

GS-20 Preliminary results of soil geochemistry surveys in support of shallow gas exploration, Manitou area, Manitoba (NTS 62G2) by M.A.F. Fedikow¹, R.K. Bezys², M.P.B. Nicolas and P. Prince³

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Summary

The Mobile Metal Ion (MMI®) analytical procedure is a surficial geochemical exploration tool that was used to assess its value in exploring for unconventional shallow shale gas reservoirs. An old capped gas well situated southwest of the community of Manitou, Manitoba, was chosen as the test site. Results from multi-element geochemistry surveys conducted along a north transect centred on the old gas well suggest that MMI technology can be used for this type of hydrocarbon exploration.

Introduction and application to hydrocarbon exploration

Surficial geochemical exploration has a long and varied history in its application to the search for petroleum. Much of this exploration has been directed towards the surface or near-surface occurrences of hydrocarbons. The hydrocarbons may present themselves as surface seeps of visible oil and gas (macroseeps) or as traces of hydrocarbons determined by sophisticated analytical methods (microseeps). Much of the current geochemical exploration focuses on the collection and analysis of soil gases and the integration of the chemical expression of hydrocarbon microseepage with geological and geophysical (seismic) databases. Based on historical precedent, the seismic approach is unsurpassed for the definition of oil and gas reservoirs. Surficial geochemical techniques can fingerprint metals associated with hydrocarbon microseepage from the same reservoirs and identify productive versus nonproductive reservoirs or seismic targets.

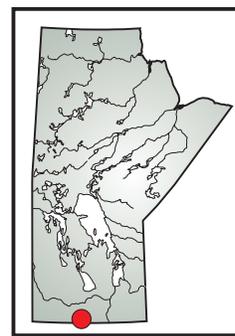
The approach to surficial geochemical exploration combines appropriate sampling and analytical technologies with interpretive strategies. The goal is to identify the geochemical signature of buried and blind sources of hydrocarbons, including their alteration haloes or distinctive geochemical fingerprint. The approach can be used to reassess active fields for extensions of known resources, or to delineate bypassed resources of oil and gas in exhausted oilfields. It can also be used to evaluate seismic targets for their prospectivity or pioneer areas for their oil and gas potential.

The trace element content of petroleum, natural gas, associated brines and coal has been established by

sophisticated analytical procedures undertaken by hydrocarbon producers and the academic community. These trace element contents or fingerprints can be used to differentiate and characterize hydrocarbons originating from oilfields in different geological environments. In effect, the various hydrocarbon reservoirs represent metal sources of variable geochemical characteristics, i.e., they contain different trace elements in varying amounts. These same trace elements can also be used to define exploration targets by measuring their concentrations in near-surface soils subsequent to ligand-based partial extraction – a new and innovative approach to geochemical exploration. This technique is referred to as Mobile Metal Ion (MMI) Process® technology.

Mobile metal ion is a term used to describe ions that have moved from buried metal sources to near-surface environments, where they become weakly or loosely attached to the surface of soil particles. These are the ions that are measured by the MMI geochemical technique to target metal sources at depth. The weakly attached ions are at very low concentrations in soil. Because the ions have recently arrived at the surface they provide a precise signal on where the sources of metal/hydrocarbons are located. When the mobile metal ions arrive in the near-surface environment they have a limited lifetime as mobile ions. At the surface, the ions are subject to weathering and are bound up by soil-forming processes (i.e., they become part of the soil during pedogenesis). Bound ions are subject to lateral movement away from the source region. The mobile ions, however, do not move away from the metal source because they do not have time to move before they are converted to a bound form.

By measuring mobile metal ions in surface soils, the MMI technology and additional related geochemical determinations can document the presence of focused apical responses (anomalies) directly over the source regions. The source may be any accumulation of metals that is in contrast with surrounding rocks, such as oil and gas within reservoirs and coal. Chemical analysis of petroleum has documented characteristic trace elements within the oil and its surrounding hostrocks. These trace elements will move to the surface and be indicative of a



¹ Mount Morgan Resources Ltd., P.O. Box 629, 50 Dobals Road North, Lac du Bonnet, Manitoba R0E 1A0

² Wildwood Geological Services, 627 Manchester Blvd. North, Winnipeg, Manitoba R3T 1N9

³ SGS Mineral Services, 1885 Leslie Street, Toronto, Ontario M3B 2M3

buried hydrocarbon accumulation. Regardless of the type of metal-enriched zone at depth, metal ions that comprise that zone will be mobilized to the surface under a variety of mechanisms. These include vapour-phase transport by light hydrocarbon gases, Hg vapour and carbon dioxide; convection; diffusion; evapotranspiration; and electrochemical mechanisms (Mann et al., 2005).

The relative importance of each of these mechanisms depends on the nature of the source region, presence of plumbing systems to channel metal-rich gases, depth to the water table and numerous other variables. However, research and case studies over known metal/hydrocarbon-bearing zones have shown that mobile metal ions and additional compounds accumulate in surface soils above these metal sources. Hydrocarbons that are present in the subsurface also leak from their structural and stratigraphic traps and move upward to the surface or along geological pathways. Hydrocarbons can move vertically through thousands of metres of rock, without obvious fractures or faults, in a period spanning weeks to years. Hydrocarbon microseepage has been documented at less than one to tens of metres per day (Schumacher, 1996). This is evidence for an ongoing and dynamic geochemical system. Published studies document zoned mineralogical and geochemical haloes that have developed in association with plumes above oil and gas reservoirs (cf., Sikka and Shives, 2002).

In this initial study, an orientation soil geochemical survey was undertaken near Manitou in southwestern Manitoba (Figure GS-20-1) to assess a shallow gas target area for indications of geochemical responses. This report describes the results to date and presents a framework for future studies in the province.

A schematic model of elements that are ascending from a buried hydrocarbon source (under the effect of light hydrocarbon gases) and the subsequent geochemical and mineralogical changes effected by this process are presented in Figure GS-20-2.

Geological setting and gas exploration

The Pembina Hills and Pembina Valley region is located in southwest Manitoba, west of the Manitoba Escarpment on the Second Prairie Level. Representing the northeastern edge of the Williston Basin, the Cretaceous strata is approximately 320 m thick in the Pembina Hills region, and has a southwesterly dip of 1.5 to 1.9 m/km. It consists of the basal sandstone of the Swan River Formation, with overlying shale sequences of the Ashville, Favel, Carlile formations and Pierre Shale (Nicolas and Bamburak, Figure GS-17-1, this volume). Jurassic, Triassic and Paleozoic strata underlie the Cretaceous sequence, and extend east beyond the Manitoba Escarpment. Cretaceous shale is near-surface in many parts of the Pembina Hills region, outcropping along the Manitoba Escarpment and in the Pembina Valley. The grey siliceous shale of

the Odanah Member of the Pierre Shale forms the cap for the Pembina Hills, and the black, noncalcareous shale of the Pembina Member of the Pierre Shale forms the base of the Pembina Valley. Nicolas (2008) and Nicolas and Bamburak (GS-17, this volume) discuss the lithology, mineralogy and geochemistry of these Cretaceous shale sequences in more detail.

