ALASKA GEMS GEOLOGIC MAPPING SYSTEM STATUS REPORT: JANUARY 1, 2016–JUNE 30, 2023

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INTRODUCTION

The Alaska Division of Geological & Geophysical Surveys (DGGS) produces and publishes numerous geologic maps each year. In the past, these maps were created and printed on paper; now these products are produced digitally with a Geographic Information System (GIS). As geologic map production transitioned to digital representations using GIS across the national geologic community, it became apparent that data standards were required. National legislation and funding were enacted in the Geologic Mapping Act of 1992 and its Reauthorizations. As a result, the U.S. Geological Survey (USGS) and the Association of American State Geologists (AASG, representing the state geological surveys) developed and published the Geologic Mapping Schema (GeMS; ngmdb.usgs.gov/Info/standards/GeMS/).

To meet Alaska's organizational and technical-based geologic mapping requirements, DGGS extended the GeMS standard and published the Alaska Geologic Mapping Schema (AK GeMS; Hendricks and others, 2021b). The geologic mapping requirements that this extension addresses include: integration with DGGS's already mature geologic feature database, ability to efficiently operate in a Linux-based computing and database infrastructure, modeling of multiple geologic layers within a map, heavy reliance on formalized picklists of attribute domains, and the ability to operate in a multi-map environment. AK GeMS was developed in such a way that we can export to GeMS without significant loss of essential information: this allows full integration into the National Geologic Map Database (NGMDB) GeMS Repository. The efficient production of high-quality, standards-based geologic maps, however, requires more than GIS software and a data standard—a comprehensive map and data production system is essential. An effective production system must address a wide range of related components that include data standards, symbology standards, and flexible field data collection methods, as well as rigorous quality assurance and quality control (QA/QC) procedures. These components must all be supported by dedicated and embedded IT and GIS support and built upon a robust IT architecture. In addition, these components must be integrated with quality documentation and well-known organizational processes supported by regular, first-rate training.

As a result of these requirements, DGGS developed the Alaska Geologic Mapping System. The Alaska Geologic Mapping System is comprised of several key components all working together to ensure that DGGS efficiently produces high-quality, standards-based geologic maps. These components consist of our published AK GeMS data and symbology standards, flexible field data collection support, custom geoprocessing tools and scripts, robust and efficient QA/QC procedures, centralized metadata creation, and an effective packaging, publishing, and sharing mechanism, along with well-documented organizational procedures and a robust training program.

This document describes the Alaska Geologic Mapping System developed and used by DGGS through June 30, 2023. It provides a history of our development process, an overview of the Alaska Geologic Mapping System, a description of our data and symbology standards, specifics of both the AK GeMS

single-map and AK GeMS multi-map implementations, an overview of our organizational procedures, and a description of how we package, publish, and share our geologic map information. This document is also a deliverable for USGS Cooperative Agreement award G21AC10712 and describes evaluation of the computing products and workflows developed, including results of database testing, observed weaknesses and strengths of the system, documentation of any optimizations suggested to increase performance, documentation of any progress to pursue those optimizations, and implications for the future NGMDB "Phase Three" large-scale geologic data management and delivery system.

Though we designed the AK GeMS Geologic Mapping System to support DGGS's Alaska-specific geologic mapping needs, we believe this system and its documentation are useful to others as well, as evidenced by the adaptation of parts of the system by other agencies and geologic community members. Beginning in 2016, DGGS's work on the mapping system was, in fact, partially funded by federal grants and cooperative agreements and conducted with the strategic goal of developing and documenting insights, methods, and tools that could be useful to other agencies. Examples of our success is this endeavor include:

- Developing, publishing, and reporting on a well-documented database schema extension is useful to other organizations, as they can see it is possible to deliver GeMS compliant databases while also addressing their organization's unique requirements.

- Organizations can learn from our attempts to support multiple layers within a GeMS database through our implementation of a layer field for database feature classes.

- Organizations can see how we support multiple maps within a GeMS compliant database.

- Our published symbology and associated style file are used by numerous organizations and is referenced in the creation of the USGS standard style.

- Organizations can learn from our efforts and experience storing and symbolizing: large volumes of data, multi-layered data, and multiple overlapping maps.

