Government of **Western Australia**
Department of **Mines and Petroleum**

RECORD 2013/8

GSWA CODE BUILDER — CONSTRUCTING AND UNRAVELLING GSWA GEOLOGICAL CODES

by
A Riganti, DJ Wallace, BC Fadadu, DM Canham, KKR Gavni, and RM Hocking



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GSWA Code Builder — constructing and unravelling GSWA geological codes

by

A Riganti, DJ Wallace, BC Fadadu, DM Canham, KKR Gavni, and RM Hocking

Abstract

Codes and underlying classification schemes differentiate various bedrock and regolith units and are a critical component of all but the simplest geoscientific maps. Over the last decade, the Geological Survey of Western Australia (GSWA) has developed bedrock and regolith classification schemes that provide coherent terminology and code structure on its maps and geoscience spatial data layers. The schemes ensure consistency of coding and naming of units within projects and across Western Australia, and are essential modules within GSWA database systems. Now, the code-generation components of the bedrock and regolith systems have been extracted into a standalone Microsoft Windows desktop application, publicly available from the Department of Mines and Petroleum (DMP) Data and Software Centre.

The GSWA Code Builder provides the geological community with a reference for, and explanation of, current rock and regolith codes used in GSWA digital products. It also allows users to add their codes to the lookup tables if desired. This Record details the logic behind the GSWA Code Builder by providing a condensed background to GSWA's approach to generating rock and regolith codes for digital products.

KEYWORDS: Bed rock, regolith, stratigraphic nomenclature, lithologic unit, stratigraphic code, rock stratigraphic unit, codes, standards, digital data

Introduction

Codes are an essential component of geological maps and geological digital layers, allowing unique characterization of different types of bedrock and regolith units. The codes summarize and provide an entry point to classification schemes that underpin the codes. Over the last decade, the Geological Survey of Western Australia (GSWA) has developed rock and regolith classification schemes (Tyler et al., 2004; GSWA, 2013) that provide consistent terminology and code structure for digital products extracted from GSWA corporate databases. Automated, table-based generation of rock and regolith codes are core modules within GSWA internal systems that ensure consistent, unique coding and naming of units within projects and across Western Australia.

The GSWA code systems cover the entire State and a large variety of rocks and regolith types, and can be complex and difficult to fathom or generate for the outside user. Consequently, the code-generation components of GSWA's systems have been compiled into a standalone desktop application, the GSWA Code Builder, available through the Department of Mines and Petroleum (DMP) Data and Software Centre at <http://www.dmp.wa.gov.au/datacentre>. The GSWA Code Builder has been tested with Windows XP and Windows 7 operating systems, and works within the 600-pixel vertical resolution of common tablet computers. This Record describes the structure of the application and provides information on the backbone of the Code Builder — the GSWA bedrock and regolith coding schemes for digital geological products. Novice users may find it helpful to install and experiment with the Code Builder and read the Record in parallel.

The Record also briefly outlines the conversion from database codes to hardcopy map code styles. This is a necessary step because alphanumeric map codes in databases cannot show the geological time characters, small capitals, subscripts, and italic fonts used in symbols on GSWA typeset manuscripts and regolith/bedrock printed maps.

In this Record, words that the user can expect to see on the screen in a dialogue box, menu choice, tab, or button are in square brackets; for example '[About]'.

GSWA Code Builder

The GSWA Code Builder application comprises two separate modules for bedrock and regolith codes (Figs 1 and 2). The former has been extracted from the GSWA

Explanatory Notes System (ENS), developed by GSWA to deliver explanatory notes for bedrock units via a digital framework (Riganti et al., 2012b); extracts from the system are already included in some GSWA Geological Information Series (GIS) packages. The regolith module is part of the in-house field observations database used by GSWA geologists (WAROX 9; Riganti et al., 2012a), extracts of which are included in GIS packages, and are used to plot structural observations on GSWA maps. By default, each module of the GSWA Code Builder opens with a concise set of tips on the right-hand side of the application window; this can be collapsed by clicking on the button to the left of [Tips] (Fig. 2).

Bedrock and regolith codes are constructed using a series of table-based drop-down menus in the [Bedrock] and [Regolith] tabs. Information on each specific field is detailed below. Codes are generated by the application as elements from various fields are progressively selected or modified from the drop-down menus; a [Reset] button at the bottom of each window clears all fields.

Bedrock and regolith codes constructed through the GSWA Code Builder match those in current GSWA digital geological layers, as the lookup tables that are at the heart of the ENS and WAROX are the same as those included in the Code Builder. In these codes (also referred to as 'Database codes' or 'English codes'), individual components of the code are always separated by hyphens, and regolith codes always start with an underscore ('_') to allow immediate distinction from bedrock units. The sections on digital vs hardcopy bedrock (or regolith) code styles in this Record provide examples of how database codes are converted to hardcopy map codes.

The [More Details] tab in the main interface (Fig. 3) provides links to relevant documents. These are this Record (Record 2013/8) and the GSWA revised regolith classification scheme (GSWA, 2013) in PDF format, and links to useful background information such as the International Union of Geological Sciences (IUGS) chronostratigraphic chart and online stratigraphic guide.

The [About] tab gives details of the version of the Code Builder followed by the date of extraction of underlying tables (because these change as GSWA work progresses). The tab allows users to link to the DMP and GSWA webpages, and to other GSWA geology and resource spatial datasets through its Data and Software Centre.

A step-by-step guide to installing the GSWA Code Builder is provided in Appendix 1 and software details are in Appendix 2. The State of Western Australia retains the copyright to the software, although users can configure some tables to add more specific terms. For example, users can add further lithological names where more detailed or field-specific nomenclature is required (see detailed instructions in Appendix 3). The Licence Agreement for the application can be viewed at any time in the [About] tab within the application.

