Data Needs and Availability

Digital Inventory of Bedrock and Mineral Deposit Geology

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Goals and Background

The goal of the World Minerals Geoscience Database Project (WMGDP), Geological Survey of Canada (GSC), is to provide high-quality datasets of global scope to describe (1) mineral deposits and (2) bedrock geology. These datasets are meant to facilitate resource assessment, environmental modeling, land use planning, and paleotectonic visualization to better understand our land masses and mineral wealth. The compilation of the initial framework will be accomplished in two 2-year cycles (1998–2000 and 2000–2002) under industry sponsorship. It is understood that compilations of this scope never will be truly complete or up to date. The aim by the end of the project is to provide datasets substantial enough in content to be a stimulating source of global information, which may in turn stimulate improvement of the database over the long term.

The WMGDP originated as the indirect result of compilations of global copper deposits that R.V. Kirkham and his associates began two decades ago. The idea of plotting deposit distributions on a world map of generalized bedrock age was inspired by the "World Atlas of Geology and Mineral Deposits" (Derry, 1980). Continent-scale diagrams from this volume were fitted to a wall map that underlay the plotted distribution of sediment-hosted copper deposits used for poster displays during the middle 1980s. To reap the advantages of reusing a geology backdrop with other data, the geology was recompiled in 1993 by generalizing it from UNESCO (United Nations Educational, Scientific and Cultural Organization) and other official maps so that it could be georeferenced for use as a geographic information system (GIS) digital information product. Attributes of general rock type as well as age were added to the dataset to test the feasibility of creating alternative thematic maps from different combinations of these elements. Paper maps showing the global distribution of sediment-hosted copper deposits (Kirkham, Carrière, and others, 1994), seafloor hydrothermal deposits (Hannington and others, 1994), and bedrock age and rock class domains (Kirkham, Chorlton, and Carrière, 1994) and the digital data on CD-ROM (Geological Survey of Canada, 1995) were released to the public at the end of the project.

A 2-year industry-sponsored World Map Project to add other global mineral deposit databases and enhance the geology subsequently was organized by R.V. Kirkham. This project resulted in the production of databases and distribution maps for porphyry and epithermal deposits (Kirkham and Dunne, 2000) and nickel deposits (Eckstrand and Good, 2000) and a database for volcanogenic massive sulfide (VMS) and sedimentary-exhalative deposits (Jenkins and Lydon, 2002). The geological dataset was revised to incorporate information such as better age ranges and magmatic composition to complement magma-related deposit databases. Enhancements to the data and revisions to many areas from new sources still are incomplete but are sufficient to provide thematic backdrops for the release of hardcopy maps showing the distribution of nickel deposits (Eckstrand and Good, 2000) and porphyry-related deposits (Kirkham and Dunne, 2000).

Designers of the WMGDP have responded to the need to make the various mineral deposit databases uniform in structure and content, while accommodating new categories of information in the structure. Feedback from compilers, colleagues, and industry sponsors is being used to enhance a preliminary deposit database schema that was adapted from one of the preexisting databases and that already accommodated many of the descriptive parameters for mineral deposits (Eckstrand, 1984; Cox and Singer, 1986; Eckstrand and others, 1995). The consequent alterations to the mineral deposit schema, data content, and terminology should ensure that the information most critical for describing a wide variety of deposit types in a global context can be captured. The bedrock geology database is undergoing continued update and will in future include a new database component describing geotectonic provinces and their timing. Project participants and their roles are listed in table 1.

General Approach

WMGDP is a compilation project that includes data from a wide range of sources—maps of many origins, scientific

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Table 1. Makeup of the World Minerals Geoscience Database Project team.

[Asterisks mark participants in the previous World Map Project. GSC, Geological Survey Canada; ON, Ontario; BC, British Columbia; ESS, Earth Sciences Sector of Natural Resources Canada; GIS, geographic information system; PGE, platinum-group elements]

Name	Location	Roles
W. Dave Sinclair	GSC Ottawa, ON	Project coordinator, publicity, communication, and administration.
Lesley Chorlton*	GSC Ottawa, ON	GIS data, geology compilation, mineral deposit database design and data management, technical and compiler support coordinator.
Robert Laramée	GSC Ottawa, ON	Database developer, mineral deposit database design, utilities programmer, internal and external technical support.
Don F. Sangster	Ottawa, ON	Compiler: Sedimentary-exhalative and Mississippi-Valley-type deposits.
O. Roger Eckstrand*	Ottawa, ON	Compiler: Nickel-PGE-chromite deposits.
Dave Good*	Dundas, ON	Compiler: Nickel-PGE-chromite deposits.
Quentin Gall	Ottawa, ON	Compiler: Nickel-PGE-chromite deposits (tectonic setting; ages; PGE).
Benoît Dubé	GSC Quebec	Compiler: Gold deposits.
Patrice Gosselin	GSC Quebec	Compiler: Gold deposits.
Rod V. Kirkham*	Delta, BC	Compiler: Porphyry-related and sediment-hosted copper deposits.
Kathryn Dunne*	Williams Lake, BC	Compiler: Porphyry-related deposits.
Antonio Rafer	Vancouver, BC	Compiler: Sediment-hosted copper deposits.
Peter Born	Ottawa, ON	Compiler: Sediment-hosted copper deposits (tectonic setting; ages).
Sunil Gandhi	Ottawa, ON	Compiler: Fe(-Cu-Au-U) deposits (Olympic Dam-Kiruna type).
Elizabeth Hillary	GSC Ottawa, ON	Library, database, and graphics support.
David Power-Fardy	GSC Ottawa, ON	Library, database, and graphics support.
Mario Méthot*	ESS Ottawa, ON	Cartography.

literature, reports, other national and provincial databases, and preexisting GSC databases. Terminology, levels of detail, and classification vary among sources. Gaps in the information available must be accommodated in the datasets and influence the design of the databases. For example, sources may record that host rocks are of a given geologic age but not indicate the type of host rock. Obtaining accurate and consistent locations from these varied sources also is a problem that may take a long time to overcome.

Because of the compiled nature of the databases, a referencing system has been added to all databases; this system can house all the information necessary to provide full bibliographic citations as output in any reference style. References can be extracted for use on the surrounds of maps and in reports or scientific papers using the information as illustration or evidence. Any number of references can be linked to each deposit or geology record, and provisions are included for identifying which general categories of data came from each source. Data source has been filled in fairly thoroughly for the geology database because the compiler had an immediate need to filter references according to the types of information required for individual thematic maps to provide a textual reference list to insert into cartographic surrounds. Auxiliary goals in developing the geology and current versions of the mineral deposit databases include streamlining the production of alternative integrated maps, diagrams, and reports directly from the databases and automating typing, symbolization, and legend tasks as much as possible.

The geological content of the WMGDP databases includes primarily parameters that are most significant for geology and mineral deposit settings on a global scale. The level of detail may therefore be considered low or superficial to many geologists. However, to accommodate geological complexity adequately, the databases must be able to represent the one-to-many and many-to-many relations among data elements that are endemic to geological information. Relational databases accommodate these kinds of relations, and relational database software is widely available to the public and to sponsors. Therefore, both the mineral deposit and geology databases are implemented in relational database style.