Gas occurrences in the Cretaceous shale have been documented in the Pembina Hills region for over a century. In the Manitou area, natural gas was first discovered in 1907 during early gas exploration activities in Twp. 2, Rge. 9, W 1st Mer.; exploration continued until ca.1936. A detailed discussion of historical and modern day exploration for shale gas in Manitoba is discussed in Bamburak (2008) and Nicolas (2008), respectively. Two known capped gas wells are still present today and have reservoir pressures of about 276 kPa (Bamburak, 2008) and methane concentrations of over 85% (Nicolas and Grasby, GS-18, this volume). The gas reservoir in this area is estimated to be between 180 and 200 m below surface (approximately 230 m asl). The natural gas reservoir in the Manitou area is likely from the Assiniboine Member of the Favel Formation, but the possibility of the gas seeping in from the underlying Belle Fourche Member of the Ashville Formation and the overlying Carlile Formation into the wellbore through the damaged casing of these wells cannot be ruled out.

Sample collection and analysis

Soil samples were collected from hand-dug 40 cm deep pits along a north-trending transect, shown in Figure GS-20-1. Sample stations are centred on a shallow gas occurrence described in Bamburak (2008) and Nicolas and Grasby (GS-18, this volume), with pits dug at variable intervals along the transect to avoid anthropogenic contamination, such as fences and farm equipment (Figure GS-20-3 and -4).

At each pit, four samples were collected at 10 cm intervals along one wall of the pit. This sampling approach is designed to assess the upper 40 cm of the soil profile for the presence of vertical differentiation of metals in an ascending metal-rich plume. The results of this type of sampling will determine at what level in the soil profile metals reach their maximum and most representative concentrations, and therefore the location of the optimum sampling position.

Approximately 200 g of soil were collected from four positions in each of 25 pits along the transect. Two pits were dug at one of the 24 sampling sites. The transect has a total length of 512 m and is centred on the shallow gas occurrence described above. Sample locations were noted with a hand-held GPS in NAD 83, Zone 14. Bagged samples were shipped to SGS Mineral Services laboratories in Toronto, Ontario, for analysis by inductively coupled plasma–mass spectrometry (ICP-MS) to determine

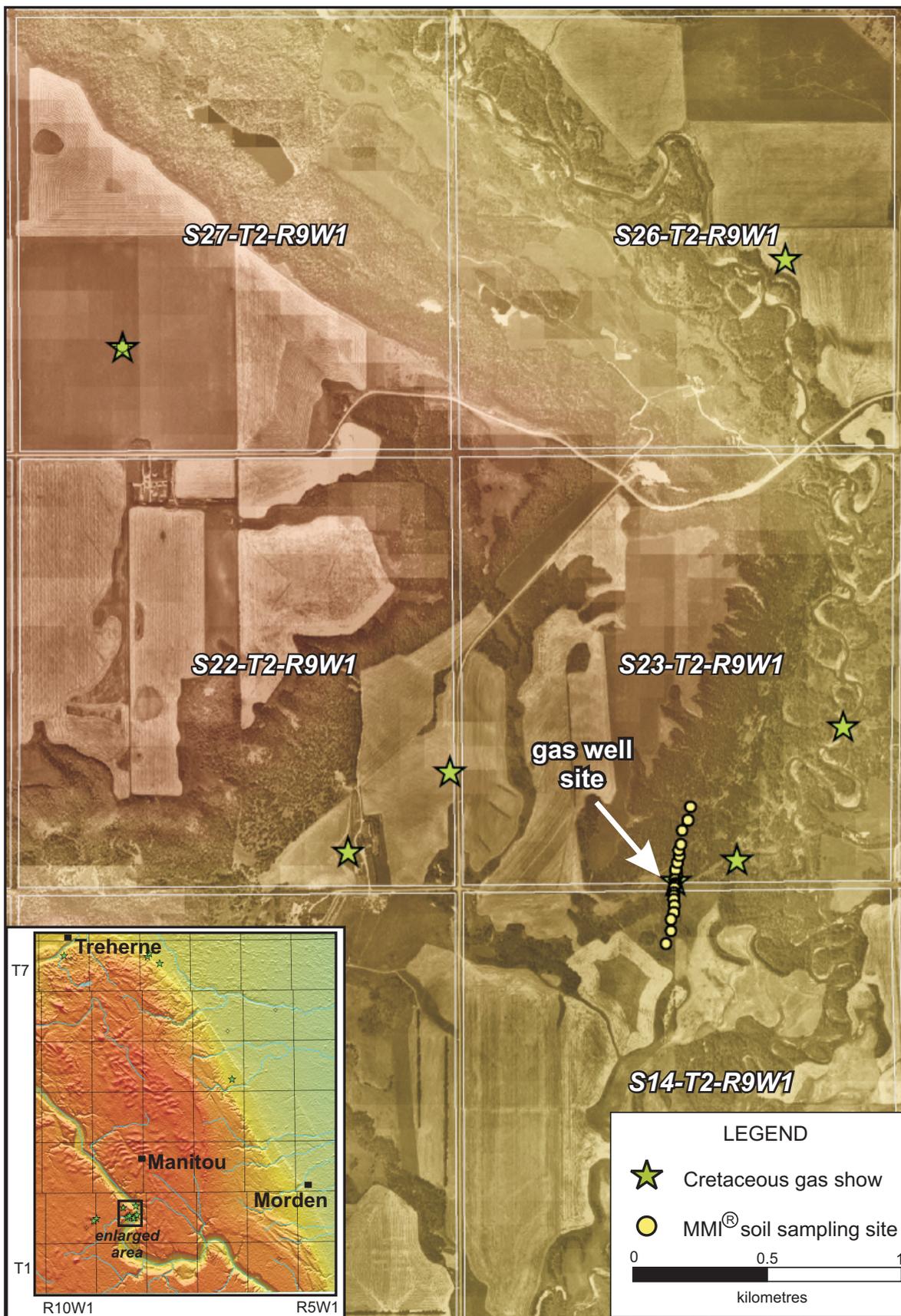


Figure GS-20-1: Digital elevation model overlain by orthophotographs showing the location of the Manitou shallow-gas, geochemical, soil-sampling transect, southwest Manitoba.