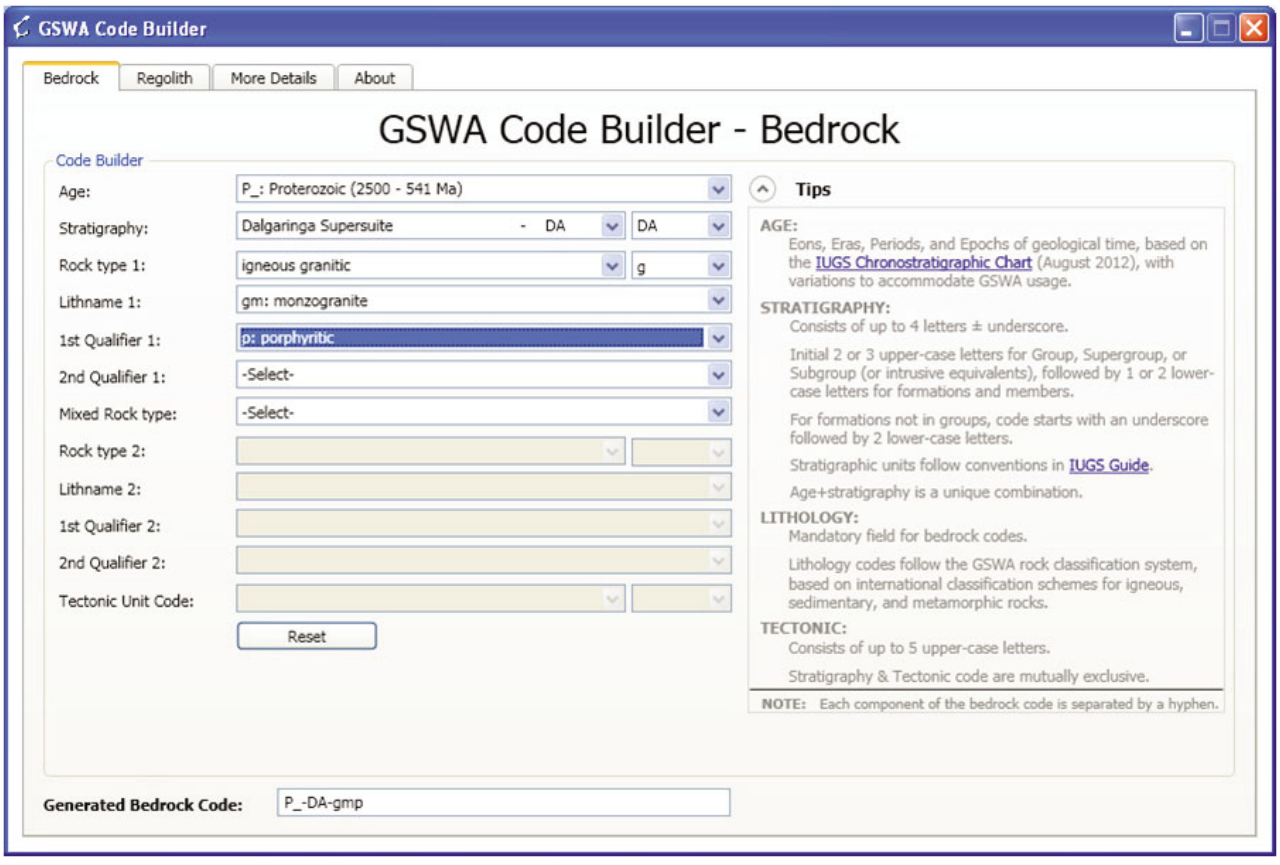

Figure 1. GSWA Code Builder interface — [Bedrock] module.

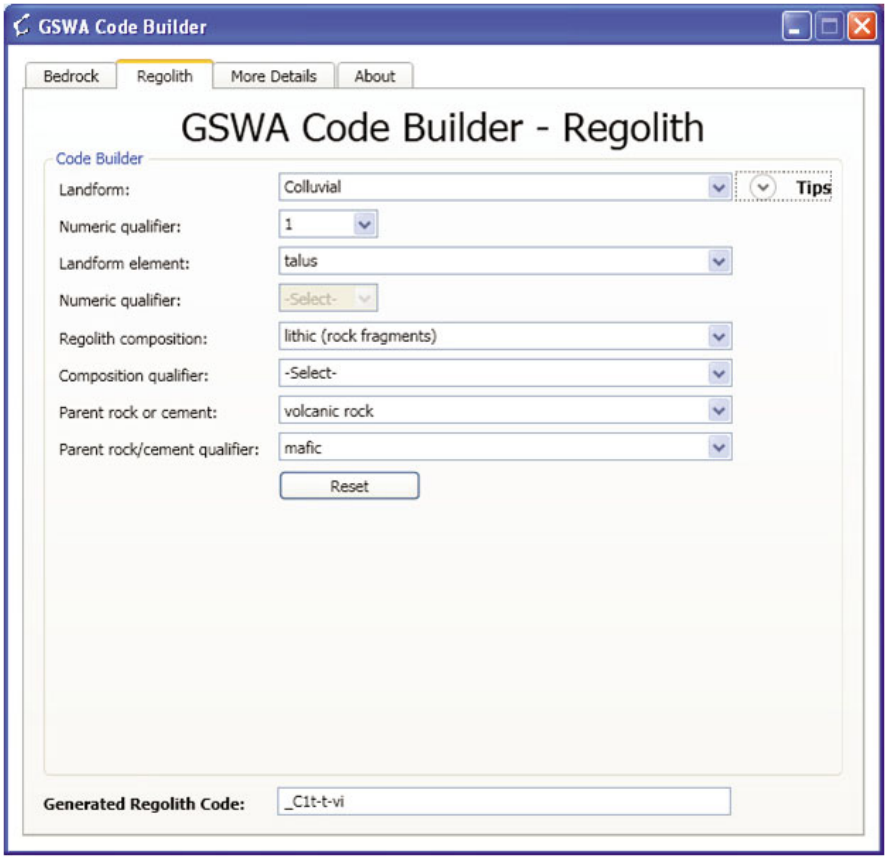

Figure 2. GSWA Code Builder interface — [Regolith] module. Note that the [Tips] section has been collapsed.

Navigation tips

Tips for easy navigation include:

- Selection from drop-down menus is simply made by typing one or more letters. Typing the same letter more than once takes the user to successive entries that start with that letter. For example, typing the letter 'P' in the Age field of bedrock codes will take the user to 'P: Permian' first, then 'P_: Proterozoic', and so on. Note that if a drop-down menu displays multiple items (e.g. age code and age name in the Age field), the selection will always be on the item displayed on the left-hand side of the drop-down menu. Therefore typing 'E' in the Age field will take the user to the age code 'E' for Cambrian, not 'E' as the start for the age names Eoarchean or Ediacaran.
- Entries for some fields (Stratigraphy, Rock type, and Tectonic Unit Code) can be selected through either one of two separate drop-down menus. This is to allow searches through either name or code, i.e. users can select a name to see what the corresponding code is, or select a code to see what name that code represents.
- All fields are simultaneously cleared by clicking on [Reset]. To clear individual fields, click on the [-Select-] entry at the very top of each list.
- Some drop-down menus do not initially offer any choice because a selection from a previous field is a prerequisite. For example, qualifiers cannot be selected unless the parent field to be qualified has been filled in.
- Similarly, greyed-out fields are only activated when the appropriate selections in other fields have been made (e.g. the Stratigraphy and Tectonic Unit Code fields are activated only after Age has been selected). Conversely, some selections will disable some dependent fields (e.g. deleting a Rock type or Lithname will void the associated Qualifier fields).
- Hovering messages alert the user to specific aspects of the application, or display in full any long entries that do not fit into the extent of specific fields. For example, when the user opens the Stratigraphy field and then hovers the cursor over any stratigraphic name, a hovering message with the full stratigraphic name appears.