On the other hand, the needs of cartographers and geological end users having low-end GIS software must be accommodated by the system. These users generally prefer to work with data in spreadsheets and spreadsheet-style GIS files. Partial datasets in flat file formats, customized to emphasize different portions of the databases (themes) depending on the end use at hand, therefore, are the main outputs of these databases. This system will ensure that only portions of data that have been reasonably well populated are published and that, if a working group ensures that the thematic data are adequately populated for a certain theme, it is possible to name the group members as the compilers or authors of the thematic product. The export datasets are prepared by using programs that rely on the structural integrity of the database and the consistency of the data content.

Experience in generating export products has shown that it is useful to have rock-type data described by using a hierarchy of different levels of generality. Broad classifiers, alone or in combination with others, can be used to filter or group the data for particular end uses, such as explanations for plots, charts, and spreadsheets. Both the mineral deposit and geology databases allow the description of rock types in three levels. The most general category indicates whether a rock component is mainly sedimentary, volcanic, intrusive, metamorphic, or tectonic. This description can be modified by more specific, but still general, classifiers such as broad suite names and predominant magma series for intrusive rocks and, for volcanic rocks, by the familiar compositional terms, magma series, and depositional setting. Any number of more specific details such as actual lithologies, internal structures, external forms, depositional settings (for sedimentary rocks), and protoliths (for metamorphic and tectonic rocks) are entered into tables found at deeper levels in the database. This structure allows compilers to add as much detail as they want to qualify the general terms.

A different approach is being taken for geologic ages. Timing is critical to the understanding of the links between tectonic activity and metallogenesis. Therefore, ages are being captured in the most specific terms available from data sources. They are rolled up into user-specified age ranges for the generalization of export data products by using a numerically calibrated lookup table. Although time calibrations constantly are being revised, one internally consistent and fairly complete source was selected for most numerical start ages and end ages (Harland and others, 1990). These calibrations were supplemented from Plumb (1991) for the new Precambrian time scale and Okulitch (1995) for miscellaneous North American subdivisions.

The mineral deposit and geology databases contain explicit, unhidden tables describing their internal content. These tables include a catalog of component tables, fields, links among tables, domain values (pick lists), and captions. These tables are being used for automating backups and the transfer of data from one format into another. They eventually will be used with programs to fill out some parts of one of the upcoming international standard metadata formats if the datasets are to be made accessible over the World Wide Web. They also may be used to transfer the data into an entirely new structure and format, such as the North American Geologic Data Model (B.R. Johnson, Boyan Brodaric, and Gary Raines, unpub. data, 1997).

Mineral Deposit Databases

Mineral deposits being compiled into WMGDP databases include porphyry and related epithermal, nickel-PGE (platinum-group elements)-chromite, gold, sedimentary-exhalative, Mississippi-Valley-type, sediment-hosted copper, and iron-oxide-copper-gold (Olympic Dam-Kiruna) deposits (table 1). Compilers are based in diverse locations and have a range of desktop computer facilities, a situation that also characterizes our industry clients, with their many international branch offices and project sites. Microsoft Access (version 7.0) was chosen as a platform because it was available to compilers and industry sponsors worldwide. The graphical utilities for entering data and navigating the database have been developed in Delphi and operate on the database through Windows connectivity mechanisms. The utilities can be used for databases that may be either upgraded to later versions of Microsoft Access or transferred onto other database management platforms.

The design of these deposit databases has evolved in stages. At the beginning of the WMGDP, the design of one of the World Map Project databases was adopted because it accommodated most of the information initially considered essential from a global perspective and was applicable to most deposit types. Preexisting databases for porphyry, nickel, gold (Jenkins and others, 1997), VMS, and sedimentary-exhalative deposits were translated into the schema to provide seed databases for additional compilation. As compilers began their literature research and data entry during cycle one of the project, they realized that some significant categories of information could not be accommodated in the existing schema, and so the schema was modified accordingly. The addition or removal of fields and tables, or changes to field definitions, is done by using upgrade programs, which automate the process without endangering the existing data. In some cases, some of the existing data must be remapped manually because the process requires geological judgment. Feedback will be used to make further adjustments, although the deposit data schema is now relatively stable. The standardization of equivalent terminology among databases is now being addressed.

A mineral deposit database is made up of tables that describe six types of entities—deposits, deposit groups (meaning a group of related deposits such as in a camp), mines, production numbers, resource numbers, and references. The overall view (fig. 1) shows how the first five entities relate to one another in many-to-many relations, except for mines and deposit groups, which are not directly connected. This lack of connection results because deposit groups may have several deposits, a mine can have more than one production record and exploit more than one deposit, and a resource record can be linked to more than one deposit or mine. The many-to-many relations are reduced to one-to-many through the use of

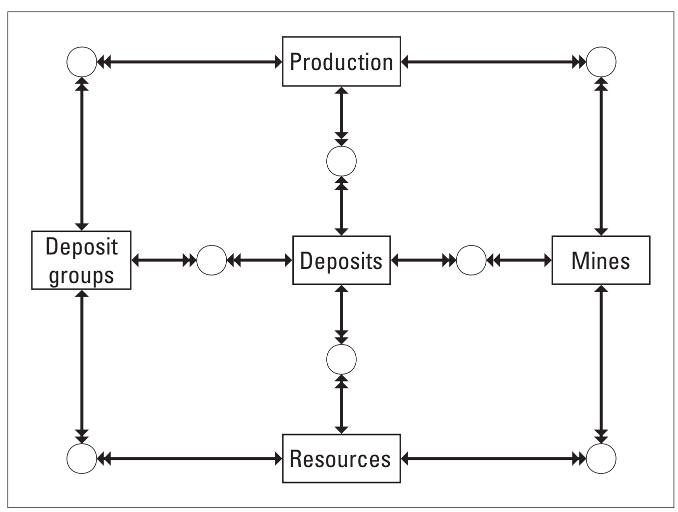


Figure 1. Overview of the mineral deposit schema. The circles represent junction tables; the double arrowheads, the many ends of one-to-many relations.

junction tables. References (not shown in fig. 1) are linked to all other entities.

The portion of the schema that describes a mineral deposit (fig. 2) is very similar to that for a deposit group. Each entity is made of a master table, here “Deposit Geology,” which contains general data applicable to the entity for which there is only one value, such as the location and most general deposit classifier. Tables referred to as detail tables to the master table house the following information categories: names; deposit status; commodities; tectonic settings for mineralization, hosts, and so on; geologic ages for mineralization, hosts, and so on; radiometric (isotopic) ages for mineralization, hosts, and so on; related magmatic rocks; host rocks; country rocks; controlling structures; metallic signatures; alteration signatures; mineralization styles; and mineralogy. The detail tables are connected to the master table in one-to-many relations and contain data that can have multiple occurrences for each entity. There also are some subdetail tables, such as individual lithologies, that are themselves detail tables to detail tables (one-to-many-to-many relations). Figure 3 shows how these detail and subdetail tables would appear to a compiler. Compilers are free to use as many or as few detail tables as dictated by the nature of the data and deposit types that they are compiling. Ideal conceptual design had to be compromised in some ways because of information gaps in the database that provided seed data and (or) in the literature. For example, although it seems logical that the host-rock age should be a detail table to host rocks, a compiler must be able to enter host-rock ages even if there is no available information to justify describing host rocks.

