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Article

Metasomatic Mineral Systems with IOA, IOCG, and Affiliated Deposits: Ontology, Taxonomy, Lexicons, and Field Geology Data Collection Strategy

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Abstract: Metasomatic iron and alkali-calcic (MIAC) mineral systems form district-scale metasomatic footprints in the upper crust that are genetically associated with iron oxide–apatite (IOA), iron oxide and iron sulfide copper–gold (IOCG, ISCG), skarn, and affiliated critical and precious metal deposits. The development of MIAC systems is characterized by series of alteration facies that form key mappable entities in the field and along drill cores. Each facies can precipitate deposit types specific to the facies or host deposits formed at a subsequent facies. Defining the spatial and temporal relations between alteration facies and host rocks as well as with pre, syn, and post MIAC magmatic, tectonic, and mineralization events is essential to understanding the evolution of a MIAC system and to evaluating its overall mineral prospectivity. This paper proposes an ontology for MIAC systems that frames the key characteristics of the main alteration facies described and links it to a taxonomy and descriptive lexicons that allow the user to build an efficient data collection system tailored to the description of MIAC systems. The application developed by the Geological Survey of Canada for collecting field data is used as an example. The data collection system, including the application for collecting field data and the lexicons, are applicable to regional- and deposit-scale geological mapping as well as to drill core logging. They respond to the need for the metallogenic mapping of mineral systems and the development of more robust mineral prospectivity maps and exploration strategies for the discovery of critical and precious metal resources in MIAC systems.

Keywords: metasomatic iron and alkali-calcic (MIAC) mineral system; iron oxide copper–gold (IOCG); iron oxide–apatite (IOA); skarn; albitite-hosted; field geology lexicons; metasomatites; replacement; breccia; open geoscience; GIS; data collection



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1. Introduction

Mineral potential maps and models are increasingly produced by governments and industry to support the discovery of the critical and precious metal resources needed for the transition to a low-carbon economy, including by taking into account conservation and biodiversity [1–3]. The prospectivity models use a wide range of geoscientific datasets and knowledge-driven mappable criteria to produce “evidence layers” left behind by the ore deposition processes at the scale of the mineral deposits and their host mineral system [1–5]. Such information can be framed by an ontology—a set of rules for describing

information in a structured way according to a model—for the studied mineral system upon which mappable criteria, the supporting taxonomies, and, where applicable, lexicons can be developed to populate the datasets to be interrogated. Field mapping applications can use the controlled vocabulary (i.e., the fixed terms agreed upon and consistently used in data collection campaigns) to map and explore the mineral systems. A suitably tailored vocabulary limits unstructured data collection in the form of textual annotations, acknowledging that large language models and artificial intelligence (AI) can now better extract structured information from such annotations [6].

The vocabularies for mapping igneous (volcanic and plutonic), sedimentary, and orogenic and contact metamorphic rocks are extensive and well defined by the Commission for the Management and Application of Geoscience Information (CGI) of the International Union of Geological Sciences (IUGS) and by geological surveys from North America, Europe, and Australia [7–12]. Where alteration and mineralization occur, they are described as a qualifier that complements the description of the sedimentary, igneous, or metamorphic protolith [9], as is common in economic geology. The lexicons to describe metasomatic rocks within these publicly available and structured vocabularies are limited. Most terms relate to mineral-based alteration types (e.g., chloritic, sericitic); alteration terms such as argillic, advanced argillic, calcsilicate, carbonate, deuteric, potassic, and propylitic; and a few metasomatite names: albitite, beresite, birbirite, epidosite, fenite, garnetite, greisen, listvenite, roddingite, serpentinite, skarn, spilite, and tourmalinite [7–12]. As Wall Kimmerer [13] would remind us, “. . . in scientific language our terminology is used to define the boundaries of our knowing. What lies beyond our grasp remains unnamed.”

Gaps in terminology to describe the metasomatites of regional-scale metasomatic iron and alkali-calcic (MIAC) mineral systems and their iron oxide and iron sulfide copper–gold (IOCG, ISCG), iron oxide–apatite (IOA), and affiliated metasomatic iron and metasomatic alkali-calcic critical and precious metal deposits remain [14,15]. MIAC-related deposit types precipitate at distinct alteration facies (as defined in Refs. [14,16]) at the expense of any rock types in areas of strong fluid–rock interactions. The spatial distribution of the alteration facies considerably exceeds the spatial coverage of the deposits they host. Adapting the petrological mapping approach for metamorphic facies of Carmichael [17] to the MIAC alteration facies and documenting the alteration facies from the regional to the thin section scale are a cornerstone of the characterization of MIAC systems and their mineral exploration targeting [14,18–23].

An extensive review of geological and exploration reports, and of datasets of rock samples, indicates that MIAC metasomatites are frequently not described or are incorrectly identified. This is in part due to a lack of adequate descriptors for documenting MIAC metasomatites (cf. available lexicons [7–12] and lexicons proposed herein). What is not mapped tends to not be analyzed for lithogeochemistry, which leads to extensive data gaps in georeferenced geological and geochemical datasets across MIAC systems and ultimately impairs data-driven machine learning and AI applications for mineral exploration, mineral prospectivity mapping, and the development of training areas, datasets, and models for MIAC systems.

In this paper, we develop an ontology for MIAC systems with supporting taxonomy and descriptive lexicons to map them. The lexicons are integrated with the Field Application of the Geological Survey of Canada as a case example [24]. The structure of the data collection system is tailored to the description of alteration facies of MIAC systems and can be adapted to describe metasomatites in any relational-based data collection systems. A fundamental element of the data collection system is that the products of alteration facies, which can be metasomatites, hydrothermal veins, and breccias, are considered

primary mappable Earth Material. This approach places alteration products on par with sedimentary, metamorphic, and igneous rocks.

2. Materials and Methods

2.1. Ontology and Taxonomy as the Foundation for Structuring the Data Collection System

An ontology is a set of concepts that allow information to be described in a structured manner according to a model, and to define the content of a database by establishing the conditions of existence and validity of the data [25–27]. The use of ontologies in information processing involves the development of sampling strategies, visualization tools, and interactive functions, as well as the optimization of these processes [27–29]. In geosciences, the set of ontological concepts allows for a better definition of the geological attributes of a mineral system and of the spatial and/or temporal relationships between its different components. This serves as a framework for the establishment of a taxonomy and a series of field-driven lexicons to capture the required information (Figure 1). A taxonomy is a classification of data into categories and subcategories. The data is ordered in a hierarchical structure, and is then compartmentalized and finally divided into different attributes to make it consistent and usable in an optimized fashion.

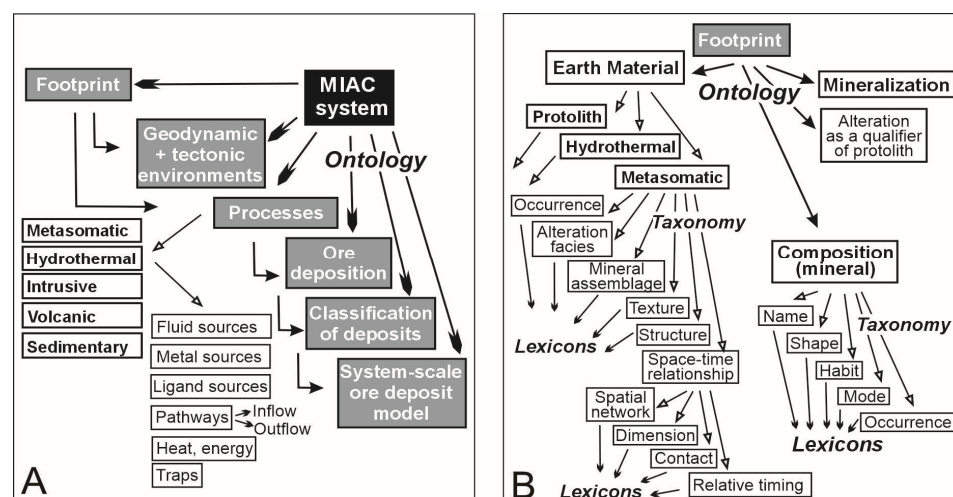


Figure 1. Ontology and taxonomy that comprise the field observation required to characterize metasomatic rocks and their mineral systems. (A) The ontology components in the grey boxes are linked to the field geology and the interpretation that can be made on the key components of mineral systems as laid out by Wyborn et al. [5]. (B) The geological footprint can be described using a series of lexicons grouped under their thematic taxonomy.

Figure 1 introduces a proposed ontology and the associated taxonomy and lexicons to structure the collection of the geological information deemed essential to describe and interpret MIAC systems. The key components of the mineral system ontology in Figure 1A are derived from those listed in Wyborn et al. [5], as they leave a tangible geological footprint in the field. The geological information is then subdivided into the three main components: (1) Earth Material, where metasomatic and hydrothermal “objects” (i.e., the root terms used) are primary lithologies, as are volcanic or plutonic rocks; (2) Composition (i.e., minerals); and (3) Alteration—Mineralization, where alteration is localized, partial, and serves to qualify a host rock in the Earth Material to which it is attached and where mineralization is attached to its hosts, including to its metasomatite or hydrothermal object (Figure 1B). A robust field geological perspective on a mineral system provides the essential foundation upon which to base interpretations derived from subsequent analyses

and research undertaken on geological samples. Many potential interpretations can be eliminated where they conflict with the observed field geology.

2.2. Data Sources and Methods to Develop Lexicons Adapted to the Description of MIAC Systems

The terms used to build the lexicons were derived and adapted from highly descriptive books and special issues (>90 pages of photos in Refs. [15,30]; [31–36]), geological atlases and contributions to mapping methods [19,37–42], and the terms needed for the 45 years of petrological mapping and field geology research by the first author. Additional key references are listed as table footnotes to the proposed lexicons. We also used websites that list geological terms to ensure that the key terms had been included in the lexicons (e.g., Mindat.org; Earth Science Australia at earthsci.org; McGill University fault rock atlas at <https://eps.mcgill.ca/blogs/faultrocks/> (accessed 23 March 2023; [43]; Wikipedia, in particular, Llista de roques metamòrfiques; minerals; webmineral.com); as well as geological dictionaries and glossaries [44,45] and examples of thorough descriptions of rocks (e.g., [46]).

The proposed lexicons were systematically refined through several campaigns of petrological mapping of alteration facies and their metasomatic rocks in MIAC systems by the authors of this paper and their collaborators. Case studies cover a variety of geological environments, including: (1) intermediate to felsic volcanic rocks, sub-volcanic intrusions, and underlying metasedimentary basins (e.g., the Great Bear magmatic zone and the East Arm Basin in the Northwest Territories, Canada [18,47–51]); (2) sedimentary basins with mafic rocks (e.g., the Romanet Horst in Québec and the Wanapitei district in Ontario, Canada [52,53]); and (3) high-grade metamorphic terranes (e.g., the Bondy gneiss complex of the Grenville Province, Canada [54]). Additional field observations of deposits and host mineral systems worldwide further helped refined the lexicons (e.g., Central Andes province and El Lago deposit, Chile; Kangdian district and Middle-Lower Yangtse River Metallogenic Belt, China; Cloncurry district and Olympic Cu-Au Province, Australia; Josette rare-earth deposit, Québec, Canada [22,55–57]). The observations cover most formational environments of MIAC systems, except for those hosted in ultramafic to mafic belts, for which ample descriptions are available from the Carajás Mineral Province in Brazil [58–60]. Among the mapped attributes were the alteration facies; the mineral parageneses of the metasomatites; the intensity of alteration expressed by mineral contents and the pervasiveness and extensiveness of alteration; the textures, structures, deformation fabrics, distribution, and relative timing of the metasomatic lithotypes; the associated mineralization; the inter-relationships of metasomatites with pre-existing, coeval, and subsequent geological events; and the remobilization events.

2.3. Summary of Alteration Facies in MIAC Systems upon Which the Lexicons Are Developed

As MIAC metasomatism proceeds (see Table 1 in Ref. [14] of this special issue), zones of alkali-rich alteration (Na, K) form regionally, while more localized and commonly mineralized alteration zones are Fe-rich, in which Fe is coupled with alkali (Na, K) and/or calcic (Ca, Mg, Ba) cations, and Fe-poor alkali-calcic alteration. Based on the field work and the descriptions derived from the mapping and analyses of MIAC systems, MIAC metasomatites are classified under six main alteration facies with which veins, breccias, and mineralization zones can be associated in addition to their extensive replacement zones, as summarized below. A detailed account of mineral assemblages for each alteration facies is provided in Refs. [19,20], and the suite of minerals within each facies is provided in Section 3.

Figure 2 illustrates how pervasive and sequentially developed metasomatism is in MIAC systems and how the field evidence for the nature of the protolith can be obliterated

by metasomatism at the outcrop scale, hence the need to describe metasomatites as their own lithology (see Section 3.2). Examples are provided for Facies 1 Na, followed by extensive overprints by Facies 2 HT Ca-Fe alteration and localized chloritization. The extensive figure caption provides insights into what needs to be described to characterize the systems. In the caption, terms included in the proposed lexicons are in *italics* where they first appear. To best illustrate the relationships among the distinct mineral assemblages of the alteration facies, the photographs of Figure 2 were slightly adjusted equally for the entire image for contrast, brightness, intensity, and sharpness. The photographs were also cropped on the sides to remove hammers, other objects used for scale, excessive lichen, and dirt. The outcrop numbers of the geological station documented by the Geological Survey of Canada are provided in the caption of Figure 2 for future linkages to the field geology datasets currently in preparation (e.g., 10-CQA-1305 or CQA-05-095, where 10 and 05 are the years 2010 and 2005, CQA refers to the project leader Louise Corriveau and her team, and 1305 and 095 are the number in the sequence visited that year or in the course of the project).