GSWA bedrock codes

No more than three parts are required to uniquely code a bedrock unit in the GSWA classification scheme for Western Australian rocks. GSWA bedrock codes consist

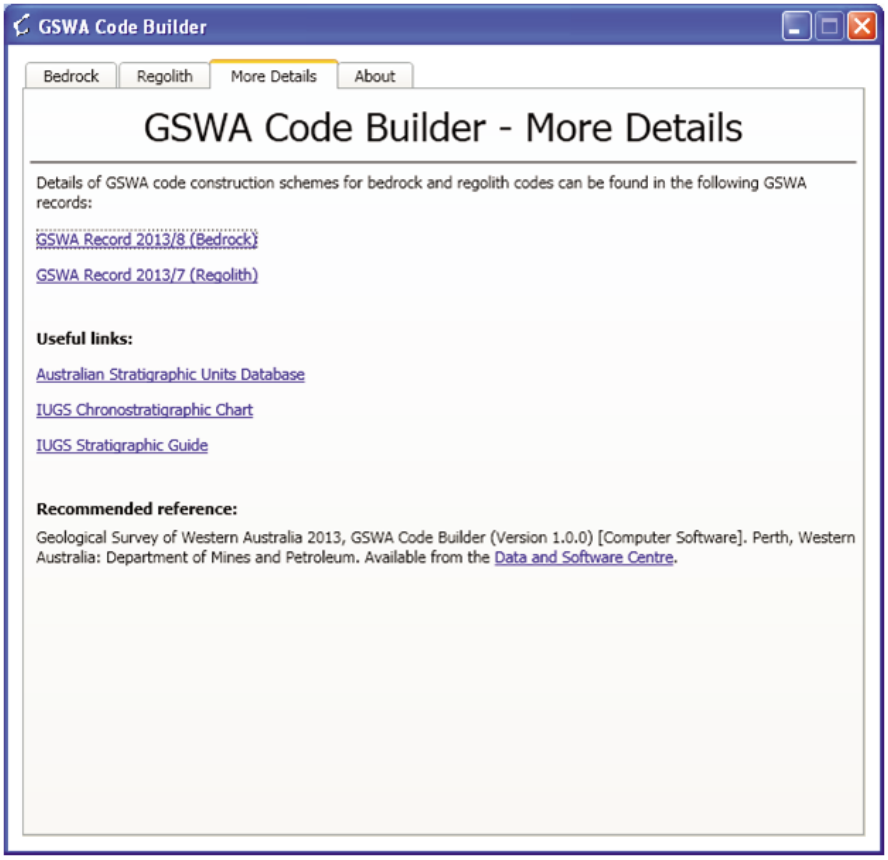

Figure 3. Image of the [More Details] window showing links to useful documentation.

of one to three separate components, each separated by a hyphen. The components are selected from a set of four parameters:

1. Geological time
2. Stratigraphy
3. Lithology
4. Tectonic unit.

The bedrock code structures allowed by the scheme are listed in Table 1. Of the four parameters above, lithology is the only mandatory component. However, most codes used in Western Australia commonly have a geological time (also referred to for simplicity in this Record as Age or geotime) and usually either a Stratigraphy or Tectonic Unit component. Stratigraphic and tectonic components are mutually exclusive, as a formally defined stratigraphic unit is inextricably linked to one or, occasionally more than one, tectonic units. The use of a tectonic or stratigraphic component mandates the selection of an age.

Figure 4 illustrates two examples of the most common code structures used by GSWA to characterize bedrock units. The following sections cover details of each individual bedrock code component, in the order in which they are entered to construct the code.

Table 1. Bedrock code structures in GSWA digital products

l	lithology
A-l	Age-lithology
A-S-l	Age-Stratigraphy-lithology
A-l-T	Age-lithology-Tectonic unit

A = Age; l = lithology; S = Stratigraphy; T = Tectonic unit

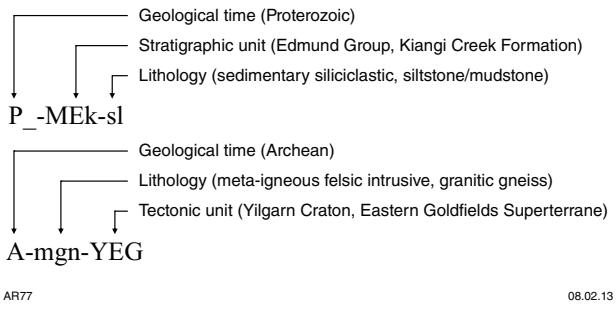

Figure 4. Examples of common structures of GSWA bedrock codes.

Age in bedrock codes

The age component for bedrock codes consists of up to four upper case letters. An underscore is used to distinguish Proterozoic ('P_') from Permian ('P'). The age names and corresponding codes displayed in the GSWA Code Builder are listed in Table 2. For convenience, throughout this document the term 'geotimes' is specifically used to refer to the names rather than the age in numbers for a specific time interval. GSWA usage of geotimes and the age boundaries that define them is consistent with the International Chronostratigraphic Chart (International Commission on Stratigraphy, 2012). Bedrock age codes (not the geotimes) are displayed alphabetically in the GSWA Code Builder. In order to keep bedrock age codes to a manageable level, only Eons, Eras, and some Periods and Epochs are used to define ages in bedrock codes.

Letters for bedrock age codes are consistent with international conventions (e.g. K for Cretaceous), although they also take into account usage by other Australian States and Territories (e.g. G for Paleogene). Some selections are designed to preserve the 'look' of codes as traditionally represented on hardcopy maps; for example 'E' for Cambrian resembles the character Є on hardcopy maps, avoids clashes with 'C' for Carboniferous, and is shorter than 'CM'. A combination of relevant letters is used for age codes that span different geotimes (e.g. JK for a Jurassic to Cretaceous age). For the Precambrian, codes have been provided for individual eras (e.g. P_M for Mesoproterozoic), although the use of these codes is deliberately limited on GSWA layers and maps. This is to avoid generating codes that are too unwieldy for display, and takes into account the fact that age boundaries in the Precambrian are not yet as well defined as for the Phanerozoic. More specific ages in millions of years (Ma) are also entered in the Explanatory Notes database for the corresponding lithostratigraphic units.

Stratigraphy in bedrock codes

The stratigraphic component of bedrock codes is used when a unit can be defined, for example, as a formation, group, or suite with a formally allocated name, or is part of (a child to) a formally named unit. The definition and naming of formal lithostratigraphic units at GSWA follows the internationally accepted conventions set out in the International Stratigraphic Guide (Salvado, 1994), an abridged version of which is available at <http://www.stratigraphy.org/column.php?id=Stratigraphic Guide>. Guidelines for formally defining and naming igneous units are also followed (Brakel, 2003); see also <http://www.ga.gov.au/products-services/data-applications/reference-databases/stratigraphic-units/igneous-unit-definition.html>).

Geoscience Australia is the custodian of stratigraphic names in Australia, on behalf of the Australian Stratigraphy Commission, which has a Western Australian Subcommission. All formally named lithostratigraphic units used by GSWA must have a status of at least 'reserved' in the Australian Stratigraphic Units Database (<http://www.ga.gov.au/products-services/data-applications/reference-databases/stratigraphic-units.html>), and will eventually attain 'formal' status as they are published and defined.