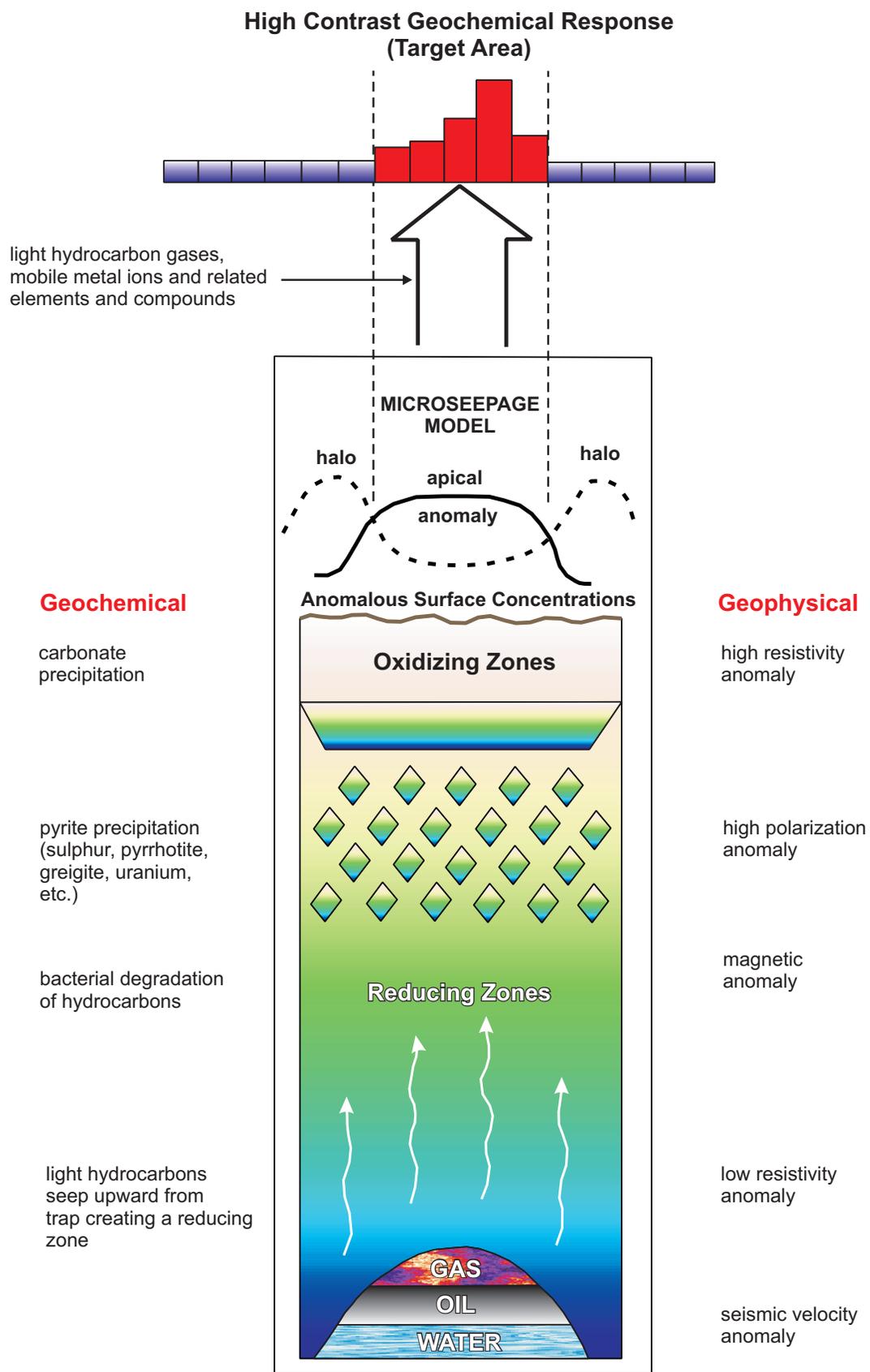


Figure GS-20-2: Microseepage model showing ascension of light hydrocarbon carrier gases from a buried hydrocarbon source and the subsequent geochemical and mineralogical changes effected in the ascension column (modified after Schumacher, 1996).



Figure GS-20-3: Sampling protocol for the Manitou shallow gas MMI® soil geochemical orientation survey, Manitoba. Individual 10 cm samples are denoted between each marker. Four samples are collected from each pit in this manner (0–10 cm, 10–20 cm, 20–30 cm and 30–40 cm).

45 elements, at part per billion and sub-part per billion concentrations, subsequent to Mobile Metal Ion–multi-element enhanced (MMI-ME) partial extraction. Additional parameters measured on the soil samples included I, Br, Cl, Hg, S and pH. Br, I and Hg were analyzed as part of the Mobile Metal Ion–multi-element (MMI-M) package. Calibration standards containing 1000 and

5000 µg/L Br, 100 and 500 µg/L I and 10 and 50 µg/L Hg were prepared from serial dilutions of 1000 µg/L individual standard solutions (supplied by Inorganic™ Ventures, Inc.) in MMI-M solution. Sulphur was measured at the same time as the other ICP-MS elements using Dynamic Reaction Cell™ (DRC™) ICP-MS. The sulphur is reacted with oxygen gas and measured as SO⁺ at mass 50 in order to remove interferences. The instrument was calibrated using 10 and 50 µg/L S standards prepared in MMI-M solution from serial dilution of a 10 000 ppm S standard solution. Chloride was analyzed by fusing a 0.2 g sample of chloride with KOH + KNO₃ and the melt dissolved in dilute HNO₃. The solution was mixed online with an equal volume of ammonium citrate. The chloride concentration was measured by the chloride ion-selective electrode using Lachat Instruments' QuikChem® flow injection analyzer.

For the determination of pH, a 50 g of sample was mixed with distilled water and the pH measured with an Orion 720 pH meter.

Results

Results of the analysis of inorganic soils collected along the sampling transect are presented in two ways. First, the data is presented as vertical profiles for samples collected from top to bottom of an individual sample pit to demonstrate where metals are being concentrated in the upper 40 cm of the soil profile. The sample pit chosen to assess vertical differentiation of metals occurs directly over the site where the shallow gas is venting and where a wellhead is located. Secondly, data is also presented as X-Y box plots to demonstrate the variability of metals along the sample transect at the high-contrast, geochemically anomalous, sample depth, where the most representative responses are developed.



Figure GS-20-4: Soil geochemical sample being dug in a wheat field south of the gas wellhead, Manitou, Manitoba. The Pembina Valley is in the background (looking southwest).

Vertical profiles and vertical differentiation

The variations in concentration of metals in the sample pit, established directly over the shallow gas occurrence, are given in Figures GS-20-5 and -6. Review of these figures indicates that the majority of elements have their maximum concentrations in samples collected between 0 and 10 cm, with a few select elements concentrated in samples from the 30–40 cm depth.

The elements Ca, Co, Ni, Zn, Cd, Mo, Sb, S, Th and Tl have maximum concentrations in the samples collected closest to the surface (0–10 cm depth interval; Figure GS-20-5) and are characterized by a steady, progressive decrease in concentration as sample depth increases. As illustrated in Figure GS-20-6, the elements Cu, Li, Mg, rare earth elements (REE; Dy, Er, Eu, Gd, Tb, Yb) and I are maximized in samples collected from the 30–40 cm

depth interval. These elements gradually increase in concentration between 0 and 40 cm.

These patterns suggest that differentiation in elements occurs through the uppermost 40 cm of the soil profile, even where no obvious changes in soil type occur. At most sample stations, the soil was a featureless, black silt-clay with occasional gritty laminae of platy shale fragments dispersed though the wall of the pit. There were no pedogenic horizons observed in any of the sample pits along the sampling transect.

The vertical sampling exercise documents a slight reduction in soil pH from the top to the bottom of the soil profile: 0–10 cm: 7.11; 10–20 cm: 6.95; 20–30 cm: 6.87; and 30–40 cm: 6.73 (Figure GS-20-5d).