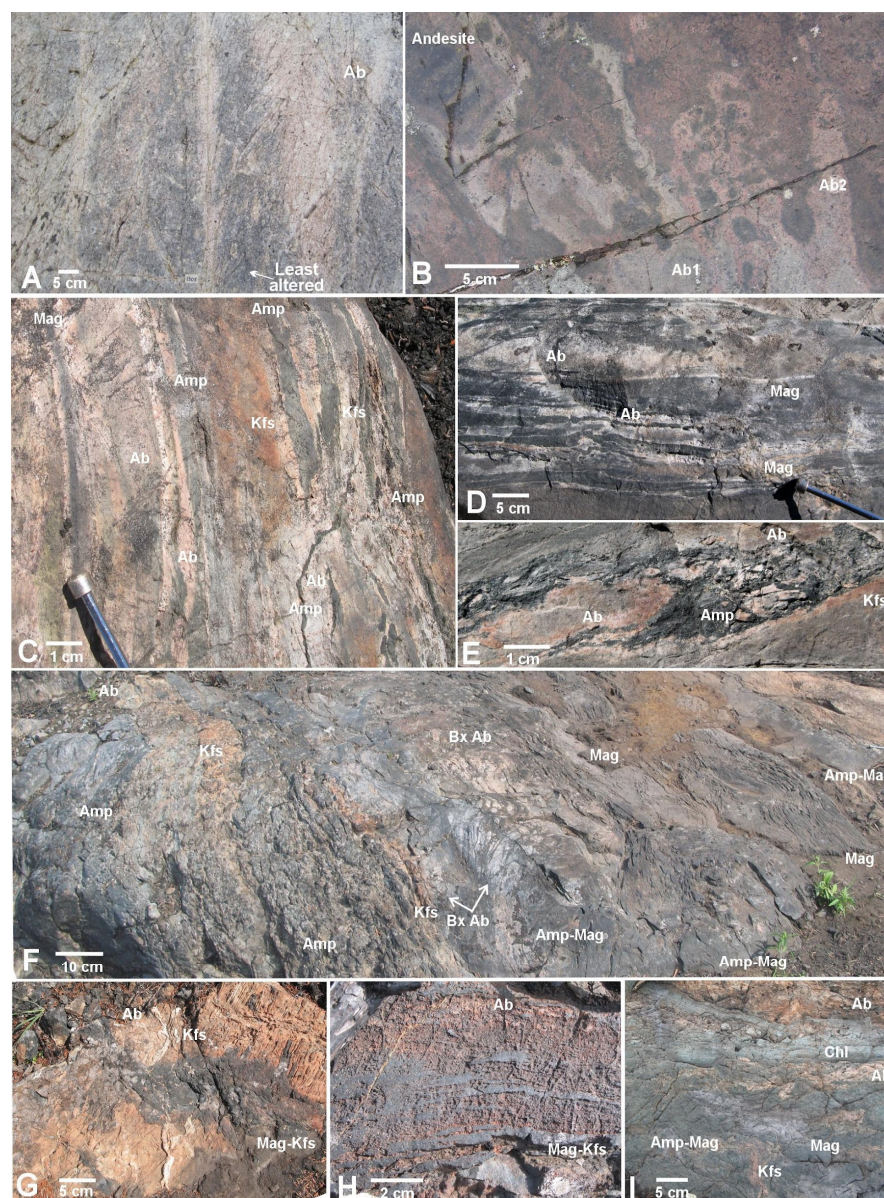


Figure 2. Replacement of andesite and metasedimentary rocks by Facies 1 to 3 *metasomatites*. Protoliths are from the Labine Group andesite and the Treasure Lake Group sedimentary rocks of the Great Bear

magmatic zone, Canada [61,62]. (A) Andesite increasingly *albitized* at Facies 1 Na through *coalescing fracture haloes* and *pervasive replacement* (outcrop 10-CQA-1305 of the Geological Survey of Canada). (B) *Relics* of andesite among *albitite* (CQA-05-095). The *albitite fronts* evolve from white to pink albitite, while very fine-grained albite–amphibole greyish *patches* form outwardly from the *core* of the albitite front, illustrating that elements leached by the fluid inflow that precipitate the albitite front are precipitated outwardly by the outflow fluid. (C) *Stratabound* amphibole to magnetite dominant alteration with albite *haloes* (HT Na-Ca-Fe facies) preferentially replace certain albitized layers in a metasiltstone (09-CQA-0050). The minerals within haloes are combined with the mineralogy of their veins or stratabound alteration zones to establish the stable alteration facies (and the type of metasomatites). Local *overprints* of albitized areas by K-feldspar alteration with minor hematization take on a darker brown–orange color. Locally, the protolith remains less altered (grey tone) and consists largely of quartz, feldspar, and biotite. (D). Example of a sequence of overprinting alteration facies within metasedimentary host rocks. *Moderate to intense* stratabound magnetite-dominant HT Ca-Fe alteration (Facies 2) overprinting albitite (Facies 1 Na) that *replaced* metasandstone (09-CQA-0050). (E) Amphibole-dominant *vein with haloes* that evolve in composition from albite-dominant (albitite) to K-feldspar-dominant diagnostic of a *transition* from *Facies 1–2 HT Na-Ca-Fe* to *Facies 2–3 HT Ca-K-Fe alteration* (09-CQA-0050). The amphibole *matrix* displays a strong *foliation* fabric, while a least-altered outcrop nearby (09-CQA-0055) preserves ripple marks [47], highlighting that the deformation is not a consequence of an orogenic overprinting the system but rather takes place during the development of the HT Ca-Fe alteration facies. (F) Outcrop of pervasively albitized thin- to medium-bedded metasedimentary rocks *overprinted by intense to megascopically complete*, stratabound to *discordant*, amphibole-dominant (left side) to magnetite-dominant (right side) HT Ca-Fe alteration. The overprint of K-feldspar stable magnetite alteration illustrates the progradation of the Facies 2 HT Ca-Fe alteration to Facies 3 HT K-Fe alteration (09-CQA-0054). The magnetite-rich alteration zone exhibits local ductile deformation (e.g., folds). Where intensity and pervasiveness of magnetite alteration decreases, an alteration is observed to *cut a brecciated zone* of albitite *infilled by* magnetite (Bx Ab, central zone of F). (G) Within the same outcrop as F, magnetite alteration cuts the pervasively albitized sedimentary beds, increases gradually in intensity, and develops stratabound magnetite *offshoots* that range from *selective* pervasive to *discontinuous selective stratabound* alteration. The K-feldspar (Kfs) halo to the magnetite alteration zone records the onset of Facies 3 HT K-Fe alteration. The primary bedding structure appears to be locally obliterated by the albitization. (H) Within the same outcrop as F, Facies 3 HT K-Fe alteration (Mag-Kfs) becomes locally pervasive. Even though the earlier albitization largely destroyed primary bedding, the replacement by magnetite forms distinct *sharp* stratabound layers along the former sedimentary bedding structure. (I) Chloritization (Fe-poor chlorite) of the earlier Facies 2 amphibole-dominant alteration. Mineral abbreviations follow Warr [63].

The onset of MIAC metasomatism within the upper crust is recorded by the development of Facies 1 Na alteration at an intensity that systematically leads to albitite at the expense of any rock types, from basalt to diorite to siltstone to carbonate to evaporite (Figure 2) [19,48,52,53,64–67]. The metasomatic albitite consists of over 80% albite and may contain a significant amount of undissolved quartz depending on the type of protolith [20,67]. Albitite are commonly brecciated, and brittle deformation prevails. Facies 1 albitite (Na) alteration transitions to Na-Ca and HT Na-Ca-Fe alteration to form a transitional Facies 1–2 (Figure 2C). This transition is marked by a gradual increase in mafic minerals (amphibole, clinopyroxene, and magnetite) or apatite in association with albite, oligoclase, or Ca-bearing scapolite. Pseudo-pegmatitic textures are common and consist of interlocking or sub-parallel rods of albitite up to 20 cm long with interstitial fine- to coarse-grained amphibole, magnetite, and/or apatite [18,68].

Facies 2 HT Ca-Fe alteration follows Facies 1 albitite (Figure 2) and can lead to Fe (magnetite) skarn and IOA deposits with Fe, P, REE, and/or Ni resources [14,56,57,69,70]. Facies 2 is also a preferential host for the precipitation of the transitional Facies 2–3 HT Ca-K-Fe alteration, where amphibole, magnetite, K-feldspar, and biotite can prevail. Facies

2–3 HT Ca-K-Fe alteration can be very extensive in sedimentary sequences containing carbonate rocks and can lead to Au-Co-Bi deposits (e.g., NICO Au-Co-Bi-Cu deposit, Canada) [49,50,71]. Both Facies 2 and 2–3 metasomatites can vary from being isotropic, with randomly oriented minerals, or brecciated to foliated, boudinaged, and folded—hence, ductilely deformed.

Facies 3 HT K-Fe alteration hosts polymetallic magnetite-group IOCG deposits, iron sulfide copper–gold (ISCG) deposits, metasomatic iron–Co deposits, and metasomatic iron–U mineralization [14,23,58]. Biotite-rich HT K-Fe alteration with sparse to abundant magnetite prevails in sedimentary and volcanoclastic rocks and typically forms stratabound replacements [57]. The biotite-rich metasomatites can be foliated and sheared. In volcanic and plutonic rocks and albitite, the K-feldspar-rich HT K-Fe alteration facies prevails and is commonly associated with brecciation under a brittle deformation regime and the precipitation of Cu-sulfides in veins or disseminations within the iron oxide-rich matrix of IOCG deposits [21,47,55,72,73].

Facies 4 consists of K-skarn in carbonate-bearing host rocks (sedimentary or hydrothermal) and K-felsite in silicic host rocks [47]. Both are commonly brecciated, and the K-skarn breccia may be replaced by a K-felsite [18]. Skarn parageneses precipitate in the matrix of breccias, while K-feldspar replaces the fragments (Figures 30 and 31 in [47]). Brittle deformation is associated with Facies 4 alteration.

Facies 5 forms a wide range of mineral assemblages and mineralization types within hematite-rich to chlorite-rich breccias and replacement zones (Figure 2I) [14,59,72,74]. Hematite not only precipitates within the matrix of breccias but also replaces and often pseudomorphs fragments, preserving their contours at megascopic scale (e.g., Olympic Dam deposit; Figure 12 in Refs. [22,74]).

Facies 6, LT K-Si-Al $\pm$ Fe-Ba (phyllic, sericitic, silicic, advanced argillic) alteration includes LT K, LT Si, and LT K-Al alteration and extensive veining. Pervasive late-stage silicification, extensive quartz veins, stockworks, and breccias are often accompanied by hematite, carbonates, barite, base metal sulfides and sulfarsenides, precious metals, and uraninite, many of which are typical of five-element veins [18]. These late-stage veins can be distal to the cores of the system or cut earlier high-temperature alteration zones. They can represent the final stage in the evolution of primary MIAC systems or can be formed much later [21]. Brittle deformation is typically associated with Facies 6 alteration.

3. Taxonomic Lexicons to Record Observation on Alteration Facies and Mineralization in MIAC Systems

This section first presents the structure of the Field Application of the Geological Survey of Canada and its adaptation to the description of alteration facies as a case example of an available application for geological mapping and mineral exploration. The section then introduces the individual lexicons required to record field observations from alteration facies in MIAC systems. The lexicons are adaptable to a variety of contexts, such as field mapping or core logging programs, description of individual rock samples, or description of thin sections. Additional terms have been added to the lexicons to expand the use of the lexicons to other metasomatic components of mineral systems (e.g., fenites within carbonatites).

3.1. Attributes and Architecture of the Field Application of the Geological Survey of Canada Adapted to the Description of Alteration Facies

The digital Field Application of the Geological Survey of Canada is built upon a simple yet effective field data collection model for bedrock geology, surficial geology, and, more recently, drill core logging [24,75–77]. The field data collection model implements the

flexibility and ease of use of a field paper notebook [24], and its first component, “field notebook,” as shown in Figure 3, is a direct tribute to the legacy of the Geological Survey of Canada field notebooks [78]. The source code is openly available on GitHub [79]. Its relational GIS database is available in the form of a Geopackage (version 1.3) as an open geospatial format supported by the Open Geoscience Consortium. Appendix A provides a diagram of the geospatial and relational database used within the Field Application and the fields that can be filled out when mapping bedrock geology (Figure A1).

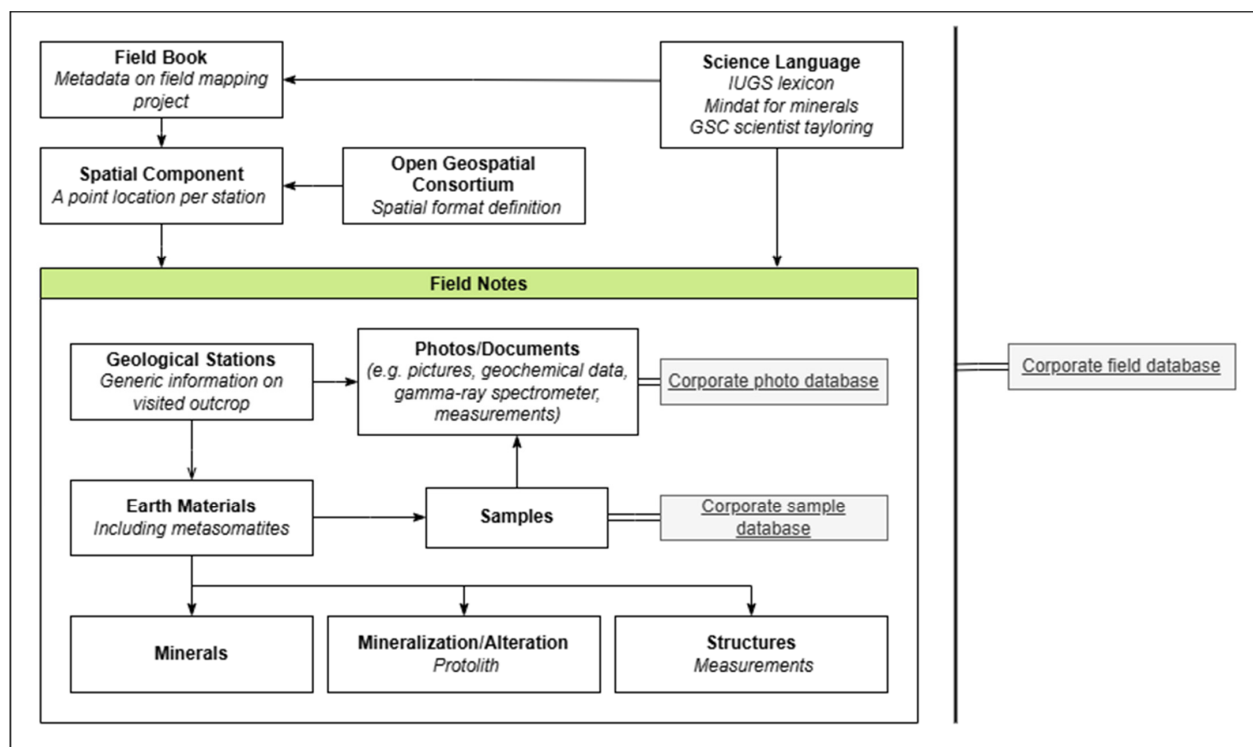


Figure 3. Conceptual data model of the relational database, focusing solely on bedrock data type. Adapted from Huot-Vézina et al. [24]. CGI is Commission for the Management and Application of Geoscience Information [10].