The stratigraphic component of bedrock codes is a combination of two to four characters, mostly upper and lower case letters; an 'underscore' and numbers are allowed for specific types of units only. A stratigraphic code always starts with either an upper case letter or an underscore, never with a lower case letter or a number. A full listing of the permitted letter combinations for the stratigraphic code component is given in Table 3. Note that sedimentary and igneous intrusive units (and metamorphosed equivalents) are coded according to two different schemes in deference to the different stratigraphic classifications for these types of rocks; although volcanic units can follow either scheme, most volcanic rocks in WA are coded using the stratigraphic scheme/ranking used for sedimentary rocks. The list below summarizes the main features of code structures:

- Two upper case letters are used to indicate a Group or a Supergroup, or their intrusive equivalents, Suites or Supersuites (Table 3). A third upper case letter is added for a subgroup or when a suite is part of a supersuite (there is no subgroup equivalent for igneous intrusive units).
- For sedimentary and volcanic successions, the two upper case letters can be followed by one or two lower case letters to define a formation and a formation with a formal member, respectively.
- For intrusive successions, a 'formation' within a suite/supersuite is coded with two upper case letters followed by two lower case letters — this is because some suites/supersuites have more than 26 'formation'-ranked formal units. If a formal member is present within the 'formation', the second lower case letter is modified.
- A formal formation not assigned to a group/supergroup or suite/supersuite is coded by using an underscore followed by two lower case letters; if a formal member is present, the second letter is modified.
- In the GSWA scheme, formation names are capitalized to emphasize the fact that formations are the fundamental building blocks of any stratigraphic scheme; i.e. no other formal stratigraphic units can be defined before a formation is formally recognized.

To prevent codes becoming too unwieldy, not all formal stratigraphic components are listed in a code. As a general rule, preference is given to the unit with the most 'significant' stratigraphic ranking, or to give the most precise code. For example, the code 'A-POw-' for the Archean Wilgie Mia Formation indicates that the formation is part of the Polelle Group, but not that this in turn belongs to the Murchison Supergroup — the preference is given to representing the group, as there is more than one group within a single supergroup. Similarly, subgroups are one of the least commonly defined formal stratigraphic units, and are therefore seldom represented

Table 2. Geotimes and age boundaries for bedrock age code components

GeoTimeName	*TimeRankName*	*OldBound*	*YngBound*	*CodeLabel*
Archean	Eon	4000	2500	A
Archean-Proterozoic	Era	4000	541	AP_
Cambrian	Period	541	485.4	E
Cambrian-Ordovician	Period	541	443.4	EO
Carboniferous	Period	358.9	298.9	C
Carboniferous-Permian	Period	358.9	252.2	CP
Cenozoic	Era	66	0	CZ
Cretaceous	Period	145	66	K
Cryogenian	Period	850	635	P_C
Devonian	Period	419.2	358.9	D
Devonian-Carboniferous	Period	419.2	298.9	DC
Ediacaran	Period	635	541	P_D
Ediacaran-Cambrian	Period	635	485.4	P_DE
Eoarchean	Era	4000	3600	AE
Eocene	Epoch	56	33.9	GE
Holocene	Epoch	0.0117	0	QH
Jurassic	Period	201.3	145	J
Jurassic-Cretaceous	Period	201.3	66	JK
Mesoarchean	Era	3200	2800	AM
Mesoproterozoic	Era	1600	1000	P_M
Mesoproterozoic-Neoproterozoic	Era	1600	541	P_MN
Mesozoic	Era	252.2	66	MZ
Miocene	Epoch	23.03	5.333	NM
Neoarchean	Era	2800	2500	AN
Neogene	Period	23.03	2.588	N
Neogene-Quaternary	Period	23.03	0	NQ
Neoproterozoic	Era	1000	541	P_N
Oligocene	Epoch	33.9	23.03	GO
Ordovician	Period	485.4	443.4	O
Ordovician-Silurian	Period	485.4	419.2	OS
Paleoarchean	Era	3600	3200	AP
Paleocene	Epoch	66	56	GP
Paleogene	Period	66	23.03	G
Paleogene-Neogene	Period	66	2.588	GN
Paleoproterozoic	Era	2500	1600	P_P
Paleoproterozoic-Mesoproterozoic	Era	2500	1000	P_PM
Paleozoic	Era	541	252.2	PZ
Permian	Period	298.9	252.2	P
Phanerozoic	Eon	541	0	IP
Pleistocene	Epoch	2.588	0.0117	QP
Pliocene	Epoch	5.333	2.588	NP
Proterozoic	Eon	2500	541	P_
Proterozoic-Cambrian	Period	2500	485.4	P_E
Proterozoic-Phanerozoic	Eon	2500	0	P_IP
Quaternary	Period	2.588	0	Q
Silurian	Period	443.4	419.2	S
Silurian-Devonian	Period	443.4	358.9	SD
Triassic	Period	252.2	201.3	R
Triassic-Jurassic	Period	252.2	145	RJ

All ages listed are in millions of years (Ma).

Table 3. Stratigraphic code structures in GSWA digital products

Sedimentary and volcanic units and metamorphosed equivalents		*Igneous intrusive units and metamorphosed equivalents*	
Supergroup, no lower ranking units	A-SS-llll	A-SS-llll	Supersuite, no lower ranking units
Supergroup, Formation, no group	A-SSf-llll	A-SSff-llll	Supersuite, 'Formation', no suite
Supergroup, Formation, Member, no group	A-SSfm-llll	A-SSfm-llll	Supersuite, 'Formation', Member, no suite
(Supergroup), Group, no subgroup and/or formation	A-GG-llll	A-SST-llll	Supersuite, Suite, no 'formation'
(Supergroup), Group, Formation	A-GGf-llll	A-SSff-llll	Supersuite, (Suite), 'Formation'
No equivalent	-	A-SSfm-llll	Supersuite, (Suite), 'Formation', Member
Group, no lower ranking units	A-GG-llll	A-TT-llll	Suite, no supersuite, no 'formation'
Group, Subgroup, no formation	A-GGB-llll	-	No equivalent
Group, (Subgroup), Formation	A-GGf-llll	-	No equivalent
Group, (Subgroup), Formation, Member	A-GGfm-llll	-	No equivalent
Subgroup, no Group — combination not possible	-	-	No equivalent
Group, Formation	A-GGf-llll	A-TTff-llll	Suite, 'Formation', no supersuite
Group, Formation, Member	A-GGfm-llll	A-TTfm-llll	Suite, 'Formation', Member
Formation, no Group	A-_ff-llll	A-_ff-llll	'Formation', no higher ranking units
Formation, Member, no higher ranking units	A-_fm-llll	A-_fm-llll	'Formation', Member, no higher ranking units

Stratigraphic ranks in parentheses, e.g. (Subgroup), indicate stratigraphic components not represented in the code.

Age code = A
Group = GG
Subgroup = B
Formation = ff or f
Member = m
Lithology code= llll

Age code=A
Suite = TT
No equivalent
'Formation' = ff or f
Member/phase = m
Lithology code = llll

in a stratigraphic code. For igneous intrusive units, when a 'formation' is part of a suite that is assigned to a supersuite, only the supersuite and the formation are represented in the code (not the suite), because 'supersuite' is the encompassing unit for igneous rocks formed during the same magmatic event. All stratigraphic relationships are an integral part of the Explanatory Notes database and the full stratigraphic tree can always be retrieved from this system.