Figure 2 also shows how references are used with deposits. Each record in the References junction table makes the

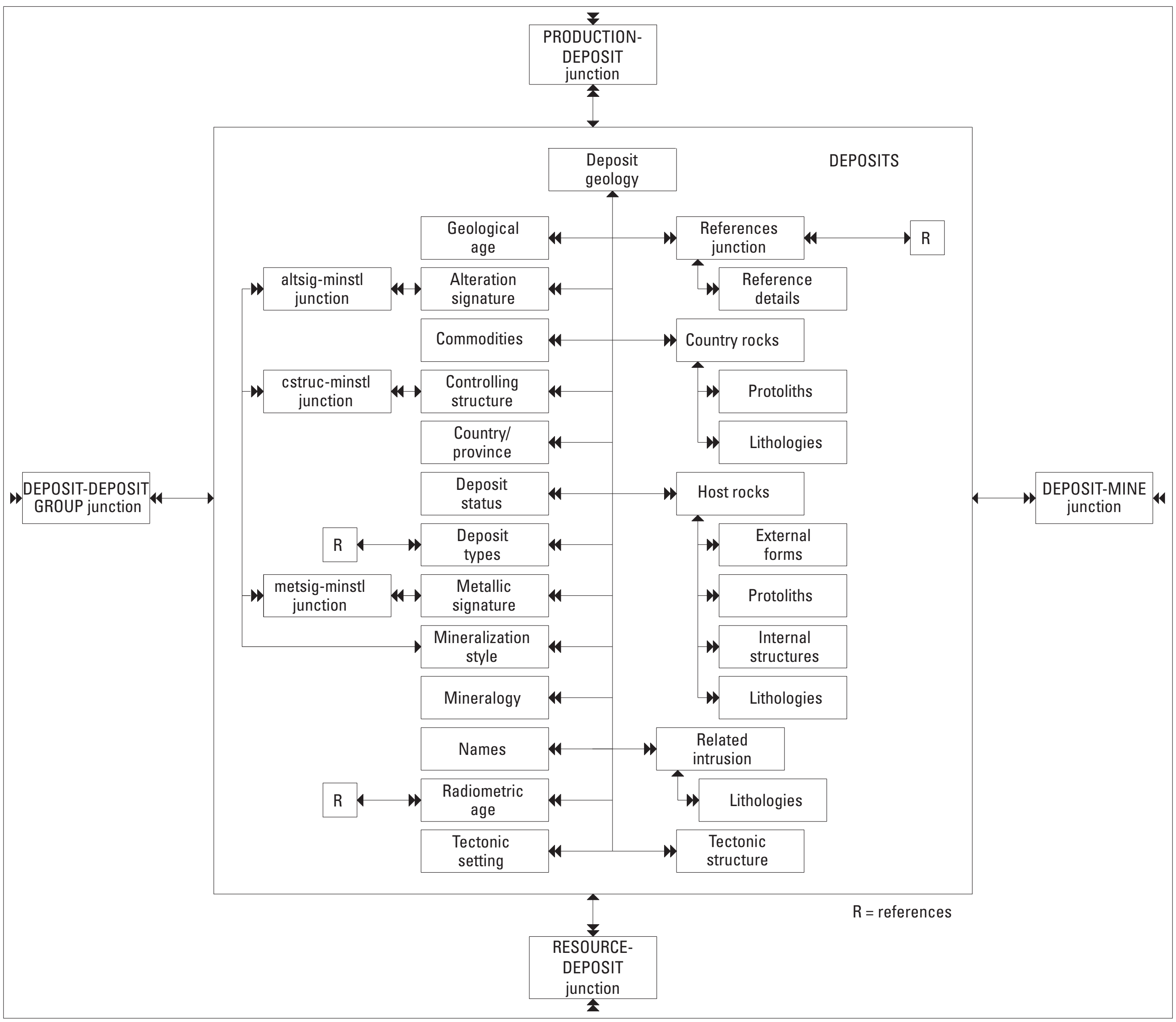


Figure 2. Schema for mineral deposits, particularly their geology.

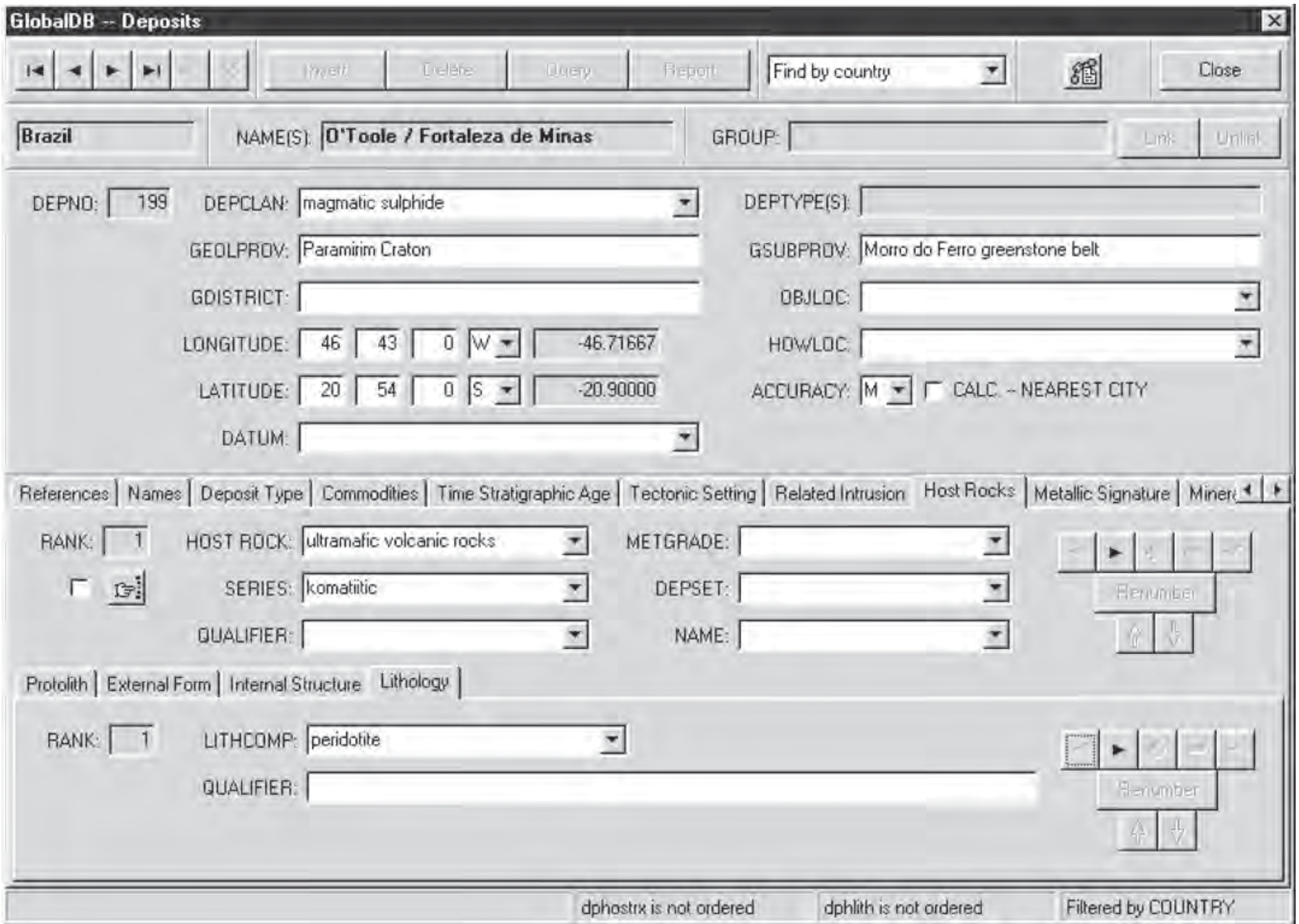


Figure 3. Data entry screen for deposits.