The Field Application is set up to work under a fully disconnected environment (no Wi-Fi, no cellular network and such), in all weather conditions, and the geoscientists can access customizable, predefined digital forms, along with a documented preset of approved scientific terms. They can also adapt lexicons, a need when mapping MIAC systems, where each individual system seems to be able to develop new textures and new ways to replace the original rocks.

Figure 3 provides a conceptual overview of the bedrock components of the Field Application and how they interact with each other, as well as how they are linked to more corporate relational databases (in light grey) for archiving purposes and subsequent use. Starting at the upper left is the “Field Book” information on the project as well as the name of the observer, so that the digital datasets are retraceable to their source. Linked to the notebook block is the spatial feature, which follows the Open Geoscience Consortium Geopackage definition and records the Geospatial Information System (GIS) data (see details in Ref. [24]). Related to all of these is the “Field Notes” block (in light green), in which a geoscientist records its observation.

All the collected field information within the Field Application is interlinked and nested with well-integrated lexicons that act as the foundational cement of all observations. The Earth Material component, which defines lithologies and their inherent attributes, is the

core and major focus of the field database. The lexicons associated with each type of Earth Material are defined and accessed within the science language component (upper center; Figure 3) and account for all literal string values that the geoscientist can select during a field survey. The lexicons can be fully exposed to either show, hide, add, reorganize, or set default terms.

This contribution focuses on the Earth Material block of the Field Note block and how it can be adapted to better map metasomatites and hydrothermal objects. The Earth Material block is a nested relational system that defines the lexicons available to describe a major geological unit based on the selected lithological group (Lithgroup). The Lithgroup represents the general grouping of rocks according to the processes that led to their formation (sedimentary, metasedimentary, volcanic, metavolcanic, volcanoclastic, metavolcanoclastic, hypabyssal, metahypabyssal, plutonic, metaplutonic, tectonic, hydrothermal, metasomatic, metametasomatic, metamorphic).

3.2. *Alteration Facies as a Primary Mappable Element in the Data Collection System*

In typical lexicons of field data collection systems, including the current version of the Field Application of the Geological Survey of Canada being updated for metasomatites, alteration is described as a transformation of a protolith from a pre-existing Lithgroup such as volcanic rocks. Alteration is thus attached to a host lithology without the possibility of being described on its own. The description of alteration uses individual minerals without the ability to group the minerals into mineral assemblages (parageneses) characteristic of the observed alteration facies. Listing minerals, not mineral assemblages, is an inappropriate option for mapping the almost complete transformation of host rocks into metasomatites across MIAC systems for the following reasons. Each alteration facies comprises a variety of mineral assemblages across an outcrop (Figure 2C,F) and from one outcrop to the another (Figure 2C–I) or along drill cores. Each assemblage has mineral proportions that range megascopically from near zero to 100 percent, even at the hand specimen and outcrop scales. In contrast, the distribution of alteration facies across and among outcrops and their sequential development are very regular, systematically mappable (Figure 2), and demonstrated to serve as pathfinders to facies-specific critical and precious metal deposit types [14,18–23]. Consequently, the data collection system for describing alteration facies in MIAC systems needs to be more flexible than one developed for localized partial alteration, and the metasomatites and their alteration facies need to be mapped as we map igneous, sedimentary, and metamorphic rocks.

Table 1 presents a structure to create nested picklists to describe **metasomatic rocks** as a primary lithological group (Lithgroup). The metasomatic Lithgroup is divided into the main lithological types (Lithtype) and into lithological details (Lithdetail), which will serve as the rock name. For example, within the volcanic Lithgroup, rhyolite falls in the Lithdetail of the volcanic–felsic Lithtype. Within the metasomatic Lithgroup, a HT Ca-Fe metasomatite falls in the Lithdetail of the Fe and alkali-calcic Lithtype. The name of the metasomatite thus falls in the Lithdetail and is its alteration facies (Table 1). Consequently, an iron-rich metasomatite with a variety of amphibole-, magnetite- and apatite-bearing parageneses is stable at the HT Ca-Fe alteration facies and is named as such in the Lithdetail of the Fe and alkali-calcic Lithtype. The term “metasomatite” has been left out of the Lithdetail list to simplify the table (Table 1). The stable mineral assemblages associated with the described alteration facies can then be defined using a qualifier field. Different mineral assemblages can form an alteration facies depending on the studied MIAC system and its geological environment; hence, different groupings of minerals can be necessary to characterize the alteration facies. Most of that is carried out in the qualifier field. Within the Lithdetail, distinctive types of HT Ca-Fe metasomatites in particular are listed and

would serve as a rock name. This is necessary because Amp-, Amp-Mag-, Ap-, Ap-Mag-, Ap-Mag-REE minerals, Ep-Mag, or Mag-dominant HT Ca-Fe metasomatites will have extremely distinct appearance, composition, and rock physical properties, thus forming distinct rock types. The minerals are put before the main rock name (i.e., before HT Ca-Fe) as one would do for nepheline syenite.

If protolith information is available on an outcrop, it is best to map it as the first Earth Material, while metasomatites developed from it are mapped subsequently as Earth Material and linked to their protolith in the relationship component of the Earth Material module. This allows mineral systems to be mapped efficiently.

Table 1. List of metasomatic lithotypes in MIAC systems and their epithermal caps (additional metasomatic rock types are listed in *italics*). Mineral assemblages qualify the alteration facies. Iron-rich minerals (in **bold**) can be oxides, silicates, carbonates, or sulfides. Mineral abbreviations follow Warr [63], except for sericite (i.e., Ser as per Ref. [80]), acknowledging that sericite is a mixture of white mica and clay and not a mineral per se.

Lithtype	Lithdetail ¹	Qualifier (Mineral Assemblages with Combinations of Minerals) ¹
Al-H+	Advanced argillic, intermediate argillic, argillic, <i>clay, greisen, undivided, Ms-, Qz-, Flr-, Tpz-greisen</i>	
Alkali-calcic Ca-Mg	LT (Ca, Fe, Mg)-CO ₂ , LT (Ca, Fe, Mg)-K, LT (Ca, Fe, Mg)-Na, LT (Ca, Fe, Mg)-Si Fe-poor gumbeyite	Cb (Ank, Cal, Dol)—(Amp, Anh, Brt, Chl, Ep, Flr, Kfs, Mca, Qz, Srp, Tlc, Tur) Cal-Kfs-Ph or Ank-Kfs-Qz-Ser
	LT (Ca, Mg, Fe)-CO ₂	Cb (Ank , Cal, Dol, Fe-Dol , Sid) ± Amp , Anh, Brt, Chl (Fe to Mg rich), Ep, Flr, Mca (can be phengitic), Srp, Tlc, Tur
	LT K-(Ca, Fe, Mg)-(CO ₂ , Si)	Cb (Ank, Cal, Dol ferroan), Chl, Kfs, Ms, Qz, Tur
K	K feldspar, <i>listvenite</i> , phyllic, sericitic	
Mg	<i>Rodingite</i> , serpentinite, soapstone, <i>steatite</i> , Tlc schist	
Na	Albitite Na metasomatite Aceite, adinole, spillite	>80% Ab ± Scp, Qz, Rt, Ttn, Zrn <80% Ab, Olg, Scp, Qz
Na-Ca	Na-Ca metasomatite	Ab, Olg, Scp, ± Qz
Fe and alkali-calcic	Skarn (i.e., HT Ca-Fe-Mg), undivided, Fe-, Mg-, K-, Mn-, W-skarn	Cpx, Ca-Grt (Adr, Grs), Mag, Sch, Amp, Ep
	Fenite (i.e., Al-poor HT Na-Ca-Fe-Mg), undivided, Ab-, Kfs-, Phl-fenite	Ab, Na-Cpx (Aeg, Aug, Di, Hd), Na-Amp (Arf, Rbk), Cb (Cal, others), Kfs, Phl, ± Ap, Rt, Qz E.g., Ab-fenite: Ab-Na Cpx (Aeg, Aug, Di, Hd)-Na Amp (Arf, Rbk)
	HT Na-Ca-Fe metasomatite	Ab and/or Scp with Amp , Ap, Cpx , Mag

Table 1. Cont.

Lithtype	Lithdetail ¹	Qualifier (Mineral Assemblages with Combinations of Minerals) ¹
	HT Ca-Fe metasomatite: undivided, Amp-, Amp-Mag-, Ap-, Ap-Mag-, Ep-Mag, REE minerals, or Mag-dominant	Amp (Act, Cum, Gru, Hbl)—(Ap, Cpx, Ep, Grt, Mag , REE minerals, Scp); Py or Pyh are rare Ap —(Amp, Cpx, Ep, Grt, Mag , REE minerals, Scp); Py or Pyh are rare Mag —(Amp, Ap, Cpx, Ep, Grt , REE minerals, Scp); Py or Pyh are rare ductile deformations of HT Ca-Fe metasomatite, leading to schist or gneiss
	HT Ca-K-Fe metasomatite: undivided, Amp-Bt-, Amp-Bt-Kfs-Mag-, Amp-Bt-Mag-, Amp-Kfs-, Amp-Kfs-Mag-dominant	Amp as Act or Hbl —(Bt, Grt, Kfs, Mag, Py, Pyh) Bt —(Amp as Act or Hbl, Grt, Kfs, Mag, Py, Pyh) Kfs —(Amp as Act or Hbl, Bt, Grt, Mag, Py, Pyh) Mag —(Amp as Act or Hbl, Bt, Grt, Kfs, Py, Pyh) Ductile deformation of Bt-rich HT Ca-K-Fe metasomatite leads to schist or gneiss
	HT K-Fe metasomatite: undivided, Bt-, Bt-Kfs-Mag-, Bt-Mag-, Kfs-Mag-dominant	Bt , biotitite, Bt-Grt, Bt-Grt-Gru, Bt-Grt-Kfs , Bt-Grt-Kfs-Mag, Bt-Grt-Mag, Bt-Kfs-Mag, Bt-Mag , Kfs-Mag; Py and Pyh can be present Ductile deformation of Bt-rich HT K-Fe metasomatite leads to schist or gneiss
	LT (Ca,Mg)-(K,Na)-Fe	Ab —(Act, Bt, Chl, Ep, Ca-Mg-Fe³⁺ Grt, Hem, Mag) + other LT minerals Act —(Chl, Ep, Ca-Mg-Fe³⁺ Grt, Hem) + other LT minerals Chl —(Bt, Ep, Hem, Kfs, Mag, Ser) + other LT minerals Ep —(Hem, Mag) + other LT minerals Hem —(Ser) + other LT minerals; hematitite, hematite ironstone Ductile deformation of Ser-rich metasomatite leads to schist or gneiss
	LT (K, Ba, Ca, Na)-(CO ₂ , F, H ⁺)-Fe	(Amp, Chl, Ep, Hem, Sid)—(Ab, Ank, Ap, Brt, Cal , Dol, Flr, Kfs, Ms, Qz, Tur) Ab, Aln, Amp (Act, Hst, Stp) , Ap, Brt, Cb (Ank, Cal , Dol), Chl, Ep, Grt, Hem, Flr, Kfs, Mag, Ms, Qz Act, Ap, Bt, Cb, Chl , LREE minerals, Ms, Py, Pyh , Qz, Tur
	LT Si-(Ba,F)-Fe	Br-Flr-Hem-Qz, Brt-Hem-Qz, Flr-Hem-Qz, Hem-Qz
	LT (Ba,Ca,Mg)-(K,Na)-(CO ₂ ,F)- Si-Fe, undivided, beresite, gumbeite	Qz —(Ab, Amp, Anh, Brt, Bt, Ep, Flr, Hem, Kfs, Mag , Py, Ser) Beresite: Ank-Py-Ser (Si > Qz) Gumbeite: Bt-Cal-Dol, Bt-Cal-Kfs, Bt-Dol-Kfs , Cal-Kfs-Ph, Ank-Kfs-Qz-Ser
Others	B	Qz tourmalinite, tourmalinite, Tur, Tur-Cb, Tur-Kfs , Tur-Kfs-Qz
	Ironstone ²	Cb ironstone, Hem ironstone, hematitite, Hem-Mag ironstone, Mag ironstone, magnetitite, oxide ironstone, silicate ironstone, sulfide ironstone
	Si	Jasper, jasper-Qz, silicification

¹ Key references [11,14,15,18–23,38,50,53,58,59,64–74,81–90]. ² Can be LT or HT Fe-rich alteration facies.

Following the inclusion of metasomatic rocks as a separate Lithgroup, Table 2 lists the observations that can be captured at a field station, on a rock sample, or along a drill core (Figure 4 adapted for geologists from the F_EARTH_MATERIAL table of Ref. [24]). The fields capture most of the taxonomy presented in Figure 4—for example, rock type, occurrences, inherent attributes such as texture/structure, and deformation fabric. The following sections define lexicons for key descriptive elements of the MIAC systems summarized in Table 2.

Table 2. Field descriptors for the GSC Field Application for the Earth Material component, with additional information concerning application to metasomatic rocks.