The combination of Age code + Stratigraphy code must be unique in WA, and cannot be matched against different lithostratigraphic unit names. For example, the code 'A-WAa-' can only be used for the Archean 'Apex Basalt' formation of the Warrawoona Group and no other Archean stratigraphic units can have the code combination 'A-WAa-'. However, the same stratigraphic codes can be used for units of different age. For example, the stratigraphic code '_bo' is used for both the Proterozoic Boondawari Formation (P_-_bo-sepg) and the Quaternary Bossut Formation (Q-_bo-kla). In order to preserve this important facet of the GSWA coding system in the GSWA Code Builder, the Age component is automatically reset to the correct geotime and Age code when a Stratigraphy code/unit is selected in Code Builder, if the two components do not match in lookup tables. Note that in the drop-down list of Stratigraphy codes only, the user has to click separately on identical listings to see what stratigraphic units and corresponding ages the codes refer to. As stratigraphic names are not filtered by age, users can view all stratigraphic names currently in the Explanatory Notes database. Names and units are continually being added, and updated lists of WA stratigraphic names will be included with ongoing releases of the GSWA Code Builder application.

The code building module within the ENS has been designed to allow some flexibility where required:

- Regolith units with formal lithostratigraphic names can be given bedrock-style codes to allow the formal name to be incorporated in the code; e.g. the Nadarra Limestone, a ?Pliocene lacustrine unit, is coded NP-_na-klul and the Miocene-aged Robe Pisolite is NM-_rb-cip.
- Use of numbers in the stratigraphic codes is permitted to define different depositional packages (e.g. 'P_-MEP1-' for the Proterozoic 'Edmund Group, Depositional package 1'), or as a preliminary subdivision of units into younger and older components (e.g. 'P_-WKg1-' and 'P_-WKg2-' for different phases of the Proterozoic Giles Suite). Codes from these examples contain a stratigraphic component, although the units they refer to have an informal status in the Explanatory Notes database, as they are informal groupings of named units or subdivisions of formal units.
- Some 'semiformal' lithostratigraphic units such as zones within igneous layered complexes are also given

a stratigraphic code component (e.g. the middle zone of the Windimurra Igneous Complex in the Archean Annean Supersuite is coded 'A-ANwm-') or informal divisions of groups (e.g. the lower Byro Group, 'P-BYL-', comprising the Coyrie Formation and Mallens Sandstone); these units are given an informal status in the Explanatory Notes database.

Extension and rationalization of GSWA map units and codes for 1:500 000 and 1:2 500 000-scale seamless map layers for Western Australia is currently in progress. This will enable the assembly of a new State map and ensure full compliance with the more rigorous code-generation process within the Explanatory Notes database. The lithostratigraphic framework for different areas of the State where GSWA is working is also continually re-assessed as mapping proceeds and datasets and geochronology are acquired or extended. Therefore, the list of names and codes provided in the GSWA Code Builder represents by necessity a snapshot of stratigraphic units current at the time of release of the application.

Lithology in bedrock codes

Since 2000, GSWA has developed and thoroughly tested a rock classification scheme that provides a consistent approach to lithological nomenclature for all units within Western Australia (Tyler et al., 2004). The scheme is applicable within all tectonic units and geological settings throughout the geological column, which in Western Australia extends back to the Eoarchean. The minimal adjustments and additions that have been required since the scheme was first introduced testify to its robustness and completeness.

As GSWA is a field-based organization, sedimentary, igneous, and metamorphic rocks are classified using objective criteria observable in rocks at outcrop, hand specimen, or thin-section scale. The scheme introduced by GSWA conforms to internationally recognized classification schemes or follows well-established principles where such schemes are unavailable (e.g. for sedimentary rocks). Nomenclature for igneous rocks follows the IUGS recommendations (le Maitre, 2002), although with a more descriptive rather than genetic approach to the classification of volcanic rocks, and a more restricted definition for pyroclastic rocks. For metamorphic rocks, GSWA follows the classification of Fettes and Desmons (2007), which ratifies the recommendations of the IUGS Subcommission on the Systematics of Metamorphic Rocks (Schmid et al., 2007), with structural terms following Brodie et al. (2007). More specific details on the background to the GSWA rock classification scheme can be found in Tyler et al. (2004).

A four-tier, hierarchical rock classification scheme is used to define lithologies in the GSWA rock classification scheme and Code Builder. In brief, lithological codes are never more than four letters long, with a rock type selected first, followed by a lithological name and one or two qualifiers. Mixed and xenolith/inclusion bearing rocks are coded by allowing a second set of four letters to identify a second component. The selection of a lithology component is mandatory for all GSWA lithostratigraphic units, and the GSWA Code Builder will not allow a code to be generated until a rock type has been selected.

Tier 1 — Rock type

At the highest level, a rock type is defined by subdivisions of the three main rock groups (igneous, sedimentary, and metamorphic), based on mineralogy (e.g. igneous extrusive/volcanic and intrusive rocks are classified as mafic, ultramafic, felsic, and so on) or depositional processes (sedimentary rocks are divided into siliciclastic, carbonate, and other chemical or biochemical). Metamorphic equivalents are distinguished on the same basis, with additions to cover for metasomatic rocks and metamorphic rocks for which a protolith cannot be identified; the latter are subdivided into schist, gneiss, granofels/hornfels, fault rock, and impactite.

Non-metamorphic rocks types are coded with a single intuitive letter (e.g. 'g' for granitic rocks or 'u' for igneous ultramafic volcanic rocks) that wherever possible matches those traditionally used on GSWA map products. Codes for metamorphic rock types always start with 'm', followed by a second letter that is, wherever possible, the same as for non-metamorphosed rocks (e.g. 'mg' for meta-igneous felsic intrusive, i.e. metagranitic, and 'mu' for meta-igneous ultramafic volcanic rocks). A notable exception to this is metasedimentary siliciclastic rocks, which are subdivided into a number of different types (e.g. ml for pelite, mt for psammite, and mx for psephite).

Rocks that are only weakly metamorphosed (greenschist facies or below) can be coded by using a non-metamorphic rock code, provided the word 'metamorphosed' is added at the end of the legend narrative that accompanies the bedrock code in the Explanatory Notes database. This practice is consistent with GSWA's field-based approach to classification, and is permitted for those units that are separated during mapping on the basis of primary features (e.g. pillowed basalts, polymictic conglomerate). Rocks that are described as deformed (e.g. foliated, schistose), as containing metamorphic mineral phases (e.g. garnet, staurolite), or by using metamorphic lithological names (e.g. schist, amphibolite, migmatite), must be represented by a metamorphic code.

Tier 2 — Lithological name

At the second level, a lithological name is selected, with automatic filtering based on the rock type already chosen. Lithological names (or 'Lithname' in the Code Builder interface, for brevity) in the GSWA rock classification scheme follow international classification, with subdivisions based on several parameters, such as:

- Composition, e.g. carbonate rocks
- Grain size, e.g. siliciclastic rocks
- Modal mineralogy, e.g. igneous volcanic and intrusive rocks
- Mineralogy and geometry, e.g. hydrothermal rocks.

The Lithname fields for some rock types are also populated with entries designed to accommodate more specific needs for Western Australia geological mapping. For example, hydrothermal lithnames include hydrothermal chert and an array of vein types distinguished by their mineralogy. For more details on lithological names used in GSWA's classification scheme, refer to Tyler et al. (2004).