bridge between a single deposit and a single reference. Each deposit can have several references, and each reference can apply to multiple deposits. The subdetail table "Reference Details" contains specific information such as page numbers and Yes/No fields to indicate what type of data came from which reference. Each record of the "Deposit Types" or the "Radiometric Age" detail tables can be linked to a single reference by storing the corresponding reference number value in a reference number field. The same is true for "Production," "Resource," and "Mine" records.

Many of the data fields in these tables are meant to contain values selected from fairly short and well-constrained value lists stored in lookup tables and made available during data entry by means of "combo" boxes. Although most of the lookup tables initially were filled with suggested values, the content of these lists has been under the control of the compilers so that they could chose the terms they needed to best describe the type of deposits they were dealing with. This method was used so that compilers would be comfortable keeping their lookup tables fairly short and the data in their deposit descriptions well constrained. During the early stages of project cycle two, the contents and terminology of the existing mineral deposit databases have been under review. Common descriptive lookup-table terms that meet the needs of these databases and their compilers, but which have varied between databases in spelling and grammatical form, gradually are being standardized, and appropriate terms are being substituted into the databases. Terminology for deposit status, tectonic settings, commodities, and host rocks and related magmatic rocks has been tackled to date. Host rocks are defined as those rocks containing, or in contact with, mineralization. The greatest adjustment is to the way of describing host rocks and related magmatic rocks. Generalized classifiers for host rocks and related magmatic rocks have been substituted for individual lithologies that were entered in some of the databases, and the lithologies have been moved down one level in the database where several may be linked to one general host-rock category. Protoliths, internal structures, and external forms also are available at the lithology level to describe host rocks.

The most appropriate generalized terms for country rock have yet to be determined. These should be more general than those used for host rocks. Country rocks are not necessarily adjacent to the deposit, and are unrelated to the mineralization event, but for some deposits, country rocks may have been a factor influencing deposit characteristics. Examples can include a tonalite-granodiorite-gneiss complex, granite-greenstone terrane, or carbonate platform.

The schemas for production and resource numbers are illustrated in figure 4. Included in the master table for each production or resource number are overall tonnage values; whether the number applies to ore, metal, or concentrate; time periods for production; date of estimate of resources; the compiler's recommendation for using or not using the number for summary reports; and a reference number. The production master table includes a check box to indicate whether or not the number is cumulative. The resource master table includes a field for resource category and a check box to indicate whether the number is a combined production and resource number. It also contains check boxes to indicate whether the number refers to an anomaly within a larger resource or represents one of multiple zones for which separate resource estimates are reported. Anomalies and adjacent zones then are linked to the related primary number. Actual grades or metal weights are accommodated in detail tables, and any number of commodities can be reported. Cutoff grades also can be entered into resource detail tables. Each production and resource number should be linked to the most precise entity that it refers to and can be linked to more than one if this is indicated in the data source. The linkage is made through junction tables; if more than one entity is linked to a number, then a proportion of the number is allocated to each entity so that the total linked adds up to no more than 100 percent.

Production and resource numbers come from data sources that conform to a variety of industry standards. Different sources use different units of weight and grade, and the criteria for the classification of resource estimates vary widely. It was decided that the units and categories of the sources should be captured as is to assist verification. There is no solution for the variable resource category classifications; however, quantitative units will be recalculated to metric units by using a conversion table for summary spreadsheets and reports.

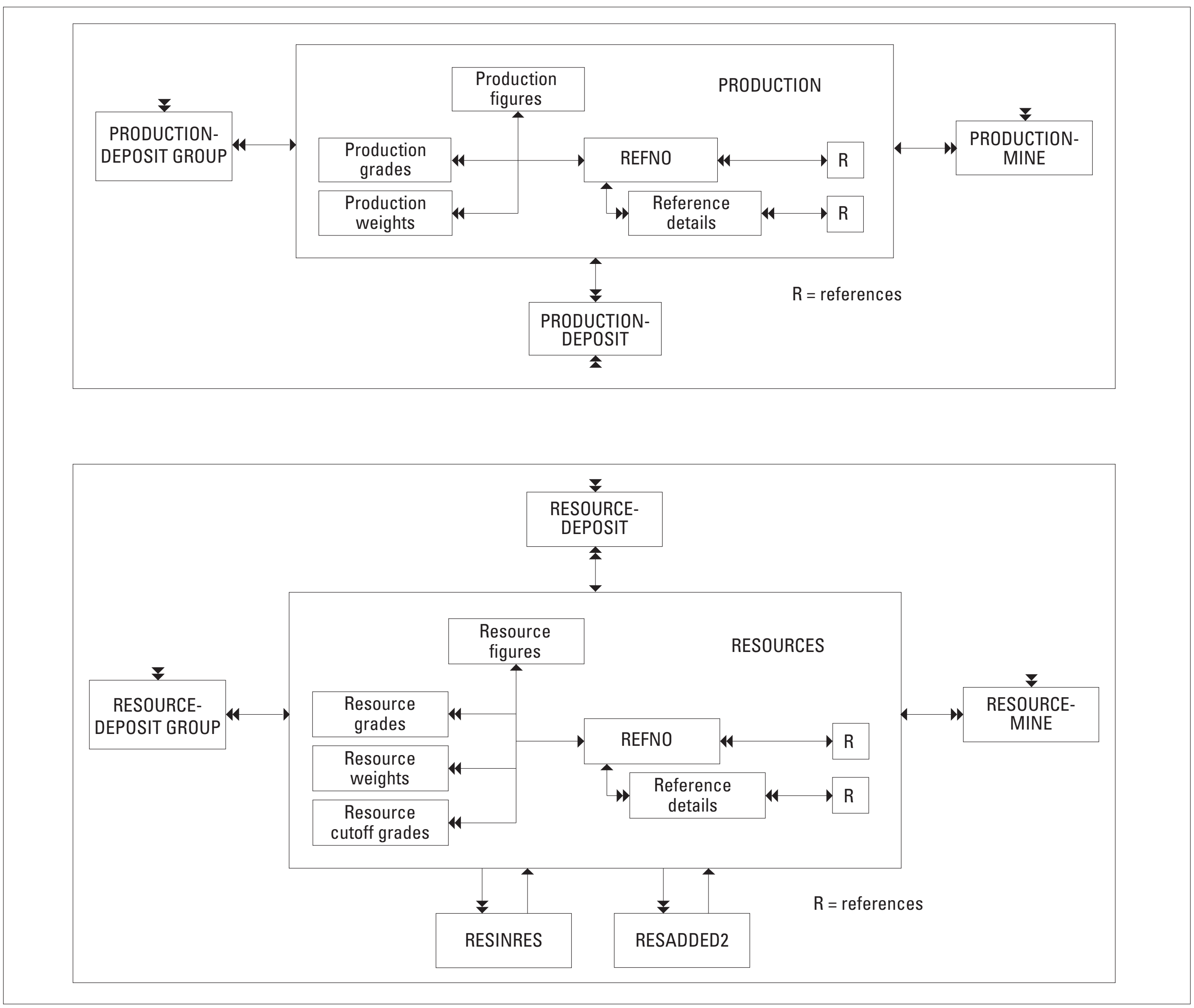


Figure 4. Schemas for production and resource numbers.