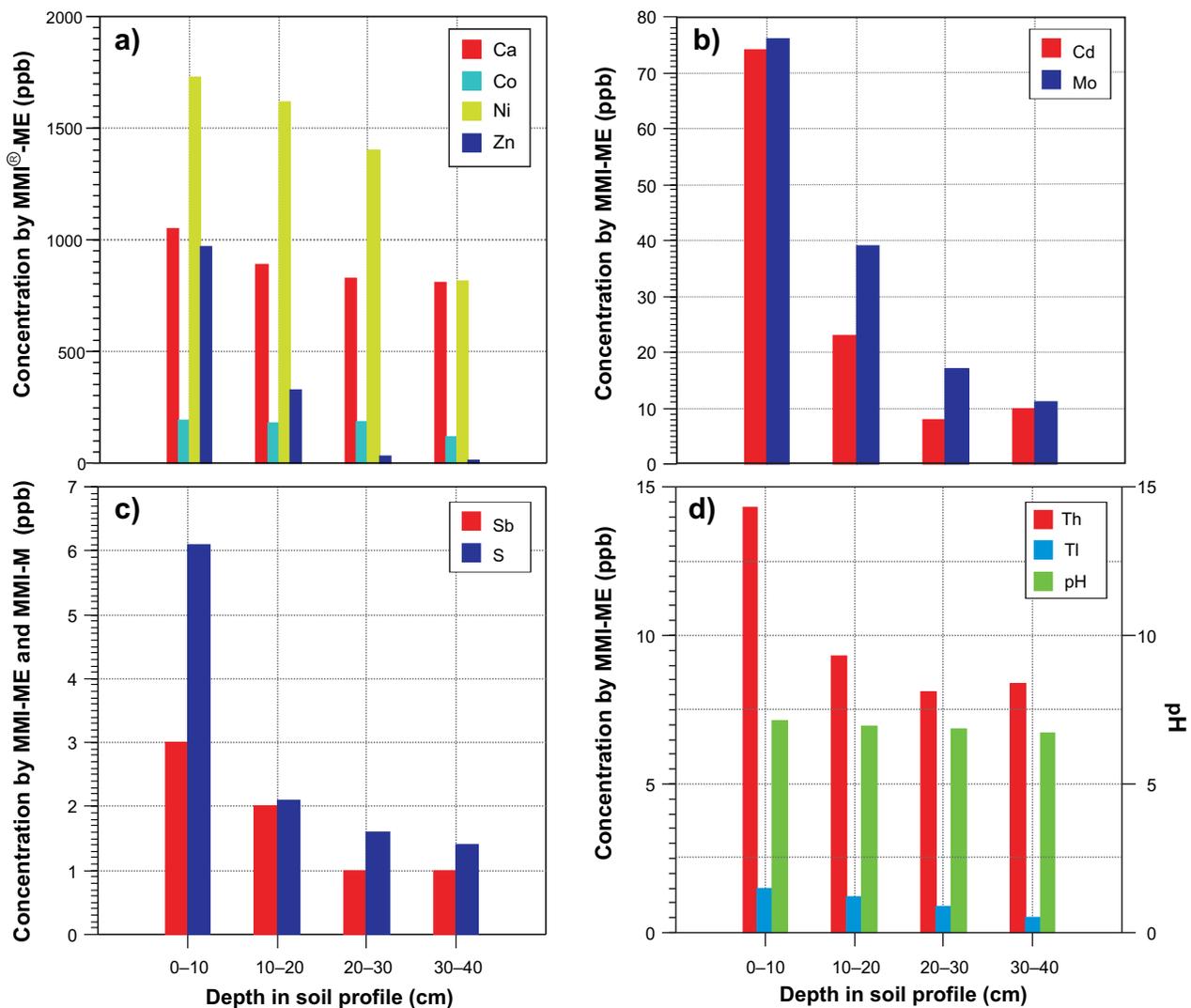


Figure GS-20-5: Vertical differentiation of partial extractable metals in soil geochemical samples collected directly over the Manitou shallow gas occurrence, Manitoba. The elements shown are those with their highest concentrations at 0–10 cm below the organic-inorganic soil interface; **a)** Ca, Co, Ni and Zn; **b)** Cd and Mo; **c)** Sb and S; and **d)** Th, Tl and pH. The location of the gas wellhead is at the 239 m point on the transect and indicated by the red arrow on Figures GS-20-7 and -8. Abbreviation: MMI®-ME, Mobile Metal Ion–multi-element enhanced.

