Planning the Execution of an Applied Geochemistry Project

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Structure of webinar

1) Introduction
2) Recommended key references
3) Stages of a phased geochemical survey in mineral exploration
4) Stages of contaminated land or property investigation, including the various stages of a stepwise phased investigation
5) Important key items and definitions
6) Planning the execution of an applied geochemistry project using a real example of a contaminated land investigation
7) Fieldwork planning and equipment
8) First phase
9) Second phase
10) Results
11) Conclusions
12) Further reading
13) References

Planning the Execution of an Applied Geochemistry Project

The key to executing a successful applied geochemistry project at any mapping scale is "*efficient planning*". Every applied geochemical project from the continental to the micrometre scale has nine independent, and yet interdependent, components, which are:

(1) Planning

(2) Sampling

(3) Sample preparation

(4) Storage of samples

(5) Laboratory analysis

(6) Quality control

(7) Data processing and map plotting

(8) Interpretation, and

(9) Report writing.

Planning the Execution of an Applied Geochemistry Project

It is stressed that failure to perform any of the aforementioned steps correctly and efficiently will have a detrimental effect on the subsequent steps.

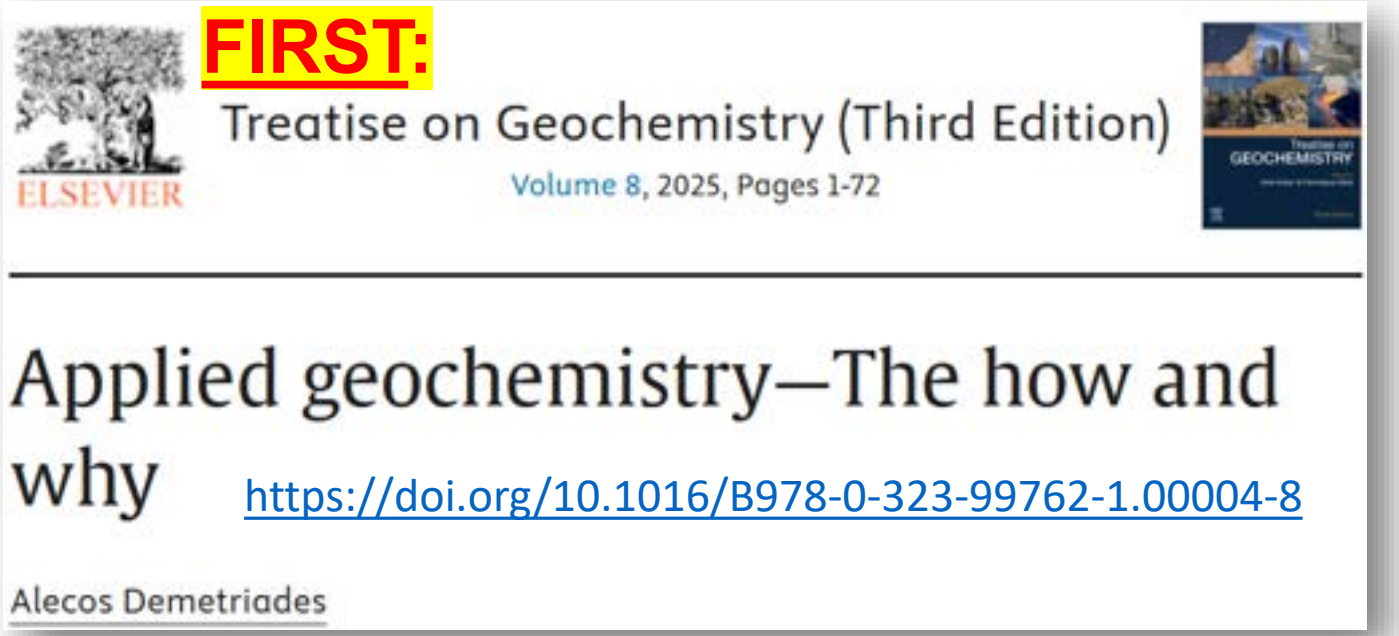
***Therefore, the aim of this seminar is to show that well-tested applied geochemistry methods can be used not only in mineral exploration but also for environmental and medical purposes, and that data interpretation varies with the objectives of the geochemical survey*.**

Of course, the applied geochemistry methods should be adapted according to the objectives of the geochemical survey.

Recommended key references …..

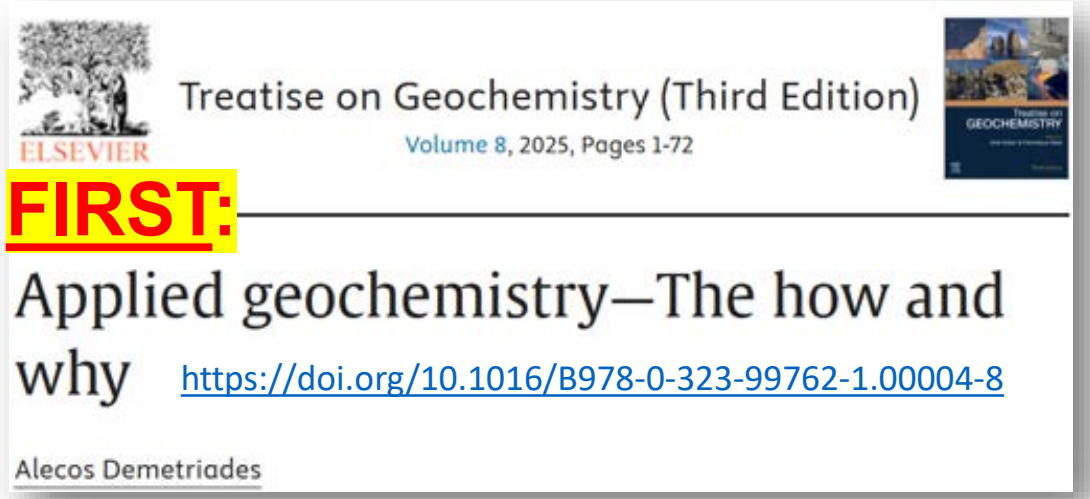
I strongly recommend for all of you to consult FIVE publications:-

FIRST:



David B. Smith (United States Geological Survey, and Commission Steering Committee member) reviewed the chapter, and his expert comments are: "*Alecos Demetriades has undertaken a very difficult task. In less than 100 pages, he is outlining principles of applied geochemistry that other authors have used entire textbooks to explain and discuss. The chapter is well-written, well-organized, and well-referenced. The figures are all very good and the captions describe the figures adequately. I think the chapter will be useful, in particular, to early-career applied geochemists who are undertaking geochemical surveys in support of mineral exploration or environmental investigations*." (IUGS E-Bulletin No. 212-213, January-February 2025, p.5; https://www.iugs.org/_files/ugd/be4613_a094b84cd2d041dca20a24edfd921307.pdf).

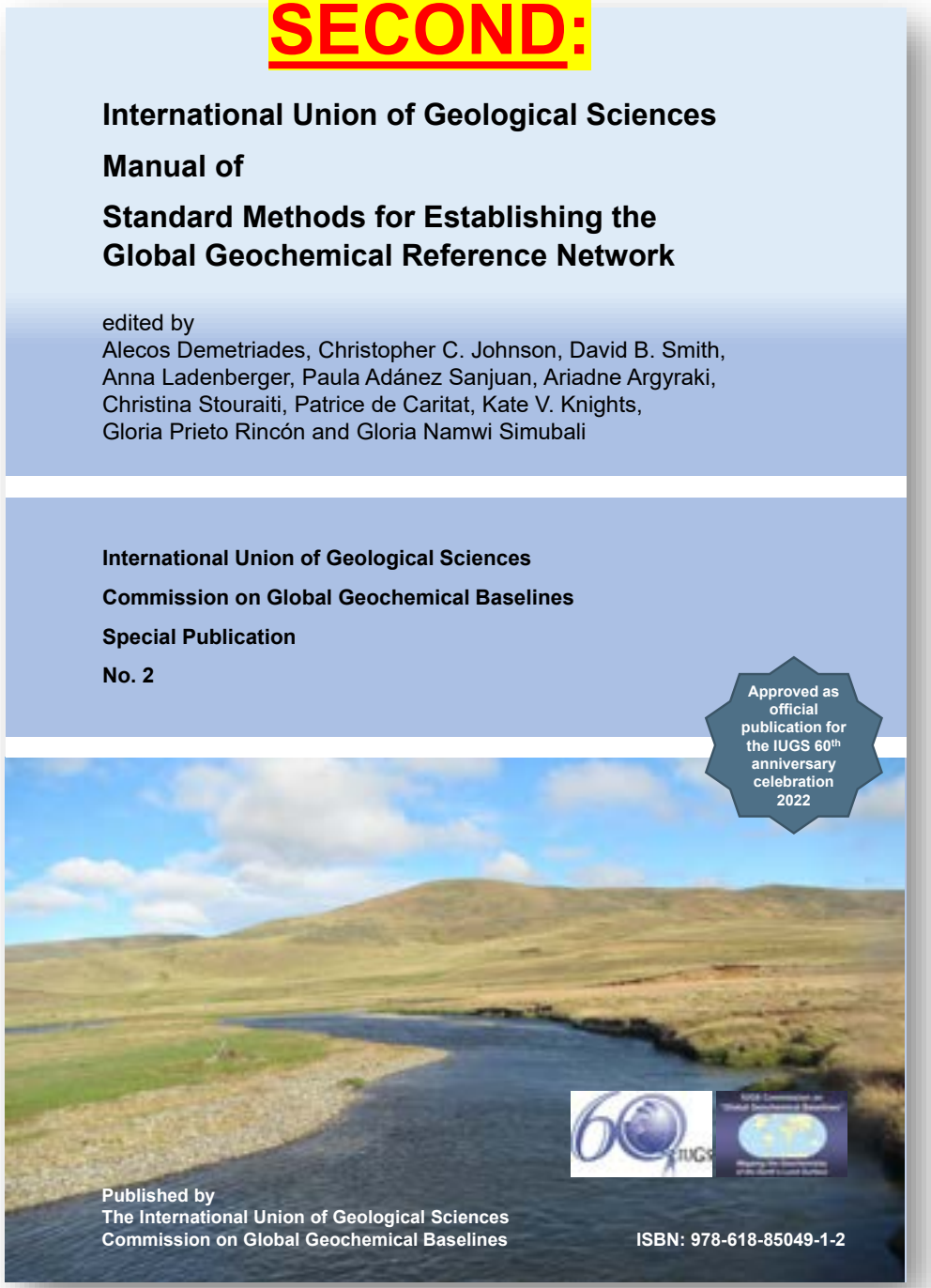
….. Recommended key references …..



The pre-publication chapter, together with the supplementary material, was given to Professor Ariadne Argyraki, who is a professor of geochemistry at the National and Kapodistrian University of Athens, for use in her teaching. Below are her comments after using the chapter during 2024:

"Dr. Alecos Demetriades' chapter on the 'How and Why of Applied Geochemistry' in the Treatise on Geochemistry has been an invaluable resource for my teaching as a professor of Geochemistry at the National and Kapodistrian University of Athens. By providing a comprehensive framework for planning and implementing geochemical surveys, this chapter equips educators with practical examples and hands-on exercises from the supplementary material to enhance student learning. The structured approach outlined in the chapter—ranging from orientation surveys to large-scale geochemical mapping—enabled my teaching about mineral exploration and environmental investigations effectively in multiple courses that I teach at both first-degree and post-graduate studies, i.e., environmental geochemistry, analytical geochemistry, and geochemical exploration methods. The emphasis on quality assurance, data analysis techniques, and 2D/3D map plotting is particularly beneficial for designing advanced coursework and research projects. Moreover, the chapter's guidelines for organizing geochemical projects offer a practical roadmap for students aiming to apply these methods in real-world scenarios, making it an essential teaching tool in applied geochemistry education. I hope that other professors will also consider it. However, it is a pity that our university does not provide access to the Treatise anymore. I hope this will change in the future." (IUGS E-Bulletin No. 212-213, January-February 2025, p.5; https://www.iugs.org/_files/ugd/be4613_a094b84cd2d041dca20a24edfd921307.pdf).

SECOND:



….. Recommended key references …..

[Chapter 2 Supplementary material]

[Chapter 2 Annexe A2.1 Supplementary material]

[Chapter 3.2 Annexe A3.2.1 Supplementary material]

[Chapter 7 Supplementary material]

[Chapter 8 Supplementary material]

[Chapter files: Word text; Original figures; PowerPoint presentations]

https://www.globalgeochemicalbaselines.eu/content/174/iugs-manual-of-methods-for-establishing-the-global-geochemical-reference-network-/

https://doi.org/10.5281/zenodo.7307696

THIRD:

URBAN GEOCHEMICAL MAPPING MANUAL

Sampling, Sample preparation, Laboratory analysis, Quality control check, Statistical processing and Map plotting

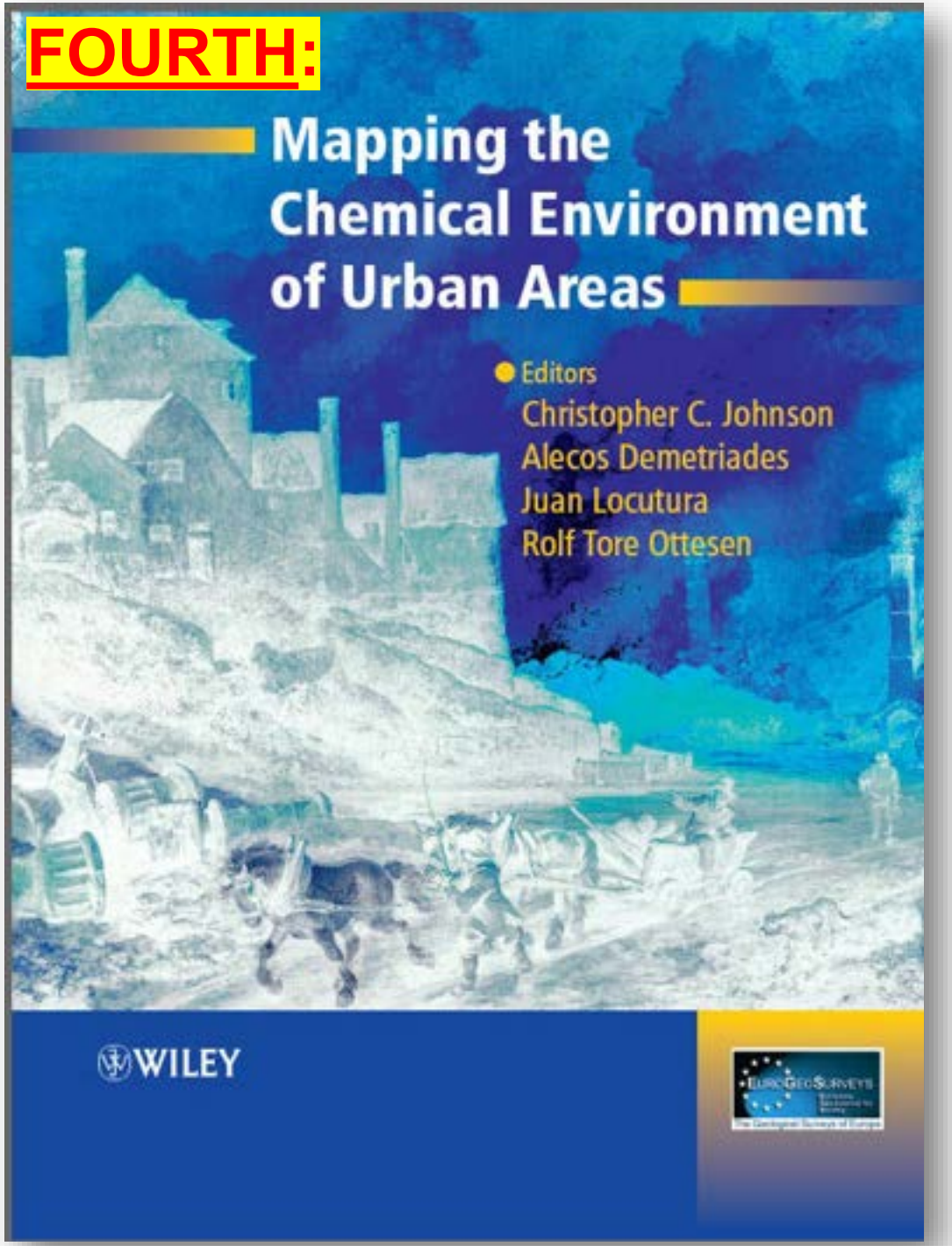
EuroGeoSurveys
Brussels 2015

APPENDIX 3: Chemical characteristics of contaminating activities

Table of contaminating activities and their probable organic and inorganic contaminants. The classification is according to the European Classification of Economic Activities, NACE (EuroStat, 2008), which has been simplified for the purposes of this manual. Note: At the end of the Table, there is a list of all abbreviations.

Activity: Industry, Enterprise	*Organic contaminants*	*Inorganic contaminants*
Agriculture (including chemical & livestock fertilisers)	Pesticides, Herbicides, Insecticides	As, B, Ba, Ca, Cd, Cr, Cu, Fe, Hg, K, Mg, Mn, Na, Ni, P, Pb, Sb, Se, Zn, NH_3, nitrates, nitrites, sulphates, CN, Cl^-, F^-
Airport	BTEX, PCBs, TPH, VHH, MOHC, Phosphate ester	As, Br, Cd, Hg, Pb, SO_2, CO_2, CO, NO_x, N_2O, NH_3
Automobile repair and painting	BTEX, MTBE, PAHs, PCBs, TPH, VHH, aliphatic hydrocarbons, Chlorinated hydrocarbons, Organolead compounds, AOX, Phenol index	Cd, Cl^-, Co, Cr, Cu, Fe, Hg, Mn, Mo, Ni, Pb, Se, Ti, Zn, Sulphate
Battery	PCBs, PAHs, Hydrocarbons	Be, Cd, Cu, Fe, Hg, K, Mg, Mn, Ni, Pb, Se, Zn, Sulphate
Beverages manufacture	BTEX, PAHs, PCBs	Cu, Cr, Pb, Zn, SO_x, Nitrates, Phosphates
Brick making industries	BTEX, TPH, PAHs, PCBs, Aliphatic hydrocarbons	Al, B, Ba, Cd, Cr, Cu, Fe, Hg, Mn, Ni, Pb, Zn

https://eurogeosurveys.org/wp-content/uploads/2022/11/Urban-Geochemical-Mapping-Manual.pdf



….. Recommended key references …..