Field Name	Field Purpose
LITHGROUP	General grouping of rocks according to the processes that resulted in their formation, such as sedimentary, volcanic, volcanoclastic, intrusive (labeled plutonic), metasomatic, hydrothermal, metamorphic (including metamorphosed metasomatites and hydrothermal rocks), and tectonic
LITHTYPE	Subdivision of LITHGROUP that groups together LITHDETAIL with common differential elements (e.g., felsic, intermediate, mafic for igneous rocks, or the nature of the metasomatite, such as iron-rich and alkali-calcic, abbreviated as IAC, or iron-poor and alkali-calcic, abbreviated as AC).
LITHDETAIL	Functional rock name of an Earth Material such as andesite, syenite, siltstone, albitite, skarn, HT Ca-Fe metasomatite, gneiss, etc. As per the mineral quartz in quartz syenite, alteration facies may be qualified by their main mineral or minerals that would not only distinguish the rock types but also help link rock types to geophysical anomalies due to their distinct rock physical properties. An amphibole-dominant HT Ca-Fe metasomatite will have rock physical properties that are very distinct from those of a magnetite-dominant HT Ca-Fe metasomatite.
LITHQUALIFIER	Modifier(s) (e.g., qualifier) to more accurately name or describe an Earth Material. For example, in the case of a felsic gneiss, the LITHQUALIFIER could have the value “granitic granodioritic,” specifying the composition range of the gneiss. For metasomatic rocks, qualifiers consist of the main mineral assemblages (i.e., the stable paragenesis), as the Mineral module does not provide a means to distinguish among minerals that precipitate together (i.e., bona fide mineral assemblages/paragenesis) from those that are spatially associated with each other through multiple overprints. Multiple values are concatenated using a pipe character.
METAFACIES	Metamorphic facies of the Earth Material are described (e.g., greenschist, granulite). This would apply to metamorphosed metasomatites.
METAINTENSITY	Qualifier to calibrate the grade of the metamorphic facies (e.g., low, high, retrograde).
MAPUNIT	Map unit to which the described Earth Material belongs.
OCCURAS	Nature of the occurrence of the Earth Material (e.g., pluton, dyke, vein, replacement, breccia).
EM_PERCENT	The estimate of the percentage occupied by the Earth Material being described on the whole outcrop.
TEXTSTRUC	Qualifier(s) relating to textural and structural properties of the Earth Material. The lexicons provided herein distinguish textures from structures, but as the terms are commonly mixed by geologists, they are currently combined in the Geological Survey of Canada Field Application. Metasomatites have such a spread to textures and structures that separating textures and structures optimizes mapping. Multiple values are concatenated using a pipe character.
GRCRYSIZE	Earth Material grain size. Multiple values are concatenated using a pipe character.
DEFFABRIC	Deformational fabrics of the Earth Material and other fabric, such as faulting, shearing, flow foliation, or fluidization foliation. Multiple values can be concatenated within this field using a pipe character.
BEDTHICK	Thickness of sedimentary and volcanoclastic beds. The field can be used for a stratabound alteration that pseudomorphs the protolith bedding. Multiple values are concatenated using a pipe character.
COLOURF	Earth Material color on a fresh surface. The color can be expressed as a single color (e.g., “grey”) or as a color, its color intensity, and a qualifier (e.g., “grey medium greenish”).
COLOURW	Earth Material color on a weathered surface. The color can be expressed as a single color (e.g., “grey”) or as a color, its color intensity, and a qualifier (e.g., “grey medium greenish”).

Table 2. Cont.

Field Name	Field Purpose
COLOURIND	Earth Material index color from 0 to 100.
MAGSUSCEPT	Magnetic susceptibility value of the Earth Material (in SI units).
MAGQUALIFIER	Empirical evaluation of the magnetic intensity of a lithology in the field using a magnet (e.g., weak, strong).
RELATED_CONTACT_NOTE	Description of the nature of the relation between rock types in space, in relative timing, and in their types of contact, or in relation to other contact records at the same station (e.g., Earth Material C is intrusive in Earth Material A and both are replaced by Earth Material B). Multiple values are concatenated using a pipe character.
CONTACTUP	The nature of the upper contact (e.g., faulted, gradational, intrusive, brecciated).
CONTACTLOW	The nature of the lower contact (e.g., faulted, gradational, intrusive, brecciated).
CONTACT_NOTE	Free text field allowing a general description of the observed relationship and/or contact between Earth Materials.
INTERP	Interpretation of the genetic origin or protolith of the Earth Material.
INTERPCONF	Levels of confidence with the Earth Material interpretation. For MIAC metasomatites, it is common that the protolith is unknown, uncertain, or inferred from regional stratigraphy and the distribution of least-altered host rocks.
NOTES	Additional notes and remarks regarding the Earth Material.

Geological Survey Canada Field Application
EarthMaterial! 10-CQA-0000
Close Save

Lithology - Setting and composition
Type
metasomatic - MIAC ; HT Ca-Fe (Mag-dominant)
Qualifier
Amp, Mag
Occurs as
replacement stratabound
Qualifier
selective-pervasive, stratabound to discordant
Percent
10
Total Mode: 20% (3)
Lithologic Modifiers
Texture/Structure
patchy selective-pervasive homogeneous stratabound to discordant
Grain/Crystal Size
fine to medium grained
Bedding Thickness
thickly laminated 3-10 mm
Deformation Fabric
folded boudinaged none

Geological Survey Canada Field Application
24GHV0003X01
Close Save ...

Description
Mineralization / Alteration
alteration
Unit
all
Mineralogy
Any values added here can be completed within Mineral form as their own record.
Search
talc
chlorite
General
Distribution
laminated
Phase
primary
Texture
acicular
Alteration facies
chloritisation
irregular
laminated

Figure 4. (A) Fields to describe the lithology within the Earth Material components of the Field Application of the Geological Survey of Canada, with a case example of a metasomatite described as a lithotype. (B) Fields to describe the localized and minor alteration overprints that characterize the protolith as well as observed mineralization. The information feeds the Earth Material components of the field database.

3.3. Lexicon to Describe the Occurrence (OCCURAS) of Metasomatites and Hydrothermal Objects

Describing the occurrence and mode of emplacement of each alteration facies in the field is essential to understanding (1) metasomatic and hydrothermal processes; (2) the conditions under which the metasomatism and hydrothermal processes occurred; (3) the influence of the host rock units on the geometries of the alteration zones, vein systems, and breccias; and (4) the temporal relationship between each alteration facies and between alteration facies and the other geological units in the region (Table 3). In the Field Application, the observed types of occurrences are listed under the “Occurs As” field and are qualified with their specific types of occurrences (i.e., “Qualifiers” in the Field Application; Figure 4).

Table 3. Lexicon for the types of occurrences of metasomatites and hydrothermal rocks as replacement zones, breccias (both metasomatic and hydrothermal), and hydrothermal objects within MIAC systems. In the Field Application, these are listed under the “Occurs As” field and qualified with more specific types of occurrences (i.e., “Qualifiers” in the Field Application). Hydrothermal objects within MIAC systems are used from Facies 1–2 to Facies 6 no matter which types of fluids/melts might ultimately be involved. Examples observed in albitite are in italic, in magnetite-rich parageneses in bold, and in both albitite and magnetite parageneses in bold-italic (see photos of outcrop exposures, rock slabs, and drill cores in Refs. [15,30]).

Occur As	Qualifier ¹
BRECCIA	
General	<i>Cave fill sediment</i> , cement, cement and matrix, druse, dyke, fragment, fragment and matrix, halo, host unit, matrix² , matrix halo, matrix with halo , parent layer, vug, wall rock, diatreme, pipe, raft, <i>chaotic</i> , <i>crackle</i> , <i>mosaic</i> , <i>edgewise</i> , <i>shingle</i> , <i>imbricated</i> , <i>jostled</i> , <i>clast-supported</i> , <i>matrix-supported</i> , cement-supported, altered albitite breccia , <i>altered fault breccia</i> , altered hydrothermal breccia, <i>altered intrusive breccia</i> , <i>altered sedimentary breccia</i> , altered tectonic breccia, altered tectono-hydrothermal breccia , <i>altered volcanic breccia</i> , altered volcanoclastic breccia , previously altered breccia
Fragment	Core , halo, intraclast, lithic clast, selvedge, vein, wall rock, fracture in fragment only , fracture in fragment and matrix , <i>fracture halo</i> , ripped up from wall Of albitite , e.g., selectively replaced , core , selvedge , ghost layering pseudomorphed Of earlier breccia, of altered breccia, <i>of metasomatite</i> , of vein, <i>of wall rock</i> , <i>of less altered wall rock</i> , of previously altered wall rock In fault breccia, in hydrothermal breccia, in sedimentary breccia protolith , in volcanic breccia protolith, in volcanoclastic breccia protolith , in tectonic breccia protolith
REPLACEMENT	
General	Endoskarn, exoskarn, main lithology , penetrative (occurs throughout outcrop/unit) , pervasive (spreads throughout object) , pseudobreccia , selective , selective discontinuous , selective pervasive , selective along a ghost layering , semi-conformable , transition zone , zoned
Front	Finger-like , irregular , roll front , vein-like , vein-like parallel set
Halo	<i>Arborescent</i> , <i>asymmetric</i> , <i>branching</i> , <i>symmetric</i> , <i>stratabound</i> , <i>stratabound selective</i> , <i>intersecting</i> , <i>coalescing (continuous or discontinuous)</i> , <i>pervasive</i> Halo to: boudin, breccia, breccia matrix , contact, fault, fracture, shear, stockwork, <i>stratabound alteration</i> , tension gash, vein
Object	Aggregate , atoll , bleb , clot , dissemination , lamination , lens , matrix , mineral , nodule, <i>overgrowth</i> , <i>overgrowth: epitaxial</i> , overprint , patch , pod , pseudomorph , <i>relict</i> , ribbon, schlieren , sheet , speck , spherule, splay , streak , train

Table 3. Cont.

Occur As	Qualifier ¹
Selvedge	To apophysis, bed, clast, dyke, fracture, fragment, layering, matrix, stockwork, <i>tension gash</i> , vein
Splay	<i>From: fault, fracture, halo, strata, stratabound replacement, vein</i>
Stratabound	<i>Pervasive, pervasive layer destructive, roll front, selective, selective pervasive, sporadic, stratabound to discordant</i>
Replaced object	<i>Intrusive, metamorphic, metasomatic, sedimentary, tectonic, volcanic or volcanoclastic objects</i> <i>Breccia object (fragment, matrix, fragment and matrix); breccia fragment (core, margin, previously altered, protolith layering); breccia fragment of albitite (core, ghost layering pseudomorphed, selvedge); breccia fragment of earlier breccia (altered pre-rebrecciation), of metasomatite, of vein, of wall rock; fracture in breccia, e.g., across fragment only, across fragment and matrix, across matrix</i> <i>Tectonic object (damage zone, fault, fracture)</i>
HYDROTHERMAL	
General	Boulder, clast, boudin-related fill, cement, enclave, erratic, fracture, layer, lens, raft, sheet, stockwork, stringer, tension gash fill, vein, veinlet , void fill, xenolith
Boudin fill	Boudin neck fill, barrel fill, bow-tie fill, fish mouth fill
Stockwork	Main lithology, cement, halo (see replacement halo)
Tension gash fill	Single, fill and halo, fill and halo selvedge, fill with selvedge, array, tension gash halo, tension gash selvedge
Vein	
General	Single vein, vein + halo , vein + <i>intersection haloes</i> , vein + selvedge, vein + selvedge + halo
Object	Branch/apophysis , enclave, fragment, fragment of vein material, center fill, antiaxial fill, ataxial fill/stretching, syntaxial fill, selvedge, selvedge antiaxial, selvedge syntaxial, halo , splay, xenolith
Tectonic type	Asymmetric fold-related, axial planar, axial planar vein + layer parallel splay, axial planar foliation-related vein, piercement vein, saddle reef, shear vein, shear vein dextral, shear vein sinistral, shear vein S plane, shear vein C plane, shear vein C' plane, tension vein, tension vein linear, tension vein sigmoidal, tension vein S-shape, tension vein Z-shape
Vein array	Concentric, conjugate, en échelon, en échelon sigmoidal, en échelon conjugate Type 1 parallel, en échelon conjugate Type II inclined towards opposite array, laminated, parallel/sheeted, parallel delamination, radial, randomly oriented, stepped

¹ Key sources of information and terms adapted for metasomatites from Refs. [7–11,15,18–23,36,38,40,47,50,65,66,81,82,91–99].

² Matrix of breccias includes milled clasts, clasts resulting from partial dissolution of protoliths, and fragments and of earlier metasomatites and syn- or post-breccia metasomatized materials. Cement relates to hydrothermal infilling of vugs.

Hydrothermal objects within MIAC systems are used from Facies 1–2 to Facies 6. Metasomatic objects are observed from Facies 1 to Facies 6. In Table 3, examples of occurrences observed in albitite are in italic, in magnetite-rich parageneses in bold, and in both albitite and magnetite parageneses in bold–italic (see photos of outcrop exposures, rock slabs, and drill cores in Refs. [15,30]).

In isotropic hosts such as volcanic rocks (Figure 2A,B), irregular, vein-like, and pervasive replacement fronts and fracture haloes, including coalescing ones, are common. In porphyritic rocks, replacement is typically selective at first, either across the fine-grained to aphanitic groundmass or across the phenocrysts or a specific mineral. In phaneritic rocks, replacement starts with a specific mineral. With incremental intensification, replace-

ment then evolves from patchy, to mottled, to pervasive. Weak to moderate alteration typically preserves host textures, and volume does not necessarily change, e.g., amygdules in volcanic hosts can remain circular and the spacing, distribution, and size of phenocrysts in metasomatized andesite remain the same as those of the least-altered host andesite. Intensification of alteration results in the gradual destruction of primary textures and the loss of protolith information [19,20,59].

In bedded or laminated protoliths (Figure 2C–I), replacement is generally stratabound, grading from selective and irregularly distributed (Figure 2C, Figure 2D left side, Figure 2H right side) to selective pervasive (Figure 2F left side) and to pervasive massive (i.e., isotropic and homogeneous), which can mask the former bedding (Figure 2D,F right sides; Figure 2G,I). As intensity increases, stratabound alteration commonly merges, anastomoses across and cuts bedding contacts (Figure 2G), and finally destroys the bedding structure to form massive alteration zones (Figure 2C,D,F,H,I).

In fragmental host rocks and in breccias, fragments can be selectively replaced [19,100–102]. In zones of intensifying alteration where initial alteration occurred as fracture haloes, replaced fractures can increasingly coalesce into massive alteration zones (Figure 2A,B). In breccia zones, alteration can selectively replace fragments or the matrix (Figure 2B) [19,22,47,64,103].

3.4. Lexicons for the Description of Textures and Structures in Metasomatites (TEXTSTRUC)

Textural and structural descriptors are essential to recording observations related to the development of metasomatites or hydrothermal objects at each alteration facies (Tables 4 and 5). These descriptors provide important information on the mode of formation of the alteration facies and the conditions under which the alteration facies was developed.

Table 4. Textures of metasomatites.