Although the mineral deposit schema covers abundant subject matter and consequently contains more than 100 tables, it will seem simple and logical to an economic geologist when viewed through the data entry interface (fig. 3). The deposit databases now are being made more accessible for end users through a personal-computer-based graphical query interface that will allow interactive filtering and the extraction of custom output that can be used in spreadsheets, displays, and reports. Use of this interface should make the benefits of standardization and generalized terminology evident to compilers and end users alike.

Geology Database

The geology database, which has evolved from Kirkham and others (1995), describes bedrock surface domains, major faults, and geotectonic provinces (fig. 5). ArcInfo is the software used to prepare the geospatial data and house the attribute database. Export datasets for desktop GIS are prepared by using Arc Macro Language scripts and then are imported into ArcView and MapInfo to create convenient end-user datasets.

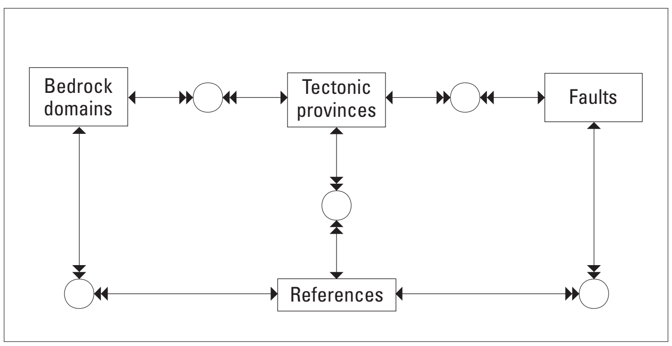


Figure 5. Overview of the geology schema.

The original simple database has been translated to a new, more comprehensive schema that better represents age ranges and rock types. Data for North America, Greenland, South America, Australia, and Africa have been substantially replaced from new sources, and updates to Asia and Europe are underway. Most effort has been directed toward bedrock domains. Data addition focused on the magmatic composition of intrusive and volcanic units to complement the concurrent compilations of nickel-PGE (platinum-group elements)-chromite and porphyry-related deposits.

The development of the geology database is as much a prototypal exercise as the development of the databases for mineral deposits because it is imperative that intact data products be released to industry sponsors during the course of the project. The arrangement of fields and tables, and the terminology, has been adjusted during the course of the WMGDP and the World Map Project to better represent the source data. Terminology still requires feedback, and users may recommend substitutions for some terms. The main objective in proceeding is to build the best framework possible under the circumstances and to test it by preparing thematic export products that can be used for diverse purposes within and outside the scope of the project.

The level of generalization of the geospatial features is being kept high for several reasons. It is primarily the distribution of elements of interest that is important in visualizing global patterns, not the geometry reflected exactly from more detailed map sources. Important elements, such as clusters of small intrusions, must be exaggerated so that they can show up on a global plot. In addition, the projection parameters of many paper source maps are missing and have had to be estimated. Many topographic bases poorly fit the standard World Data Bank II base used for the world geology or the nearly identical Digital Chart of the World; therefore, depicting too much detail would be misleading.

Bedrock Surface Domains

The bedrock surface database consists of a set of geospatial features (a polygon coverage in ArcInfo) that can be linked to an attribute database of tables describing the age range, rock-type components, names, tectonic settings, and significant commodities of input source units (fig. 6). Attributes housed by the source unit master table include primary and foreign keys, a textual input unit code or description of color or pattern on the original input map source(s), whether the unit is exposed onshore or offshore, and whether it is the default unit for quick plots. In complex areas where many very small, fragmented units are exposed, or in areas where multiple important units are exposed that may be too small to portray to scale on a global map, one polygon may be delin-

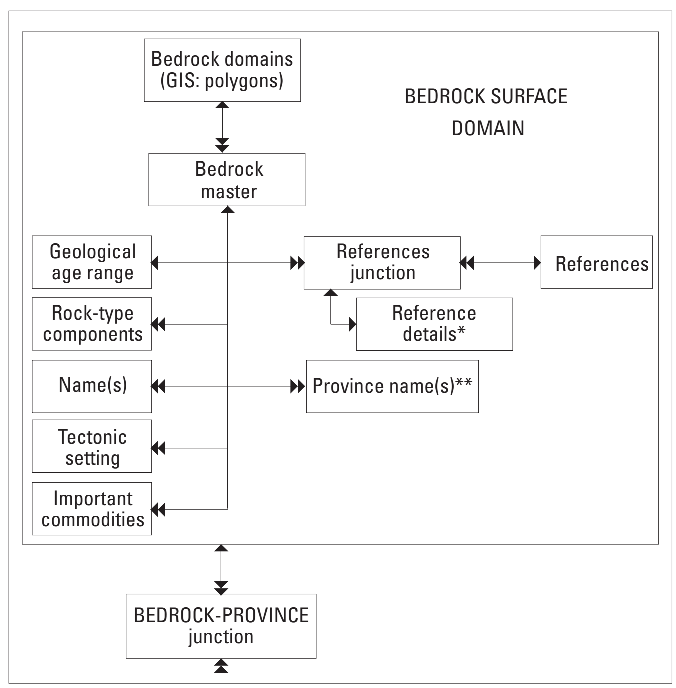


Figure 6. Schema for bedrock surface domains. GIS, geographic information system.

eated and linked to many units in the attribute database. The unit occupying the greatest cumulative area is tagged as the default unit. Alternative units for display may be retrieved on the basis of underlying attributes according to a specific end use. This generalization technique permits the derivation of alternative map views or export layers based on user-defined queries emphasizing different aspects of the attribute database. Different export layers will be superimposed appropriately when displayed with desktop GIS because they will be derived from the same geospatial framework.

The most significant and most thoroughly populated sets of descriptors for the unit are age and type. There can be many rock-type components for each unit but only one age range. The terms used for start age and end age are as close as possible to the terms used by the best age data source, and age-rollups are performed with the use of the numerically calibrated lookup table.

Rock-type components are described hierarchically, with broadly grouped classifiers at the top level and progressive levels of ungrouping deeper in the database. The most general classifiers are sedimentary, volcano-sedimentary, volcanic, intrusive, crystalline-metamorphic, and tectonic. Most of the bedrock domains in the dataset have been classified to this level. These top-level classifiers are stored in a rock-type table that links directly to the master table (fig. 7). Different attribute types and different terms normally are used to describe each class in more detail and therefore are stored in separate tables one level further down in the database (fig. 7). The status qualifiers that indicate whether components are the only components in the unit (SIMPLE or MIXED), and whether they are described in more than one type of detail table (DUAL or DUAL/MIXED), are stored with the general rock group. Whereas a sedimentary component should lead to only one record in the sedimentary detail table, a primarily metamorphic component showing significant sedimentary attributes could be described in sedimentary as well as metamorphic terms by placing one record in each table. A volcano-sedimentary component also may have details in either or both of the sedimentary and volcanic detail tables. If a component requires more than one entry in one of these detail tables, then it should be recorded as more than one component.

