Brian K. Townley

Writing Geochemical Reports

Second Edition

Guidelines For Surficial Geochemical Surveys

The Association of Exploration Geochemists Special Volume No. 15

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DEDICATION

This guideline to *Writing Geochemical Reports* is dedicated to the memory of Dr. Stanley (Stan) J. Hoffman. Stan obtained his joint Honours B.Sc. degree in Geology and Chemistry in 1969 from McGill University winning the Logan Gold Medal for highest standing. He went on to complete his M.Sc. (1972) and Ph.D. (1976) degrees at the University of British Columbia with Dr. K. Fletcher. While obtaining his degrees at UBC, Stan began his working career with BP Minerals where he remained as Chief Geochemist until 1990. He then formed Prime Geochemical Methods Ltd. where he provided geochemical consulting services until his untimely passing in 1994.

Stan could be described as a passionate geochemist dedicated to improving the knowledge base of geochemists and "nongeochemists". He was outspoken in pointing out the reasons for failures of geochemical surveys and how surveys were misapplied or misinterpreted. Stan's "Pearl Harbour" column in the *Explore* newsletter described these failures and provided suggestions for improvement so that all could avoid repeating the same mistakes.

He was visionary in advocating the application of selective extractions for use in mineral exploration, back in his AEG presidential address in 1989, and I'm sure would be pleased to see its application with the use of multi-element data for almost the complete periodic table. Stan was always passionate on the use of multi-element *aqua regia* ICP data for more than base metals alone as the data frequently provided much insight to help interpret the data. He was an advocate of what could be learned from multidisciplinary studies in the environmental, agriculture, remote sensing, hydrology, analytical, computer technology and other fields of study, and has been described as "one of the few who really understood geochemistry".

Stan worked tirelessly as AEG Councilor and President of the association as well as on AEG symposia and recruiting new members for the association. In fact I was one of his recruits both into the field of geochemistry and as a member of the AEG. The first version of *Writing Geochemical Reports* was put together as a consultative document by Stan in 1986 and provided a much-needed reference for what should be included in a geochemical report. This second edition revises and updates the previous edition to current standards, and builds upon Stan's foundation.

Eric L. Hoffman, PhD
Ancaster, Ontario
November, 2000

CONTRIBUTORS (Second Edition)

The following individuals have made a significant contribution to preparation of this document. This is not to say that all contributors would agree with all aspects of this manual, but their efforts have been instrumental in achieving the consensus represented by this work. Their assistance is gratefully acknowledged.

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1.0 INTRODUCTION

"Writing Geochemical Reports" is designed to provide guidelines for the preparation of exploration geochemical survey reports. The guidelines are primarily applicable to early-phase exploration surveys such as the collection of soils, stream sediments, lake sediments and other near surface sample media. *Writing Geochemical Reports* is not a procedure manual; a geochemist should be consulted for program design, implementation and interpretation.

Writing Geochemical Reports is directed toward geologists and geochemists employed by mining companies who write routine internal reports or reports suitable for distribution to joint venture partners. Other requirements for securities exchanges or for the purpose of submission to governments (in order to keep properties in good standing) may not be included in *Writing Geochemical Reports*. Readers are advised to consult with local authorities to determine specific requirements, if any.

A primary function of any geochemical report is to provide a permanent record of the work performed and the results obtained. In addition, the writer must provide the reader with all the information necessary to confirm the statements and conclusions of the user as well as to consider alternative interpretations. For these reasons, the first responsibility of the writer is to provide the original data, in an unaltered form.

The second objective of the report is to document areas prospective for mineralization based on geochemical surveys. A full description of the sampling and analytical methods as well as the data and assumptions used to generate the interpretation must be provided.

These guidelines have been developed to ensure that descriptions of procedures and data are complete and systematic. In addition, specific criteria for the preparation of geochemical maps are recommended.

Writing Geochemical Reports is not intended as a style guide and does not include references to English grammar, abbreviations or spelling. Readers are referred to other documents such as Grant (1998), Hansen (1991), Berkman (1989) and Bates *et al.* (1999).

It is assumed that individuals writing reports will have access to computers with at least spreadsheet and word processing software. In some instances, drafting or map generating software may not be available, and some consideration is given to circumstances where maps will be drafted manually. Presumably, the report writer will have access to photocopiers and the facilities to reproduce large maps. Some recommendations are included regarding the use of software and hardware that may not currently be available to all authors, but it is expected that these items will become more common in the future (*i.e.*, use of Geographic Information Systems, advanced statistical software, CD-ROM Read/Write hardware, scanners, colour plotters, *etc.*).

2.0 GEOCHEMICAL REPORT OUTLINE

The standard format of a comprehensive geochemical report is outlined in Table 1.

Each of the sections will be described in sequence. Note that the summary section is written after the Discussion of Results section but is often positioned at the beginning of the report. This brings key information to the early attention of readers and also facilitates the decision as to whether or not the report is of sufficient interest to warrant in-depth study of re-evaluation.

3.0 TITLE PAGE

The title page heading the report contains the following information:

- a concise title,
- the property, concession or claim name (*e.g.*, The GOLD Claims),
- company/organization affiliation,
- a map reference to the property location,
- the author(s) of the report and their professional designation (*e.g.*, P.Geo, Ph.D., *etc.*),
- date the report was completed, and
- report number (optional).

