuming truck access, while only a fraction of the stream sediment sampling sites was to be accessed by truck and the rest by helicopter.

Proposed till sampling locations for the regional sampling program were based on an offset grid with 7 km point spacing. Optimally, the staggered grid is oriented perpendicular to ice flow, so each AOI was divided into sections based on the dominant orientation of streamlined bedforms within Alberta's surficial geology dataset (https://open.alberta.ca/opendata/gda-dig_2014_0022). The grid sections within each AOI division were rotated to be perpendicular to the dominant ice flow direction. Using the province-wide digital surficial geology compilation (https://open.alberta.ca/opendata/gda-dig_2014_0022), the National Road Network shapefiles for Alberta (Alberta, 2016), and point-specific interpretations of the available 1.5-m resolution SPOT satellite imagery and digital elevation data, each point was evaluated and adjusted to target till with suitable access. The target sample spacing for the final proposed sampling sites was between 4 and 10 km.

A pilot drill-supported till sampling program was planned along existing access routes, including roads and unvegetated seismic lines. AOI-3 was chosen for the pilot program because opportunities for standard pick-and-shovel sampling were limited by the mantle of glaciolacustrine material overlying till and poor road access. The program was completed during the winter to take advantage of the improved mobility over the swampy and organic-rich landscape afforded by the snowpack and frozen ground. Proposed sampling sites were chosen along roads and seismic lines that are oriented roughly perpendicular to ice flow direction, as with the main sampling program. Samples were collected roughly every 1 km along the transects, focussing on areas where suitable pullouts could be identified in the satellite imagery and where till was likely to be located within 10 m of the surface. A line locate request was submitted through the Alberta One Call system for each planned site prior to field work. Only sites that were cleared by all registered utility companies were included in the final program design.

An initial framework based on a 20-km grid was used to determine potential stream sediment sampling locations. Digital stream network data (AEP, 2018) was intersected with the grid to identify suitably sized and suitably located catchments. Proposed sampling locations were chosen based on visual evaluation of stream flow and sediment accumulation in the satellite imagery. Higher-order streams were preferentially selected to increase the probability of sample composition that reflects local bedrock; however, this was not always possible as the higher-order streams commonly have impractically small catchments. Sampling these streams would have created large data gaps. In general, the uplands of AOI-1 provided sampling opportunities in higher-order streams with smaller catchments, while still maintaining good coverage. The flatter plains of AOI-2 and AOI-3, however, generally required sampling of larger catchments to achieve suitable data coverage. The actual sample spacing was a function of catchment sizes and the design aimed to prevent dilution by avoiding excessively large catchments while minimizing data gaps.

2.2 Sampling methods

Regional till and stream sediment sampling was completed by nine field crews using standard pick-and-shovel sampling techniques over a five-week period within September and October 2022. The pilot drill-supported till sampling was completed by one field crew using Palmer's Shock-auger shallow-drilling system over a 10-day period in January 2023. Each till and stream sediment sampling crew was led by a Quaternary geologist or fluvial geomorphologist who was supported by an experienced field assistant. All crews were trained on the specific sampling protocols of this program during their field orientation to ensure consistency. Till sampling was primarily truck-supported but included a few days of helicopter-supported sampling in AOI-2. The stream sediment sampling was dominantly helicopter-supported, although one crew was able to access a number of sites by truck in AOI-1. The field crews used local accommodations, moving as required to minimize travel distances between accommodations and sampling areas.

2.2.1 Till Sampling

2.2.1.1 Hand Tool Sampling

All till sampling was completed following the methods established by the GSC (McClenaghan *et al.* 2020; GSC, 2017). Crews navigated in the field by using georeferenced maps and GPS-enabled devices and aimed to identify suitable sampling locations within 2 km of the proposed sample site. Sampling was preferentially completed from opportunistic exposures such as road cuts, stream cuts or borrow pits (Figure 5) that provided access to the target C-horizon material. Sampling from hand-dug soil pits was completed where necessary.

At each potential till sample site, C-horizon material was carefully assessed for texture, structure, density, matrix percentage, clast mode, clast shape and presence of striations. If the sample was determined to be subglacial till, the sample observations and site information, including location, type of exposure, soil development, surficial map unit, topographic position, aspect, slope, drainage and any stratigraphic information, were recorded on a digital till sample form. When suitable subglacial till was not found, characteristics about the Quaternary deposits were recorded on a surficial geology observation digital form (Appendix C). Digital data were backed up daily.

Till samples were collected at a minimum target depth of 80 cm to ensure C-horizon material was collected. A 1.5- to 2.5-kg sample was collected at each site for geochemical analysis. Geochemistry samples were collected in Hubco sentry sample bags with an attached sample number tag, which were then placed inside a 2-mil polyethylene bag. A larger 10- to 15-kg sample for mineralogical analysis was collected at approximately every other site. Minerology samples were collected in 6-mil polyethylene bags. A minimum of three pictures was taken at each site to show the sampled material, sample pit and the broader landscape context of the site. All samples were stored and transported in plastic pails. The contents of all pails were verified at basecamp and certified reference standards were inserted.

Figure 5. Typical sample sites: a) road cut; b) stream cut; c) borrow pit; d) soil pit.

2.2.1.2 Drill-Supported Sampling

Drill-supported sampling was completed using a Shock-auger, which is a recently developed, rotary percussion drilling system specifically tooled for till sampling (Figure 6). The drill was transported on a trailer along roads and driven to the sampling sites using the onboard tracks, or was towed on skis behind a tracked UTV along the seismic lines. The system was configured to operate to a maximum depth of 10 m. This configuration allows for rapid collection of till samples below thick covers of glaciolacustrine material. A custom, reinforced 60-mm-diametre flow-through style sampler was used to collect *in situ* material from the boreholes. Boreholes were twinned when collecting minerology samples to acquire enough sample volume, keeping a consistent sampling depth. Till was sampled using the same protocols as above and the sediment stratigraphy of the borehole was described at each location.

Figure 6. Shock-auger shallow-drilling system used to sample till beneath glaciolacustrine cover in AOI-2.

2.2.2 Stream Sediment Sampling

Stream sediment sampling was completed following the NGR protocols provided by the GSC (Friske and Hornbrook, 1991). Field crews navigated using georeferenced maps and GPS-enabled devices and aimed to identify suitable sampling locations as close to the proposed sites as possible. Some flexibility was required when selecting a suitable sample site based on landing site availability, proximity to possible sources of contamination, or the identification of a more appropriate site.

Optimal sample locations had bars, either lateral or mid-channel, that would be subject to inundation during spring flood conditions. Bars at such optimal sites were composed of a surface “pavement” layer of pebbles to small boulders armouring finer subsurface sediment. At each stream sediment sample site, 1.5 to 2.5 kg of silt-rich sediment was collected for geochemical analysis with a clean shovel. Samples were collected from within a 2 m radius in the active stream channel. If suitable fine-grained sediment was not located, moss-trapped sediments were collected from seasonally inundated areas. Samples were placed in Hubco sentry sample bags and the sealed sample bag placed inside a 2-mil polyethylene bag.

Material for mineralogical analysis was sampled from a separate shovel-dug pit dug ranging in depth from 30 to 100 cm. Preferred sites for mineralogy samples were located at upstream points of exposed mid- or side-channel bars. If a site lacked well-developed bars, the sample was taken directly from the channel bed or at boulder and vegetation traps where sediment was able to accumulate. To the extent possible, pits were dug deeper rather than wider to sample a large temporal range of materials (Figure 7). Material was wet sieved to a grain size of less than 2 mm in the field. Ten to 12 kg of the sieved material was placed in a 6-mil polyethylene bag. If a site was dry, a mineralogy sample was not taken. Samples were stored and transported in plastic pails and returned to base camp where the contents of all pails were verified and certified reference standards were inserted.

Figure 7. Stream sediment sample sites on exposed mid- or side-channel bars that are inundated during spring flood conditions.

Sample sites and material were described on digital stream sediment sample forms. A minimum of three pictures was taken at each site to show the sampled material, sample pits, and the broader landscape context of the site. Digital data were backed up daily.

2.3 Laboratory Methods

2.3.1 Geochemical Analysis

Geochemical analysis was completed at Bureau Veritas Laboratories in Vancouver, BC. Till and stream sediment samples were oven-dried at 60°C and sieved to produce a silt+clay (<0.063 mm) size-fraction. A 15 g aliquot of the silt+clay underwent a modified aqua-regia digestion (1:1:1 ratio of HNO_3:HCl:H_2O) and was analyzed by inductively coupled plasma mass spectrometry (ICP-MS) for 65 elements (53 elements +

REE; lab method code AQ251-EXT+REE). Analytes, their detection limits and the reported concentrations of certified reference material (CRM) OREAS47 for AQ251-EXT+REE are provided in Table 3. Another aliquot was subjected to lithium borate fusion followed by nitric acid digestion. Eighteen major oxides and elements were determined using inductively coupled plasma-emission spectrometry (ICP-ES) and loss-on-ignition was completed by weight difference after ignition at 1000°C (lab method code LF300). In addition, 45 trace elements, including 14 precious and base metal elements, were determined by ICP-MS following the lithium borate fusion dissolution (lab method code LF100-EXT). Analytes, their detection limits, and the reported concentrations of CRM OREAS-47 for LF300 and LF100-EXT are provided in Table 4.

Table 3. Elements, units of measurement, lower detection limit (LDL) and upper detection limit (UDL) for analytical package AQ251-EXT+REE (aqua-regia digestion and ICP-MS).

Element	Unit	LDL	UDL	OREAS47 certified value
Ag	ppb	2	100000	107
Al	pct	0.01	10	0.81
As	ppm	0.1	10000	9.53
Au	ppb	0.2	100000	32.4
B	ppm	1	2000	-
Ba	ppm	0.5	10000	62
Be	ppm	0.1	1000	0.19
Bi	ppm	0.02	2000	0.15
Ca	pct	0.01	40	0.547
Cd	ppm	0.01	2000	0.5
Ce	ppm	0.1	2000	44.7
Co	ppm	0.1	2000	49.9
Cr	ppm	0.5	10000	30.4
Cs	ppm	0.02	2000	1.19
Cu	ppm	0.01	10000	160
Dy	ppm	0.02	2000	1.26
Er	ppm	0.02	2000	0.58
Eu	ppm	0.02	2000	0.6
Fe	pct	0.01	40	1.65
Ga	ppm	0.1	1000	3.28
Gd	ppm	0.02	2000	1.92
Ge	ppm	0.1	100	0.075
Hf	ppm	0.02	1000	0.2
Hg	ppb	5	50000	140
Ho	ppm	0.02	2000	0.21
In	ppm	0.02	1000	0.037
K	pct	0.01	10	0.116
La	ppm	0.5	10000	25.2
Li	ppm	0.1	2000	8.83
Lu	ppm	0.02	2000	0.07
Mg	pct	0.01	30	0.484
Mn	ppm	1	10000	270
Mo	ppm	0.01	2000	12.7
Na	pct	0.001	5	0.091
Nb	ppm	0.02	2000	0.92
Nd	ppm	0.02	2000	17.8
Ni	ppm	0.1	10000	80
P	pct	0.001	5	0.055
Pb	ppm	0.01	10000	284
Pd	ppb	10	100000	43.1
Pr	ppm	0.02	2000	5.3
Pt	ppb	2	100000	25.7
Rb	ppm	0.1	2000	7.15
Re	ppb	1	100000	-
S	pct	0.02	10	0.046
Sb	ppm	0.02	2000	0.2
Sc	ppm	0.1	100	3.17
Se	ppm	0.1	100	-
Sm	ppm	0.02	2000	2.66
Sn	ppm	0.1	100	2.54
Sr	ppm	0.5	2000	31.4
Ta	ppm	0.05	2000	-
Tb	ppm	0.02	2000	0.23
Te	ppm	0.02	1000	0.016
Th	ppm	0.1	2000	3.25
Ti	pct	0.001	5	0.07
Tl	ppm	0.02	1000	0.083
Tm	ppm	0.02	2000	0.084
U	ppm	0.1	2000	0.47
V	ppm	1	10000	24.7
W	ppm	0.1	100	0.11
Y	ppm	0.01	2000	5.75
Yb	ppm	0.02	2000	0.5
Zn	ppm	0.1	10000	213
Zr	ppm	0.1	2000	6.7

Table 4. Elements, units of measurement, lower detection limit (LDL) and upper detection limit (UDL) for analytical packages LF300 and LF100-EXT (lithium borate fusion followed by ICP-ES/MS).

Analyte	Method	Unit	LDL	UDL	OREAS47 certified value
SiO_2	LF300	pct	0.01	100	72.78
Al_2O_3	LF300	pct	0.01	100	11.96
Cr_2O_3	LF300	pct	0.002	10	165
CaO	LF300	pct	0.01	100	3.27
Fe_2O_3	LF300	pct	0.04	100	3.97
K_2O	LF300	pct	0.01	100	1.42
MgO	LF300	pct	0.01	100	1.67
MnO	LF300	pct	0.01	30	0.064
Na_2O	LF300	pct	0.01	100	3.47
P_2O_5	LF300	pct	0.01	100	0.129
TiO_2	LF300	pct	0.01	10	0.379
Ba	LF300	ppm	5	5	473
Nb	LF300	ppm	5	1000	17.9
Ni	LF300	ppm	20	10000	91
Sc	LF300	ppm	1	10000	9.27
Sr	LF300	ppm	2	50000	402
Y	LF300	ppm	3	50000	11.6
Zr	LF300	ppm	5	50000	161
LOI	LF300	pct	0.1	100	1.02
Sum	LF300	pct	0.01	100	-
Ag	LF100-EXT	ppm	0.1	100	-
As	LF100-EXT	ppm	1	10000	9.67
Au	LF100-EXT	ppm	0.5	100000	-
Ba	LF100-EXT	ppm	1	50000	473
Be	LF100-EXT	ppm	1	10000	0.97
Bi	LF100-EXT	ppm	0.5	2000	-
Cd	LF100-EXT	ppm	0.1	2000	-
Ce	LF100-EXT	ppm	0.1	50000	56
Co	LF100-EXT	ppm	0.2	10000	52
Cs	LF100-EXT	ppm	0.1	1000	2.01
Cu	LF100-EXT	ppm	0.1	10000	149
Dy	LF100-EXT	ppm	0.05	10000	2.11
Er	LF100-EXT	ppm	0.03	10000	1.16
Eu	LF100-EXT	ppm	0.02	10000	1.01
Ga	LF100-EXT	ppm	0.5	10000	14.1
Gd	LF100-EXT	ppm	0.05	10000	2.83
Hg	LF100-EXT	ppm	0.01	50	-
Hf	LF100-EXT	ppm	0.1	10000	4.1
Ho	LF100-EXT	ppm	0.02	10000	0.42
La	LF100-EXT	ppm	0.1	50000	30.9
Lu	LF100-EXT	ppm	0.01	10000	0.16
Mo	LF100-EXT	ppm	0.1	2000	12.7
Nb	LF100-EXT	ppm	0.1	1000	17.9
Nd	LF100-EXT	ppm	0.3	10000	24
Ni	LF100-EXT	ppm	0.1	10000	91
Pb	LF100-EXT	ppm	0.1	10000	-
Pr	LF100-EXT	ppm	0.02	10000	6.58
Rb	LF100-EXT	ppm	0.1	1000	37.6
Sb	LF100-EXT	ppm	0.1	2000	-
Se	LF100-EXT	ppm	0.5	100	-
Sm	LF100-EXT	ppm	0.05	10000	4.01
Sn	LF100-EXT	ppm	1	10000	6.14
Sr	LF100-EXT	ppm	0.5	50000	402
Ta	LF100-EXT	ppm	0.1	1000	0.46
Tb	LF100-EXT	ppm	0.01	10000	0.39
Th	LF100-EXT	ppm	0.2	10000	3.84
Tl	LF100-EXT	ppm	0.1	1000	-
Tm	LF100-EXT	ppm	0.01	10000	0.17
U	LF100-EXT	ppm	0.1	10000	0.79
V	LF100-EXT	ppm	8	10000	61
W	LF100-EXT	ppm	0.5	10000	-
Y	LF100-EXT	ppm	0.1	50000	11.6
Yb	LF100-EXT	ppm	0.05	10000	1.08
Zn	LF100-EXT	ppm	5	10000	217
Zr	LF100-EXT	ppm	0.1	50000	161

Carbon content was determined by LECO analysis (lab method code TCCRB), which determines total carbon, graphite carbon, organic carbon, and inorganic carbon present in the sample. All forms of carbon were converted into CO_2 through combustion in an induction furnace, and the concentration was measured by adsorption in an infrared spectrometric cell. To determine graphitic carbon, the samples were leached with dilute HCl, followed by ignition at 500°C and analysis of the residue. Inorganic carbon was directly measured by analyzing the CO_2 evolved from a sample split leached with perchloric acid. Organic carbon was calculated by subtracting the inorganic and graphitic carbon from the total carbon. Analytes and their detection limits for TCCRB are provided in Table 5.

Table 5. Elements, units of measurement, lower detection limit (LDL) and upper detection limit (UDL) for analytical package TCCRB (carbon analysis by LECO).

Analyte	Unit	LDL	UDL
Total C	pct	0.02	100
Organic C	pct	0.02	100
Inorganic C	pct	0.08	100
Graphite C	pct	0.02	20

2.3.2 Grain-Size Analysis

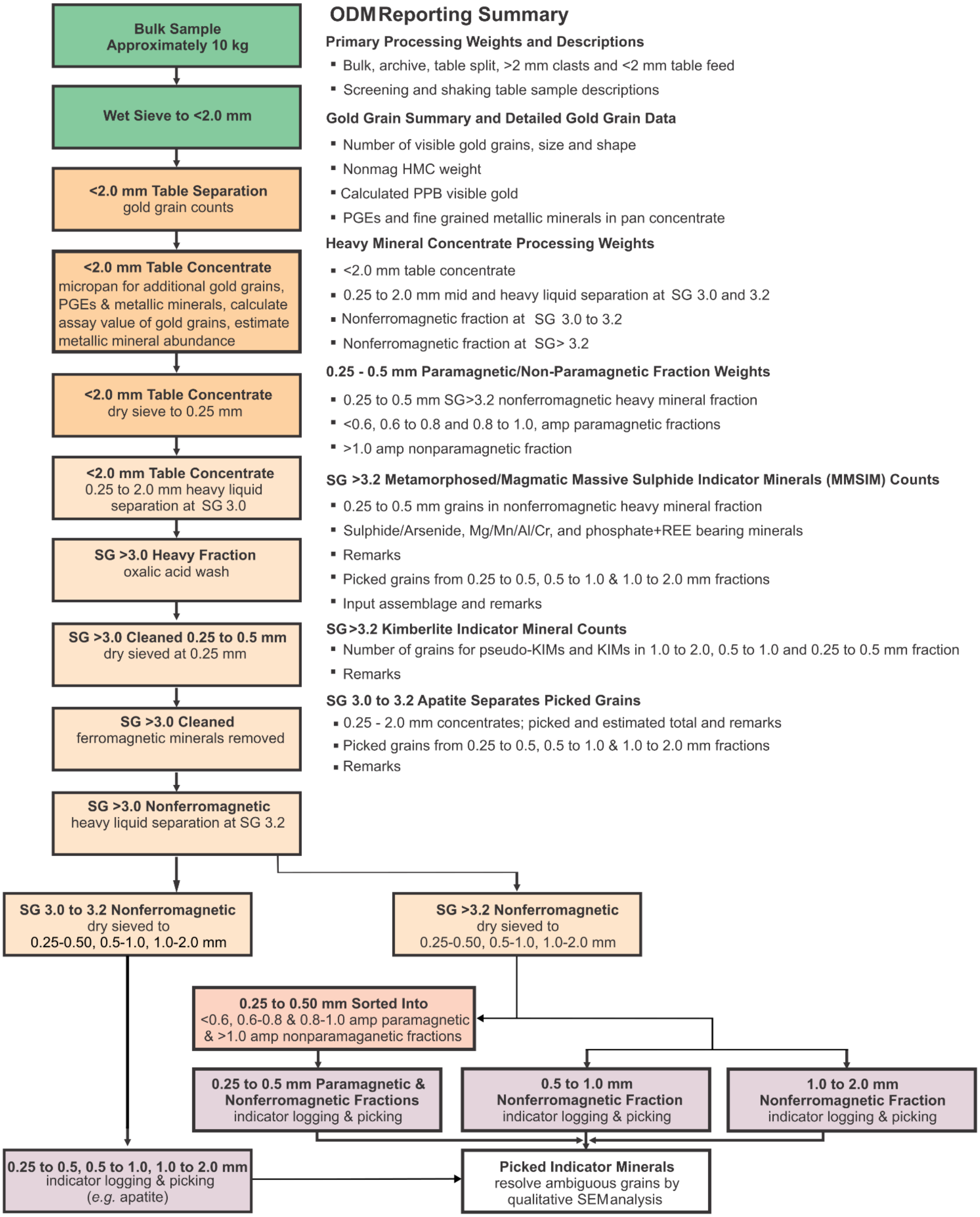
A 300-g split of the till matrix was sent to Saskatchewan Research Council (SRC) Geoanalytical Laboratories in Saskatoon, SK for grain-size analysis. For the fall 2022 field program, the 300-gram split was taken from the original sample at Bureau Veritas prior to processing. This split was placed in a paper bag and shipped to SRC. Samples collected during the 2023 winter program were split into approximately 300 g sample sizes in the field and shipped directly to SRC.

The moisture content of the samples was determined by weighing them as received, drying them at 60°C, and reweighing them. The samples were disaggregated using a rolling pin and sieved to ±2 mm. Sand fractions were determined by sieving using 2 mm, 1 mm, 250 µm, 125 µm, and 63 µm sieve sizes. Determination of the sand, silt and clay size-fractions was completed using the hydrometer method. Ten grams of the <2 mm size-fraction was transferred to a flask and deflocculated with Calgon® and deionized water. The flask was then shaken until the contents were thoroughly mixed, and the mixture was sieved through a screen into a graduated cylinder. After a certain period, dependent on ambient room temperature, an aliquot of clay was removed from the cylinder, while the sieved sand and aliquots of sample material were dried and weighed again. The calculations to determine the percentage of sand, silt, and clay size fractions were based on the total dry weight. Quality control for this analysis involved testing an in-house sand, silt, and clay standard that was inserted every 12 samples. Replicate samples were also inserted after every 40 samples or at the end of a smaller group. The reported detection limit of the analysis 0.01%.

2.3.3 Mineralogical Analysis

Of the 511 bulk samples collected in the field, approximately 60% (102 till and 201 stream sediment) were sent for indicator mineral separation and identification at Overburden Drilling Management Ltd. (ODM), in Nepean, ON. A 300-g representative split for archiving was collected from the center of each sample at the laboratory. Medium-density mineral concentrates with a specific gravity (SG) of 3.0 to 3.2 and heavy-density mineral concentrates with an SG greater than 3.2 were produced using a shaking table and heavy liquids (Figure 8). Primary processing involved wet sieving to 2 mm and a shaking table split. The >2-mm clasts were described by composition, and the <2-mm matrix was described by grain size distribution and colour. The table concentrates were micro-panned for gold grains, platinum group elements and fine-grained metallic indicator minerals. The assay value of visible gold was determined using a calculation outlined in Averill and Zimmerman (1986) and the metallic mineral abundance was estimated. Next, the table concentrates were dry sieved to 0.25 mm, and the 0.25- to 2-mm fraction underwent a heavy liquid separation at an SG of 3.0. An oxalic acid wash was applied to the heavy concentrate (SG >3.0). The cleaned concentrates were then dry sieved at 0.25 mm, and ferromagnetic minerals were removed. A heavy liquid separation at SG 3.2 was used to create the nonferromagnetic medium-density (SG 3.0 to 3.2) and high-density (SG >3.2) concentrates. Both concentrates were sieved into 0.25 to 0.5-mm, 0.5 to 1-mm and 1.0 to 2-mm size fractions. Indicator minerals, specifically apatite, were visually identified and picked from these size fractions of the medium-density concentrate.

The 0.25 to 0.5-mm size-fraction of the high-density concentrate was further sorted with a Carpco® drum magnetic separator into <0.6-, 0.6 to 0.8- and 0.8 to 1.0-amp paramagnetic fractions and a >1.0-amp nonparamagnetic fraction. Indicator minerals were visually identified and picked from the paramagnetic and nonferromagnetic 0.25 to 0.5-mm size-fractions, and from the nonferromagnetic 0.5 to 1 mm and 1 to 2 mm size fractions. As well, the Scheelite grains were identified using short wave-ultraviolet light. A scanning electron microscope (SEM) was used when required to qualitatively verify the mineral identification.



ODM Reporting Summary

Primary Processing Weights and Descriptions

- Bulk, archive, table split, >2 mm clasts and <2 mm table feed
- Screening and shaking table sample descriptions

Gold Grain Summary and Detailed Gold Grain Data

- Number of visible gold grains, size and shape
- Nonmag HMC weight
- Calculated PPB visible gold
- PGEs and fine grained metallic minerals in pan concentrate

Heavy Mineral Concentrate Processing Weights

- <2.0 mm table concentrate
- 0.25 to 2.0 mm mid and heavy liquid separation at SG 3.0 and 3.2
- Nonferromagnetic fraction at SG 3.0 to 3.2
- Nonferromagnetic fraction at SG> 3.2

0.25 - 0.5 mm Paramagnetic/Non-Paramagnetic Fraction Weights

- 0.25 to 0.5 mm SG>3.2 nonferromagnetic heavy mineral fraction
- <0.6, 0.6 to 0.8 and 0.8 to 1.0, amp paramagnetic fractions
- >1.0 amp nonparamagnetic fraction

SG >3.2 Metamorphosed/Magmatic Massive Sulphide Indicator Minerals (MMSIM) Counts

- 0.25 to 0.5 mm grains in nonferromagnetic heavy mineral fraction
- Sulphide/Arsenide, Mg/Mn/Al/Cr, and phosphate+REE bearing minerals
- Remarks
- Picked grains from 0.25 to 0.5, 0.5 to 1.0 & 1.0 to 2.0 mm fractions
- Input assemblage and remarks

SG >3.2 Kimberlite Indicator Mineral Counts

- Number of grains for pseudo-KIMs and KIMs in 1.0 to 2.0, 0.5 to 1.0 and 0.25 to 0.5 mm fraction
- Remarks

SG 3.0 to 3.2 Apatite Separates Picked Grains

- 0.25 - 2.0 mm concentrates; picked and estimated total and remarks
- Picked grains from 0.25 to 0.5, 0.5 to 1.0 & 1.0 to 2.0 mm fractions
- Remarks

Figure 8. Flowchart describing indicator mineral processing and identification methods.

2.4 Quality Control

2.4.1 Geochemistry

Verification of the accuracy and precision of geochemical analyses is necessary to ensure their reliability. Each block of 20 samples submitted for geochemical analysis included a field duplicate (FDUP), an analytical duplicate (ADUP), and an aliquot of CRM. The field duplicates were randomly selected and collected from the same pit as the routine field sample to test sample site variability. The analytical duplicate is a split of the field duplicate, which was completed in the lab after the initial sieving sample preparation. The CRM (OREAS47) is an augmented Canadian subglacial till from a source location near Chibougamau, Quebec. It was used as the reference standard to measure the accuracy of the laboratory results, by providing a comparison between the analytical results and known values. Reliability of the results was measured by statistical evaluation of analytical results from the CRM, field duplicate samples, and analytical duplicate samples.

To estimate the analytical accuracy of the analyses, 23 samples of OREAS47 were introduced into the till sample batch and 24 into the stream sediment batch prior to lab submission. Results for the OREAS47 standard are compared to the recommended values provided by OREAS using percentage recovery values. Percentage recovery, which represents a measure of accuracy, is defined by the following equation (*cf*. Ziegler and Combs, 1997):

$$Percentage\ Recovery = 100 \times \frac{C_m}{C_A}$$

where:
C_m = the measured concentration of the standard sample
C_A = the actual concentration of the standard sample (recommended or provisional value)

Percentage recovery values near 100% indicate a high degree of accuracy. If 50% or less of the results for an element were below the lower detection limit (LDL), values below the LDL were set to one half of the LDL for the percentage recovery calculation. If more than 50% of the results for an element were below the LDL, the percentage recovery was not calculated. In addition, the OREAS47 standard is not adequately characterized for some elements, thereby precluding percentage recovery calculations.

The percent relative standard deviation (%RSD) of repeated analyses of OREAS47 provides a measure of precision. Low %RSD values indicate a high degree of precision. The %RSD is defined by the following equation:

$$\%\ Relative\ Standard\ Deviation = 100 \times \frac{s}{x}$$

where:
s = standard deviation
x = mean of replicate determinations

If 50% or less of the results for an element were below the LDL, values below the LDL were set to one half of the LDL for the %RSD calculation. If more than 50% of the results for an element were below the LDL, the RSD was not calculated.

The till and stream sediment sample batches submitted to BV each included 23 and 24 field duplicates, respectively. An analytical duplicate was created from each field duplicate, resulting in the same number of analytical duplicate pairs for each sample type. The average of the relative percentage difference (RPD) for each analyte represents a measure of precision (*cf*. Ziegler and Combs, 1997; Zimmerman et al., 2001). The RPD for a set of duplicate pair results is defined by the following equation:

$$Relative\ Percent\ Difference = 100 \times \frac{|C_1 - C_2|}{C_x}$$

where:
C_1 = concentration of the analyte in duplicate 1
C_2 = concentration of the analyte in duplicate 2
C_X = mean of the concentration in the duplicates

If values below the LDL were returned for an element in both samples of a duplicate pair, that pair was removed from the RPD calculation for that element. If a given duplicate pair returned one value below the LDL and one measurable value, then value below the LDL was set to half of the LDL for the purpose of the RPD calculation.

Analytical differences between the field and analytical duplicate pairs should reflect the homogeneity of the sample pairs and the analytical precision (low values indicating a high level of homogeneity and analytical precision).

2.4.2 Mineralogy

Quality control for heavy mineral sample analysis followed best practices as outlined by Plouffe *et al.* (2013). A total of 15 samples with known quantities of indicator minerals were submitted along with minerology samples collected in the field for analysis. These included two blank samples to monitor for cross-contamination, and thirteen spiked samples to assess the effectiveness of the processing laboratory. The quality control samples were represented by similar sample numbers and contained a similar weight of material in comparison to the routine samples to make them indistinguishable. The sample material used was derived from Brownvale till collected by AGS in 2022 from an exposure where no previous KIM results were identified. All garnet, chromite, olivine (forsterite), chrome diopside, and ilmenite grains inserted into the samples originated from samples picked by ODM and were collected in 2003 from a stream in the southeastern Buffalo Head Hills within an area of known kimberlites. Selected grains were photographed and inserted into a sample vial where a final count was confirmed. The grains were then added to the Brownvale till in a hole approximately 15 cm deep in the centre of the sample that was created with a clean trowel. After the grains were transferred to the sample the vial was examined to confirm all grains were introduced into the sample and the hole was covered.

3. Results and Discussion

3.1 Geochemistry Quality Control Evaluation

APR values for determinations by lithium-borate fusion ICP-ES/MS are generally within 5% of 100%. APR values for determination by aqua-regia ICP-MS are generally within 15% of 100% (Table 6). The low APR values for S and Ga (<85%) and high APR values (<115%) for Au by aqua-regia ICP-MS fall outside the accepted limit of two times the relative standard deviation of the CRM certified values, indicating errors in accuracy. Blank APR values in Table 6 represent the undefined concentrations of select elements in the certified reference material (CRM). Blank %RSD values occur when more than 50% of the results for an element are below the LDL.

RPD values for the field and analytical duplicates of major oxide determinations by lithium-borate fusion ICP-ES are mostly less than 5%. RPD values for field and analytical duplicates of trace element, precious and base metal determinations by lithium-borate fusion ICP-MS are generally less than 10%. RPD values for elemental determinations by aqua-regia ICP-MS have greater a greater range, from <5% to <20%. Typically, elements with RPD values of >20% (B, W, Sn, Se, Te, S, Au, Pt, Ni) have several measured values near or below the LDL. Elements with RPD values >50% (Be, Re, Pt) have mostly measured values near or below the LDL. Blank RPD values in Table 6 are the result of all measured values for that element being below the LDL.

Table 6. Quality control results for analytical precision by percent relative standard deviation (%RSD), and accuracy by average percent recovery (APR) for OREAS47 certified reference material. Average relative percent differences (RPD) for field and analytical duplicates (FDUP; ADUP). %RSD and RPD values in blue are between 15% and 30%, values in orange are between 30% and 50%, and values in red are >50%. APR values in orange are within 5 to 15% of 100%, and values in red are within 15 to 25% of 100%.

		Till				**Stream sediments**			
Element	*Analytical method*	*%RSD (OREAS47)*	*APR (OREAS47)*	*Average RPD value (FDUP)*	*Average RPD value (ADUP)*	*%RSD (OREAS47)*	*APR (OREAS47)*	*Average RPD value (FDUP)*	*Average RPD value (ADUP)*
Ag	AQ251-EXT+REE	7.4	99.3	7.5	6.7	4.6	100.1	10.3	4.9
Al	AQ251-EXT+REE	7.1	98.6	4.9	5.8	4.6	102.8	6.1	3.5
As	AQ251-EXT+REE	7.3	96.6	7.8	5.0	4.2	99.2	9.3	4.1
Au	AQ251-EXT+REE	5.4	**115.4**	11.8	16.8	6.9	**117.6**	**38.6**	**40.0**
B	AQ251-EXT+REE	**32.8**	-	**16.1**	**21.8**	**26.7**	-	**16.0**	9.9
Ba	AQ251-EXT+REE	8.5	**94.9**	11.9	5.5	4.9	96.5	10.3	8.8
Be	AQ251-EXT+REE	**15.4**	**105.3**	9.8	14.0	14.9	**109.3**	**16.5**	14.6
Bi	AQ251-EXT+REE	7.9	**94.0**	5.6	6.1	5.8	**93.9**	7.6	5.1
Ca	AQ251-EXT+REE	7.6	104.6	12.0	8.0	4.8	**109.0**	10.7	3.1
Cd	AQ251-EXT+REE	9.6	97.0	12.2	10.0	6.1	99.5	10.5	6.4
Ce	AQ251-EXT+REE	7.6	**92.8**	5.0	6.7	3.8	**93.2**	6.0	4.3
Co	AQ251-EXT+REE	7.0	96.2	6.9	4.3	2.0	98.6	6.6	4.0
Cr	AQ251-EXT+REE	7.9	101.5	4.6	5.2	4.0	104.6	6.2	5.9
Cs	AQ251-EXT+REE	8.6	**93.5**	5.3	7.8	4.2	**94.3**	8.8	8.6
Cu	AQ251-EXT+REE	7.0	**94.0**	5.9	5.2	2.6	95.7	9.2	4.4
Dy	AQ251-EXT+REE	7.4	-	5.0	7.2	5.7	-	7.1	4.7
Er	AQ251-EXT+REE	8.3	-	4.4	8.4	5.2	-	6.5	4.0
Eu	AQ251-EXT+REE	10.3	-	5.3	6.9	6.4	-	6.7	5.2
Fe	AQ251-EXT+REE	7.1	95.2	3.4	3.8	2.2	97.7	5.9	2.3
Ga	AQ251-EXT+REE	10.0	**80.1**	4.1	5.6	7.7	**84.2**	7.0	4.5
Gd	AQ251-EXT+REE	9.3	**88.4**	4.4	7.1	6.0	**88.4**	6.5	4.1
Ge	AQ251-EXT+REE	-	-	-	-	0.0	-	-	-
Hf	AQ251-EXT+REE	9.6	-	12.4	10.5	7.8	-	**17.6**	8.1
Hg	AQ251-EXT+REE	**24.1**	-	9.3	7.8	12.7	-	11.9	10.9
Ho	AQ251-EXT+REE	8.1	**89.6**	4.8	8.0	6.7	**91.2**	6.9	5.6
In	AQ251-EXT+REE	14.2	95.2	**16.1**	10.2	14.6	99.8	**19.1**	**19.6**
K	AQ251-EXT+REE	8.3	97.7	5.6	6.2	6.4	101.5	7.0	4.8

		Till				**Stream sediments**			
Element	***Analytical method***	***%RSD (OREAS47)***	***APR (OREAS47)***	***Average RPD value (FDUP)***	***Average RPD value (ADUP)***	***%RSD (OREAS47)***	***APR (OREAS47)***	***Average RPD value (FDUP)***	***Average RPD value (ADUP)***
La	AQ251-EXT+REE	7.3	96.0	4.7	5.8	4.2	96.3	5.5	4.4
Li	AQ251-EXT+REE	9.6	95.2	4.2	5.4	5.6	99.1	6.5	4.7
Lu	AQ251-EXT+REE	8.2	**85.0**	5.5	8.2	8.3	**87.4**	8.8	6.1
Mg	AQ251-EXT+REE	7.9	96.9	5.2	3.0	3.3	101.5	8.6	2.6
Mn	AQ251-EXT+REE	7.5	99.6	10.5	5.2	3.2	102.9	13.6	2.4
Mo	AQ251-EXT+REE	6.9	**93.5**	10.7	7.6	2.2	95.7	8.3	4.3
Na	AQ251-EXT+REE	10.5	101.3	4.4	5.6	11.4	**106.8**	6.5	3.7
Nb	AQ251-EXT+REE	**15.8**	-	9.8	13.2	**16.1**	-	13.4	11.2
Nd	AQ251-EXT+REE	8.6	96.4	4.4	6.8	4.6	96.3	4.9	4.5
Ni	AQ251-EXT+REE	6.9	96.0	5.4	5.2	2.5	98.1	6.8	4.6
P	AQ251-EXT+REE	7.0	**95.0**	3.9	3.8	3.4	96.2	5.4	3.2
Pb	AQ251-EXT+REE	6.8	**92.8**	4.9	4.5	3.4	**94.1**	7.1	4.1
Pd	AQ251-EXT+REE	9.4	101.4	-	-	8.0	101.4	-	-
Pr	AQ251-EXT+REE	9.0	**94.2**	4.1	6.9	4.6	**94.9**	5.8	4.9
Pt	AQ251-EXT+REE	7.9	96.2	-	66.7	6.3	97.5	**66.7**	-
Rb	AQ251-EXT+REE	7.8	95.3	4.5	6.0	3.8	99.0	6.6	6.5
Re	AQ251-EXT+REE	-	-	**51.5**	**47.6**	-	-	**42.1**	**31.3**
S	AQ251-EXT+REE	**19.7**	**84.8**	**26.9**	8.7	6.5	**88.6**	13.7	3.5
Sb	AQ251-EXT+REE	6.4	96.2	8.5	12.1	6.1	**94.4**	12.7	14.1
Sc	AQ251-EXT+REE	9.3	**92.1**	5.0	5.5	7.1	96.7	6.4	4.0
Se	AQ251-EXT+REE	**28.9**	-	**22.9**	**21.9**	**34.4**	-	**15.6**	13.8
Sm	AQ251-EXT+REE	8.8	95.5	4.7	7.2	5.2	95.5	6.6	6.4
Sn	AQ251-EXT+REE	9.4	**89.8**	**15.6**	8.4	7.1	**92.2**	14.6	6.3
Sr	AQ251-EXT+REE	8.3	102.7	6.5	5.7	5.4	**107.1**	6.4	3.8
Ta	AQ251-EXT+REE	-	-	-	-	-	-	-	-
Tb	AQ251-EXT+REE	8.7	**86.3**	4.8	6.6	6.3	**85.5**	6.2	4.9
Te	AQ251-EXT+REE	0.0	-	**25.0**	**22.2**	14.1	-	**24.3**	**25.6**
Th	AQ251-EXT+REE	9.4	**92.9**	5.6	5.4	6.6	95.2	4.9	5.5
Ti	AQ251-EXT+REE	9.6	101.9	6.0	12.2	5.3	103.0	9.2	7.7
Tl	AQ251-EXT+REE	9.3	**92.4**	6.7	6.9	4.1	**95.0**	6.9	6.7
Tm	AQ251-EXT+REE	11.7	-	5.5	7.8	5.6	-	7.1	5.2
U	AQ251-EXT+REE	9.3	**86.1**	5.3	4.4	7.8	**87.6**	7.0	4.1
V	AQ251-EXT+REE	8.4	95.8	4.8	5.8	5.6	100.1	5.6	4.2

		Till				**Stream sediments**			
Element	***Analytical method***	***%RSD (OREAS47)***	***APR (OREAS47)***	***Average RPD value (FDUP)***	***Average RPD value (ADUP)***	***%RSD (OREAS47)***	***APR (OREAS47)***	***Average RPD value (FDUP)***	***Average RPD value (ADUP)***
W	AQ251-EXT+REE	-	-	**15.4**	0.0	-	-	-	-
Y	AQ251-EXT+REE	8.7	**94.9**	5.2	7.2	4.1	96.7	6.4	3.8
Yb	AQ251-EXT+REE	10.9	**89.1**	5.4	8.5	6.6	**90.4**	6.4	5.6
Zn	AQ251-EXT+REE	6.6	96.6	4.6	3.4	1.8	98.1	5.1	3.5
Zr	AQ251-EXT+REE	9.9	**89.0**	9.9	7.9	6.5	**87.7**	13.5	7.5
SiO_2	LF300	0.3	98.7	1.9	0.4	0.2	98.7	1.9	0.8
Al_2O_3	LF300	0.9	101.1	1.7	1.8	0.9	101.0	3.7	1.2
Cr_2O_3	LF300	6.8	**89.8**	7.7	7.8	4.1	**91.4**	6.6	10.7
CaO	LF300	0.9	100.6	10.9	6.7	0.9	101.0	11.1	2.6
Fe_2O_3	LF300	0.9	101.1	2.7	2.4	1.1	101.3	5.4	2.3
K_2O	LF300	1.6	101.5	1.9	2.1	1.7	101.0	3.5	1.8
MgO	LF300	1.0	102.7	4.5	1.6	0.8	103.0	6.9	1.7
MnO	LF300	7.7	101.9	11.0	4.5	5.3	**107.0**	**15.6**	0.6
Na_2O	LF300	1.2	98.9	5.4	4.2	0.9	98.9	4.8	1.6
P_2O_5	LF300	4.0	96.7	4.9	3.4	6.0	98.7	6.4	3.2
TiO_2	LF300	1.2	99.9	2.1	1.8	1.3	100.8	2.1	1.1
Ba	LF300	1.3	98.4	4.7	1.8	1.6	99.8	4.3	2.4
Nb	LF300	12.0	98.2	**16.8**	**18.5**	13.9	**105.9**	**19.1**	**19.8**
Ni	LF300	3.3	96.0	9.5	**16.3**	4.5	96.3	**28.4**	**23.5**
Sc	LF300	0.0	97.1	2.4	2.3	0.0	97.1	5.3	3.2
Sr	LF300	0.7	99.2	2.5	3.7	1.0	99.2	4.1	1.3
Y	LF300	4.7	95.7	3.5	4.8	4.4	**94.8**	6.2	2.6
Zr	LF300	2.9	100.6	5.3	4.4	3.1	101.0	14.1	5.6
Ag	LF100-EXT	0.0	-	12.9	7.5	0.0	-	13.4	5.6
As	LF100-EXT	3.0	-	8.6	5.0	4.9	-	10.4	5.0
Au	LF100-EXT	6.8	-	**16.3**	**26.1**	6.9	-	**43.6**	**54.9**
Ba	LF100-EXT	4.8	96.6	5.4	4.4	3.6	98.5	4.2	3.3
Be	LF100-EXT	**50.0**	-	**91.2**	**93.4**	**75.3**	150.7	**106.6**	**112.3**
Bi	LF100-EXT	0.0	-	8.0	7.9	**28.6**	-	**17.4**	**15.2**
Cd	LF100-EXT	4.3	-	9.4	7.1	12.7	-	11.5	10.9
Ce	LF100-EXT	5.7	98.2	3.7	5.8	5.6	98.1	5.7	6.8
Co	LF100-EXT	6.1	97.2	7.2	6.5	4.0	97.8	7.7	5.6

		Till				**Stream sediments**			
Element	***Analytical method***	***%RSD (OREAS47)***	***APR (OREAS47)***	***Average RPD value (FDUP)***	***Average RPD value (ADUP)***	***%RSD (OREAS47)***	***APR (OREAS47)***	***Average RPD value (FDUP)***	***Average RPD value (ADUP)***
Cs	LF100-EXT	7.6	**94.1**	3.6	8.8	8.1	96.6	9.6	6.5
Cu	LF100-EXT	2.2	-	5.7	4.4	3.1	-	8.8	4.4
Dy	LF100-EXT	5.7	95.8	4.5	5.5	5.9	99.5	4.7	6.3
Er	LF100-EXT	5.3	97.1	5.6	6.1	5.7	98.8	7.0	5.8
Eu	LF100-EXT	5.1	97.0	4.5	5.8	4.4	96.9	6.8	6.6
Ga	LF100-EXT	7.2	**90.5**	3.9	7.6	4.9	**94.2**	6.3	5.7
Gd	LF100-EXT	3.8	101.1	4.1	4.9	4.8	100.6	5.7	4.2
Hg	LF100-EXT	4.5	95.7	7.0	5.4	5.0	97.6	12.6	5.2
Hf	LF100-EXT	**35.0**	-	9.6	9.0	**34.2**	-	14.1	**18.3**
Ho	LF100-EXT	4.7	**92.1**	4.6	6.2	6.3	95.8	5.8	5.9
La	LF100-EXT	4.8	100.7	4.1	5.1	5.8	99.9	4.6	5.6
Lu	LF100-EXT	7.4	98.2	5.6	6.7	7.2	100.0	6.4	4.7
Mo	LF100-EXT	3.1	95.6	13.1	8.9	3.6	97.9	11.8	9.0
Nb	LF100-EXT	5.3	**89.0**	3.5	5.4	3.4	**90.8**	4.2	4.7
Nd	LF100-EXT	4.4	99.0	3.5	5.6	4.9	99.0	5.1	5.7
Ni	LF100-EXT	2.3	**88.6**	5.0	4.5	3.3	**88.0**	7.9	3.6
Pb	LF100-EXT	3.8	-	4.2	4.5	4.4	-	7.2	5.1
Pr	LF100-EXT	4.3	99.2	2.7	4.3	3.9	99.7	4.9	4.7
Rb	LF100-EXT	4.9	97.4	2.7	5.1	3.1	98.4	4.8	3.1
Sb	LF100-EXT	0.0	-	12.0	10.6	13.9	-	12.8	12.3
Se	LF100-EXT	-	-	**37.1**	**23.9**	-	-	**20.6**	**15.5**
Sm	LF100-EXT	4.7	**93.9**	3.7	5.7	5.2	**93.8**	5.3	5.0
Sn	LF100-EXT	10.0	102.4	**29.6**	**28.5**	**22.3**	102.7	**34.6**	**45.3**
Sr	LF100-EXT	6.1	97.2	3.1	5.9	5.3	99.0	4.8	3.9
Ta	LF100-EXT	14.8	**94.2**	12.8	10.6	**17.0**	**89.5**	**16.9**	10.7
Tb	LF100-EXT	4.5	95.2	3.4	5.9	4.7	96.7	5.5	4.5
Th	LF100-EXT	5.0	100.2	4.5	5.3	4.0	101.8	7.0	7.1
Tl	LF100-EXT			4.7	6.4	-	-	11.6	14.1
Tm	LF100-EXT	5.6	**92.4**	5.0	7.9	7.0	**94.3**	6.0	5.3
U	LF100-EXT	10.1	97.1	6.2	7.1	11.0	99.3	9.5	6.5
V	LF100-EXT	6.2	**94.0**	4.3	6.9	7.6	96.9	6.4	4.8
W	LF100-EXT	**29.4**	-	**21.9**	**23.8**	-	-	**29.3**	**28.1**
Y	LF100-EXT	5.3	96.6	4.1	7.5	3.6	96.0	5.7	4.5

		Till				Stream sediments			
Element	***Analytical method***	***%RSD (OREAS47)***	***APR (OREAS47)***	***Average RPD value (FDUP)***	***Average RPD value (ADUP)***	***%RSD (OREAS47)***	***APR (OREAS47)***	***Average RPD value (FDUP)***	***Average RPD value (ADUP)***
Yb	LF100-EXT	4.5	99.0	4.3	5.9	5.3	98.0	6.6	5.6
Zn	LF100-EXT	2.5	97.3	5.1	3.3	3.4	98.3	6.1	4.1
Zr	LF100-EXT	5.2	95.8	6.1	6.0	4.6	98.5	11.6	5.3

3.2 Mineralogy Quality Control Evaluation

Results of the mineralogy quality control samples indicate an average spiked grain recovery rate of 74% (Appendix B5). The acceptable recovery rate for spiked samples is >70%. Of the 13 spiked samples included for analysis, however, six samples did not meet the expected recovery rate (*i.e.*, AER22TS-5009, AER22TS-5039, AER22TS-5070, AER22TS-5074, AER22TS-5087, and AER22TS-5116). Three potential opportunities for error were identified by ODM in the recovery of HMC: 1) the extraction of an archive split; 2) clay-rich material limiting the efficacy of sample processing (*e.g.*, shaking table separation), and the use of KIMs that were not previously verified by SEM (ODM, *pers*. *comm*., March 28, 2023). All samples with <70% indicator mineral recovery rates were investigated by ODM by processing the archive split, reprocessing table rejects and the HMC fraction was re-examined. During reprocessing, a total of 13 grains were recovered from archive splits, 1 grain was recovered from table rejects, and 4 grains were recovered from re-examination of the HMC. These additional grains are included in the recovery rate reported above.