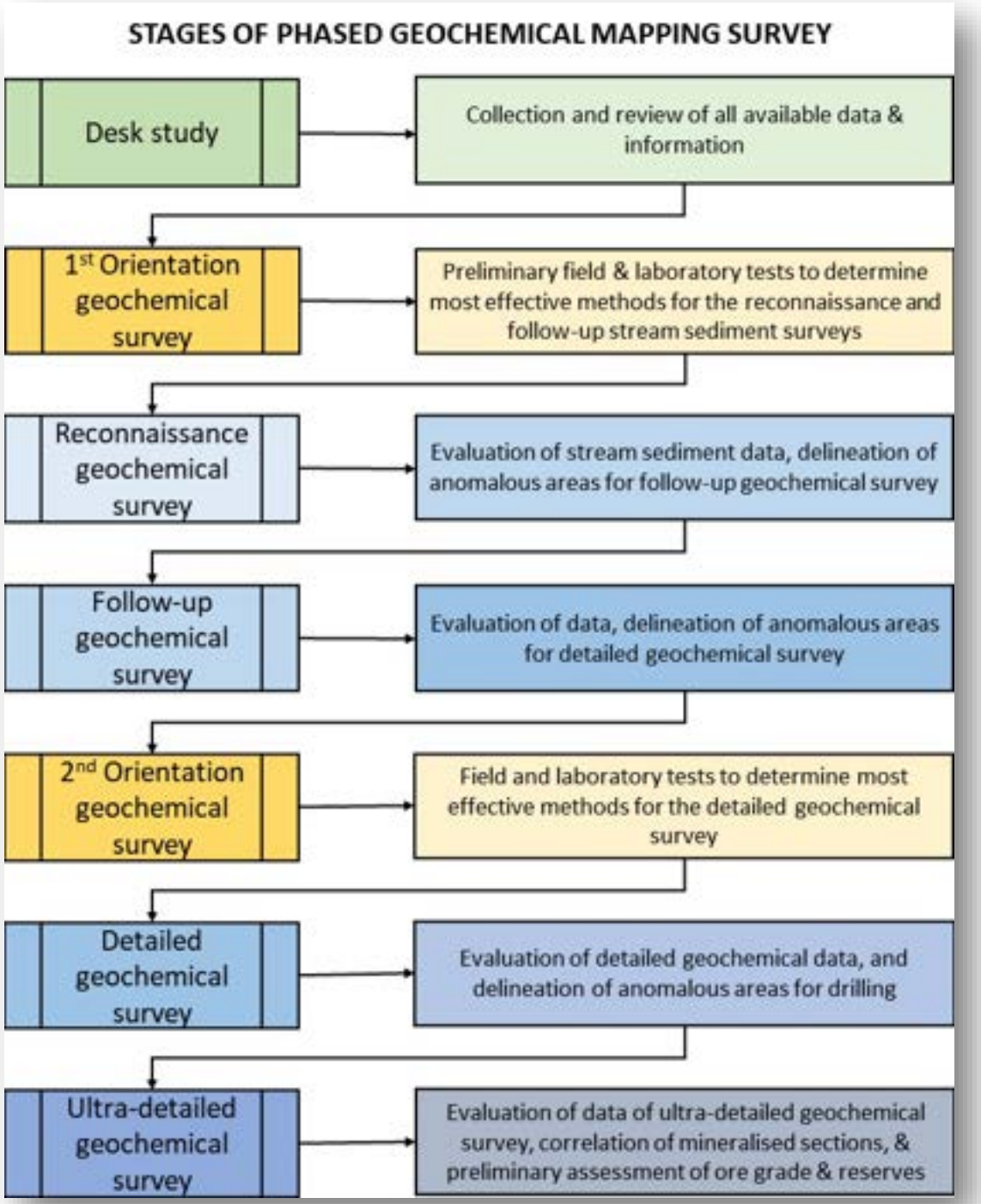
Johnson, C.C., Demetriades, A., Locutura, J., Ottesen, R.T. (Editors), 2011. Mapping the Chemical Environment of Urban Areas. Wiley, 616 pp. https://doi.org/10.1002/9780470670071.

….. Recommended key references

Almost all papers provide the original data sets, as well as the quality control data.

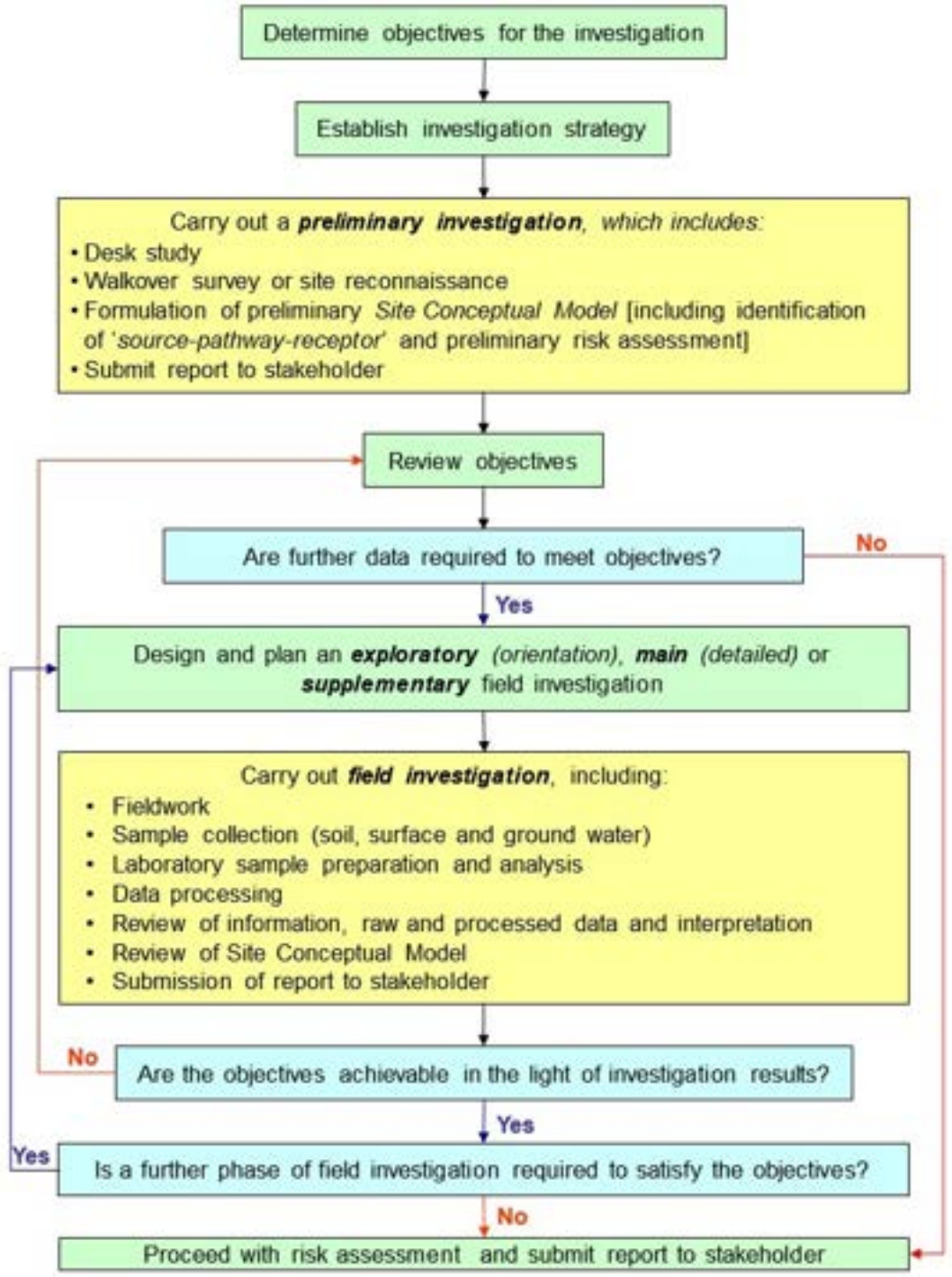
So, it is good for teaching purposes.

https://www.sciencedirect.com/journal/journal-of-geochemical-exploration/vol/187/suppl/C



Flow-chart showing the stages of a phased geochemical survey in mineral exploration. Plotted with Microsoft® 365 PowerPoint.

(From Demetriades, 2025, Fig. 4, p.7; slightly modified from Demetriades, 2021, Fig. 1, p.268)



Flow-chart showing a typical approach of contaminated land or property investigation, including the various stages of a stepwise phased investigation. It illustrates how data and information obtained at each stage is reviewed to determine if the investigation strategy requires modification, or the objectives have been met. The review process also enables the revision of the Site Conceptual Model (see Fig. S11 in Text S1), **the requirements of risk assessment and the objectives of site or property investigation** (modified from BSI, 2005, Fig. 1, p.7). Plotted with Microsoft 365 PowerPoint®.

(From Demetriades, 2025, Fig. 29, p.32)

Production of high quality harmonised Geochemical Databases at any mapping scale depends on:-

Sampling

Sample preparation

- These are the two most crucial stages of any geochemical survey.
- Any errors during these two stages is carried forward, and can result in the failure of a whole survey.

Laboratory analysis

- Errors can be corrected by re-analysis of samples, provided there is enough sample material available.

From Demetriades, 2025, Fig. 57, p.63: ***Stages of a geochemical mapping survey, stressing the importance of carrying out the sampling and sample preparation procedures efficiently***. Plotted with Microsoft® 365 PowerPoint.

CONCLUSION

The main job of the Applied Geochemist is to ensure that the field and laboratory procedures (sampling, sample preparation and chemical analysis) are applied correctly, and the produced data are of high quality and integrity.

Interpretation of the results is completely another matter and depends on the training and experience of the Applied Geochemist.

Cartoon by © 2013 Roger Harvey Cartoonist

Geochemical Baseline Data

For a realistic assessment of *contamination*

it is significant to have high quality

GEOCHEMICAL BASELINE DATA

about the natural element variation before humans began to contaminate the environment.

Geochemical Anomaly due to natural processes (without any human induced influences)

Geochemical anomaly ≡ **Natural variation of element** *Lithology «Background»* + **Abnormal concentration of element** *Mineralisation & Lithology*

The Geochemical Baseline

THERE ARE TWO SOURCES OF ABOVE NORMAL CONCENTRATIONS OF ELEMENTS

Baseline

Natural geogenic variation of element

≡

Natural variation of element

Lithology «Background»

\+

Abnormal concentration of element

Mineralisation & Lithology

1

ANTHROPOGENIC CONTAMINATION

≡

Natural geogenic variation of element

\+

Concentration of element from anthropogenic activities

2

This concept is not understood or unknown to decision makers and the general public

DEFINITIONS .....

According to Govett (1983, p.30) to define a *geochemical anomaly* "*it is necessary to consider the value of the measured parameter, the physico-chemical nature of the sample material, the physico-chemical environment from which the sample is taken, and the spatial distribution pattern of the measured variable*." Hence, he arrived at the following appropriate definition of a geochemical anomaly:-

"An abnormal high or low content of an element or element combination, or an abnormal spatial distribution of an element or element combination in a particular sample type in a particular environment as measured by a particular analytical technique."

Following the above definition given to the *geochemical anomaly* by Govett (1983, p.30), *background and threshold depend also on the particular sample type in a particular environment as measured by a particular analytical technique.*

..... DEFINITIONS .....

Again, according to Govett (1983, p.30), "*an anomaly cannot be recognised unless background can be defined. The content of any element in any geological material cannot be represented as a single number. Apart from variations due to error in sample preparation and analysis that are inevitably present in the reported value for a particular sample, there is an inherent variability in the content of an element even in a small and petrologically homogeneous granite or in B-horizon soil samples overlying an homogeneous rock. In statistical terms, the recognition of an anomalous sample depends upon establishing the statistically probable range that occurs in the background samples – background population – and calculating (for some defined confidence level) an acceptable upper limit – threshold – of background fluctuation. Any sample that exceeds this threshold (which is the lowest anomalous value) is then regarded as possibly anomalous and belonging to a separate population. Similarly, for negative anomalies, threshold defines the lower limit of background fluctuation.*"

..... DEFINITIONS .....

The first definition of "background" was given by Hawkes (1957, p.336): *"The abundance of an element or any chemical property of a naturally occurring material in areas where the chemical pattern has not been affected by the presence of a mineral deposit".*

Finally, Hawkes and Webb (1962, p.23) modified the background definition to *"The normal abundance of an element in barren earth material"* and elaborated it further: *"For any particular element, the background value is naturally likely to vary considerably according to the nature of the earth material in which it occurs. Furthermore, the distribution of an element in any particular class of material is rarely uniform. Thus, it is usually more realistic to view background as a range rather than as an absolute value."*

Hawkes (1957, p.338) has also defined *threshold* with respect to geochemical prospecting as *"the limiting anomalous value below which variations represent only normal background effects, and above which they have significance in terms of possible mineral deposits."*

FINAL DEFINITION OF GEOCHEMICAL ANOMALY

Geochemical anomaly or anomaly is: An abnormally high or low content of an element or element combination, or an abnormal spatial distribution of an element or element combination

- **in a particular sample type and**
- **in a particular environment**

as measured on

- **a particular grain size by**
- **a particular analytical technique** (Govett 1983, p. 30, slightly modified).

(From Demetriades, 2025, p.5)

Background and Threshold should be similarly defined

FINAL DEFINITION OF BACKGROUND

Background is: **the non-anomalous concentration range of an element or element combination**

- **in a particular sample type and**
- **in a particular environment**

as measured on

- **a particular grain size by**
- **a particular analytical technique.**

(From Demetriades, 2025, p.5)

FINAL DEFINITION THRESHOLD

Threshold is: the limiting anomalous value of an element or element combination

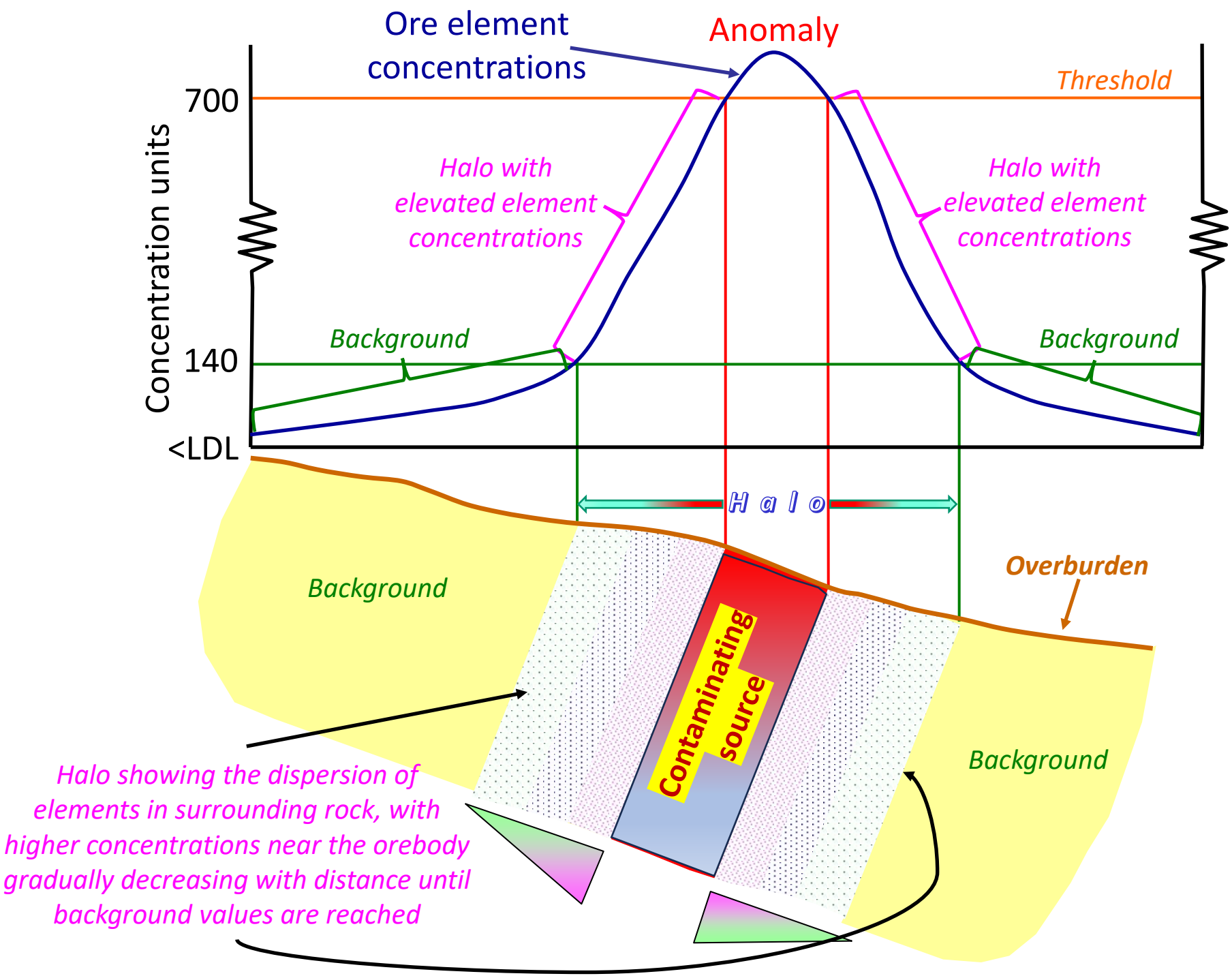
- **in a particular sample type and**
- **in a particular environment**

as measured on

- **a particular grain size by**
- **a particular analytical technique**

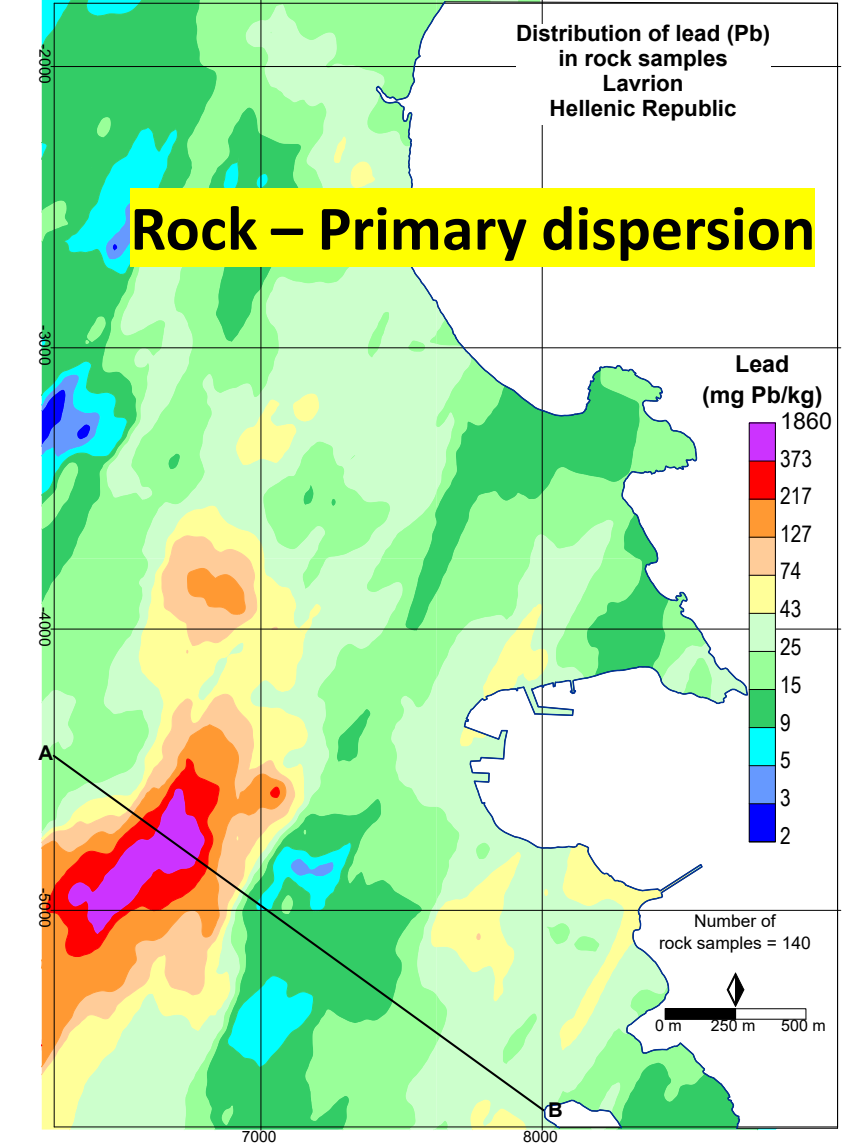
below which variations represent only normal background effects, and above which element concentrations are significant in terms of potential (i) mineralisation, or (ii) environmental contamination.