Table 1. Standard format of a comprehensive geochemical report

Table of Contents	Appendices	Maps
• Title Page • Summary • Table of Contents • Introduction • Location and Access • Climate and Vegetation • Legal Property Description and Ownership • Property History/Previous Work • Geology • History of Weathering and Transport • Geophysics (if available) • Surficial Environment • Orientation Surveys • Field Procedures • Laboratory Procedures • Quality Control • Description of Results (mostly factual) • Discussion of Results (geochemical interpretation) • Conclusions • Recommendations (with budget if appropriate) • References	• Sample Descriptions and Locations • Analytical Procedures • Quality Control Data • Laboratory Certificates/ • Tabulation of Geochemical Data • Univariate Statistics • Multivariate Statistics • Summary of Costs (if necessary) • Statement of Qualifications of the Author (if necessary)	• Location • Geology • Quaternary Geology or Regolith Landforms • Sample Locations • Data Postings • Interpretive Maps (symbol plots, contour maps, colour images, G.I.S. presentations) • Anomaly Ranking or Target Map

4.0 INTRODUCTION

The introduction summarizes the survey logistics. The aim and specific objective(s) of the study, the scope of the work program, the number of samples collected for each type of material, and the sampling plan are stated.

The number of kilometres of grid line sampled and/or area covered by the work is specified. The names of field personnel and dates of sample collection, and the name of the contractor performing the fieldwork are indicated here, if appropriate.

5.0 LOCATION AND ACCESS

The location of the survey area is described with reference to a major centre of population. Convenient routes and modes of transportation from a major centre are indicated. Any difficulties with logistics or sources of supply are specified.

An index location map of the province, state, or country is included at an appropriately small scale to show the approximate location of the survey area. A more detailed map showing local access is also presented. The specific latitude-longitude and/or UTM coordinates of the property or survey area are stated.

6.0 CLIMATE AND VEGETATION

Average summer and winter temperatures and annual rainfall are indicated. Climatically induced factors of geochemical importance such as flood periods, presence of permafrost, location of the alpine or arctic treeline and the balance between precipitation and evaporation are noted.

General characteristics of the distribution of trees, shrubs and grasses are outlined. Each visually distinctive area is described separately if it is associated with a significant proportion of the landscape.

A more detailed description of plant species and their general distribution is required if a biogeochemical survey is being conducted.

7.0 LEGAL PROPERTY DESCRIPTION AND OWNERSHIP

The land status of all claims, licenses or concessions (referred to as "claims" in this document) held within the survey area, is summarized from government sources or the owners' documents. The source of the information is clearly defined.

A summary table is presented including:

- claim names,
- claim sizes or areas,
- a legal description of the locations,
- dates of acquisition, and,
- dates title must be renewed.

A page-size map is suitable to show the location of property boundaries.

Proximity to environmentally sensitive areas (*e.g.*, parks), aboriginal land claims, private surface rights or other cultural features are mentioned, if there is a potential impact on mineral tenure.

8.0 PROPERTY HISTORY / PREVIOUS WORK

A comprehensive report includes a review of the exploration history of the area. The exploration history is usually presented in chronological order, covering the mineral resources previously sought, the methods used, and the scope of exploration techniques (reconnaissance *vs.* detailed) applied by others. Reference is made to government documents, public assessment reports by industry and unpublished information available to the author. A summary of recent exploration activity by the current investigator should also be included.

Only a brief summary of the exploration history is included if the above information is more thoroughly documented elsewhere and the reference is quoted. The exploration history summary in a geochemical report includes descriptions and the results of previous geochemical surveys. The previous results that have influenced the design or implementation of the current survey should be documented in detail.

In cases where the results from previous geochemical surveys are compared or merged with results from the current geochemical survey, the differences in procedures are described with respect to the potential impact on interpretation.

9.0 GEOLOGY

Each major lithologic unit within the survey area is described in three or four sentences. Structural features and known mineral occurrences are mentioned towards the end of the section. A comprehensive report divides the geology section into:

- regional geology,
- local geology (rock units, metamorphism),
- structure,
- mineralization, and,
- alteration.

10.0 HISTORY OF WEATHERING AND TRANSPORT

The principal processes that have affected the current landscape are described. In glacial terrains, the glacial history of an area is described including the timing of ice advances, ice directions, melt water effects, estimated distance of transport and other features that may affect interpretation of geochemical surveys. In glacial terrains of the northern hemisphere, this section is more commonly called "Quaternary History".

Weathered terrains are described with reference to climatic changes in the Phanerozoic and the impact of uplift, erosion and deposition. Processes affecting the distribution of residual and transported regolith are described to allow the delineation of materials having different origins, compositions and geochemical responses.

11.0 GEOPHYSICS

Reference is made to previous or concurrent geophysical surveys in cases where:

- the current geochemical survey is designed to prioritize geophysical targets,
- geophysical surveys identify major lithological units that are not recognizable in the field,

- geophysical surveys are used to identify terrain conditions or overburden depths, and,
- other features of geophysical surveys directly impact the interpretation of geochemical data.

The detailed description of geophysical surveys and interpretation should be reported separately.

12.0 SURFICIAL ENVIRONMENT

This section is divided into subsections to describe parameters that are of fundamental importance to subsequent geochemical interpretation. Field observations are augmented with information obtained from topographic maps, air photographs and satellite imagery, in this section of the report.

12.1 Physiography

Points to be noted are listed below:

- maximum, minimum and average elevations,
- generalized description of the landscape surface, (*i.e.*, mountainous, rolling, flat, glaciated, *etc.*),
- general character of topographic slopes (*i.e.*, gentle, steep, undulating, *etc.*),
- prominent landforms that could influence trace element distributions (terraces, eskers, lacustrine deposits, sand dunes, salt lakes, *etc.*), and,
- landscape features that could have a marked influence on metal distributions (bogs, seepage zones, *etc.*).