After reprocessing by ODM, two indicator grain recovery limiting factors remain. First, there is still potential for indicator grain loss by adherence to the handheld tool used to extract the archive split. These grains would have been washed off and lost when the tool was cleaned between samples (ODM, *pers*. *comm*., March 28, 2023). Second, the KIMs used as spike material were not SEM-verified when they were originally picked. This could explain the 12% recovery rate of mantle garnets in the spiked samples. The lack of chemical verification and human error could explain several instances where KIMs were reported from the quality control samples where they should not have been present. Examples include excess purple to red peridotitic garnet (one grain reported from blank AER22TS-5014), excess Cr-diopside (grains reported in AER22TS-5009, AER22TS-5022, AER22TS-5061, and AER22TS-5074), excess chromite (grains reported in AER22TS-5005), and excess forsterite (grains reported in AER22TS-5005, and AER22TS-5022).

3.3 Sampling Results

A total of 554 till samples and 804 stream sediment samples were systematically collected across the three AOIs (Table 7). Of the 554 till samples, 358 are geochemistry samples, 150 are mineralogy samples, 23 are field duplicates, and 23 are CRM. Of the 804 stream sediment samples, 398 are geochemistry samples, 360 are mineralogy samples, 24 are field duplicates, and 24 are CRM. Till mineralogy samples were collected at roughly half of the sample sites, while stream sediment mineralogy samples were collected at all sampling sites with appropriate sampling opportunities.

The spatial distribution of samples varies across the three AOIs (Figure 9). The largest number and best spatial distribution of till samples were collected in AOI-1. This is because AOI-1 is the largest area and has the most extensive road access. In AOI-2 and AOI-3, till samples are well distributed along the accessible road networks. Stream sediment samples, on the other hand, are well distributed in AOI-2 and AOI-3, while they are concentrated in the west central portions of AOI-1 due to a lack of suitable sampling opportunities.

Table 7. Cumulative number of till and stream sediment samples acquired.

	Geochemistry	Mineralogy	Field Duplicates	Reference Standards	Total Samples
Till	358	150	23	23	554
Stream sediment	398	360	24	24	806

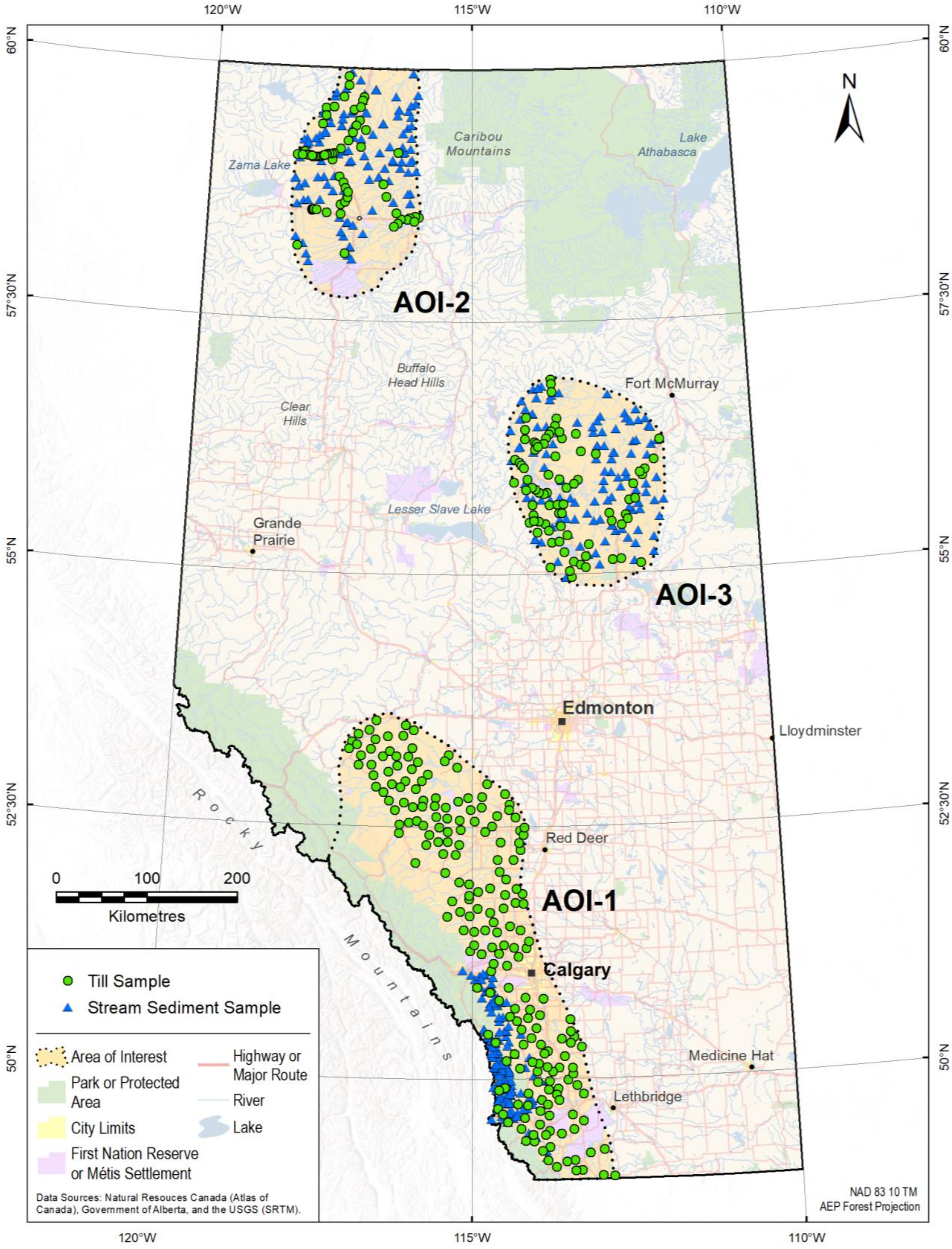


Figure 9. Till and stream sediment sample locations from this survey.

3.3.1 Till Sampling

In AOI-1, 327 till samples were collected, including 211 geochemistry samples, 90 mineralogy samples,13 field duplicates, and 13 reference standards (Figure 10). The distribution and coverage of till samples in AOI-1 is very good. Most large data gaps are a result of avoiding national and provincial parks, First Nations Reserves, urban areas, and existing mineral exploration leases (*e.g.,* the northwestern portion of AOI-1 and around Calgary and Lethbridge). Some proposed sample sites were not reached because they were on private land, behind gates, or because buried utilities were present. Widespread glaciofluvial sediments precluded sampling west of Red Deer. Descriptions of these sediments were recorded at planned sample sites. Data gaps in the northern portion of the AOI and to the southeast of Calgary are related to the presence of networks of buried utilities at planned sites.

In AOI-2, 101 till samples were collected, including 66 geochemistry samples, 25 mineralogy samples, 5 field duplicates, and five reference standards (Figure 11). Public road access in AOI-2 is poor and, although sample coverage is good along the road networks, samples could not be collected across large portions of the AOI. Extensive glaciolacustrine mantles further reduce sampling opportunities. Prior to the drill-supported sampling, most till samples collected in the areas covered with glaciolacustrine material were acquired from deeply incised stream cuts near roads.

Up to five days of helicopter-supported till sampling were scheduled to improve sample coverage where access roads do not exist. These sites typically required a pit to be dug, which increased sampling times. In addition, it was difficult to predict the occurrence of till at the surface because of the ubiquitously flat nature of the land surface, and to identify suitable landing locations because the density and height of new tree and shrub growth could not be determined from the available satellite imagery. Ultimately, these factors reduced sampling rates to three sites per day, which was not a high enough rate to justify the helicopter costs, and the program was terminated after two days.

The drill-supported sampling program was intended to identify till sampling methods and protocols that would be effective in the challenging conditions of limited access, thick glaciolacustrine sediments overlying till, and swampy, organic-rich terrain. The program focussed on collecting samples along the Zama City Highway (Township Rd 1165A) and along Highway 58, west and southwest of High Level (Figure 9). The drill provided an effective means to collect till from any location where it occurred within 10 m of the surface. *In situ* subglacial till was recovered from every hole in which it was intercepted. Samples for geochemistry were generally collected in less than an hour. Samples for mineralogy generally took two hours because custom-built, larger flow-through samplers that are more suitable for collection of high-volume samples were not available in time for the program. As a result, fewer mineralogy samples were collected during this pilot program that was planned.

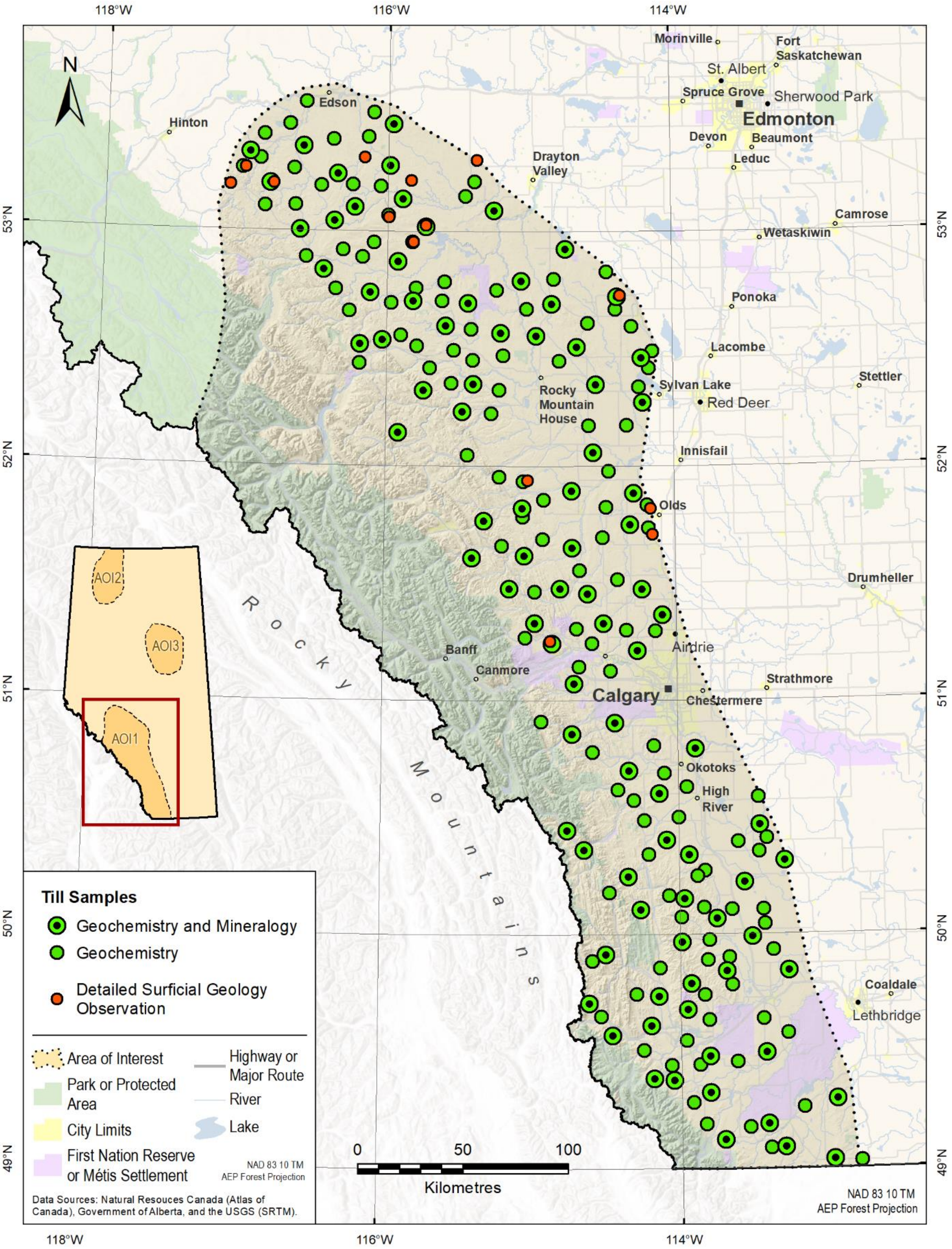


Figure 10. Till sample locations in AOI-1. Symbols with black dot indicate where samples for mineralogical analysis were collected.

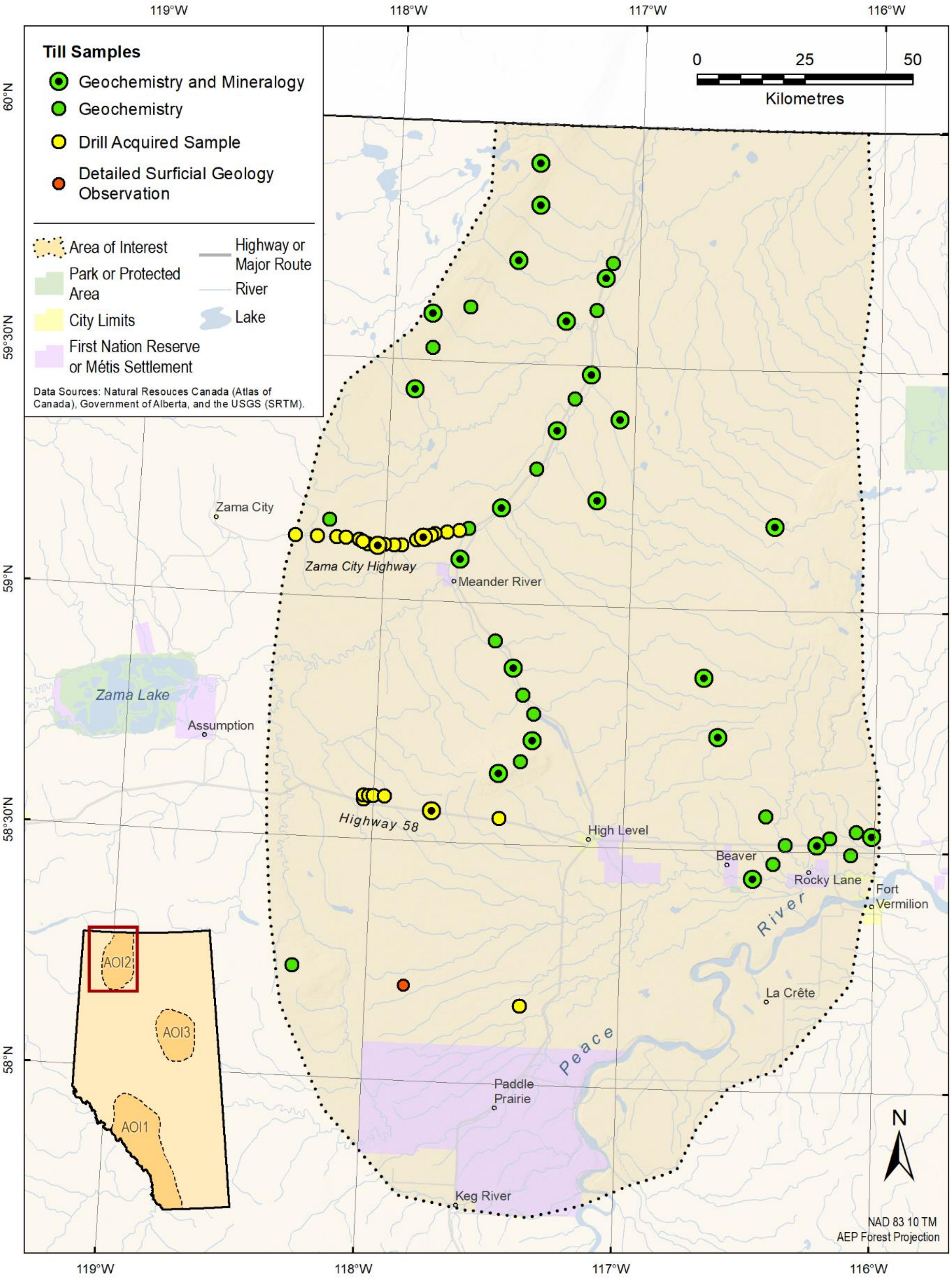


Figure 11. Till sample locations in AOI-2. Symbols with black dot indicate where samples for mineralogical analysis were collected. Yellow symbols indicate drill-supported sampling.

The efficacy of the drill-supported sampling is evident in the consistent, tightly spaced sample distribution along the Zama City Highway. The method was also effective along seismic lines. However, this was only attempted in a few locations because the pilot program lacked sufficient time to properly prepare the lines, which generally requires packing a trail with a snowmobile the day before towing the drill on custom skis behind a tracked UTV. The number of sample sites was less ideal southwest of High Level and along Highway 58. Southwest of High Level, the glaciolacustrine mantle exceeded 10 m in thickness in most places. A different configuration of the drill is required to reach these depths. An issue along Highway 58 was a lack of locations where the crew could safely pull over to unload the equipment. Potential sampling locations were identified where suitable pullouts could be seen in the satellite imagery; however, there was no opportunity to complete reconnaissance of the winter access prior to the program and these pullouts were not cleared of snow. The high snowbanks at the edge of the road left insufficient space to safely pull over, especially with the high volume of logging truck traffic. In general, most of these issues could be overcome with enough lead time to provide proper site and access preparation. The program did demonstrate that significant improvements in till sample coverage can be achieved by traversing roads and seismic lines with a lightweight shallow-drilling system.

In AOI-3, 126 till samples were collected, including 81 geochemistry samples, 35 mineralogy samples, 5 field duplicates and 5 reference standards (Figure 12). The distribution of till samples in AOI-3 is moderate and, again, mainly associated with road access. Crews were unable to collect till samples at some of the proposed sample sites due to private roads and gates restricting vehicle access. Generally, gaps in till sample data along road networks are due to the presence of glaciolacustrine or glaciofluvial materials at surface and no till being accessible with hand tools. There are large gaps in till sample coverage throughout the northeast and central portions of the AOI. These gaps may be filled using the drilling protocols tested in AOI-3; however, the extent of the seismic lines is limited, so helicopter support to move the drill would help optimize coverage.

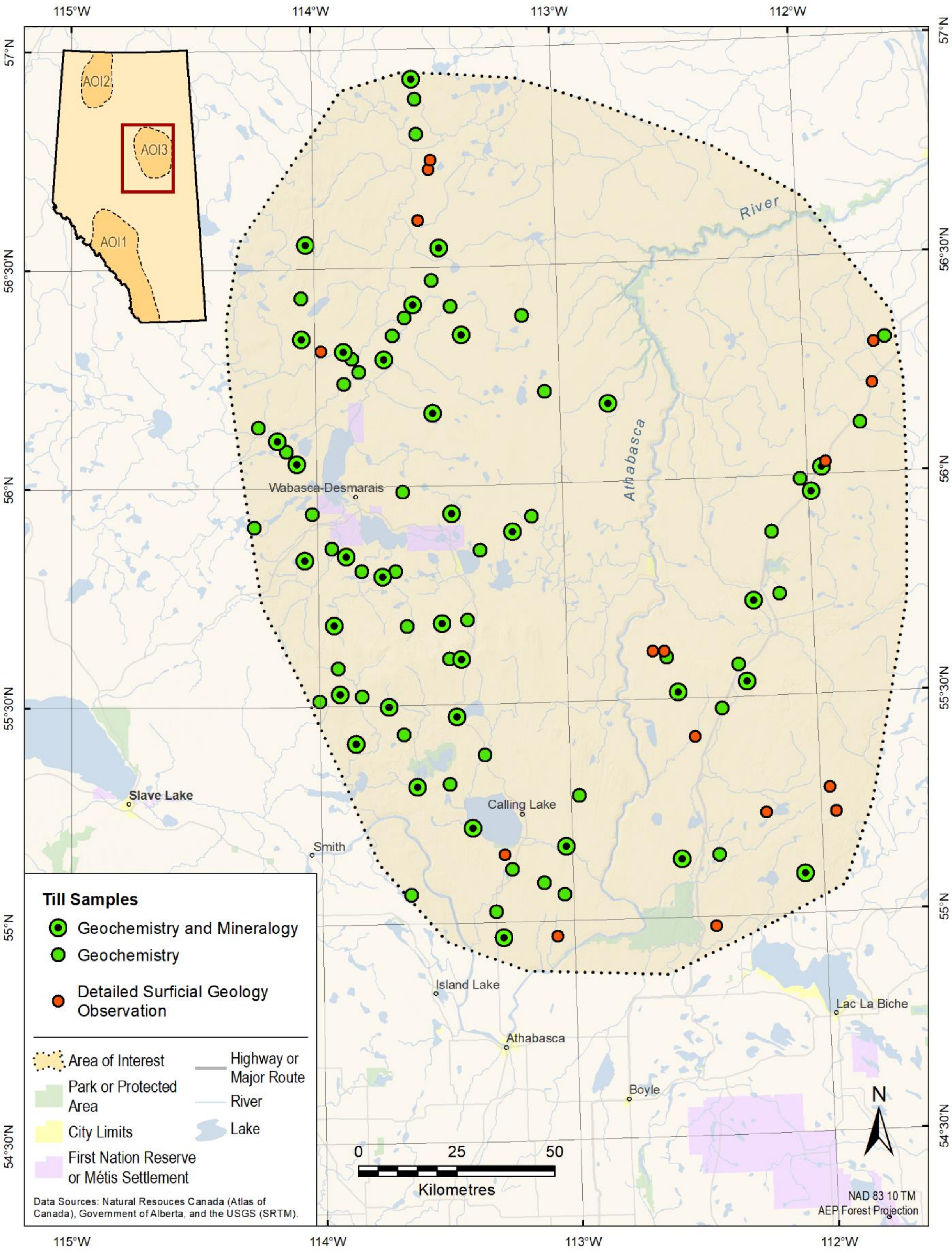


Figure 12. Till sample locations in AOI-3. Symbols with black dot indicate where samples for mineralogical analysis were collected.

3.3.2 Stream Sediment Sampling

In AOI-1, 368 stream sediment samples were collected, including 176 geochemistry samples, 170 mineralogy samples, 11 field duplicates, and 11 reference standards (Figure 13). The samples are concentrated in the central western portion of the AOI. Sample density is higher than in other AOIs because the mountainous terrain provides more sampling opportunities due to an increased density of streams and smaller catchments. Some proposed sites were not sampled for minerology because they were dry at the time of sampling (Figure 14). Sample coverage is notably lacking in the eastern and southern parts of the AOI. This is partially a function of the stream systems being less extensive and the streams being unsuitable for sampling (*e.g.,* lacking depositional features), but, more commonly, it was because the streams flow through private ranch land occupied by livestock that would have been disturbed by the helicopter. Parkland in the northern and southwestern portions of AOI-1 was also avoided.

In AOI-2, 218 stream sediment samples were collected, including 121 geochemistry samples, 85 mineralogy samples, 6 field duplicates, and 6 reference standards (Figure 15). Sample distributions are relatively uniform, and good overall coverage was achieved; however, mineralogy samples could not be collected at a large portion of sites due to flooding, a lack of bar exposure, or the occurrence of muddy material that is not suitable for mineralogical analysis (Figure 14). Data gaps in the south are due to a lack of landing sites along streams that meander over glaciolacustrine plains (Figure 14). Some planned sites were found to be inaccessible due to new vegetation growth, including trees and shrubs, or recent flooding that made it unsafe for the helicopter to land. Additionally, numerous proposed sampling sites within AOI-2 were not completed because of beaver dam-induced flooding (Figure 14). Beaver dams were very common and are present at multiple locations along entire lengths of streams. Beaver dam flooding made many proposed sample locations inaccessible and inundated the features that had been targeted for sampling based on the interpretation of available imagery.

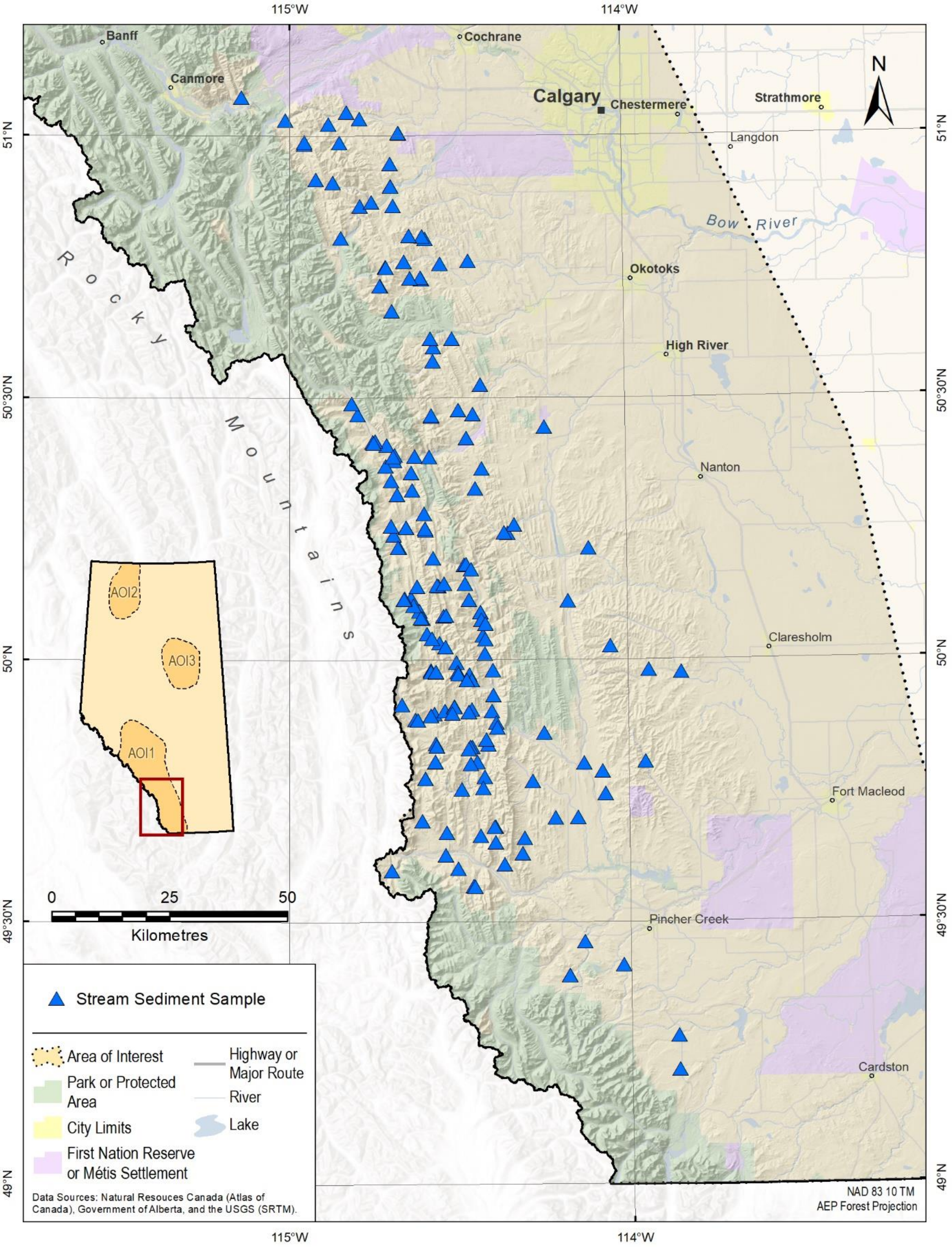


Figure 13. Stream sediment sample locations in AOI-1.

Figure 14. Terrain conditions precluding collection of stream sediment geochemistry or mineralogy sample: a) example of a beaver dam commonly present in both AOI-2 and AOI-3; b) stream meandering along glaciolacustrine plain with no exposed bars and surrounded by organic deposits; c) muddy material unsuitable for mineralogical analysis; d) dry stream bed.

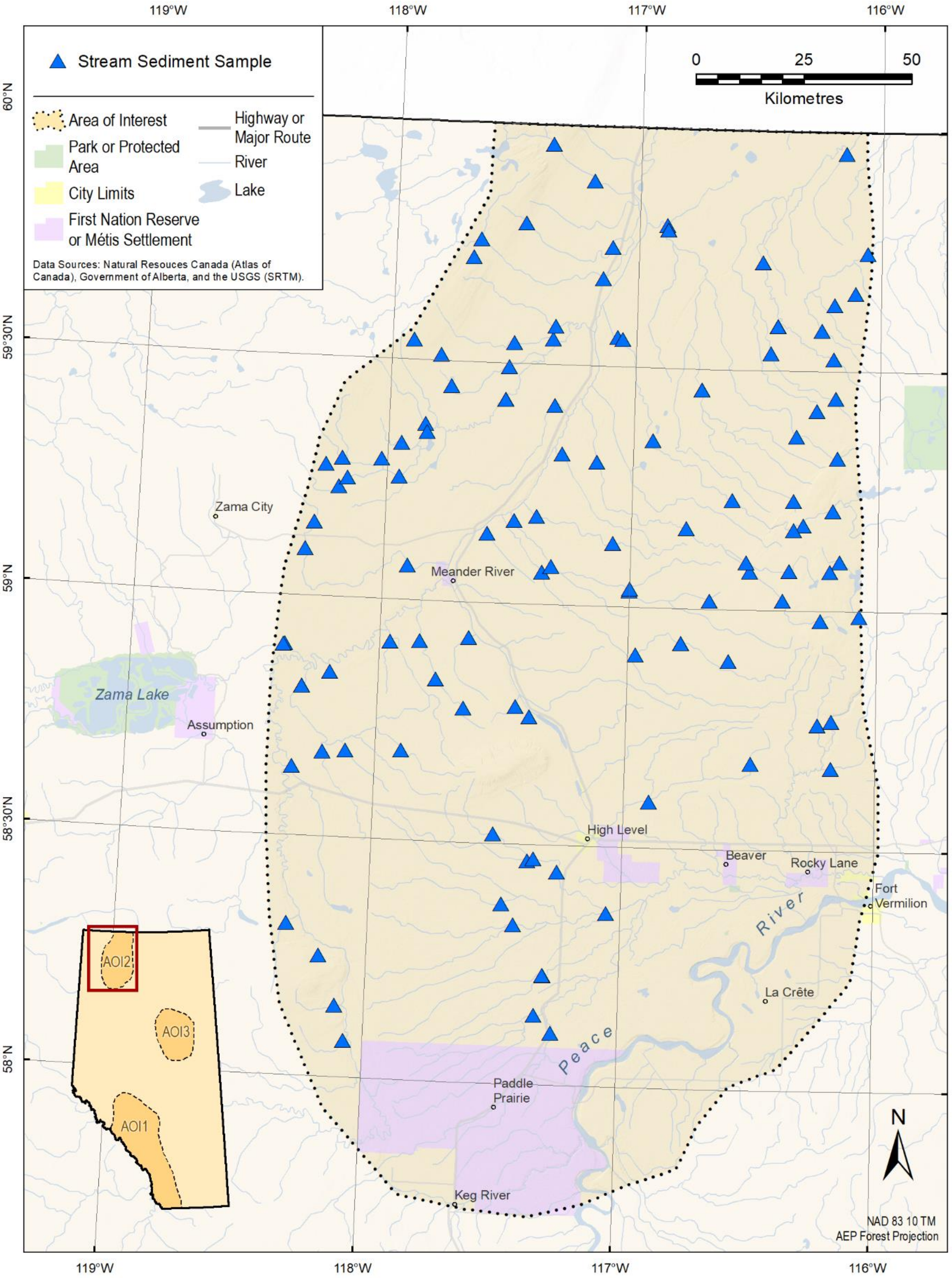


Figure 15. Stream sediment sample locations in AOI-2.

In AOI-3, 224 stream sediment samples were collected, including 106 geochemistry samples, 106 mineralogy samples, 6 field duplicates, and 6 reference standards (Figure 16). Sample distribution and coverage are good throughout the AOI. Gaps in sample data mainly occur in the central portion of the area due to a lack of landing sites and the presence of unsuitable sampling materials. Similar to AOI-2, this was largely due to the presence of abundant beaver dams and streams that flowed over extensive glaciolacustrine mantles, leading to wetland conditions unsuitable for stream sediment sampling.

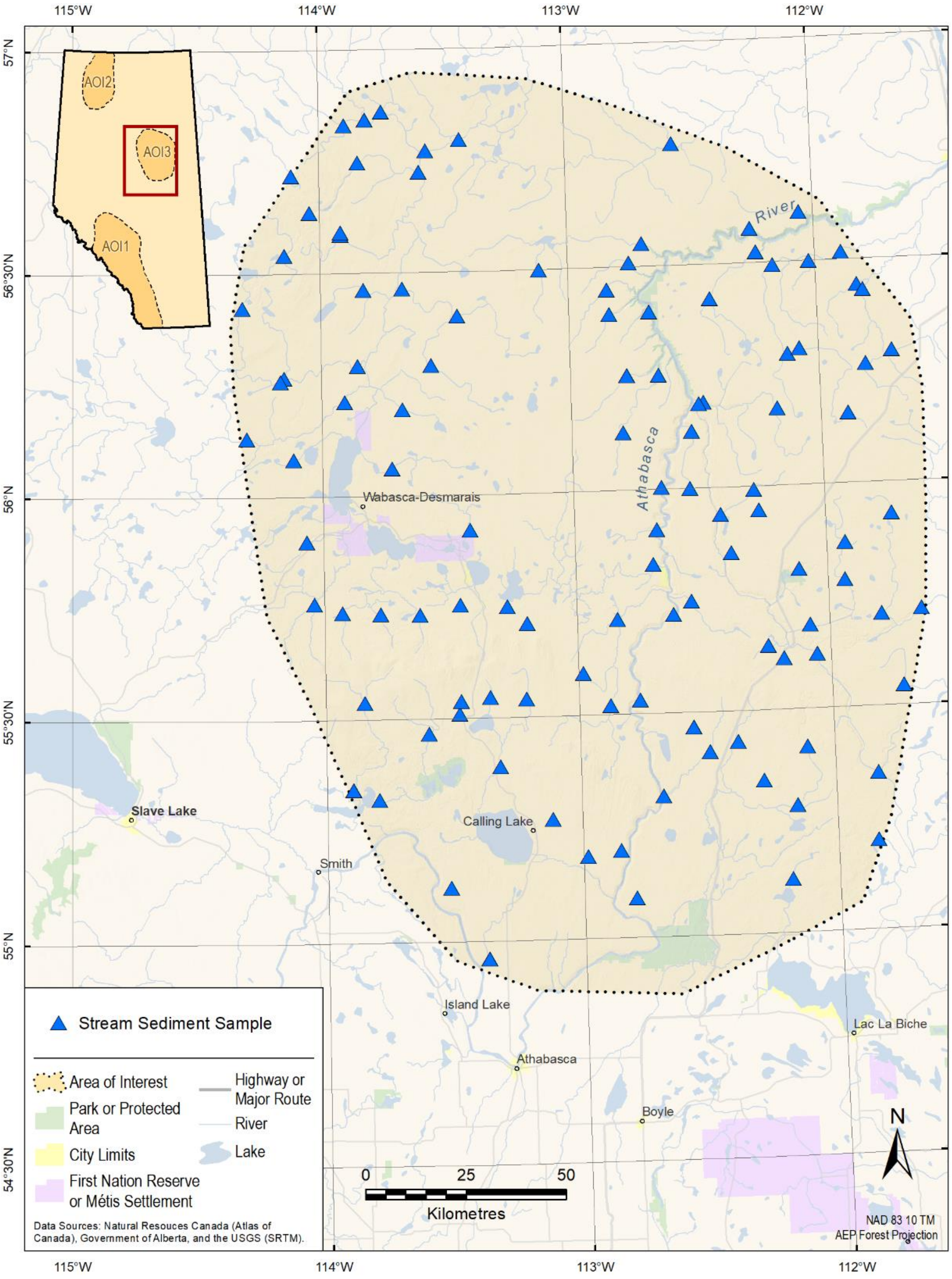


Figure 16. Stream sediment sample locations in AOI-3.

3.4 Analytical Results

All geochemical and mineralogical analytical results are provided in Appendix A in spreadsheet and spatial formats. Lab certificates are provided in Appendix B.

3.4.1 Geochemistry

Proportional-dot plots for a number of elements related to mineralization or lithological discrimination are provided in Figures 17-80. These diagrams are for illustrative purposes only. Symbology breaks are based on standard progressive percentiles that are calculated separately for each material type and AOI to reduce the influence of geographic variation on the data presentation. The data have otherwise not been treated to avoid common issues with regional geochemical datasets such as censored and non-normal data distributions (*cf.* Grunsky, 2010).