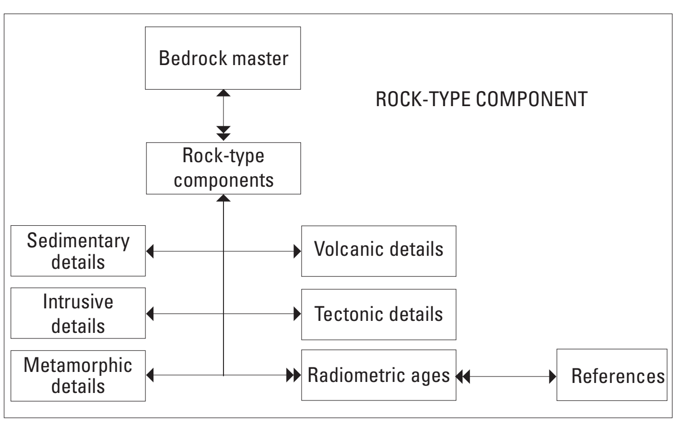


Figure 7. Schema for rock types.

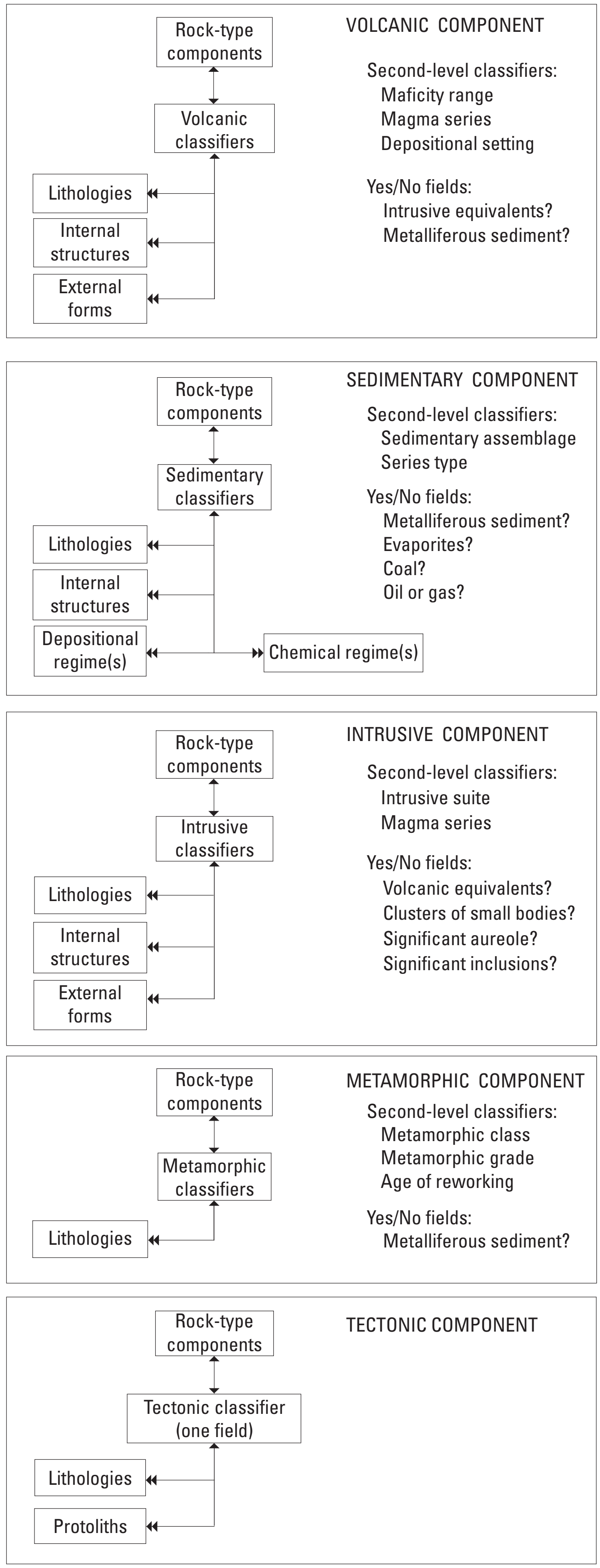


Figure 8. Schemas showing details for volcanic, sedimentary, intrusive, metamorphic, and tectonic rocks.

The structures and contents of the five rock-type detail tables are illustrated in figure 8. The main second-level classifiers are chosen from commonly used terms, mainly of broadly compositional nature, and are single valued for each component. The second-level classifiers may be further qualified by multiple lithologies, depositional settings and chemical regime (sediments), internal structures, or external forms. Whether a volcanic component is mafic, intermediate, intermediate-felsic, felsic, or ultramafic commonly is depicted on geologic maps and constitutes the main second-level classifier. Information about predominant magma series and depositional setting can be entered into separate fields. Intrusive rocks may be compositionally complex and are best grouped in terms of broad suites, such as granite suite, granodiorite-tonalite suite, gabbro-diorite suite, or mafic-ultramafic suite. The term "monzonite suite," or the alternative term "quartz monzonite-monzogabbro suite" used to reflect a possibly broad compositional range, may be applied to a large number of Cordilleran intrusive complexes. There indeed will be overlap between terms, and geological judgment will be required at times to pick the most appropriate suite name.

Sedimentary rocks, which commonly are interbedded mixtures, have been the most difficult to classify broadly. The initial approach has been to identify significant sedimentary components named in generalized but familiar terms that are commonly found in general map legends. These terms are applied in the lateral sense to avoid nuances because it often is uncertain exactly how the terms were applied in the original data sources. The term "mudstone" includes shale; "conglomerate" includes breccia; "quartzite" includes quartz arenite; and "carbonate" includes limestone, dolomite, dolostone, and even marble if the sedimentary detail table is being used to describe a metamorphic rock. The terms for the most substantial components in the sedimentary assemblage then are strung together in an order set by the system, which keeps the list of possible values within reason. An alternative method is to record the significant presence of any of these components as Yes/No fields in a small index file, together with the Yes/No fields for presence of metalliferous sediment, evaporite, coal, and oil or gas. This method may make it easier for a compiler to enter the information, but it may be more awkward to query by using the generic query interface. In any case, even minimal sedimentary information is harder to acquire than shallow magmatic information; therefore, the sedimentary information will be relatively incomplete at the end of the project.

The tectonic setting parameters for each unit also are significant in a global context. These include the realm, overall deformation environment, and the tectonic element by name. These fields are duplicated in the new geotectonic provinces dataset and are explained under that heading in table 2.