It is useful to include photographs of the area in this section as an overview of the regional physiography or to document different landforms and landscapes.

12.2 Drainage

Streams are described using the following characteristics:

- drainage pattern type,
- relative abundance of streams (expressed as a density of channels per square km),

- nature of the stream source area(s),
- relationship of streams to bogs and lakes,
- presence of terraces, old channels and other noteworthy features that are normally apparent on topographic maps or air photographs,
- range of widths and depths and other noteworthy characteristics of stream channels,
- stream gradients and flow,
- range of drainage settings that relate to sample locations (bogs, lakes, seepages, freely drained valleys, *etc.*), and,
- pH conditions.

Many of these factors require field observations, and field notes should be retained but do not have to be incorporated in the report.

In some areas, it is important to report recent hurricanes, cyclones or other major storms that could have a significant impact on sediment distribution. If streams are seasonally dry, the duration and timing should be reported.

Lakes are described using the following characteristics:

- usual and unusual spatial distribution of lakes on the landscape,
- average shape and size,
- type of shoreline (rocky or sandy *vs.* boggy),
- nature of shoreline vegetation,
- average and range of depths,
- nature of lake bottoms,
- sample types with respect to composition and texture, and,
- lake water chemistry.

Seasonal variations such as freezing and drying and their duration should be noted. Field observations or water analyses are normally required.

12.3 Overburden

Overburden is defined as all unconsolidated surficial deposits overlying unweathered bedrock. The term "regolith" is commonly used in deeply weathered terrains to describe the weathered portion of the profile to depths occasionally exceeding 100 m.

The limits of transported overburden and residual material from the top of the *in-situ*, weathered profile are described for deeply weathered terrains. In areas of Quaternary glaciation, reference is made to types of glacial deposits and direction(s) of ice advance(s) if these are applicable. Areas where glacial drift is absent are noted.

Materials are described in terms of:

- the process of deposition (*e.g.*, glacial till, alluvium, volcanic ash, residual material),
- provenance and estimated transport distances,
- distribution relative to bedrock and other landscape features,
- drainage characteristics,
- composition and texture,
- an estimate of the average and range of overburden thicknesses,
- influence on soil trace metal levels and the control(s), and,
- special overburden conditions, (*e.g.*, the presence of glaciofluvial or glaciolacustrine deposits, loess, calcrete, laterite, silcrete or bentonite layers) which might depress or enhance geochemical dispersion from bedrock.

It is important to document special overburden conditions, if they were the determining factor in not sampling a part of the survey area by a specific method.

All the above features should be incorporated into a Regolith Landform or Quaternary Geology map that is often referred to as a "geochemical control map". The map is discussed in the context of defining:

- the most appropriate sampling methods for a given area,
- the economic constraints on collection of optimum sample media,
- the type of sample(s) collected at different sites,
- the most appropriate interval between samples, and,
- the thresholds set for areas of variable overburden cover for data interpretation (*e.g.* residual laterite-derived soils, compared with distal colluvium).

The Regolith Landform or Quaternary Geology map demonstrates that the surficial processes have been carefully considered and that sampling has been undertaken in a considered and methodical fashion.

12.4 Soils

Soils are developed at the land surface and constitute the naturally occurring, unconsolidated material (or organic material at least 10 cm thick) capable of supporting plant growths (Agriculture Canada Expert Committee on Soil Survey, 1987). Soil-forming processes typically affect the upper 1 to 2 m of the regolith, modifying the physical and chemical characteristics of the parent material.

In temperate regions, a soil profile typical of the area is described using one of two standard soil classification procedures, the "Canadian System of Soil Classification" or the "US Department of Agriculture" nomenclature. Other aspects of soil development within the area are also described including:

- representative soil horizons,
- soil horizon thickness,
- soil horizon physical characteristics, and,
- relationship of soil types to landscape features, parent material, water content, and proximity to bedrock.

In tropical or arid regions, horizon development in soils may be much less well developed than in temperate regions, and it is difficult to apply a standard soil classification system. In such circumstances, a description should be given of representative soil profiles paying attention to:

- the colours of the materials,
- textures (rounded *vs.* angular, fine- *vs.* coarse- grained, matrix *vs.* clast-supported, *etc.*), and,
- amount of organic material present.

12.5 Geochemical Sampling at Depth

When transported overburden is present, samples may be collected at depth using augers or drilling equipment. The report describes the rationale behind collection of a specific sample media, depth or horizon. Also water samples may be collected at different depths. Possible sources of downhole contamination are described and the errors associated with estimating the sample depth.

All sampled materials must be placed into a regolith or glacial context so that results from like materials can be compared during statistical treatment of data.

12.6 Anthropogenic Influences

Possible sources of contamination in the survey area or human activities that may have disturbed the sampling medium and/or affect geochemical survey results should be documented. These may include but are not limited to:

- proximity to human activity,
- smelters, mining operations, tailings ponds,
- recent forest fires,
- previous drilling activity,
- garbage dumps, and,
- farming activity.

13.0 ORIENTATION SURVEYS

Orientation surveys are preliminary surveys to determine the optimum field, analytical and interpretive parameters that can distinguish an anomaly from background. Orientation surveys are described in terms of:

- proximity to known mineralization,
- sampling interval,
- sampling medium,
- size fraction to be analyzed,
- elements to be analyzed and by which analytical method,
- the most efficient sample collection methods,
- whether geochemical methods are applicable, and,
- if contamination is a factor.

