



GEOLOGICAL SURVEY OF CANADA
OPEN FILE 4598

**A GLOBAL DATABASE OF SEAFLOOR HYDROTHERMAL SYSTEMS,
INCLUDING A
DIGITAL DATABASE OF GEOCHEMICAL ANALYSES OF
SEAFLOOR POLYMETALLIC SULFIDES**

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prepared by

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Microsoft Excel[®] spreadsheet of literature references for SEADATA.XLS and GEOCHEM.XLS

1. Introduction

1.1 Background

In 1994, the Geological Survey of Canada (GSC) produced the first in a series of databases on the worldwide distribution of seafloor polymetallic sulfide deposits, as part of its Seafloor Minerals Project. The purpose of this project was to produce high-quality, organized geoscience datasets of global seafloor hydrothermal systems. Phase I of the project was completed in 1994 with the release of a World Map of Seafloor Hydrothermal Systems (GSC Open File 2915c). This phase of the project was supported by the U.S. Minerals Management Service through the Marine Minerals Technology Center, under the former U.S. Bureau of Mines. A supplemental map (GSC Open File 3421) was released in 1999, entitled Shallow Submarine Hydrothermal Systems, which was a compilation of known occurrences of submarine hydrothermal deposits in the near-shore environment. Phase II of the project was a digital database of geological descriptions of more than 250 known occurrences of seafloor polymetallic sulfides, with complete location information, geological and biological descriptions, and bibliographic references (referred to hereafter as the Hydrothermal Vents Database). The Hydrothermal Vents Database is accessible through the InterRidge web site at <http://triton.ori.u-tokyo.ac.jp/~intridge>. Phase III of the project was initiated in 2000 to link this database to a searchable listing of all known whole-rock geochemical analyses of samples from seafloor hydrothermal sites.

Through a new Agreement in 2002 (Appendix 1), the GSC and International Seabed Authority (ISA) sought to complete Phase III of the project and to make the geochemical database accessible on the worldwide web through the Central Data Repository of ISA.

1.2 Purpose and Organization of this Report

This report documents Phase III in the compilation of a Global Database of Seafloor Hydrothermal Systems, including the Digital Database of Geochemical Analyses of Seafloor Polymetallic Sulfides. The data products generated in this project are provided separately on a CD-ROM (Version 1.0 of a Global Database of Seafloor Hydrothermal Systems, including the Digital Database of Geochemical Analyses of Seafloor Polymetallic Sulfides prepared by M.D. Hannington, S. Petersen, P.M. Herzig, and I.R. Jonasson for the International Seabed Authority, Central Data Repository).

The tables included in Version 1.0 of the Global Database of Seafloor Hydrothermal Systems provide a fully searchable compilation that can be interrogated on multiple levels for resource assessment purposes and scientific study. The linked databases allow detailed analysis of geochemical data by area, region and jurisdiction and provide the most up-to-date characterization of the mineral endowment in specific volcano-tectonic settings of the ocean floor.

2. Overview and Data Sources

2.1 The Nature of Seafloor Polymetallic Sulfides

A number of different types of seafloor hydrothermal systems and associated seafloor mineral deposits are recognized. These are grouped into 6 categories according to deposit type or the nature of the associated hydrothermal venting: 1) polymetallic massive sulfide deposits (PMS), 2) low-temperature hydrothermal vents and associated mineral deposits (LTH), 3) near-field metalliferous sediments (NFS), 4) distal metalliferous sediments (DIS), 5) vein and breccia deposits (VSD), and 6) known occurrences of hydrothermal plumes (PLUME) (i.e., remotely-detected but unconfirmed high-temperature vent sites).

Polymetallic massive sulfide deposits (PMS) are typically associated with high-temperature (ca. 350°C) black smoker vents that occur in areas of active or recently active volcanism (e.g., deep-sea mid-ocean ridges, sedimented ridges, mid-plate seamounts, arc volcanoes, back-arc rift environments). The known deposits range in size from a few thousand tonnes up to a maximum of about 10 million tonnes. Accurate sizes have been determined in only a few cases where drilling information is available (e.g., Middle Valley, Juan de Fuca Ridge; TAG Mound, Mid-Atlantic Ridge). The deposits consist of massive accumulations of sulfide minerals, including mainly pyrite, pyrrhotite, chalcopyrite and sphalerite. Polymetallic massive sulfides (PMS) account for the majority of the known accumulations of seafloor hydrothermal mineralization. Most of the available geochemical data for seafloor hydrothermal systems compiled for this report is from samples of polymetallic massive sulfide deposits. Detailed descriptions of the individual deposits can be found in the references cited in the accompanying digital files.