Type	Attribute ¹
General	Acicular, allotriomorphic granular, anhedral/idiomorphic, aphanitic, arborescent, bladed (parallel, radial, randomly oriented), blebby, blocky, cataclastic, chicken-wire texture (i.e., through replacement of nodular anhydrite), comb-textured, coronitic, crystalline, dendritic, dissolution, equigranular, euhedral/idiomorphic, fan-shaped/divergent, felted, fibrous, fissile, friable, glassy, globular, gradational, granoblastic, granophyric, granular, heterogeneous, holocrystalline, homogeneous, hornfelsic, hydrothermally altered, hypidiomorphic granular, impregnation, in situ, incipient, inequigranular, interdigitated, intergranular, intergrown, interstitial, irregular, lithophysae, lobate, megacrystic, mesh, miarolitic, microlitic, migmatitic, moderately porous, mosaic, net-textured, nodular, ocellar, open-space filling, orbicular, ovoid, panidiomorphic, patchy, pegmatitic, penetrative, pervasive, phaneritic, pitted, platy, porous, porphyroblastic, porphyroclastic, protolith texture (destructive, preserving, pseudomorphing, recrystallized), radial, randomized, recrystallized, relict (metamorphic, plutonic, sedimentary, volcanic, volcanoclastic), replacement, retrograde, rod shape, rosette, salt and pepper, selective, selective pervasive, seriate, sieved, slabby, spheroidal, spherulitic, spotted, spotty, stellate, stockwork, straight, stratified, sub-angular, subhedral/hypidiomorphic, sugary, tabular, texturally continuous, texturally discontinuous, unaltered, unstratified, varicolored, variegated (irregular + interconnected), vari-textured, veined, vermicular, visible porosity, vitreous, vuggy, well developed, wispy, woody, xenomorphic
Pseudo-igneous/ sedimentary texture	Pseudo-acicular, aplitic, axiolitic, bladed, brecciated (i.e., breccia texture acquired by dissolution), clastic (i.e., breccia texture acquired by dissolution/mottled replacement) diabasic, microlitic, pegmatitic, rod (blurred/fuzzy edge, ragged edge, sharp-edged, inclusion free, inclusion-laden, inclusion-poor, well-developed rod shape), spherulitic
Pseudomorphic of object	Plutonic, sedimentary, volcanic, volcanoclastic texture, amygdule, blade, bladed hematite, cross-bed, fossil, nodule, phenocryst, pumice, scoria, stromatolite, trachytic texture, variole
Zonation	Zoned (simple growth, oscillatory growth, inclusion-defined), zoning disrupted, zoning replace

¹ Key sources of information from Refs. [7–11,19–23,31–36,38,40,47,48,50,59,64,67,73,81,82,91,92,104].

Table 5. Structures of metasomatites.

Type	Attribute ¹
General	Amoebooid, anastomosing, anastomosing network, atoll, banded, boudinaged, box-like sets, branching, brecciated, compositional layering, concretionary, concentric, concentric banding, concentric irregular, concentric parallel, clustering, columnar jointing, conjugate set, continuous, dense, diffuse, discontinuous, dismembered, disseminated, faulted, fissile, flame, flow fabric, folded, foliated, fractured, fragmented, gneissic, imbricated, irregular, irregular jointing, lenticular, lenticular layered, massive, multi-directional, nodular, nodular layered, parallel, parted, ribbon bedded, ribboned, scattered, schistosed, schisted, sheared, stockwork-like, straight, stratabound, stratiform, stratabound to discordant, stretched, structureless/massive, train, vent tube, veined, vermicular
Lamination and layering	Laminated, laminated: oblique, laminated: parallel, layered, layered: compositional, layered: irregular, layered: lenticular, layered: oblique to main trend, layered: parallel to main trend, layered: perpendicular to main trend, layered: train of lenses
Pseudomorphism	Pseudomorphically preserving (breccia structures, metamorphic structures, plutonic structures, sedimentary structures, volcanic structures, volcanoclastic structures), pseudomorphically boudinaged, pseudomorphically brecciated, pseudomorphically cross-bedded, pseudomorphically cross-bedded: planar tabular, pseudomorphically cross-bedded: trough, pseudomorphically cross-laminated, pseudomorphically flow layered, pseudomorphically folded, pseudomorphically fossiliferous, pseudomorphically graded bedded, pseudomorphically graded normal bedded, pseudomorphically graded reverse bedded, pseudomorphically nodular bedded, pseudomorphically pillowed, pseudomorphically soft-sediment folded, pseudomorphically stromatolitic, pseudobreccia, rhythmically layered
Zonation	Zoned, zoned laterally, zoned vertically, zoned longitudinally

¹ Key sources of information and terms adapted for metasomatites from Refs. [7,8,10,11,19,38,47,81,82].

3.5. Lexicons to Describe Syn- to Post-MIAC Deformation and Syn MIAC Flow of Metasomatic Mushes (DEFFABRIC)

Deformation of MIAC systems is common in orogenic environments and leads to extensive remobilization of primary metals and their reconcentration as veins and breccias. Deformation is also common during the development of MIAC systems and ranges from brittle and brittle–ductile deformation at all facies to ductile deformation at Facies 2, biotite-rich Facies 2–3, biotite-rich Facies 3, and sericite-rich Facies 5 [19–22]. In addition, syn-MIAC deformation can evolve from folding to boudinage to brecciation and, at the extreme, to fluidization along shear zones. Fluidized breccia and breccia dykes are common in IOA mineralization, with well-exposed examples sharply cutting albitite in addition to having delamination of brecciated albitite fragments along the walls and inclusions as xenoliths [14,22,70]. Thus, Table 6 describes deformation and flow fabrics that have been observed or may occur in MIAC systems, while a detailed discussion on these topics is provided in Section 4.2.3.

Table 6. Lexicons for deformation and flow fabrics, including textures and structures, with most attributes having been observed within non-metamorphosed MIAC systems.

Related to	Attributes ¹
General fabric	Anastomosing fabric, augen, brecciated, cleaved, communitized, flaser fabric, flattened, flattened clasts/fragments, foliated, foliated oblique to contact, foliated parallel to contact, foliated perpendicular to contact, fracture cleavage, fractured, fractured (conjugate), fragmented, gneissic, high strain, isotropic (massive), jointed, layered, lenticular, lineated, low strain, medium strain, mineral lineation, mullions, phyllitic, pinch and swell, porphyroclastic, pressure fringe, pressure solution cleavage, ribbon, rotated, rotated porphyroclast, schistose, sheared, sheared (conjugate), slaty cleavage, spaced cleavage, strained fossils, streaky, stretched, stretched clasts, stylolite, tension gash, transposed bedding, wavy

Table 6. Cont.

Related to	Attributes ¹
Boudinage	Boudinage, boudinaged fold, boudin block, boudin neck (inter-boudin zone), boudin Boudin: chocolate tablet, ribbon-like, symmetric, drawn, torn, asymmetric, tapered, domino, planar domino, dilational domino, gash boudin, forked gash boudin, sigmoidal gash, shear band boudin, barrel, barrel infilled, bow-tie infilled, fish mouth, fish mouth infilled, en échelon, folded, irregular, rhombic and rotated (shear fracture boudinage), rotated, straight face, concave face, necked (pinch and swell structure), bone-type, blocky Boudin as single object, boudin of multiple layers, boudin of a single layer, boudin of foliation, boudin train (foliation parallel, foliation oblique), boudin flanking (foliation, fold, massive, shear-band, ptymatic fold)
Brecciation	Brecciated Brecciated layer: continuous (without significant disorientation of fragments), disrupted (with significant disorientation of fragments), folded and continuous, folded and disrupted, fluidized Aligned clasts, detached, dismembered, durchbewegung structure, fragmented, imbricated, piercement cusp, piercement vein
Cusp and flame	Cusp, flame, flame: dendritic, horn, horn compounded
Faulting and mylonite	Blastomylonitic, cataclastic, faulted, faulted dextral displacement, faulted sinistral displacement, mesomylonitic, mylonitic, protomylonitic, ultramylonitic
Fluidization	Aligned clast, communited fragment train, flow foliation, layering, shadow zones behind large blocks (i.e., fragments pile up on the back of a large fragment during flow)
C, L, S fabric	C fabric, C-S fabric, C' fabric, L tectonite, L < S tectonite, L > S tectonite, L-S tectonite, S tectonite
Folding	Folded, contorted, crenulated, crenulation cleavage, crinkled, fabric warping Fold: asymmetric, cuspsate-lobate, detached, detached fold core, ptymatic, symmetric

¹ Key sources of information from Refs. [7–10,19,23,38–40,91–95,98,104–109].

3.6. Lexicons for the Relative Timing Relations Between Different Rock Types (RELATED_CONTACT_NOTE)

This section provides a lexicon to describe the nature of the relation between rock types in space, in relative timing, and in their types of contact or in relation to other contact records at the same station (Table 7). In the notes, examples could include “Earth Material C is intrusive in Earth Material A. Earth Material A is replaced by Earth Material B. Earth Material B (metasomatite) occurs along Earth Material C.”

Table 7. Space–time relationships of metasomatites, hydrothermal occurrences, and breccias with other Earth Material. Each entry is linked to a described Earth Material.

Type	Relationship (Details) ¹
METASOMATITE	
Spatial	Main lithology, above, below, across, along, around, in, abuts against, abuts against and follows contact of, aligned with, alternate with, apophysis of, branching from, follows contact of, footwall of, hanging wall of, anastomosed within, associated with, intercalated with, interdigitated with, coalescing from, coalescing from breccia bodies, coalescing from fracture network/array, coalescing from vein network/array, halo along, halo along (see occurs along), haloed by, distribution shared with, distribution partly shared with
Contact	In disconformity with, in diffuse contact with, in discordant contact with, in fault contact with, in sharp contact with, in transitional contact with, gradational contact with
Selvedge	In Earth Material, in dyke, in fragment, in stockwork, in tension gash, in vein, see occurs in
Transition	To Earth Material, to same assemblage but distinct mineral contents, to distinct assemblage, to breccia, to fluidized breccia, to fracture network, to replacement, to stockwork, to vein

Table 7. *Cont.*

Type	Relationship (Details) ¹
Occurs along/in	Apophysis, axial plane, axial planar cleavage, axial planar foliation, beds, breccia, breccia in wall rock, breccia matrix, breccia matrix within fragment, clast, crystal/phenocryst, dyke, fault, fault splay, fault offset, fault walls, fabric: S plane, fabric: C plane, fabric: C' plane, foliation plane, fold hinge, fold short limb, fracture, fracture of breccia fragment, fragment, jog, laminae, layers, lineation, lithological contact, margin, pillow, shear zone, sill, stockwork, tip of fault, unconformity, and below unconformity, and above unconformity, along, below and above unconformity, vein
Timing	Brecciated by, brecciates, cut by, cuts, delaminated by, delaminates, dissolved by, dissolves, fractured by, fractures, fragmented by, fragments, has enclaves of, host rock to, hosted in, in enclave in, inclusion in, inclusion of, infilled by, infills, infiltrated by, infiltrates, injected as fluidized mush in, injected by a fluidized mush of, intruded by, intruded by, overprinted by, overprints, post-brecciation, pre-brecciation, pseudobrecciated by, pseudobrecciates, resembles, syn-brecciation, veined by, veins
Replacement	Replaces, replaces subtly, replaces weakly, replaces moderately to strongly, replaces intensely, replaces megascopically completely, replaces pervasively, replaces selectively, replaces variably, replaces (prograde), replaces (retrograde), replaced subtly by, replaced weakly by, replaced moderately to strongly by, replaced intensely by, replaced megascopically completely by, replaced pervasively by, replaced selectively by, replaced variably by, replaced by (prograde), replaced by (retrograde)
Process relationships	Parent layer, brecciated by, brecciates, cemented (infilled) by, coalescing from, coalescing from fracture network, coalescing from main breccia body, fragment of, overprints, overprinted by, replaced by post brecciation, replaced by pre brecciation, replaced by syn brecciation, veins of confined to fragment, veins of continuous through fragments and matrix, veins of preferentially within fragments, wall rock
Fragment	Compositionally distinct to wall rocks, compositionally identical to wallrocks, core: replaced by, delaminated by, embedded in, fractured by, fragment of albitite selectively replaced by, halo (external): replaced by, in diffuse contact with, in sharp contact with, in situ from wall rocks, in transitional contact with, infilled by, matrix: altered seamlessly by, near source transport from wall rocks, refragmented by, replaced by, replaced by post brecciation, replaced by pre brecciation, replaced by syn brecciation, rotated with respect to, selectively replaced by, selvedge (internal): replaced by, veined by
Fragment transport	Distally transported with respect to source, transported with respect to source
Breccia contact	Gradational with wall rocks (grading into brecciated and fractured rocks), sharp with wall rocks
HYDROTHERMAL	
Spatial	Main lithology, above, above unconformity, abuts against, abuts against and follows contact of, across, across unconformity, aligned with, along, along unconformity, alternating with, anastomosed within, apophysis of, associated with, below, below unconformity, branching from, brecciated by, brecciates, clustered with, coalescing from, cut by, cuts, delaminated by, delaminates, discordant to, disseminated in, disseminations of, dissolved by, dissolves, distribution partly shared with, distribution shared with, embedded by, embedded in, enclaved in, enclave of, fractured by, fractures, fragmented by, fragments, halo along, halo in, haloed by, host rock to, hosted in, in, in (diffuse) contact with, in (discordant) contact with, in (fault) contact with, in (gradational) contact with, in (sharp) contact with, in footwall of, in hanging wall of, infilled by, infills, infiltrated by, infiltrates, intruded by, intrudes, interbedded with, intercalated with, interconnected with, interdigitated with, interstitial in, intruded by, oblique to, oblique to main trend, overprinted by, overprints, parallel to, parallel to main trend, perpendicular to, perpendicular to main trend, prograde stage
Timing	Replaced (subtly by, weakly by, moderately by, strongly by, intensely by, completely by, pervasively by, selectively by, variably by), replaces (subtly, weakly, moderately, strongly, intensely, completely, pervasively, selectively, variably), resembles, retrograde stage, retrograde to, selvedge in, transition to, transition to a distinct assemblage, transition to same assemblage, distinct mineral contents, veined by, veins

¹ Key sources of information from Refs. [7,19,20,22,31–36,38,40,47,48,50,59,64,73,81,82,92].

3.7. Lexicons to Describe Observable Protolith Objects in Metasomatites (OCCURAS)

As alteration facies develop in MIAC systems, the metasomatic rock can replace many primary objects in the protoliths. Recognizing and collecting information on these primary altered objects in host rocks is important, as it can help to define the nature of the replaced

rocks in zones of strong alteration. Table 8 lists the protolith objects that were observed to be replaced by MIAC metasomatites identified in our case studies in Section 2. Table 8 also lists geological objects that serve to establish temporal relationships and regional markers such as felsic dyke swarms (e.g., NICO Au-Co-Bi-Cu deposit, Canada [49,68]) and swarms of commingled dykes (Josette REE deposit, Canada [55]).

Table 8. Examples of protolith objects that are replaced within MIAC systems and intrusive objects that provide timing relationships and regional markers.