HISTORY

The current Alaska Geologic Mapping System is built upon a rich history of Alaska geologic mapping by both the USGS and DGGS. Alaska's earliest geologic maps were traditional hand-drafted maps created at the start of the twentieth century, primarily by the USGS. DGGS's predecessor, the Alaska Division of Mines and Minerals began geologic mapping in the 1960s.

By the turn of the century, digital representation, storage, and distribution of geologic data and maps were becoming more popular. DGGS Annual Reports from the early 2000s noted several digital-data-focused projects that helped build the foundation for the current Alaska Geologic Mapping System. The division's Scanning and Document Conversion Project, courtesy of federal funding under the Alaska Minerals Data and Information Rescue Program, began converting approximately 1,900 reports and 3,000 maps from paper to digital scanned files in .tiff and .pdf format (DGGS Staff, 2001). The division's web site made these products available online in 2000, after which work began on a searchable bibliographic database (DGGS Staff, 2001). This searchable database of map images and files went live in 2005, and GIS data became available in 2007 (DGGS Staff and Papp, 2005). At this time, DGGS also saw a marked increase in online activity as customers accessed the website for digital versions of publications (Athey and DGGS Staff, 2014; Athey, 2017).

As early as the 1990s, DGGS was generating geologic maps using GIS software (Davidson, 1998; Athey and DGGS Staff, 2011). Interestingly, the difficulties with data standards and metadata documentation were already identified in 2004. The 2004 Annual Report described a project to convert legacy

geologic map data to modern data standards as well as create Federal Geographic Data Committee (FGDC) metadata: "The documentation of those geospatial data sets has been neglected because of the geologists' need to initiate new mapping projects. This project is designed to go back through those legacy geospatial data sets and document and upgrade the existing data to modern formats and documentation practices" (DGGS Staff, 2005).

In 2000, DGGS began creating a geologic database system to "provide consistent data and information input, organization, and storage architecture" (DGGS Staff, 2001). This database was named Geologic and Earth Resource Information Library of Alaska (GERILA). By 2005, GERILA successfully evolved to become the primary clearinghouse for distributing Alaska's geologic data in digital formats both to internal users and to the general public (DGGS Staff and Papp, 2005; Seitz and others, 2024).

GERILA was developed to include location and geometry of spatially referenced information such as geologic sample locations, fault surface traces, areas covered by geologic maps, or surface exposures of geologic formations (DGGS Staff, 2005). As early as 2002, the division started planning for and providing the information necessary to make the data in GERILA available through NGMDB (ngmdb.usgs.gov/; DGGS Staff, 2002).

A modernized version of the GERILA database, running on a Linux-based PostgreSQL database, is still in use today and drives our publications and metadata distribution process (Hendricks and others, 2023; Seitz and others, 2024). It also stores all stations, samples, and map extents used to build web services and web apps, including the popular Map Index Web App (geoportal.dggs.dnr.alaska.gov/portal/apps/webappviewer/index.html?id=16376999425043e88343e5b76a05a549).

During the period of transition from hand-drawn maps to the current digital geologic map production system, there was mixed use between GIS software—whose traditional strength is spatial data storage and analysis—and high-end graphics programs, such as Adobe Illustrator. For many years, GIS software was incapable of easily producing high-quality final map products, and graphics software packages were unable to store and utilize robust spatial data models. The resulting mixed use of these two approaches created inefficiencies in the mapping process. Over time, as graphics and layout support increased with GIS software, DGGS transitioned to nearly exclusive use of Esri GIS software for its geologic mapping requirements.

In 2008, the State Geologist established a committee to review the process by which DGGS collects and publishes geologic data and to make recommendations to streamline the mapping process. An analysis of time spent completing common tasks showed that DGGS staff was overcommitted with projects and that the time necessary to facilitate publication needed to come from streamlining the publications process and hiring additional support staff (Athey and DGGS Staff, 2011). In 2010, a cartographer was hired to create map layouts and to manage, edit, and QC data. The addition of this position saved geologists significant time and enabled DGGS to begin implementing the USGS's FGDC Digital Cartographic Standard for Geologic Map Symbolization using ArcMap style files and representations (Gallagher, 2013; USGS, 2006).