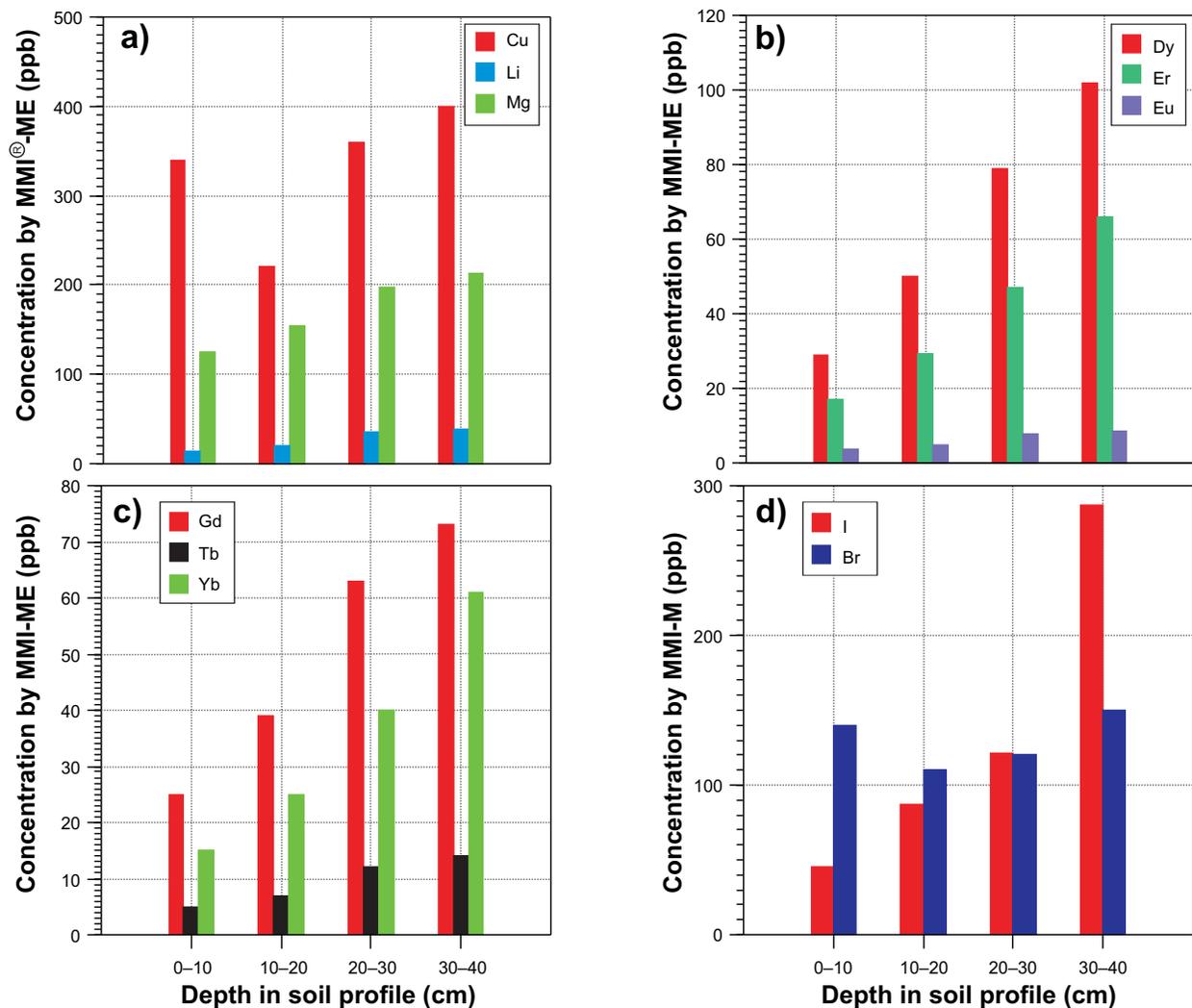


Figure GS-20-6: Vertical differentiation of partial extractable metals in soil geochemical samples collected directly over the Manitou shallow gas occurrence, Manitoba. The elements shown are those with their highest concentrations at 30–40 cm below the organic-inorganic soil interface; a) Cu, Li and Mg; b) Dy, Er and Eu; c) Gd, Tb and Yb; and d) I and Br. The location of the gas wellhead is at the 239 m point on the transect and indicated by the red arrow on Figures GS-20-7 and -8. Abbreviations: MMI®-M, Mobile Metal Ion–multi-element; MMI®-ME, Mobile Metal Ion–multi-element enhanced.

Lateral profiles and responses to shallow gas

Of the four samples collected from each sample pit, the 0–10 cm samples were extracted from the database and plotted along the length of the transect (Figure GS-20-7). In addition, a select number of elements in the 30–40 cm samples appear to be indicative of the presence of shallow gas, and these are plotted in Figure GS-20-8. In each plots of Figures GS-20-7 and -8, the location of the shallow gas vent site is marked with a red arrow. Observations are presented below as a geochemical narrative.

Soil profile interval 0–10 cm (Figure GS-20-7)

Mo: A four-sample, high-contrast anomaly is developed on the transect between 218 and 240 m and is situated directly over and to both the north and south of the gas vent site. There is a subsidiary elevated response that

is of lower contrast between 0 and 141 m at the southern end of the transect where no known vent site exists.

Tl: A three-sample, high-contrast anomaly is centred on the shallow gas vent site, on the transect between 226 and 240 m. There is an equally high-contrast response developed in a two-sample anomaly between 045 and 090 m on the southern portion of the transect. Both Tl anomalies are encapsulated by the Mo anomalies, described above.

Co: A four-sample, high-contrast anomaly, coincident with both the Mo and Tl central anomalies, is developed between 218 and 240 m on the transect and situated directly over the shallow gas vent site. The southern transect is also marked by an elevated Co response between 90 and 141 m, which places this anomalous response adjacent to but outside the Tl anomaly.

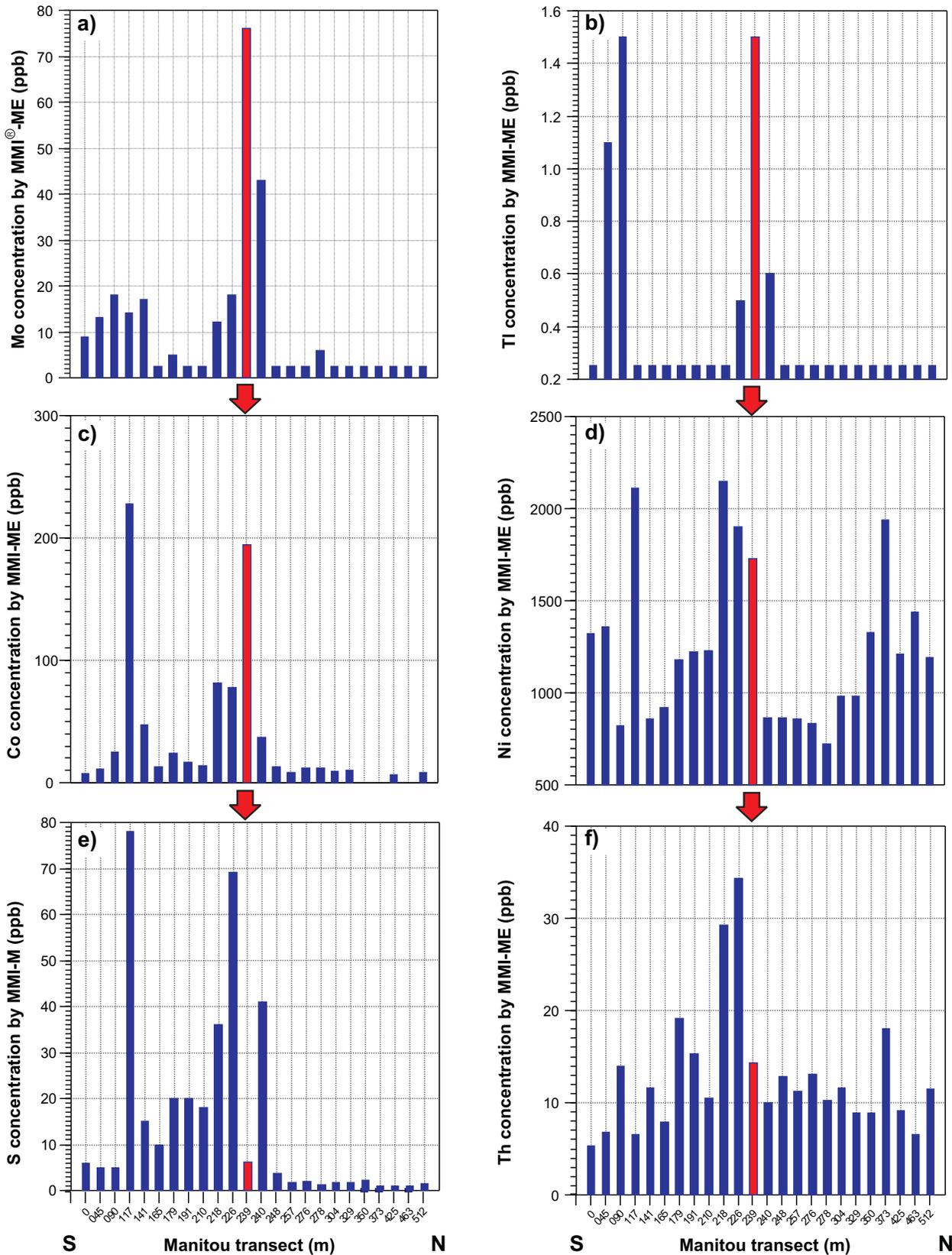


Figure GS-20-7: Lateral variability along the Manitou, Manitoba, sampling transect for elements concentrated in the 0–10 cm depth interval; a) Mo; b) Tl; c) Co; d) Ni; e) S; f) Th; g) Ca; h) Sb; i) pH. The location of the gas wellhead is at the 239 m point and indicated by the red arrow. Abbreviations: MMI®-M, Mobile Metal Ion–multi-element; MMI®-ME, Mobile Metal Ion–multi-element enhanced.