Type	Occurrence As ¹
Intrusive	Apophysis, commingled dyke, composite phase, chilled margin, dyke, enclave, flow banding, fragment, groundmass, internal part, phenocryst, pipe, plug, plutonic rock, porphyritic intrusion, raft, sheet, sill, xenocryst, xenolith
Sedimentary	Bed, block, cement, clast, concretion, cross-bed, erosional trough, lamina, layer, lens, matrix, nodular bed (evaporite), nodule, pebble, stromatolite, stromatolite lamina, trough bedding
Metamorphic	Gneissosity, gneissic layering, hornfels, leucosome, metamorphic rock, schist, gneiss
Metasomatic	Albitite, albitite breccia, breccia, stratabound alteration, alteration front
Tectonic	Axial planar cleavage, axial planar foliation, axial plane, fold hinge, fold hinge fracture, fold limb, foliation plane, shear zone, shear zone structure (C' plane, C plane, S plane, stretching lineation), boudin (neck), fracture (off set, splay, jog), damage zone (fracture-defined, inferred from distribution of alteration, along fault, along vein, around tip, en échelon, fault footwall, fault hanging-wall, intersection, linking steps), fault (en échelon, footwall, hanging-wall, intersection, off set, splay, tip, zone)
Volcanic	Amygdale, crystal, enclave, flow banding, fragment, groundmass, phenocryst, pillow (matrix, selvage), varivole, vesicle
Volcaniclastic	Block, clast, clast core, clast margin, clast and matrix, lamina, lapillus (core, margin), juvenile clast, lithic clast, matrix

¹ Key references and sources from Refs. [8,10,11,15,18–23,47,50,65,66,97–99,110].

The metasomatic objects listed in Table 8 represent the metasomatites most commonly overprinted by (and thus a protolith to) subsequent alteration facies. As metasomatism proceeds in stages, nearly all metasomatites can become protoliths themselves, such as the albitite acting as a host to the HT Ca-Fe parageneses in Figure 2C–I. The relationships among the different types of occurrences of the metasomatites and hydrothermal objects (Table 3) help to assess their temporal relationships, which commonly have significant implications for assessing the mineral potential of the system [14]. For example, mapping the veins in relation to their host metasomatites is now proving to really help decipher the extent and impact of remobilization of the primary metals within the system and the nature of subsequent events that allows for the recirculation of fluids and the remobilization of metals within a primary MIAC system to form ore [14,21,23].

3.8. Descriptive Terminology for Individual Minerals in MIAC Systems

Once an Earth Material has been described, a mineral can also be associated with the described rock type. The description of the percentage, habit, mode, and occurrence of the minerals refines the mineralogical information (Table 9). Because the alteration facies are identified by the sum of their coprecipitating minerals, the lexicon for the occurrences of minerals in the Mineral module is proposed to also include terms such as “in matrix,” “as selvages,” “as haloes,” etc. (Table 9). Accordingly, a vein with amphibole and magnetite in the vein matrix flanked by its coeval albite haloes within the host has an HT Na-Ca-Fe metasomatite as the Lithdetail. Within the Mineral module, albitite is said to occur as haloes.

In some cases, the haloes are so extensively developed (e.g., magnetite haloes to a magnetite vein that leads to stratabound alteration) that it is worth describing them as a Lithdetail with an occurrence as a halo (Table 3) and linked to the vein in the relationship component (Table 7). The relational database table (Table 2) is brought as a user interface (Figure A1), in which the geoscientist describes the protolith or any other material observed on site. Figure A1 showcases the usage of an applied ontology and taxonomy for MIAC systems.

Table 9. Lexicon for minerals.

Mineral	Attributes
Type	Acmite, actinolite, adularia, aegirine-augite, akermanite, albite, alkali-feldspar, allanite, almandine, aluminosilicate, amphibole, analcite, anatase, andalusite, andesine, andradite, anhydrite, ankerite, annite, anorthite, anthophyllite, antigorite, apatite, apophyllite, aragonite, arfvedsonite, arsenopyrite, augite, axinite, azurite, barite, beryl, biotite, boehmite, bornite, brookite, brucite, bustamite, bytownite, calcite, cancrinite, carbonate, cassiterite, celestite, chabazite, chalcocite, chalcopyrite, chlorite, chloritoid, chondrodite, chromite, chrysocolla, chrysotile, clinoamphibole, clinoenstatite, clinoferrrosilite, clinohumite, clinopyroxene, clinozoisite, coesite, copper, cordierite, corundum, covellite, cristobalite, cummingtonite, diaspore, digenite, diopside, dolomite, dravite, eckermannite, edentite, elbaite, enstatite (ortho), epidote, eudialite, fassite, fayalite, feldspar, ferroactinolite, ferroedenite, ferrosilite (ortho), ferrotschermakite, fluorite, forsterite, fuschite, galena, garnet, gedrite, gehlenite, geothite, gibbsite, glauconite, glaucophane, goethite, gold, graphite, grossularite, grunerite, gypsum, halite, hastingsite, hauyne, hedenbergite, hematite, hercynite, heulandite, hornblende, humite, illite, ilmenite, jadeite, jasper, johannsenite, kaersutite, kalsilite, kaolinite, kataphorite, K-feldspar, kornepurine, kyanite, labradorite, laumontite, lawsonite, lepidolite, leucite, limonite, lizardite, loellingite, maghemite, magnesiokataphorite, magnesioriebeckite, magnesite, magnetite, malachite, marcasite, margarite, martite, melilite, microcline, molybdenite, monazite, monticellite, montmorillonite, mullite, muscovite, mushketovite, natrolite, nepheline, norbergite, nosean, oligoclase, olivine, ophacite, orthoamphibole, orthoclase, orthopyroxene, paragonite, pargasite, pectolite, pentlandite, periclase, perovskite, phlogopite, pigeonite, plagioclase, prehnite, protoenstatite, pumpellyite, pyrite, pyrope, pyrophyllite, pyroxene, pyrrhotite, quartz, rhodochrosite, rhodonite, riebeckite, rutile, sanidine, sapphirine, scapolite, schorl, see comment field, sericite, serpentine, siderite, sillimanite, silver, sodalite, spessartine, sphalerite, spinel, spodumene, staurolite, stilbite, stilpnomelane, stishovite, strontianite, talc, thompsonite, titanite (sphene), topaz, tourmaline, tremolite, tridymite, troilite, tschermakite, ulvospinel, uraninite, vermiculite, vesuvianite, witherite, wollastonite, wustite, zeolite(s), zircon, zoisite
Form	Anhedral, euhedral, subhedral, see comment field
Habit	Acicular, allotriomorphic, anhedral, arborescent, atoll, barrel-shaped, bladed, blocky, botryoidal, capillary, circular, cleavable, colloform, columnar, comb, conchoidal fractured, coronitic, cruciform, cubic, cylindrical, decussate, dendritic, dipyrnidal, disseminated, divergent, dodecahedral, dodecahedral, drusy, earthy, elongate, embedded, equant, equigranular, euhedral, fan-shaped, fibrous, flaky, foliated, framboidal, friable, globular, granular, heterogranular, hopper, hypidiomorphic, idiomorphic, intersertale, labradorescent, lamellar, lath, lath-like, mammillary, massive, micaceous, needle, nodular, ocellar, octahedral, oikocryst, oolitic, opalescent, panidiomorphic, pisolitic, platy, plumose, powdery, prismatic, pseudo-hex, pseudomorphed, pseudomorphous, pyramidal, radiating, radiating, ragged, reniform, reticulate, rhombohedral, rod-like, rosette, scaly, see comment field, sheave, sieved, skeletal, spherical, stellate, striated, striated, stubby, subhedral, tabular, tetrahedral, trapezoidal, vermicular, waxy, weathered, wedge-shaped, Widmanstätten-like pattern, wiry, woody, xenomorphic, zoned
Mode	Absent, accessory (1%–10%), dominant (51%–99%), exclusive (100%), major (11%–50%), present, trace (<1%), 1, 2, 3, 5, 4, 6, 7, 8, 9, 10, 15, 20, 25, 30, 35, 40, 45, 50, 55, 60, 65, 70, 75, 80, 85, 90, 95, 100
Occurrence	Accessory, aggregate, amygdule, augen, cement, clast1, clast2, clast3, clot, concretion, constituent, core, crystal, dissemination, encrustation, epitactic, fragment, globule, glomerocryst, groundmass, halo (external), inclusion, infill, intergrown, interstitial, matrix, megacryst, micaceous book, nodule, nugget, overprint, phenocryst, poikiloblast, porphyroblast, porphyroclast, pseudomorph, relict, replacement, replacement 1, replacement 2, replacement 3, resorbed, ribbon, rutilated, selvage (internal), variole, vug filling, xenocryst, see comment field
Appearance	Pearly luster, iridescent, labradorescent, pitchy luster, opalescent, resinous luster, multicolored

3.9. Descriptive Terminology for Breccias in MIAC Systems

In the Field Application of the Geological Survey of Canada, breccias are currently included within the tectonic, volcanoclastic, and other Lithgroups, and there are no modules specifically adapted to their description (e.g., fragment size, roundness, etc.). Beyond resolving the shortcomings of current breccia definition, classification, and descriptions, adding fragmentites as a lithological group in the future would significantly improve the description of breccias, as discussed and illustrated in detail by Laznicka [31,91]. Tables 7 and 10, Tables 11 and 12 provide the lexicons to describe breccias from their hydrothermal open-space filling attributes to their metasomatic attributes (replacement of host, host fragments, and sequentially metasomatized fragments).

Table 10. Lithdetail for the breccia Lithtype and textures of metasomatic, hydrothermal, and tectono-hydrothermal breccias.

Type	Attribute
Lithtype	Lithdetail
BRECCIA	Lithdetail burst, chaotic, collapse, collapse, communiton, crackle, crumple, decompression, diatrema, dissolution, dissolution pseudobreccia, dissolution-collapse, durchbewegung, edgewise, explosion, floating clast, fluidized, hydraulic, hydrothermal, hydrothermal explosion, hydrothermal fault, magmatic-hydrothermal, milled matrix, mosaic/jigsaw, pebble dyke, phreatomagmatic, pseudobreccia (undivided), shingle, stope fill, tectono-hydrothermal
Texture	Attribute ¹
General	Cataclastic, chaotic, communiton, crackle, durchbewegung, equidimensional, flattened, foliated, fluidized, fractured, gradational, heterogeneous, heterometric, homogeneous, in situ, incipient, irregular, isometric, lithic-rich, monomict, mosaic, open-space filling, polymict, recrystallized, texturally continuous, texturally discontinuous, transported, unaltered, varicolored, veined, vuggy/drusy, well cemented, well developed, zoned
Maturity	Mature, moderately mature, immature
Porosity	Highly porous, moderately porous, non-porous, vuggy
Sorting	Chaotic/unsorted, moderately sorted, poorly sorted, very well sorted, well sorted, graded, normal graded, reverse graded, massive (non-graded) distribution
Support	Fragment supported no cement/matrix, fragment supported with cement, fragment supported with matrix, fragment supported with voids, fragment and matrix supported, fragment and cement supported, cement supported, matrix supported, matrix to fragment supported
Goodness of fit	Embedded, jigsaw-fit (non-rotated), dilated (partially rotated, rotated)
Fragment margin	Smooth, slightly pitted, striated, polished, faceted, solution rounded and pitted, stylolitic, ragged, armored by picked-up microfragments, brecciated envelope, jagged, embayed (through dissolution), pseudobrecciated by dissolution, gradational, diffuse
Fragment roundness	Angular, rounded, slight edge blunting, sub-angular, sub-rounded
Fragment surface	Concave, convex, curvilinear, cusped, embayed/indented, forked, gradational/diffuse, irregular, lobate, planar/straight, resorbed, sigmoidal, sharp, matching fragment outlines

¹ Key sources of information from Refs. [7–11,19,20,22,23,31–36,38,40,47,48,50,59,64,67,73,81,82,91,92].

Table 11. Structures of metasomatic, hydrothermal, and tectono-hydrothermal breccias.

Type	Attribute ¹
General	Array (parallel alignment, multiple orientations); bedded (oblique, parallel); deformed (foliated, sheared, stretched); brecciated, laminated (straight, oblique, parallel, fluidization lamination); layered (oblique, parallel, straight, compositionally, fluidization, stratified); lineated (fluidization), massive (isotropic + homogeneous), rebrecciated, unstratified
Contact type	Floor preserving, erosive, basal scour, angular floor depression (plucked fragments removed, with partially plucked fragments), compaction pockets, injections in dilatation wedges, soft deformation, branching, sheeted (with wall-parallel fractures, with delaminated fragments), with halo, with splay breccia, gradational

Table 11. *Cont.*

Type	Attribute ¹
Contact margin	Rough, smooth, slightly pitted, solution rounded and pitted, stylolite-bound, ragged, diffuse
Internal organization	Uniform, non-uniform and randomized: in fragment rounding, in fragment size, in fragment type, in matrix type, non-uniform and organized (zoned, asymmetric, asymmetric layered parallel, symmetric, symmetric layered parallel), block-choked segment
Shape ²	Anastomosing, branching, cap, cone, cylindrical, dome, dyke, filled fissure, fold hinge, fold breccia (flexural flow), irregular, pipe, tabular (horizontal, sub-horizontal, inclined, sub-vertical, vertical), diatreme, bended wall rock, pierced wall rock
Zonation	Zoned (laterally, vertically, longitudinally), cavity, isotropic, discontinuous, collapse structure, crackle, mosaic, fluidized
Fragment	Intraclast, ripped-up fragment, altered, fractured, refragmented, veined, zoned
Fragment shape	Amoeboidal, bent platy, chocolate tablet, convex lens, curvilinear, elliptical, elongate, equant, folded platy, irregular, multi-faceted, necked, pinch and swell, rectangular, rhomb, rhomb angular, rhomb sigma, ribbon-like, round, sausage-shaped, sheet-like, sickle-shaped, sigmoidal, swell, tabular, tapered, triangular, wedge
Fragment alignment	Comminuted fragment train, fluidization (foliation, lineation, layering, randomized), deformed (foliated, sheared, stretched), imbricated/edgewise/shingled (downward from wall, upward from wall), oblique to wall, onion form, parallel, parallel to wall, parallel wall-delaminated, perpendicular to wall, randomly oriented, rotated, shadow zones behind large blocks (i.e., fragments pile up on the back of a large fragment during flow)
Fragment sphericity	Length/width: >1, >2, >5, >10, >20

¹ Key sources of information from Refs. [7–12,19,20,22,23,31–36,38,40,47,48,50,59,64,67,73,81,82,91,92]. ² See Figures 3–5 and page 85 of Laznicka [31] and the extensive illustrations of breccias from MIAC systems throughout this book, derived from the Cloncurry district (Australia), Wernecke Breccia (Canada), and other global settings.

Table 12. Lexicons for textures and structures in veins and breccia cements.