In 2006, the USGS published the FGDC Digital Cartographic Standard for Geologic Map Symbolization (USGS, 2006). With the help of our newly hired GIS cartographer, DGGS quickly began implementing this standard using ArcMap style files and representations (Gallagher, 2013). Eventually the use of representation was abandoned and DGGS focused on developing, documenting, and publishing a robust ArcMap style file that referenced standard FGDC symbol codes (Ekberg and others, 2021). This ArcMap style has since been upgraded to an ArcPro-compatible style file. Our work on developing and publishing standards-based

symbology has been helpful to numerous organizations and was a critical reference when the USGS developed, though the efforts of the South Carolina Geological Survey, the ArcGIS Pro style implementation of FGDC Standard found on the GeMS Resource page, ngmdb.usgs.gov/Info/standards/GeMS/.

In addition to cartographic standardization, the USGS proposed a standard data format for geologic map publications led by the USGS National Cooperative Geologic Mapping Program in 2009 (originally named NCGMP09 and later renamed GeMS; USGS NCGMP, 2010, 2020). The design was a logical database schema to encode content analogous to that contained in a traditional geologic map. DGGS adopted the NCGMP09 schema as the division's geologic map database standard. This emphasis on map data fostered the notion that the spatial and non-spatial data associated with a map are important unto themselves and not just a way to draw a map. Implementing the new standard, however, was challenging. In 2013, DGGS initiated a major training program to transition from "do whatever works" to using the NCGMP09 standard (Gallagher, 2014). By the following year, DGGS began developing workflows for creating and publishing geologic maps using the NCGMP09 data standard (Gallagher, 2015).

In 2016, with endorsement from the NGMDB, DGGS engaged in preliminary development of an enterprise, multi-map database schema and computing infrastructure with three years of funding from the Environmental Protection Agency (EPA), Environmental Information Exchange Network (Athey and Hendricks, 2016; Athey and others, 2017, 2018, 2019, 2020). For the EPA-funded project, DGGS delivered a preliminary schema of the multi-map database, as well as a data dictionary, documentation of the ArcGIS Enterprise-PostgreSQL computing environment, and a pilot lightweight data-transfer schema (geologic feature service) for geologic polygons, contacts, and faults, with documentation.

In October 2019, DGGS began work under Cooperative Agreements with the NGMDB (2019–2022 award G19AC00411; 2021–2023 award G21AC10712) to develop a larger GeMS-based geologic GIS data creation and management process, of which the EPA deliverables (the multi-map database schema and geologic feature service) are components. Other elements include field-data collection, project-based working databases, databases of analytical and reference data, and a published map archive database (fig. 1). The AK GeMS data dictionary is available from Hendricks and others (2021b); a second version of the documentation and schema is in production. The ultimate goal of the NGMDB Cooperative Agreements was to scale up the GeMS standard to accommodate potentially thousands of geologic maps in a single spatial database and to define work-flows to facilitate population of the database as well as data transfer—these being significant challenges for implementation of NGMDB "Phase Three", a long-term federal program goal of providing public access to a comprehensive set of standardized geologic map data, and to facilitate its use for public and private decision making. Our work will hopefully be insightful as the national "Phase Three" database is implemented in the future.

To assist in the development process associated with these grants, from 2016 to 2022 DGGS initiated and led the Collaborative Database Effort for Geology (CDEFG) to develop a multi-map, multi-user database model for geologic data based on the single-map GeMS standard. DGGS coordinated technical input and guidance on the system by organizing regular meetings among colleagues and by maintaining an online resource (dggs.alaska.gov/gemswiki/). Representatives from state geologic surveys, the USGS, and Canada met monthly to discuss critical aspects of GeMS-based geologic mapping. As part of this effort, the CDEFG group identified specifications for an ideal multi-map database that was used to develop the multi-map database component of the Alaska Geologic Mapping System. For additional information, see the AK GeMS Multi-Map Database Repository section and appendix A.