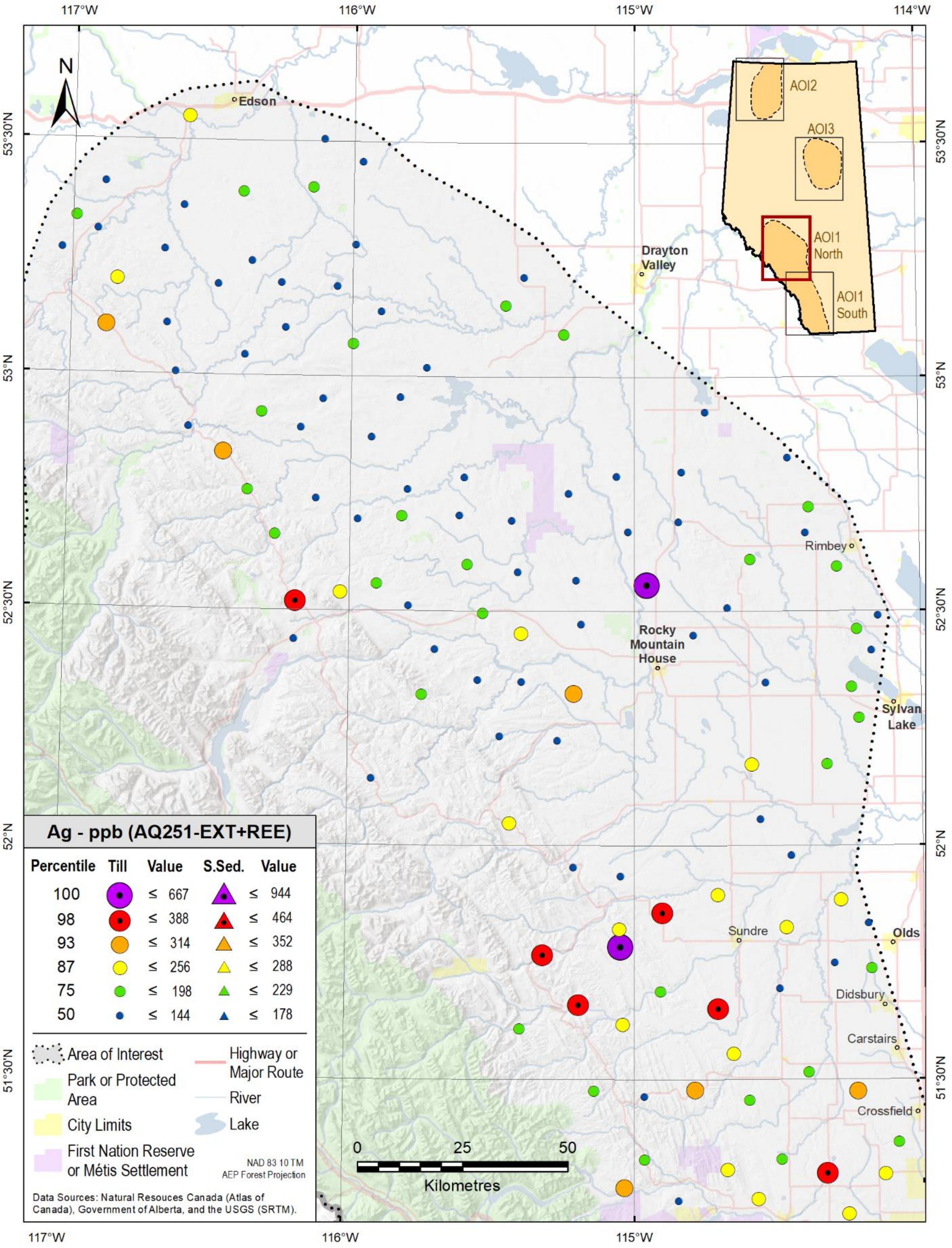


Figure 17. Silver (Ag) concentrations in till in the northern half of AOI-1.

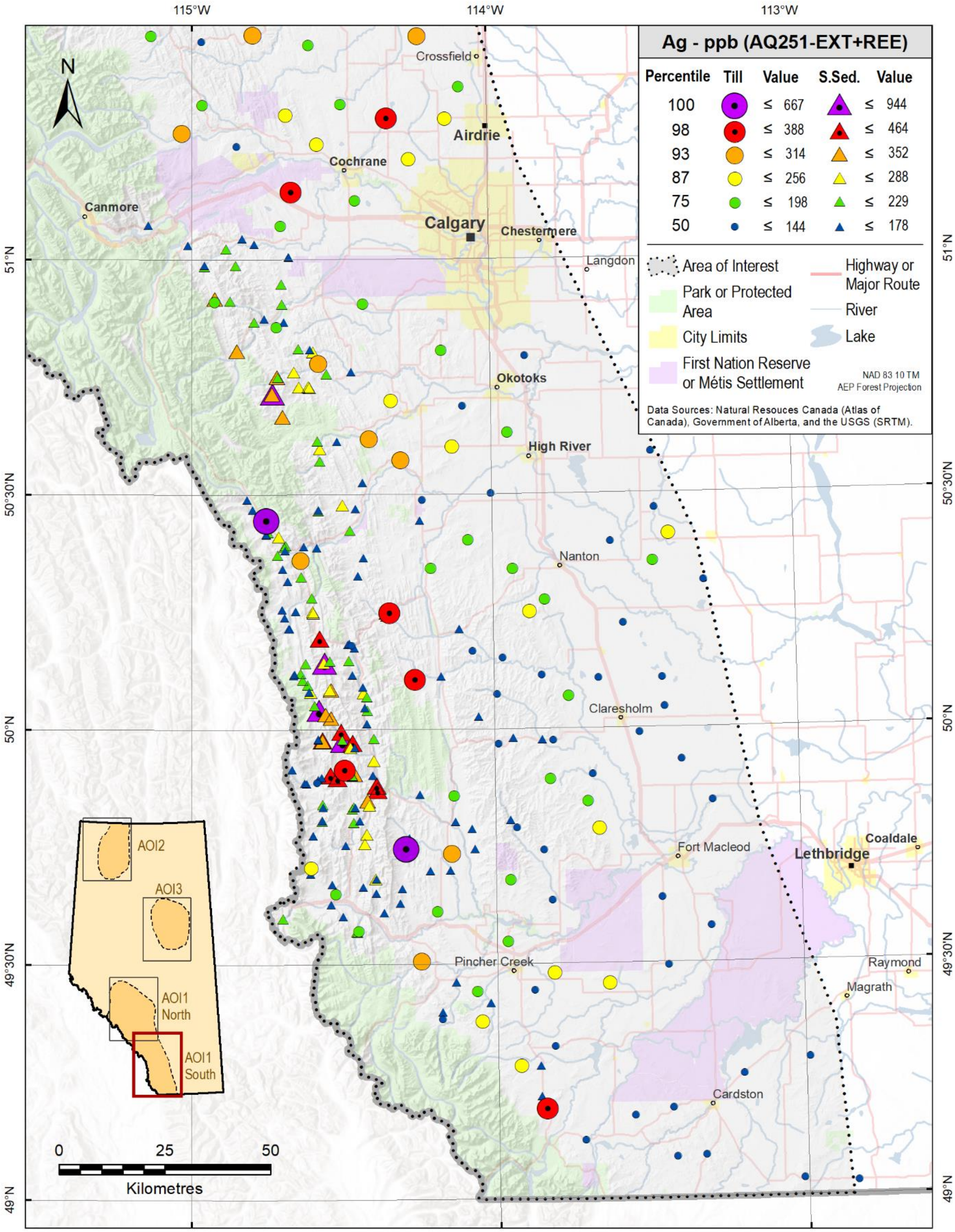


Figure 18. Silver (Ag) concentrations in till and stream sediments in the southern half of AOI-1.

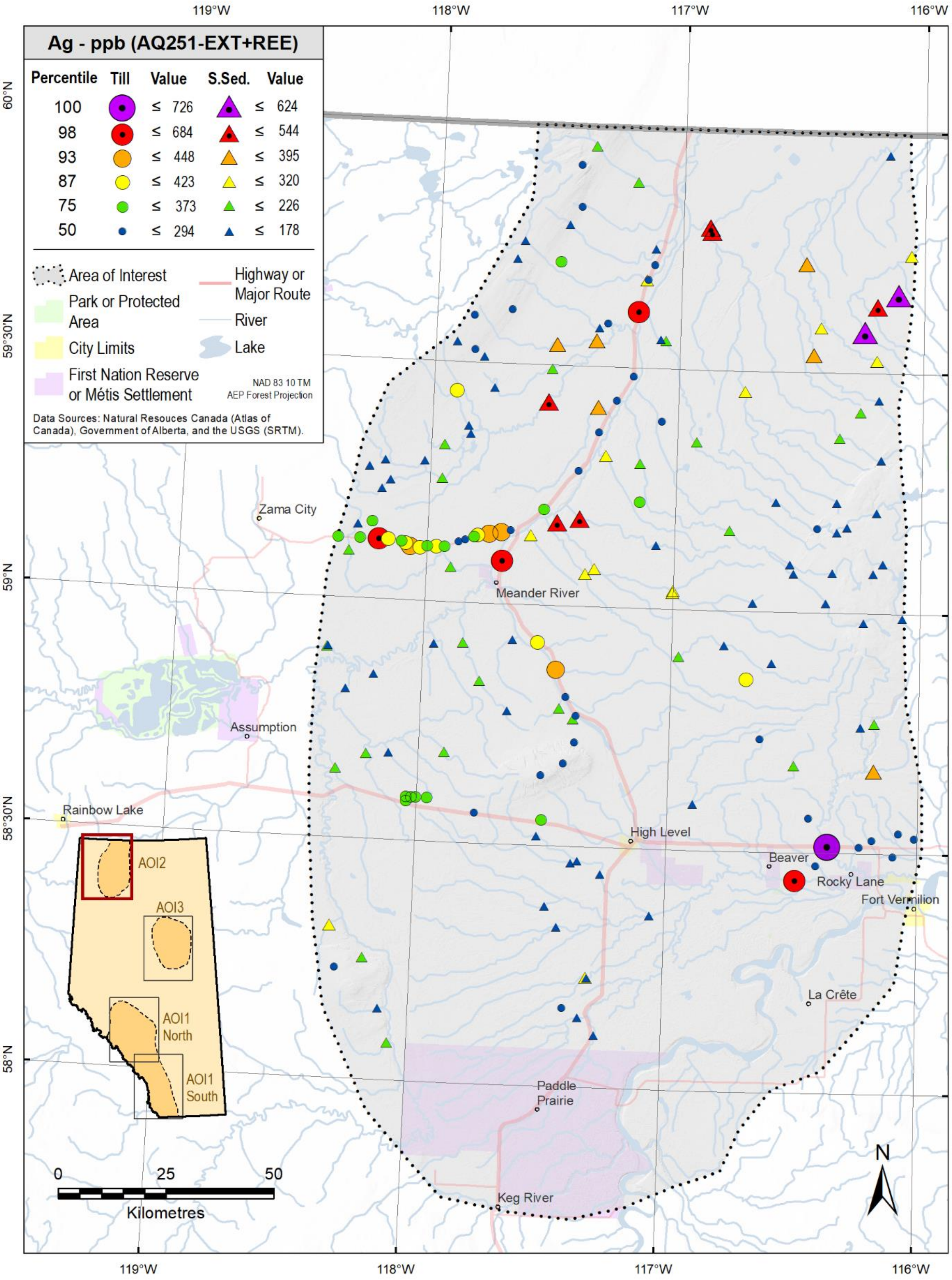


Figure 19. Silver (Ag) concentrations in till and stream sediments in AOI-2.

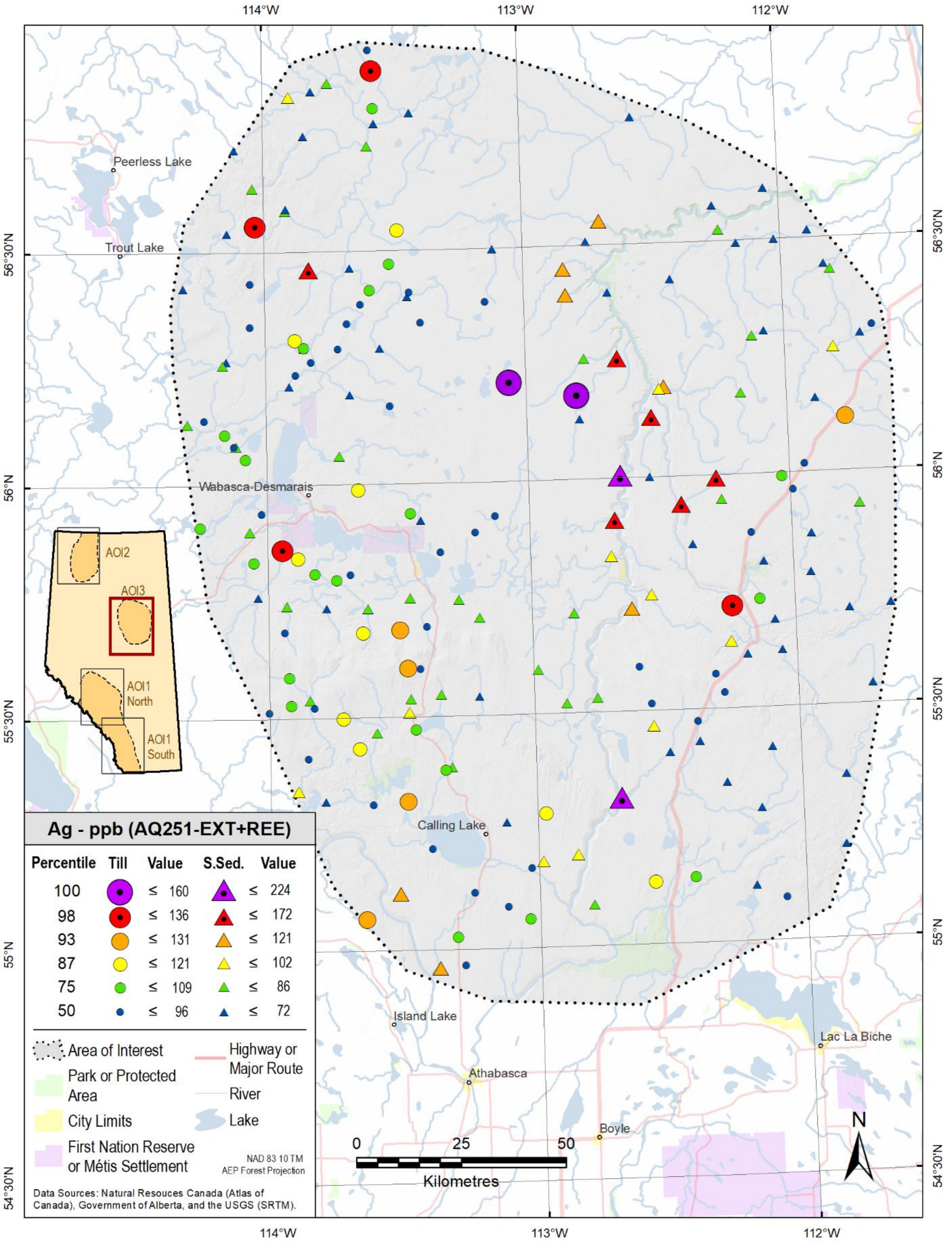


Figure 20. Silver (Ag) concentrations in till and stream sediments in AOI-3.

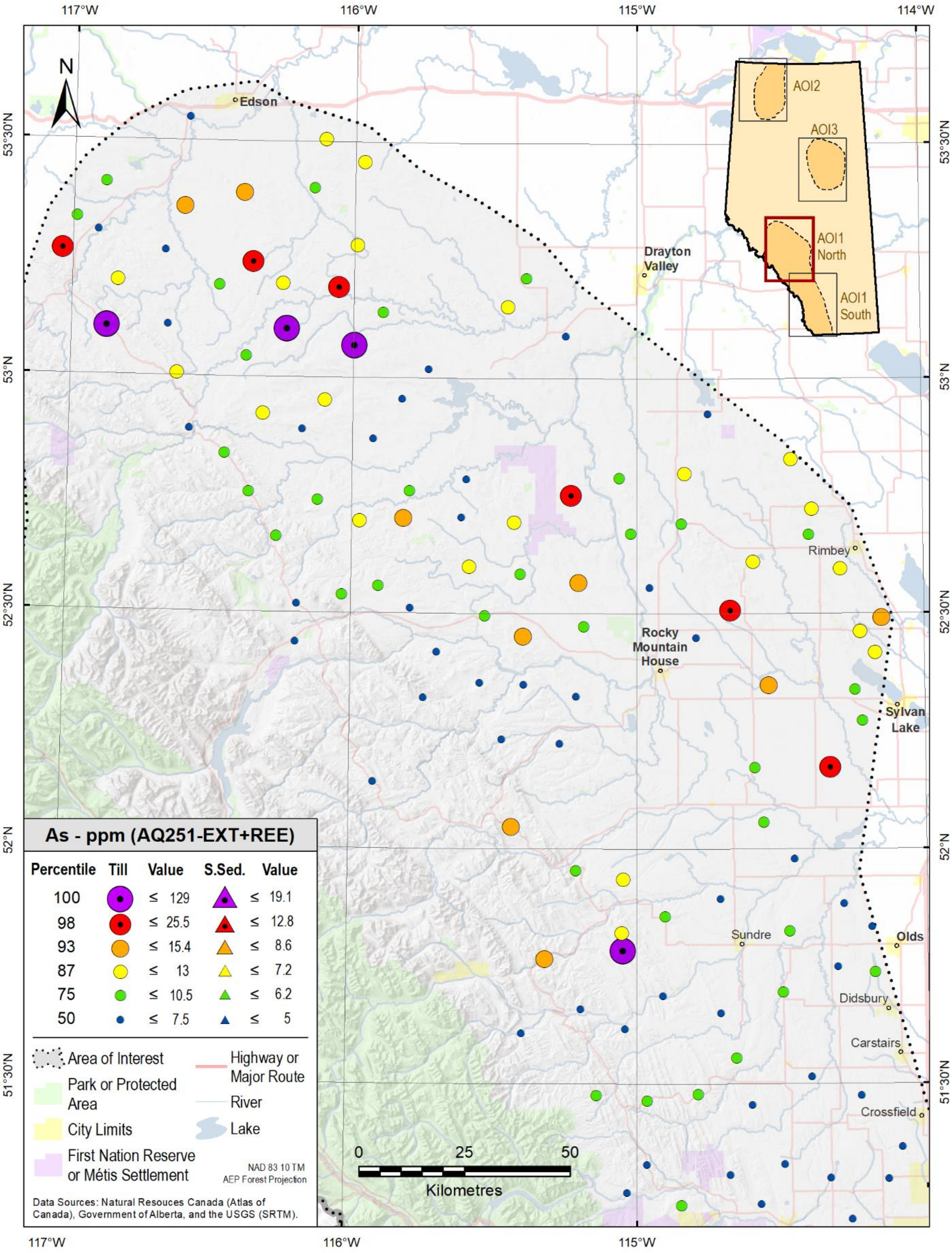


Figure 21. Arsenic (As) concentrations in till in the northern half of AOI-1.

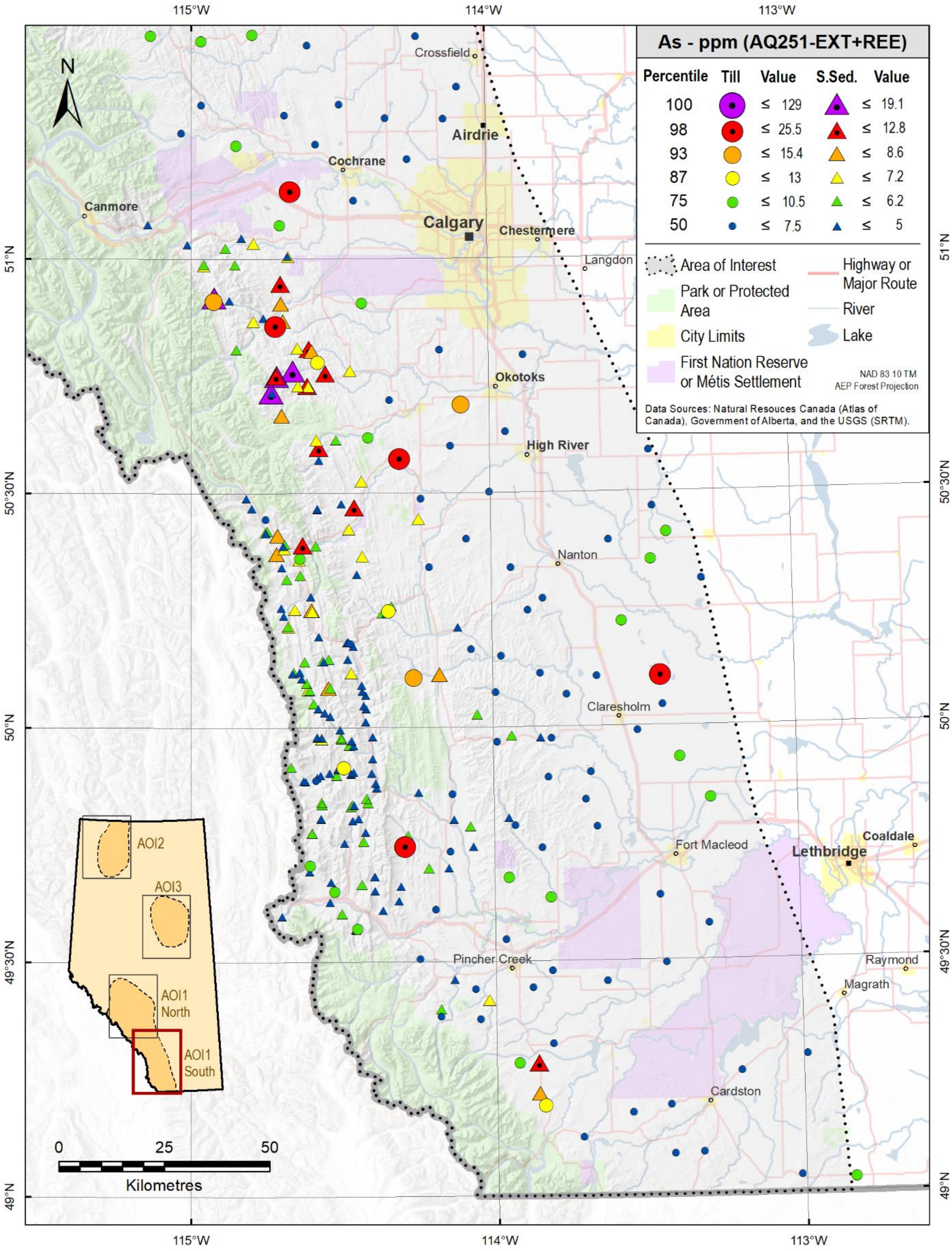


Figure 22. Arsenic (As) concentrations in till and stream sediments in the southern half of AOI-1.

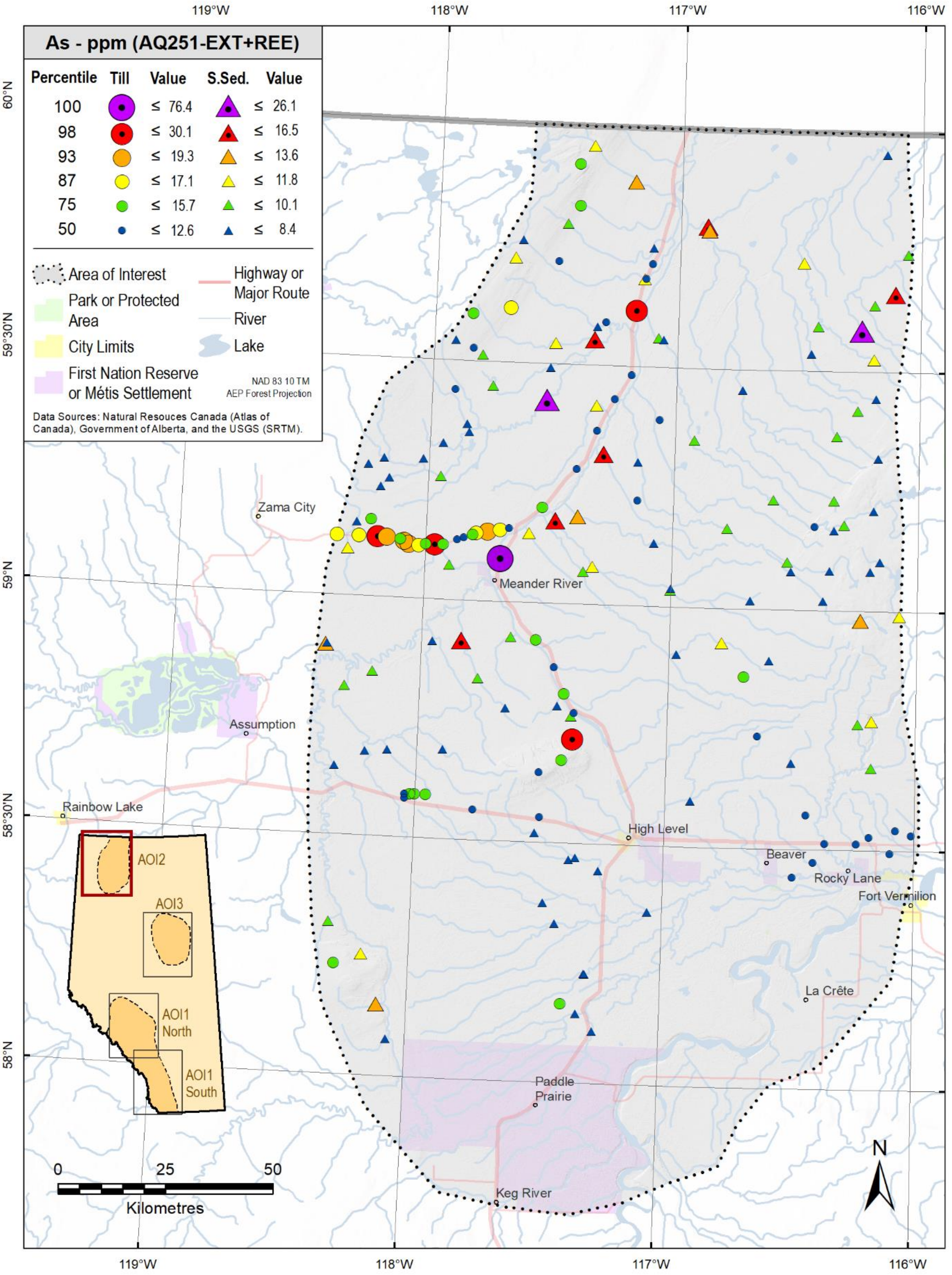


Figure 23. Arsenic (As) concentrations in till and stream sediments in AOI-2.

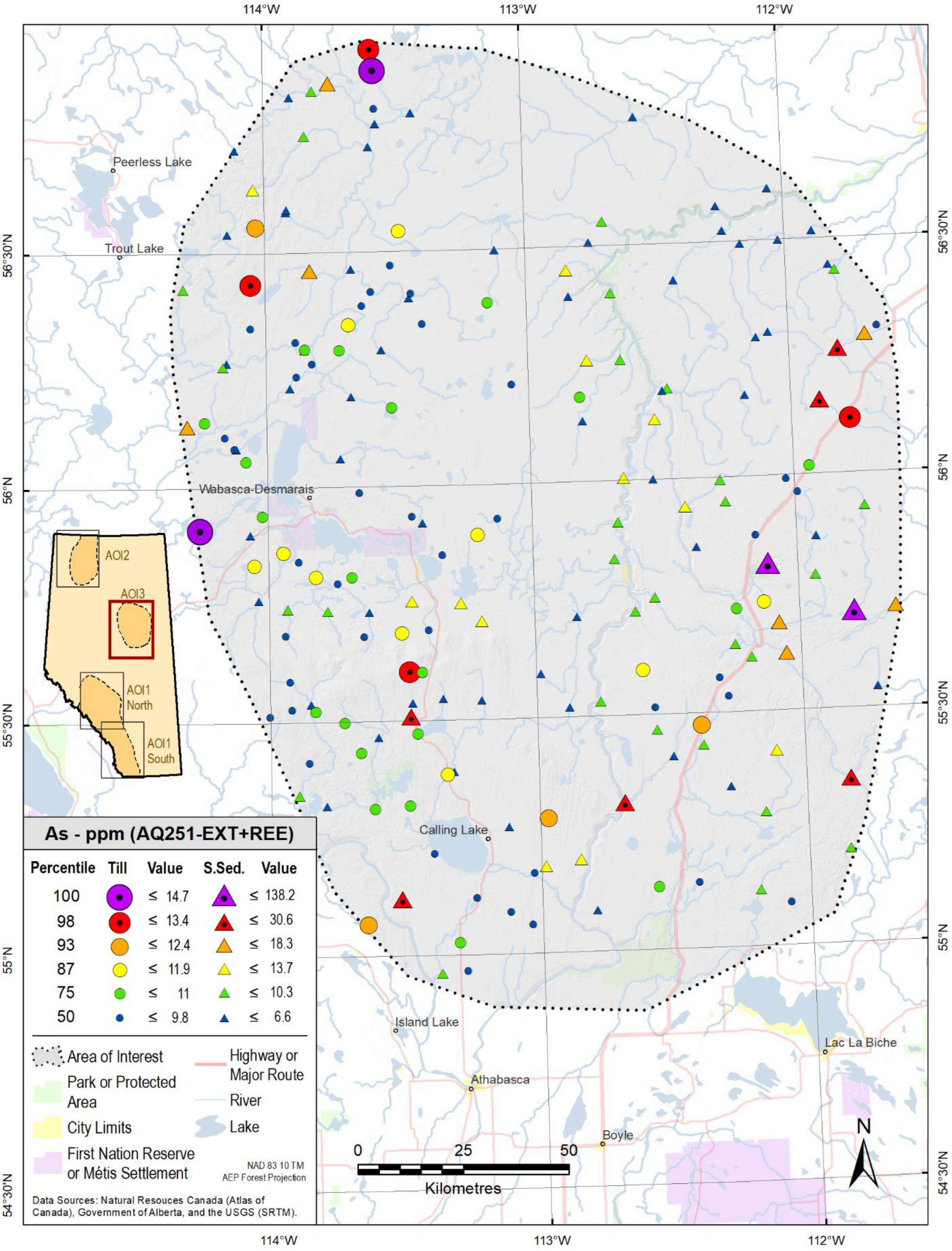


Figure 24. Arsenic (As) concentrations in till and stream sediments in AOI-3.

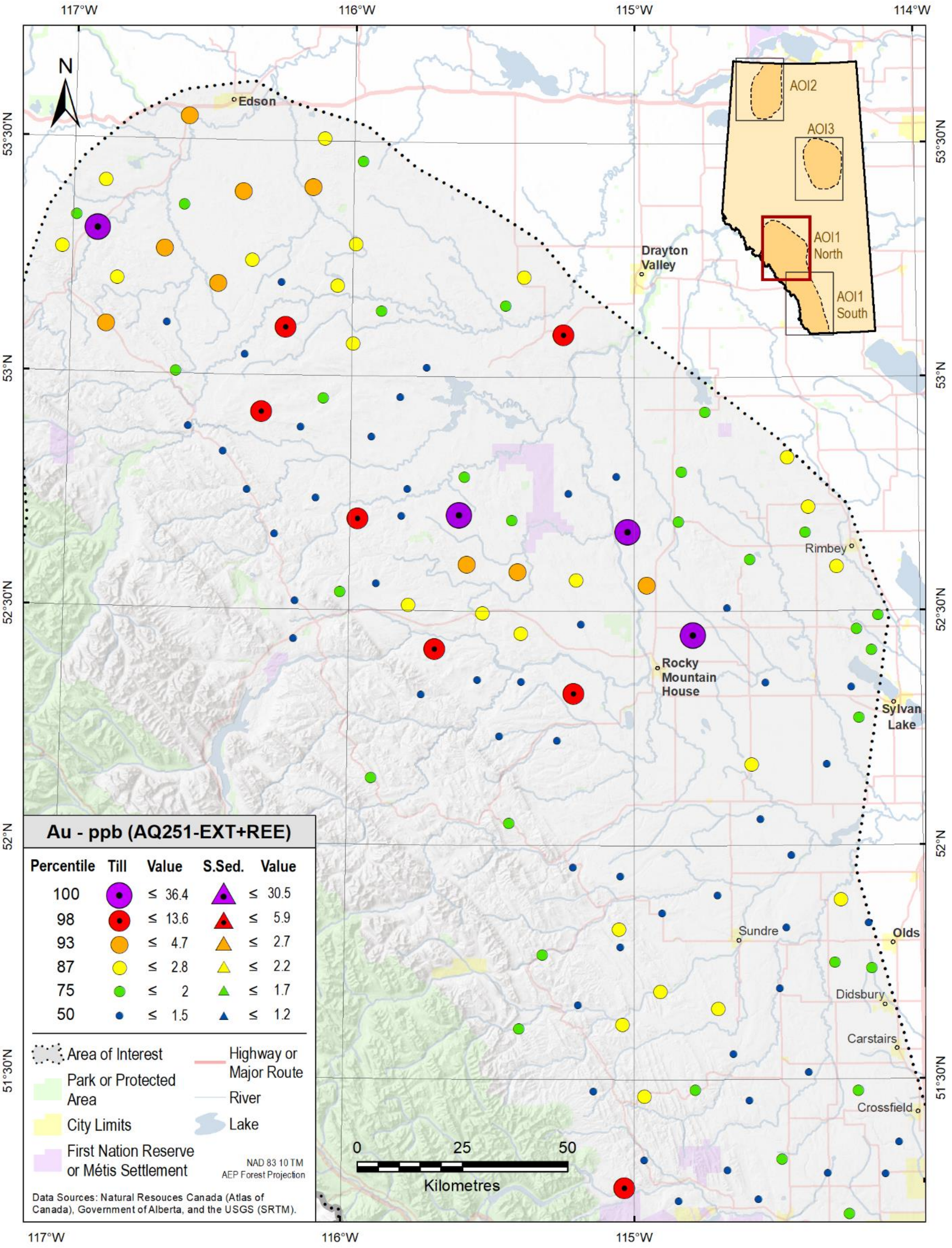


Figure 25. Gold (Au) concentrations in till in the northern half of AOI-1.

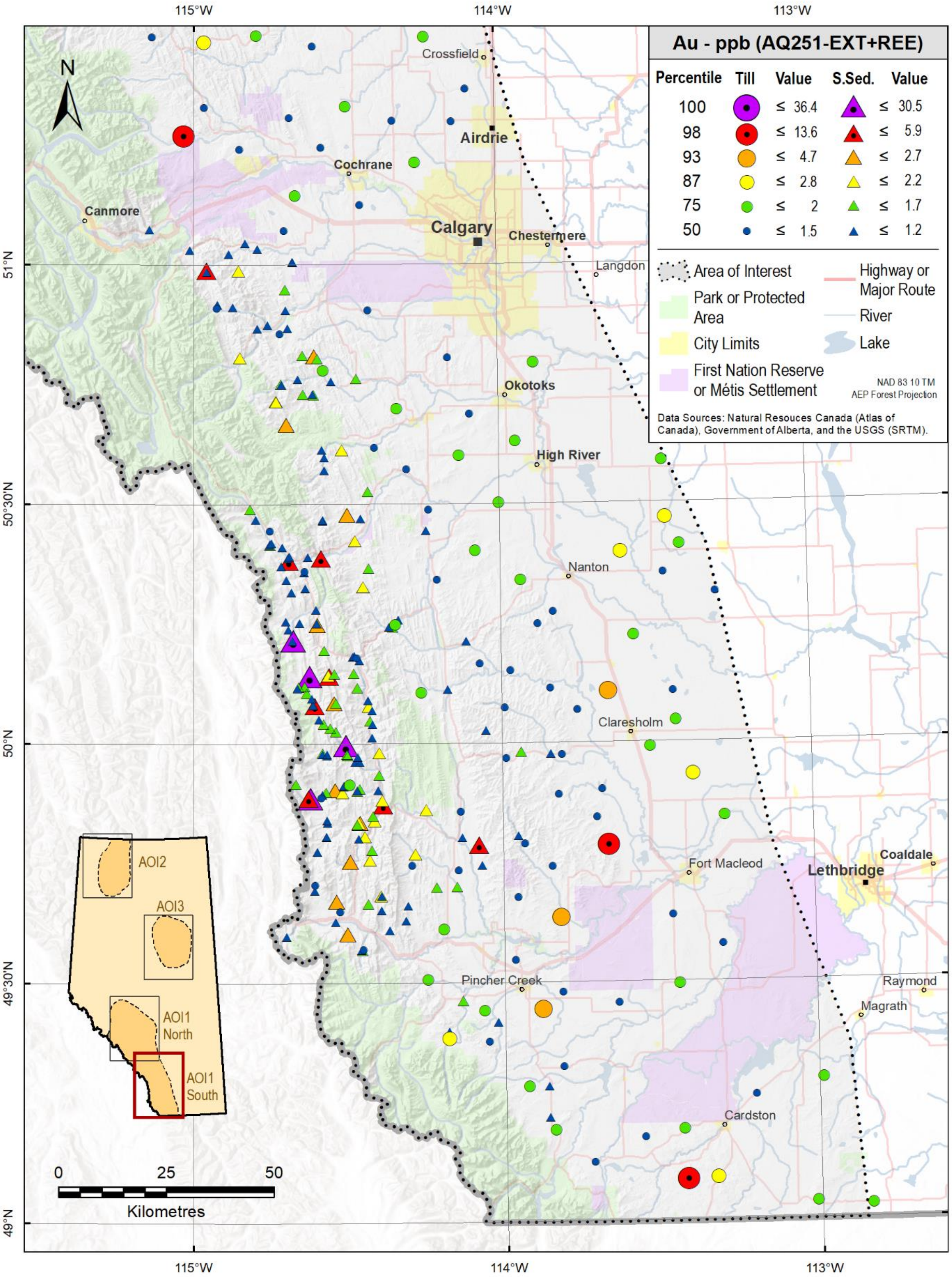


Figure 26. Gold (Au) concentrations in till and stream sediments in the southern half of AOI-1.

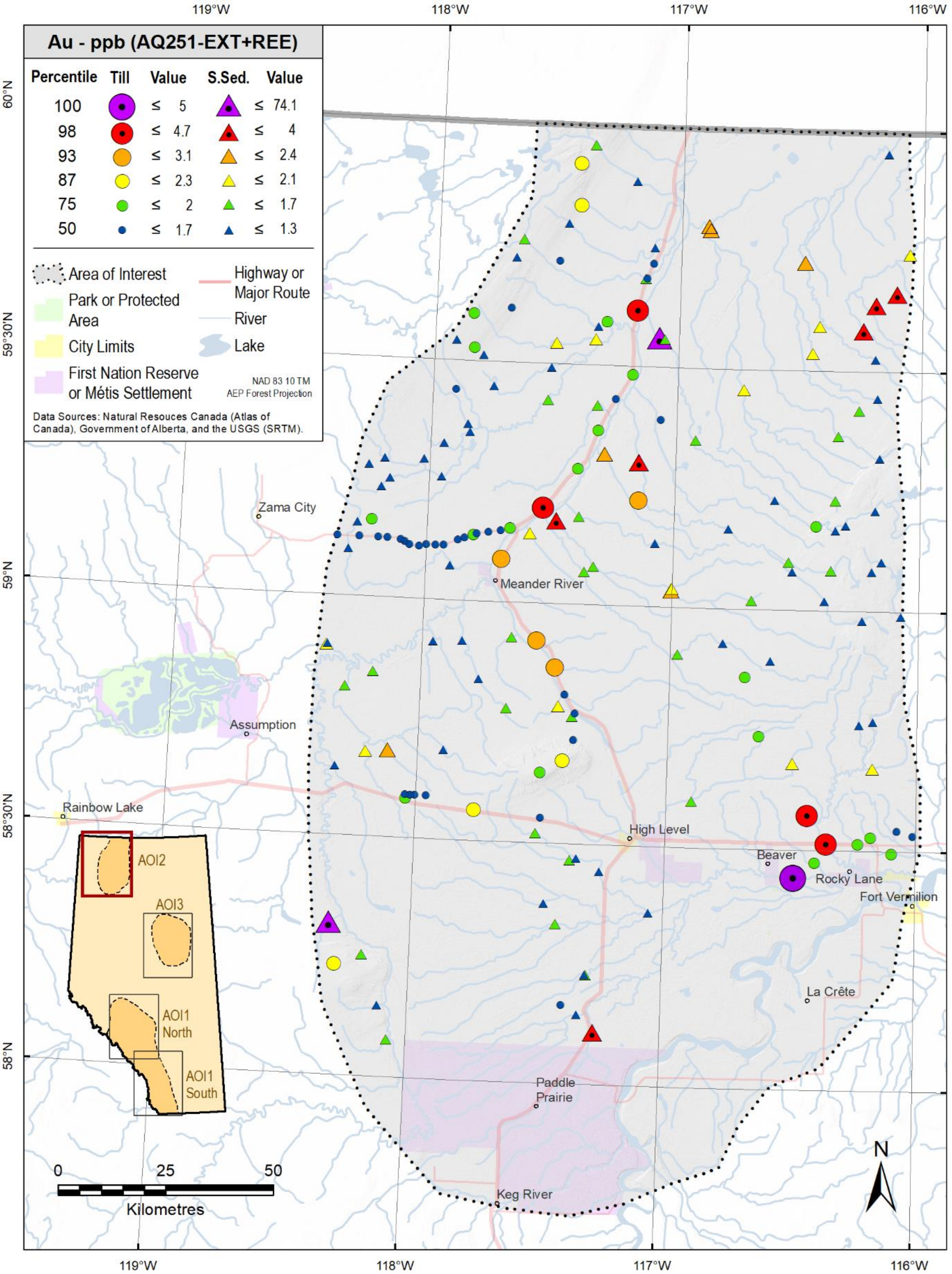


Figure 27. Gold (Au) concentrations in till and stream sediments in AOI-2.

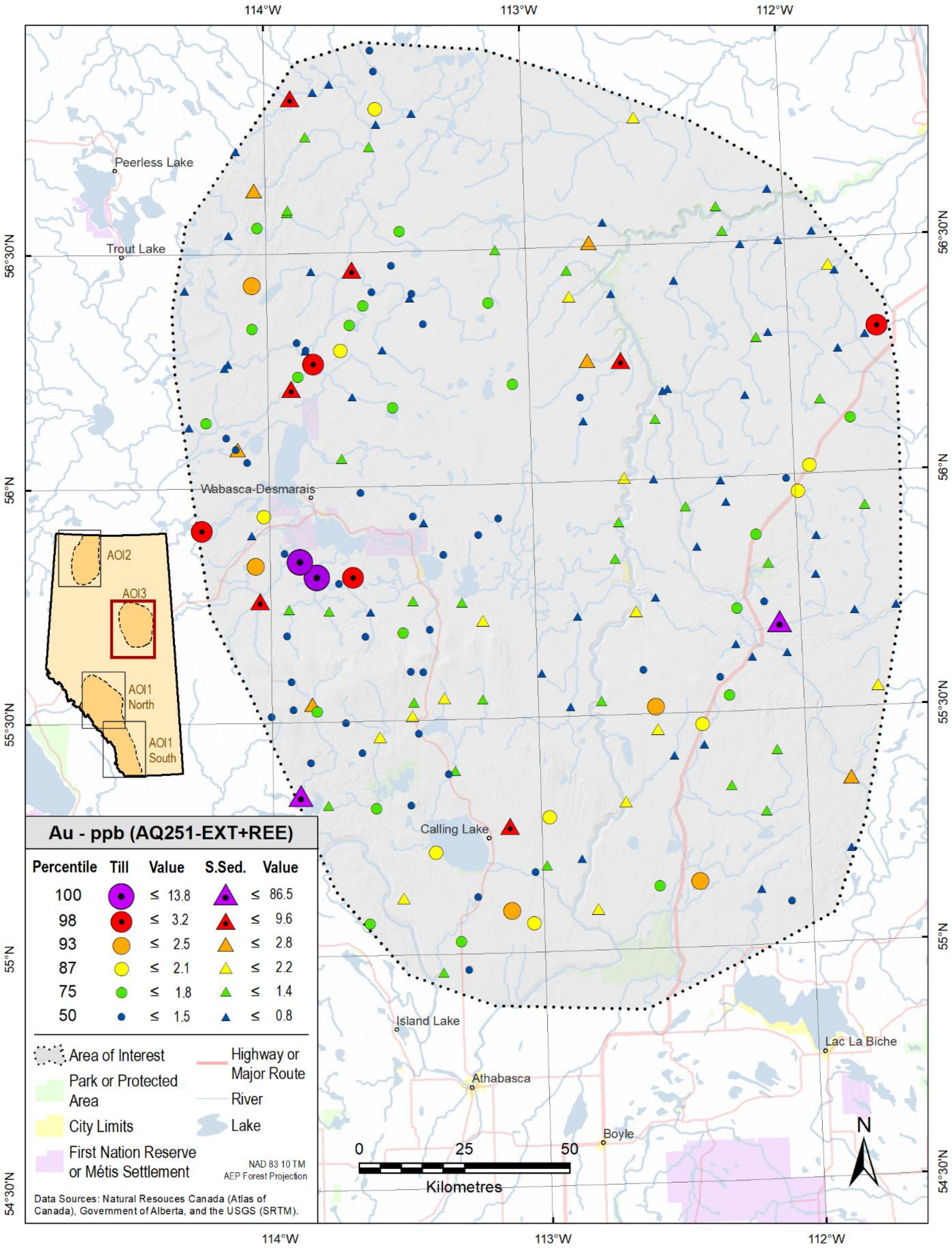


Figure 28. Gold (Au) concentrations in till and stream sediments in AOI-3.