Orientation survey results justify the parameters selected for the surveys described in the report. In addition to orientation surveys conducted on the property, relevant technical papers can be reviewed to demonstrate why the selected survey parameters are expected to be applicable.

14.0 FIELD PROCEDURES

14.1 Sample Sites

The method of determining the sample location is described. Procedures for laying out grid lines, line cutting, station markings and verification of grid locations are described. Variations in line orientation from the idealized are documented.

For samples that are not collected on a grid, it is necessary to describe methods used to determine sample locations such as air photographs, topographic maps and global positioning systems (GPS). When a GPS unit is used, the manufacturer, settings and reliability of the measurements are reported. The system used in the field to mark sample collection sites, such as flagging tape or aluminum tags, is described. If a system has been implemented to verify that samples were collected from the reported sites, such as duplicate site sampling by supervisors or photographic records, it is described in this section of the report.

The line spacing and sample interval constituting the sample plan are described. The basis for setting the survey parameters is described, and may include the results of orientation studies.

14.2 Sample Collection

The method of collection and/or training of samplers are indicated. Systematic avoidance of any material(s) (such as organic-rich soils) or other instructions for the samplers is noted. These instructions may include the locations within the stream that were sampled, the sample depth or horizon collected for soils, *etc.*

The target weight or volume of the samples is stated. If the target size of the samples was not regularly achieved, an explanation is required.

The sample bags or containers are described. The recording of sample numbers on the containers or the use of sample tags is described. Where low-level metal values will be measured (*i.e.*, waters, gases or soils for selective extractions), any possible sources of contamination from sample containers is described or procedures used to eliminate sources of contamination (such as rinsing plastic containers with high purity acid).

Any tools or instruments used to collect samples are described. These may include piezometers for water sample collection, plastic collector cups for gas surveys, pumps or other devices. Any possible sources of contamination from the equipment or the possibility of sample cross-contamination are discussed.

Sample preparation at the sample site may include sieving, panning and/or splitting. These procedures are described in detail using the same criteria as in Section 15.

The method of drying, either at ambient temperatures or in a field-drying oven, is indicated if samples are dried in the field prior to submission for analysis to a laboratory.

Details of sampling procedures for biogeochemical surveys are provided, and may include the type of vegetation, years of growth, plant parts and other specifications. Other specialized surveys, such as for gases or water, may require additional specifications.

When rock samples are collected, it is specified whether chip samples were collected from various locations on an outcrop or a single site was sampled. It must be specified when rock samples are collected to test mineralized veins, but are not representative. Other procedures, such as removing weathering rinds, are described.

Conductivity, pH, weather conditions and other parameters may be measured in the field at the same time that samples are collected. All procedures are described as well as possible sources of error.

14.3 Sample Locations and Descriptions

The location for each sample is recorded, either as a grid coordinate or with reference to latitude/longitude and/or UTM coordinates.

Along with the location assigned to each sample number, descriptive information from field notes is recorded. The data are usually recorded in an appendix and may include:

- the sample medium,
- sample depth,

- deviations from the usual sample material (*e.g.*, change of soil horizons),
- sample location in a stream or lake (*e.g.*, inlet or outlet),
- colour,
- texture, and,
- source of contamination (fertilized fields, logging, fuel spills, scrap metal, spoil from previous drilling, old mine dumps, *etc.*).

Descriptive characteristics of the samples are summarized such as the ranges of colour, depth, and texture and any recognized pattern of spatial distribution. Other field data, such as geomorphological environment, descriptive or interpreted characteristics of the sample or the location need be supplied only to the extent that these data are discussed and interpreted in the report. As an example, if samples of transported overburden are disregarded because of their uncertain provenance, original data indicating which samples are transported overburden and which are not must be included. Alternatively, if values are simply contoured without regard to sample type or genesis, it is probably not necessary to list these details in the report, although it would generally not be harmful.

If the field data are to be included in the report, copies of the original field notes should be included as an appendix, if practical; however, field notes are normally recorded on cards or in field notebooks. As such, they can be voluminous and impractical to include in a report. In these cases, it is acceptable to include a listing of the field data, in a tabular form. If the field data are included as copies of original field notes or tabular listings, it is important to provide translation rules for any codes or abbreviations used in the field data. Regardless, it is recommended that the storage location of the original field data be specified in the report.

The frequency of quality control samples (*i.e.*, blanks, field duplicates and standards) and numbering schemes are described in this section. Guidelines for quality control programs may vary between jurisdictions and the report should indicate if specific guidelines were followed. General guidelines and the definition of quality control terms are included in references such as Bloom (2000). Quality control samples will not have location or descriptive information, but data recording forms can be used to record which sample numbers are assigned to quality control samples.

15.0 LABORATORY PROCEDURES

15.1 Sample Preparation

A summary of sample preparation procedures is presented. The following details are required to allow the reader to assess the validity of the analytical results:

- name and location (city) of the laboratory that performed the sample preparation,
- laboratory accreditation (if any),
- laboratory audit results (if any),
- relationship between the sample preparation facility and the mining company, if not arm's length, and,
- drying procedures including the drying temperature and whether samples were dried in the original sample bags or transferred to drying pans.

For samples that require pulverizing, the following details are required:

- description of jaw crusher equipment,
- description of secondary jaw crusher or rolls crusher, where necessary,
- mesh size of primary and secondary crushed material,
- splitting procedures to achieve a representative sub-sample for pulverization,
- weight of the sub-sample pulverized,
- description of pulverizing equipment, and,
- mesh size of the pulverized material.