Alaska DGGS Geologic Mapping System Components

Organizational Procedures

Tools

AK GeMS Data Dictionary

Alaska DGGS — Field Event Geodatabases

Mapping Process

Alaska DGGS — **AK GeMS Single Map** Production Geodatabases

Convert & Load

Alaska DGGS — **AK GeMS Multi Map** Geodatabase

In Final Development

Geologic Feature Services

Style

AK GeMS SYMBOLOGY

Quality Control

Data Reviewer Rules & Python Tools

Four Categories of Production
- New Mapping
- Conversions
- Digitizations
- Compilations

Print, pdf, & Rasterize

Cartographic Product

Geologic Map Image Services

Product Web Page

Export

Alaska DGGS — **AK GeMS Single Map** Geodatabase

Convert

USGS — **GeMS Single Map** Geodatabase

GeMS Validation

To USGS

AK GEMS DATA DICTIONARY: A DESCRIPTION OF THE AK GEMS DATABASE SCHEMA, MP 169
- Report
- Data Dictionary
- Entity-Relationship Diagram
- XML Workspace Document

AK GEMS SYMBOLOGY: A DESCRIPTION OF THE AK GEMS STYLE FILE, MP 167
- Report
- AK_GeMS_symbology_documentation_ver_1.xls (Excel)
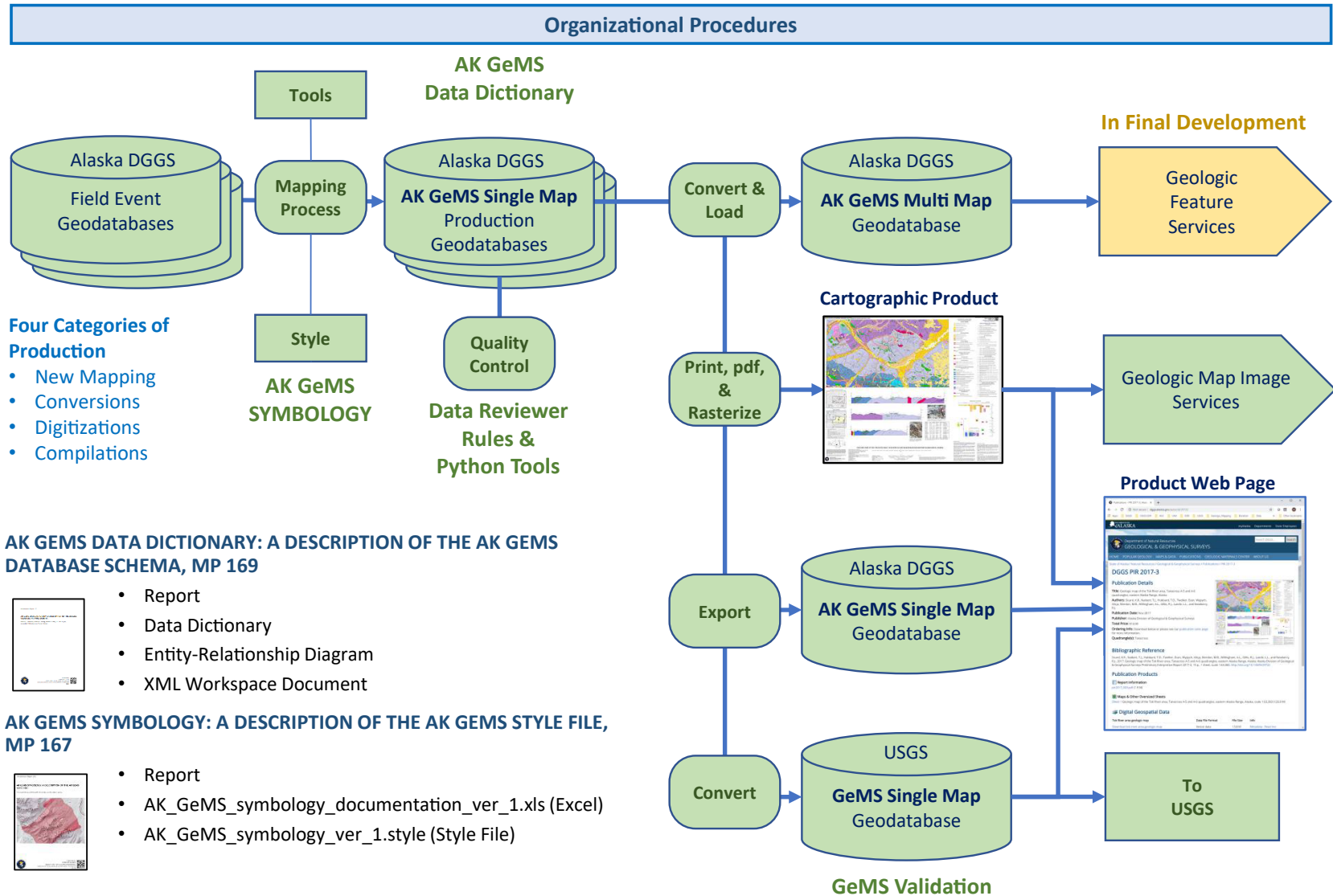- AK_GeMS_symbology_ver_1.style (Style File)

Figure 1. Alaska Geologic Mapping System conceptual architecture.