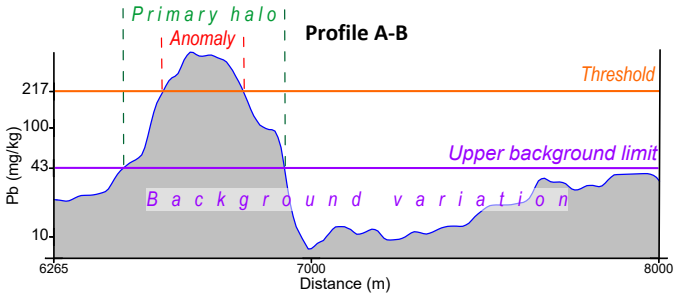
(From Demetriades, 2025, p.5)



Schematic representation of a cross-section across a vein deposit emplaced in a single type of host rock, e.g., a limestone, and covered by overburden (e.g., soil or till). The diagram shows the anomalous pattern over the orebody (>700 units), and the dispersion of elements in the surrounding host rock, the halo, which is indicated by elevated ore element concentrations gradually decreasing with distance from the orebody (700 to 140 units), until the unaffected rock is reached with background element concentrations (140 to <LDL units). Notation: LDL = lower detection limit of analytical method. Plotted with Microsoft® 365 PowerPoint.

From Demetriades, 2025, Fig. 1, p.3.



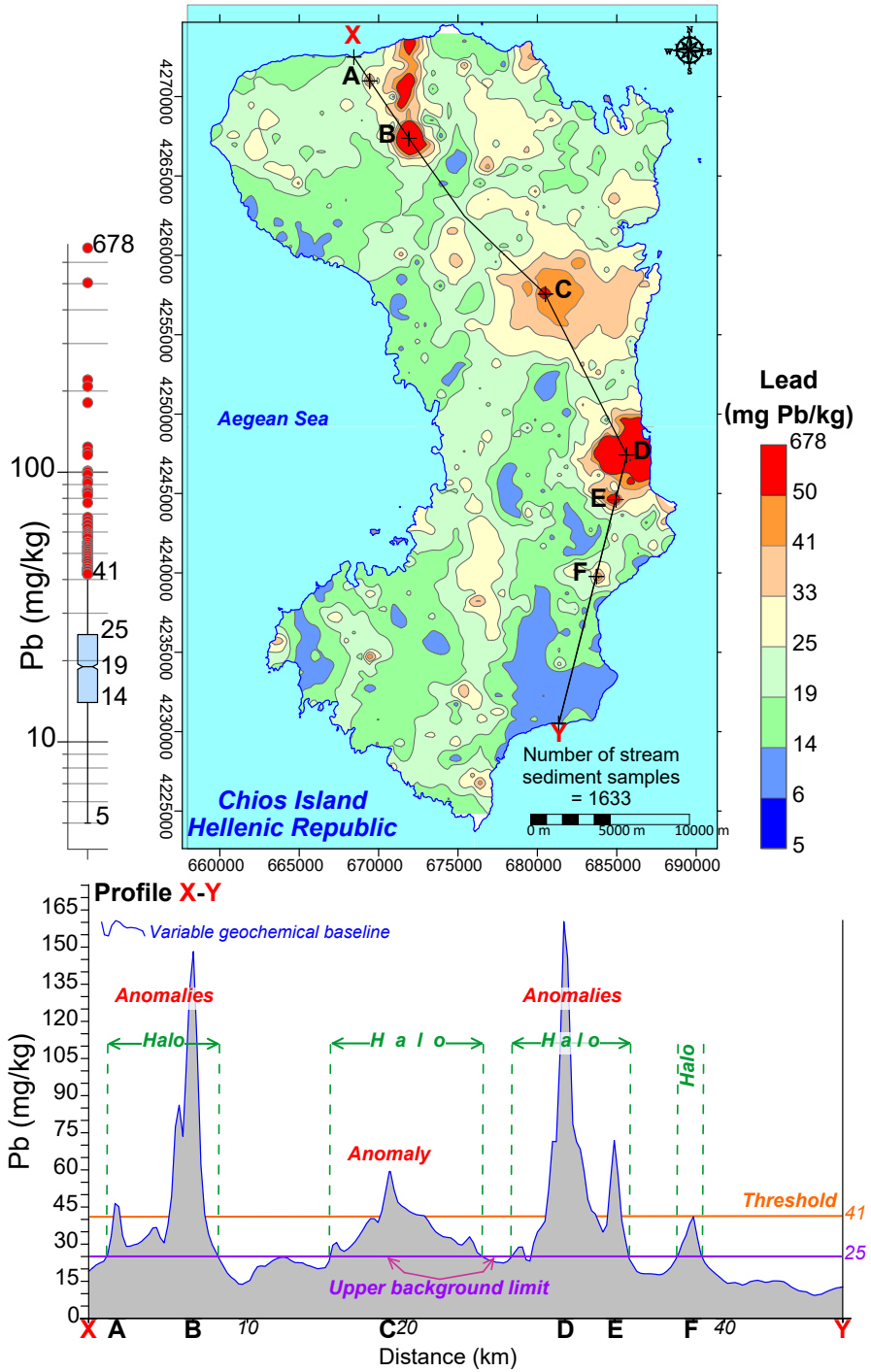


Distribution of lead (Pb) in the <0.074 mm grain size of rock samples following a hot aqua regia extraction and determination by double-beam atomic absorption spectrometry (AAS) with a lower detection limit at 1 mg Pb/kg, Lavrion, Attiki Prefecture, Hellenic Republic.

The colour-surface geochemical map of Pb shows its primary dispersion in rocks.

The profile displays the primary geochemical dispersion features caused by the polymetallic mineralisation in the host rocks, namely anomalous concentrations of Pb (>217 mg/kg), the halo over and about the mineralisation (>43 to 217 mg/kg), and the variable background concentrations (<43 mg/kg).

The data were plotted with Golden Software's program Surfer™ v25 (From Demetriades, 2025, Fig. 2, p.4, modified from Demetriades, 2011a, Fig. 25.4, p.435).



Distribution of lead (Pb) in the <0.177 mm grain size of stream sediment samples following a hot regia extraction and determination by double-beam atomic absorption spectrometry with a lower detection limit at 2 mg Pb/kg, Chios Island, Eastern Aegean Sea, Hellenic Republic (Kaminari and Labropoulos, 1989).

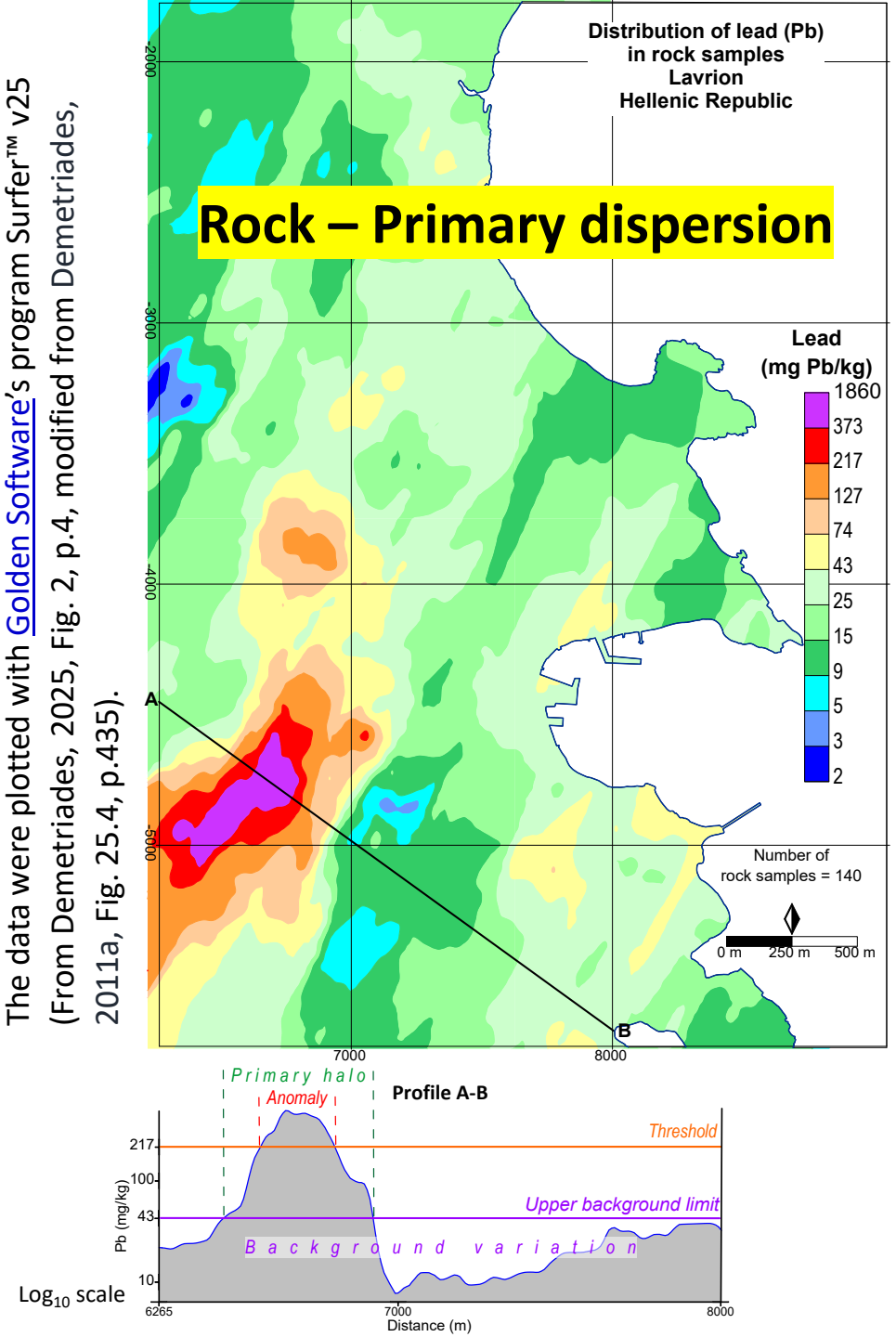
The colour-surface geochemical map of Pb shows the geochemical baseline of this area for the 1980s, the time of the sampling campaigns.

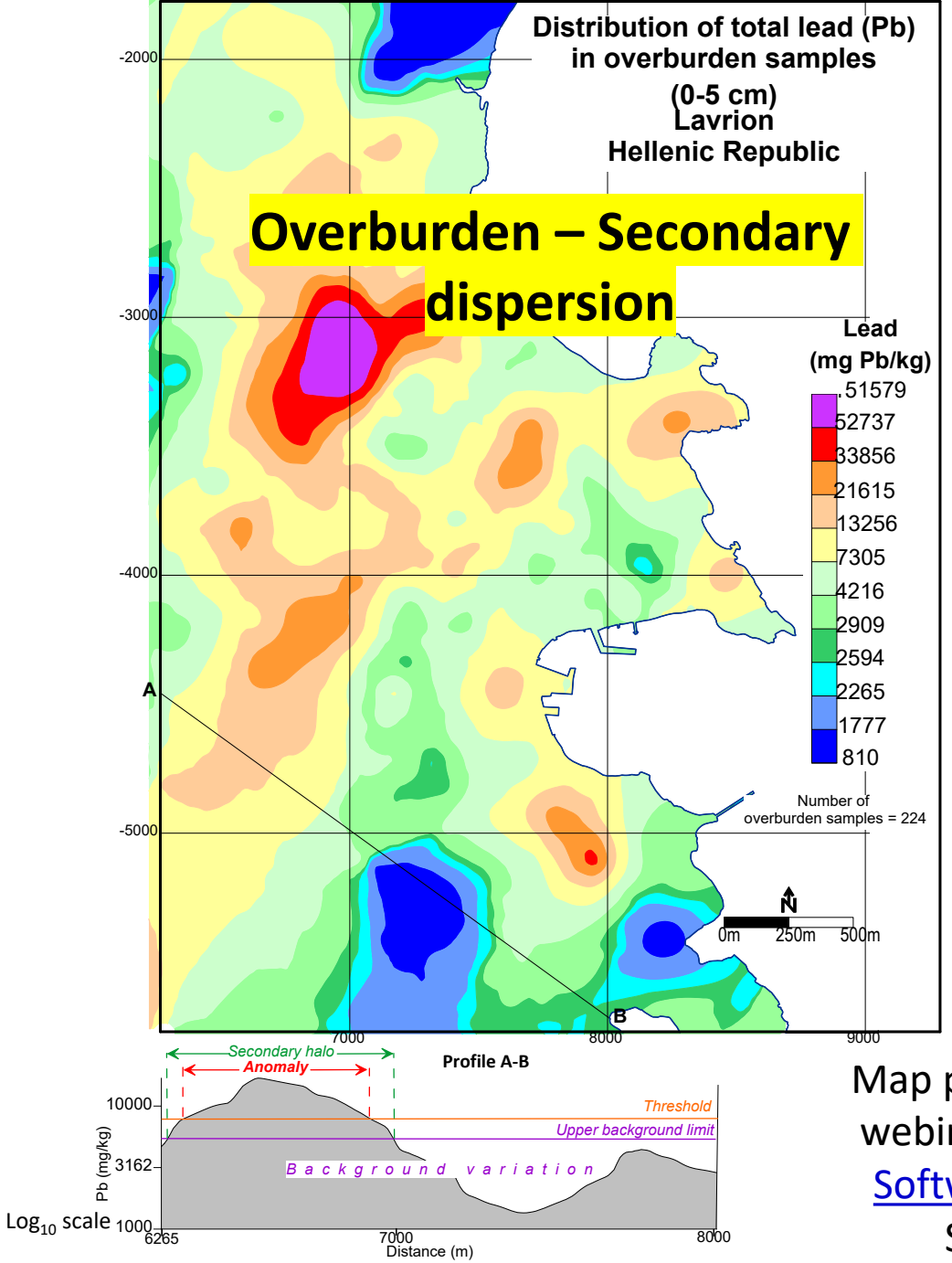
The profile displays:

(i) the secondary geochemical dispersion features in stream sediment samples caused by the weathering and erosion of the polymetallic mineralisation, namely anomalous concentrations of Pb (A, B, C, D, E), the haloes about the anomalies, and the background concentrations, and

(ii) the variable geochemical baseline of Pb in stream sediment samples (blue colour line). Anomaly F, although is below the threshold value, warrants further investigation. The notched-boxplot displays in the $\log_{10}$ scale the statistical distribution of Pb concentrations. The upper background limit and threshold at 25 and 41 mg/kg Pb, respectively, were estimated by studying the spatial distribution, and the notched-boxplot. The map and notched-boxplot were plotted with Golden Software's program Surfer™ v25 and Grapher™ v21, respectively. **From Demetriades, 2025, Fig. 3, p.5.**

The data were plotted with Golden Software's program Surfer™ v25 (From Demetriades, 2025, Fig. 2, p.4, modified from Demetriades, 2011a, Fig. 25.4, p.435).





The extremely high Pb concentrations in the contaminated overburden are caused by the metallurgical processing wastes, which are distributed in many parts of the urban and suburban area.

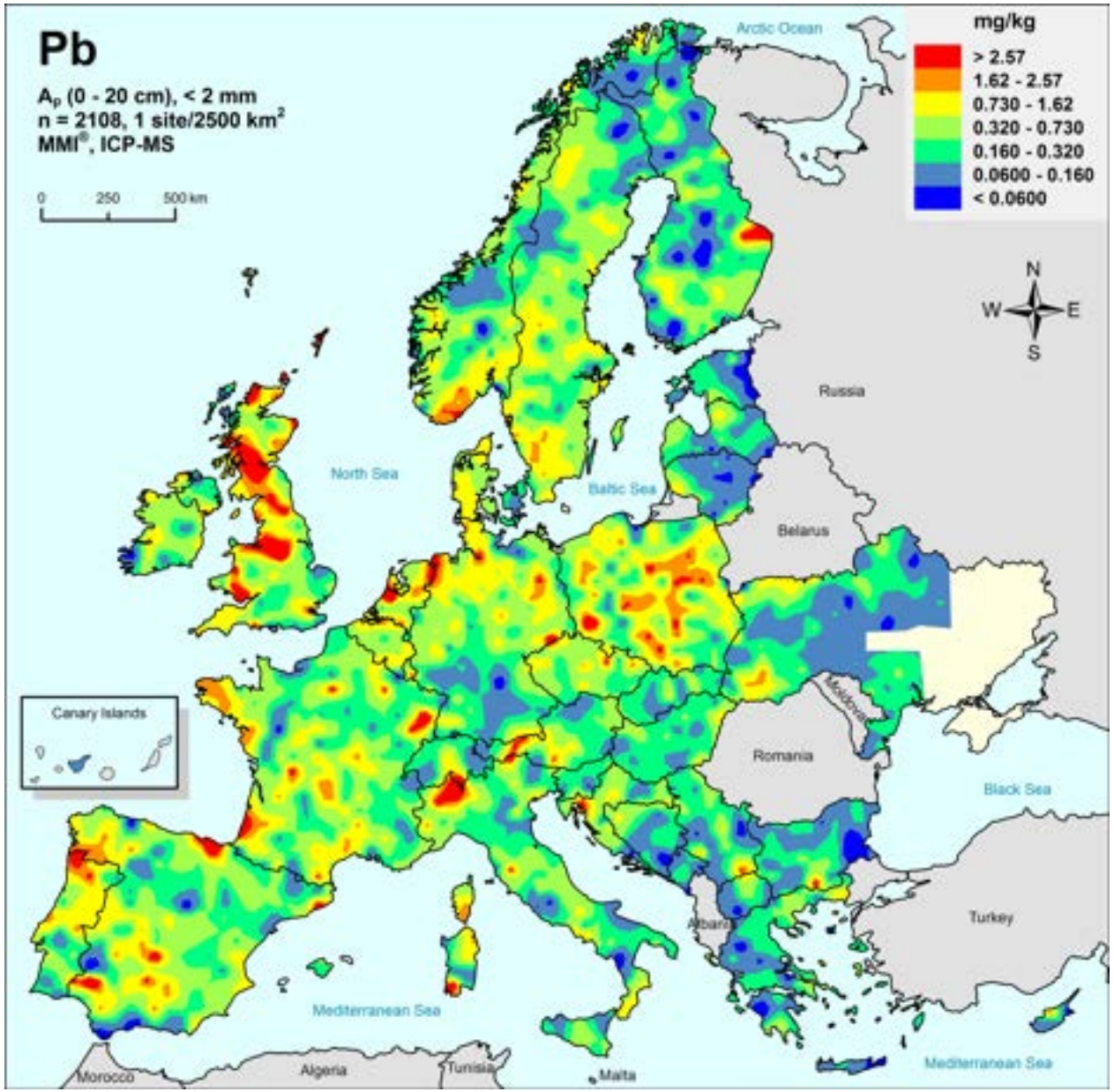
Map prepared for this webinar with Golden Software's program Surfer™ v32

GEMAS project agricultural soil samples analysed by three different analytical methods

METHOD	N	UNIT	DL	%<DL	Min.	Q10	Q25	Q50	Q75	Q90	Max.	Powers
MMI®	2108	mg/kg	0.01	0.24	<0.01	0.09	0.16	0.32	0.73	1.6	58	4.1
AR	2108	mg/kg	0.01	0	1.55	6.3	9.9	16	24	35	1309	2.9
XRF	2108	mg/kg	3	1	<3	11	15	21	30	40	1287	2.9

MMI® = cold Mobile Metal Ion; AR = hot Aqua Regia; XRF = X-ray fluorescence; DL = Detection limit; Q = Quantile

Table 11.41.1 (p.337) from Reimann, C., Demetriades, A., Birke, M., Filzmoser P., O'Connor, P., Halamić, J., Ladenberger, A. & the GEMAS Project Team, 2014. Distribution of elements/ parameters in agricultural and grazing land soil of Europe. Chapter 11 In: C. Reimann, M. Birke, A. Demetriades, P. Filzmoser & P. O'Connor (Editors), Chemistry of Europe's agricultural soils – Part A: Methodology and interpretation of the GEMAS data set. Geologisches Jahrbuch (Reihe B102), Schweizerbarth, Hannover, 103−474; https://www.schweizerbart.de/publications/detail/isbn/9783510968466.