In addition, the following procedures should be documented:

- sample preparation cleaning procedures including the regularity of cleaning with compressed air, coarse "barren" cleaner for crushers and "silica sand cleaner" for pulverizers,
- procedures for monitoring the mesh size of crusher and pulverizer products,
- procedures for preparation of internal laboratory quality control samples such as duplicate pulps or rejects, and,
- procedures for preparation of quality control samples such as duplicate pulps or rejects, at the request of the project manager.

Specialized drying procedures, sieving or heavy mineral separation procedures are described in similar detail.

15.2 Analytical Procedures

A brief description of all analytical procedures is included in the body of the report. Where possible, the method code used by the laboratory is included. Complete descriptions of the analytical methods are included in appendices, preferably as provided by the laboratory and on laboratory letterhead.

In addition to a description of the analytical methods, an overview of the laboratory's quality control procedures, such as inclusion of in-house standards, laboratory duplicates and blanks, is provided.

The description of the analytical method should include:

- sample weight,
- digestion or fusion procedure including reagents, temperature and length of time (where required),
- instrumentation with attention to discriminating between
  - sequential *vs.* simultaneous inductively coupled plasma spectrometry (ICP-AES)
  - ICP-AES *vs.* inductively coupled plasma spectrometry-mass spectrometry (ICP-MS)
  - atomic absorption spectrophotometry (AAS) *vs.* AAS with hydride generation,
- lower detection limits, and,
- upper limits of detection.

Digestions or fusions used for multi-element analyses may not provide optimum dissolution of all minerals and/or elements. Laboratories often provide lists of elements that may be underestimated due to incomplete dissolution or losses due to volatility. These cases are documented in the description of the analytical method.

Special instructions to the laboratory concerning "over range" analysis are summarized. It is often necessary to specify assay procedures for samples where analytical results exceed the upper limit of detection for the analytical technique and the conditions for these additional analyses need to be documented.

If methods changed during the course of the project, it is necessary to document which analytical methods were used for specific sample batches or the date the change was implemented. When results of a recent survey are being compared with historical data, it is important to document whether the same analytical methods have been used, and if necessary specify the differences and how the differences could affect the comparison of results.

15.3 Laboratory Quality Control Procedures

In addition to the quality control programs instituted by field geologists (as discussed in Section 16), laboratories also have quality control programs. When using company or commercial laboratories the following items should be documented:

- frequency of quality control samples,
- use of standards and certified reference materials (CRMs),
- participation in programs to compare results with other laboratories (*i.e.*, round robins),
- accreditation, and,
- procedures applied when quality control results are not in compliance.

The use of standards and certified reference materials are discriminated. Standards are homogeneous materials that are used to monitor the accuracy of an analytical method, and to assess for long-term bias, equipment stability, and to correlate between analytical methods. Certified reference materials are a specialized type of standard that has undergone rigorous testing at different laboratories usually including different analytical methods and are available through government organizations. Due to the high cost of these materials, laboratories and mineral explorationists commonly use standards produced in-house or purchased commercially. These materials may not have been subjected to the same rigorous tests for homogeneity as certified reference materials and are usually only analyzed at a few different laboratories using a limited number of analytical methods.

Most major laboratories will supply descriptions of their quality control systems that can be included as appendices and summarized in this section.

16.0 QUALITY CONTROL

The quality of the data is stated in terms of precision and accuracy. If samples were randomized prior to analysis, a description of randomization plots is provided to highlight within-batch and interbatch variation. This is followed by details of the variance associated with the sample and sample site as calculated from sample and field duplicates.

The largest component of variance, which is typically associated with the sample site, is compared with the between-site variance to establish whether or not observed anomalies are valid. Although the determination of data quality is interpretive, it is necessary to ensure that the data are valid prior to describing results.

16.1 Sampling and Analytical Precision

Confidence in analytical results and interpretation of geochemical data is improved when reproducibility of results is documented. Data reproducibility depends on an accumulation of natural errors including site variation, homogeneity of the sample material at any stage where a sub-sample is selected, and laboratory reproducibility.

The description of tests undertaken to establish data reproducibility should include:

- number of test samples,
- number of test samples as a percentage of the total number of samples in the survey,
- method of selection for test samples, for example whether the selection was random or biased toward specific metal concentrations,
- reference to appendices that contain raw data,
- graphs to compare two sets of data for the same site, size fractions, *etc.*,
- summary statistical data, and,
- the impact on data interpretation.

Graphical representation of the results for various types of duplicates or replicates is an optional but useful tool for displaying data reproducibility. Suitable graphs include simple x-y plots of the two sets of data or graphs plotting the mean of the results on the x-axis and the difference between results on the y-axis. Precision can be estimated using Thompson-Howarth plots (Howarth and Thompson, 1976, Thompson and Howarth, 1978) if the absence of bias has been verified.

16.2 Reporting on Data Accuracy

The documentation for any tests taken to establish data accuracy includes:

- the number of test samples,
- the number of test samples as a percentage of the total number of samples in the survey,
- the provenance and preparation of control standards,
- the determination of accepted values for control standards or alternatively the commercial supplier and recommended values, and,
- control charts for each control standard for elements of economic or interpretive significance.

Unacceptable results for control standards may have resulted in requests for re-analyses, changes in procedures or a change in service provider. Any errors that were identified and the actions taken to correct these errors are documented.

Results for field blanks (barren material) are reported similarly.