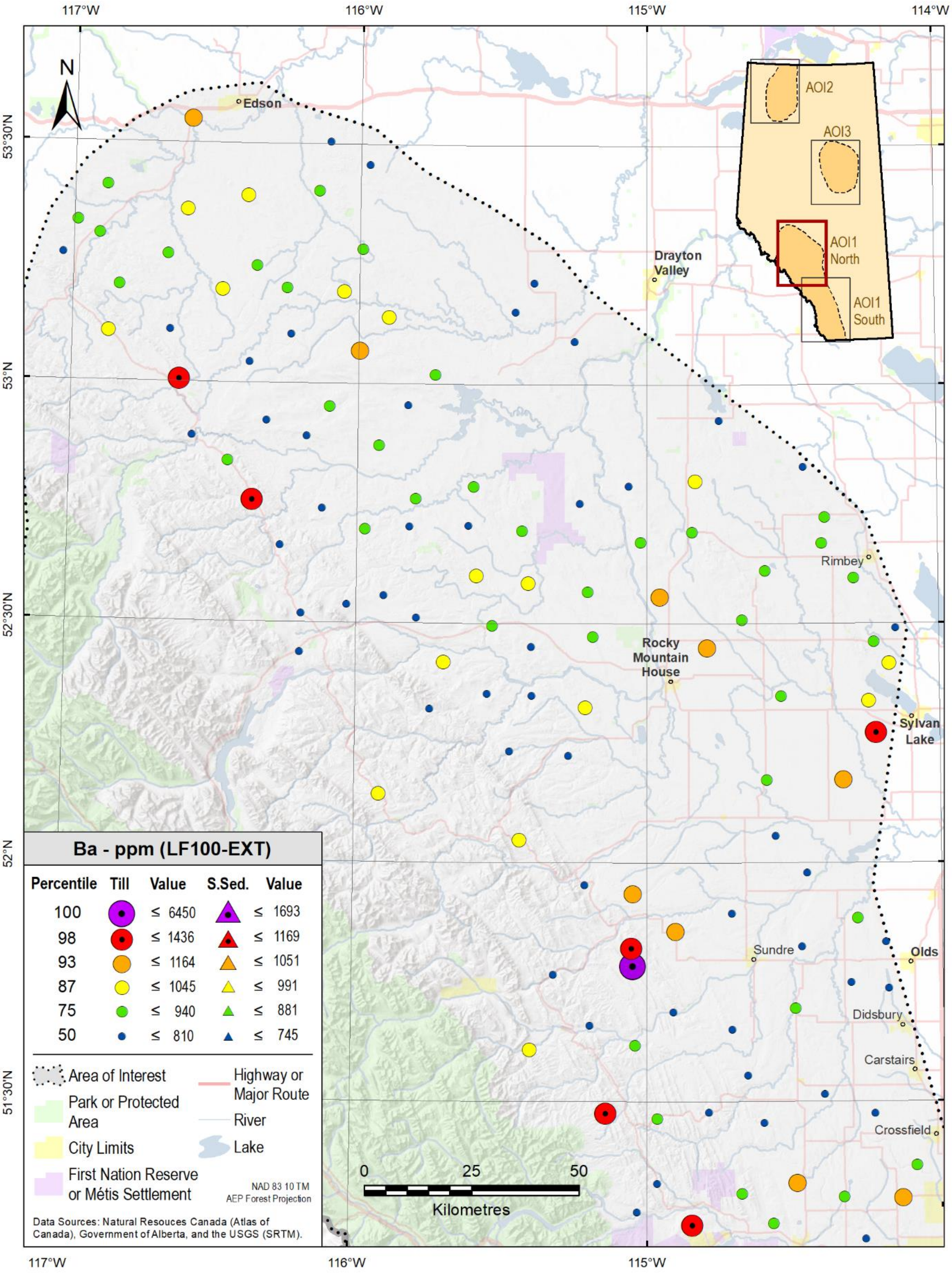


Figure 29. Barium (Ba) concentrations in till in the northern half of AOI-1.

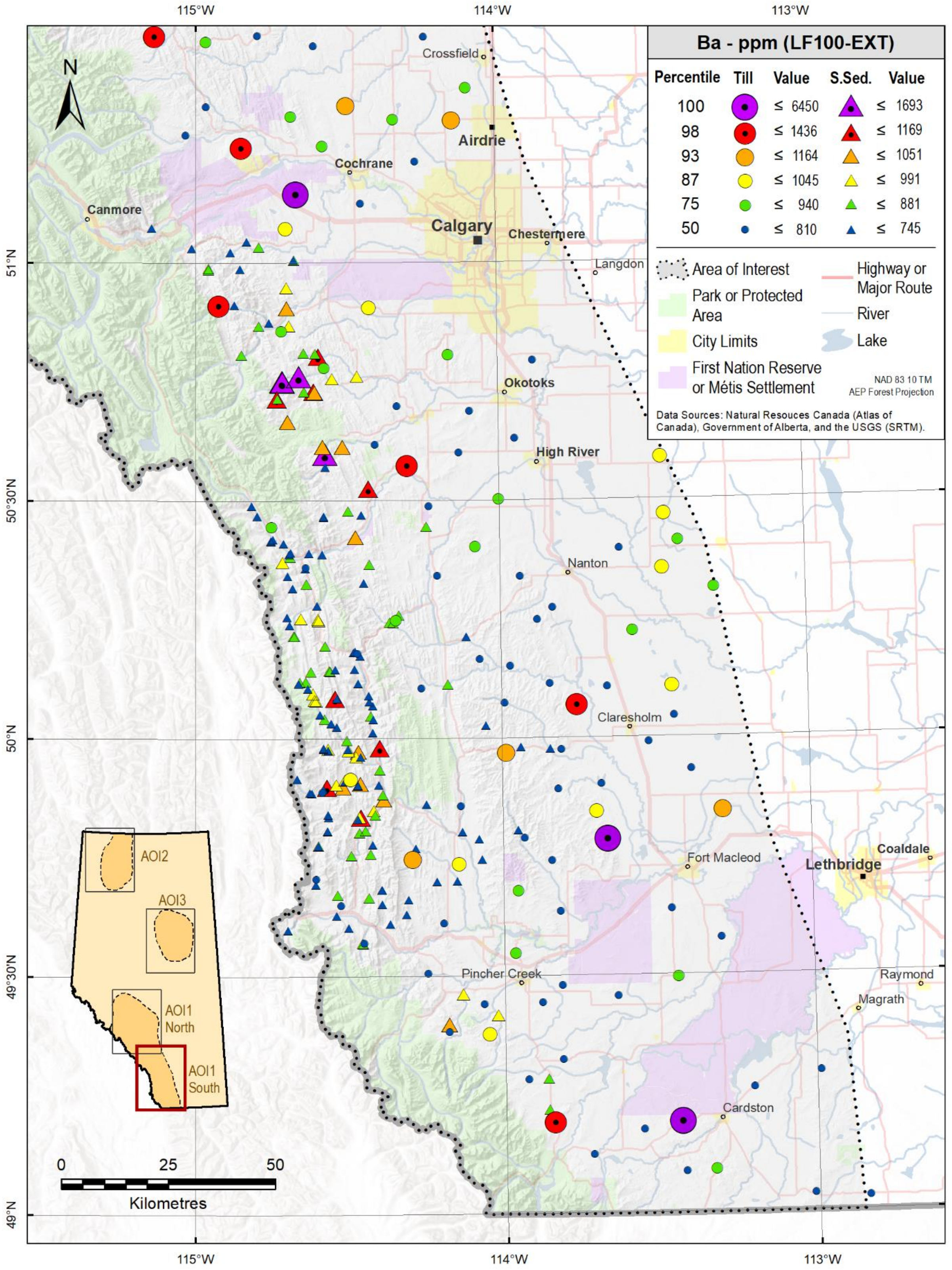


Figure 30. Barium (Ba) concentrations in till and stream sediments in the southern half of AOI-1.

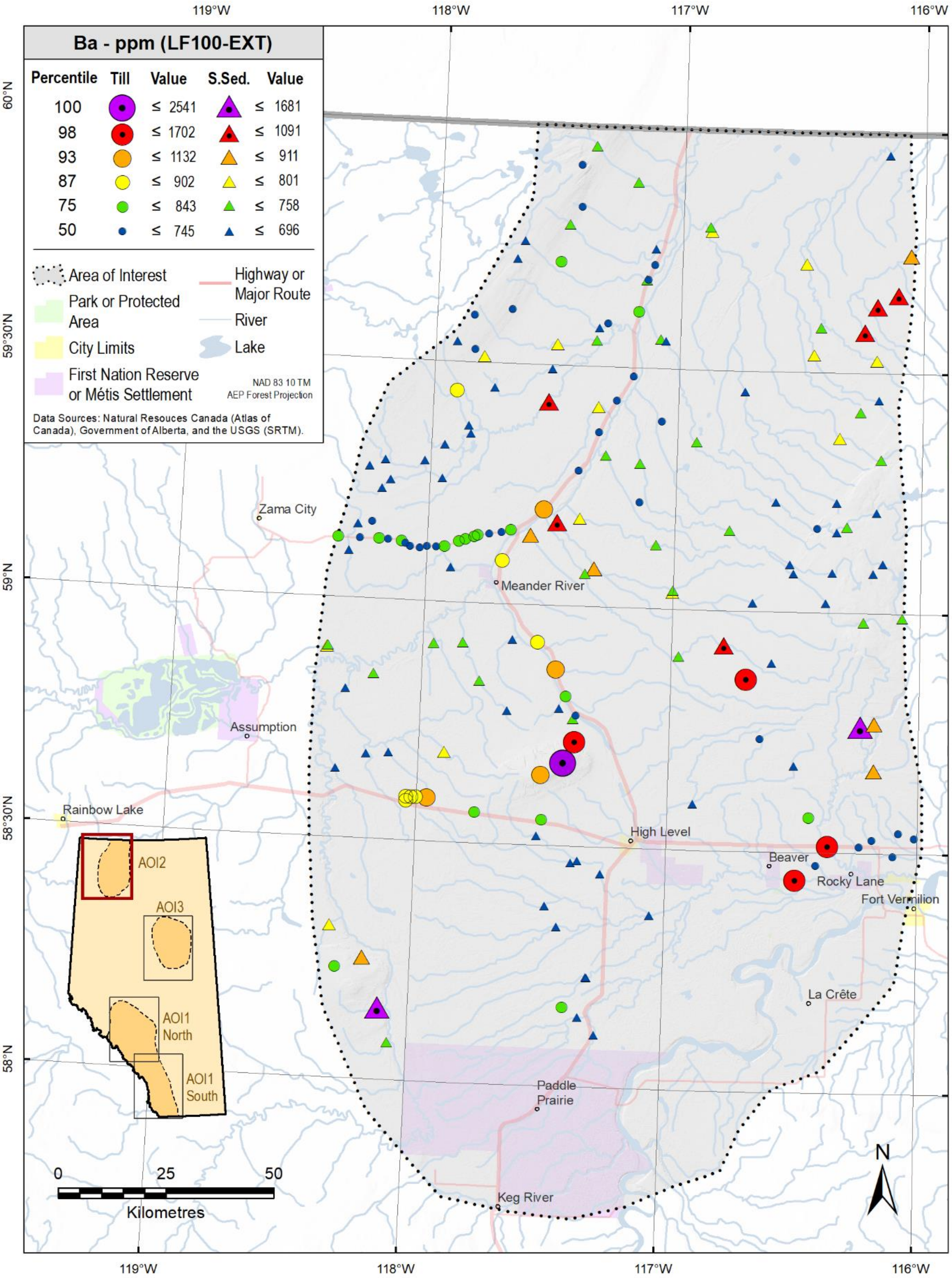


Figure 31. Barium (Ba) concentrations in till and stream sediments in AOI-2.

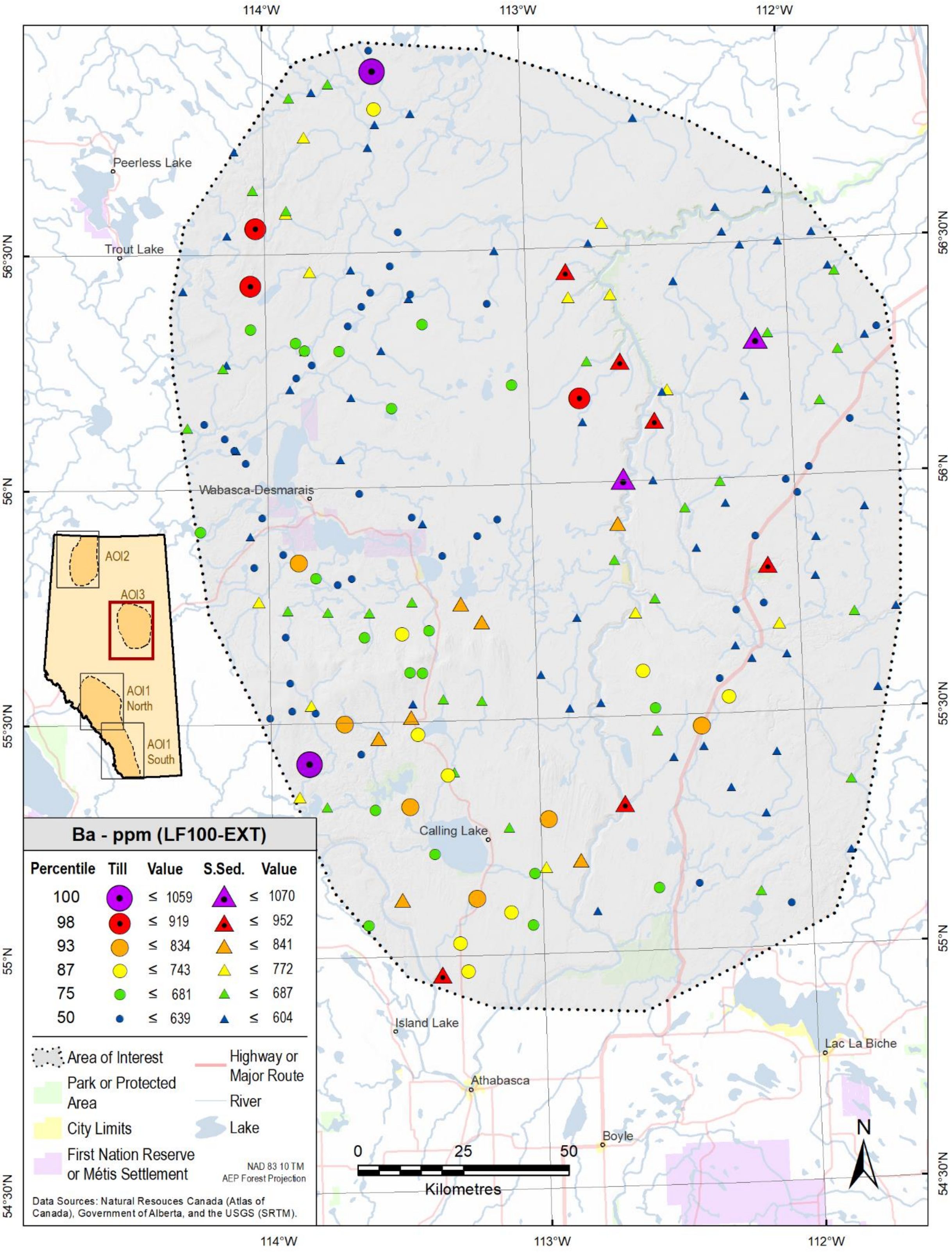


Figure 32. Barium (Ba) concentrations in till and stream sediments in AOI-3.

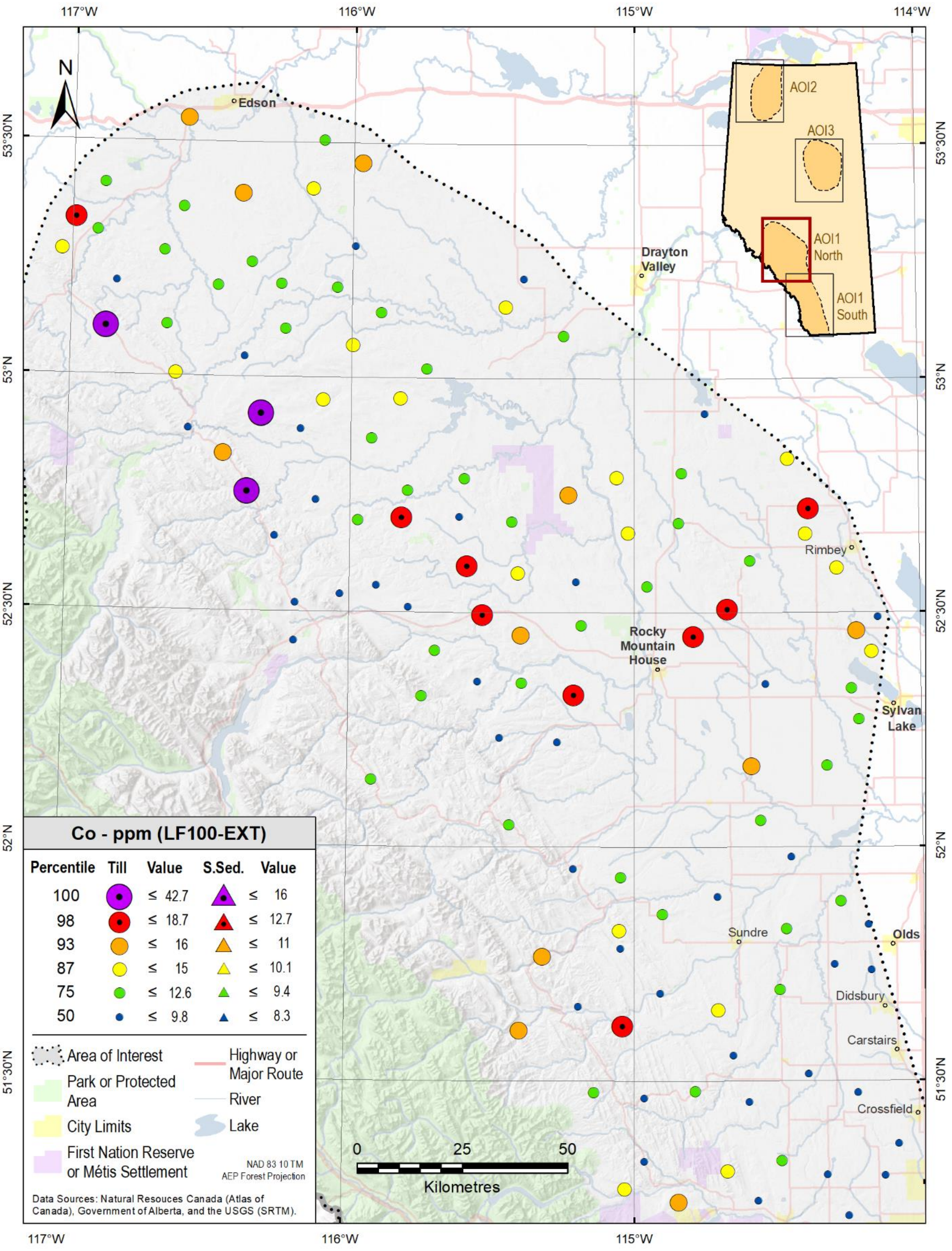


Figure 33. Cobalt (Co) concentrations in till in the northern half of AOI-1.

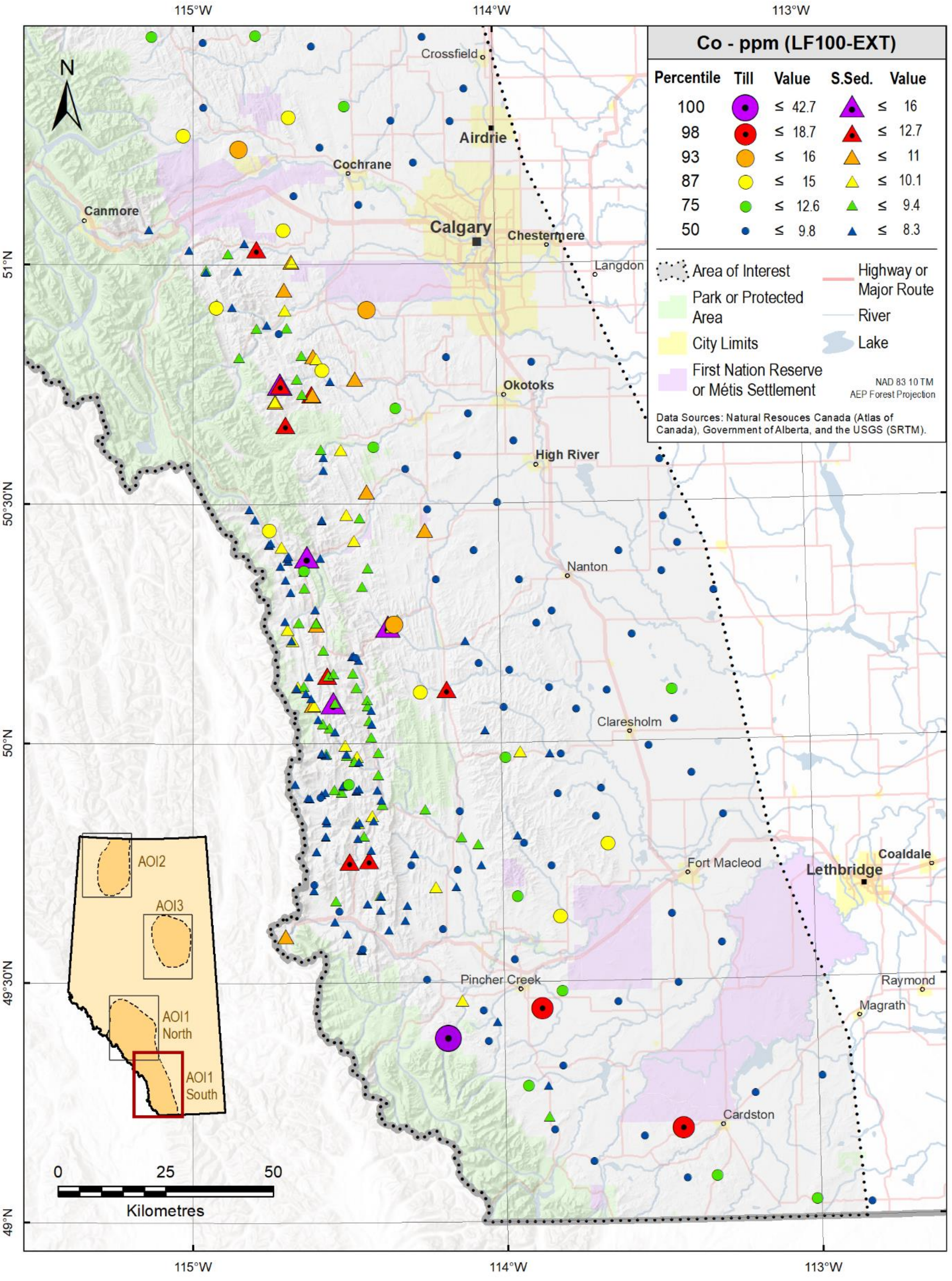


Figure 34. Cobalt (Co) concentrations in till and stream sediments in the southern half of AOI-1.

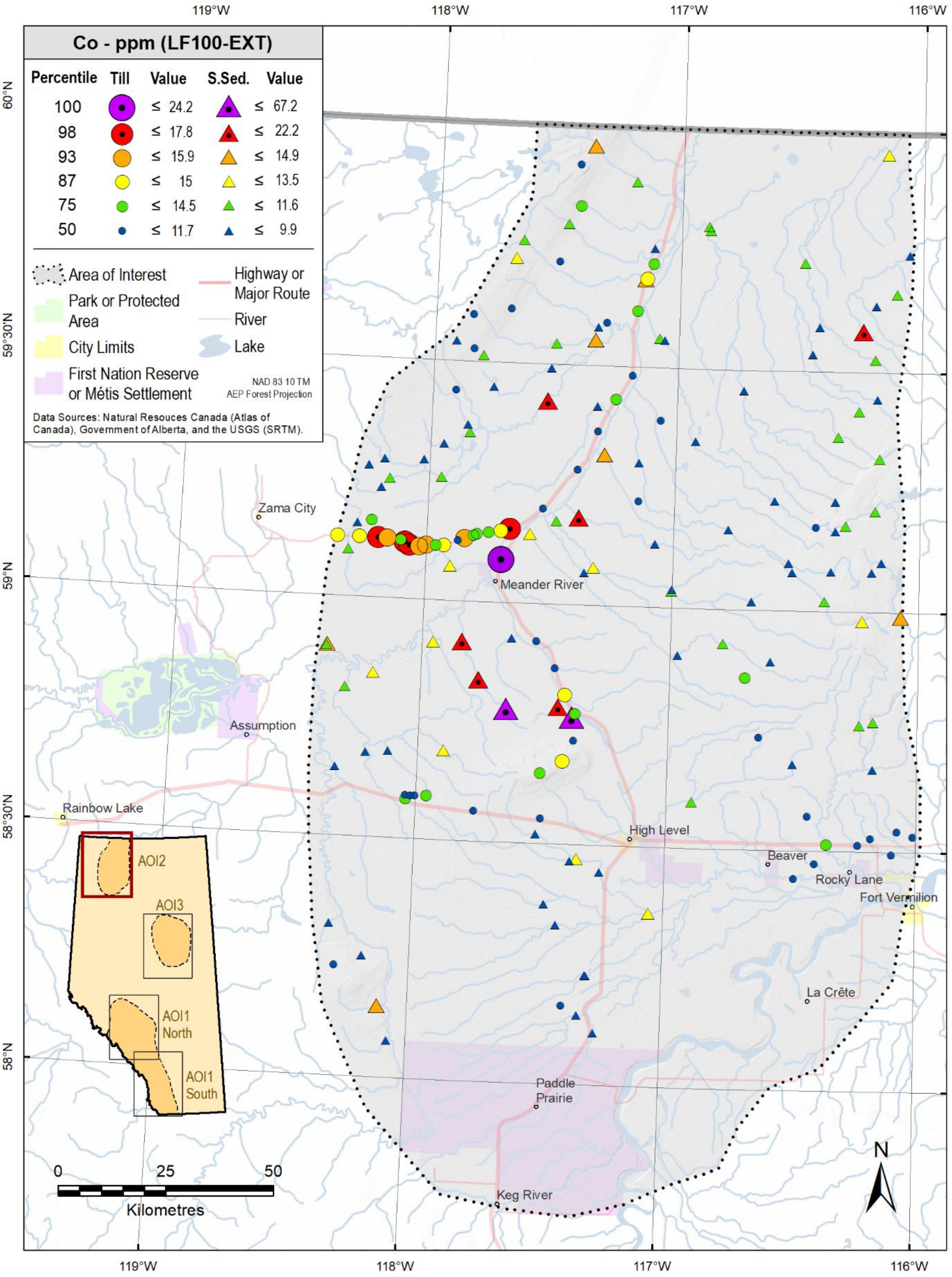


Figure 35. Cobalt (Co) concentrations in till and stream sediments in AOI-2.

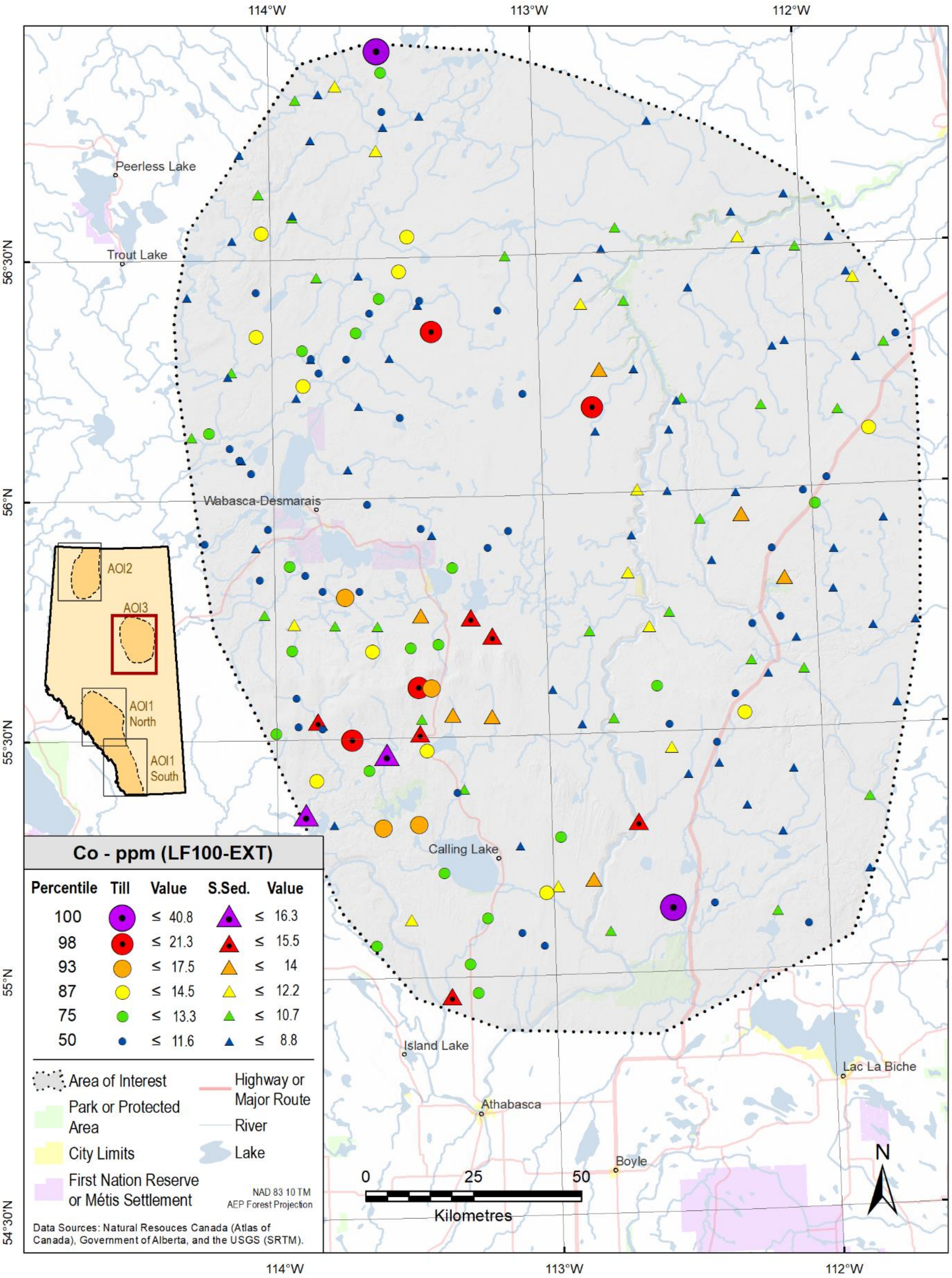


Figure 36. Cobalt (Co) concentrations in till and stream sediments in AOI-3.

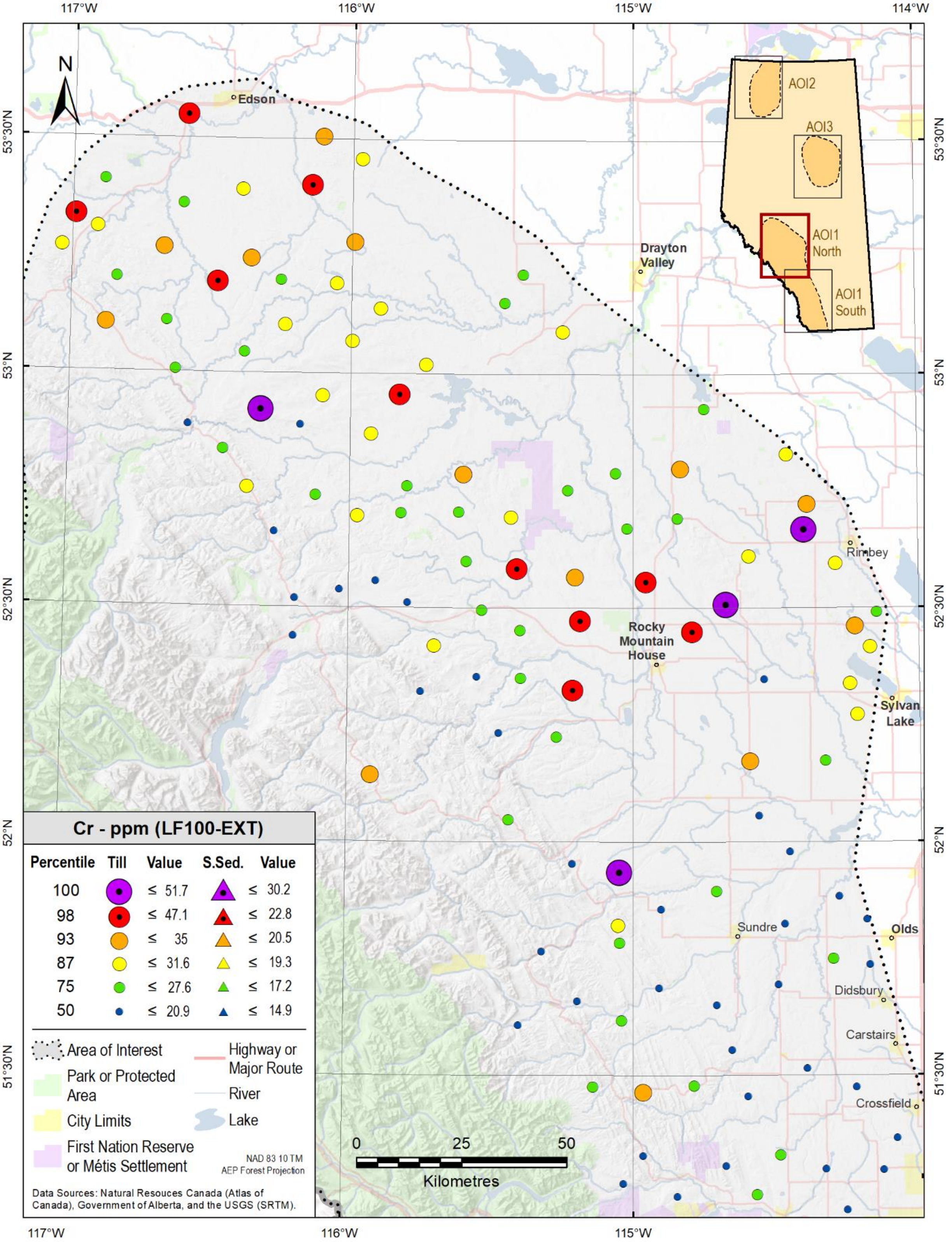


Figure 37. Chromium (Cr) concentrations in till in the northern half of AOI-1.

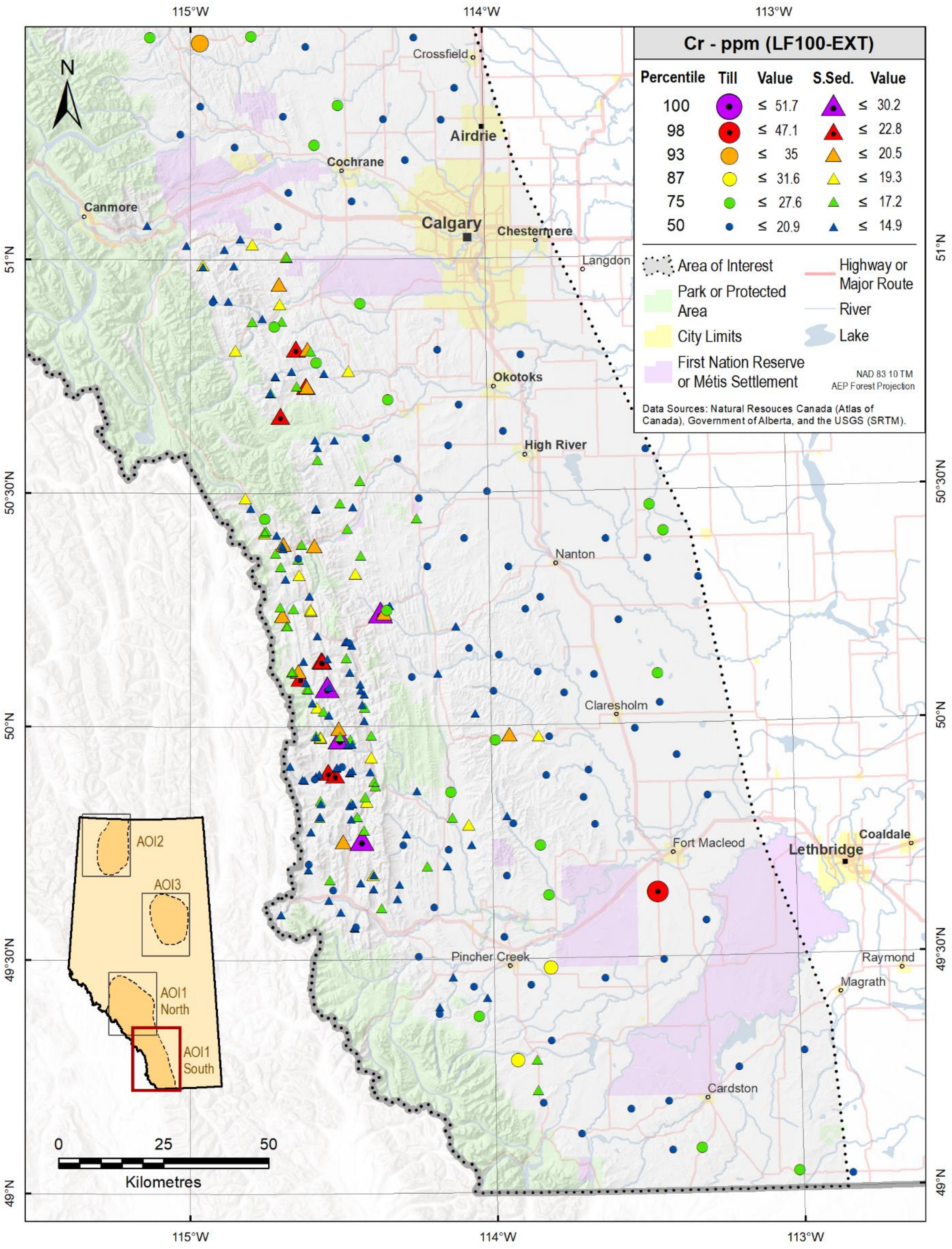


Figure 38. Chromium (Cr) concentrations in till and stream sediments in the southern half of AOI-1.

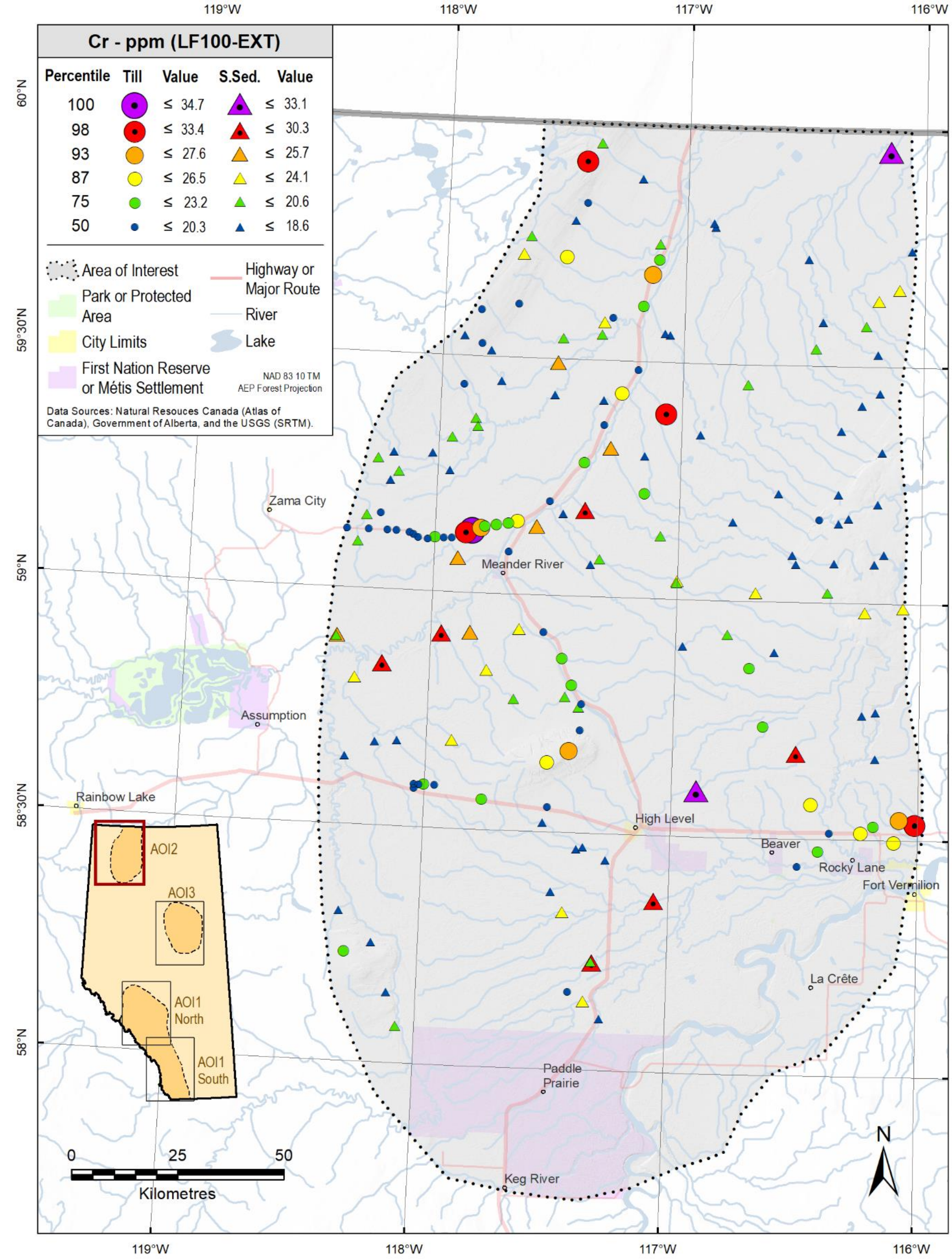


Figure 39. Chromium (Cr) concentrations in till and stream sediments in AOI-2.