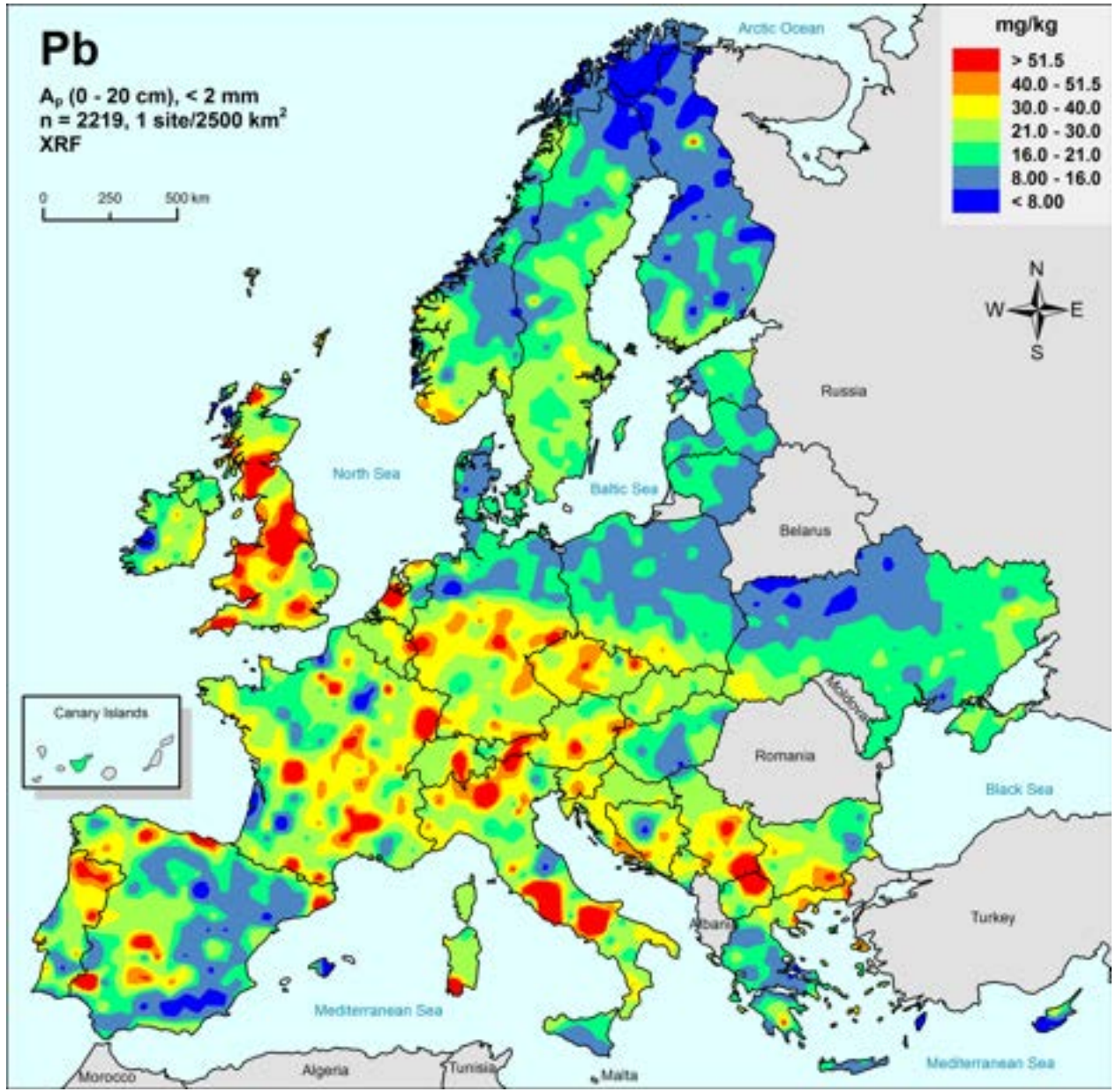
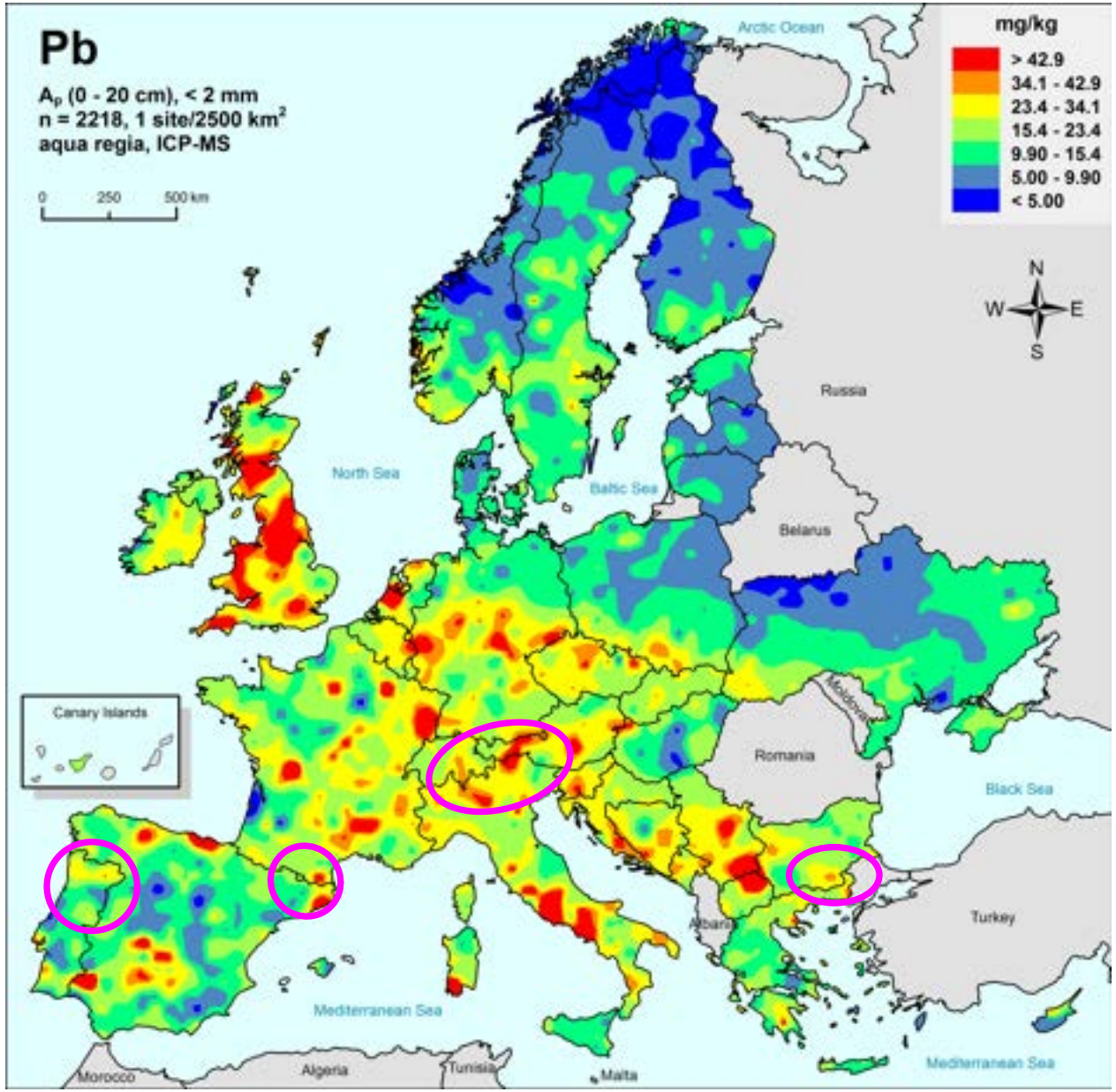


Figure 11.41.5 (p.341-342) from Reimann, C., Demetriades, A., Birke, M., Filzmoser P., O'Connor, P., Halamić, J., Ladenberger, A. & the GEMAS Project Team, 2014. Distribution of elements/ parameters in agricultural and grazing land soil of Europe. Chapter 11 In: C. Reimann, M. Birke, A. Demetriades, P. Filzmoser & P. O'Connor (Editors), Chemistry of Europe's agricultural soils – Part A: Methodology and interpretation of the GEMAS data set. Geologisches Jahrbuch (Reihe B102), Schweizerbarth, Hannover, 103−474; https://www.schweizerbart.de/publications/detail/isbn/9783510968466.



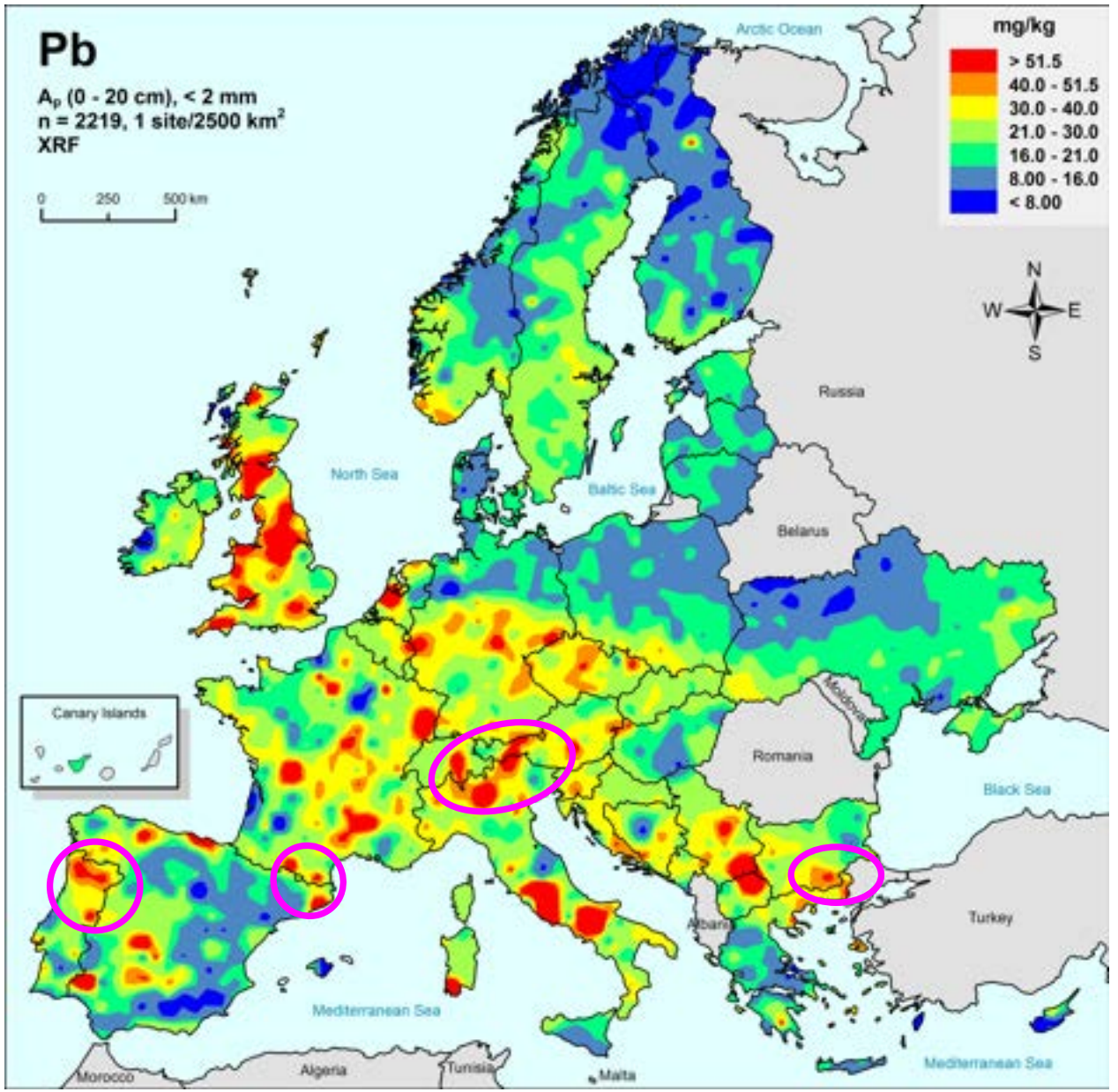


Figure 11.41.5 (p.341-342) from Reimann, C., Demetriades, A., Birke, M., Filzmoser P., O'Connor, P., Halamić, J., Ladenberger, A. & the GEMAS Project Team, 2014. Distribution of elements/ parameters in agricultural and grazing land soil of Europe. Chapter 11 In: C. Reimann, M. Birke, A. Demetriades, P. Filzmoser & P. O'Connor (Editors), Chemistry of Europe's agricultural soils – Part A: Methodology and interpretation of the GEMAS data set. Geologisches Jahrbuch (Reihe B102), Schweizerbarth, Hannover, 103−474; https://www.schweizerbart.de/publications/detail/isbn/9783510968466.

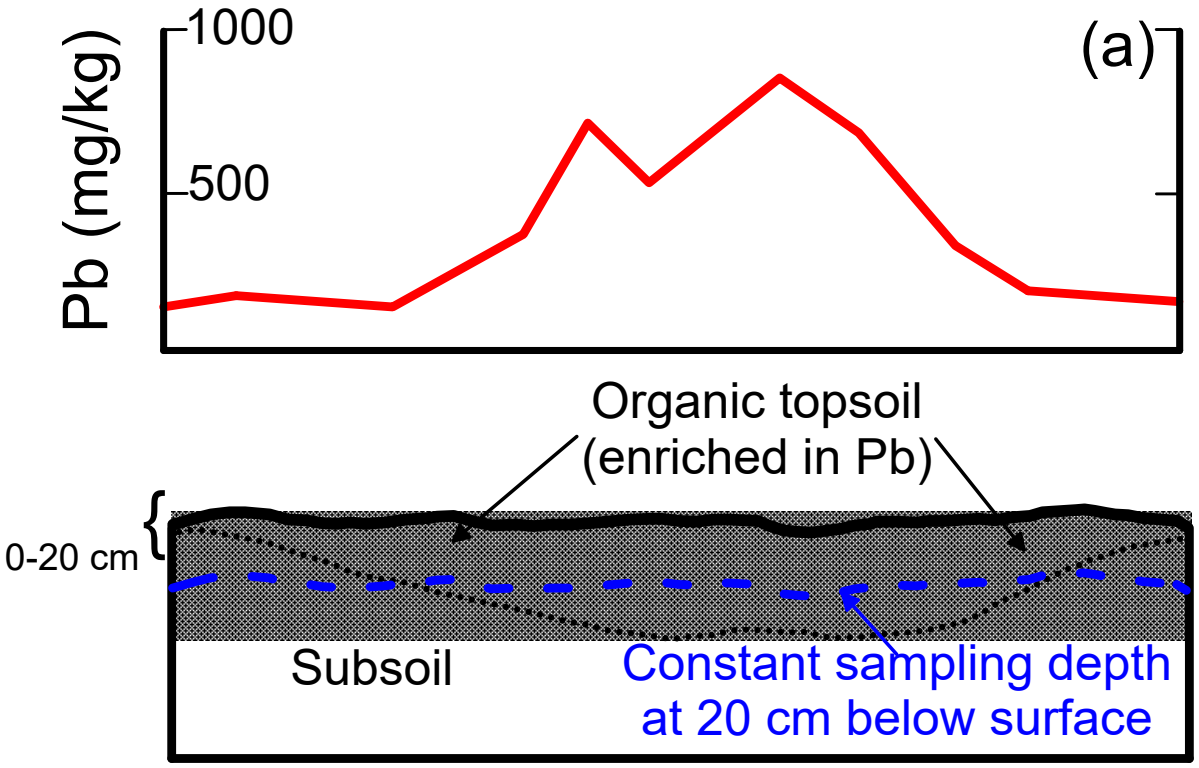
Be careful of

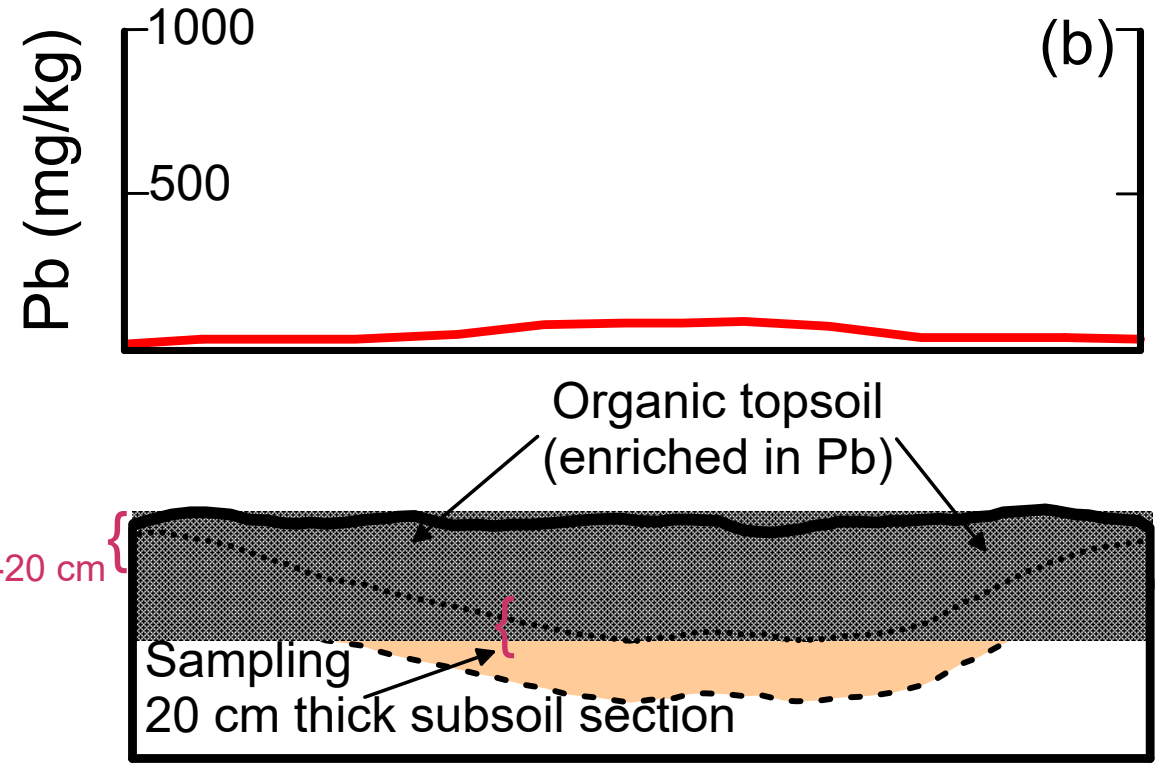
NON-SIGNIFICANT GEOCHEMICAL ANOMALIES

From Demetriades, 2025, Fig. 6, p.11. Hypothetical examples of

(a) a non-significant geochemical anomaly due to the collection of soil samples at a constant depth range that crosscuts different soil horizons (Open University, 1972, Unit 6 Applications of Geochemistry, Fig. 10, p.14, modified).