17.0 DATA MANAGEMENT, STATISTICAL ANALYSIS AND MAP PRESENTATION

17.1 Data Management

Increasingly, digital data on magnetic storage media provide a convenient, compact and reliable method of storing and transmitting data, such as that described above. A floppy disk or compact disk can be attached to an inside cover or placed in a pocket and subsequent workers can begin using the same data immediately. Data can be password-protected to avoid tampering.

In addition to the geochemical database, original records such as assay certificates can be scanned and stored as images. Where possible, numerical and descriptive data are also stored in tabular form so they will be more useful to subsequent users. Modern database and spreadsheet programs are obvious choices for organizing, manipulating and storing data; however, they may not be the best format for long-term storage, such as that accompanying a report. The format most likely to be useful in the future, irrespective of advances in information technology, is standard ASCII (comma and quote delimited) or rich-text format (RTF). Storing the data in more than one format reduces the chances of later problems for the reader.

Ideally, both hardcopy listings and electronic data are included with a report. Magnetic media will physically deteriorate and hardware and software to read older formats will become increasingly difficult to locate. Only water, fire and insects can render the paper listing unusable.

All geoscience reports that originate from government organizations have attached "metadata" descriptors and a similar approach is suggested for corporate documents. This facilitates indexing in digital catalogues and makes searching reports easier. Commonly accepted metadata standards include Government Indicator Locator Service (GILS) and Federal Geographic Data Commission (FGDC). These standards contain specific fields that document information about a report and survey.

Illustrations, photographs and maps should be stored in high-resolution raster format (such as tiff or jpeg formats). Maps and vector-based illustrations are more problematic as there is no clear standard that preserves the spatial and associated data. In this case, the software used to generate the illustrations is clearly identified, including version numbers.

Issues regarding the storage of digital data will evolve over time. Archiving of data and illustrations should take into consideration the changes in storage media and formats.

17.2 Statistical and Graphical Data Analysis

Statistical and/or graphical data analysis are not absolute requirements for geochemical reports. Most reports benefit from statistical and graphical summaries of element distributions as well as statistical analysis to identify patterns or structure in the data.

17.2.1 *Statistical and Graphical Single-element Summary*

Univariate statistics are used to compare data and to set the framework for discussion later in the report. A table with elements listed down the page and some combination of the parameters (listed below) across the page normally suffices:

- number of samples,
- detection limit (analytical and practical),
- number (or percent) of samples less than detection limit,
- mean (arithmetic),
- standard deviation (arithmetic),
- extreme values excluded from calculations (specify the criteria used to exclude values),
- number of excluded values,
- mean (excluding high values),
- standard deviation (excluding high values),
- geometric mean (after log transformation),
- standard deviation (log units),
- percentiles, such as 25th (first quartile), 50th (median), 75th (third quartile), *etc.*,
- preferred transformation to normalize the data distribution (*e.g.*, log, reciprocal, none),
- degree of normalcy with the preferred transformation (a relative measure of how (statistically) normal the resulting distribution is with the preferred transformation),
- anomaly threshold(s) (see below), and,
- number (or percent) of samples above the anomaly threshold(s).

The parameters listed above are included where relevant to the subsequent discussion. In cases where transformation of the data is required, a clear statement is required that the transformed data have been used in any subsequent statistical calculations that assume a normal distribution.

Typical graphs that provide details of single-element distributions include histograms (frequency distributions), cumulative frequency diagrams, probability plots (Sinclair, 1974, 1976, 1991), box plots and one-dimensional scatter plots (Kurzl, 1988). These graphs are usually presented in an appendix and are referred to in the discussions of thresholds, anomalies and correlations. Graphs should be clearly labeled and include the number of samples represented and a description of any subsets that are used.

17.2.2 *Background, Threshold and Anomaly Determinations*

The terms "threshold" and "anomaly" are commonly specified in geochemical reports. Their definitions, according to Rose *et al.* (1979), are as follows:

Background: "Normal abundance of an element in unmineralized earth materials"

Threshold: "Concentration of an element above which a sample is considered anomalous"

Anomaly: "Deviation from the norm"

Due to the general nature of these concepts, the method used to define the threshold and anomalous values is defined. It is stated if high values (*i.e.*, outliers) were excluded, multiple data populations were recognized and data transformations (such as logarithmic or square root) were applied.

In some situations, threshold and anomalous values are assigned for different sample media, terrain characteristics, lithologies or other considerations. The method of developing threshold and anomalous values is described in detail with statistics and graphs to support the approach.

Other methods of defining element distributions are evolving but need to be documented and described if they are applied.

17.2.3 *Multivariate Statistics*

Correlation coefficients are included in the report to quantify the (linear) correlation between two variables. The formula for this statistic is well known, so it need not be defined; however, any transformations or data exclusions on the data are clearly identified. Correlation matrices, which show the correlation between all pairs of variables, may be included as a compact way of communicating relationships between variables, and are included when between-element relationships impact on the interpretation of the results.

Correlation coefficients assume linear correlations between variables, and that the data are normally distributed. Scatter plots (*i.e.*, x-y or bivariate graphs) are included in the report to demonstrate that the relationship between two variables either complies with these assumptions or that other relationships exist. These graphs are included either in the text of the report for any element pairs that are critical to conclusions or interpretations, or in appendices for reference.

After the necessary single element (*i.e.*, univariate) statistics and two-element correlations have been discussed, statistics that treat multiple variables can be introduced. Multivariate statistical techniques, such as multiple regression, factor and principle component analysis, discriminant analysis, and cluster analysis, can be discussed although they are not a necessary requirement of most geochemical reports. Results from these highly specialized and complex methods are included in a report if they are informative and necessary to make a point.