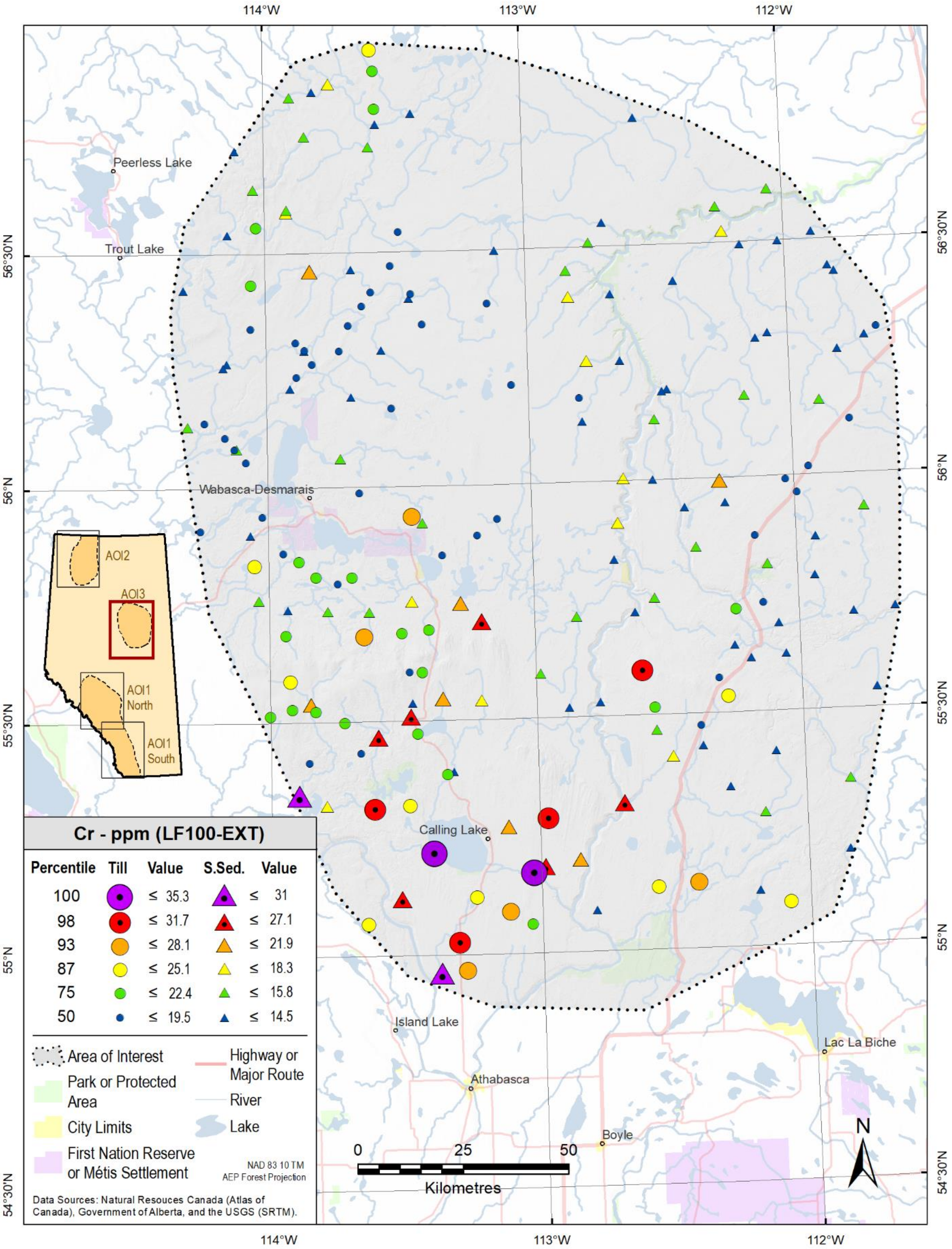


Figure 40. Chromium (Cr) concentrations in till and stream sediments in AOI-3.

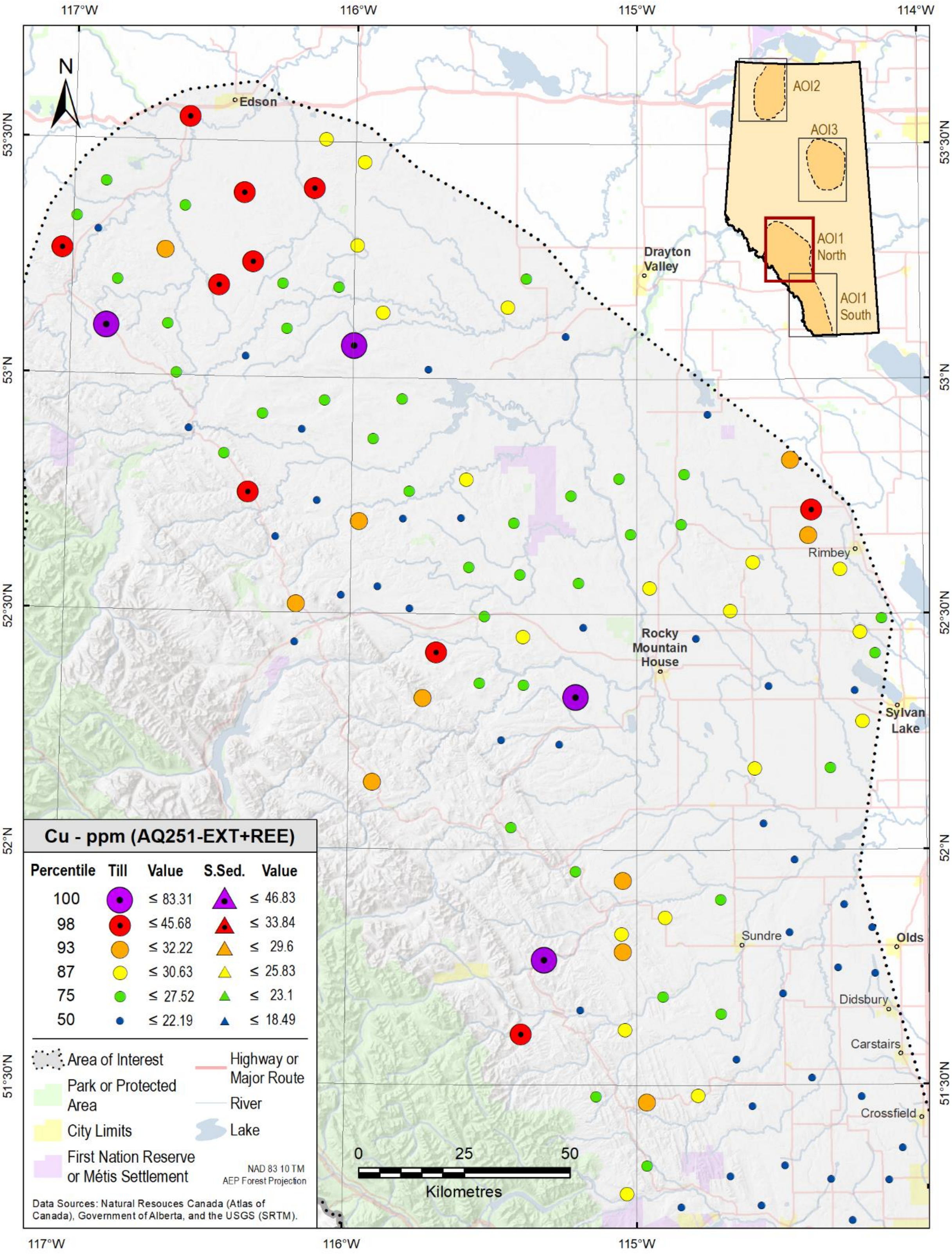


Figure 41. Copper (Cu) concentrations in till in the northern half of AOI-1.

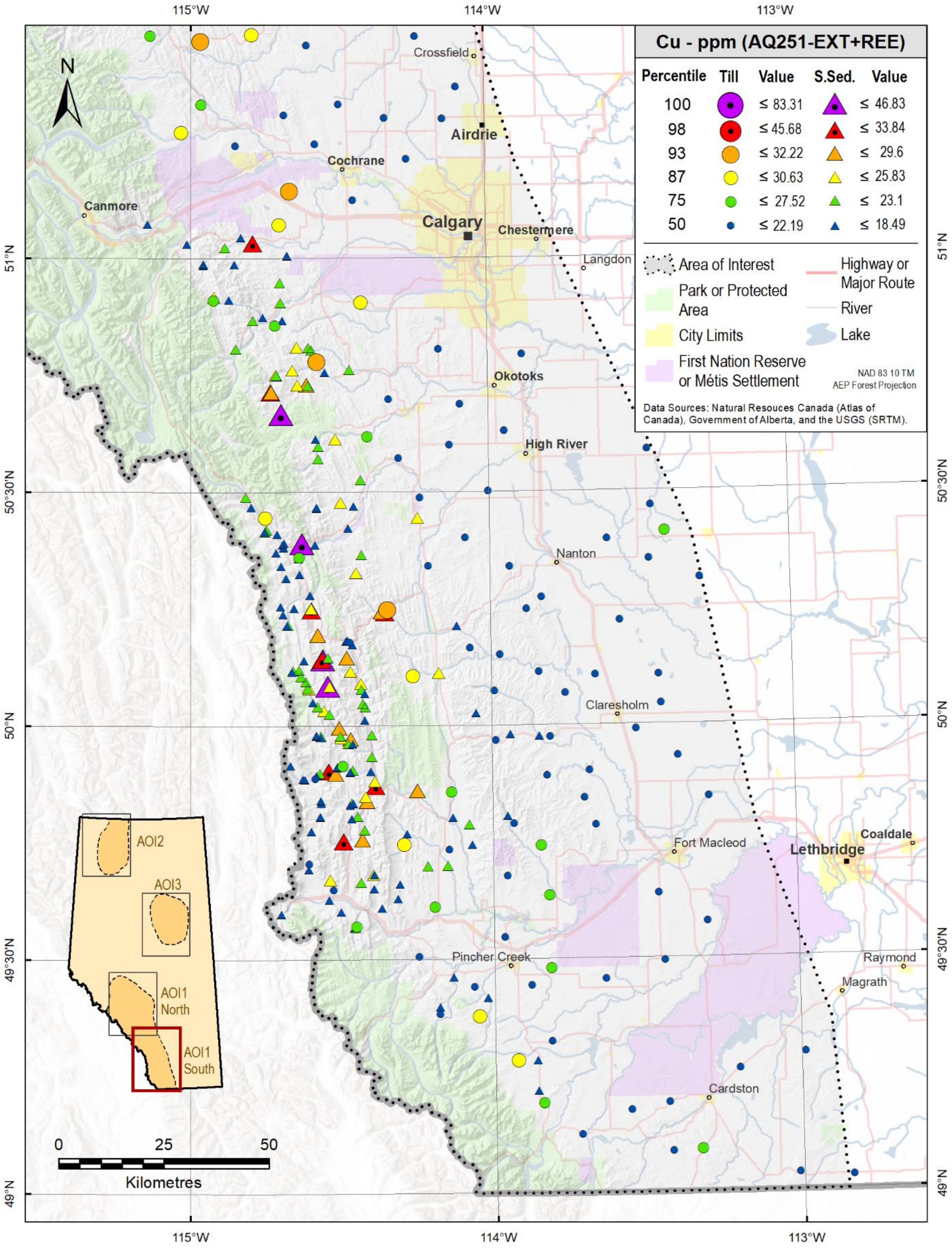


Figure 42. Copper (Cu) concentrations in till and stream sediments in the southern half of AOI-1.

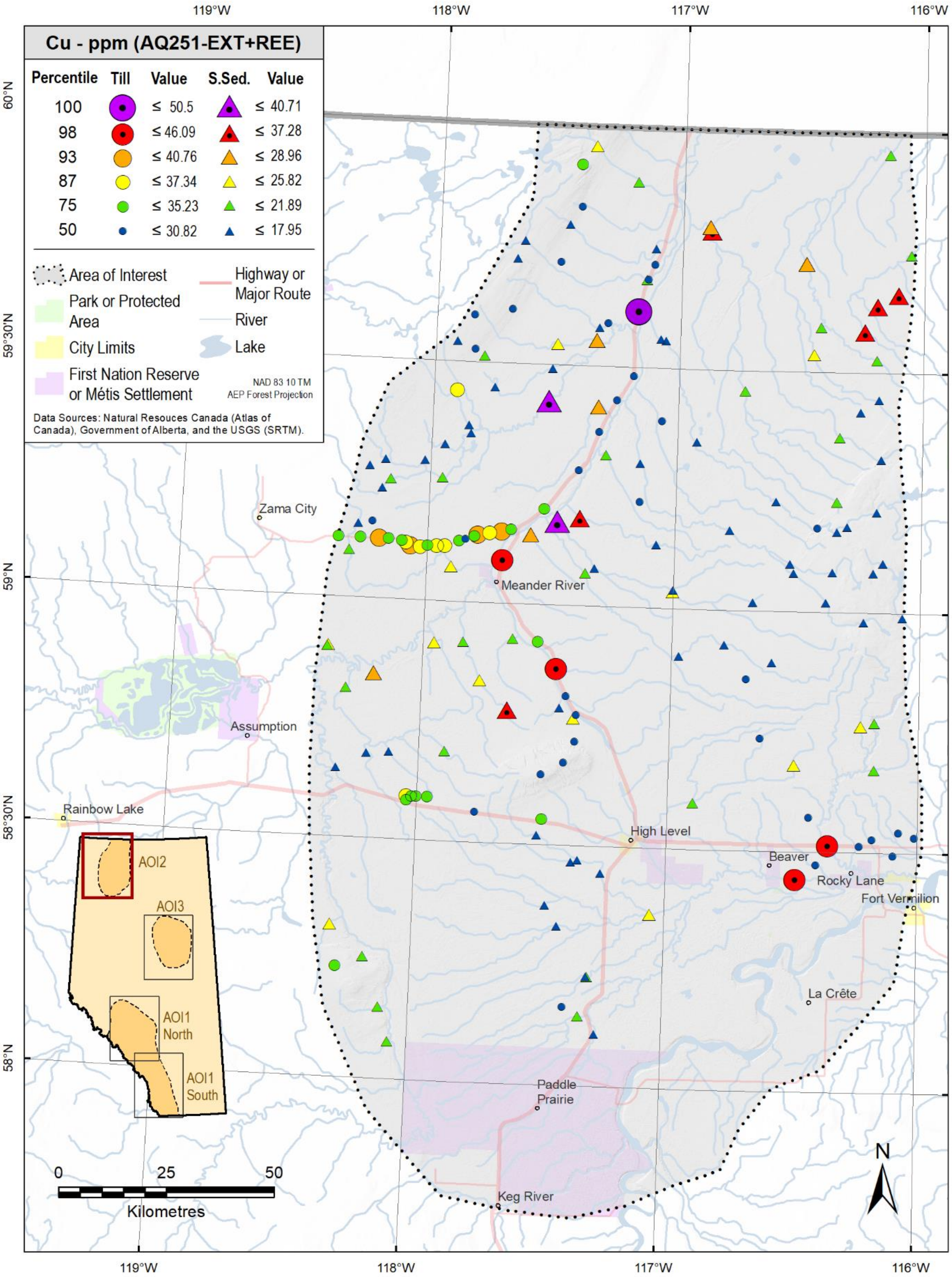


Figure 43. Copper (Cu) concentrations in till and stream sediments in AOI-2.

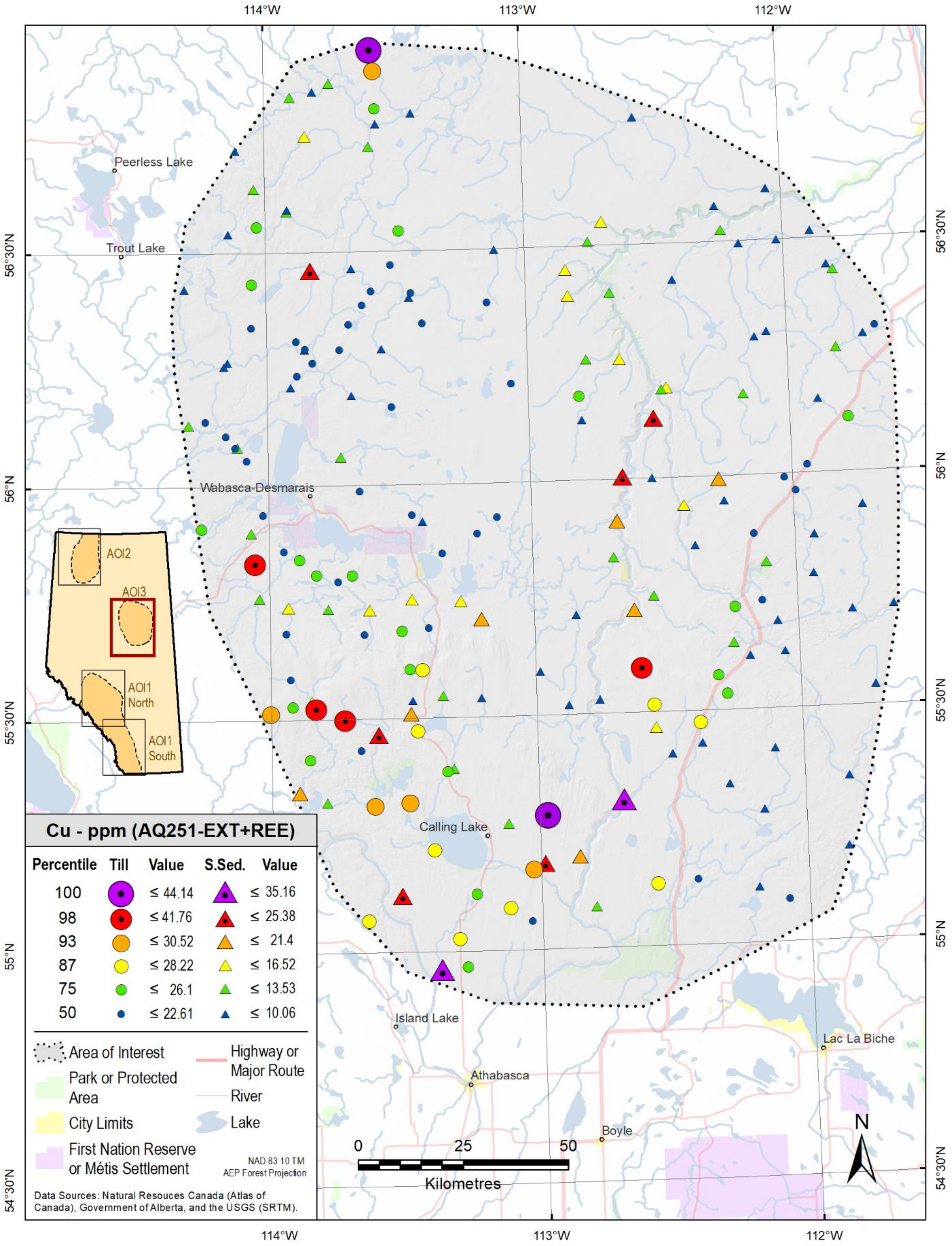


Figure 44. Copper (Cu) concentrations in till and stream sediments in AOI-3.

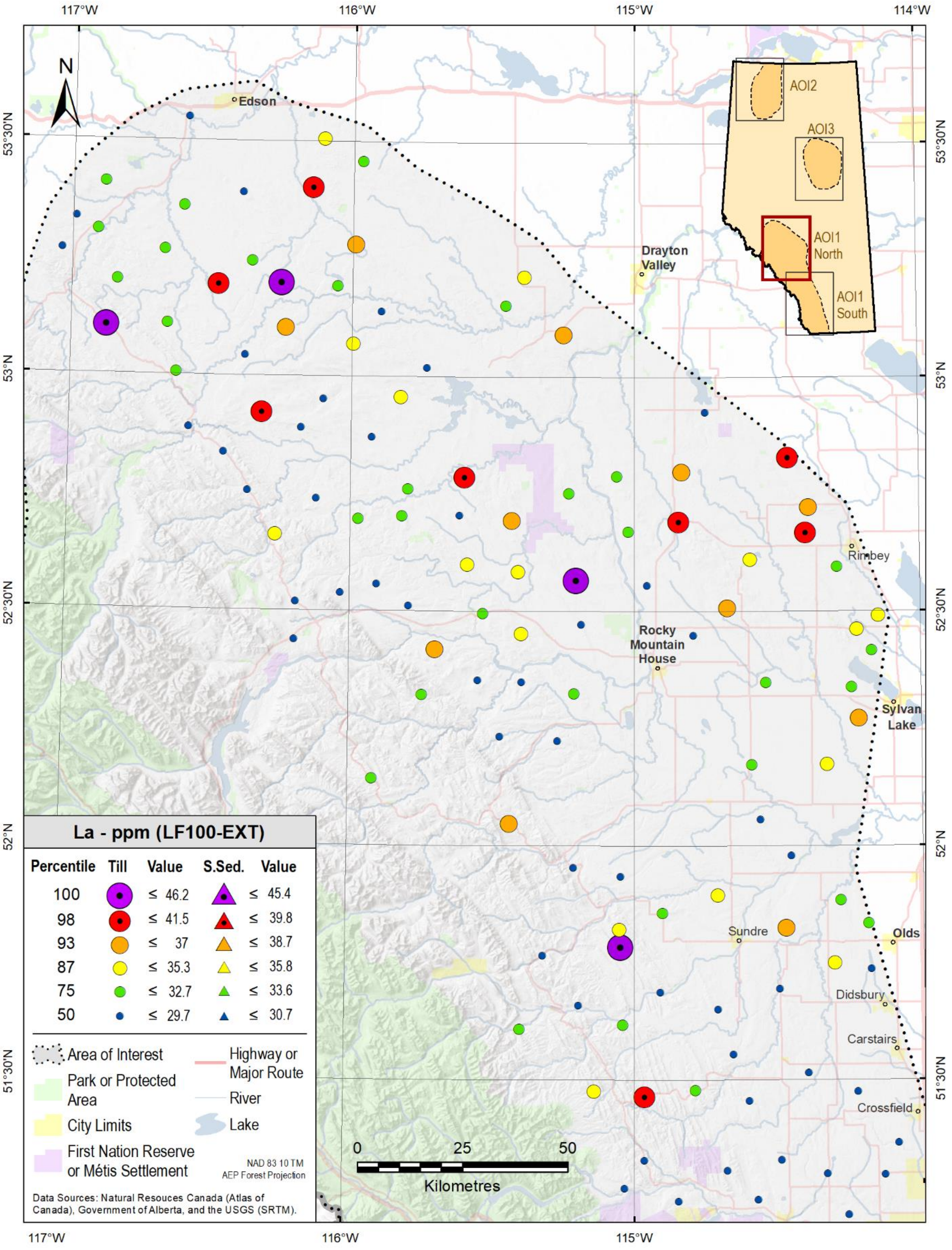


Figure 45. Lanthanum (La) concentrations in till in the northern half of AOI-1.

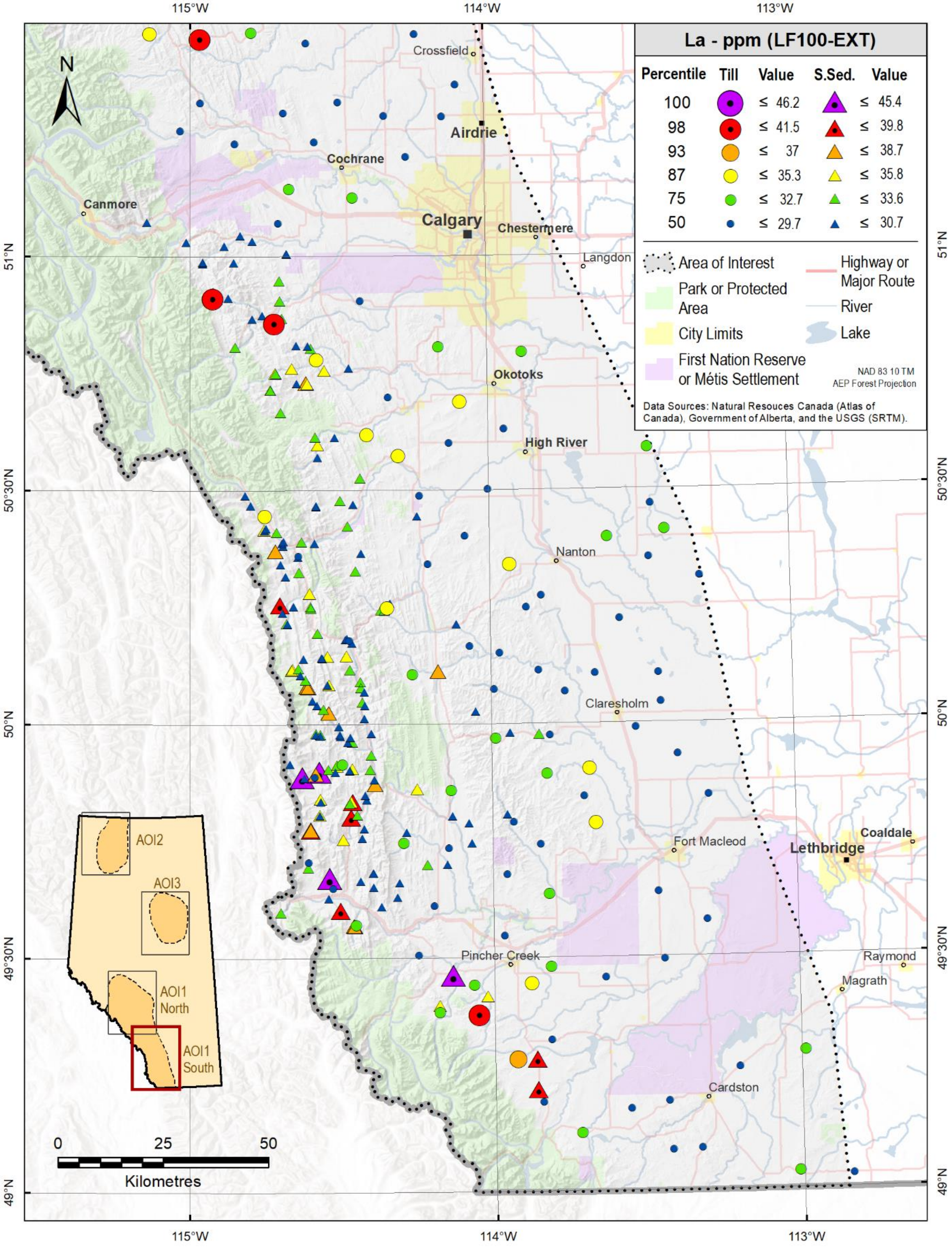


Figure 46. Lanthanum (La) concentrations in till and stream sediments in the southern half of AOI-1.

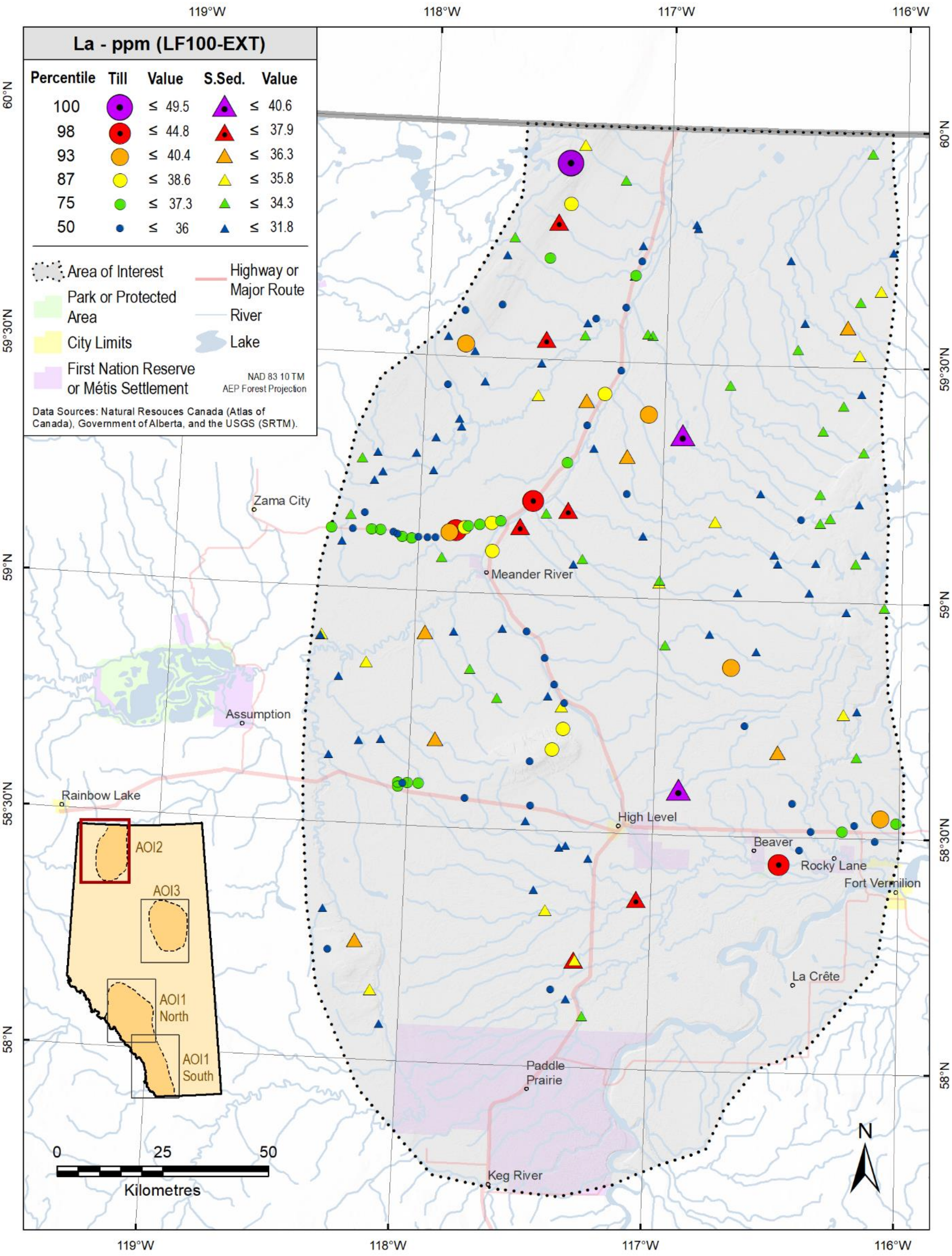


Figure 47. Lanthanum (La) concentrations in till and stream sediments in AOI-2.

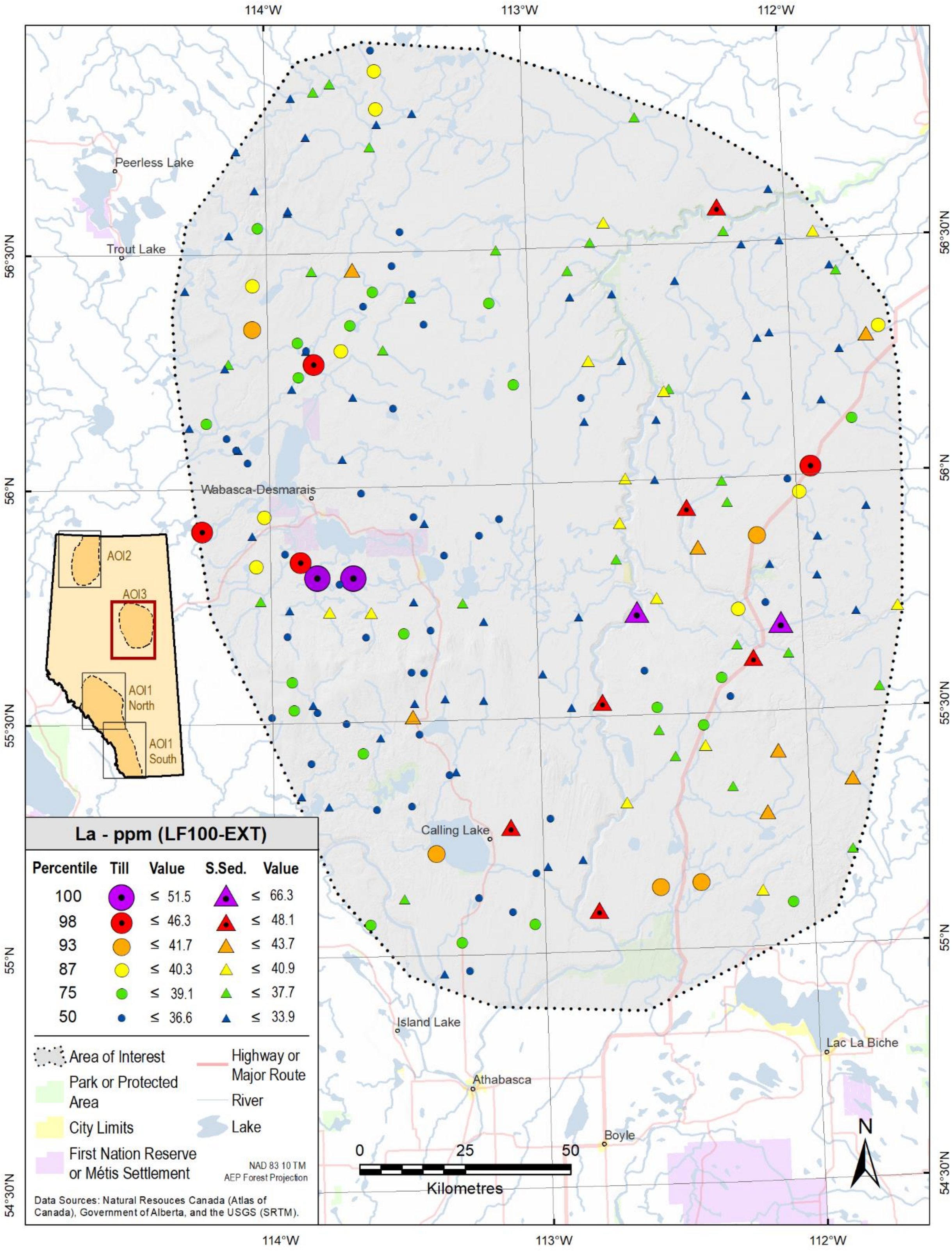


Figure 48. Lanthanum (La) concentrations in till and stream sediments in AOI-3.

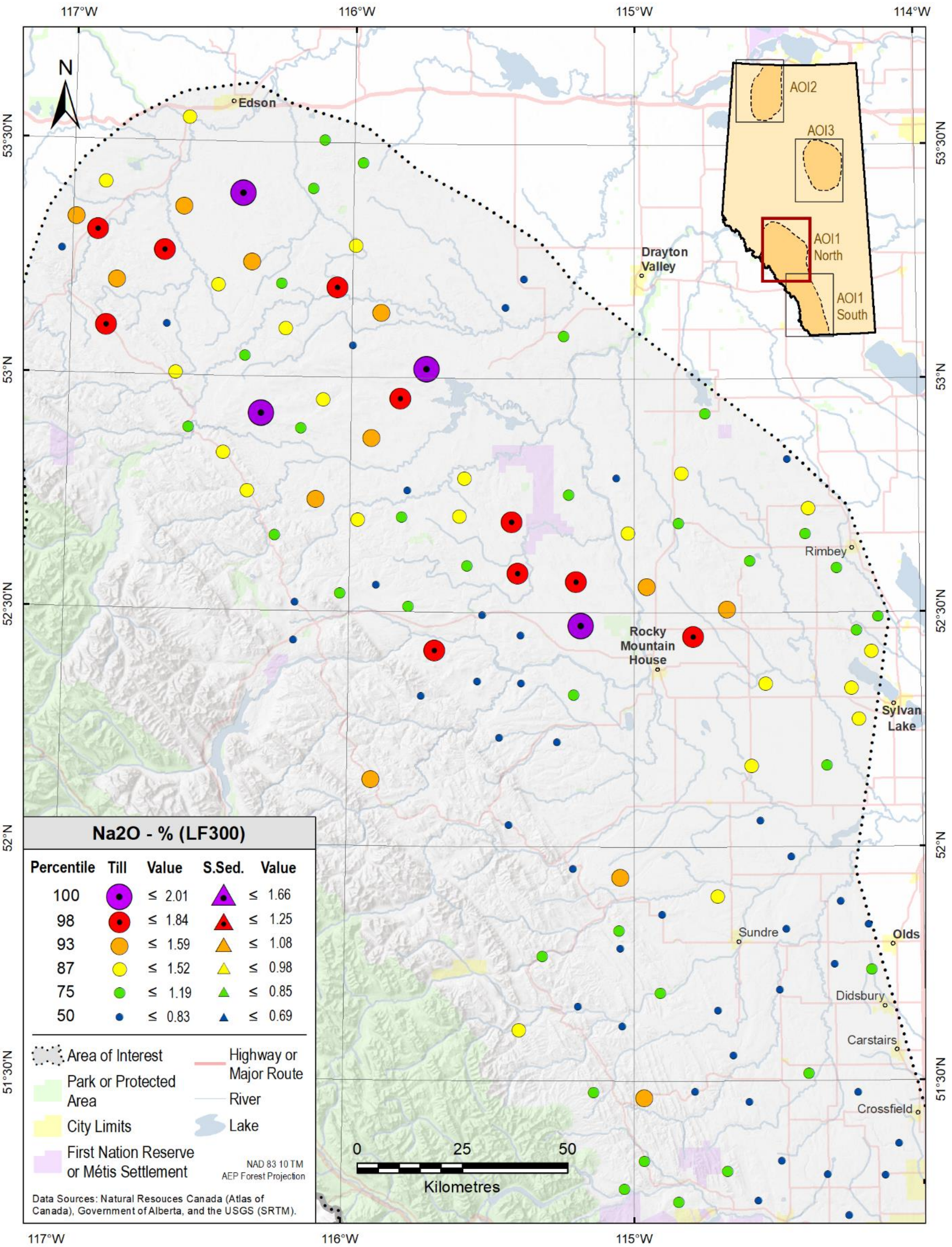


Figure 49. Sodium (Na_2O) concentrations in till in the northern half of AOI-1.

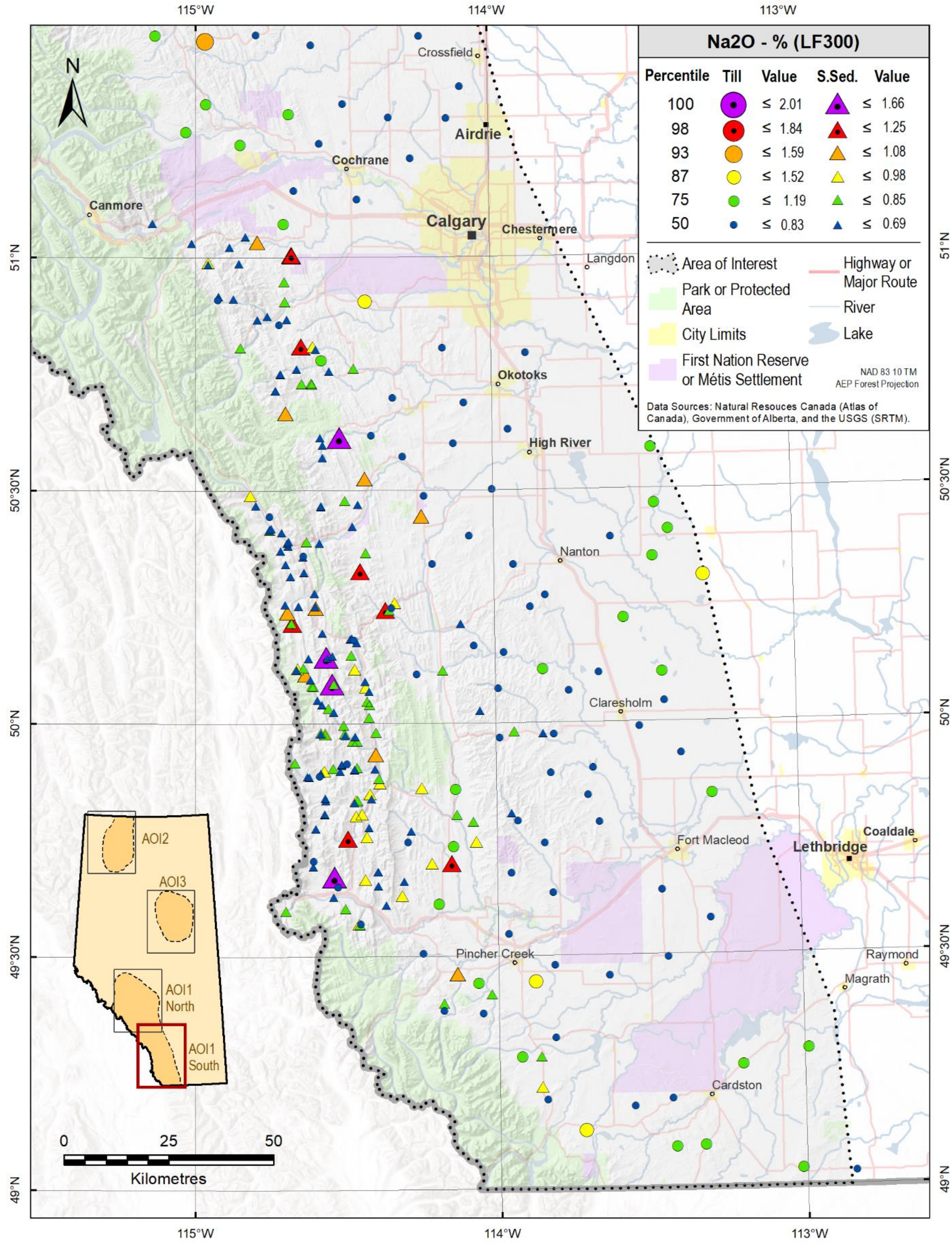


Figure 50. Sodium (Na_2O) concentrations in till and stream sediments in the southern half of AOI-1.

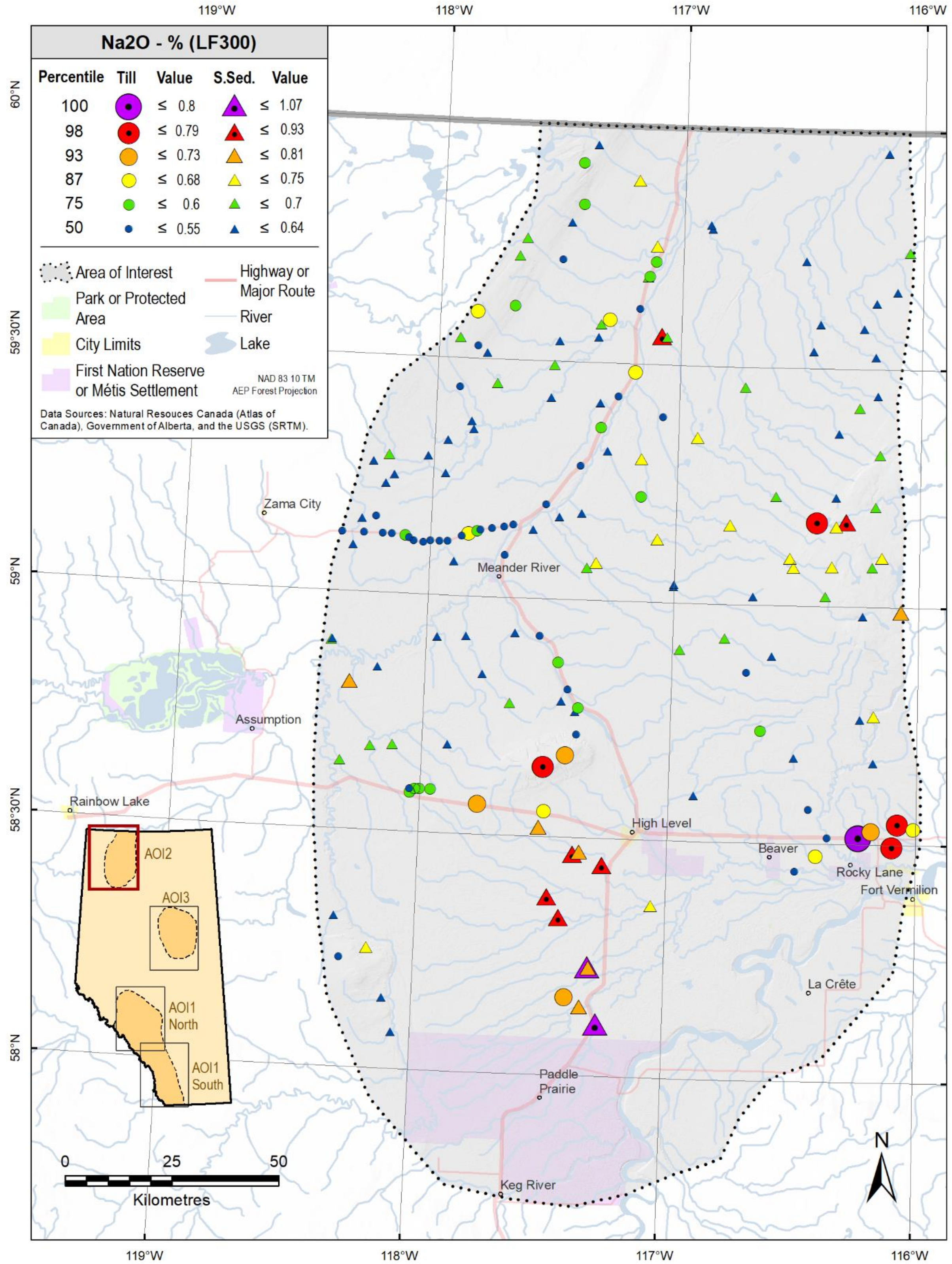


Figure 51. Sodium (Na_2O) concentrations in till and stream sediments in AOI-2.