Lithname codes follow the general rules:

- For non-metamorphic rocks, a letter is added to the 'rock type' code; e.g. 'm' is added to 'g' to generate the two-letter code 'gm' for monzogranite.
- For metamorphic rocks, an identical approach is used; e.g. 'm' is added to 'mg' to generate the three-letter code 'mgm' for metamonzogranite.
- In addition to common lithnames (e.g. metabasalt, pelite), metamorphic lithnames include more general terms to describe schist, gneiss, and granofels/hornfels derived from the rock type selected. Also, metamorphic lithnames include more general categories to describe silicified and mylonitized lithologies under the selected rock type.
- Note that in the GSWA Code Builder the codes displayed for lithnames is always inclusive of the letter(s) that define the corresponding rock type, although these are not duplicated in the code. So 'g' can be selected for a granitic rock type, and 'gm' for a monzogranite, but the resulting lithological code is simply 'gm' (and not 'ggm').

Tier 3 — Qualifier 1

At the third level, a qualifier can be added to a preselected lithological name to further describe the unit mapped. Volcanic, igneous, and sedimentary rocks each have their own set of letter qualifiers, up to a maximum of 26. It is left to the user's geological knowledge not to combine qualifiers and lithnames that are geologically incompatible. For metamorphic rock types, most lithnames already have three letters in the code, so only one Qualifier code is selectable (in the Qualifier 2 field). For metamorphic lithnames consisting of two letters only (e.g. 'mg' for 'metagranitic rock'), the selection of either Qualifier 1 or 2 is blocked for two reasons: (i) these are the broadest of lithnames categories, and a geologist should be able to better characterize the lithological type before further qualifying it; and (ii) this practice is necessary to avoid generating codes that use the same combination of letters to describe different lithologies.

Tier 4 — Qualifier 2

At the fourth level, a qualifier can be selected for both non-metamorphic (following the preselection of a Qualifier 1) and metamorphic lithological codes (following the preselection of a Lithname code consisting of three letters). To allow maximum flexibility, for igneous and metamorphic rocks types, many qualifiers are repeated in the lists for Qualifier 1 and Qualifier 2; however, the system prevents the selection of the same qualifier twice. Note that for igneous intrusive rock types, grain sizes can only be selected as Qualifier 1. All three divisions of sedimentary rocks make use of the same set of environmental qualifiers once they have been initially qualified based on composition, grain size, and/or texture.

More than ten thousand combinations of Rock type, Lithname, Qualifier 1, and Qualifier 2 can be generated through the GSWA Code Builder. In the compilation of the lithological codes, as much care as possible has been taken to avoid being able to select the same sequence of letters from a combination of different qualifiers. The reader is reminded that in addition to the GSWA Code Builder, users of GSWA digital map layers can always refer to the lookup tables provided in the GSWA digital packages for an explanation of individual lithological codes (select the [More details] hyperlink displayed in GeoMap.WA when interrogating geological polygons or lines). The user can also consult the geol_lut.mdb file in the DATABASES folder of the GSWA digital packages.

'Mixed' and 'Xenolith/Inclusion Bearing' lithologies

The GSWA bedrock classification scheme allows for coding of mixed and inclusion- or xenolith-bearing rock types, as these are in places significant or necessary mappable units. Under the field for Mixed Rock type in the [Bedrock] tab, an 'x' prefix to the lithological component of the code marks a mixed rock type. Two lithological bedrock codes are then entered in order of importance, separated by a hyphen. Thus, 'xmb-g' can represent intrusion of granitic rocks into meta-igneous mafic volcanic rocks, 'xmba-mgs' the tectonic interleaving of amphibolite and granitic schist, and 'xk-u' the intercalation of carbonate and ultramafic rocks. Note that a mixture of lithologies within individual rock types where no single lithology is predominant is best dealt with within each classification scheme by creating an appropriate code, if necessary. For example, within the 'sedimentary siliciclastic' classification, siltstone/mudstone would appear as 'sl', interbedded sandstone and siltstone as 'ss', siliciclastic and lesser carbonate as 'sk', without the need for 'x' (mixed) codes.

The same coding principle is used when a mappable unit has significant inclusions or xenoliths (a common occurrence in granite–greenstone terrains and orogenic belts). A 'j' prefixes the main lithology, and the second lithology describes the nature of the inclusions/xenoliths. For example, 'jg-b' represents a granitic rock with mafic volcanic xenoliths, whereas 'jo-g' is used for a gabbro with granitic xenoliths.

If there are two formally named units, one of which is present as inclusions/xenoliths in the other, the stratigraphic component of the host rock is placed in the code, and the name of the unit present as inclusions/xenoliths is given in the legend narrative. For example, the Petroglyph Gneiss unit coded 'A-TApe-xmgtn-mggb' is described in ENS as 'Tonalitic orthogneiss, with sheets of homogeneous grey metagranodiorite (Kavir Granodiorite)

and leucogranite'. A similar approach can be used for tectonically interleaved formal units; the stratigraphic code used should be that of the volumetrically more abundant unit.

Tectonic unit in bedrock codes

Tectonic Unit Code components are appended to GSWA bedrock codes when a lithostratigraphic unit is not stratigraphically assigned (i.e. a unit cannot be ranked as a group, formation, and so on, with a formally defined name) but its association with a tectonic unit is proven. In the ENS, GSWA retains the basic grouping of tectonic units into basins, cratons, and orogens, with some modifications to accommodate the improved understanding of Western Australia tectonic evolution through time (Tyler and Hocking, 2002). For example, GSWA recognizes 'special' tectonic units that may cross tectonic boundaries, such as large igneous provinces and dyke swarms, as well as litho-tectonic units such as greenstone belts.

The tectonic unit component of bedrock codes consists of up to five upper case letters. High-ranking tectonic units are usually coded with one or two letters, with further subdivisions commonly defined by adding extra letters to the code. For example, the Yilgarn Craton is coded 'Y', and its main subdivisions are coded 'YYO' — Youanmi Terrane, 'YEG' — Eastern Goldfields Superterrane, and YNA — Narryer Terrane. Tectonic codes are unique within Western Australia, and the corresponding units are listed alphabetically by name in the GSWA Code Builder.

Tectonic units are modified (and even abandoned) as mapping and understanding progresses. A State-wide re-evaluation is in progress to assemble seamless, attributed, reference spatial layers at 1:500 000 and 1:2 500 000 scales. In parallel, the establishment of the Explanatory Notes database is allowing much more rigorous controls on the creation of tectonic unit codes. As a result, the listing provided in the GSWA Code Builder might not contain a complete or current set of tectonic unit names and codes for Western Australia. The date of extraction of lithostratigraphic and tectonic tables is shown in the [About] pane in parentheses immediately following the GSWA Code Builder version number.

Digital vs hardcopy bedrock code styles

Bedrock codes for digital map layers are converted to hardcopy map codes by using specific fonts and removing hyphens wherever possible. Hyphens are preserved only where they are needed to avoid possible confusion between different components of the code. The conversion adheres to the following steps:

- **Age codes**: These are converted to unique symbols using specific font sets. For example, 'E' for Cambrian is converted to the familiar ticked C (Ȼ), and 'P_' is converted to the Proterozoic character Ᵽ.
- **Stratigraphy codes**: Upper case letters are converted to small capitals; lower case letters are left unchanged. The hyphen between Age and Stratigraphy codes is removed unless Age and Stratigraphy codes finish and start with a lower case letter, respectively.
- **Lithname codes**: Left as lower case letters. The hyphen between Stratigraphy and Lithnames is removed only when there are no lower case letters in the Stratigraphy part. For mixed and xenolith-bearing codes, the hyphen between the two Lithname components is always preserved.
- **Tectonic Unit codes**: Left as upper case letters. The hyphen between Lithname and Tectonic Unit code components is always removed.