Multivariate statistical techniques often yield "scores" that represent some weighted combination of the individual elements. These "scores" are interpreted to represent an optimal measure or quantification of some process or phenomenon. The assignment of a score to a process or cause is highly interpretive, which is acceptable, provided the rules and logic of the interpretation are described in the report. Also, the score formulae must be clearly defined.

Some typical approaches to assessing geochemical data are prone to difficulties such as:

- the closure problem when handling weight percent oxide data,
- the exclusion of outliers when data populations need to be normalized for statistical analysis, and,
- selection bias when comparing assays from different laboratories.

The report should specify what rules were applied to address these issues.

17.2.4 *Statistical Formulae*

Formulae for common statistical calculations are not necessary in the report. Reference is made to the statistical software used including the version numbers when complicated multivariate statistics have been applied.

If the data have undergone transformation or subsetting, or have been modified in some other way before the statistical calculations, this must be specified. Formulae for more complex or less well-known calculations are shown in the report, or reference is made to generally-available literature where the techniques employed are described in detail.

17.3 Map Presentation

Raw data geochemical maps are always provided. Maps that summarize interpretations are supplied in a report if the factual data have first been made available. Maps should always be as clear and concise as possible.

Typically a "base map" is created that contains the layout for all subsequent maps, including the coordinate grid lines, block, legend areas, scale and north arrow. Often, interpretation of geochemical results are augmented by the inclusion of other information on the base map, which will be repeated on all subsequent maps. For instance, topography, cultural features, simplified geology, location of mineralization, alteration or prospects may be shown. It is important, however, that the base map not become so cluttered as to obscure the geochemical data. The ancillary information can be faded or "screened" to make it subordinate to the geochemical information.

All maps include:

- reference coordinates (latitude/longitude and/or
- UTM (Universal Transverse Mercator) grid),
- local control coordinates (grid line markings),
- north arrow,
- scale bar,
- area location inset map (optional, provided the inset is present at the beginning of the report under "Location and Access"),
- title block, and,
- legend.

The legend should include:

- sample type,
- reference to subsets on the basis of sample preparation or analytical procedures,
- laboratory, and,
- survey date.

The latter three items are included on maps only if samples have been submitted for several types of analysis or were collected at different times.

Space should be left for a legend specific to each single- or multi-element map to include:

- explanation of contours or symbols,
- statement of threshold, and,
- optional histogram, cumulative frequency diagram, or probability plot.

17.3.1 *Data Maps*

Sample Location Plan. A sample location plan is included, which has a symbol posted for each sample location and the number of the sample collected at that location. The sample numbers correspond with the sample numbers that appear on the assay reports.

Data-Posting Maps. The most elementary and factual of geochemical maps is the "posting" of values for one or more variables next to each sample location. This factual information is a necessary component of a geochemical report. Depending on the specific requirements of the report, it may be necessary to provide single-element "postings" for each and every element reported. If such information is too voluminous and does not contribute to the interpretations or conclusions of the report, not all elements are posted, provided the raw data and sample locations are provided elsewhere in the report.

Colour is added to the posted data and/or sample location symbols according to concentration ranges, to improve visualization of the data. The method of selecting cut-points for assigning different colours is described.

Symbol Maps. Symbol maps are included to improve visualization of the data. Different symbol shapes, sizes or colours are used to depict discrete concentration ranges. The method of selecting cut-points for assigning different shapes, sizes or colours is described.

Data are posted next to the assigned symbols in cases where it is desirable to ensure that the symbol maps remain strictly factual.

17.3.2 *Interpretive Maps*

Contour Maps. When the rules of contouring are strictly followed, manually contoured maps can be relatively factual, although some detail of the data, such as location of data points, is often lost. Manually contoured maps can also be distorted convolutions of the factual data, particularly if the data are irregularly spaced and sparse relative to the natural variation of values relative to distance (variography).

Contour maps generated by computer programs can be more objective than manually contoured maps, although these too can represent distortions of the facts, either intentionally or unintentionally. Most contouring software packages require specification of multiple parameters, such as grid node spacing, search radius as well as various weighting functions. Specifying inappropriate values can result in significant distortions or misrepresentation of the data. For these reasons, it is important to specify the software used and the parameters specified, when computer-contoured maps are included in a report.

Imaged Geochemical Data. Computer contoured maps can be made more interpretable by adding colour ranges to the different contour levels, which aids the identification of topology. Imaging does not modify the data from that supplied by the machine contouring, so the important parameters for imaging are the contouring parameters, and these are stated.

In the case of three-dimensional plots, where x- and y-grid variables represent two of the axes, and the third axis (z) represents an element or geochemical parameter, the resulting "terrain-like" diagram can assist in visualization of the data. The scales for all three axes are included on the map.

"Score" Maps. "Scores" derived from statistical calculations, such as factor scores, regression residuals, ratios, or element sums, may also be plotted as data postings, symbol plots or contoured maps. The derivation of the scores is indicated in the map legend as well as the criteria used to assign symbols or contours.