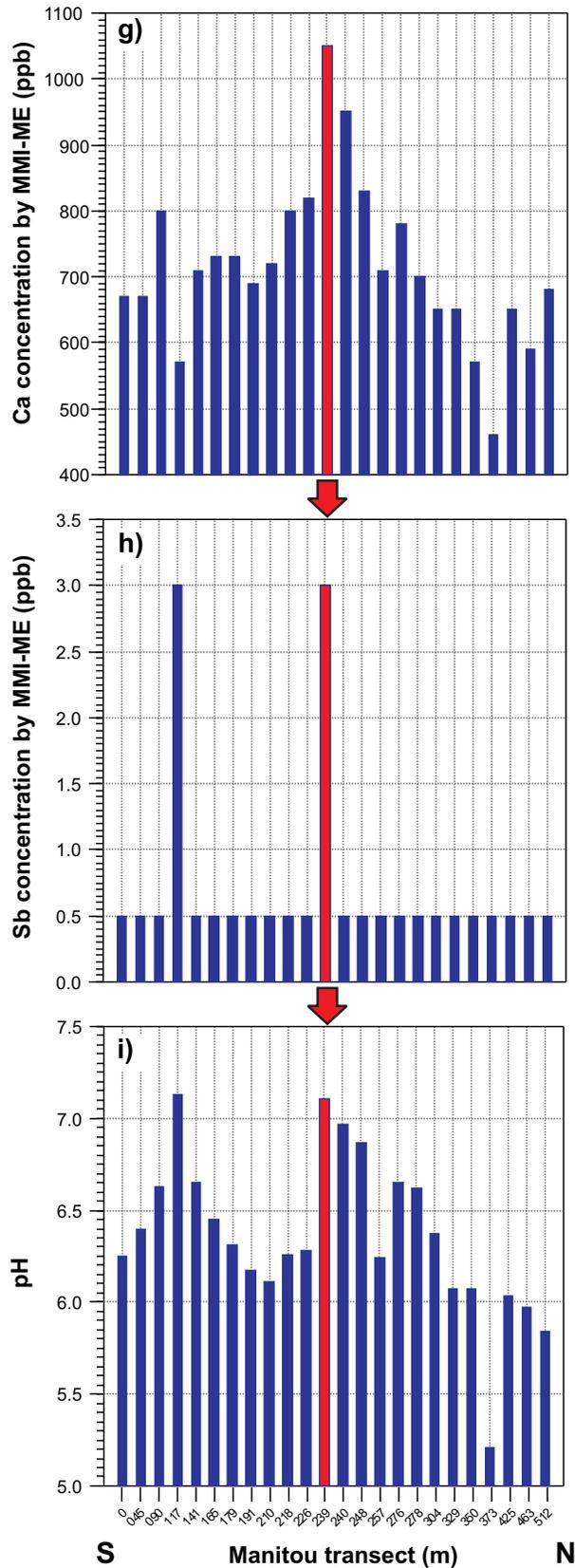


Figure GS-20-7 (continued): Lateral variability along the Manitou, Manitoba, sampling transect for elements concentrated in the 0–10 cm depth interval; **a)** Mo; **b)** Tl; **c)** Co; **d)** Ni; **e)** S; **f)** Th; **g)** Ca; **h)** Sb; **i)** pH. The location of the gas wellhead is at the 239 m point and indicated by the red arrow. Abbreviations: MMI®-M, Mobile Metal Ion–multi-element; MMI®-ME, Mobile Metal Ion–multi-element enhanced.

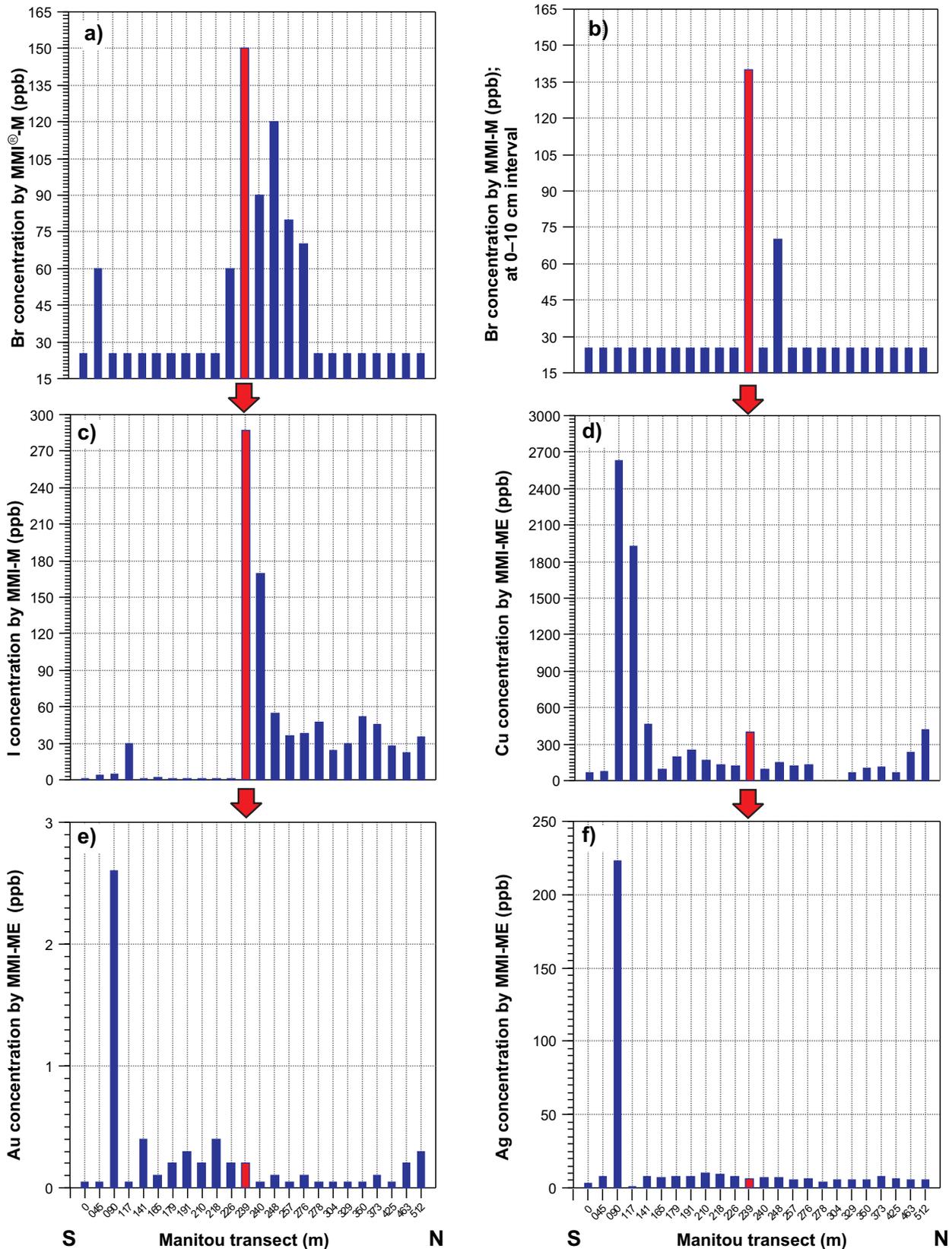


Figure GS-20-8: Lateral variability along the Manitou, Manitoba, sampling transect for elements concentrated in the 30–40 cm depth interval (unless otherwise indicated); **a)** Br; **b)** 0–10 cm Br for comparison with the 30–40 cm profile; **c)** I; **d)** Cu; **e)** Au; **f)** Ag; **g)** Dy; **h)** Er; **i)** Eu; **j)** pH. The location of the gas wellhead is at the 239 m point and indicated by the red arrow. Abbreviations: MMI[®]-M, Mobile Metal Ion–multi-element; MMI[®]-ME, Mobile Metal Ion–multi-element enhanced.