Low-temperature hydrothermal vents and associated mineral deposits (LTH) are typically found at the margins of high-temperature vent fields or in shallow-water settings adjacent to volcanically active land masses. These deposits consist low-sulfide accumulations of such minerals as pyrite, marcasite, amorphous silica, barite, anhydrite, and Fe-oxides. Near-field metalliferous sediments (NFS) are accumulations of metal-rich particulates, mainly from plume fallout originating at nearby black smoker vents. Distal metalliferous sediments (DIS) are accumulated from the same source, but typically are found in sediments far away from black smoker vents (e.g., basal metalliferous sediments on the flanks of the East Pacific Rise). Vein and breccia deposits (VSD) may be found where faulting and uplift have exposed the roots of a hydrothermal system. They consist of stockwork mineralization (e.g., quartz and sulfides) as veins in the host volcanic rocks or cementing brecciated rocks.

For more information, the reader is referred to overview papers on this topic by Hannington et al. (1995) and Herzig and Hannington (1999, 2000). Additional information can be obtained from *Polymetallic Massive Sulfides and Cobalt-rich Ferromanganese Crusts – Status and Prospects*, published in the International Seabed Authority Technical Study No. 2 (see [Selected References](#)).

2.2 Data Sources

The original Hydrothermal Vents Database was created at GSC in 1994 and published on the InterRidge web site in 1999. The database was built from DBase[®] tables containing information on latitude and longitude, depth, geographic region, jurisdiction, site description (geology and biology), types of hydrothermal activity, mineral deposit description, tectonic setting, and bibliographic references. The Hydrothermal Vents Database was the first in a series of digital databases created for InterRidge, and it remains the only database of its kind available on the internet. The database structure allows for users to log-on and add to or modify the database as new discoveries are made or as additional site information becomes available. In the existing database, known (i.e., ground-truthed) sites are listed together with sites of suspected hydrothermal venting (i.e., plumes observed but vents not yet located). The InterRidge site now hosts similar databases for vent fauna, seafloor biological samples, and a bibliographic database on hot-spots.

The original Hydrothermal Vents Database was an outgrowth of GSC Open File 2915c, which focused on mainly deep marine hydrothermal systems. The original database was subsequently merged with data from Open File 3421 to provide descriptive information for more than 250 sites of seafloor hydrothermal activity worldwide (the new database described herein contains entries for an additional 77 sites verified since 1994). Both Open Files 2915c and 3421 included World Maps of Seafloor Hydrothermal Vents at 1:35,000,000 scale. The InterRidge site also displays vent site location information on a world map. This interactive map is provided here with new links to the Digital Database of Geochemical Analyses of Seafloor Polymetallic Sulfide Deposits (see Web Resources).

The Digital Database of Geochemical Analyses of Seafloor Polymetallic Sulfide Deposits is a compilation of published and publicly available data on the chemical compositions of hydrothermal precipitates in seafloor polymetallic sulfide deposits. Data has been collected for more than 2600 samples.

2.3 Compiling the Database

Compilation of data for the Digital Database of Geochemical Analyses of Seafloor Polymetallic Sulfide Deposits began on March 31, 2000. Additional work under the agreement between GSC and ISA was carried out in two parts: (i) technical editing of the dataset, including sorting of the digital files, checking references, and adding new data, and (ii) scientific validation of the geochemical data and analytical protocols. The quality and quantity of data reported in the literature are highly variable, owing to different analytical methods, detection limits, sample size, and different standards for reporting of data. A major part of the compilation was to standardize the presentation of the data and to ensure that the compiled data are "sound", including cross-checking references, making interlaboratory comparisons and developing a reporting protocol for different chemical data (e.g., detection limits for different elements and different analytical methods). The validation of the database was carried out by a qualified research scientist who inspected the data and decided what should be included and how it should be reported.

The database contains more than 61,000 records and is similar in size to the existing databases for manganese nodule resources and, to our knowledge, is the most comprehensive resource of its kind. Based on past experience, the database can be expected to increase in size by about 10% per year, as new deposits are discovered and new data are published. With this in mind, annual updates of Version 1.0 will be produced, beginning in 2003.