(b) normal background values due to the collection of soil samples from the same horizon and different depths according to its topographical morphology. Plotted with Golden Software's MapViewer™ v8.





A CASE STUDY EXAMPLE

Since this is a SEGH Fellows Seminar, the example that will be described is an environmental contamination case study that was carried out in 1996.

Because the results are confidential, the exact name and location will not be given.

Case study: Disused dry-cell battery factory.
Note: No Ni-Cd batteries were produced.

Objectives:
(1) To determine potential contamination of soil and groundwater by such elements as Hg, Zn, Mn, Pb, Cd, (Cu, Co, Sb, As, Ni).
(2) To determine the depth of contaminated soil, and
(3) To estimate the volume of contaminated soil.

Mapping scale: 1:5,000.

Planning Stage .....

INFORMATION PROVIDED BY THE COMPANY

1. **Plan of the factory building and the industrial plot without any coordinates.**

2. **The plant produced dry-cell batteries for 23 years (1969-1992) in two phases:**

   - **1969-1981: production of dry-cell batteries which contain Hg, Zn, Mn and Pb, and**
   - **1981-1992: production of dry-cell batteries which contain Zn, Mn and Pb.**

It is noted that the second period is characterised by the absence of Hg from the production of dry-cell batteries.

….. Planning Stage …..

PRELIMINARY INVESTIGATION

1. Site reconnaissance of the site with 1:50,000 and 1:5,000 topographical maps for recording the exact location of the battery factory.
2. The factory site was situated on a comparatively flat surface. In fact, on the floodplain of second-order streams.
3. The surface soil varied from silty-clay to sandy-silt, and was moist and covered by grass, and other bushy vegetation.
4. Sheep were grazing on the neighbouring field, and according to information from the factory worker, they also grazed on the land of the battery factory.
5. The dominant wind directions, according to the local weather station, were from the North-west and West, with the latter being the most dominant.
6. Bibliographical search about the materials used for the production of dry-cell batteries.

….. Planning Stage …..

….. PRELIMINARY INVESTIGATION

6. The 1:50,000 geological map shows that the industrial area is covered by Tertiary – Holocene riverine alluvial sediments comprising mainly marl, clay, sand and conglomerate of Lower Pliocene age. The marls and clays have a high carbonate content. Hence, it is anticipated that the soil samples would have a high concentration of calcium, which was subsequently verified by analysis of the collected samples.

7. Based on the 1:50,000 hydrogeological map, the alluvial sediments are permeable, although towards the north-eastern part of the study area, the proportion of clay is high, resulting in a comparatively impermeable cover, with stagnant rainwater. The water level in the borehole to the east of the property was at a depth of 66.2 metres, and the one to the north-east was at 27.0 metres. The groundwater level in the study area appears to be about 1 metre below the ground surface (based on observations from storm drains around the building, provided, of course, they are connected to the local aquifer).

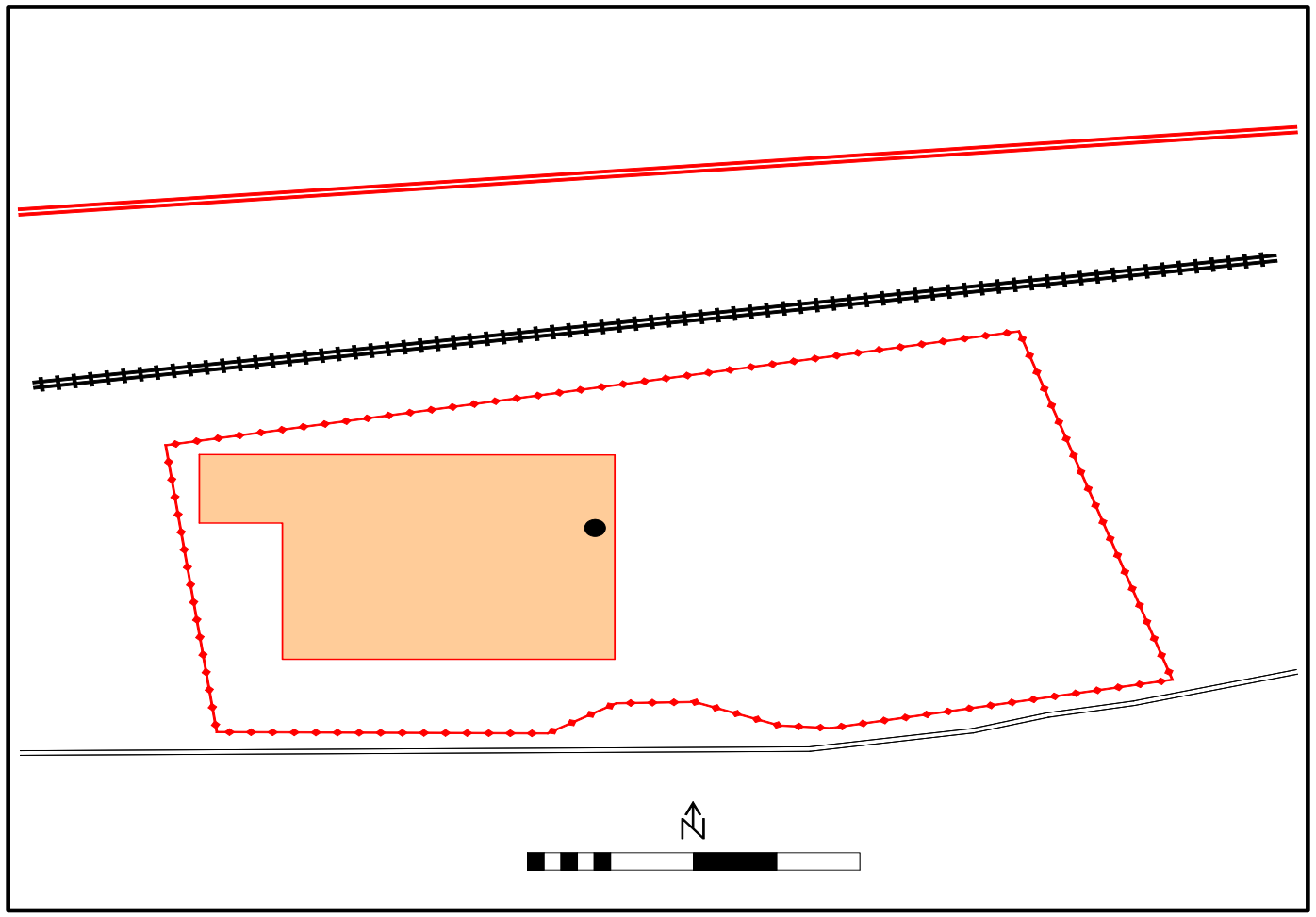
….. PRELIMINARY INVESTIGATION

8. The assessment of contamination by the dry-cell factory is slightly complex when other nearby contaminating sources (the roads and railway) emit the same toxic elements, such as lead (Pb) and zinc (Zn+Fe+Cd). However, the potential contamination from the dry-cell battery factory is more complex, *i.e.*, Pb, Hg, Cd, Mn, Zn, Sb and As. Hence, this difference will be used to distinguish the contamination caused by the roads and railway [Pb ± (Zn+Fe+Cd)] from the more complex battery factory contamination [Hg+Zn+Mn+Pb+Cd ± (Sb+As+Cu+Co+Ni)].

9. The factory chimneys were only about 1 metre above the roof. Hence, it is not expected that the aerial contamination from the single emitting chimney would have travelled a long distance from the factory.

BATTERY FACTORY

….. Planning Stage …..



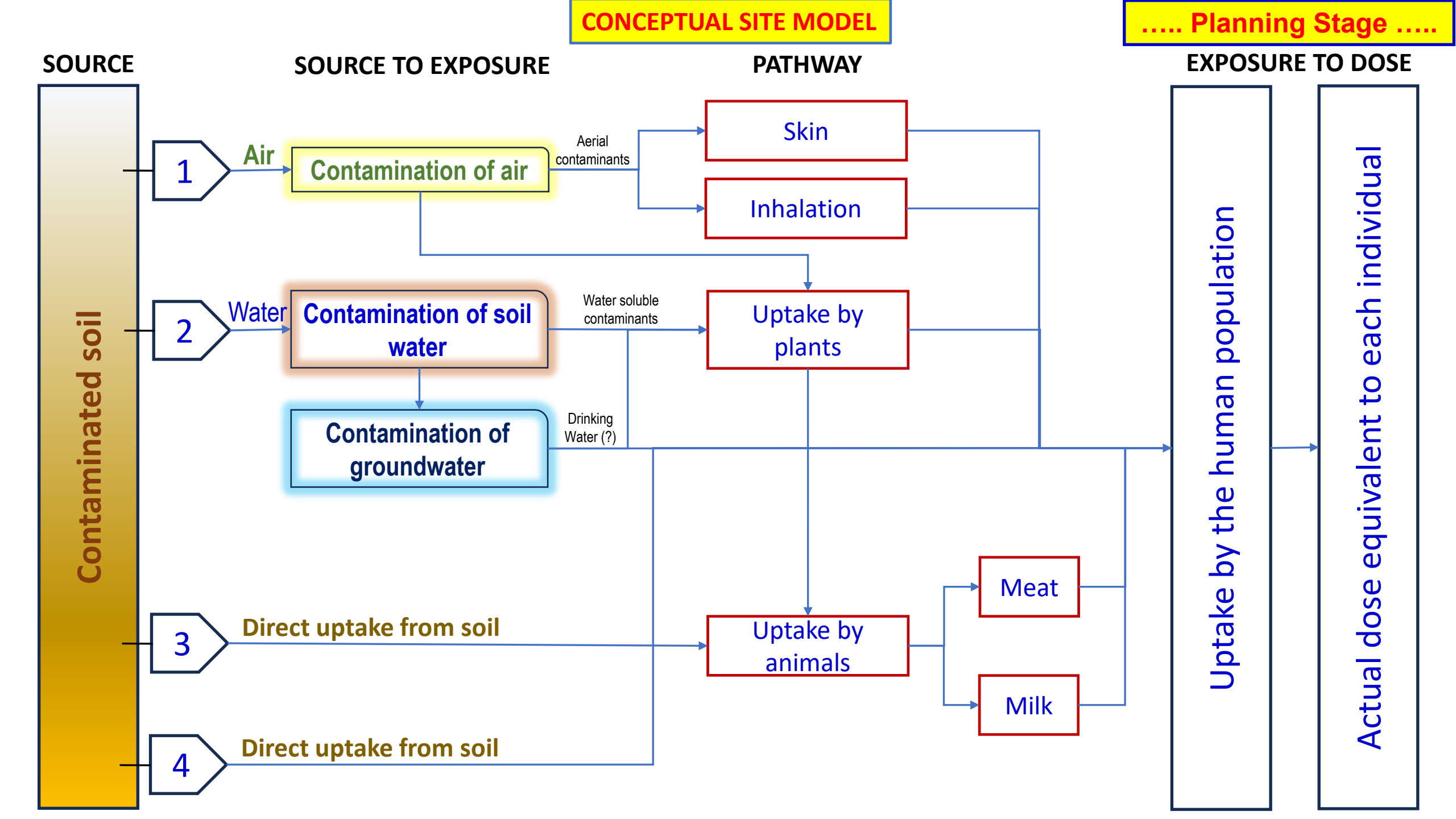
Specifications:

- **Building height 3.5 metres**
- **Height of chimneys above the flat roof was 1.0 metre**

There was only one industrial-emission chimney; the other four chimneys are not industrial emitters but were for aeration.

Plotted with Golden Software's MapViewer™ v8.

10. Based on the collected information, a Conceptual Site Model was developed:-


CONCEPTUAL SITE MODEL
….. Planning Stage …..
SOURCE
SOURCE TO EXPOSURE
PATHWAY
EXPOSURE TO DOSE
Contaminated soil
1
Air
Contamination of air
Aerial contaminants
Skin
Inhalation
2
Water
Contamination of soil water
Water soluble contaminants
Uptake by plants
Contamination of groundwater
Drinking Water (?)
3
Direct uptake from soil
Uptake by animals
Meat
Milk
4
Direct uptake from soil
Uptake by the human population
Actual dose equivalent to each individual

..... Planning Stage .....

Thinking process .....

How to plan an effective sampling plan?

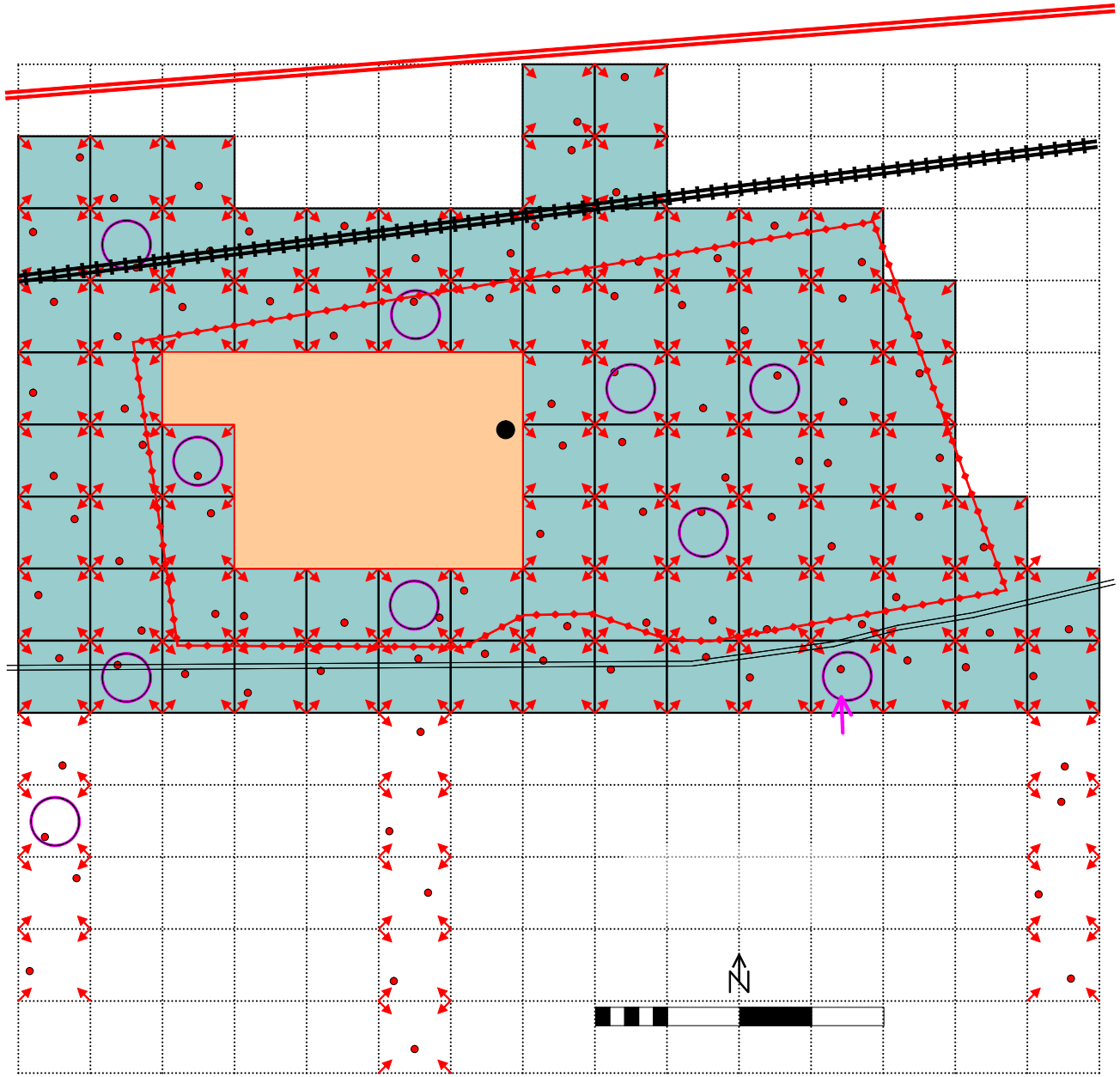
Image produced with Microsoft® Copilot 365

Since, the assessment of contamination should be done in a cost-effective way to reduce the rehabilitation cost, different schemes were tested, *i.e.*, square blocks of

(a) 50 x 50 m;
(b) 25 x 25 m and
(c) 20 x 20 m.

The 50x50 m and 20x20 m block schemes were rejected because the first would be too costly for remediation, and the second too dense, as many samples would be collected.