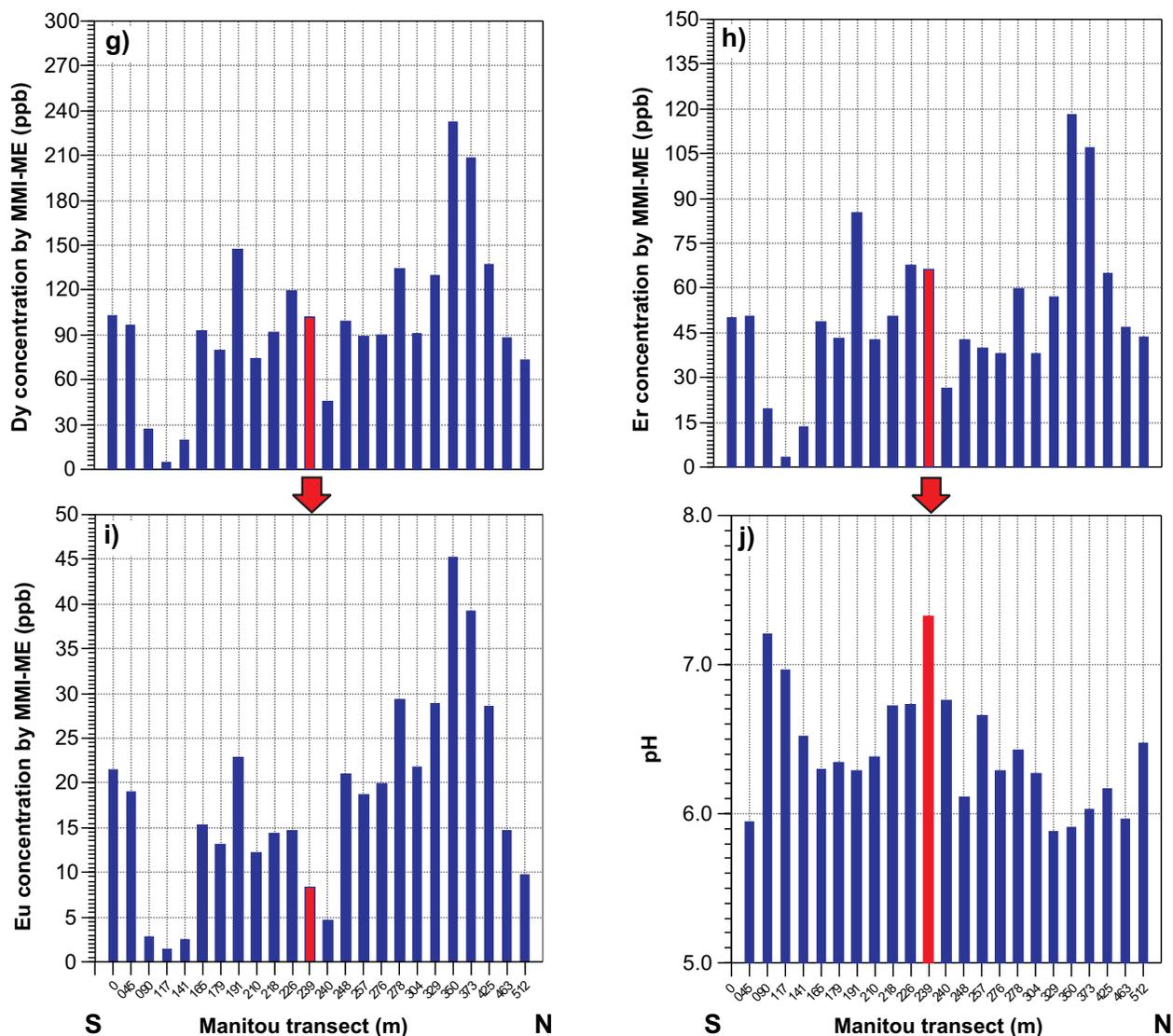


Figure GS-20-8 (continued): Lateral variability along the Manitou, Manitoba, sampling transect for elements concentrated in the 30–40 cm depth interval (unless otherwise indicated); **a)** Br; **b)** 0–10 cm Br for comparison with the 30–40 cm profile; **c)** I; **d)** Cu; **e)** Au; **f)** Ag; **g)** Dy; **h)** Er; **i)** Eu; **j)** pH. The location of the gas wellhead is at the 239 m point and indicated by the red arrow. Abbreviations: MMI®-M, Mobile Metal Ion–multi-element; MMI®-ME, Mobile Metal Ion–multi-element enhanced.

Ni: The Ni responses along the transect are marked by lower-contrast responses but significant Ni concentrations. Patterns document the presence of a three-sample anomaly between 218 and 239 m, developed slightly asymmetric to the gas vent site. Additional elevated responses are present at 0, 045 and 117 m on the southern portion of the transect. There is also a broad five-sample elevated response at the north end of the transect between 350 and 512 m. Maximum Ni content in the soil sampled along the transect is 3000 ppb.

S: The shallow gas vent site is marked by a low or background S response but is flanked to the north by a single high-contrast response and to the south by a number of elevated S responses that continue to the end of the sampling transect. Responses to the north are flat. This

type of response may be attributed to the presence of a different rock type in an adjacent stratigraphic unit.

Th: A two-sample Th anomaly is developed adjacent to and south of the vent site between 218 and 226 m on the transect. These responses are low contrast.

Ca: A broad, low-contrast Ca anomaly is centred on the shallow gas vent site. The core of the anomaly has two elevated responses with progressively decreasing responses to the north and south. A subsidiary response is noted from the southern portion of the transect coincident with the Mo-Tl-Co anomaly developed in this area.

Sb: The Sb responses along the transect are marked by the presence of two single-sample but high-contrast diagnostic responses. One anomalous response occurs

directly over the shallow gas vent site and the other is coincident with the Mo-Tl-Co anomaly, described earlier.

Br: Bromine concentrations are elevated over the gas vent site and to the north of the vent (Figure GS-20-8b). The remainder of the responses on the transect are below detection limit for this element.

Soil profile interval 30–40 cm (Figure GS-20-8)

There are only a few elements from samples collected in the 30–40 cm depth interval that are diagnostic in terms of the location of the shallow gas vent site on the sampling transect; however, the nature of the responses are as diagnostic as those from elements from the 0–10 cm depth interval samples. In addition, there are three responses documented from the 30–40 cm depth interval samples that provide an unusual and unexpected base- and precious-metal anomaly.