3. Data Structures and Variables

3.1 Deposit Information

The primary data tables for the Data Repository are [SEADATA.XLS](#) and [GEOCHEM.XLS](#). SEADATA.XLS contains location data (latitude and longitude in decimal degrees), geological information, and descriptions of 327 sites of seafloor hydrothermal activity and mineral deposits. These are grouped according to the 6 deposit types or categories outlined above: polymetallic sulfides (PMS), low-temperature hydrothermal vents and associated deposits (LTH), near-field metalliferous sediments (NFS), distal metalliferous sediment (DIS), vein and breccia deposits (VSD), and known occurrences of hydrothermal plumes (PLUME) (i.e., unconfirmed high-temperature vent sites). The database includes descriptive information for 197 deposits of seafloor polymetallic sulfides (PMS and LTH) and listings of 130 other known sites of seafloor hydrothermal mineral deposits and activity.

[REFERENCE.XLS](#) includes citations of 540 literature references and other data sources that were used to construct SEADATA.XLS and GEOCHEM.XLS. The bibliographic listing in REFERENCES.XLS is alphabetical, sorted by a "short author reference" corresponding to the citations given in SEADATA.XLS and GEOCHEM.XLS.

The SEADATA.XLS table has the following variables:

DEPCAT	- Deposit category as described above (PMS, LTH, etc.)
LOCNAME	- Deposit name (LOCNAM is the linking variable to data in GEOCHEM.XLS)
LONG	- Location longitude (decimal degrees, negative values denote West longitude)
LAT	- Location latitude (decimal degrees, negative values denote South latitude)
LOCAREA	- Location area (major geographic features associated with the deposit)
TECTONIC SETTING	- Regional tectonic setting
DEPTYPE	- Deposit type
DEPTH	- Water depth in meters
DESCRIPT	- General description of the deposit
REFS	- Short author references for primary data sources

3.2 Geochemical Database

GEOCHEM.XLS contains the primary geochemical data listing for the Central Data Repository. This includes geochemical analyses for 2,640 samples of seafloor polymetallic sulfides and related hydrothermal precipitates from 69 different sites worldwide. Approximately half of the polymetallic sulfide deposits in SEADATA.XLS are represented in the GEOCHEM.XLS database. The compilation includes more than 61,000 entries for 70 different elements.

The database structure consists of a single table containing the following information: sample number, analytical method (see 3.3. Analytical Methods), chemical analyses for up to 70 elements, mineralogical information, sample type, deposit location and bibliographic references. The samples are grouped by deposit name, and location information is given in SEADATA.XLS. The data are also linked to the interactive Reference Maps described under Web Resources. In some cases, latitude and longitude are provided for specific samples, where these were indicated in the primary reference. However, Location 1 and 2 are reserved for deposit name and location as given in SEADATA.XLS. Other location information such as the name of a specific vent may be included in Locations 2 and 3.

Geochemical data are listed according sample number taken from the original reference. Sample type and sample location information are also listed at the end of each row of data, together with the primary references for the data. Each analysis is for a single sample only, unless otherwise indicated. In some cases, multiple references are cited for individual samples where multiple analyses of the same sample were reported in different sources. In such cases, the data are combined as a single listing of elements under one sample number. In some cases, averages of several samples have been included where data for specific samples was not available. Sample types (e.g., chimneys, talus, core samples, dredge samples, etc.) are indicated where this information was provided in the primary data source. Mineralogical compositions are also indicated where this information was reported. See below for mineral abbreviations. Most samples are representative grab samples (a few 10s of grams up to several kilograms in size). However, this information is rarely reported and was not included in the compilation. The reader is referred to the original references for information concerning sample size, methods of collection, or other details.

Most samples have data listings for at least 5 to 10 key elements (e.g., Cu, Fe, Zn, Pb, S, Au, and Ag). However, data have also been compiled for each of the following elements: Fe, Cu, Zn, Pb, Au, Ag, Mn, As, Bi, Be, Cd, Co, Cr, Ga, Ge, Hg, In, Mo, Ni, Rb, Sb, Se, Sn, Sr, Sc, Te, Tl, U, V, W, Y, Zr, S, Si, Ba, Ca, C, Al, Mg, Ti, Na, K, P, Ir, Pd, Pt, Cl, F, B, Br, Hf, Li, Nb, Ta, Th, La, Ce, Pr, Nd, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, Lu. The methods used for each analysis are indicated in the "Method" column of the GEOCHEM.XLS table and described according to the key in the [METHODS.XLS](#) table. Some elements are analyzed by more than one method. The choice of method used in this report varies for some elements. As an example, data for Ag is included for two separate methods: Ag(1) lists results obtained by instrumental neutron activation techniques; Ag(2) includes mainly data that was obtained by AAS or ICP methods (see Analytical Methods for details).