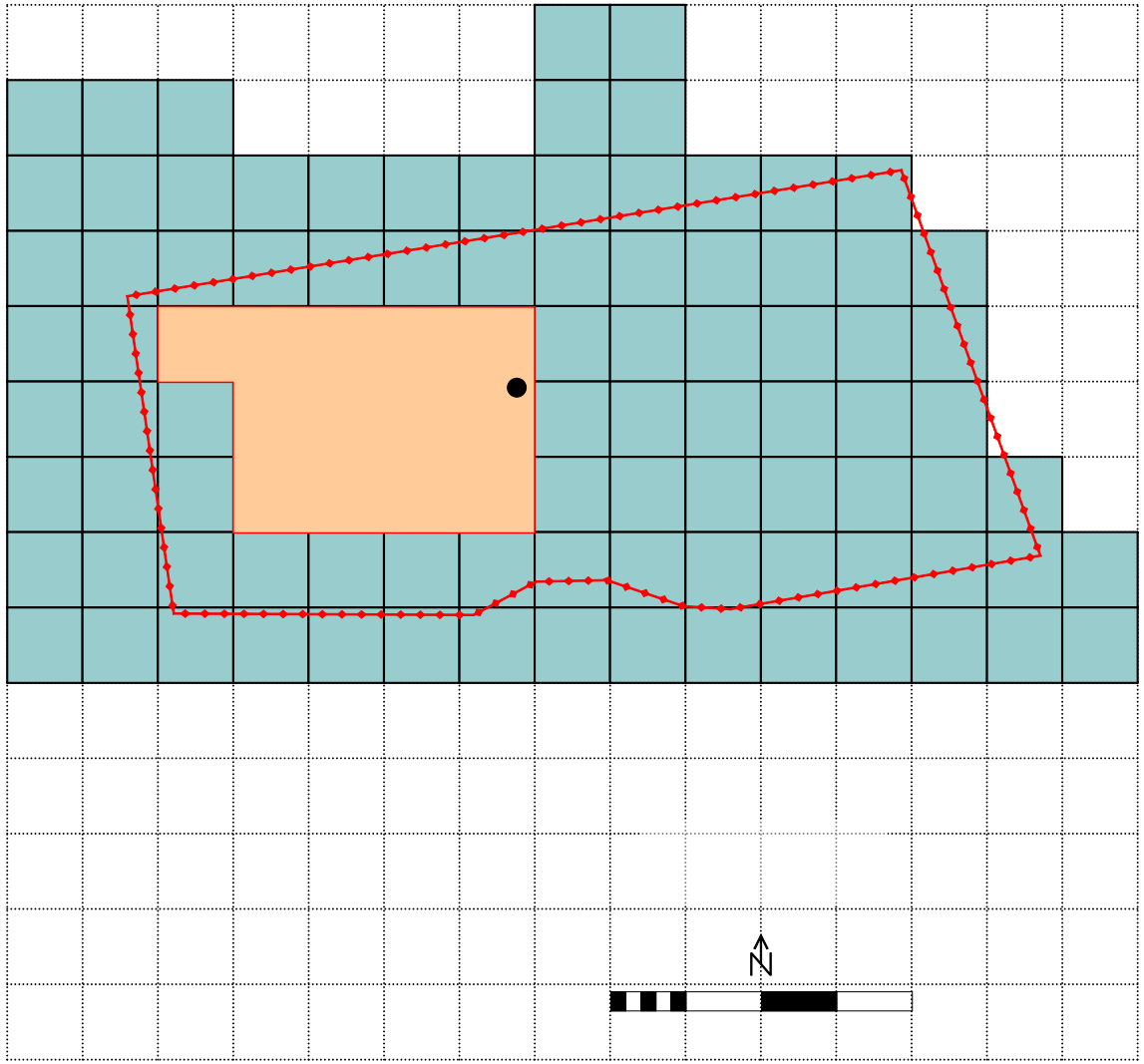
The 25x25 m blocks appear to be the most cost-effective and best suited to the geometry of the factory area.



Based on the collected information and the company's wish for a cost-effective investigation and remediation strategy, the sampling design was decided. It had to take into account other potential sources of contamination, *e.g.*, the Main Road, the Railway Line, and the Secondary Road. Therefore, the sampling plan was extended beyond the factory area to include these potential sources of contamination.

Since, the company wished to know the volume of contaminated soil, an effective sampling scheme had to be developed using square blocks, as already mentioned. The most cost-effective plan was 25 x 25 m blocks. Plotted with Golden Software's MapViewer™ v8.

NOTE: THE RANDOM NUMBERING SYSTEM OF THE SQUARE BLOCKS, AND HENCE THE COLLECTED SAMPLES WERE IN RANDOM ORDER.



Plotted with Golden Software's MapViewer™ v8.

In 1996, the 102-random-number sequence was generated using an in-house FORTRAN program.

Nowadays, the 102 random number sequence can be generated by using the sequence routine at the following web page:-

https://www.random.org/sequences/

Numbers 103, 104, 108, 110 and 118 were added during the sampling campaign because of the decision to extend the blocks to the south of the property.

PROPOSAL TO THE COMPANY

A three-stage survey was proposed to the company management:

i. **Orientation survey, mainly to determine the depth of soil contamination at selected sites.**

ii. **Square block sampling, and after the evaluation of the results, and**

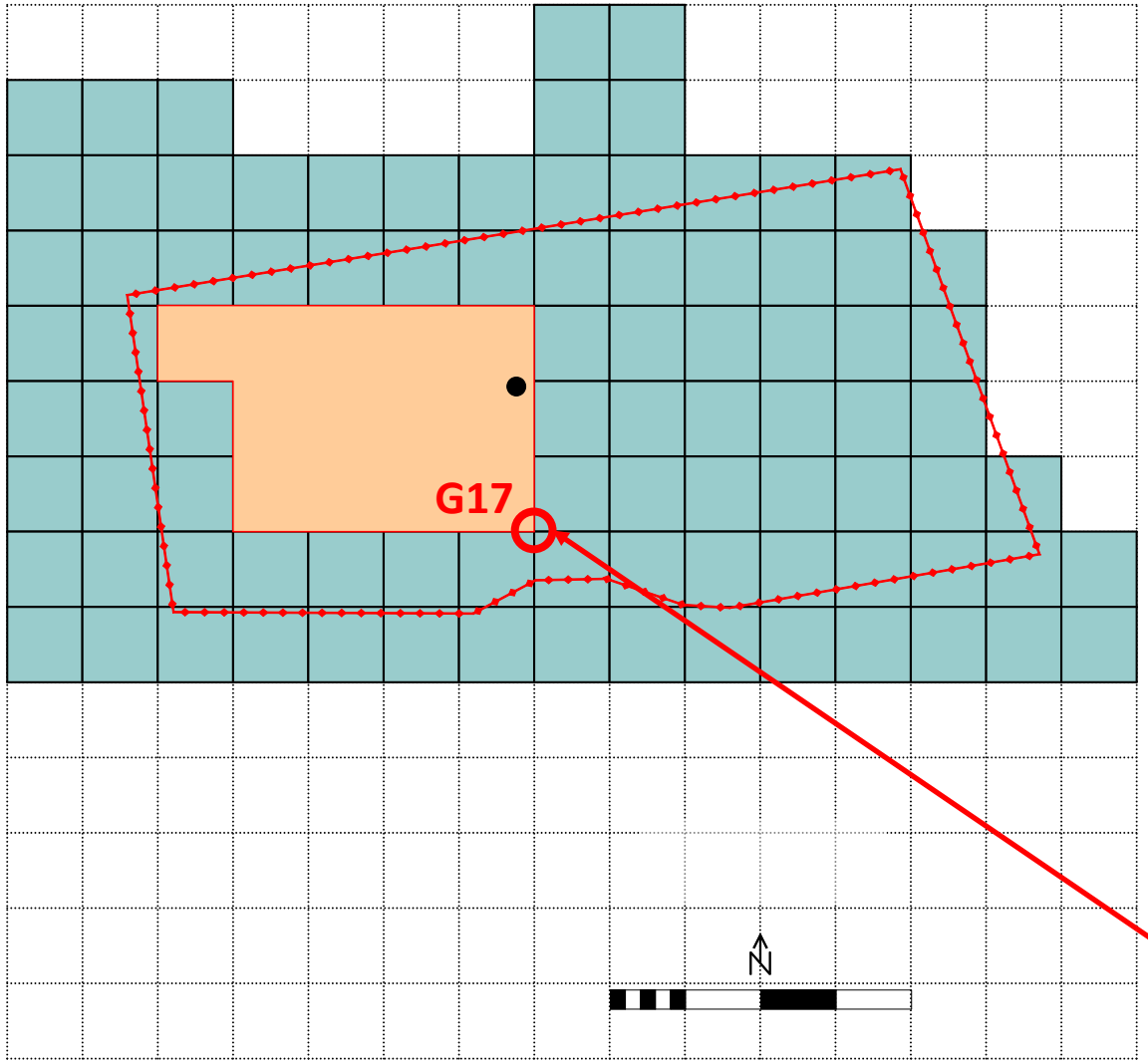
iii. **Sampling of contaminated blocks down to a depth of 100 cm.**

The company management wished to shorten the investigation period as much as possible. So, the recommendation was to proceed directly with stage (ii) the sampling of square blocks, and after the evaluation of the results to proceed with stage (iii).

The company's wish was to carry out the geochemical survey without any outsiders noticing the work performed.

The company provided one local worker to assist in the sampling.

FIELDWORK PLANNING



1. **Laying out the grid**: Since the company did not want any obvious signs to be seen by outsiders, the only solution for marking the sampling sites, instead of using painted wooden pegs, was to use 10-cm-long steel nails with a short red ribbon tied on the top and to write the site number on the ribbon with a black permanent ink marker.
2. A compass and a 50-metre steel tape measure were used to measure the 25-metre distances between the sample sites.

G17 was the reference starting point.

Plotted with Golden Software's MapViewer™ v8.

SAMPLING EQUIPMENT

1.5 inch auger

1.0 inch auger

Sampling soil with an auger is very rare in countries with a Mediterranean-type climate because the soil is usually dry and lacks sufficient clay to retain the sample as the auger is withdrawn from the hole. Fortunately, in this particular case, the soil was moist, and its clay content was adequate for using an auger.

Soil sampling of the first 20 cm was performed with a 1.5 inch auger.

For the soil sampling at depth, two different augers were used:

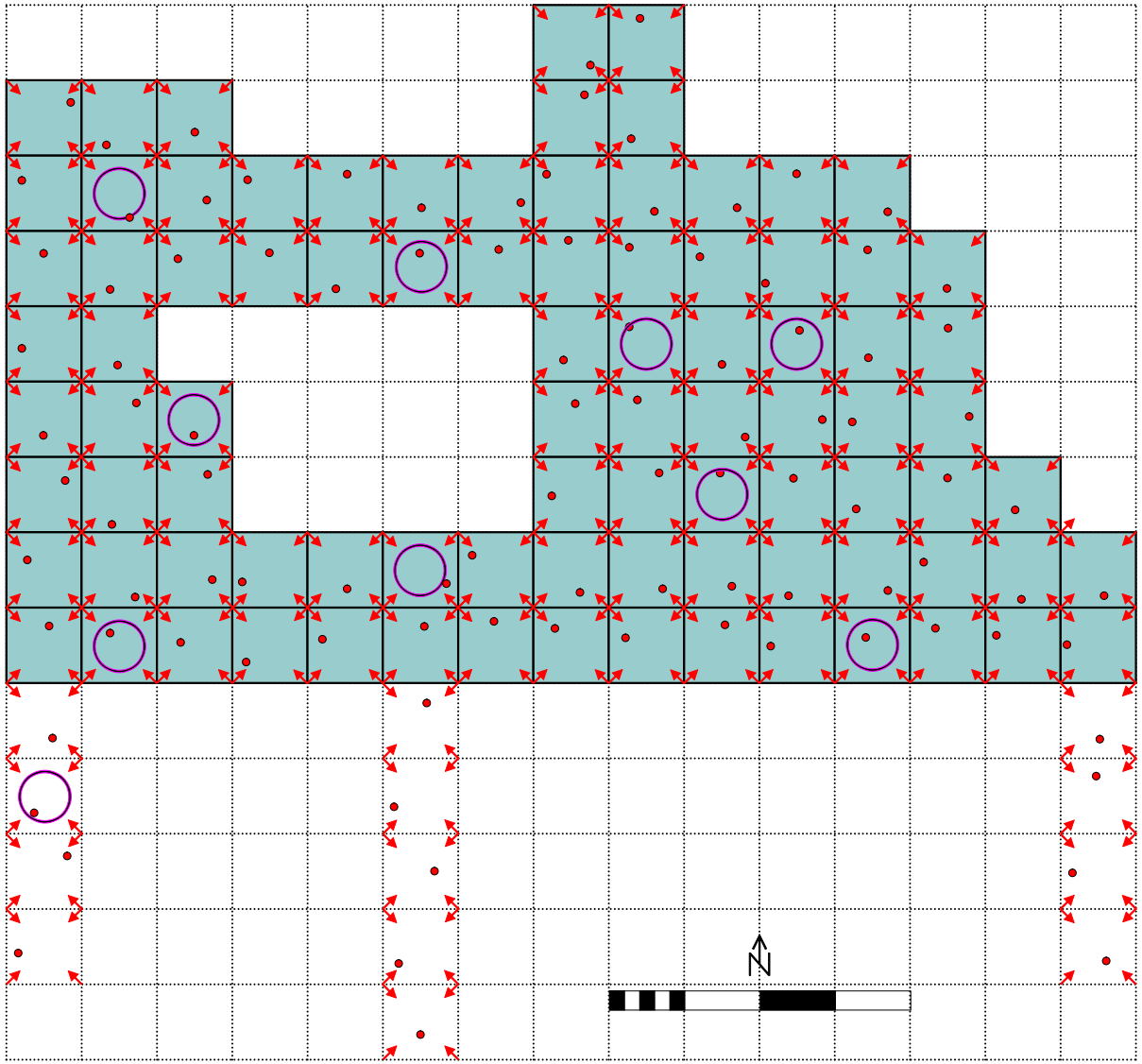
- 1.5-inch auger down to a depth of 40 cm, and
- 1.0-inch auger from 40 to 100 cm depth.

SAMPLING EQUIPMENT

Other sampling equipment was:

- Leather gloves.
- White plastic scoops of two different sizes.
- Chisel-end geological hammer.
- Cotton-lint or white cotton rags for cleaning sampling equipment.
- Certified trace-element free Rilsan® bags.
- 30x60 cm strong plastic bags for packing the Rilsan® sample bags, as a safety precaution during transportation to the sample preparation laboratory.
- Plastic strip locks (or plastic cable ties) for securing the outside plastic sample bags.
- 6x10 cm white cards for writing the sample number on both sides.
- 7.5x11.5 cm zip-lock plastic bags for holding the 6x10 cm white cards.
- Blank permanent ink markers.
- Heavy-duty carton boxes for packing samples.
- Strong PVC packing tape.
- 6 mm natural sisal rope.
- Heavy-duty cutter knife with replacement blades.
- Portable first aid kid.

SAMPLING: FIRST PHASE .....



Map showing the square block sampling scheme over the battery factory property. Each square block has been assigned a random number for sampling, and the 10 duplicate field samples were again randomly selected and are indicated by magenta-coloured circles.

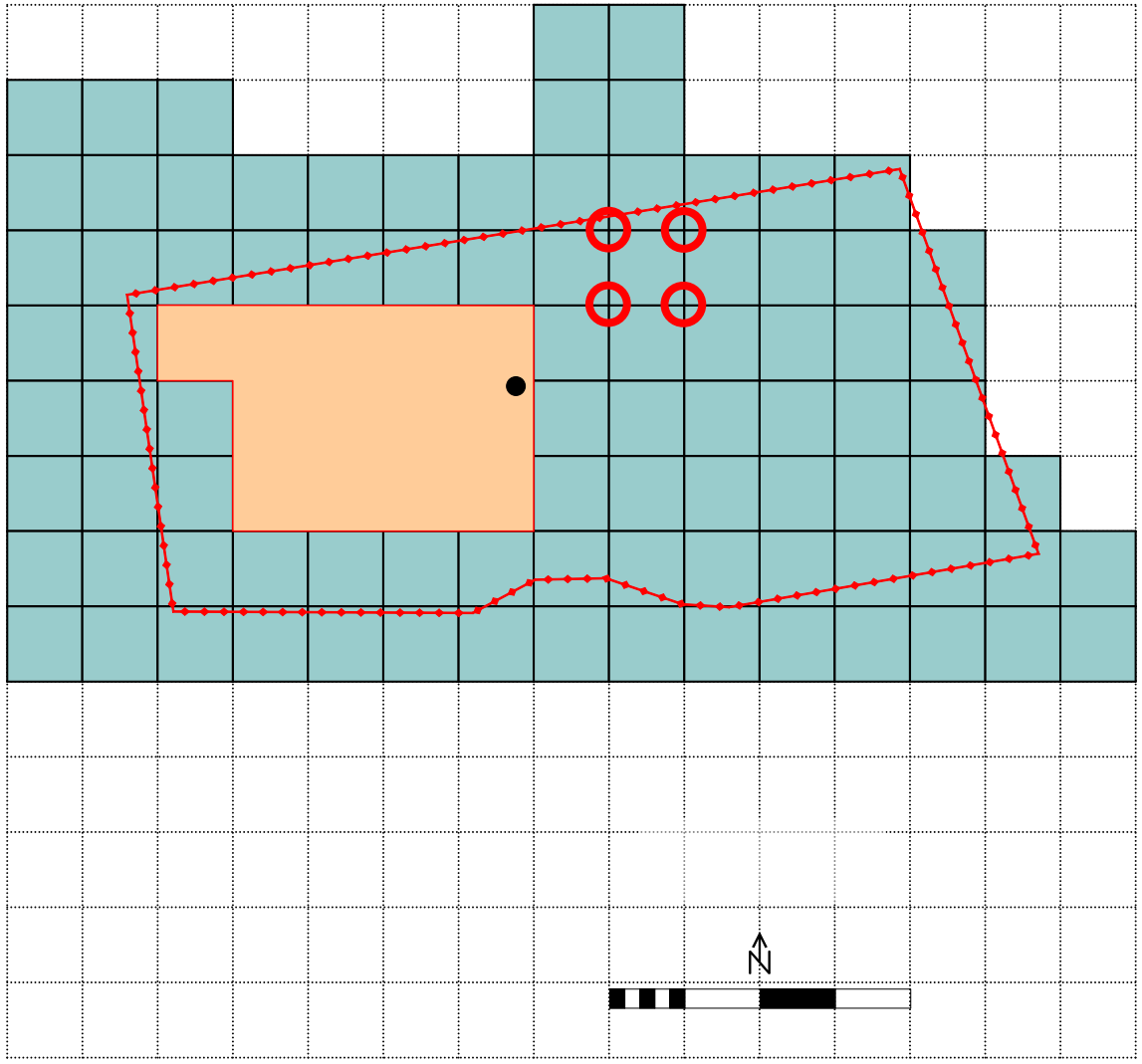
The composite surface soil samples (0-20 cm) of 1 to 1.5 kg were collected from the four corners of each block, and the fifth sampling site (red dot with black rim) was randomly selected within each square.

Rolling sampling scheme: The red arrows at the corners of each square block show how each corner soil sample was split into equal portions and placed in the sampling bag of the neighbouring square block. The blue-coloured sample numbers indicate the soil samples collected outside the factory property to estimate the geochemical background. Plotted with Golden Software's MapViewer™ v8.

(From Demetriades, 2025, Fig. 30, p.33).

NOTE: At each sampling site, field observations were recorded in a notebook.

….. SAMPLING: FIRST PHASE …..