Related to	Attributes ¹
Texture	Acicular, anhedral, aphanitic, arborescent, banded, bladed, bladed (parallel), bladed (radial), bladed (randomly oriented), blebby, blocky, botryoidal, buck, cataclastic, cockade, colloform, comb-textured, comb-drusy, coronitic, coxcomb, crustiform, crystalline, dendritic, drusy, equigranular, fan-shaped/divergent, felted, fibrous/fiber, fissile, flaggy, flattened, fracture-fill, framboidal, friable, glassy, globular, gradational, granoblastic, granular, herringbone, heterogeneous, holocrystalline, homogeneous, hydrothermally altered, hypidiomorphic grains, hypidiomorphic granular, idiomorphic grains, inequigranular, interdigitated, interfingering, intergrown, interstitial, irregular, laminated, megacrystic, mesh, miarolitic, moderately porous, mottled, muddy, net-textured, non-porous, ocellar, open-space filling, panidiomorphic, phaneritic, polygenetic, porous, porphyroclastic, prismatic, pseudo-acicular, pseudo-bladed, radial, recrystallized, reniform, replaced (pervasively, selectively, variably), reticulate, ribbon, rosette, saccharoidal, semi-massive, seriate, slabby, spheroidal, spherulitic, spotted, spotty, stellate, stockwork, stylolite, sugary/saccharoidal, unaltered, varicolored, variegated, vari-textured, veined, vitreous, vuggy/drusy, xenomorphic, zoned
Structure	Anastomosing, antitaxial, ataxial, banded, bladed, brecciated, closed veins, compositional layering, concentric (banding, irregular, parallel), concretion, crustiform banding, faulted, filled vesicles, filled vugs, folded, foliated, fractured, fragmented, irregular jointing, laminated (oblique, parallel), layered (oblique, parallel), massive ² , nodular, open-space filling, ptigmatitic vein, rhythmically layered, sheared, sheeted, stratified, stretched, syntaxial, vein parallel, waxy, zoned (laterally, vertically, longitudinally)

¹ Key sources of information from Refs. [7–11,19,38–40,92,93,95,106–108,111]. ² Both isotropic and homogeneous.

An example of the description of breccias needed within the metasomatic Lithogroup instead of the hydrothermal Lithogroup is the development for the K-feldspar-rich Facies

3 HT K-Fe alteration in volcanic, volcanoclastic, and plutonic rocks and albitite that leads to magnetite-group IOCG deposits [22,72]. Intricate relationships among brecciation and sequential replacement is observed, whereas bona fide hydrothermal cements in open-space filling commonly takes place subsequently as quartz and carbonate become stable. At Facies 3, magnetite-rich breccias form and commonly develop an external halo rich in K-feldspar (i.e., a K-felsite halo). Internally, the matrix of magnetite, $\pm$ biotite, and $\pm$ chalcopyrite develops K-feldspar haloes that alter breccia fragments to K-feldspar, first along fragment margins and fractures, and then increasingly pervasively across them [18–20,22]. Further intensification of the alteration facies leads to the replacement of the K-feldspar-altered fragments by magnetite and sulfides. The contours of the fragments become increasingly ragged and diffuse, and the original breccia texture is increasingly destroyed. Brittle deformation to brittle–ductile shearing is associated with K-feldspar-rich HT K-Fe alteration. The description of the HT K-Fe breccias thus requires the extensive use of the breccia and replacement lexicons of Tables 3–5 and 10–12, and detailed accounts of the spatial distribution and relative timing of the objects being brecciated and replaced (Table 7). This availability of terms to describe breccias can contribute to avoiding misinterpreting magnetite and K-feldspar formed coevally at Facies 3 from brecciation of a K-felsite infilled with magnetite or from a K-feldspar overprint on a magnetite breccia.

At Facies 5 LT K-Fe alteration, hematite not only precipitates within the matrix of breccias but also commonly replaces fragments, pseudomorphically preserving their contours at megascopic scale, which leads to a pseudobreccia texture, as observed at the Olympic Dam deposit [22,74]. Hence, the description of breccias at Facies 5 needs to account for the extensive replacement of fragments as alteration intensifies, as per Tables 3–5, and the pseudobreccia can be described using some of the components of Tables 10 and 11. Descriptions must also attempt to discriminate replacement from hydrothermal precipitation in open space, as per Table 12, and need to establish the spatial distribution and relative timing relationships among described Earth Material, as per Table 7.

4. Discussion

4.1. Metasomatites as a Record of the Development of a MIAC System

The geological processes that can be interpreted from the footprint of a MIAC system comprise those provided by the host rocks as a source of cations, metals, and complexing agents (e.g., evaporites), or as a buffering, oxidizing, reducing, or acid-neutralizing environment that can impact ore deposition. The descriptive lexicons to capture this information are widely available [7–11]. The geological structures provide information on the potential fluid flow architecture, while the metasomatic record provides conclusive evidence of where the fluid flow took place. The metasomatites can also record information on the pH, oxidizing, or reducing conditions of the fluid plume and their high or low temperature of precipitation. It also constrains the metal and element speciation across the system as dissolution and reprecipitation processes take place, as the primary fluid plume that triggers the MIAC system evolves based on the distribution and relative timing of alteration facies and associated mineralization types, as discussed extensively in Ref. [14].

With the lexicons provided in this contribution (Tables 1–12), the geological megascopic information recorded by metasomatites can be mapped in detail by considering metasomatites as bona fide lithotypes (Table 1; Figure 1, Figure 2, and Figure 5) and describing their parageneses, minerals, textures, structures, deformation fabrics, timing relationships, and linkage to a host rock (Tables 2–9). The data collection system proposed and its lexicons will facilitate the production of the regional alteration and metallogenic maps required for the characterization and exploration of MIAC mineral systems [5]. The lexicons to describe the space–time relationships (Table 7) between the metasomatites and

the other geological lithotypes listed in Table 8 provide insights into potential thermal perturbations and rapid changes in the physical conditions of the fluid plume that favored ore deposition, including within structural traps [5,14]. The ontology thus builds on the geological footprint of the mineral system (Figure 1B) to provide information on all the taxonomy components of the ontology, as shown in Figures 1A and 5.

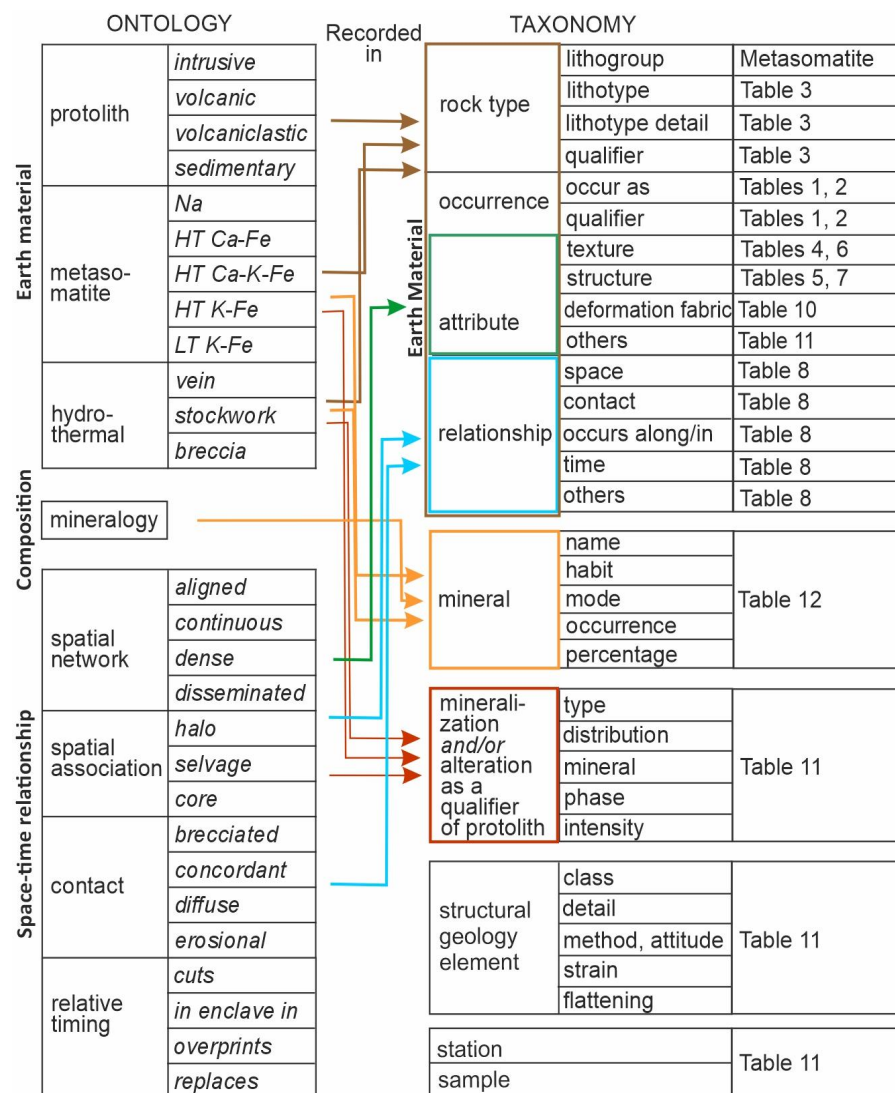


Figure 5. Ontology and taxonomy that illustrate the field observation required to characterize metasomatic rocks and their mineral systems.

4.2. Examples of Textural and Structural Observations That Optimize Genetic Interpretation

Metasomatism preserves or destroys protolith textures and structures or creates textures similar to those of sedimentary, volcaniclastic, plutonic, and metamorphic rocks (Tables 4, 5, 10 and 11). Mapping the attributes of incremental metasomatism helps in genetic interpretation and identification of exploration vectors. Being aware of potential pitfalls in field interpretation is also paramount to effective exploration and research. The lexicons therein describe the metasomatites in the detail needed to support robust interpretations of mineral systems and eliminate genetic interpretations that conflict with field geology.

4.2.1. Interpreting Metasomatic Pseudomorphing and Textural Transformation

Among all MIAC replacements of protoliths, those with magnetite are the best to pseudomorph the textures of their hosts. Tables 4, 5 and 7 list a wide range of textural, structural, and relationship information in the proposed lexicons to account for the large spectrum of examples observed to date. Porphyritic andesite and fossil-bearing sedimentary rocks replaced by magnetite preserve some of the best evidence of isovolumetric alteration. Examples include the selective statabound alteration of stromatolite laminae by magnetite. In andesite, the distribution, orientation, size, and spacing of albitized phenocrysts among a groundmass replaced by magnetite can remain megascopically identical to those of the protolith [19,27,112]. The distribution, size, and spacing of faint phenocryst ghosts in albitite [19] also indicate that the replacement of protoliths by albite can be largely isovolumetric (including porosity as per Ref. [100]).

Hematite alteration at Facies 5 can pseudomorph granitic or volcanoclastic fragments into breccias, as discussed in Section 3.9. This process forms pseudobreccia textures in which pervasive replacement (including mineralization) of both primary fragments and hematite-rich matrix prevails over fragmentation, cementation, and void-filling hydrothermal precipitation of ore. This observation has implications for the interpretation of the geological processes associated with mineralization. In porphyritic andesite, textural pseudomorphing of phenocrysts by quartz and of the groundmass by hematite can intensify to pervasive textural transformation of the host to a layered hematite ironstone, again having an impact on the genetic interpretation of such ironstones globally. Field observations documented in Corriveau et al. [22] illustrate that an increase in preferred orientation and a decrease in abundance of plagioclase phenocrysts pseudomorphically replaced by quartz occurred as the groundmass became increasingly replaced by hematite. The texture marked a gradient between randomly oriented plagioclase phenocrysts in the host to pseudomorphed laths oriented parallel to a dissolution-induced foliation. As the dissolution of the former phenocrysts increased, the hematite-rich groundmass started to develop a layering parallel to the metasomatic foliation. At the extreme, all phenocrysts were dissolved and the hematite-dominant metasomatite became layered with a metallic grey hue to an earthy color typical of some banded iron formation [22]. Taken in isolation, the banded hematite ironstone could have been misinterpreted as sedimentary in origin. If bearing gold, a banded iron formation-hosted Au mineralization model could have been invoked and explored accordingly instead of the appropriate MIAC ore deposition model being used [14,21]. Having the terminology at hand in field applications to describe the evidence left by metasomatic processes is key in providing the petrological alteration mapping tools for the genetic interpretation of ore deposition and the appropriate ore deposit model.

4.2.2. Examples of Interlinkages Between Metasomatism, Brecciation, Brittle to Ductile Deformation, and Fluidization

As metasomatism proceeds, brittle deformation takes place at Facies 1 to 6 with the development of fractures, veins, and breccias. Brittle to ductile deformation is common at Facies 2, Facies 2–3, and biotite-rich Facies 3, where mineral foliation and folds can form. Fluidization is most common in magnetite-dominant Facies 2 HT Ca-Fe alteration (i.e., in IOA mineralization) but also occurs at the K-feldspar-rich HT K-Fe alteration. The lexicon for deformation fabrics within MIAC systems thus includes all terms to describe brittle, ductile, and flow fabrics (Table 6).

For example, where albitite forms along fault zones, reactivation of the faults leads to extensive breccia zones of albitite, which are often replaced by subsequent alteration facies. The description of brecciated albitite uses many of the breccia characteristics listed in Tables 10 and 11 in combination with replacement-type occurrences, textures, and structures

(Tables 4 and 5; Figure 2). Brecciation not only leads to isotropic crackle, mosaic, or chaotic breccia, but can also be fluidized and develop pervasive flow fabrics where fragments are aligned and can display textures that allow for the assessment of flow direction, as described in Laznicka [31]. In addition, where magnetite-rich Facies 2 HT Ca-Fe and biotite-rich Facies 3 HT K-Fe alteration replace albitite breccia, the breccia and alteration zones can be deformed ductilely and become foliated, folded, or boudinaged [19], requiring the use of the breccia and replacement lexicons of Tables 3–5, 10 and 11 and a detailed account of the spatial distribution and relative timing of the objects being brecciated, replaced, and subsequently deformed as MIAC metasomatism proceeds (Table 7).

4.2.3. Distinguishing Syn-Metasomatic Ductile Deformation from Orogenic Overprints

At Facies 2 HT Ca-Fe, Facies 2–3 HT Ca-K-Fe, and Facies 3 HT K-Fe biotite-rich alteration, high-temperature fluids can give rise to ductile deformation coeval with precipitation of the metasomatic mineral parageneses, as described above. The development of penetrative mineral foliation, stretching lineation, schistosity, shear zones, and local folds are common and spatially restricted to their host alteration facies (Table 6) [19,22,49]. Syn-metasomatic recrystallization to amphibole $\pm$ garnet and/or magnetite schists, amphibolite-looking rocks, biotite-amphibole $\pm$ garnet and/or magnetite schists, and biotite $\pm$ garnet and/or magnetite schists is common, as observed in the Great Bear magmatic zone, Canada [47]. Such ductile deformation fabrics do not represent evidence for post-metasomatic accretionary or collisional orogenesis nor for the presence of regional metamorphism. They highlight that the distribution of alteration in MIAC systems is structurally controlled along tectonic discontinuities and that the metasomatites formed along shear zones at high temperatures can resemble metamorphic rocks [19,21].