Major elements are reported in weight percent (wt.%). Minor and trace elements are reported in parts per million (ppm) or parts per billion (ppb), as indicated. Non-metals are normally reported with the major elements as wt.% oxides. All other elements are reported as elemental concentrations. Some elements that were reported as oxides in the literature source (e.g., MnO, Fe₂O₃) or sulfates (e.g., BaSO₄, CaSO₄) have been recalculated as elemental concentrations in this table. In cases where an element may occur in more than one form (e.g., sulfur as sulfide or sulfate) all of the that element has been converted to the indicated elemental concentration. Some elements, such as the major metals (Cu, Fe, Zn, and Pb), are reported in wt.%, although

they may have been determined at much lower concentrations and originally reported in ppm. For ease of comparison between the samples, these values have been converted to a common concentration unit throughout the table. The primary reference should be consulted for details.

Note: The cells of the table are preformatted to show an appropriate number of significant figures for each element based on the analytical method and detection limits (see METHODS.XLS). Any change in formatting of the table may result in the loss of this information. Some cells may contain fewer significant figures than are shown in the formatted table. Other cells may contain more significant figures than are shown; this is an artifact of calculating elemental concentrations from concentrations originally reported in another form (e.g., where oxide wt.% are recalculated to elemental concentrations in ppm). Analyses indicated as "<" are below the reported detection limits for that element by the particular analytical method used (see METHODS.XLS). Some entries may have odd-numbered detection limits (e.g., 77 ppm Mn). This is also an artifact of recalculating a detection limit in ppm from an original detection limit in wt.% oxide (i.e., <0.01 wt.% MnO is equivalent to <77 ppm Mn).

Mineral Abbreviations used in GEOCHEM.XLS: ac, atacam = atacamite; anh = anhydrite; arag = aragonite; ba = barite; bn = bornite; cc = chalcocite; chl, cl = chlorite; cp, cpy = chalcopyrite; crist = cristobalite; cv = covellite; dg = digenite; ga = galena; iss = intermediate solid solution (isocubanite); lim, go, goe, he, hm = Fe-oxides (limonite, goethite, hematite); mc, ma = marcasite; mhsh = magnesium-hydroxy sulfate; po = pyrrhotite; py = pyrite; py/mc = mixed pyrite and marcasite; qtz = quartz; si, sil, silica = amorphous silica; sm = smectite; sp, sph = sphalerite; wtz = wurtzite.

In addition to the listing of elemental concentrations, the GEOCHEM.XLS table has the following variables:

SAMPLE	- Sample identifier taken from the primary data source
METHOD	- Analytical method(s) keyed to listing in METHODS.XLS
SAMPLE TYPE	- Specific sample type, where indicated in the primary data source
MINERALOGY	- Major minerals comprising the sample, where indicated
DESCRIPTION	- Brief description of sample characteristics or sample type
LOCATION 1,2,3	- Descriptive information of sample location, where indicated
LONGITUDE	- Longitude for specific sample location, where indicated
LATITUDE	- Latitude for specific sample location, where indicated
DEPTH	- Water depth for specific sample location, where indicated
REFS	- Short author references for primary data sources

3.3 Analytical Methods

METHODS.XLS contains information on methods used for analyzing the different sample suites. For each sample in GEOCHEM.XLS an analytical method is indicated and referenced to a protocol in METHODS.XLS. The analytical method used for each element is listed together with the reported or inferred detection limit for that element by the specified method. Many references do not cite analytical methods or cite the analytical methods in non-specific terms (i.e., without reference to specific methods used for different elements or without detection limits). In such cases the analytical method is left unspecified.

The METHODS.XLS table includes listings for 110 different analytical protocols employed by about 23 different institutions that have published geochemical data on seafloor sulfides. Of the different methods listed in the table, four techniques account for the majority of the data. These are atomic absorption spectrometry, optical emission spectrometry, X-ray fluorescence, and instrumental neutron activation analysis. The absorption and emission spectrometry methods vary according to the techniques used to introduce the analyte into the spectrometer. In atomic absorption analysis (AAS), this normally involves direct aspiration of the liquid into a flame source. In the last decade, this method has been largely replaced by optical emission spectrometry using an inductively-coupled plasma source (ICP). Both AAS and ICP methods require that the sample is first pulverized (and possibly fused) and then dissolved prior to analysis. For INAA and XRF, no dissolutions are required, and the powdered samples may be analyzed directly or following fusion to a glass disc. The particular method of sample preparation is typically not reported in the literature. However, this can be important, particularly for possible contamination introduced during fine grinding of sample powders (e.g., Cr-steel mills can introduce up to 340 ppm Cr and 17 ppm Mn; tungsten-carbide mills can introduce up to 270 ppm W or Co; steel disk mills can introduce up to 130 ppm Mn and 76 ppm Cr; ceramic mills can introduce up to 1 wt.% Al_2O_3 ; agate mills contaminate samples the least, but they are the most expensive to use: see *Sample Contamination by Grinding*, Canadian Mineralogist, v. 24, p. 585-589).