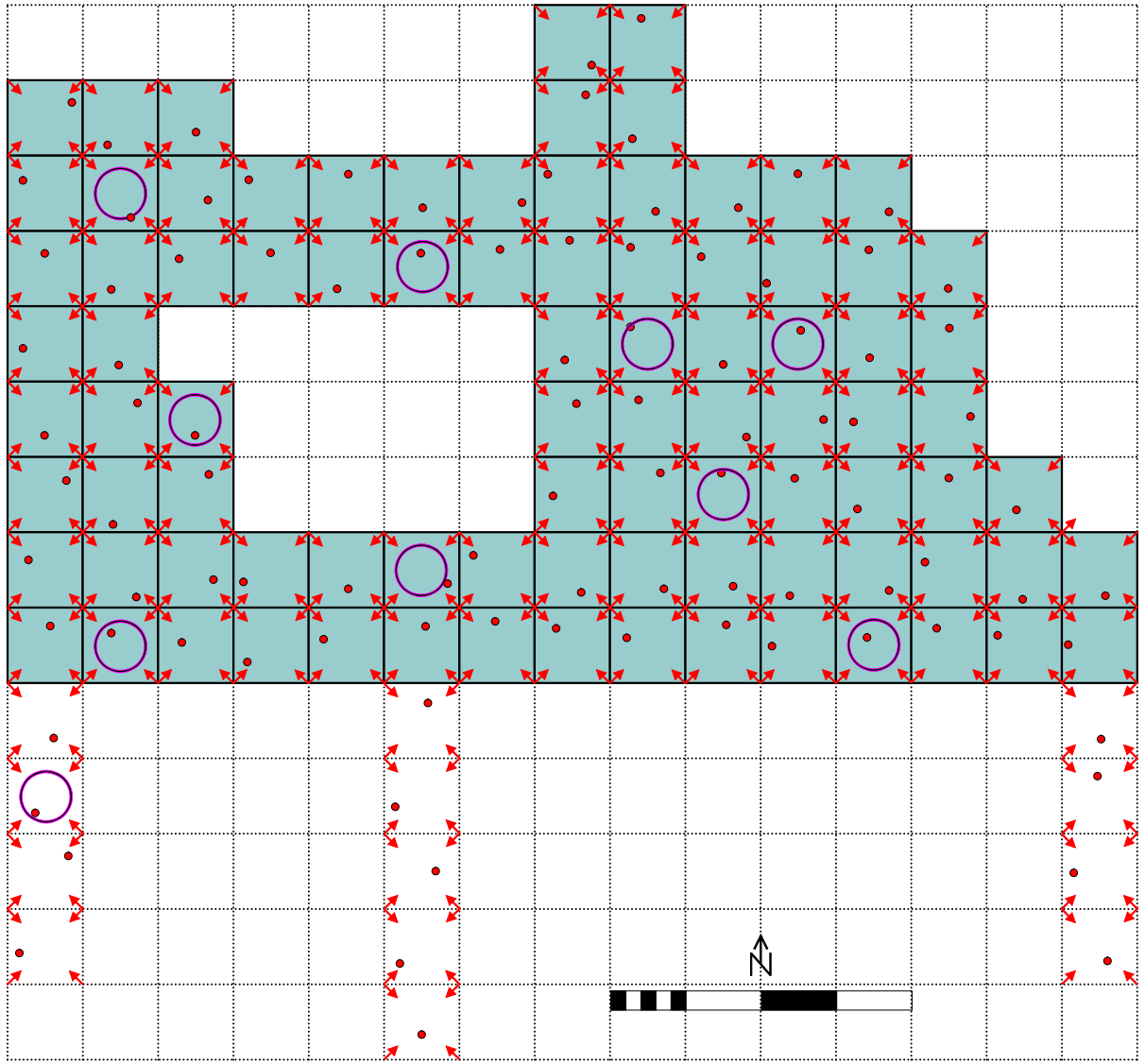
Plotted with Golden Software's MapViewer™ v8.

In addition to collecting composite surface soil samples from 0 to 20 cm, it was decided during this phase to test the depth to which industrial contamination extends.

Composite soil samples were collected at 20 cm intervals down to a depth of 80 cm from sites K18, K19, L18, and L19, which delineate block 52.

The reason for selecting these sampling sites was that they were near the temporary disposal and storage area of the factory's solid wastes. Also, this area was waterlogged. Hence, it was a likely place for the transport of contaminants to deeper soil horizons.

….. SAMPLING: FIRST PHASE …..



Plotted with Golden Software's MapViewer™ v8.

The 20-cm thick profile soil samples were taken with extra care to avoid any cross-contamination.

The auger and plastic scoop were thoroughly cleaned before collecting the next sample.

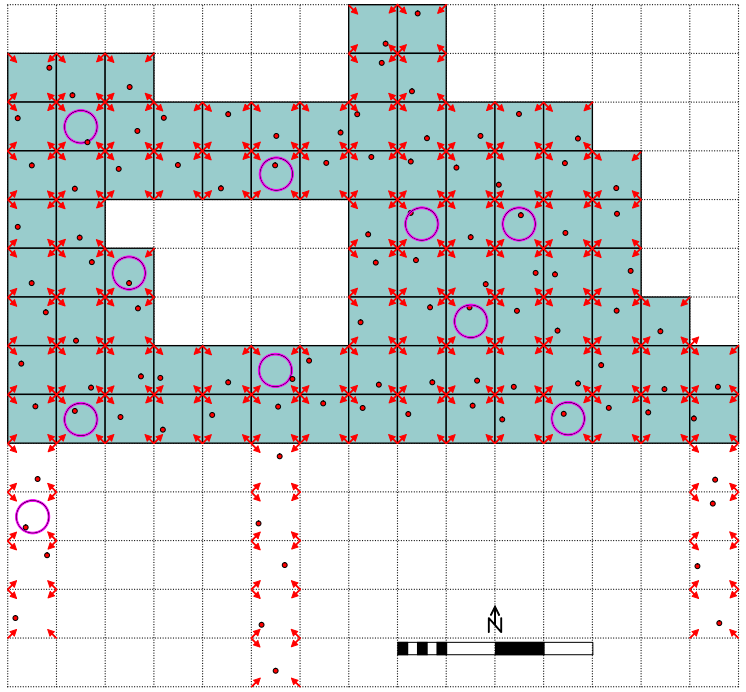
ALL soil samples were placed in pre-numbered Rilsan® bags, and the pre-numbered card in the small self-sealed plastic bag was placed on top of the sample. The bag was secured with a plastic strip lock.

For safety during transportation, the Rilsan® bag containing the soil sample was placed in a strong plastic bag and secured again with a plastic strip lock.

….. SAMPLING: FIRST PHASE …..

How was the soil sample subdivided into equal parts for placing in different sample bags?

1. **The 20-cm auger soil samples retrieved from four holes around the sampling point were placed on a thick transparent square plastic sheet of 50 x 50 cm.**
2. **They were broken up with the chisel-end geological hammer and homogenised.**
3. **Depending on the position of the sample site, the homogenised sample was divided into 2, 3 or 4 equal parts, and the sub-samples were placed in different pre-numbered bags.**



Plotted with Golden Software's MapViewer™ v8.

Images generated with Microsoft® Copilot 365.

LABORATORY: Sample preparation and analysis

The 102 surface soil samples were placed in consecutive number order and sent by the company, together with the 10 duplicates and 16 profile soil samples to OMAC Laboratories Ltd. (Loughrea, County Galway, Ireland) – now part of ALS Laboratories.

Sample preparation: The soil samples were dried in thermostatically controlled ovens at a temperature <35°C, because Hg is sensitive to higher temperatures. After drying, the soil samples were disaggregated in a porcelain mortar with a porcelain pestle, and sieved through a <0.177 mm (<80 mesh) screen.

Laboratory analysis of soil samples: An aliquot of 4 grams of the <0.177 mm fraction was digested by hot aqua regia, and Ca, Cd, Co, Cu, Fe, Mg, Mn, Ni, Pb, and Zn were determined by double-beam Atomic Absorption Spectroscopy (AAS). Arsenic and Sb were determined by a hydride generation apparatus, and Hg with an AAS flameless reduction method. The pH of the soil was also determined.
The laboratory re-analysed every tenth project sample, as well as international and internal reference materials and method blanks.

LABORATORY: Sample preparation and analysis

The battery factory contamination is caused by the following elements:

Hg+Zn+Mn+Pb+Cd ± (Sb+As+Cu+Co+Ni).

In addition, Ca, Fe and Mg were determined.

<u>Calcium</u>: The combination of high concentrations of Ca with an alkaline pH severely restricts the mobility of contaminants in solution.

<u>Iron</u>: Its purpose was to ascertain whether the contaminants are adsorbed onto iron oxides, since in such a case their release is hindered.

<u>Magnesium</u>: High concentrations of Mg in soil have the property of hindering the uptake of chemical elements from soil (Gough *et al*., 1979).

LABORATORY Results

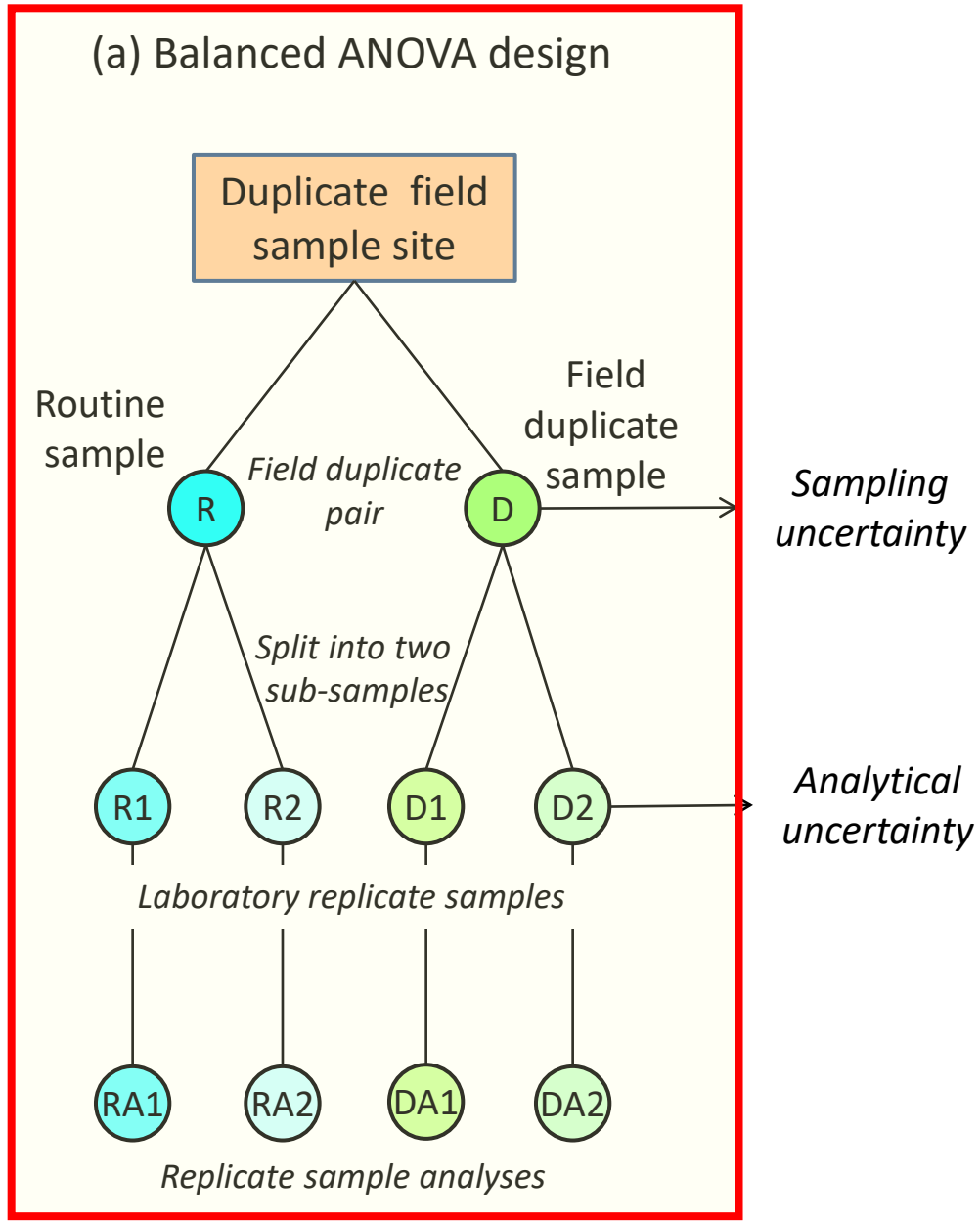
SampleNo	HG_ppb	Hg_ppb_Repeats
S1	140	110
S2	<50	40
S3	<50	50
S4	<50	40
S5	<50	30
S6	310	380
S8	<50	60
S9	<50	30
S10	<50	50
S11	<50	50
S12	<50	160
S13	<50	30
S14	560	610
S15	290	290

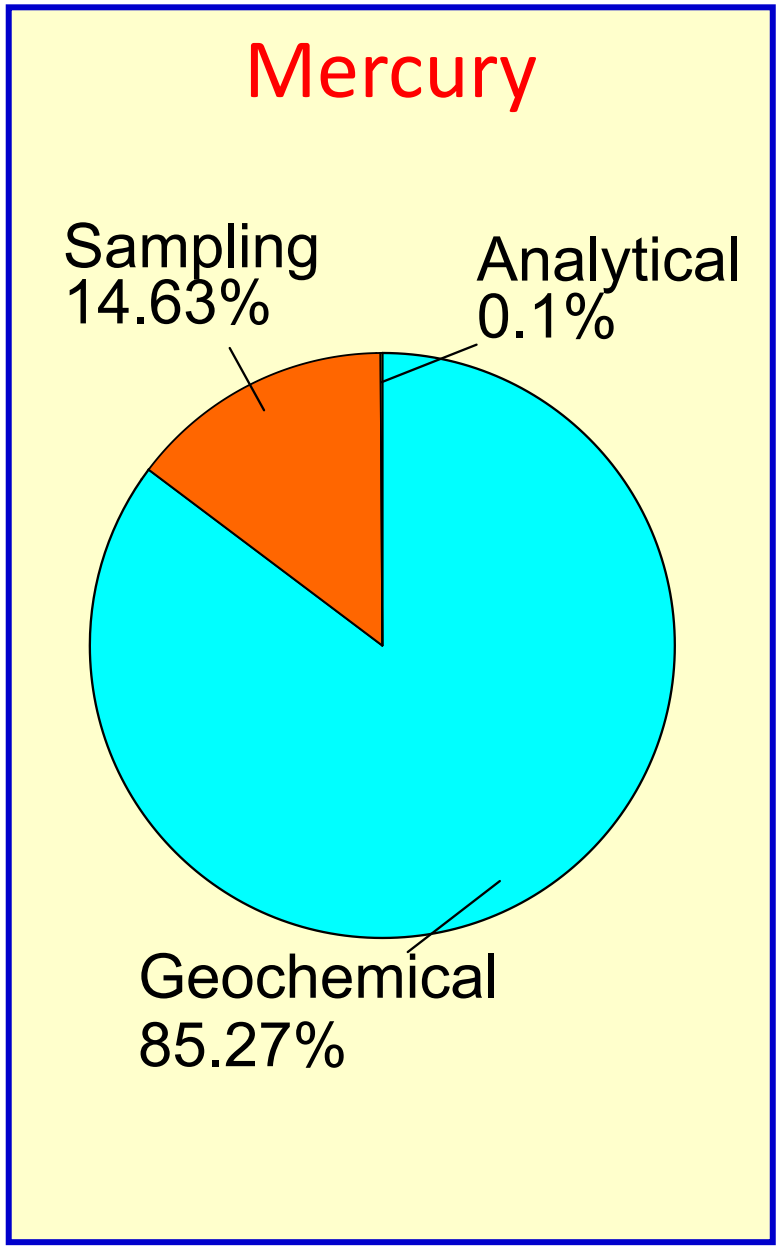
Upon receiving the analytical results, a visual check is usually made.

The Hg results appear to have a high lower detection limit (50 ppb), and the reagent blanks also showed the same results. Hence, the laboratory was contacted for an explanation.

It was discovered that the reagents used contained 50 ppb Hg. Hence, Hg was reanalysed with a detection limit at 10 ppb, and it can be seen that there is an improvement in the results, especially at the lower end – the geochemical background.