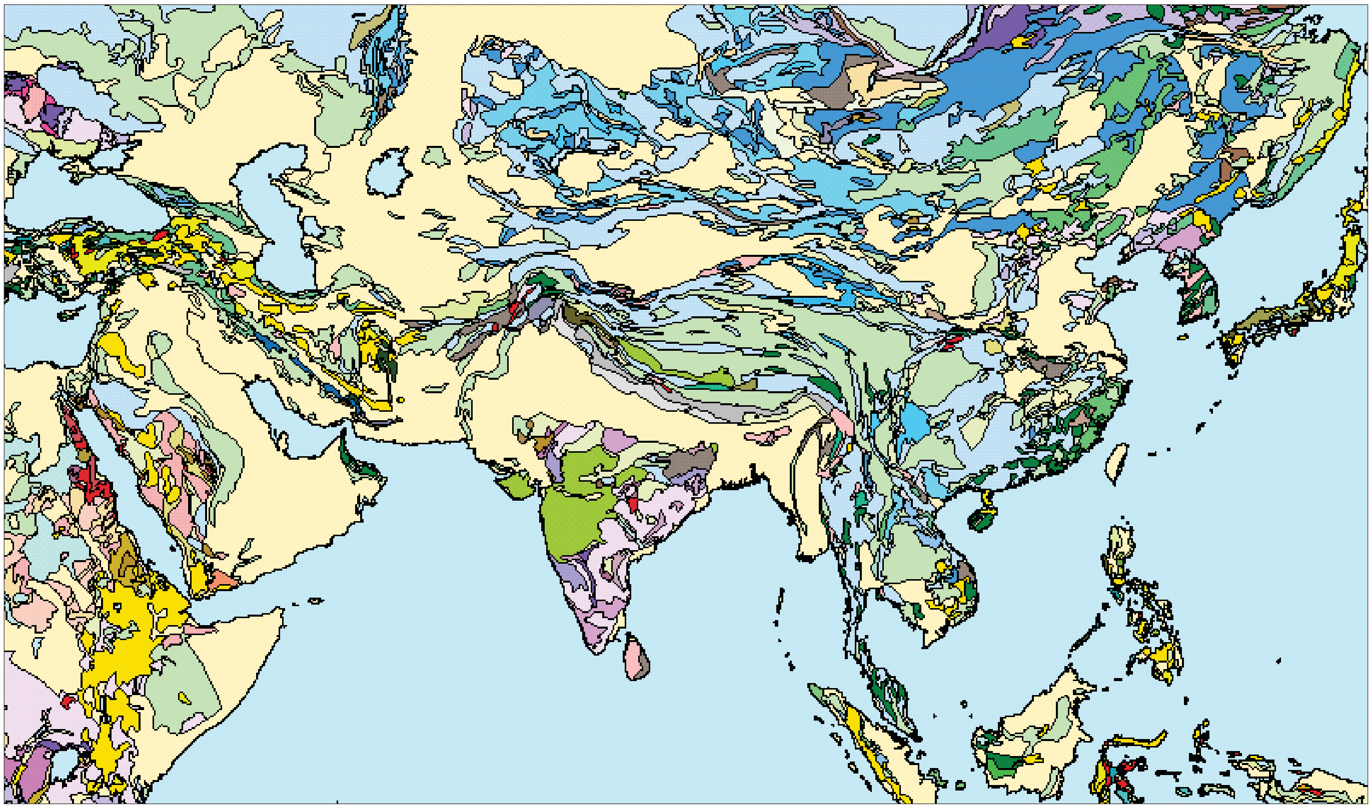
In some cases, judgment must be exercised in deciding exactly how to enter the data from an input unit with more than one rock-type component. The production of default export datasets will be automated in batch by a program that applies a series of age and rock-type queries to the dataset, attributes a copy of the geospatial data to produce a flat file, and discards redundant contacts (fig. 9). For example, a unit of a certain general age may be described in the source explanation as being sedimentary but containing felsic volcanic components and dolerite dykes. If all components are included in one unit and it is tagged as a default, then the output rock type will be classified as sedimentary and volcanic rocks or sedimentary, volcanic, and intrusive rocks, depending on how many components are requested by the program. If the unit normally is viewed locally as overwhelmingly sedimentary, then it would be preferable to store the three components as separate units in the database, thus making the sedimentary unit the default, so that just sedimentary rocks would be assigned to the output rock type. This storage method would not preclude the use of the felsic volcanic component for a more specialized theme that emphasizes the maximum extent of felsic volcanism. There is now provision in the attribute data for approximate quantification at the master and rock-type levels that could be used to solve this problem, although very little of this information has been entered.

Faults

The fault data schema (fig. 10) is very similar to the bedrock schema. Major faults are notorious for focusing different types of displacement at during different periods of Earth history. Therefore, there may be more than one master record in the fault-attribute database for each fault feature (arc) in the geospatial data. Although each period of fault activity has one age range, the fault may have exhibited different displacement

Table 2. Explanation of the attributes of the geotectonic province dataset.

Field name	Explanation
Name	Geotectonic province name.
Basis	The type of activity that the province is defined to represent, such as sedimentation, sedimentation and deformation, or magmatism.
Realm	Realm of deposition, such as continental, oceanic, continental marginal, or ocean plate marginal.
Regime	Deformation regime descriptor, such as extensional, stable, or transpressional.
Element	Basic tectonic element class, such as arc, basin, platform, or orogenic belt.
Qualifier	Refinement of element class, such as back-arc, fore-arc, or foreland.
Start age	Start geologic age.
End age	End geologic age.