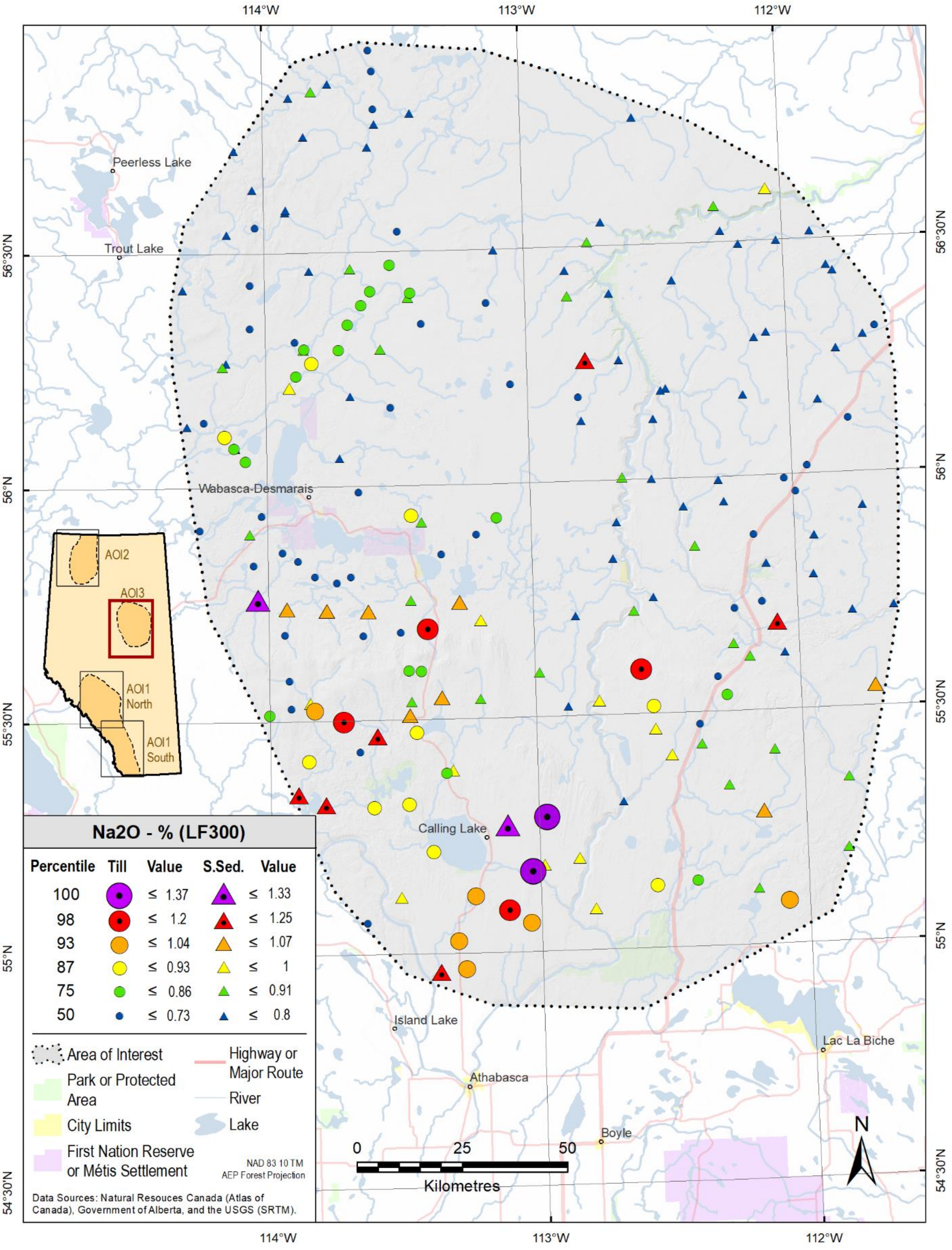


Figure 52. Sodium (Na_2O) concentrations in till and stream sediments in AOI-3.

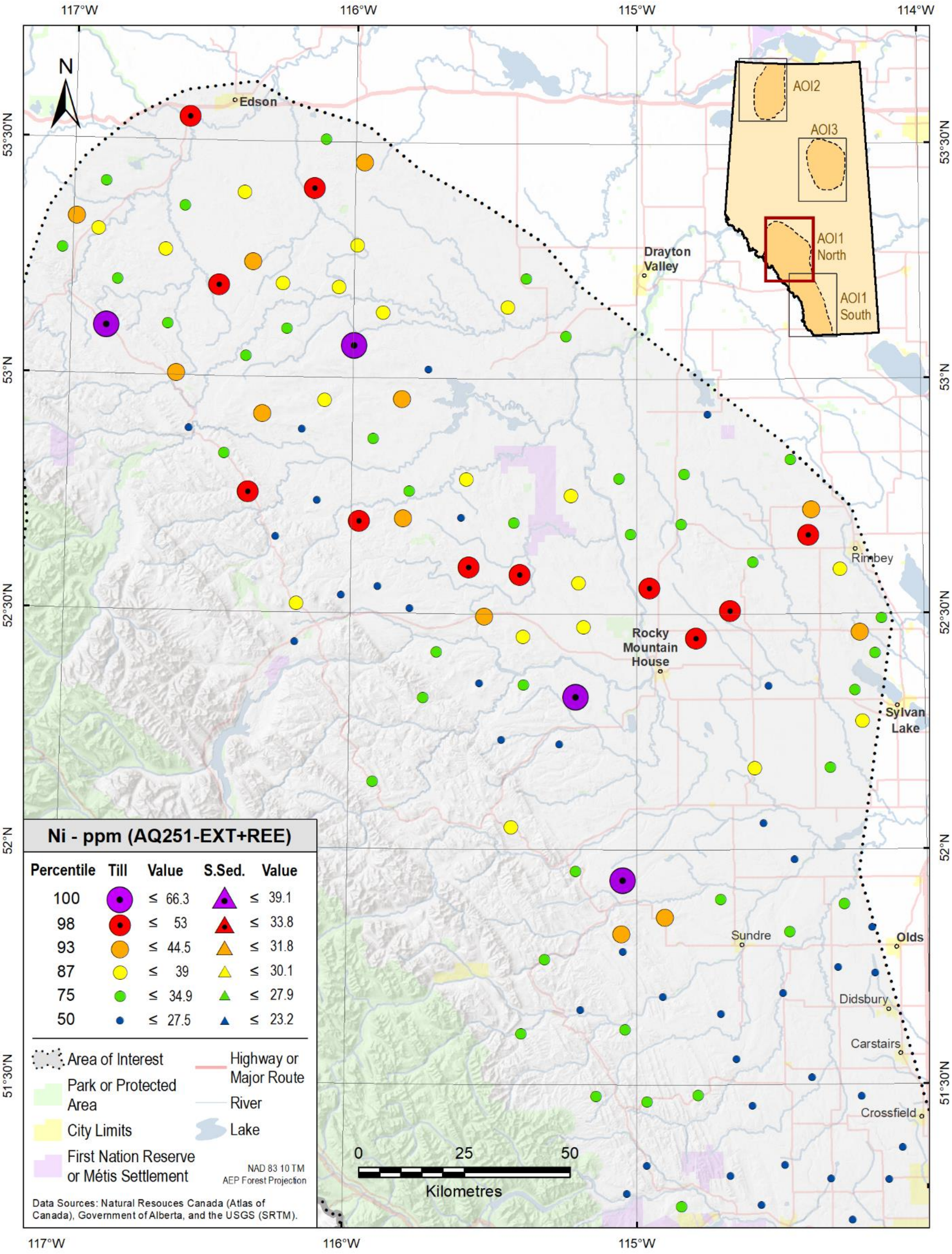


Figure 53. Nickel (Ni) concentrations in till in the northern half of AOI-1.

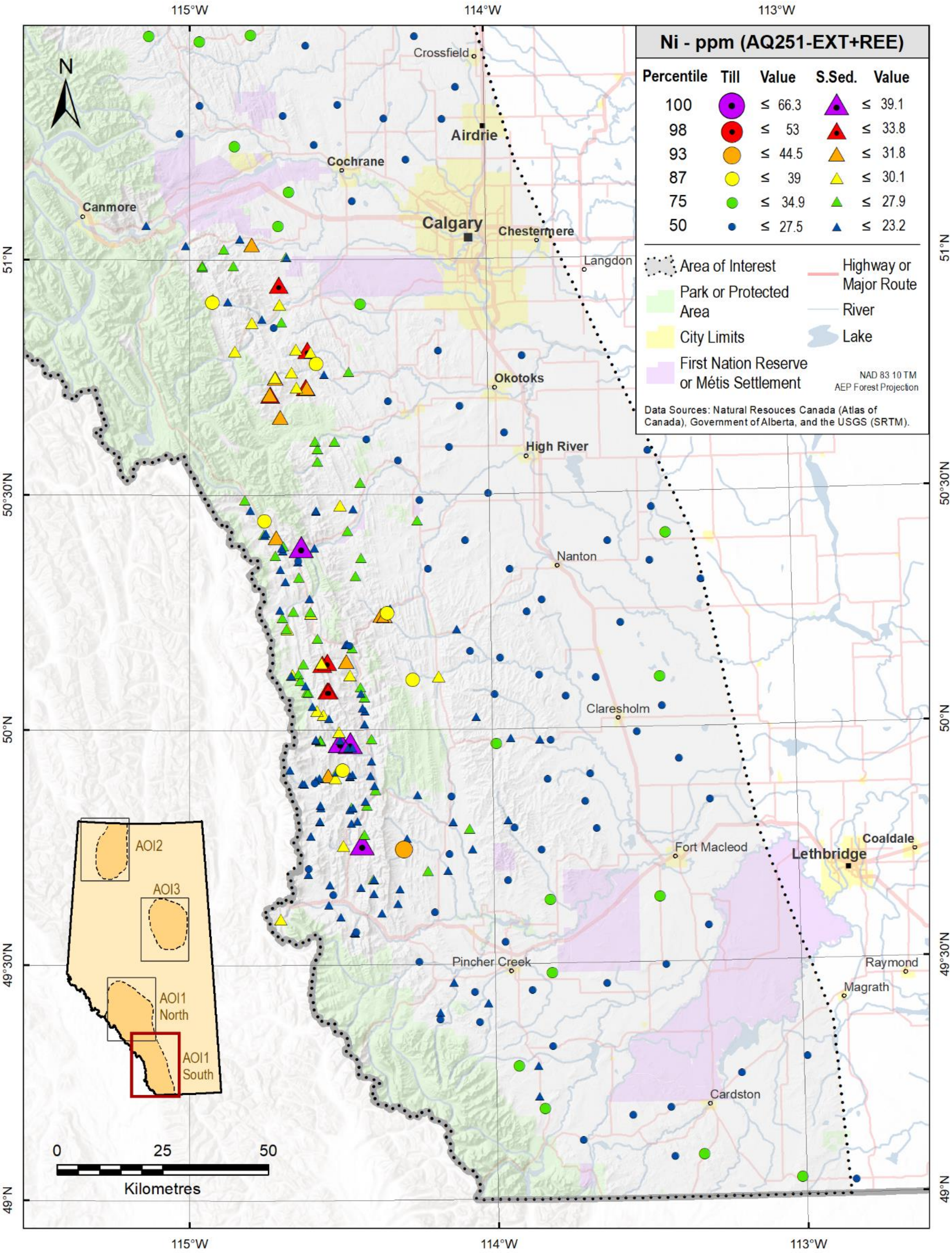


Figure 54. Nickel (Ni) concentrations in till and stream sediments in the southern half of AOI-1.

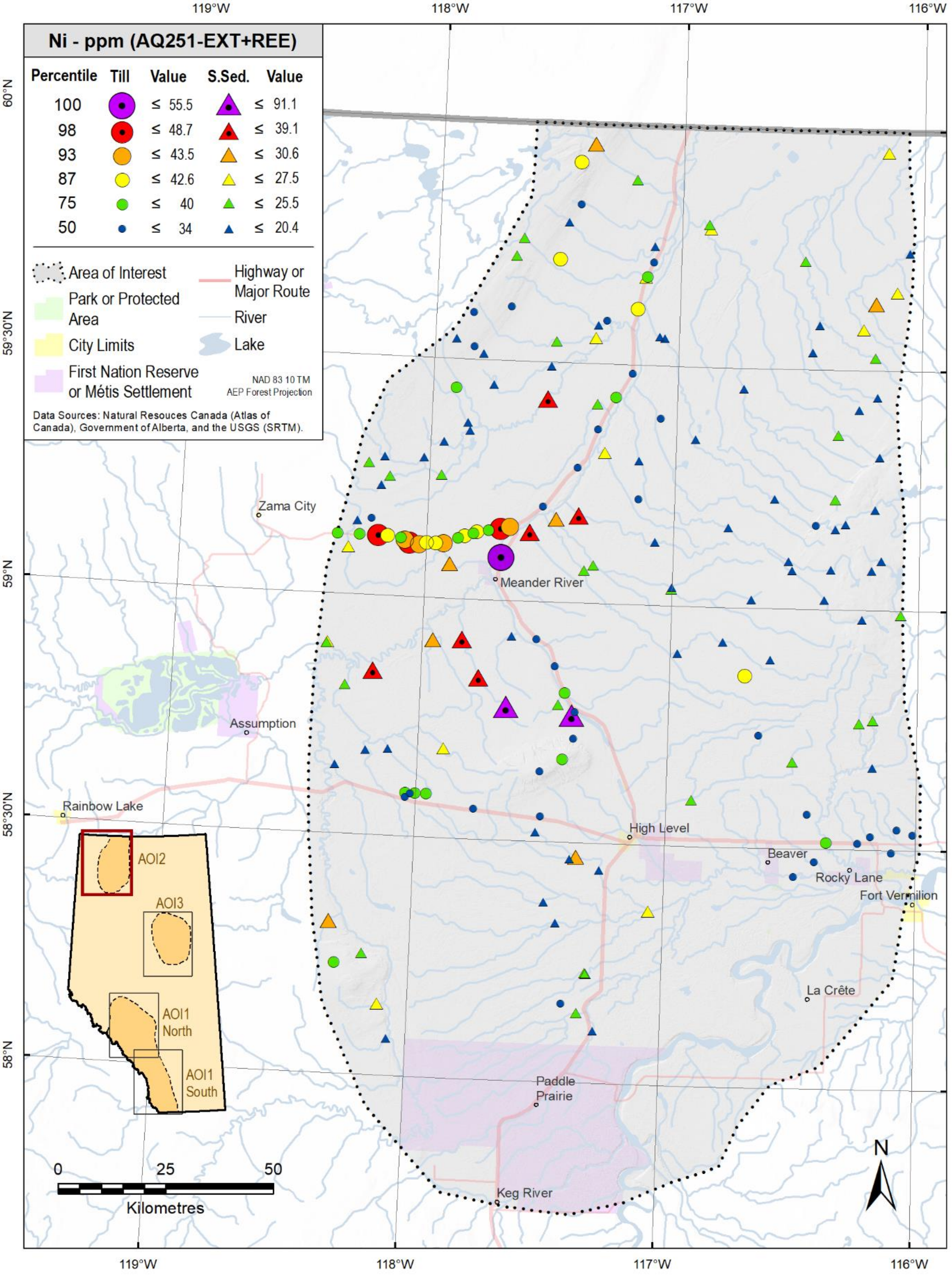


Figure 55. Nickel (Ni) concentrations in till and stream sediments in AOI-2.

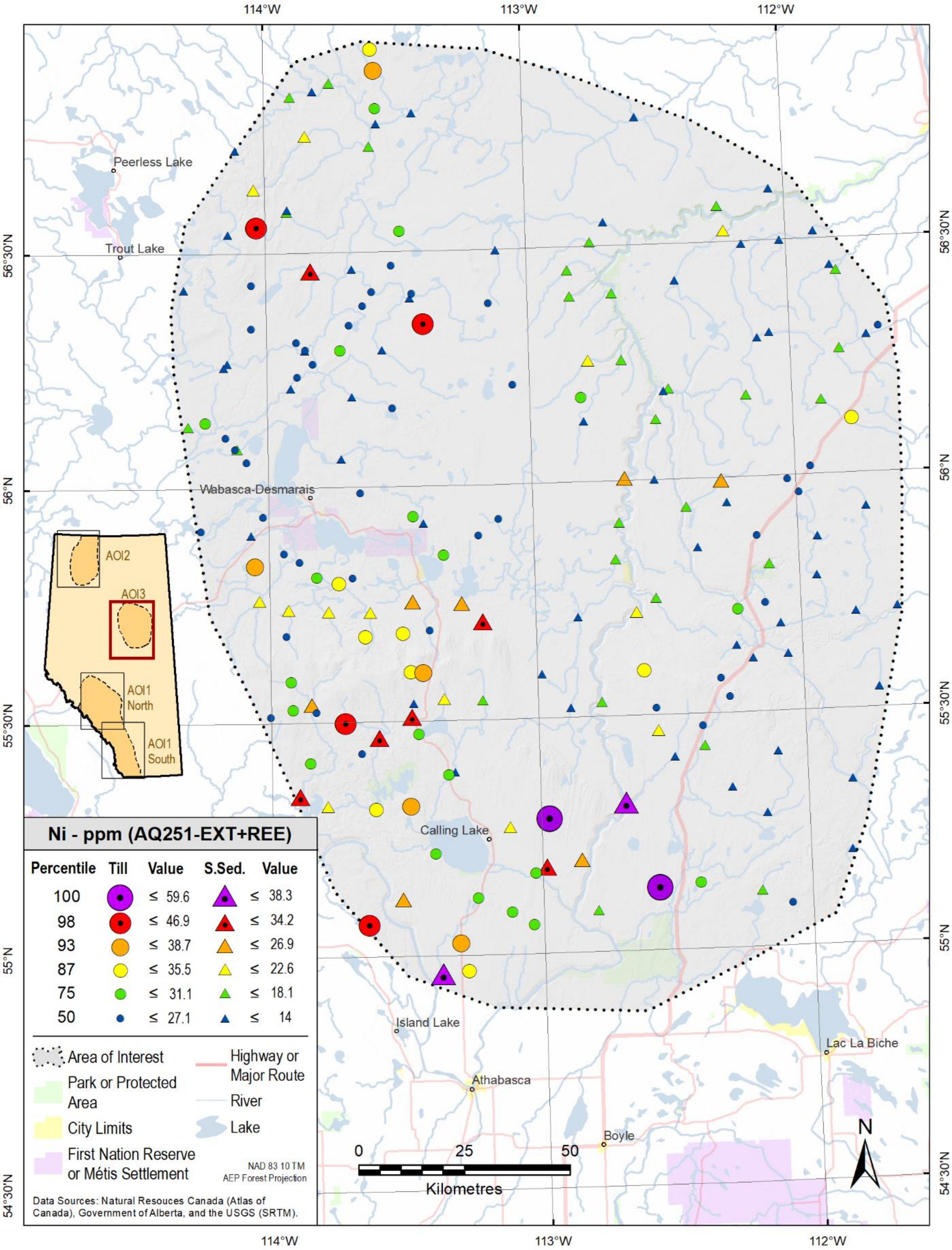


Figure 56. Nickel (Ni) concentrations in till and stream sediments in AOI-3.

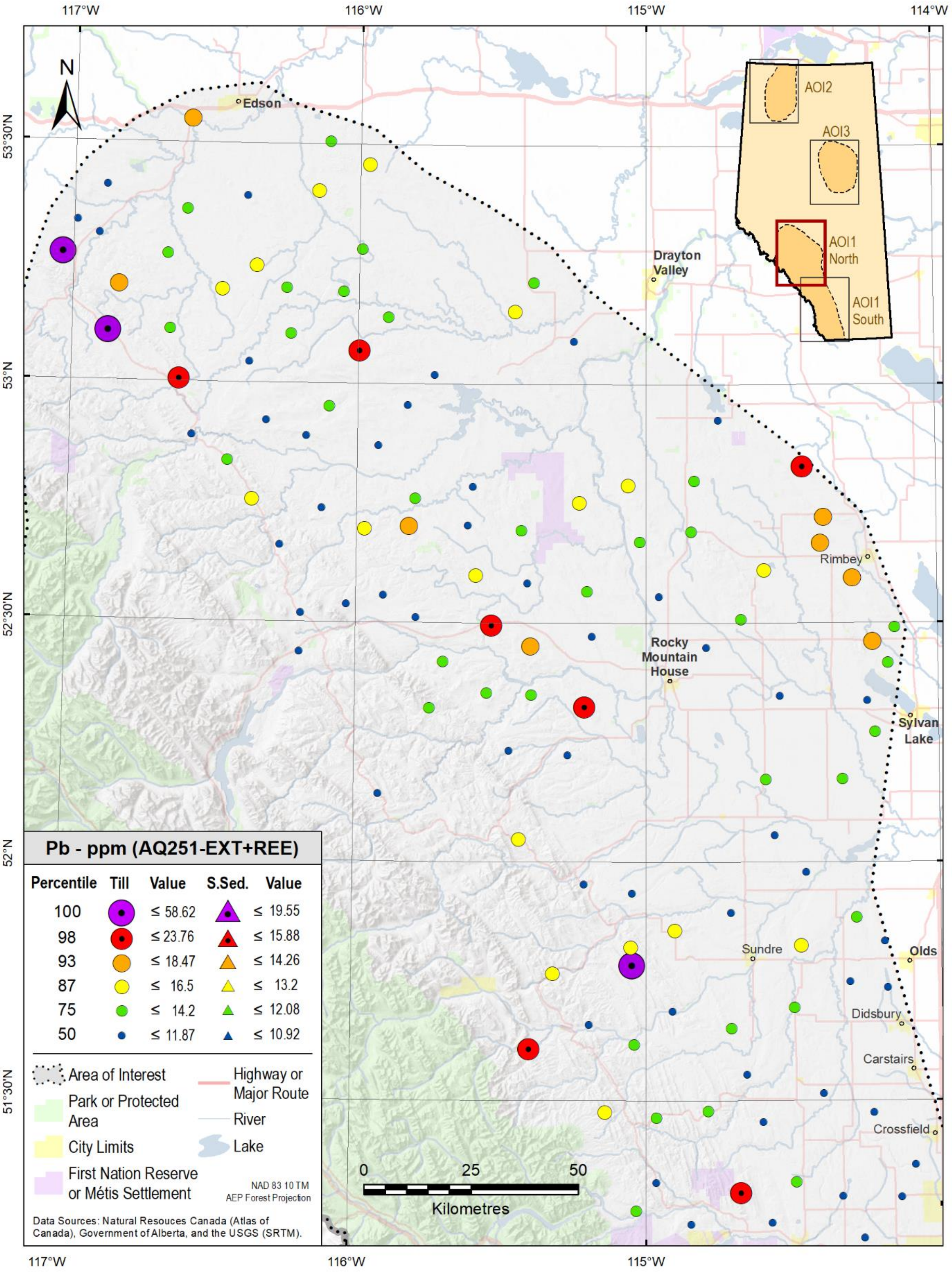


Figure 57. Lead (Pb) concentrations in till in the northern half of AOI-1.

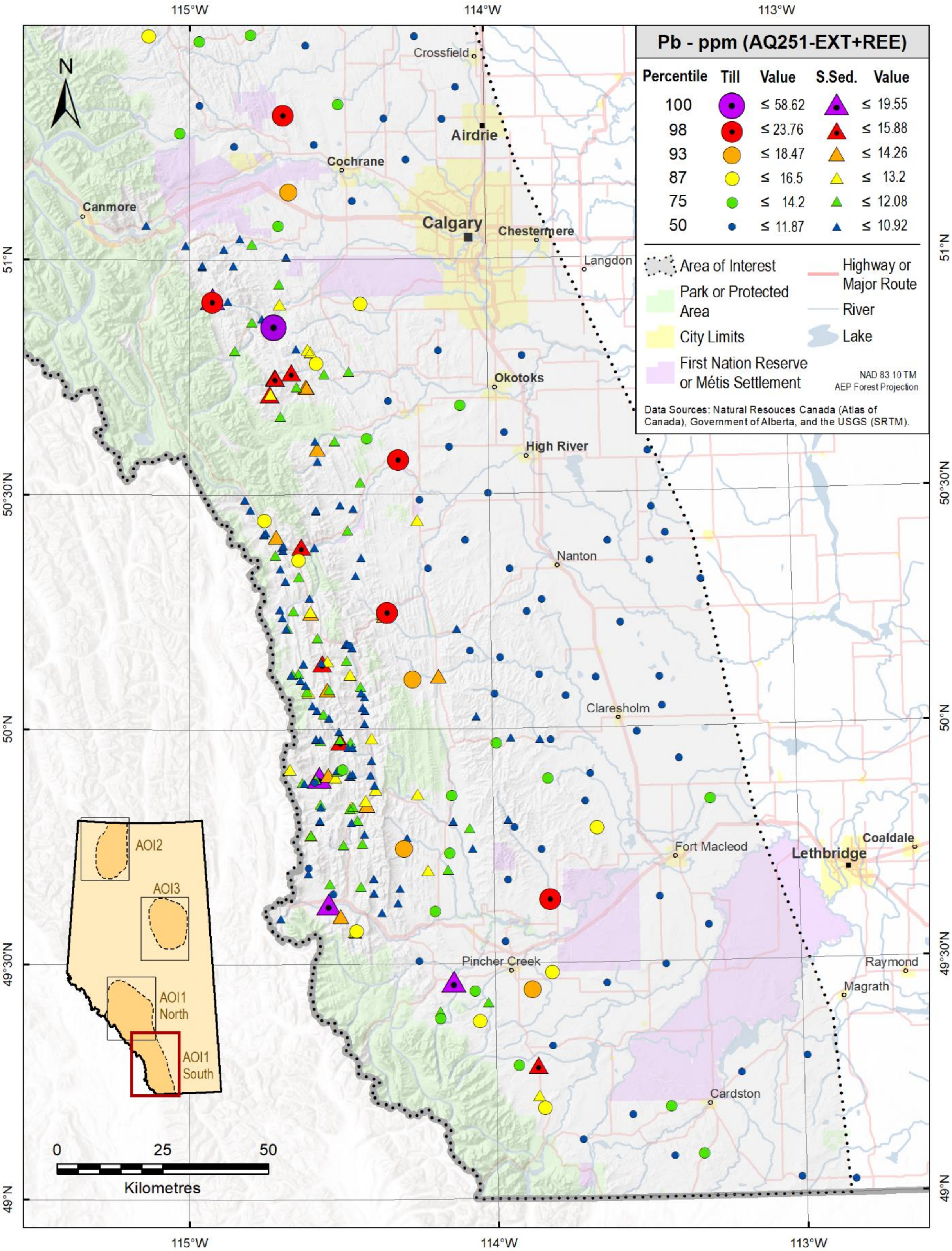


Figure 58. Lead (Pb) concentrations in till and stream sediments in the southern half of AOI-1.

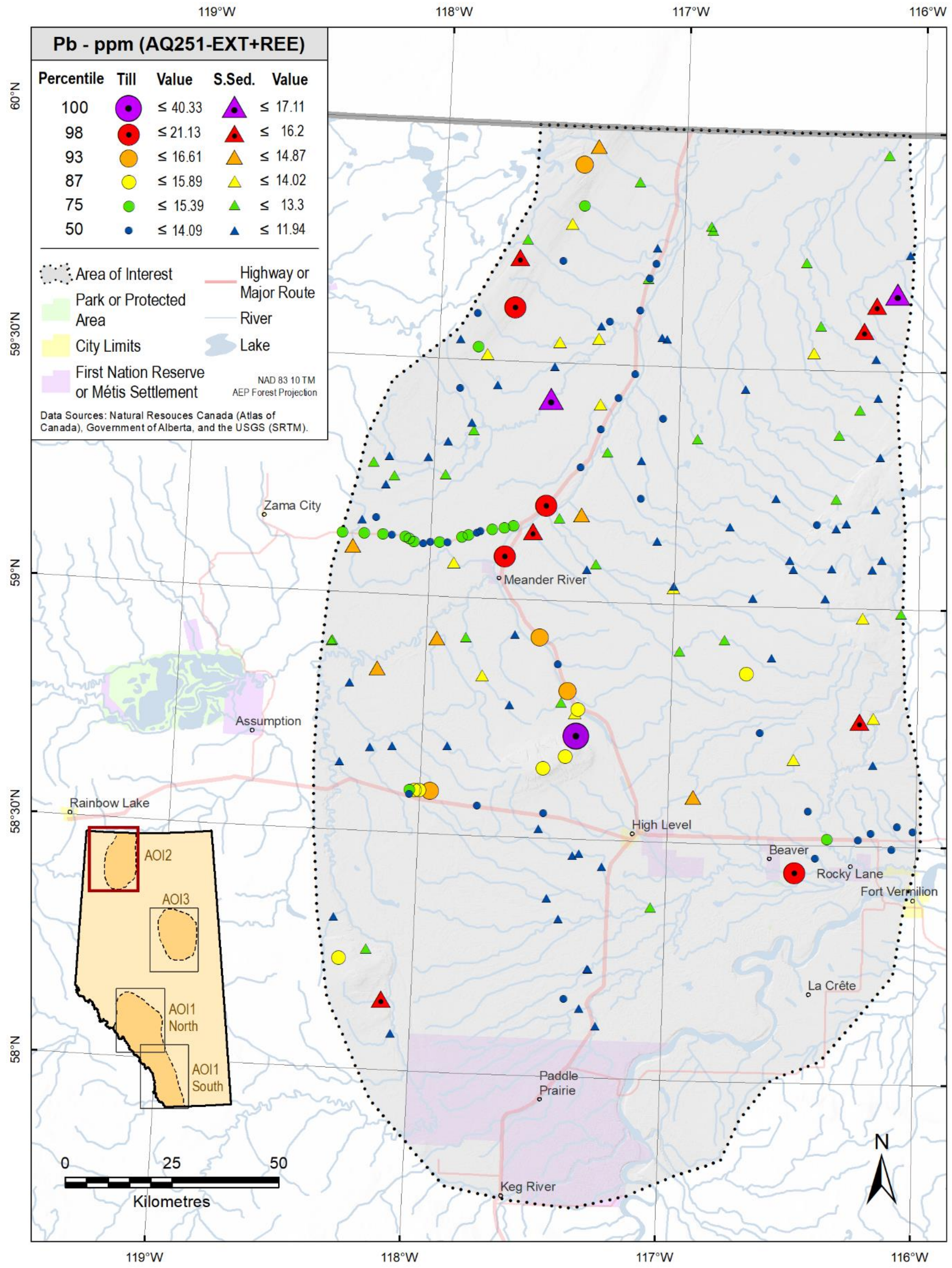


Figure 59. Lead (Pb) concentrations in till and stream sediments in AOI-2.

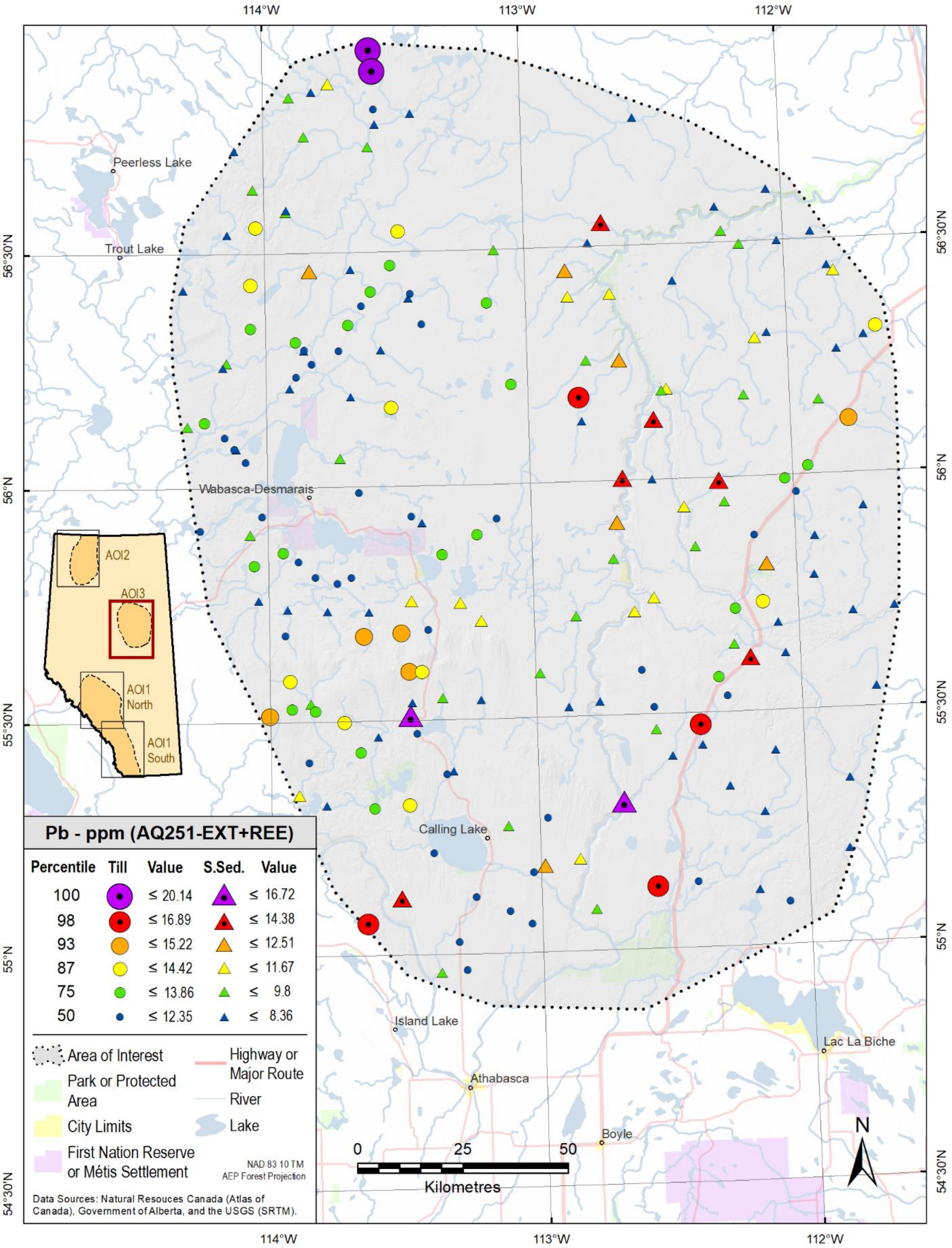


Figure 60. Lead (Pb) concentrations in till and stream sediments in AOI-3.

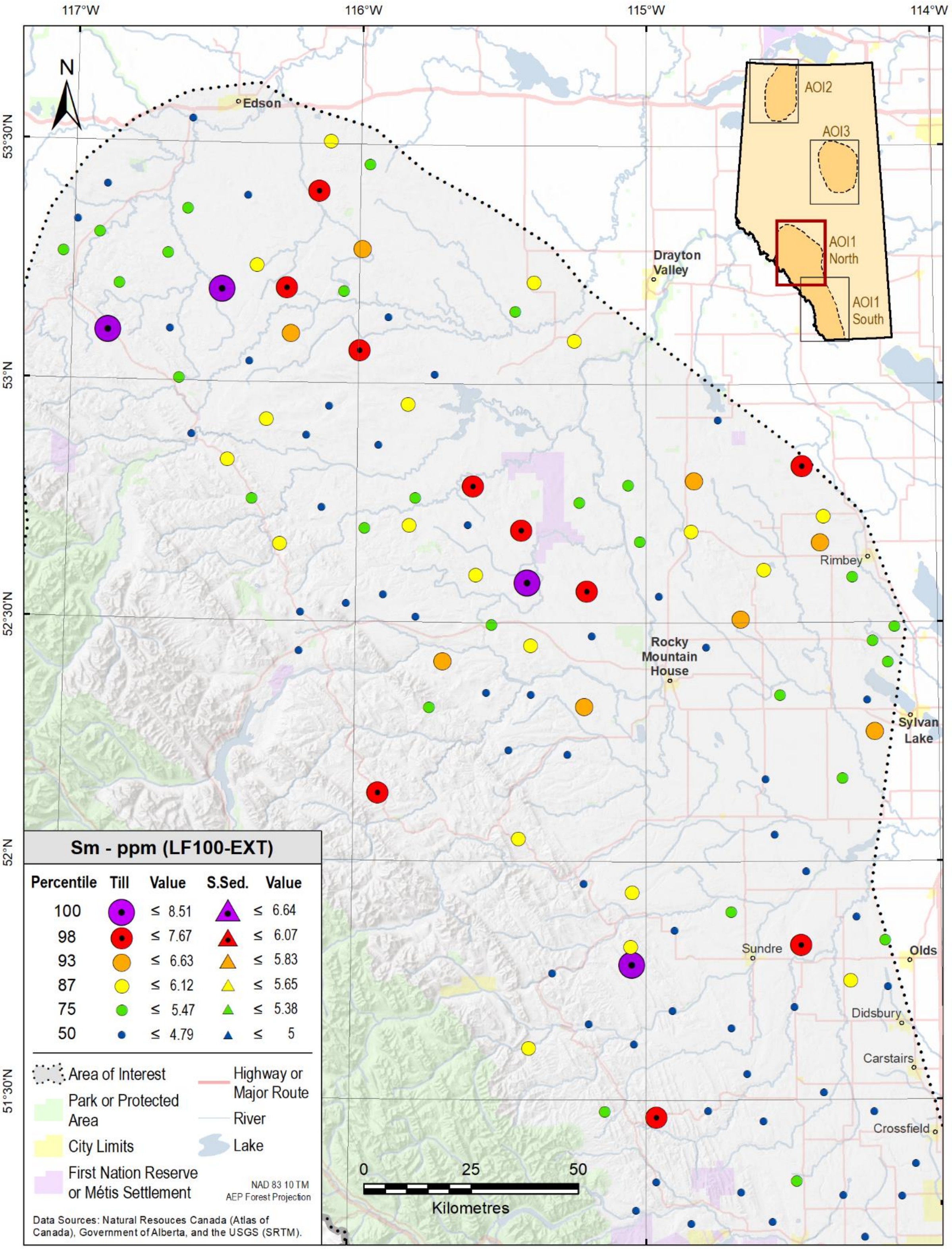


Figure 61. Samarium (Sm) concentrations in till in the northern half of AOI-1.

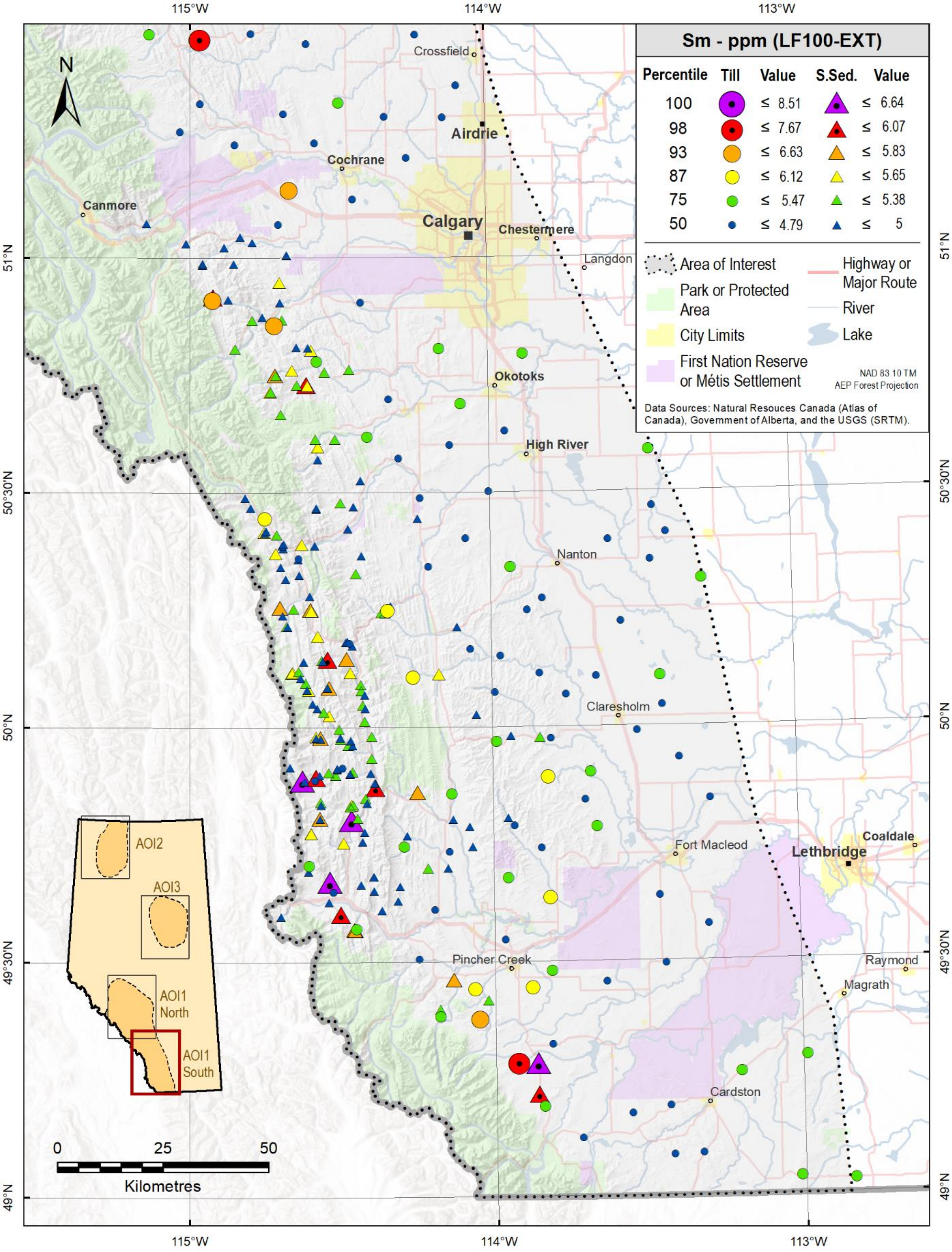


Figure 62. Samarium (Sm) concentrations in till and stream sediments in the southern half of AOI-1.