Br: A well developed and diagnostic six-sample anomaly is centred over the gas vent site. This anomaly extends from 226 to 276 m and is the most extensive anomaly present on the transect. A single-sample anomalous response at 45 m is coincident with the Mo-Tl-Co anomaly described from the southern portion of the transect. When compared to the Br response for the 0–10 cm interval (Figure GS-20-8b), the Br response from the 30–40 cm samples offers much better definition of an anomalous response and is based on a larger number of samples.

I: A two-sample, high-contrast anomaly is present at the gas vent site and a more subdued zone of weakly elevated responses to the north may be suggestive of a discrete stratigraphic unit rather than a shallow gas occurrence. The I pattern to the south of the gas vent site is almost flat with the exception of a one-sample, weak response, which coincides with the Mo-Tl-Co anomaly in the 0–10 cm samples.

Base- and precious-metal responses

The Manitou survey was directed towards an assessment of partial-extractable element variation in the vicinity of a shallow gas vent site. The multi-element approach in this study, however, revealed strongly elevated Cu, Au and Ag responses near the southern end of the survey transect.

The anomaly is characterized by a two-sample, high-contrast Cu response (2630 and 1930 ppb) at stations 090 and 117 m, coincident with high concentrations of Au (2.6 ppb) and Ag (223 ppb) in single-sample responses, both at station 090 m (Figure GS-20-8). The range in Cu concentrations for all sample depths is 1370–6290 ppb and indicates significant metal enrichment that may be associated with the Mo-Tl-Co anomaly described earlier in the 0–10 cm profiles.

Rare earth elements: There is a lack of diagnostic response for the REE in relation to the shallow gas vent site. The geochemical coherence of the REE is demonstrated for Dy, Er and Eu in Figure GS-20-8g–i. A low-contrast REE response between 278 and 425 m could be indicative of a discrete stratigraphic unit, similar to that described for I.

pH

The slight reduction in pH from a high of 7.11 in the 0–10 cm sample to a low of 6.73 in the 30–40 cm sample is documented in the vertical profile (Figure GS-20-5d). The lateral pH profile for both 0–10 cm and 30–40 cm samples is very similar and low-contrast pH elevations are noted in association with the anomalous responses at the shallow gas vent site and in association with the southern transect multi-element anomaly. The neutral pH at the surface progressing to a slightly less than neutral pH at the base of the pit is not considered to be significant and has little or no effect on element distribution, as determined by the MMI-ME extraction or the determination of Cl, I, Br, S and Hg.

Discussion

This orientation survey was designed to assess the potential for partial extractable soil geochemical signatures associated with a shallow gas occurrence near Manitou. The survey has demonstrated that multiple diagnostic responses for elements, determined using the MMI-ME method, are present in the soil profile. High-contrast responses for a number of elements were dominantly observed in the 0–10 cm depth interval samples whereas in the 30–40 cm depth interval the subsidiary elements Br and I are also diagnostic of the shallow gas vent site.

The Br response in the 30–40 cm samples (Figure GS-20-8a) produces the most extensive halo-effect around the vent site (50 m along the transect) and as such should be considered as an extremely valuable pathfinder element in soil geochemical surveys for shallow gas. The drawback may be the requirement to sample at a depth of 30–40 cm versus 0–10 cm for the remainder of the elements. The Br response at the 0–10 cm interval, albeit of high contrast, is somewhat less diagnostic than at the 30–40 cm interval.

There are also indications in the data of possible controls to element responses (e.g., I and S) that are related to geochemical signatures developed due to crossing a boundary from one stratigraphic unit to another. This concept needs to be further investigated in the field and may find application in sorting out stratigraphic mapping problems where no outcrop is available. Similarly, if the location of shallow gas vent sites can be shown to be localized along geological features such as faults or other lineaments, then the MMI-ME approach will have merit in the exploration for vent sites along these linear structures.

The presence of a multi-element, high-contrast anomaly at the shallow gas vent site is indicative of metals being mobilized from the origin of the gas, along with the gas itself. The gas therefore may be acting as a carrier that brings the metals to the surface, or the gas may be liberating the metals from bedrock sources as the gas ascends to surface. The metals are then fixed on the surfaces of individual soil particles and stripped by the MMI partial extraction then held in solution by a complex suite of ligands until measured by ICP-MS.

A second multi-element anomaly is present on the southern portion of the survey transect and consists of almost all the indicator elements contained within the anomalies delineated at the shallow gas vent site. A review of the sample sites in the vicinity of this southern anomaly indicates the presence of an active stream or possibly a seep with black, euxinic sediment at the sample site. It is noted, however, that sample sites adjacent to the southern anomaly site yielded sediment similar to samples taken elsewhere along the transect. Perhaps the only difference is the wet, low-lying nature of the southern anomaly site. If a seep is present, then the multi-element geochemical signature developed at the southern anomaly site may be related to a second, previously unknown, shallow gas vent site. The lower responses for many of the elements, however, may indicate the transect crossed the periphery of the site rather than lying directly over it.

The presence of anthropogenic contamination, such as wire fences and a wellhead, at the shallow gas vent site was initially worrisome during sample collection. If the observed geochemical responses were limited to the immediate area of the wellhead, then the potential for the survey to have documented anthropogenic contamination would have been a concern. In reality, the anomalous responses are developed away from potential anthropogenic contamination and are up to 50 m wide in the case of the Br responses. In addition, there are no metal anomalies such as Zn, Cu or Fe associated with the wellhead, and the association of Br and I with hydrocarbons is not unexpected.

Conclusions

The following conclusions flow from this preliminary soil geochemical survey based on the MMI partial extraction of metal and additional elements:

- a multi-element signature consisting of Mo, Tl, Co, Ni, S, Th, Ca, Sb and Br characterizes the immediate area of the shallow gas vent site;
- this anomaly is documented on the basis of the partial extraction of soil samples using MMI-ME extraction, and separate determinations for I and Br;
- the optimum sample position for the delineation of this anomaly is between 0 and 10 cm in the soil profile although diagnostic responses were obtained for Br in the 30–40 cm samples;
- the optimum distance between sample sites based on this limited survey is 25 m;
- the anomaly at the vent site has maximum dimensions of 50 m;
- the subsidiary multi-element anomaly present on the southern portion of the transect has geochemical similarities to the shallow gas vent site and may be (part of) a separate, previously unknown vent site or seep;
- the presence of high-contrast Cu-Au-Ag responses at the southern transect anomaly is unexpected and requires additional study to determine whether the black euxinic mud at the sample site is simply a geochemical sink for these metals or indications of a base- and precious-metal mineralized zone; and
- pH changes are minimal in soils collected vertically through the soil profile and laterally along the sampling transect.

Economic considerations

The discovery of new oil and gas resources has become challenging in recent years, and the increased need for natural gas has prompted a worldwide search for unconventional reservoirs previously bypassed. Unconventional shale gas occurrences require new techniques to find the best site to drill an economic well since these types of resources tend to be expansive but not necessarily economical over their entire expanse. The application of MMI technology could assist in locating gas sweet-spots prior to investing heavily in drilling a potentially marginal gas well. Application of this technology opens up shallow gas exploration opportunities in southwestern Manitoba, particularly where shallow stratigraphic test drilling is expensive and commonly has poor and nonreliable drill-chip or core recovery.

Acknowledgments

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