QUALITY CONTROL

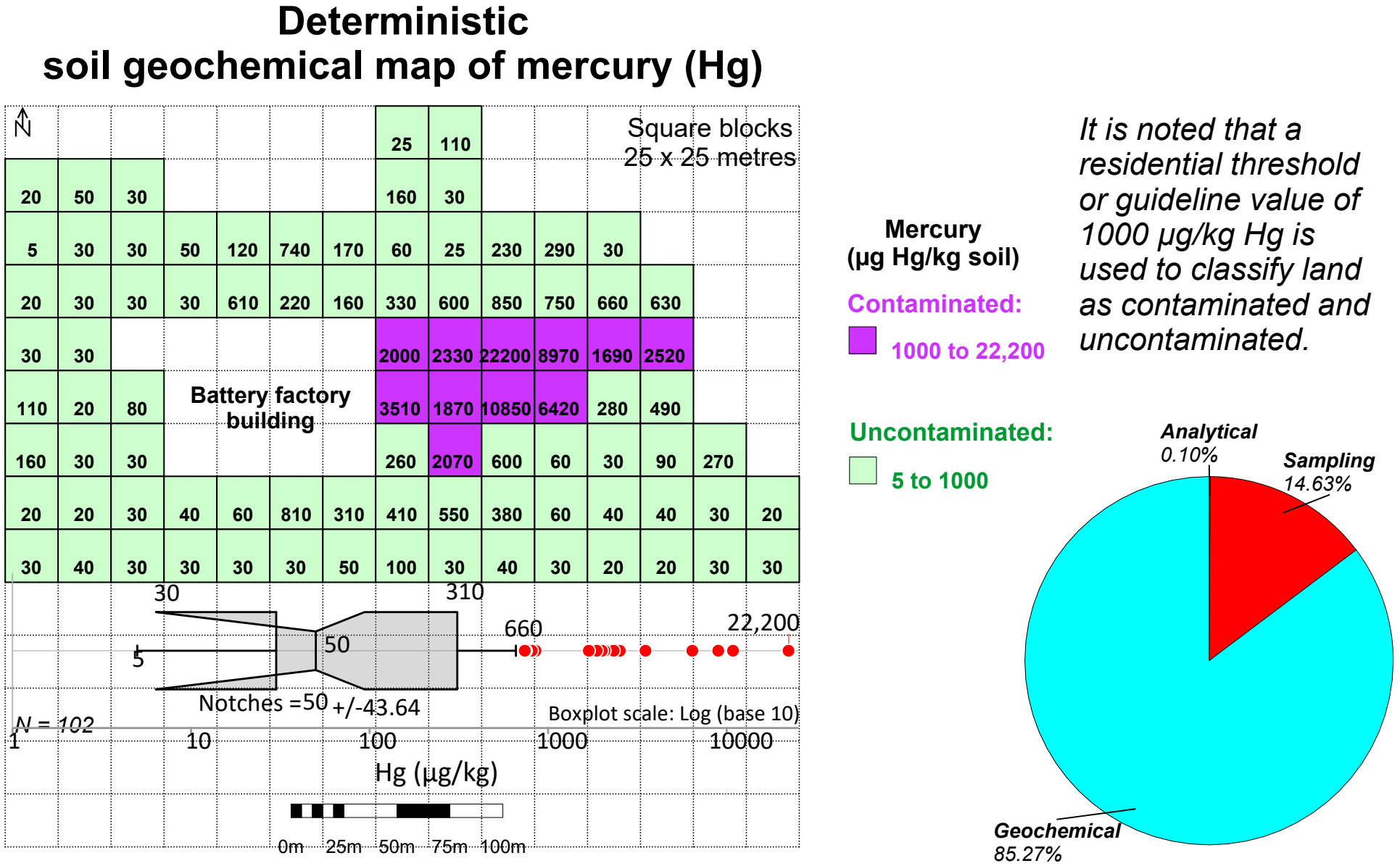




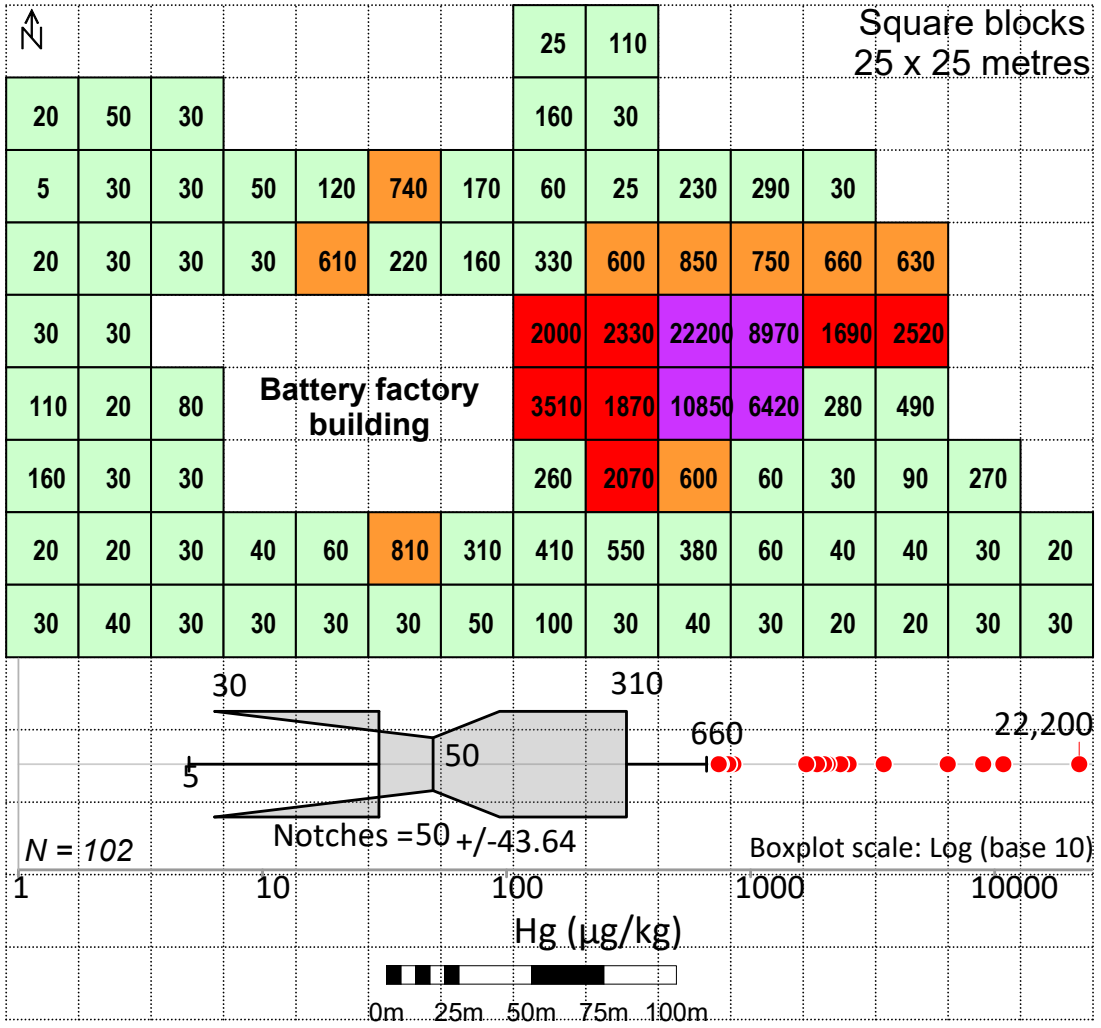
(a) Balanced and (b) unbalanced ANOVA sampling and analytical designs for the estimation of sampling, analytical and geochemical variance, and measurement uncertainty. Plotted with Microsoft® 365 PowerPoint.

(From Demetriades, 2025, Fig. 31, p.34).

Deterministic geochemical map showing the distribution of Hg concentrations in surface soil samples in blocks of 25 x 25 m. The contaminated and uncontaminated parts of the battery factory property are defined by the residential guideline value of 1000 µg/kg Hg. The pie chart shows the apportionment of variance, and the notched boxplot the statistical distribution of Hg data (From Demetriades, 2025, Fig. 32, p.35; modified from Demetriades, 2011b, Fig. 6.4, p.90). Map and diagrams plotted with Golden Software's MapViewer™ v8 and Grapher™ v21, respectively.



(a) Probabilistic soil geochemical map of mercury (Hg)



Mercury (µg Hg/kg soil)

Contaminated:

4263 to 22,200

Probably contaminated:

1000 to 4263

Possibly contaminated:

566 to 1000

Uncontaminated:

5 to 566

Using the "short-cut" method the uncertainty is expressed on the threshold value of 1000 µg/kg Hg, i.e.,

Upper limit:
T+ U = T(1+ U%/100)
Lower limit:
T - U = T(1 - U%/100)

Expanded uncertainty at the 95% confidence level is
U% = 76.54%
U = 76.54/100 = 0.7654

Probabilistic classification is calculated by:

Contaminated:
C = T + U or C - U = T
*C - 0.7654*C = 1000*
*0.2346*C = 1000*
C = 4263 µg/kg Hg

Uncontaminated:
C = T - U or C + U = T
*C + 0.7654*C = 1000*
*1.7654*C = 1000*
C = 566 µg/kg Hg

Probabilistic risk assessment geochemical map showing how the results of the balanced quality control design of duplicate field sampling were used to estimate measurement uncertainty, and to classify the blocks into:

(i) uncontaminated,

(ii) possibly contaminated,

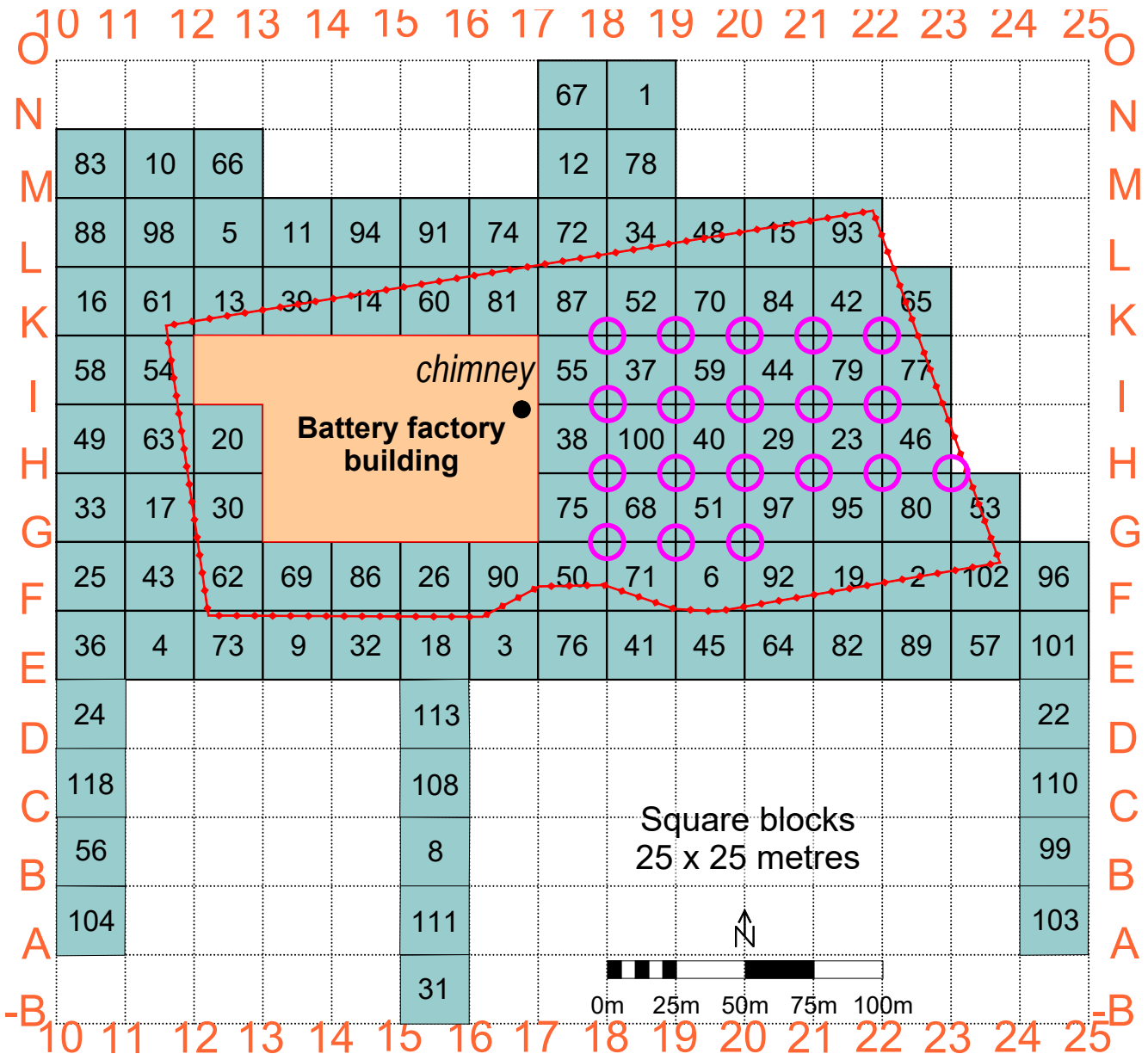
(iii) probably contaminated, and

(iv) contaminated

using the guideline value of 1000 µg/kg Hg as threshold.

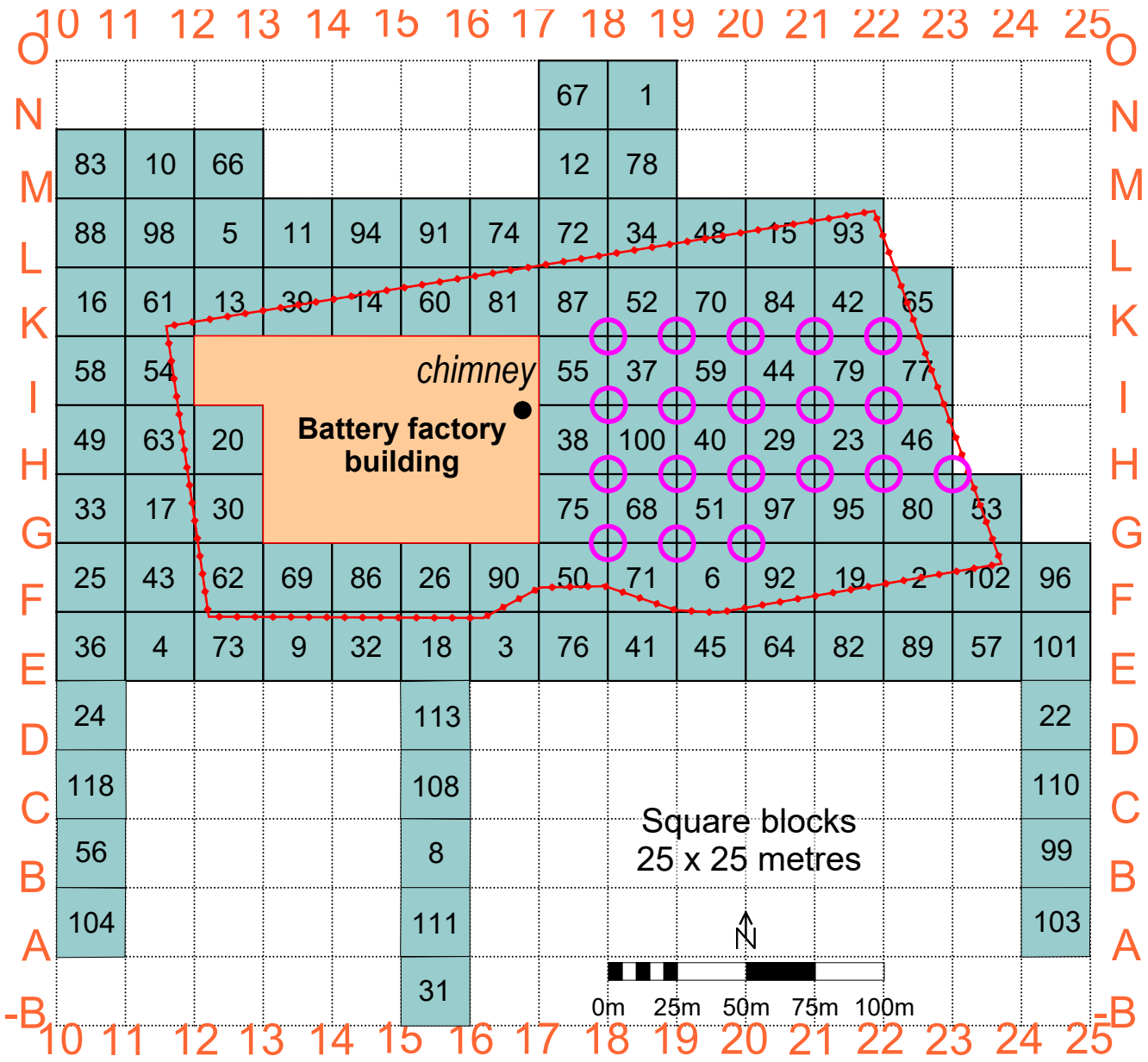
(From Demetriades, 2025, Fig. 33, p.36; modified from Demetriades, 2011b, Fig. 6.5, p.91). Map and notched-boxplot plotted with Golden Software's MapViewer™ v8 and Grapher™ v21, respectively.

INTERIM REPORT



With the completion of the first geochemical survey using surface soil, soil samples down to a depth of 20 cm, and the first 4 profile samples down to a depth of 80 cm, an interim report was submitted to the company, together with the proposed plan for sampling down to a depth of 100 cm at selected sites where the Hg and Zn had high concentrations.

SOIL PROFILE SAMPLES



SECOND PHASE

In total, 87 soil samples were collected from 19 sites down to a depth of 100 cm from G18-20, H18-23, I18-22 and K18-22.

ENSURING COMPARABILITY

Since it was important to ensure comparability between the May 1996 analytical results and those from August 1996, the following 10 samples were randomly reanalysed within the 87 soil profile sample suite: S23, S25, S38, S40, S59, S79, S83, S86, S92, and S100.

GROUNDWATER SAMPLING and RESULTS

In total, 8 groundwater samples were collected:

- **Two from the borehole that provided water to the kitchen and garden water tap, and**
- **Six samples from the stormwater wells.**

The analytical results for the 8 groundwater samples did not show elevated concentrations of the elements (Cd, Co, Cu, Fe, Hg, Mn, Ni, Pb, and Zn) originating from the dry-cell battery plant's operation.

The pH of groundwater varied from 7.0 to 7.5. So, under these conditions, the groundwater is unlikely to dissolve potentially toxic elements adsorbed to soil particles.

CONCLUSIONS IN THE FINAL REPORT

The emissions of potentially toxic elements during the production of dry-cell batteries and the incineration of wastes, such as paper impregnated with Hg (1969-1981), caused the aerial transportation and deposition of toxic elements (mainly Hg and Zn) in soil to the eastern part of the factory because of the prevailing westerly winds.

The soil profiles show that toxic element contamination is primarily in the first 20 cm of soil and gradually decreases with depth. Transport to lower soil layers occurs in areas where rainwater accumulates.

Mercury and Zn appear to be loosely bound on the Fe-Mn oxides in soil, as indicated by their low correlation coefficient with Fe and Mn, and are also possibly adsorbed to clay minerals.

It was concluded that although Hg and Zn contamination of soil is significant, the risk analysis indicates that their spread and environmental impact effects are low. Since, the property is in an industrial area, and the groundwater has not been affected, soil remediation is not necessary.

Further reading

GEMAS Quality control report on the aqua regia extraction analysis results

http://www.ngu.no/upload/Publikasjoner/Rapporter/2009/2009_049.pdf

GEMAS Quality control report on the results of

- **total C and S (NGU)**
- **XRF major & trace elements (BGR)**
- **TOC (FUGRO)**
- **CEC (Slovak Republic)**
- **pH in $CaCl_2$-extraction (NGU)**
- **PSD - particle size distribution (FUGRO)**

Particle Size Distribution results are the only GEMAS-results that could not be accepted due to poor quality.

PSD was predicted using CSIRO's MIR-spectra based on a model developed for European soils (cooperation between BGR, CSIRO & ARCHE).

http://www.ngu.no/upload/Publikasjoner/Rapporter/2011/2011_043.pdf

GEMAS Quality control report on the results of

- Particle size analysis (clay, sand, silt – estimated by MIR)*
- Lead isotopes
- Extraction by Mobile Metal Ions method (SGS)
- Quality control of project standards Ap & Gr

* Collaboration between BGR, CSIRO & ARCHE for the development of European MIR model

http://www.ngu.no/upload/Publikasjoner/Rapporter/2012/2012_051.pdf

Association of Applied Geochemists

Writing Geochemical Reports

3rd Edition

Lynda Bloom and Owen P. Lavin

Editors

I strongly recommend the consultation of this particular report.

https://www.appliedgeochemists.org/publications/writing-geochemical-reports-3rd-edition

Rebuilt front cover by Microsoft® Copilot 365

ORIGINAL POWERPOINT PRESENTATIONS

Apart from the YouTube Video of this seminar talk, which will be uploaded to the SEGH Fellows website page, and the PDF file of the presentation (https://segh.net/seghlive-fellows), you can download the **original PowerPoint presentation** by using the following hyperlink:

https://u.pcloud.link/publink/show?code=kZXDB40Z6h5xSQzk2BBRn4zf8d2B5H64xfuV

In the same folder, you will also find the original PowerPoint presentations of my previous SEGH Fellows seminars.

The IUGS Manual of Standard Methods presents, for the first time, a comprehensive overview of the standardised methods that should be employed across the land surface of the Earth to map the distribution of chemical elements in rock, soil, sediment and water.

IUGS

IUGS Commission on "Global Geochemical Baselines"

Mapping the Geochemistry of the Earth's Land Surface

What is needed is a robust project management structure that is independent of the interest of an individual nation or organisation, and most importantly Political will.

Thank you for your attention

@CGGBIUGS

@CGGB_IUGS

https://www.youtube.com/channel/UC51fN-9mrg3_br6I-xbeO9Q/videos

https://www.globalgeochemicalbaselines.eu/

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Open University (1972) Geochemistry—A Second Level Course: (4) Geochemical Reactions; (5) Geochemical Cycles; (6) Applications of Geochemistry. Walton Hall: The Open University Press.