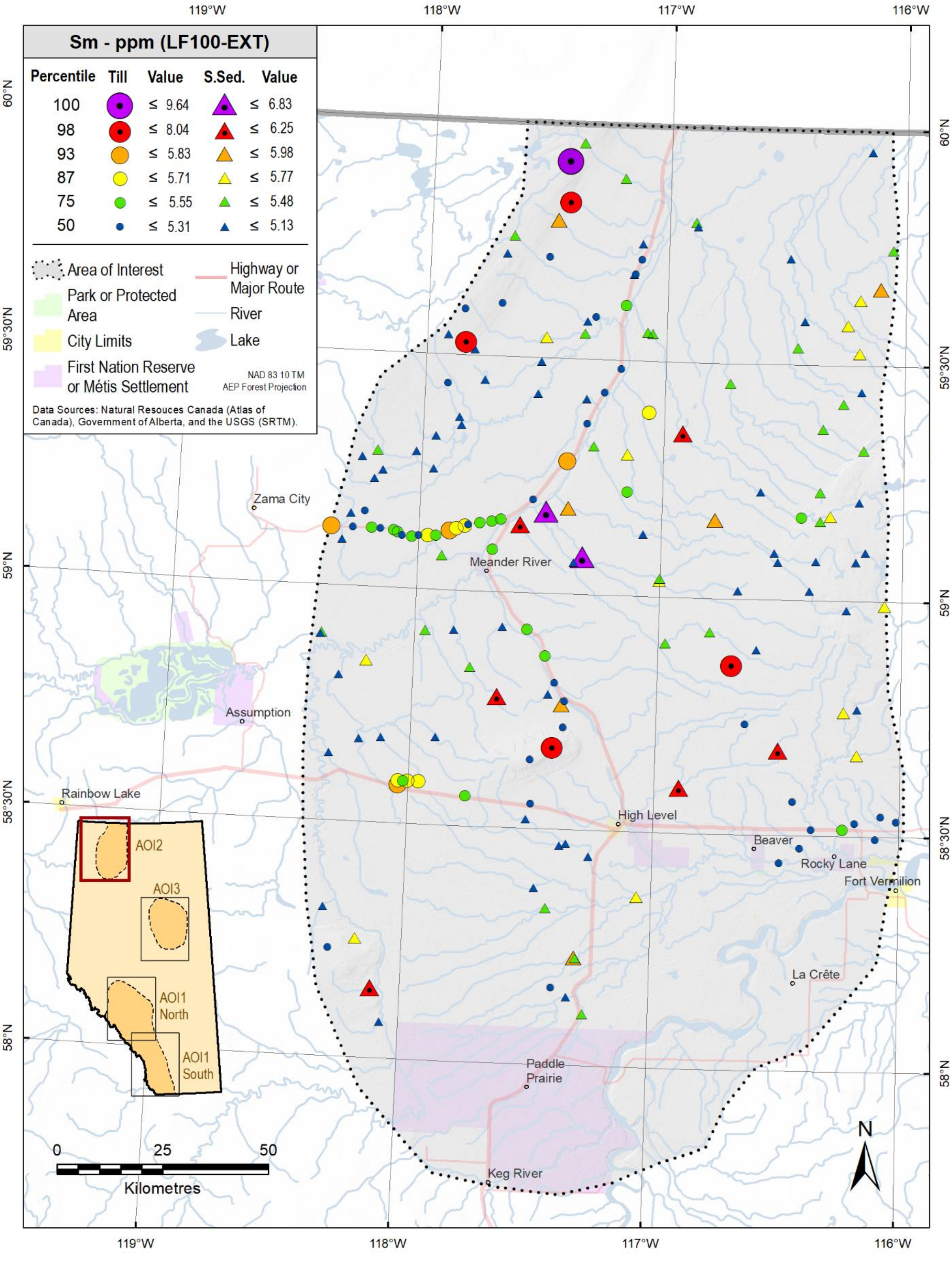


Figure 63. Samarium (Sm) concentrations in till and stream sediments in AOI-2.

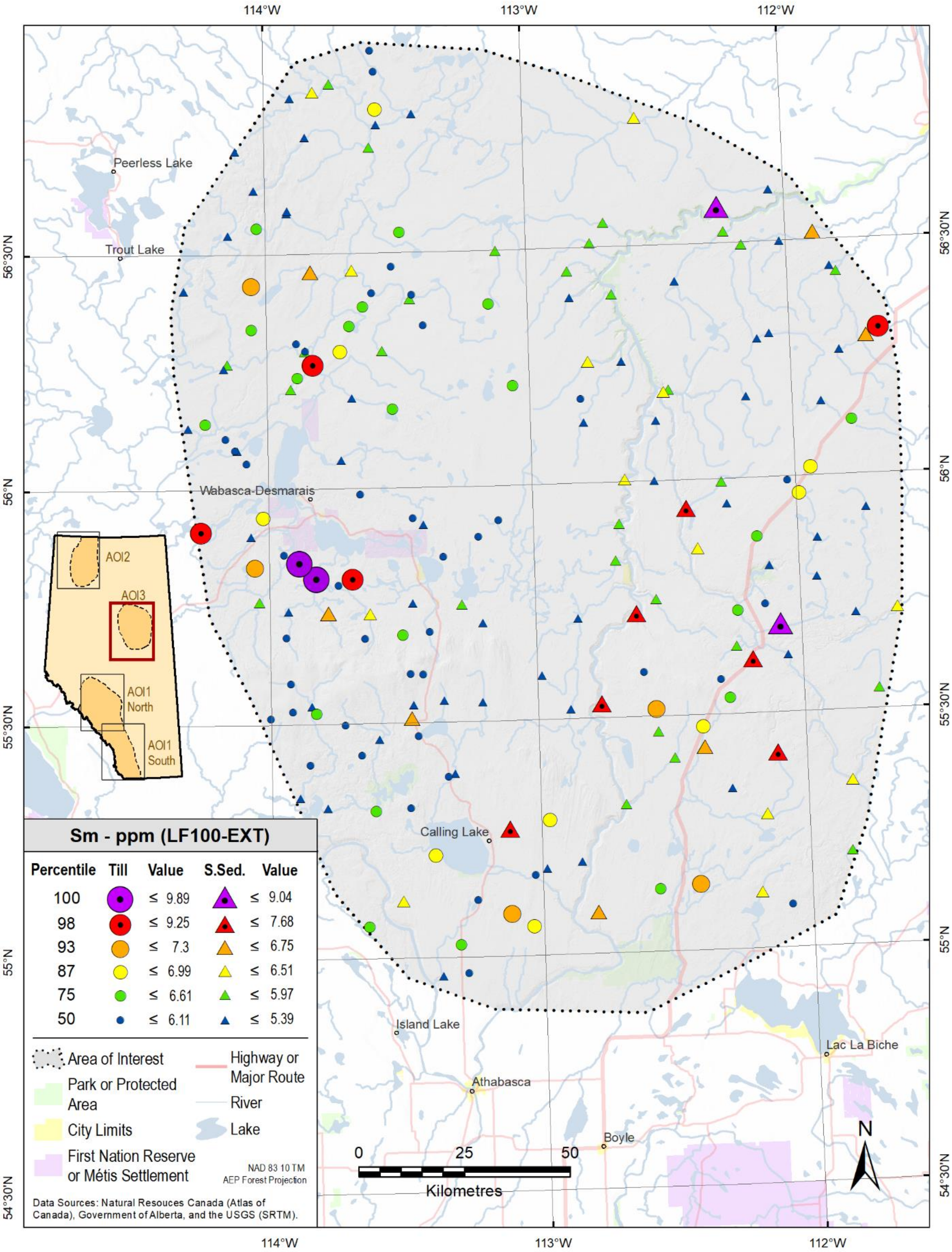


Figure 64. Samarium (Sm) concentrations in till and stream sediments in AOI-3.

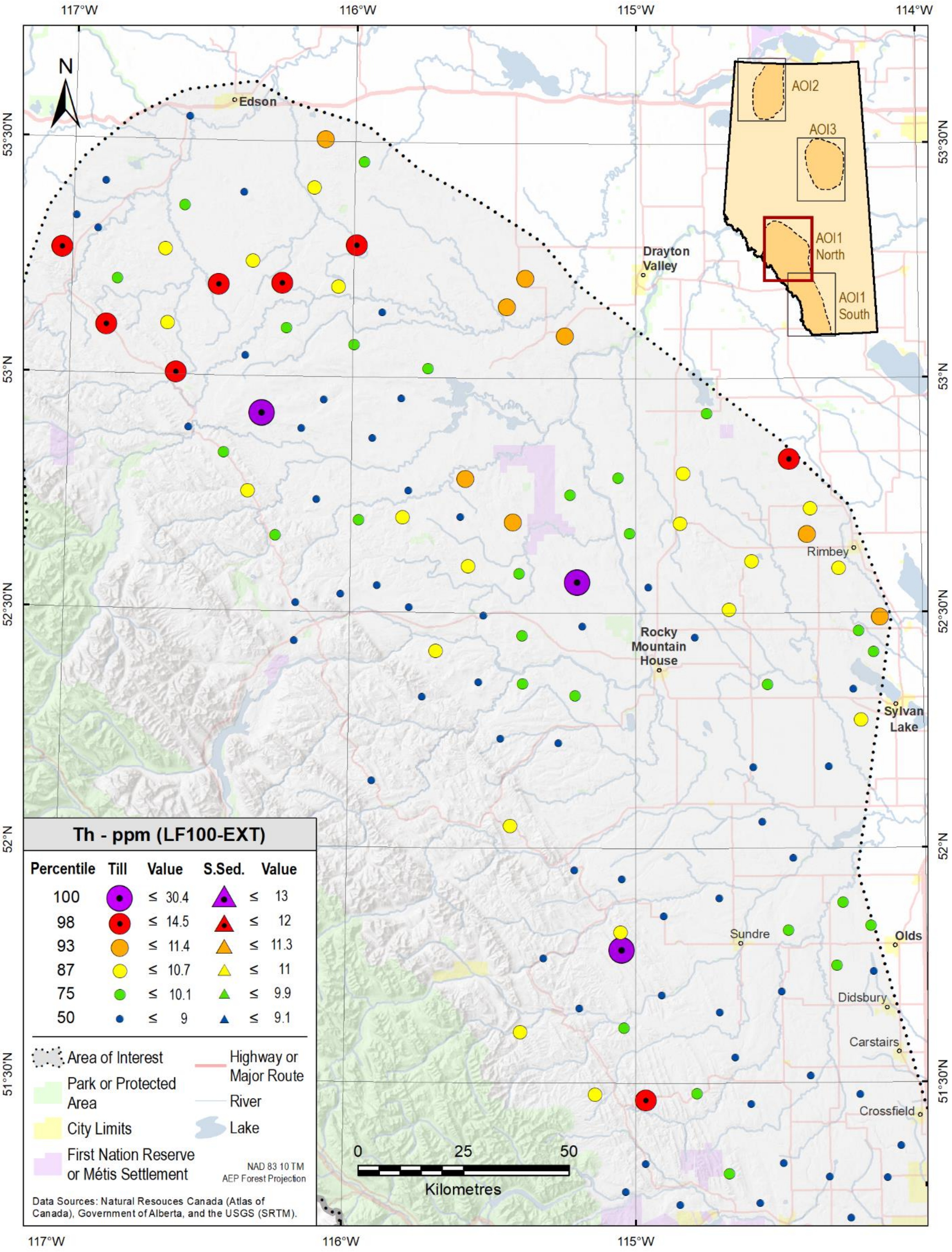


Figure 65. Thorium (Th) concentrations in till in the northern half of AOI-1.

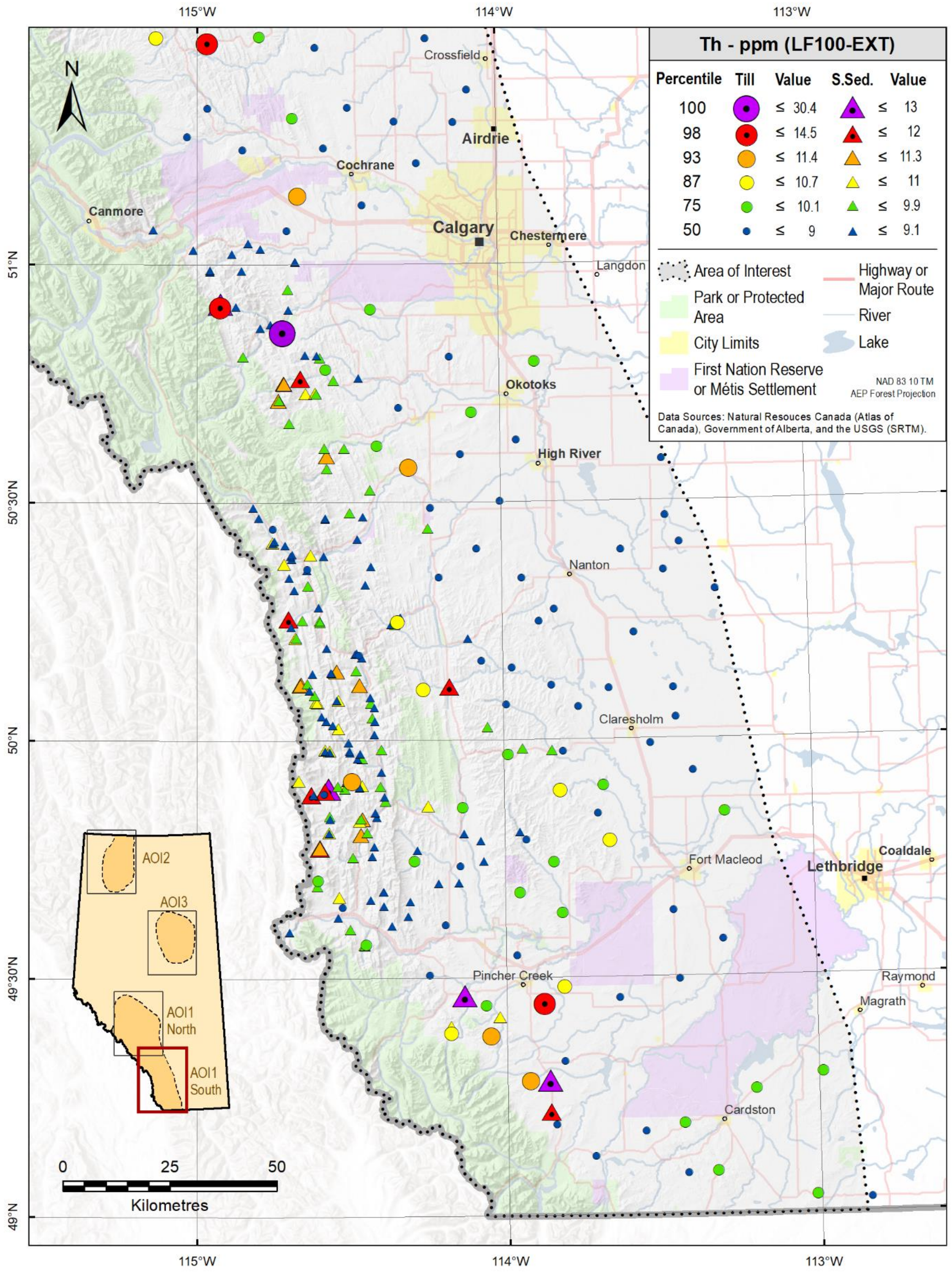


Figure 66. Thorium (Th) concentrations in till and stream sediments in the southern half of AOI-1.

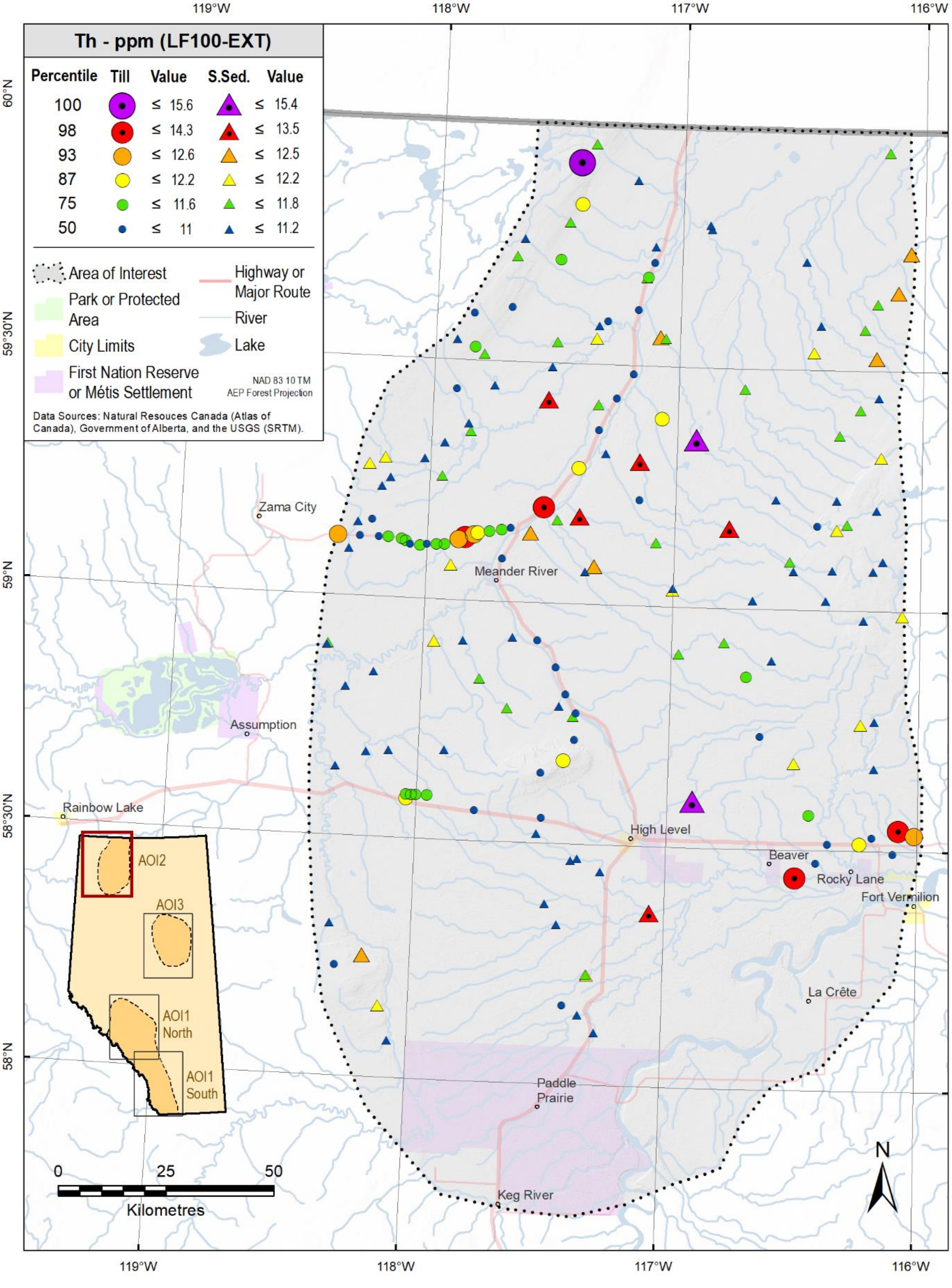


Figure 67. Thorium (Th) concentrations in till and stream sediments in AOI-2.

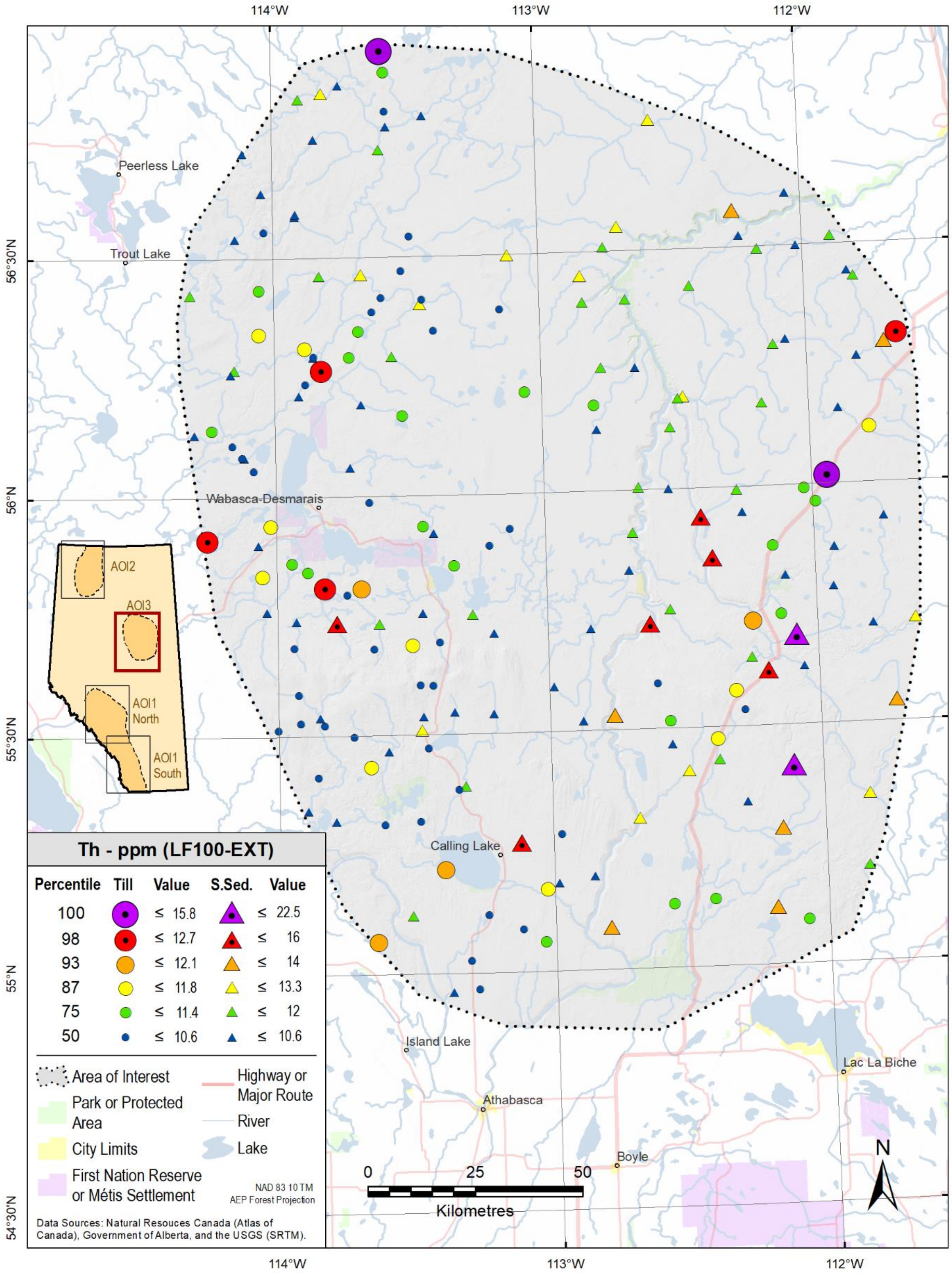


Figure 68. Thorium (Th) concentrations in till and stream sediments in AOI-3.

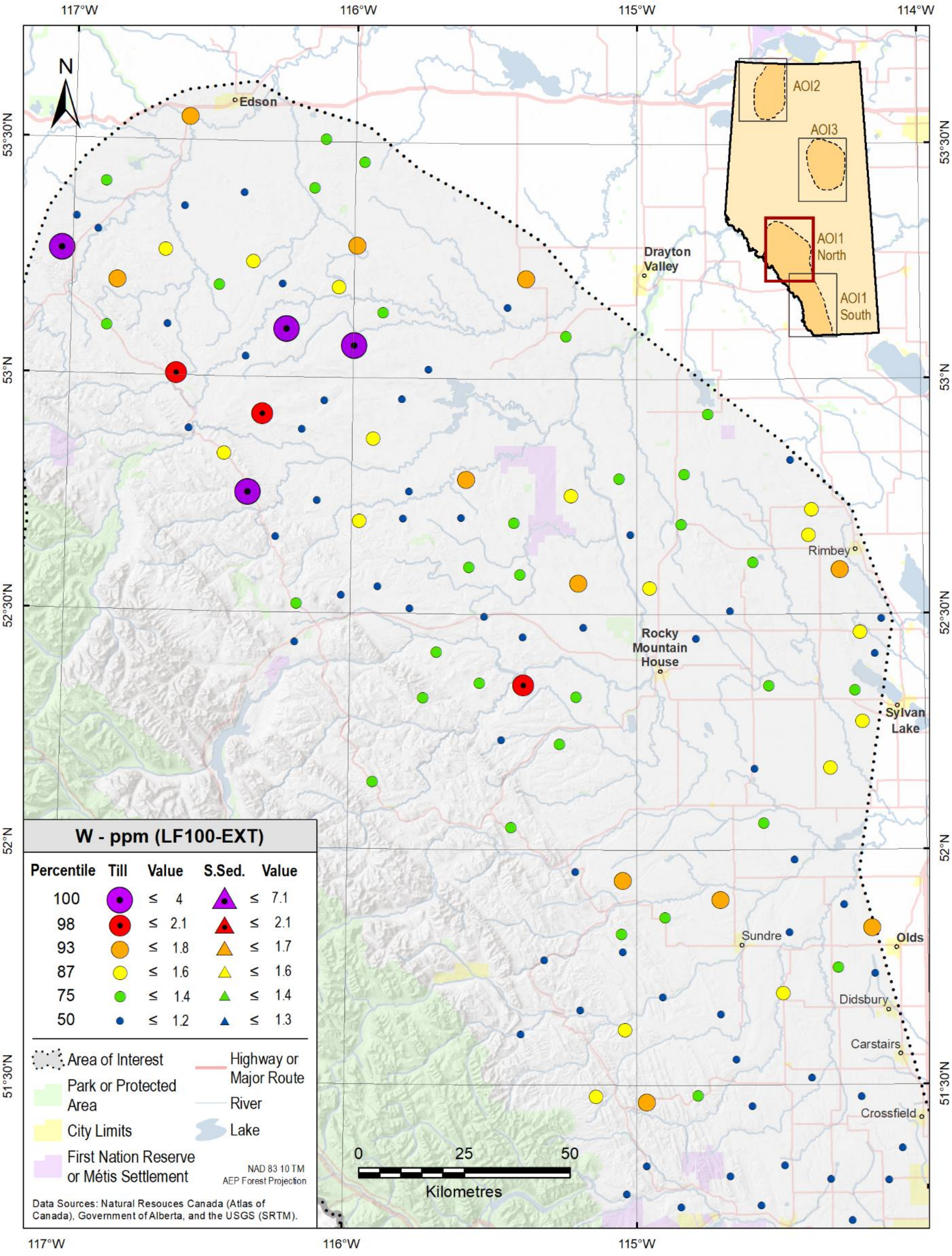


Figure 69. Tungsten (W) concentrations in till in the northern half of AOI-1.

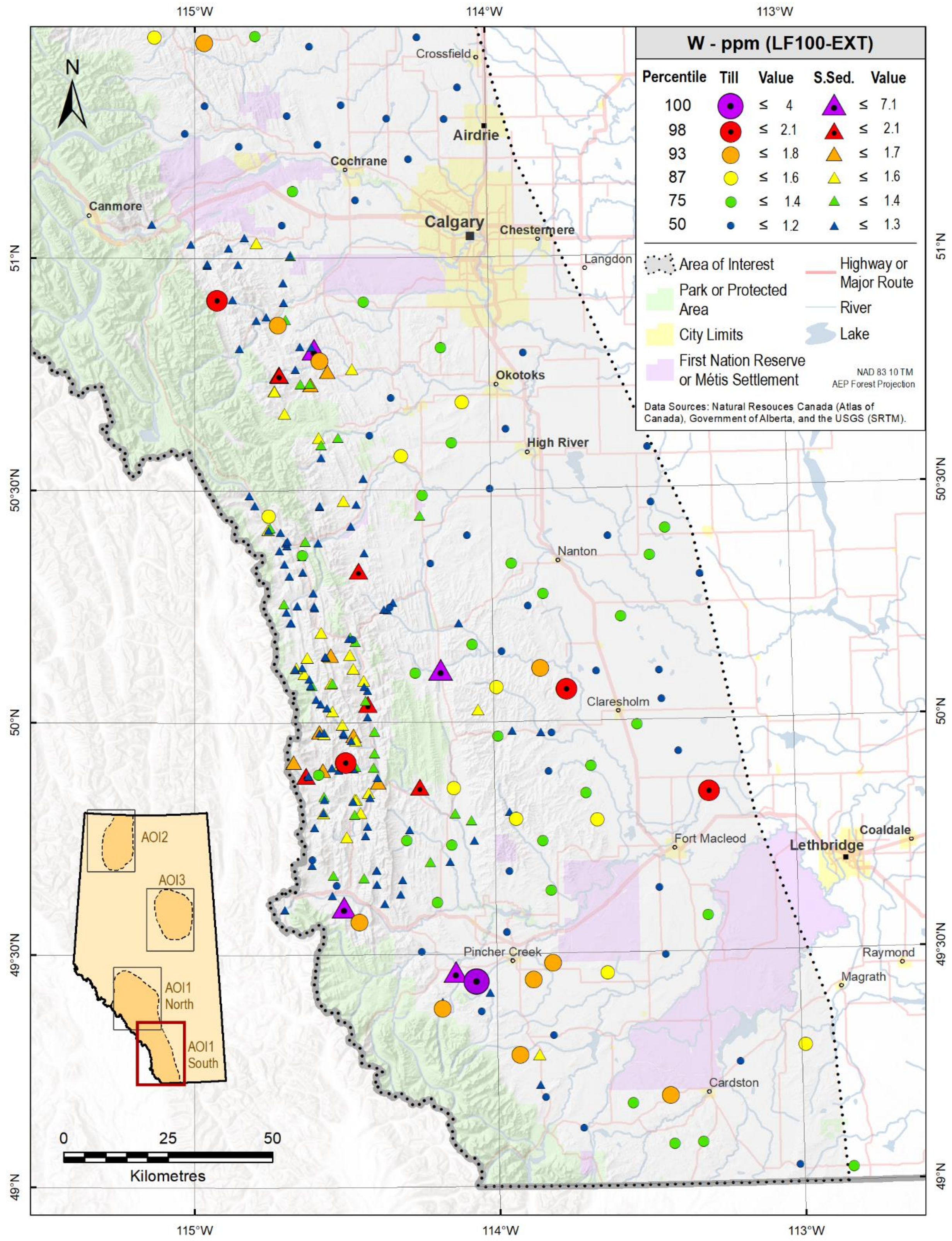


Figure 70. Tungsten (W) concentrations in till and stream sediments in the southern half of AOI-1.

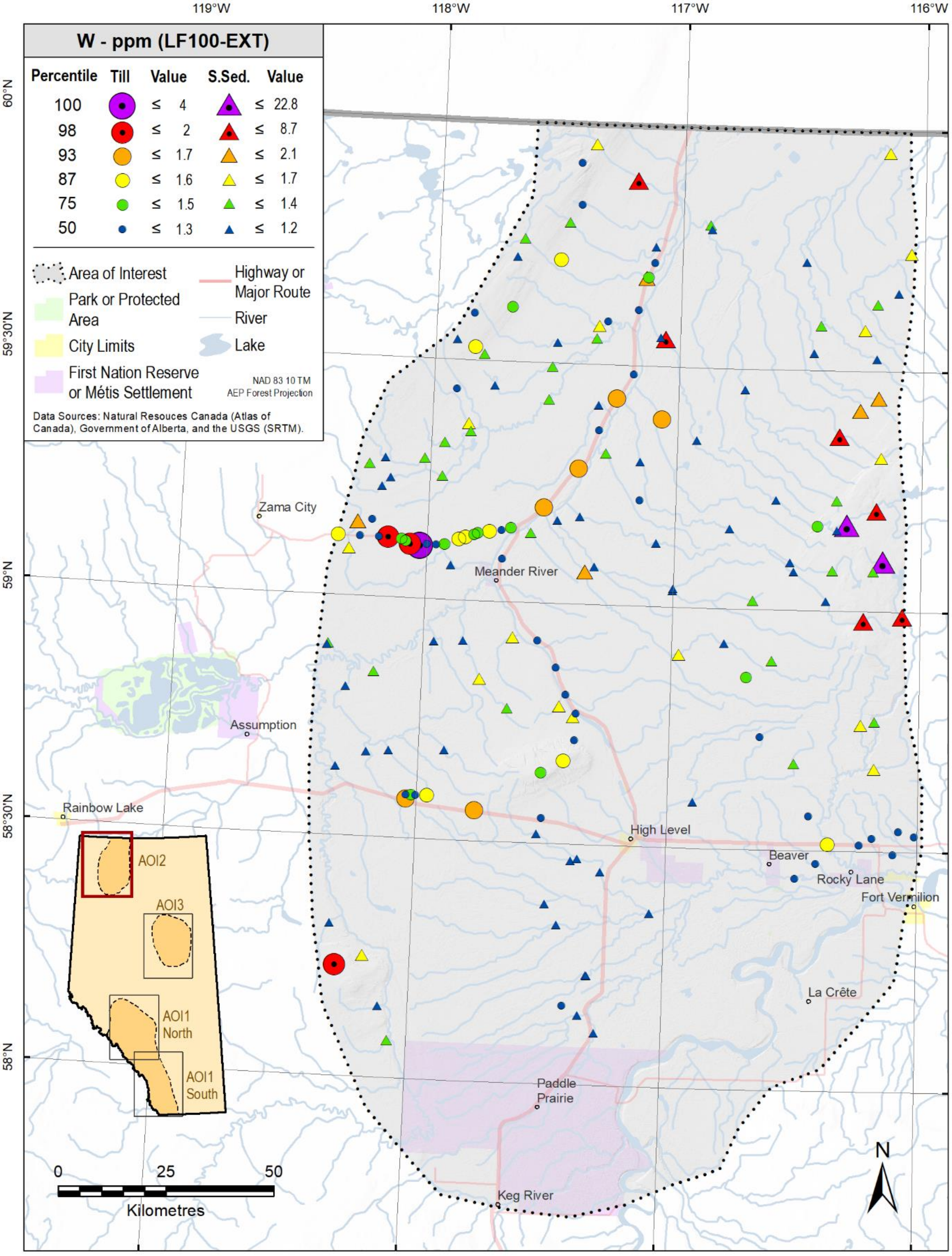


Figure 71. Tungsten (W) concentrations in till and stream sediments in AOI-2.

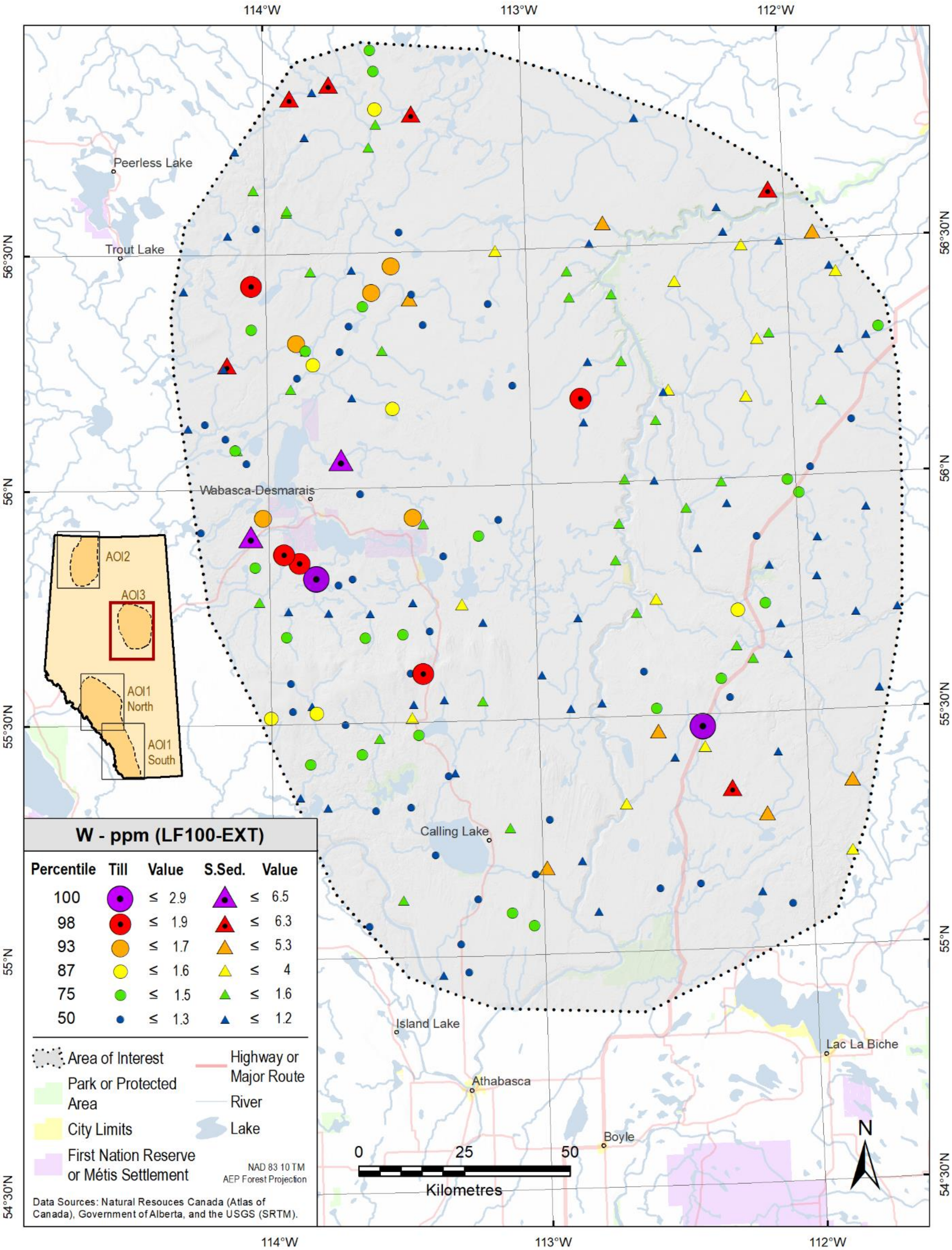


Figure 72. Tungsten (W) concentrations in till and stream sediments in AOI-3.

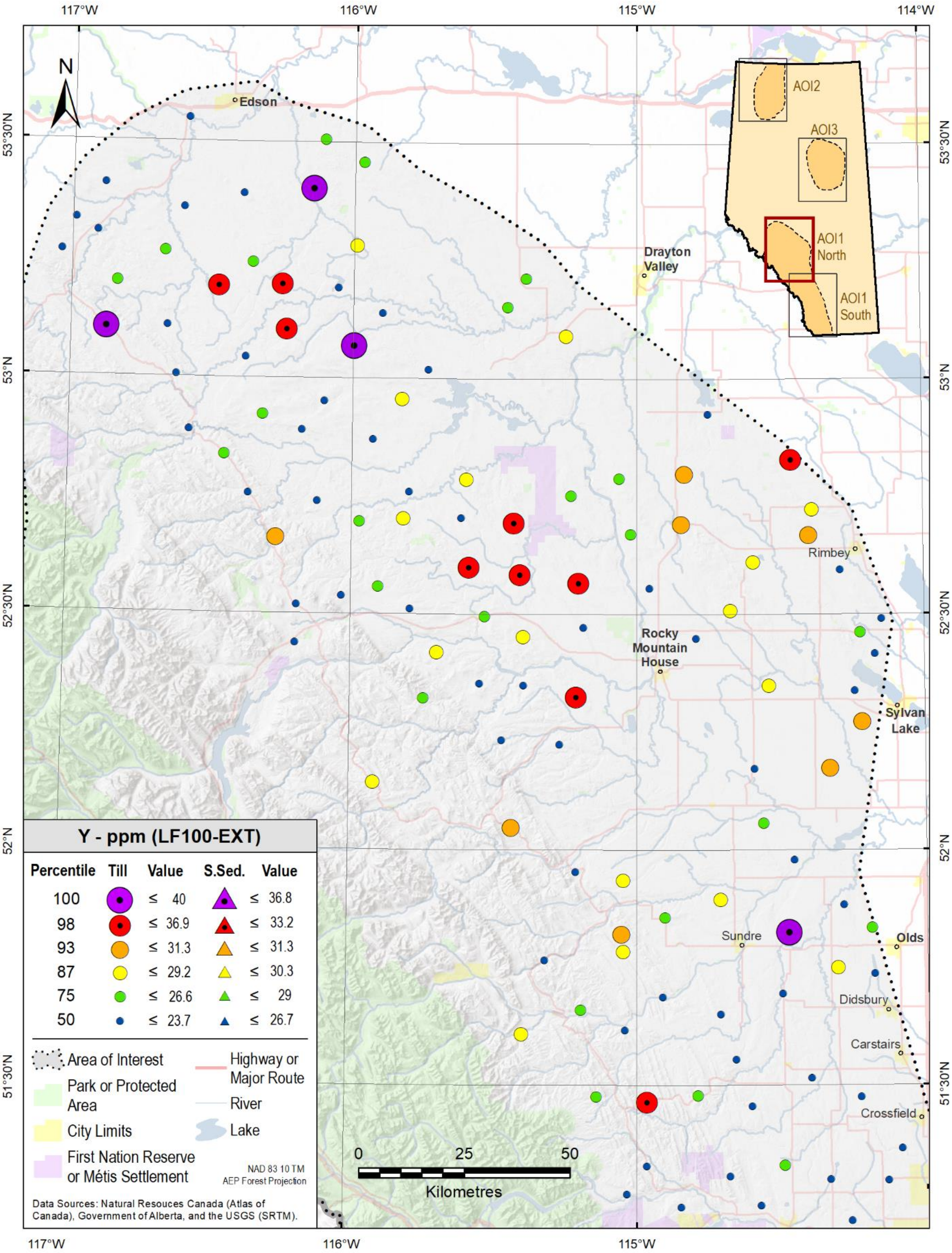


Figure 73. Yttrium (Y) concentrations in till in the northern half of AOI-1.

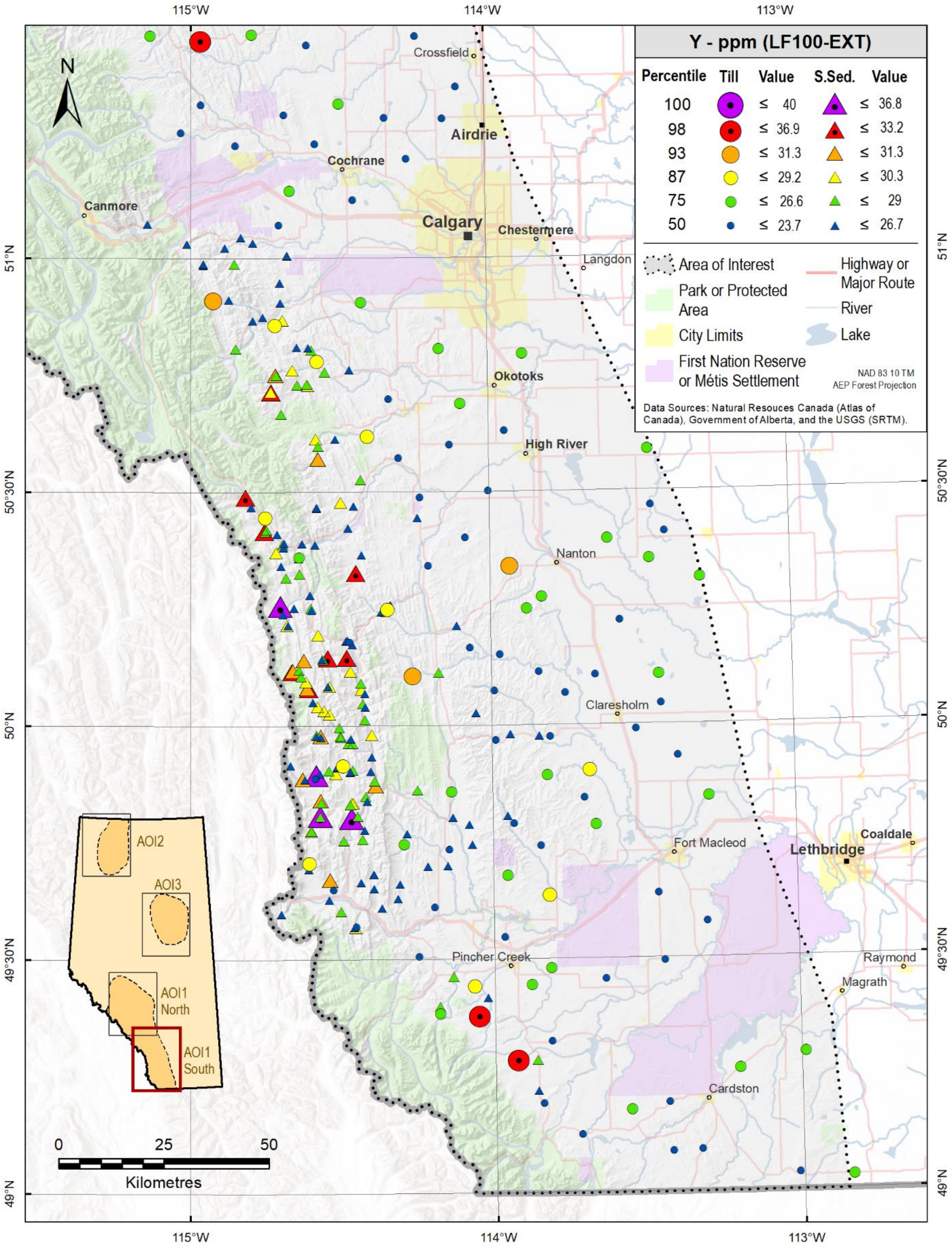


Figure 74. Yttrium (Y) concentrations in till and stream sediments in the southern half of AOI-1.