Through subsequent orogenesis, Facies 2 HT Ca-Fe, Facies 2–3 Ca-K-Fe, Facies 3 HT K-Fe biotite-rich alteration, Facies 5 sericite-rich alteration facies, and tourmaline replacement of earlier alteration facies become recrystallized to amphibole $\pm$ garnet and/or magnetite schists or gneisses, biotite-amphibole $\pm$ garnet and/or magnetite schists or gneisses, biotite $\pm$ garnet and/or magnetite schists or gneisses, muscovite-rich schists and gneisses, garnetites, and tourmalinites, as illustrated by the Nautanen North deposit in Sweden [23], the Bondy Gneiss Complex in Québec [54], and the Johnnies Reward prospect in Australia [113]. Such rocks are often mapped as amphibolite or metasedimentary rocks, including as metaexhalites. Recognition of such lithotypes as Facies 2 HT Ca-Fe, Facies 2–3 HT Ca-K-Fe, and Facies 3 HT K-Fe alteration and MIAC-related tourmaline replacement helps to interpret subsequent vein-rich IOCG deposits, such as the Nautanen North deposit in Sweden, as the mineralized veins can be derived from in situ remobilization of the primary metal endowment of older alteration facies and remain spatially restricted to their alteration zones [23].

4.2.4. Distinguishing Pre-Existing and Syn-Metasomatic Breccia and Pseudobreccia

The metasomatic breccias associated with Facies 3 to 5 can develop on pre-existing tectonic, sedimentary, volcanic, or albitite breccias; L-tectonites; least-altered precursor rocks; or Facies 1 (Na) and Facies 2 (HT Ca-Fe) alteration. It is thus essential to distinguish overprints of K-Fe facies on precursor fragmental rocks from their most intense form, which causes syn-alteration brecciation and leads to metal precipitation. Intense replacement of a pre-existing breccia or other fragmental units can be associated with striking, selective replacement of fragments, preserving the appearance of a breccia even where replacement is pervasive. Documenting the nature of the relative timing of replacement has significant exploration implications, as different metal associations and deposit types characterize each alteration facies.

4.2.5. Translating Misnaming of Metasomatites into Targeting Potential MIAC Systems

Metasomatites can take on the appearance of common rocks and can be mapped as sedimentary, volcanic, volcanoclastic, intrusive, or metamorphic rocks. Application of natural language processing (NLP) to the increasingly available digitized geological reports from governments and the private sector [6] could thus be used to filter potential targets through re-interpreting their context, a task currently undertaken by field geologists familiar with MIAC systems. Table 13 thus lists the rock types that metasomatites have been formerly mapped as, the various names they have been given, and additional rock types they can resemble (e.g., iron formations, as discussed in Williams [101] and Bonyadi et al. [114], among others). For example, the recognition of albitite can be locally impaired by the abundant residual quartz and a very fine grain size, which renders albitite similar to and commonly mapped as silicification zones. Identification of albitite can also be impaired by a pervasive coarsening of grain size to a hypidiomorphic–granular texture, particularly in areas where albitite zones are formed adjacent to coeval sub-volcanic intrusions. The albitites in these zones are white, pink, or, more rarely, lilac color, and resemble tonalite, syenite or granite, and anorthosite, respectively. Examples include those of the Wernecke breccias, as pointed out by Laznicka and Edwards [66]. Confusion about such rocks can be avoided by moving away from the albitite zones to map the gradual transformation of the protolith towards the most intensely metasomatized rocks using the varied lexicons provided herein.

Table 13. List of rock types and names that have been used or that can be potentially used in scientific publications and drill core logs to describe misidentified metasomatites.

Metasomatite	Mapped or Potentially Mapped as Distinct Rock Types
Albitite	Syenite, episyenite, anorthosite, tonalite, rhyolite, felsite, aplite, spilite, volcanoclastic breccia, agglomerate, bleached rock, silicification, quartzite, chert, hornfels, red rock, buff-weathered rock, maroon feldspar or salmon/smokey grey alteration, tan and pink quartz alteration, salmon crackle brecciated; if metamorphosed to high grades they become a quartzofeldspathic gneiss
HT Ca-Fe	Amphibolite, amphibole schist or gneiss, magnetite-rich schist or gneiss, banded iron formation and other sedimentary ironstones, magnetite flow, albite diabase, albite basalt; selective replacement of breccia fragments can be interpreted as evidence for pre-brecciation magnetite or amphibole alteration or as fragments of a sedimentary iron formation; if metamorphosed to high grades they become amphibolite, amphibole- to magnetite-rich schist or gneiss
HT Ca-K-Fe	Amphibolite (K-feldspar would be cryptic in the field), biotite-rich amphibolite, biotite–amphibole schist or gneiss, magnetite-rich biotite and biotite–amphibole schist or gneiss, banded iron formation; if metamorphosed to high grades they become amphibolite, magnetite-rich or garnet–amphibole-biotite schists or gneisses
Biotite-rich HT K-Fe	Biotite schist or gneiss, magnetite-rich biotite schist or gneiss, glimmerite, banded iron formation; if metamorphosed to high grades they become a biotite- or biotite–magnetite-rich garnetite, a biotite schist or gneiss and are interpreted as semi-pelitic or pelitic sedimentary rocks or as an exhalite
K-feldspar-rich HT K-Fe	Agglomerate; K-feldspar-altered fragments commonly interpreted as predating the precipitation of magnetite; if metamorphosed to high grades they become garnetite, magnetite-rich quartzofeldspathic gneisses and are interpreted as sedimentary rocks or as an exhalite
K-felsite	Arkose, syenite, rhyolite, red rock; if metamorphosed to high grades they become a quartzofeldspathic gneiss

Table 13. Cont.

Metasomatite	Mapped or Potentially Mapped as Distinct Rock Types
LT K-Fe	Banded iron formation, sericite schist; if metamorphosed to high grades they become a garnetite (e.g., biotite-, magnetite- or quartz-rich garnetite) or a magnetite-rich quartzofeldspathic gneiss
Tourmaline alteration	Exhalite, meta-exhalite; if metamorphosed they become a tourmalinite or a tourmaline-rich schist or gneiss with or without kornerepine veins
Argillic to advanced argillic	Sericite schist; if metamorphosed to high grades they become sillimanite-bearing and commonly interpreted as a pelitic schist or gneiss

5. Conclusions

Prior to this work, field geology lexicons were well defined to describe magmatic, sedimentary, and metamorphic rocks, but gaps remained in naming alteration facies and describing the diversity of metasomatites that lead to ore deposition at district and deposit scales. A failure to systematically map metasomatites during government mapping programs and exploration campaigns leads to misinformation and a lack of data that is detrimental to mineral potential assessment, to the production of national prospectivity maps, and to mineral exploration. This lack of mappable metasomatic data is particularly damaging to the identification of metasomatic iron alkali-calcic (MIAC) mineral systems and the exploration of their IOCG, IOA, and affiliated deposits in greenfield environments.

The new taxonomies and lexicons provided in this paper are tailored to describe, map, and explore MIAC systems and their IOA, IOCG, and affiliated critical and precious metal deposits using an alteration facies approach to mapping. The alteration facies are framed within an ontology that relates mappable alteration, brecciation, and mineralization processes among themselves and with host rocks and coeval and subsequent regional-scale geological events. For example, Facies 1 Na forms albitite corridors that can subsequently brecciate and become a preferential site for albitite-hosted U deposits. Facies 2 HT Ca-Fe evolves from amphibole- to magnetite- to apatite-dominant alteration and leads to IOA or Fe-skarn deposits. Facies 3 HT K-Fe alteration precipitates polymetallic magnetite-group iron oxide copper–gold (IOCG) and iron sulfide copper–gold (ISCG) deposits. Facies 4 consists of K-skarn and K-felsite alteration and is regularly brecciated. Facies 5 and its extensive variety of metasomatites lead, for example, to hematite-rich breccias and IOCG deposits. Facies 6 comprises LT K-Si-Al $\pm$ Fe-Ba (phyllitic, sericitic, silicic, advanced argillic) and late-stage veins.

The robust terminology catalog and the adaptability of the lexicons to the wide range of attributes characteristic of alteration facies optimize mapping and mineral exploration in evolving multi-stage mineral systems like MIAC systems. The taxonomies and lexicons focus on the description of alteration facies using mineral assemblages instead of individual minerals to favor the identification of the different steps in the evolution of the system described. Reporting alteration as single mineral alteration of a protolith leads to inadequate characterization of the mineral systems and hampers the development of robust exploration strategies based on the relationship between alteration facies and mineralization types. Furthermore, when combining minerals that are spatially associated due to overprints instead of mapping (commonly best done megascopically or with a micro-XRF), the varied overprinting assemblages can lead to misinterpretation of the stable mineral assemblages, which then masks the stable alteration facies and limits their potential use as pathfinders for specific mineralization types with distinctive metal associations.

To prevent misinterpretation during regional mapping and exploration programs, a modern field application like the Field Application of the Geological Survey of Canada, with its extensive lexicons for metasomatic rocks, can be used to map MIAC systems. This user-friendly digital data collection program made for fieldwork or drill core logging streamlines the recording of the data in the field using the defined taxonomies and lexicons. This allows all observational data to be consistently reported and searchable while minimizing compilation errors.

The lexicons are very extensive, and we acknowledge that not all terms will be toggled on during data recording. The terms listed highlight what has been observed so far and can be adjusted using the lexicon editor, which allows users to adapt the scientific language used behind the digital forms to describe MIAC systems. Having a list of possibilities and a pre-established framework facilitates field mapping, while the customization of the data collection forms improves field efficiency.

Edge cases of metasomatic facies and refinements to the terminology of low-temperature alteration facies will further improve available lexicons and help reevaluate the data structure and inner components of the Field Application. As the understanding of MIAC systems progresses, the lexicons for all the new occurrences will necessarily evolve. This contribution lays down the ground bases and the framework to attain it. Further work is also needed to make any compilation efforts easier for tracking and describing studied MIAC systems and their associated IOA, IOCG, and ISCG via online services or structured datasets using the FAIR principle [12] or linked data, which would allow a user to follow all publications and datasets related, or spatially related, to said linked data [115].

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Abbreviations

Mineral abbreviations of Warr [63] are used in this manuscript, with additional ones from Ref. [80].

Appendix A

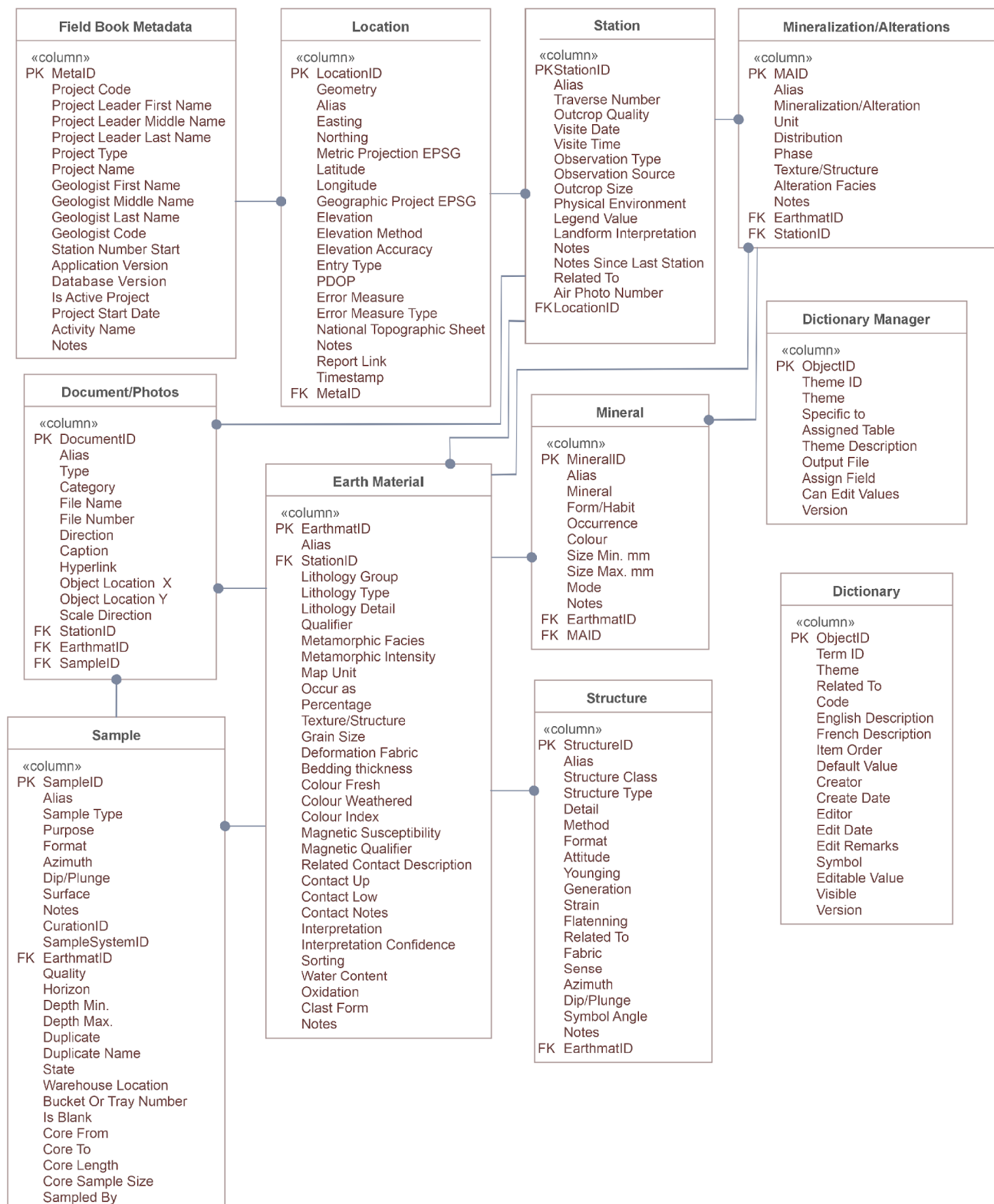


Figure A1. Diagram of the geospatial and relational database used within the GSC Field Application information. Current fields that can be filled when mapping bedrocks are listed using geological terms adapted for geologists from the GIS specialist version in Huot-Vézina et al. [24]. Foreign keys are marked as FK and primary keys as PK.

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