Table 4 provides some examples of code conversion between database and hardcopy map codes.

GSWA regolith codes

The current GSWA regolith classification scheme and the construction of regolith codes on GSWA digital layers and maps are detailed in GSWA Record 2013/7 (GSWA, 2013). This document re-evaluates the classification of regolith set out in GSWA Records 2001/4 (Hocking et al., 2001) and 2007/8 (Hocking et al., 2007). The approach to the classification of regolith in GSWA aims to be 'uniform, comprehensive, flexible, and reasonably intuitive' (Hocking et al., 2001). It uses a hierarchical approach, from the highest level landform setting and process, down to regolith composition, and then parent rock type or cement. The scheme allows the creation of detailed map unit codes that can be 'rolled up' to a higher level for use at progressively smaller map scales.

For entry into a GSWA digital layer, regolith codes are prefixed by an underscore ('_'). This allows immediate distinction from bedrock codes, and alerts cartographers to the need for a different procedure during conversion to hardcopy map codes (refer to the section 'Digital vs hardcopy regolith code styles', below).

Regolith codes consist of three components:

- Landform (primary code)
- Regolith composition (secondary code)
- Parent rock or cement type (tertiary code).

Primary codes are always upper case letters; secondary and tertiary codes always lower case. Each code component is separated by a hyphen. Each primary, secondary, and tertiary code may be immediately followed by a single lower case letter as a qualifier (i.e. qualifiers are never preceded by a hyphen). For example, in code _Rd-f-sg, the letters 'd' and 'g' qualify the primary and tertiary codes respectively.

Numbers are used to indicate relative ages or degree of consolidation, with 1 designating the youngest generation of regolith or the least consolidated. Numbers can qualify either a landform code (e.g. _R1r-f) or a landform

Table 4. Examples of code conversion from digital environment to hardcopy maps

	Database code	*Hardcopy map code*
Bedrock codes	A-WA-bb	AWAbb
	A-WKho-og	AWKho-og
	NM-_pi-sr	Nm-pi-sr
	P_-WYa-mh	PWYa-mh
	P-BY-sf	PBYsf
	P_-MEk-sl	PMEk-sl
	A-mgn-YEG	AmgnYEG
Regolith codes	_A1f-kd-k	$A1_f k_d k$
	_Ld2-eg-k	$L_d 2 e_g k$

qualifier (e.g. _Rr1-f); these links are mutually exclusive, which means only one number can be used in a regolith code. Based on current usage on GSWA maps, where no more than three generations of codes have ever been distinguished in regional regolith mapping, the GSWA Code Builder allows up to five generations of regolith.

Tables listing the full sets of primary, secondary, and tertiary regolith codes and associated qualifiers are part of GSWA Record 2013/7 (GSWA, 2013). The GSWA regolith classification scheme also recognizes three higher level primary regolith codes (K for coastal, D for depositional, and V for Valley), used for rolling-up regolith units in smaller scale maps; these are not displayed in the regolith Code Builder.

Digital vs hardcopy regolith code styles

Regolith digital codes are converted to hardcopy map codes by:

- Removing the initial underscore
- Converting all letters/number to italics, and a serif font
- Subscripting the second letter if qualifiers are present (i.e. if in the database code there are two consecutive letters not separated by hyphens)
- Never subscripting relative age numbers.

Examples of regolith code conversion from database to hardcopy styles are shown in Table 4.

Conclusions

A successful coding scheme for bedrock and regolith units has to be applicable within all tectonic components and geological settings, and throughout the geological column. The GSWA code systems have been thoroughly tested for over a decade, and have proven suitable for covering the large variety of rocks and regolith types found in Western Australia.

The GSWA Code Builder application is a guide to the construction and understanding of GSWA codes as used in digital products and map layers. It provides the geological community with a solid reference for and an explanation of rock and regolith codes used in current GSWA digital products, and allows exploration and mining companies to follow the GSWA scheme if desired.

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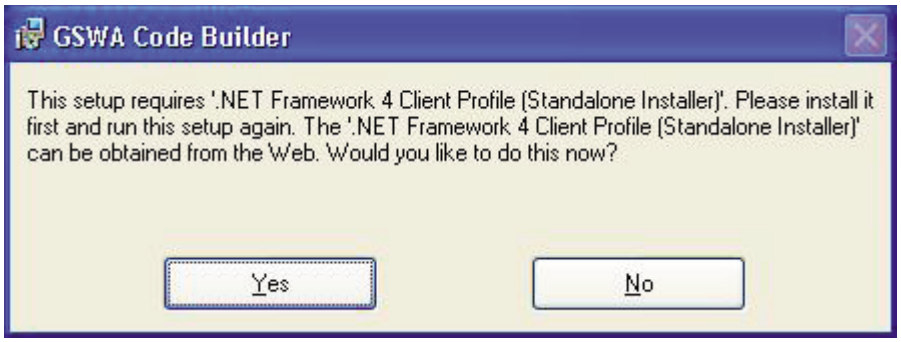
Appendix 1

GSWA Code Builder installation guide

Steps for installing the GSWA Code Builder application

The installation of this application is a single-stage process if the users have '.NET Framework 4 Client Profile (Standalone Installer)' already installed on their computer. If not, this must be installed before the GSWA Code Builder application.

1. Double click **GSWA Code Builder.msi**, the installation package for the Code Builder.
2. If .NET Framework 4 is not found on the computer, the prompt below will appear.



3. Clicking [No] will cancel the installation process.
4. If [Yes] is selected, the user is taken to the Microsoft page at <http://www.microsoft.com/en-au/download/details.aspx?id=24872>, and prompted to click on [DOWNLOAD], which starts the installation of the .NET framework.
5. This installation may take several minutes, and the user might be asked to restart the computer.
6. When .NET Framework 4 is installed, double click on **GSWA Code Builder.msi** again to install the GSWA Code Builder application.
7. At the end of the installation, a shortcut to the application will be placed on the Desktop and in the Programs menu, which can be accessed by clicking Start > Programs/All Programs > GSWA Code Builder > GSWA Code Builder.

Uninstalling GSWA Code Builder

This application can be uninstalled in two ways:

1. Go to Start > Programs/All Programs > GSWA Code Builder > Uninstall GSWA Code Builder.
2. Go to Start > Settings > Control Panel > Add or Remove Programs > GSWA Code Builder, and click [Remove].

Appendix 2

Technical specifications and software requirements

Updated August 2020

GSWA Code Builder is a standalone Microsoft Windows desktop application that can be installed onto a user's laptop, netbook, tablet or desktop computer.