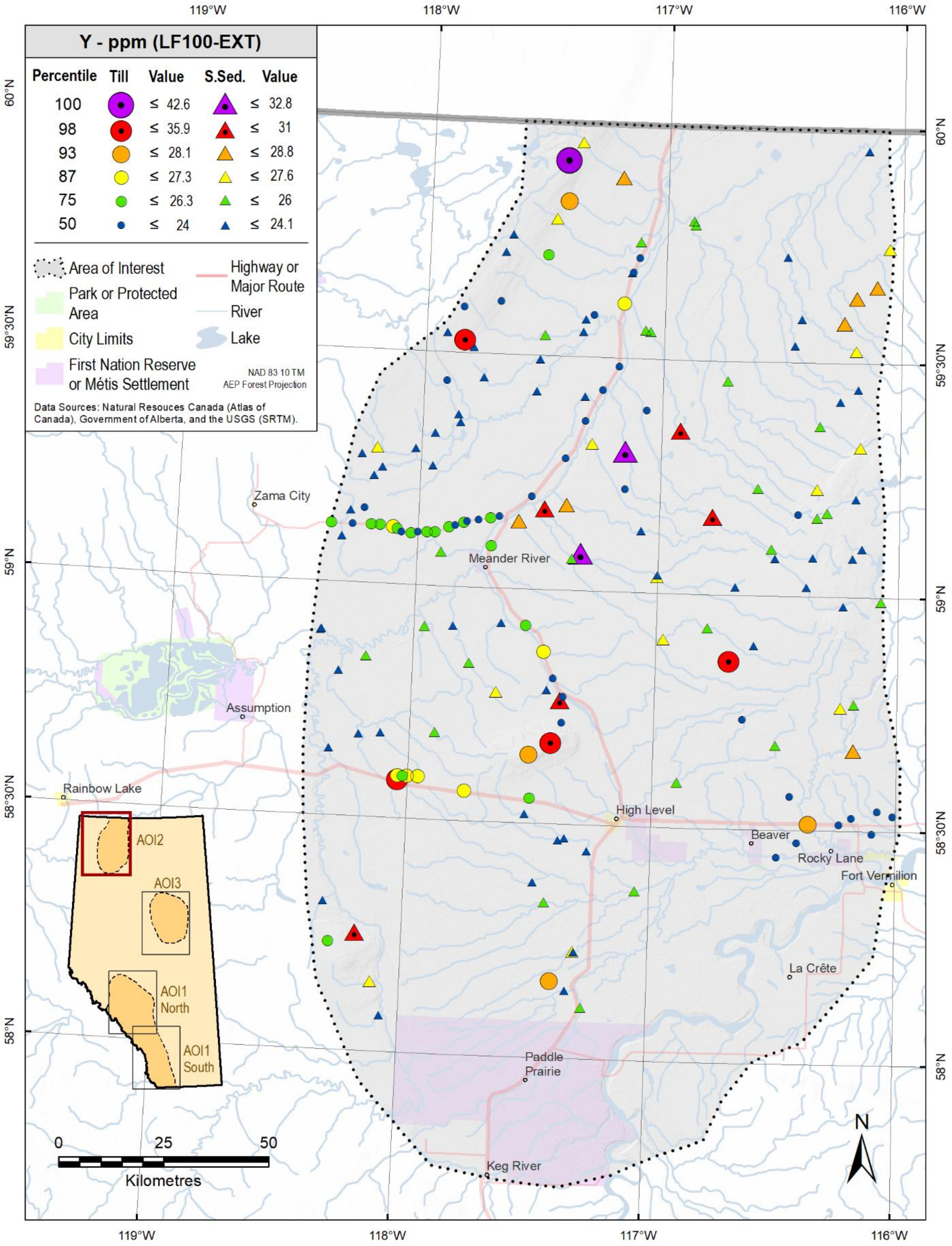


Figure 75. Yttrium (Y) concentrations in till and stream sediments in AOI-2.

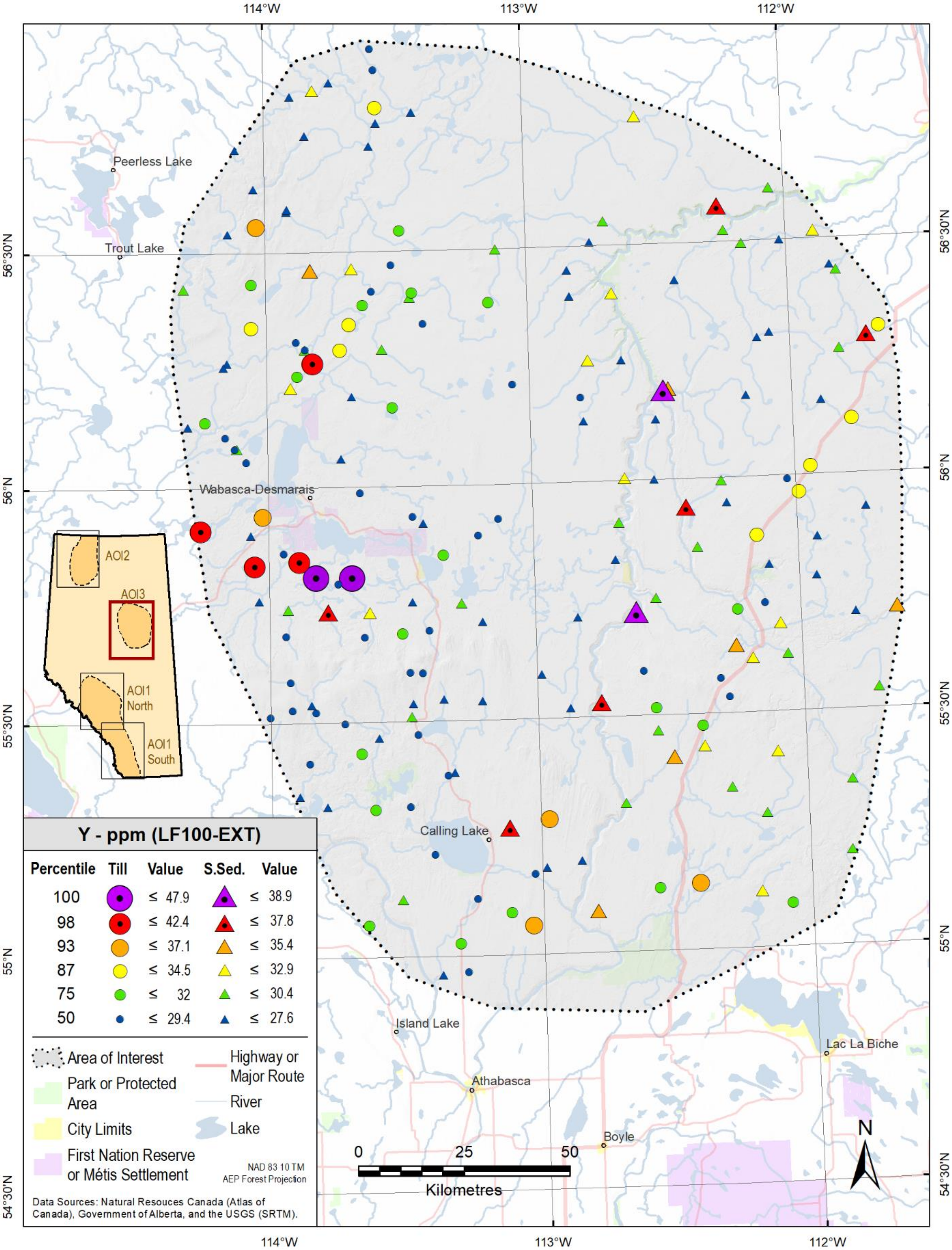


Figure 76. Yttrium (Y) concentrations in till and stream sediments in AOI-3.

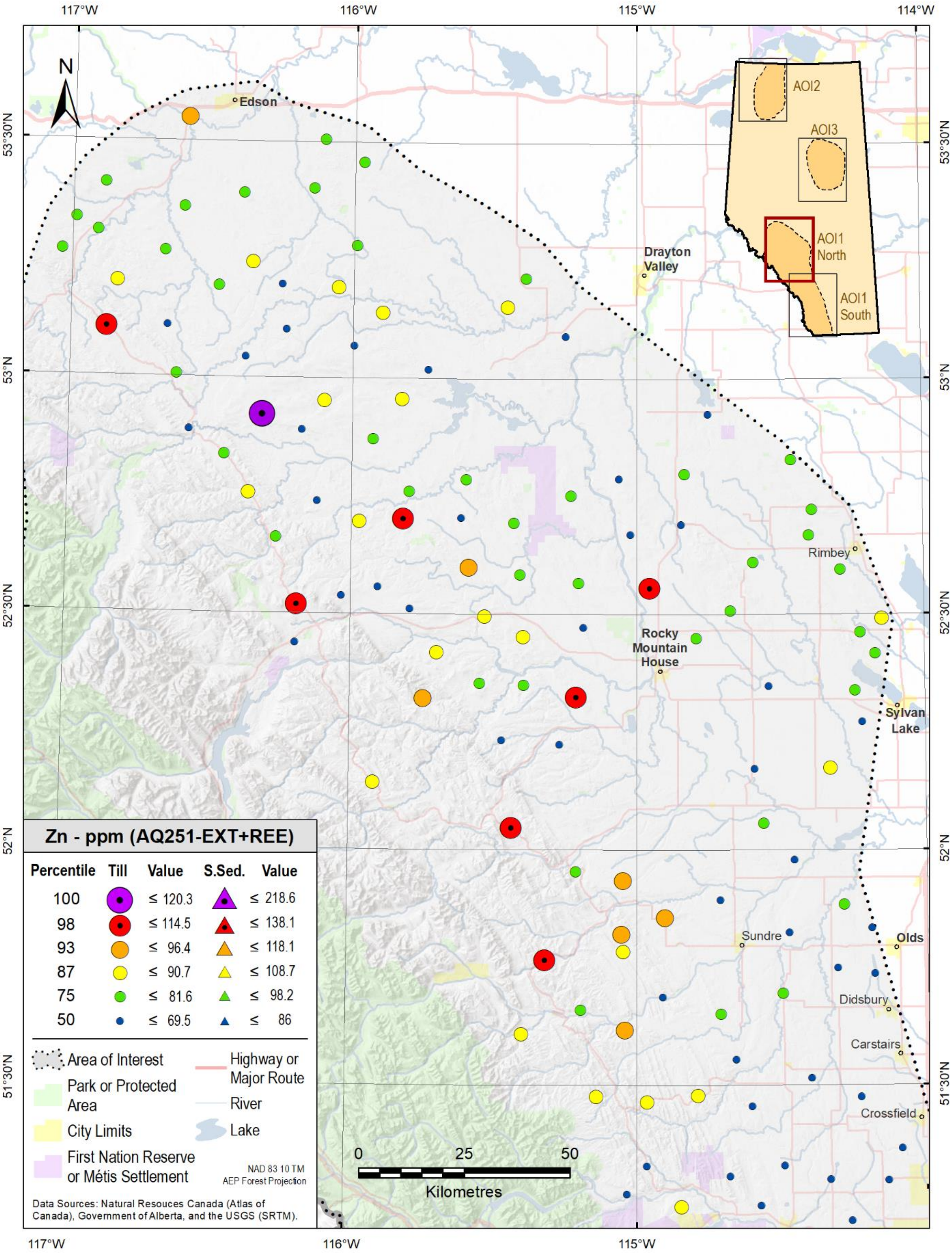


Figure 77. Zinc (Zn) concentrations in till in the northern half of AOI-1.

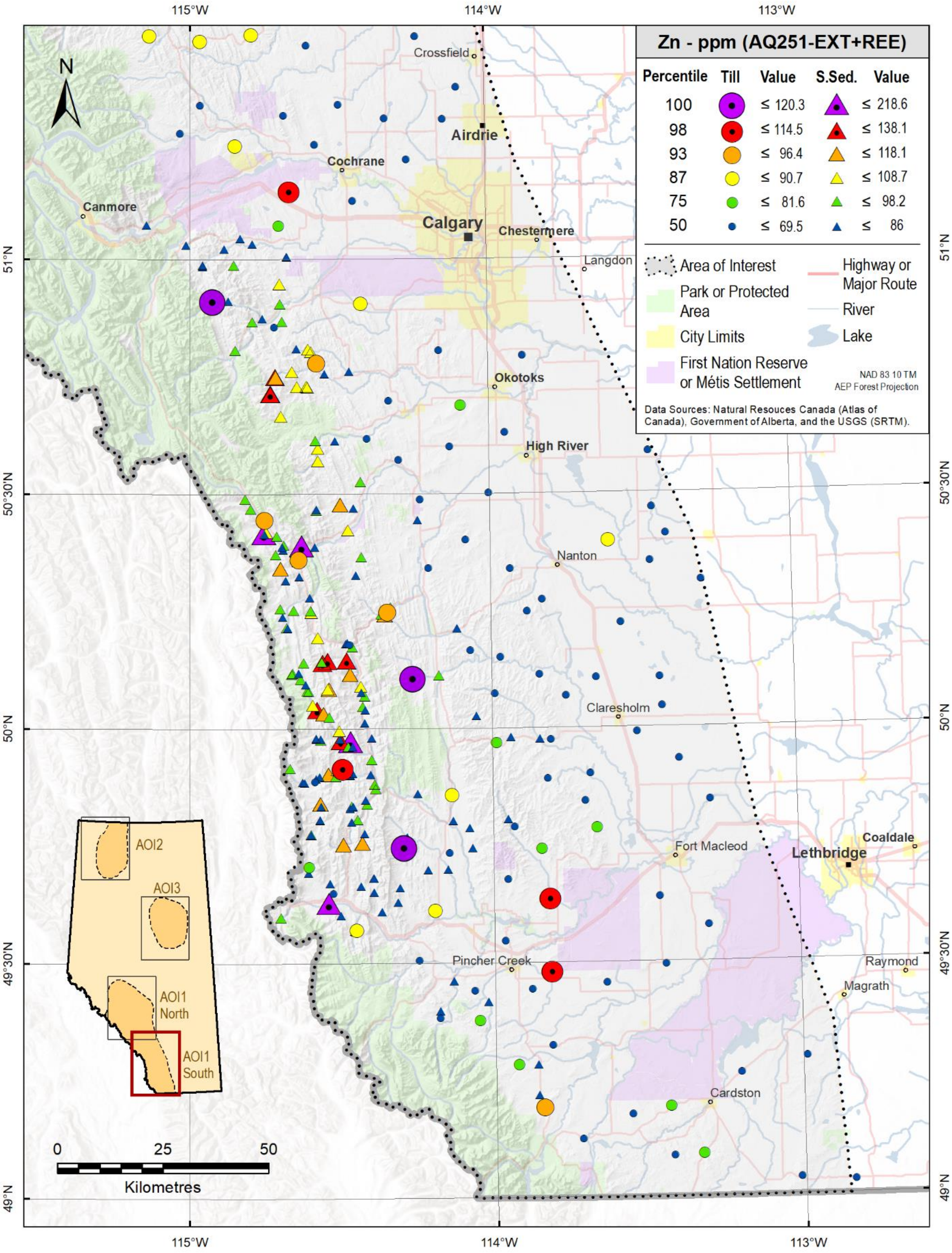


Figure 78. Zinc (Zn) concentrations in till and stream sediments in the southern half of AOI-1.

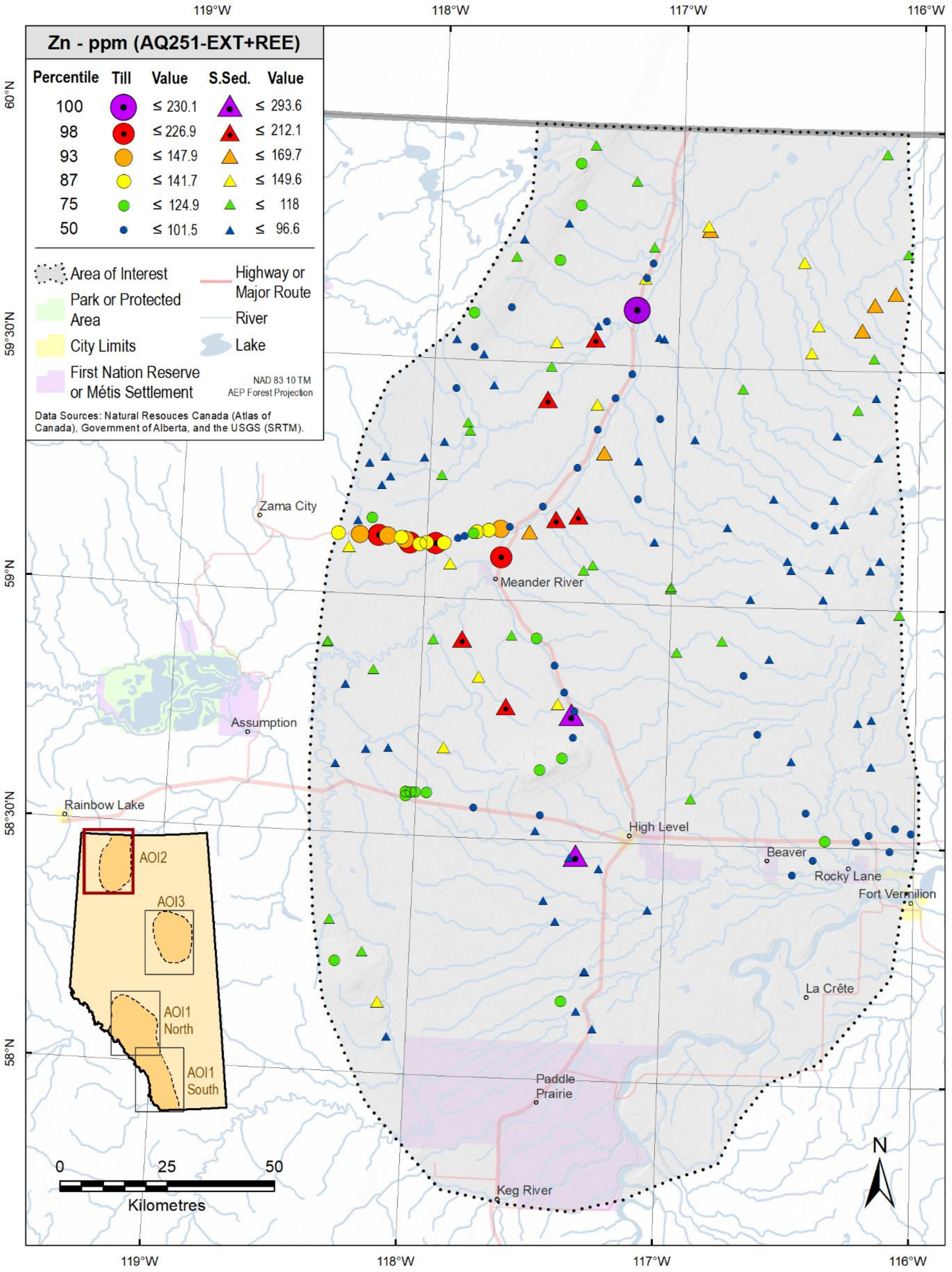


Figure 79. Zinc (Zn) concentrations in till and stream sediments in AOI-2.

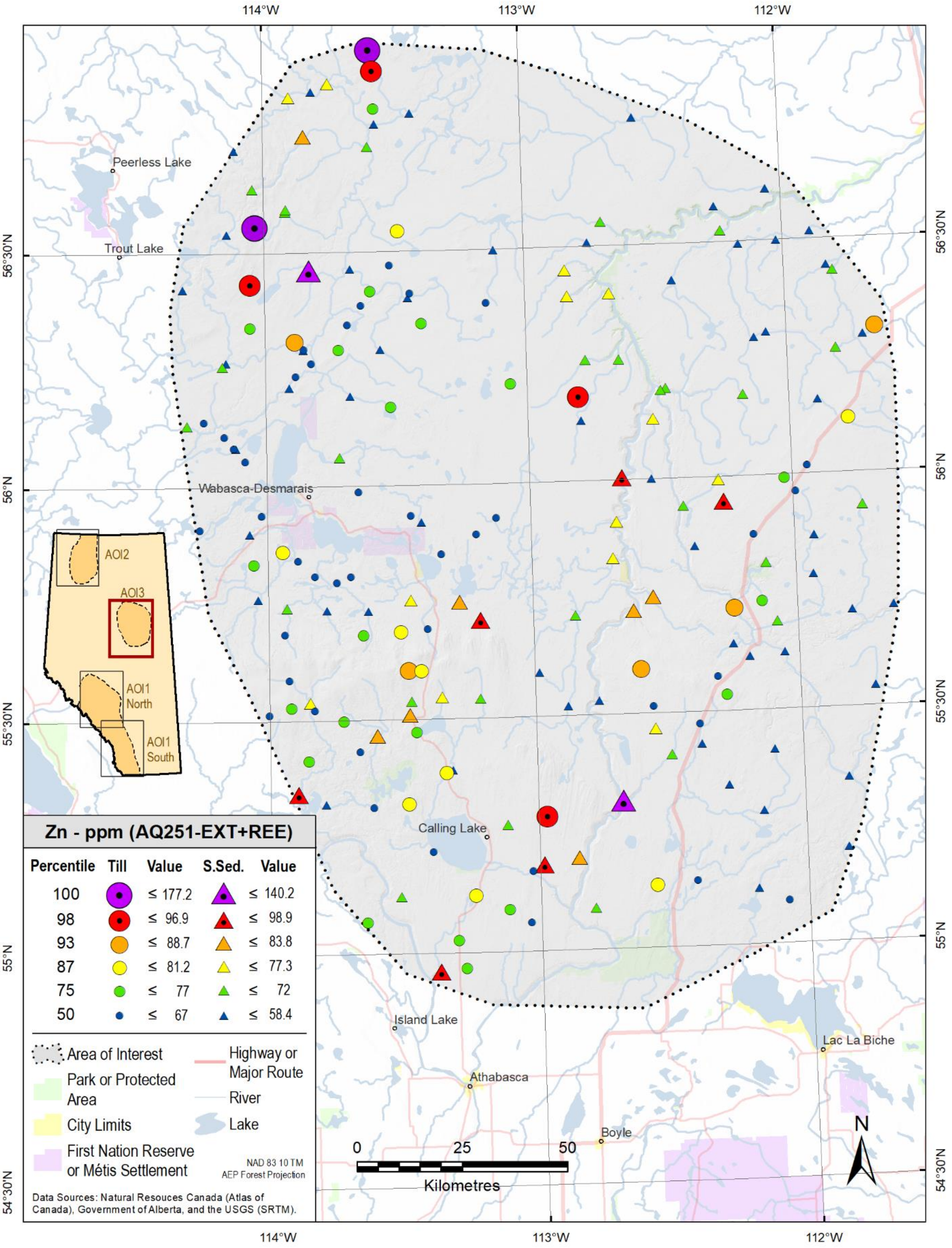


Figure 80. Zinc (Zn) concentrations in till and stream sediments in AOI-3.

3.4.2 Mineralogy

Concentrations of select minerals related to mineralization are provided in Figures 81-83. Symbology is directly proportional to the grain counts normalized to 10 kg <2 mm table concentrate weight. These data presentations are for illustrative purposes only. Mineral concentrations in till samples from AOI-2 and AOI-3 are very low compared to those in AOI-1. This is due to the fine-grained nature of the tills in the northern part of Alberta. Larger sample sizes are required in these areas to recover more practical concentrations of mineral grains.

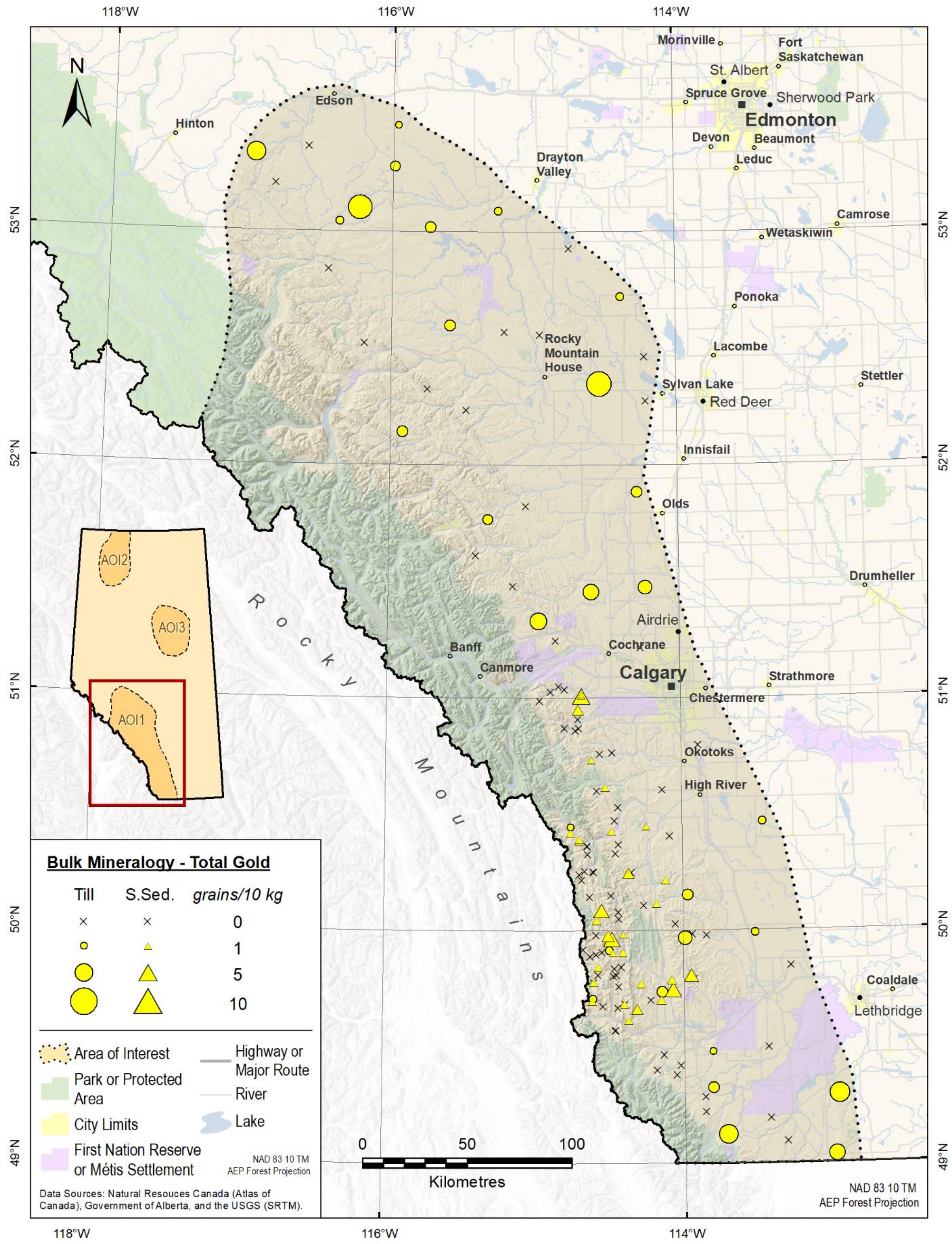


Figure 81. Gold grain concentrations for till and stream sediment samples normalized to 10 kg of the <2 mm size fraction.

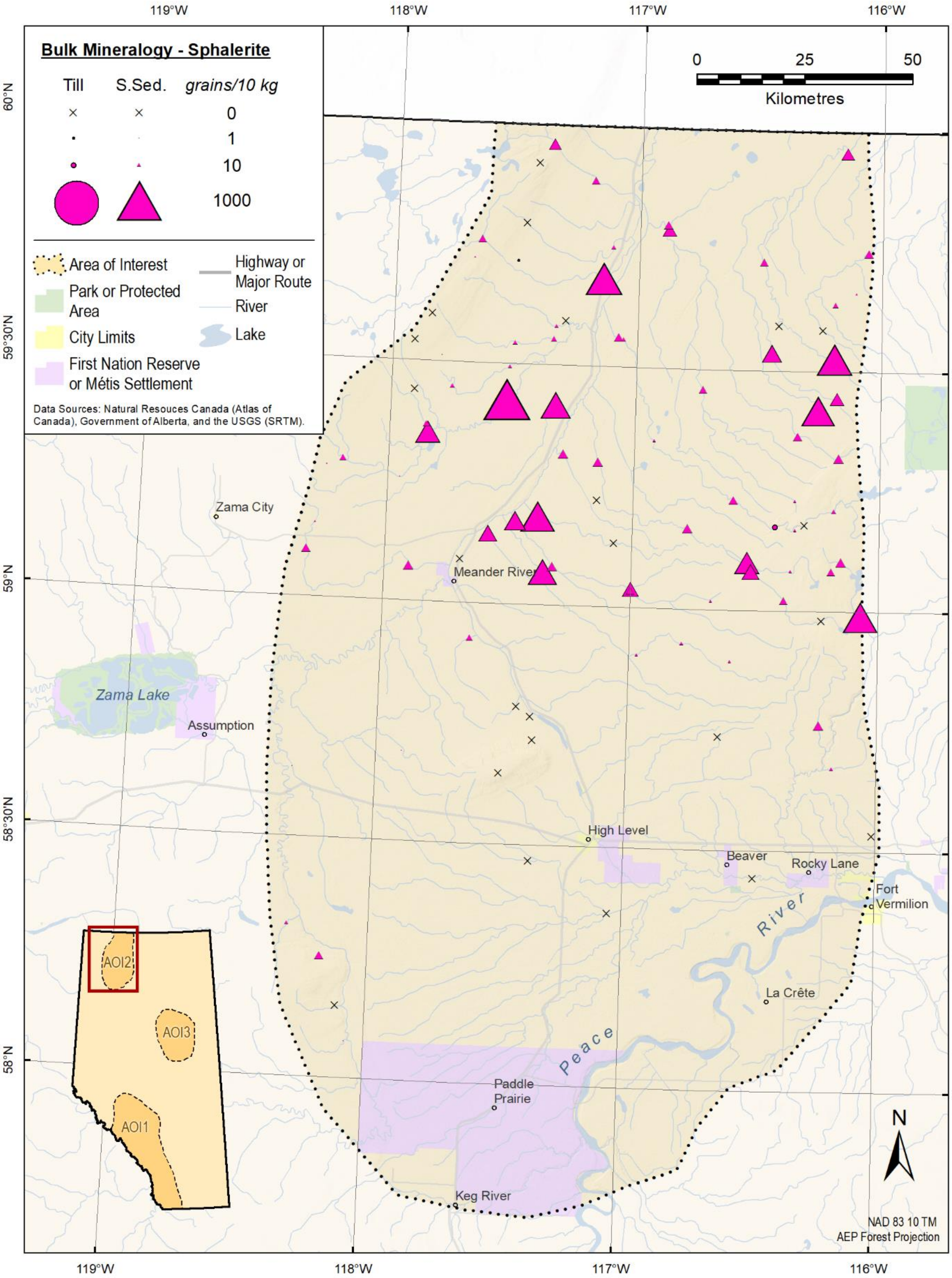


Figure 82. Sphalerite concentrations for till and stream sediment samples normalized to 10 kg of the <2 mm size fraction.

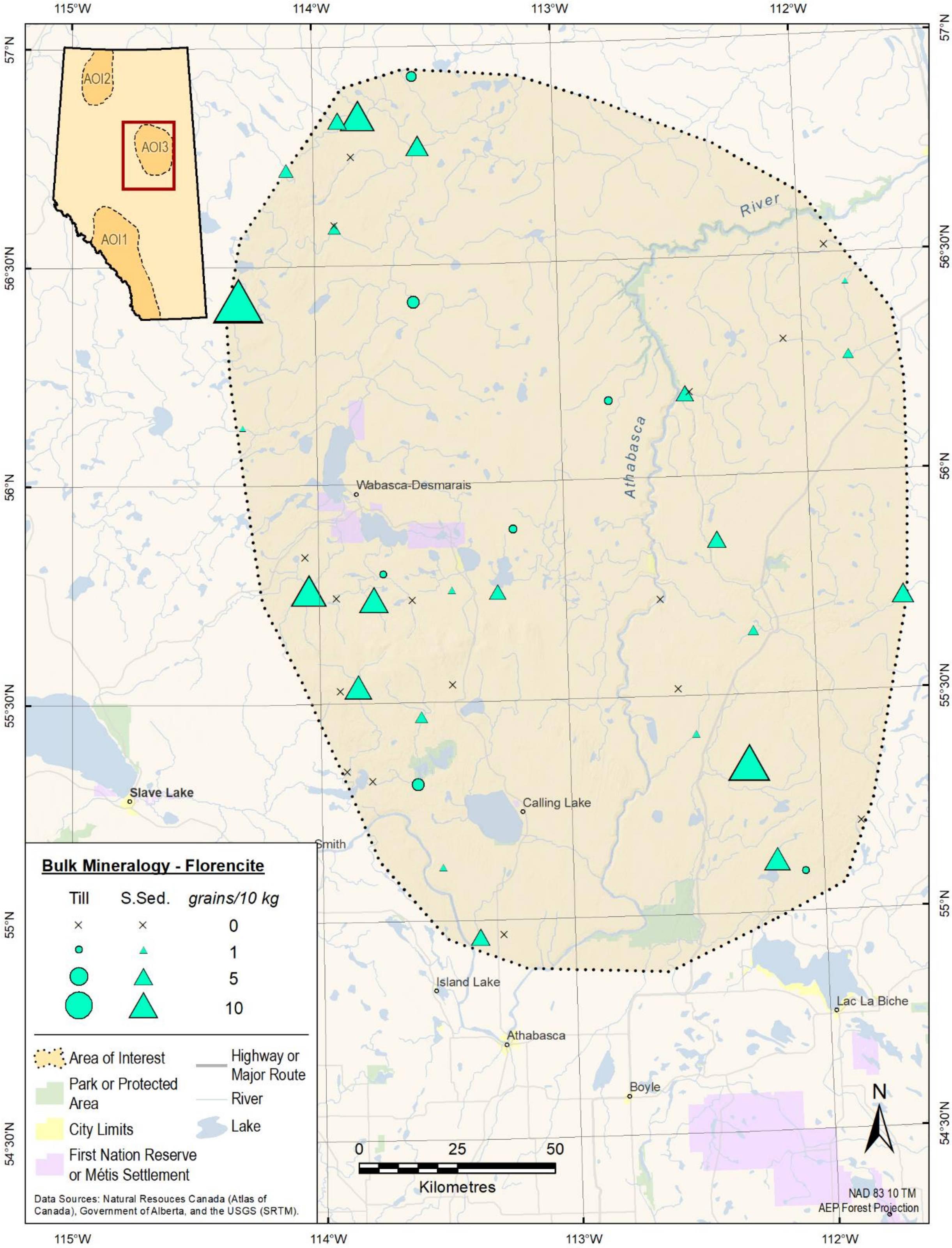


Figure 83. Florencite concentrations for till and stream sediment samples normalized to 10 kg of the <2 mm size fraction.

3.4.3 Grain-Size Analysis (Till Samples Only)

The results of the grain-size analysis exhibit three groupings that may be related to the specific characteristics of each AOI (Figure 84). AOI-1 shows the largest spread in matrix composition, which likely reflects the various sediment source areas. Sandier samples are likely derived from the Rocky Mountains and were probably transported by the Cordilleran Ice Sheet, while siltier samples are more likely associated with sedimentary packages in the plains regions of Alberta that were deposited by the Laurentide Ice Sheet. Samples from AOI-2 have a dominantly sandy-mud composition, likely reflective of the numerous fine-grained and poorly lithified sedimentary lithologies present in the central plains. The composition of these samples may also be affected by the integration of pre-existing silt and clay deposits into the subglacial bedload. Fenton *et al.* (2006) observed silt and clay below till in drill core near AOI-2 that could have been entrained during glacial advance. Samples from AOI-3 show the tightest grouping, straddling the sandy-mud and muddy-sand categories. Again, these results are most likely a reflection of relatively consistent ice-flow deriving sediment from fine-grained sedimentary rocks.

A number of samples from AOI-1 and AOI-3 have sand concentrations near 80%, which are likely a function of local bedrock lithology, but could also indicate that the material has been slightly reworked by post-depositional processes resulting in the winnowing of the silt and clay component. On the other end of the spectrum, some samples in AOI-2 and AOI-3 have very high concentrations of silt and clay with less than 10% sand. Again, this may be a function of the local bedrock, but these tills could be associated with glaciolacustrine sediments, potentially being sampled from a gradational contact between till and the overlying glaciolacustrine mantle, or the till may be a product of an ice readvance that overran glaciolacustrine material and diluted the subglacial bedload with silt and clay. Regardless of the mechanism causing these compositional outliers, analytical results from samples that have heavily skewed grain size concentrations may not be directly comparable to the rest of the dataset.

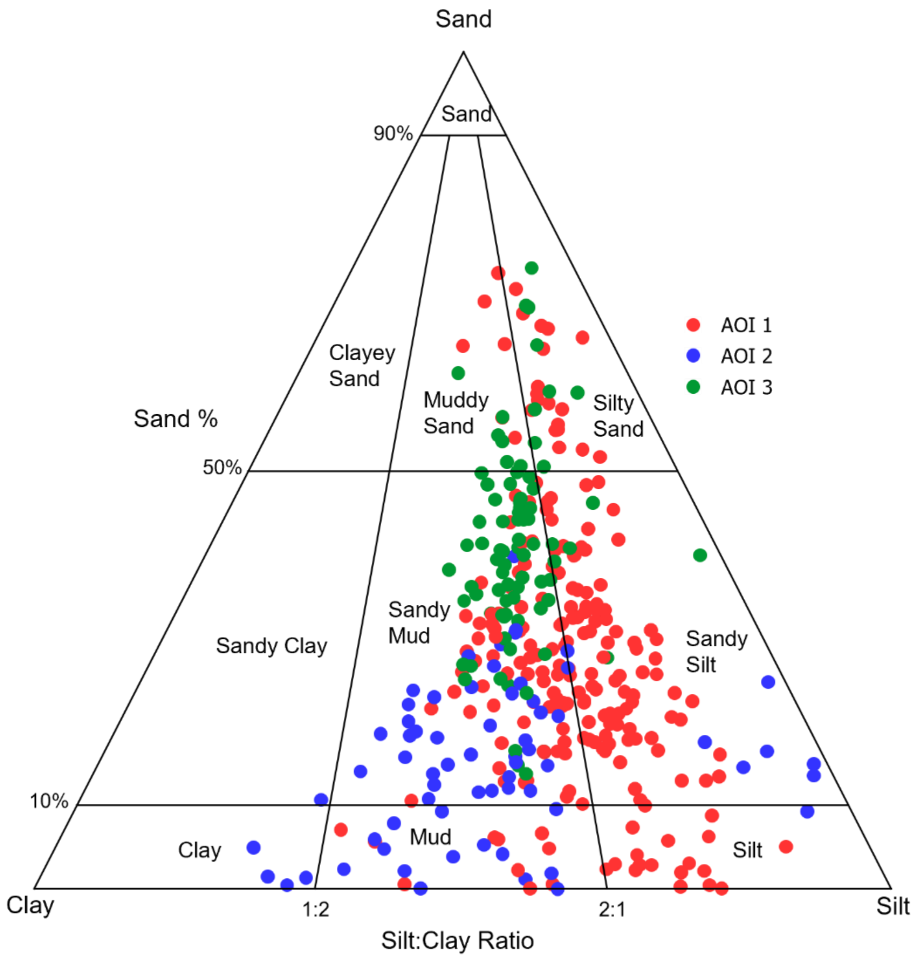


Figure 84. Ternary diagram showing the percentage of sand, silt, and clay in the till matrix, following Folk's (1954) classification.

4. Conclusions

A critical component of Alberta's Minerals Strategy and Action Plan is to inform future regulatory decisions, unlock critical information to inform industry operations, and support non-industry stakeholders with their understanding of minerals in the province. AER is contributing to this plan through its Mineral Mapping Program, which, amongst other initiatives, aims to generate high-quality and comparable regional-scale geochemical and mineralogical data that builds upon the existing publicly available datasets.

This ambitious till and stream sediment sampling program was completed, from survey planning to the release of analytical results, in roughly six months and generated new data for a large portion of the province that is largely underexplored. Over 1350 new till and stream sediment samples were collected analysed using methods that conform to strict quality control specifications and have resulted in the production of a comprehensive geochemical and mineralogical dataset.

The till sampling program achieved good coverage through most accessible areas; however, there are still numerous opportunities to improve coverage in the northern AOIs by utilizing the existing network of seismic lines. The pilot drill-supported till sampling program demonstrated that purpose-built, shallow-drilling technology can be used to efficiently collect till samples in areas where standard pick-and-shovel approaches are inadequate. The equipment extends sampling opportunities to areas where glaciolacustrine deposits hinder till sampling. In addition, the versatility of the equipment allows for year-round data collection, either on tracks in the winter or mounted on an amphibious vehicle in the summer. The stream sediment sampling program was also very successful, achieving excellent coverage in the areas where stream sediment sampling is applicable. Additional sampling opportunities likely exist from higher-order streams, which should be targeted for follow-up work in anomalous catchments.

The combined datasets cover the majority of the AOIs and provide a comprehensive dataset that can be used by exploration companies and others to further their exploration goals. Targets generated through the evaluation of these data will likely attract investment to the province and stimulate interest in Alberta’s mineral potential, achieving the goals set out in the province’s Minerals Strategy and Action Plan.

5. Acknowledgments

This program was funded entirely by AER. Palmer would like to thank Aurora Geosciences Ltd. for its exceptional contributions to the planning of this ambitious program and for providing a capable field assistants and field equipment. A special thanks is owed to W. Jackaman at Noble Exploration Ltd., who drew on his many years of experience to help plan the stream sediment sampling program and orient and train each stream sediment sampling crew. We would also like to give a big thank you to Anomalous Exploration Ltd., H. Bains and J. Constandinou for their support in the field and to the entire field crew whose willingness to “dig just a little bit deeper” helped to ensure the quality of the samples. Reliable helicopter support was provided by Whitesaddle Air Services, Delta Helicopters and Mustang Helicopters. Lastly, we appreciate the assistance provided by the team at AER and AGS, who was always available to provide support, guidance, and useful information throughout the program.

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Appendix A

Till and stream sediment analytical results

Provided separately as:

A1 TILL GEOCHEM.xlsx

A2 TILL MINERALOGY.xlsx

A3 Till analytical results spatial

A4 STREAM GEOCHEM.xlsx

A5 STREAM MINERALOGY.xlsx

A6 Stream analytical results spatial

A7 Till and Stream analytical text files

Appendix B

Till and stream sediment analytical certificates

Provided separately as:
B1 Till Geochemistry Lab Certificates
B2 Till and Stream Sed Mineralogy Lab Reports
B3 Till Grain Size Analysis Lab Reports
B4 Stream Sed Geochemistry Lab Certificates
B5 Mineralogy Quality Control Results.pdf

Appendix C

Surficial Geology Field Observations

Provided separately as:
C1 Surficial Geology Observations