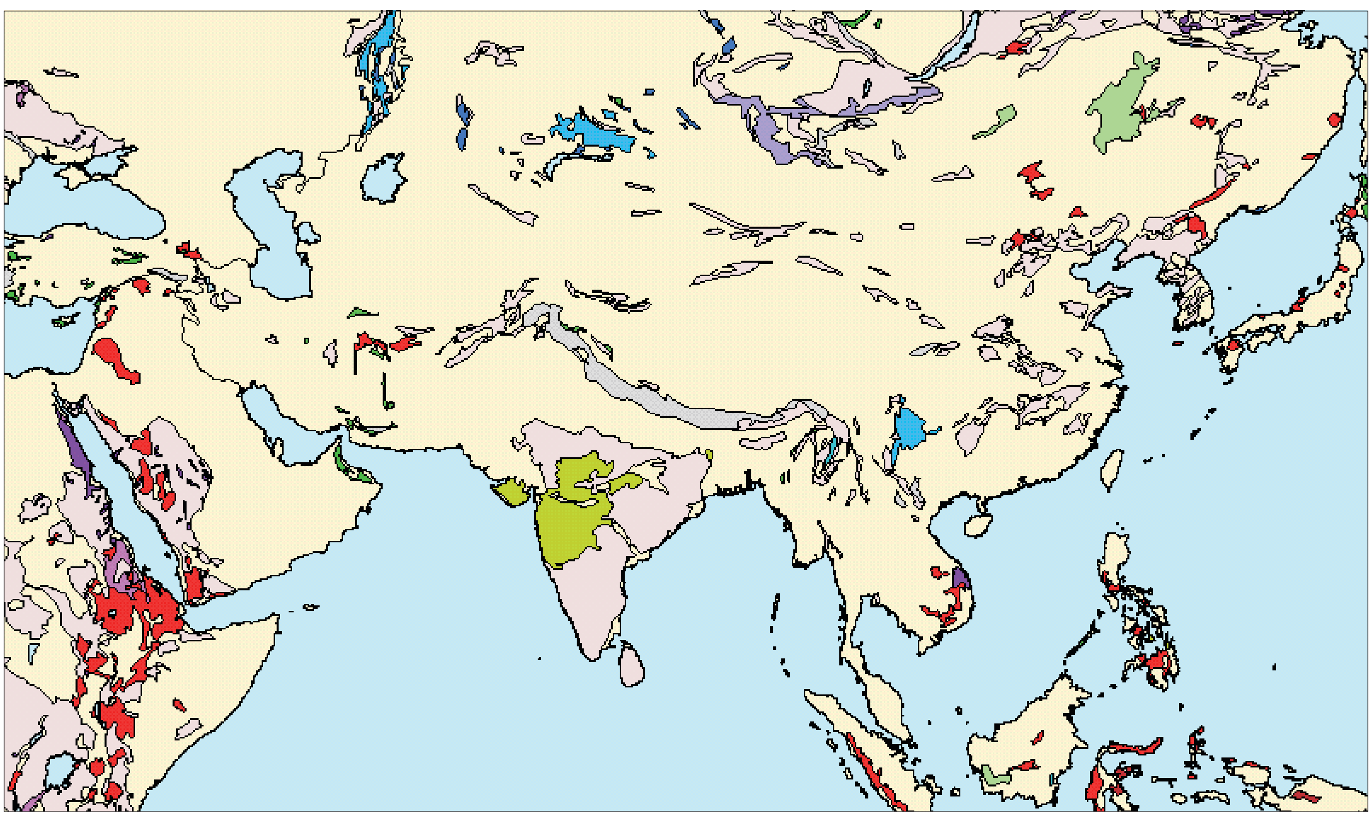


Figure 9. Maps showing alternative desktop geographic information system datasets derived from the generalized geology bedrock dataset. Default rock type (top) and mafic and (or) ultramafic intrusive and volcanic rocks (bottom), both subdivided by era-level age ranges.

components during this period. For the purpose of this database, fault displacements are classified as overthrust or nappe, high-angle reverse, normal, strike slip, shear zone, or unknown. Displacement senses are chosen as the quadrant pointing toward the overriding sheet, the downdip subquadrant, or the rotational sense, depending on the class of fault. Name(s) and tectonic regimes are accommodated in exactly the same way as they are in the bedrock surface database. Despite the enhancement of the data framework for faults, it has not expanded greatly in content since Kirkham and others (1995) because it ranks below bedrock geology as a context for mineral deposits.

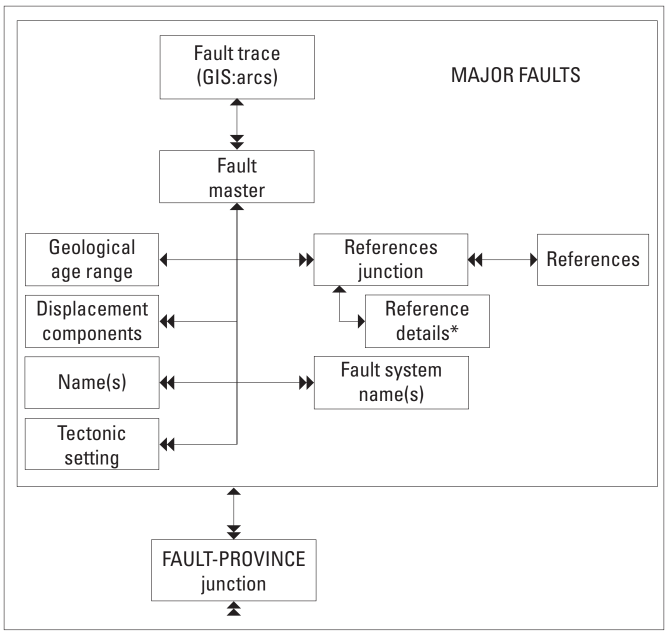


Figure 10. Schema for major faults. GIS, geographic information system.

Geotectonic Provinces

The geotectonic provinces dataset is in its early stages, and its schema still is undergoing refinement. It will contain information about basins, platforms, arcs, trenches, orogenic belts, and sutures. Data from the U.S. Geological Survey World Energy Project (Persits and others, 1997; Wandrey and Law, 1997; Steinshouer, and others, 1999) are being modified for the initial geospatial framework of world provinces. The emphasis in these source datasets is on petroleum basins. Therefore, the boundaries of the other province types will be redefined, and new province boundaries will be added.

The attributes that are being compiled for these provinces are name, basis of definition, realm, deformation regime, general element classifier, qualifier, start age, and end age (table 2). Many provinces have undergone different types of tectonic activity over different periods of time, and some include the remnants of earlier, completely unrelated tectonic provinces. These complexities will be accommodated in the schema in the same way that they are accommodated for faults and bedrock domains. The tectonic provinces dataset can be linked to bedrock surface domains and faults through junction tables (fig. 5), but this will not be attempted in the near future.

Discussion

Members of the World Minerals Geoscience Database Project aspire to have a moderately comprehensive data framework on world geology and mineral deposits available to the public after 2002 and to provide a source of maps and visualization layers to support and communicate global mineral exploration strategy. Questions posed to the mineral deposit databases about timing, host rocks or related intrusions, and tectonic setting may be posed independently to the geology database to discover areas permissive for the occurrence of undiscovered mineral deposits and can lead explorationists to examine more detailed data sources for further clarification. Perhaps the most intriguing potential academic use for these data will involve extracting data subsets for mineral deposits, bedrock, faults, and geotectonic provinces for user-defined intervals of time. Software that manipulates GIS data for plate tectonic reconstruction is now available.

The subject matter of these data overlaps that of the larger scale metallogenic maps prepared for the Commission for the Geological Map of the World (CGMW), also being prepared now in GIS format (Veselinovic-Williams and others, 1999). In some ways, these data also may complement the CGMW datasets by providing generalized world overviews for visualization, and by incorporating subjective interpretation to a greater degree. Subjective interpretation that is not desirable for an official international map series (for example, Veselinovic-Williams and others, 1999) may be stimulating for visualization, provided that it is kept up to date.

The mineral deposit databases overlap the MRDS (Mineral Resources Data System) and MAS/MILS (Minerals Availability System/Minerals Industry Location System) databases of the U.S. Geological Survey (McFaul and others, 2000; U.S. Geological Survey, 2005), both in geological subject matter and global scope, but lack some of the administrative division information and provision for free-form comments available in MRDS and MAS/MILS. The datasets will be complementary, will be useful for cross-verification, and may be used to supplement one another for resource assessment applications, especially if some of the overlapping, generalized terminology were to be standardized between datasets.

The flexibility of the generalized geology dataset as a source of custom display output, as well as its high level of generalization, may make it useful in the communication of global resource assessment results. The dataset lacks the spatial resolution required for a final quantified global resource assessment but could provide test data while methods of automation are being refined. If it is used to supplement spatial information in areas for which greater detail is unavailable, then these areas must be cut out and reprojected because global projections misrepresent area values too grossly for any area-based analysis. On the other hand, the geotectonic province component of the database may be a useful starting point for the definition of metallogenic tracts (see also Nokleberg and others, 1997) in regions that have not yet been subjected to modern metallogenic study (Nokleberg and others, this volume).

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