Technical specification

Development environment	Microsoft Visual Studio 2010
Framework	Microsoft Dot net (.NET) Framework 4
Technology	Windows Presentation Foundation (WPF)
Language	C-Sharp (C#)

Software requirements

- Microsoft .NET Framework 4 Client Profile (Standalone Installer) or Microsoft .NET Framework 4.5 or higher
- Windows 8 or higher.

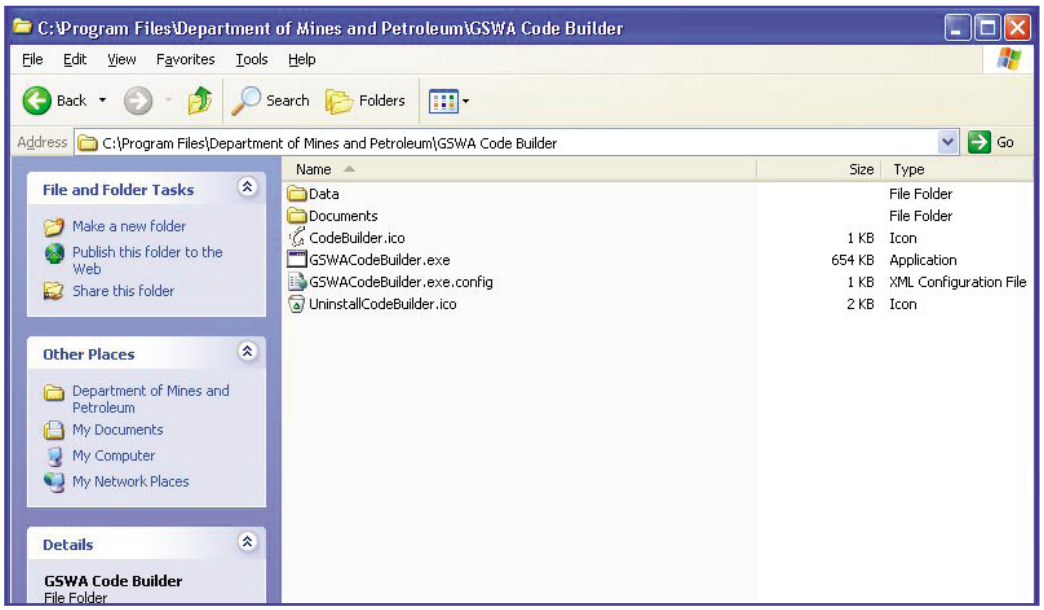
There are no minimum hardware requirements for this application to run. The application is designed with a window size of 1000 pixels (W) by 600 pixels (H) to enable viewing on a tablet device. It is best viewed with a screen resolution of 1920 pixels by 1080 pixels.

Appendix 3

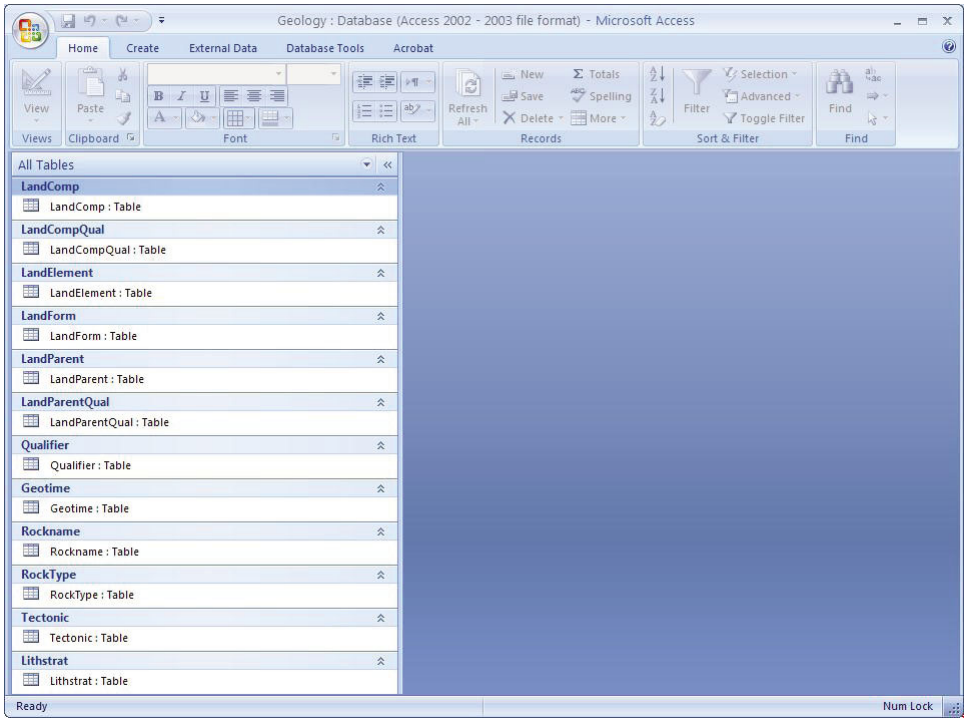
Customization of GSWA Code Builder application data

Users can add their own data to any of the supplied Microsoft Office Access database tables in order to build customized bedrock and regolith codes. This must be done in compliance with the Licence Agreement, which can be viewed under the [About] tab in the GSWA Code Builder application. Steps for users to insert additional entries in a table are outlined below.

1. When installing the application, the files listed in the screenshot below are loaded into the user's computer. Note that the location of the application might vary depending on the location the user selected while installing the application.



2. The Data folder contains a Microsoft Office Access database named **Geology.mdb**, shown below. Double click on this database file to open it (note that users must have Microsoft Office Access installed on their computers in order to open this file). This database contains the tables used in the GSWA Code Builder to generate bedrock and regolith codes.



3. The table below lists the field headings used in the [Bedrock] tab and [Regolith] tab next to the names of the tables from which field entries are sourced. Note there is no table for the Mixed Rock type field, as the two values for this field have been hard-coded in the application.

Bedrock codes	
Field name	*Table name*
Age	Geotime
Stratigraphy	Lithstrat
Rock type 1, Rock type 2	RockType
Lithname 1, Lithname 2	Rockname
1st Qualifier 1, 2nd Qualifier 1	Qualifier
1st Qualifier 2, 2nd Qualifier 2	Qualifier
Tectonic Unit Code	Tectonic
Regolith codes	
Field name	*Table name*
Landform	LandForm
Landform element	LandElement
Regolith composition	LandComp
Composition qualifier	LandCompQual
Parent rock or cement	LandParent
Parent rock/cement qualifier	LandParentQual

Customizing table entries

The following steps allow a user to customize table entries.

1. Navigate to the folder where the application is installed and click on 'GSWA Code Builder' folder. The default path is shown in the screenshot at the beginning of Appendix 3.
2. Double click on the Data folder.
3. Double click on the **Geology.mdb** file, which is a Microsoft Office Access database that contains all the tables used in the application to generate codes. This will open the Access database as shown above.
4. Open the desired table by double clicking on it and add the new data at the end of the table.
5. Save the changes.
6. Open the GSWA Code Builder application. The newly added data will be shown in the relevant field.

Note that if data are added that do not comply with the standards of GSWA DMP code constructions routines, customized entries will not be displayed in the application.

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GSWA Code Builder — constructing and unravelling GSWA geological codes

Riganti et al.

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