17.4 Other Considerations for Map Production

- Numbers and letters must be legible at the final map scale.
- If colour is not allowed for a given report requirement, or if it is unlikely that colour copies can be made, the map should be constructed such that black-and-white copies adequately portray the results.
- To the extent possible, geochemical maps are generated at the same scale and with the same frame as accompanying maps of geology, topography, land status, *etc*.
- If other features, such as geological, topographic or cultural features are helpful for the interpretation of the map, they are included on the geochemical maps to the extent that they can be added without making the map unduly cluttered.
- If it would be useful to compare the results on one map with another, such as another element, or some geological, topographic or cultural features, maps may be produced on clear film, so that they can be overlain with other map layers for simultaneous viewing.
- If maps can be produced at a suitable scale, it is preferable to include page-size maps within the body of the report.
- When it is not possible to plot the map at page-size and still show the necessary detail, oversized maps should accompany the report. It is normally most convenient to fold the oversized maps and place them in envelopes that are bound into the report. A map is folded such that the title is visible without removing the map from the envelope.

Geographic Information Systems (GIS) are commonly used to combine information from various data sets. GIS and other computer-based technologies will continue to evolve and improve data presentation. The requirements for these presentations are similar to those discussed above, including map references, definition of data sources and clarity.

18.0 DESCRIPTION OF RESULTS

In the "Description of Results" section, geochemical results are described objectively in a logical sequence, and interpretive aspects are kept to a minimum.

Reference is made to the discussion in the Quality Control section on the reliability of the data and whether or not observed anomalies are considered valid.

Results are described in terms of inter-element relationships, controls on selection of threshold and anomalous values (*e.g.*, sample type, lithology, terrain conditions), and definition of anomalous areas.

Key points for describing anomalous conditions include:

- the maximum extents, morphology (*i.e.*, elongate *vs.* equidimensional), and preferred orientations of anomalies,
- the degree of contrast with background values, taking into account variations associated with the analysis, sample, and sample site,
- the relationship of anomalies to metal-rich zones, topography, drainage, landscape, overburden disposition, and outcrop occurrence,
- the single or multi-element character of anomalous zones, and,
- the spatial relationship of anomalies to:
  - geophysical anomalies, structures, and known mineralization
  - slope, seepage zones and bogs
  - overburden disposition and landscape
  - outcrop occurrence
  - anthropogenic features (*e.g.*, mine dumps)
  - possible sources of contamination.

A summary geochemical map showing the distribution of anomalous areas accompanies the discussion of anomalous areas. The multi-element nature of anomalous distributions is reflected on this map. Anomalous areas on the map may be assigned numbers, usually in order of priority for reference purposes.

19.0 DISCUSSION OF RESULTS

This section synthesizes the observations of the previous section with conceptual geochemical and ore deposit models. Concepts on the probable genesis of anomalies and possible relationships of one anomaly to another are introduced. Case history geochemical relationships reported at other mineral occurrences of the same type are compared and contrasted if relevant. The relationship of current work to geochemical models developed elsewhere for the same deposit type is similarly considered.

Geochemical anomalies and their possible significance are placed in a geological context. Anomalies are given a ranking for follow-up, and the criteria used in the classification are indicated.

Implications of the significance of survey results are discussed with comments on the course of action that should be taken to further evaluate (follow-up) defined anomalies. Specific details, including costs, are compiled in the following "Recommendations" section.

The discussion should review the objectives of the report described in the introduction including:

- analysis of whether the survey met the objectives of the program,
- reasons that the survey did not meet the objectives of the program, if this is so, including limitations due to overburden cover, access, *etc.*, and,
- assessment of the effectiveness of the survey methods and recommended alternatives, if necessary.

20.0 CONCLUSIONS

Conclusions should be relatively brief, no more than half a page. The main outcomes of the program are summarized. Objectives are reviewed and related to discoveries or other significant findings. Unattained objectives should be noted. Implications of the results for continued exploration are described.

21.0 RECOMMENDATIONS

Recommendations of a geochemical report will probably have a geochemical inclination, but they should also reflect the understanding by the writer of other exploration technologies (*e.g.*, geology and geophysics) that might assist anomaly assessment. Recommendations might include the need for additional sampling in outlying areas and more detailed sampling within anomalous areas to better define the relationship between the geology and the geochemical anomalies.

Additional sampling is not recommended when new information will not materially change the status of an anomaly, and physical work (*i.e.*, trenching or drilling) is clearly warranted. Authors should be willing to acknowledge that no further work is needed if the survey results are negative in terms of perceived mineral potential and/or current exploration objectives. It may also be necessary to explain that alternative surveys or techniques would be more suitable than those described in the current report.

Recommendations should be priority rated to the best of the writer's ability, and the objective of each recommendation should be specified. Recommendations can be included following the discussion of results, particularly if they are lengthy. In some cases, it is appropriate to include a budget for proposed work. The most critical recommendations are repeated, in brief form, in the summary.

22.0 REFERENCES

Publications cited in the report are listed in a "References" section after the text of the report and before the appendices are inserted. The format for references is in a standardized format, such as that used in the References section of this document, or following a style guide such as Grant (1998), Hansen (1991), Berkman (1989) and Bates *et al.* (1999).

23.0 SUMMARY

The summary appears towards the beginning of the report, after the title page and before the table of contents. It is discussed here, because it is normally written last, after all the details have been assembled and discussed.

The summary is a reduced version of the report. The length of the summary is no more than 10% of the volume of text in the main report. Each major section of the report is represented in the summary, but without detailed data, figures and tables. The conclusions and recommendations are emphasized in the summary relative to the other sections.

The summary includes the following:

- the objective(s) of the sampling program,
- findings of the program,
- outstanding local features of the geochemical distributions (*i.e.*, anomalies),
- reference to geochemical models or geochemical expressions from other areas, if available and relevant, and,

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