It is important to consider analytical methods and detection limits when interrogating the database and comparing analyses for different samples. Not all analytical methods reported in the literature are quantitative, and some methods are more sensitive than others. This can often be determined by careful consideration of the quoted detection limits. Those methods with high detection limits may be only semi-quantitative. Values that are reported close to the detection limit are less reliable than concentrations well above the detection limit. Owing to the difficulty of making accurate determinations of most elements at concentrations close to their analytical detection limits, such analyses should be considered to have an accuracy of no better than $\pm 100\%$.

Analytical detection limits are indicated where they have been reported in the primary data source. Where a particular analytical method has been specified but without detection limits, the detection limits may be estimated, based on similar methods used in other laboratories. In other cases, the detection limit is inferred from the tabulated data in the original data source (e.g., a listing of <0.01 wt.% in the Table implies a detection limit of 0.01 wt.% for that element). Entries are left blank where not information is available and no detection limits can be inferred. The performance of a particular analytical method may vary between laboratories, owing to instrumental differences or differences in analytical procedures. Therefore, quoted detection limits are not always the same for a particular method. Some detection limits also have improved with time, owing to advancements in technology and methodologies. For example, a detection limit of 10 ppm for a particular element by ICP-ES in 1980 might have been considered good at the time, but the same element may be routinely analyzed at a detection limit of <1 ppm by the same method today.

The originating institution is indicated at the end of each analysis. This helps to identify the particular laboratories and analytical routines that were used for the analysis. In many cases the analyses were performed by external or commercial laboratories that are not specifically mentioned in the primary reference. For this information, the user is encouraged to contact the originating laboratory.

4. Web Resources

4.1 Reference Maps

The database files for Version 1.0 are accompanied by five basic HTML reference maps that can be readily accessed through a web browser. The reference maps used for this purpose are from The Hydrothermal Vent Database hosted by InterRidge (<http://triton.ori.u-tokyo.ac.jp/~intridge/>). Different geographic regions of the reference maps are linked to data tables derived from GEOCHEM.XLS (see below).

4.2 Data Tables

The GEOCHEM.XLS master table has been split into subsets of 19 XLS files for the different geographic regions represented in the database. By clicking on a specific region of the interactive maps, a link is created to a subset data table containing the geochemical data for deposits in that region from GEOCHEM.XLS. The subset XLS files are:

NE_Pacific_JF_Ridge (Juan de Fuca Ridge sites)
NE_Pacific_Gorda_Ridge (Gorda Ridge sites)
NE_Pacific_California (Gulf of California sites)
NE_Pacific_N_EPR (Northern part of the East Pacific Rise)
NE_Pacific_Eq_EPR (Equatorial part of the East Pacific Rise and Galapagos Rift)
Pacific_S_EPR (Southern East Pacific Rise)
Central_Pacific (mid-Pacific seamounts)
N_Atlantic_MAR30_39 (Mid-Atlantic Ridge between 30° and 39° N latitude)
N_Atlantic_MAR20_29 (Mid-Atlantic Ridge between 20° and 29° N latitude)
N_Atlantic_MAR10_19 (Mid-Atlantic Ridge between 10° and 19° N latitude)
Indian_Ocean (Central Indian Ridge)
Mediterranean (Tyrrhenian and Aegean Seas)
Red_Sea
NW_Pacific_Izu_Bonin (Izu-Bonin Arc)
NW_Pacific_Okinawa (Okinawa Trough)
NW_Pacific_Mariana (Mariana Arc and Mariana Trough)
SW_Pacific_Manus_Solomons (Manus Basin and adjacent island archipelagos)
SW_Pacific_Fiji_Basin (Fiji Basin)
SW_Pacific_Lau_Basin (Lau Basin and Havre Trough, New Zealand)

5. Selected References

Hannington, M.D., 1999, Shallow Submarine Hydrothermal Systems - Preliminary Map: *Geological Survey of Canada Open File Report 3421*, Map 1:35,000,000.

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6. Disclaimer

The database tables contained in this compilation were derived principally from the open literature. The data reported in the accompanying digital files are reproduced as accurately as possible from original reference(s). However, the data have been reformatted for presentation purposes, as outlined in this document. The authors take full responsibility for any errors that may have occurred during coding, transcription or reformatting. However, the authors are not responsible for accuracy or completeness in the original data sources.