Throughout the development and growth of the Alaska Geologic Mapping System, DGGS has documented and presented on numerous related topics and maintains a web page highlighting content related to the AK GeMS project, including relevant publications, presentations, and posters: dggs.alaska.gov/pubs/project/1607.

ALASKA GEOLOGIC MAPPING SYSTEM OVERVIEW

The Alaska Geologic Mapping System controls the process of collecting, producing, converting, packaging, publishing, and sharing geologic map data. The cornerstone of this system is the Alaska Geologic Mapping Schema (AK GeMS), which was developed to meet Alaska's specific requirements. AK GeMS is an extension of GeMS, the national schema developed by the USGS and AASG, and was designed in such a way that data can be converted from AK GeMS to the more-generic GeMS format. This ensures that DGGS can deliver GeMS-compliant data when necessary.

The system's overall conceptual architecture addresses geologic map data management, as well as the critical organizational procedures required to ensure efficient map and data production (fig. 1).

Key Components

The Alaska Geologic Mapping System is built upon published data and symbology standards, primarily "AK GeMS Data Dictionary: A description of the AK GeMS Database Schema" (Hendricks and others, 2021b), which is an extension to the more-generic USGS published GeMS schema, and the symbology standard: "AK GeMS Symbology: A Description of the AK GeMS Style File" (Ekberg and others, 2021). The system supports four major categories of geologic mapping production: new mapping, conversions to AK GeMS from other digital data formats, digitizations (i.e., conversion of paper maps or map images to map databases), and more recently, compilations. During the mapping process, geologists heavily reference the published data dictionary and style file. See the GIS Data and Symbology Standards section for more information.

The collection of field data is a critical aspect of geologic mapping. The AK DGGS Geologic Mapping System does not define a specific field data collection schema or hardware setup to be used by all geologists. However, GIS staff assist field teams in creating field data collection schemas and collection methods that meet their needs while also ensuring that the collected data efficiently integrate into the AK GeMS data standard during the geologic mapping production process. To support large-scale, long-term field events without internet connectivity, DGGS has built and maintains a Field Portal (Nudson and others, 2022).

After field work starts and (or) is completed, geologic interpretation begins and the database is populated, after which the map is generated. The creation of a geologic map is a complex process that can take years, a time frame that our system and procedures take into account. Currently, the geologic mapping process is based on a single-map production paradigm, though experiments with the use of a centralized geologic map production database are being conducted. Note that this document discusses basic data and GIS procedures but does not address geologic and scientific interpretation issues.

DGGS has produced several geoprocessing tools, scripts, and calculations to support geologists in the mapping process (e.g., creating correctly attributed polygons from lines [contacts] and attributed points). To support single-map production, a Model Builder-based toolbox, as well as a Python toolbox, is now the primary development environment. In addition, two Python toolboxes support multi-map database efforts—a toolbox for users of the database, and a toolbox for multi-map database management. See appendix B for a list of geoprocessing tools, scripts, and calculations associated with the Alaska Geologic Mapping System.

In addition to providing symbology styles and geoprocessing tools to support the geologic mapping process, DGGS has placed a heavy emphasis on developing robust and efficient QA/QC procedures (see Quality Assurance [QA] and Quality Control [QC] Procedures section).

After a geologic map and its data are produced and approved for distribution, standards-based metadata are created (currently in FGDC-authored Content Standard for Digital Geospatial Metadata [CSDGM] format). DGGS maintains a centralized metadata production process with a single geologist responsible for metadata creation; database-level metadata files heavily reference the published database schema. Metadata for individual map products are provided as standalone files as well as embedded in the file geodatabase.

After metadata are created, we package, publish, and share data in multiple ways. Four of the most common are described below (for details on the various methods that are used to prepare and share geologic maps and data, see Packaging, Publishing, and Sharing section and Hendricks and others [2023]).

The most-fundamental method of sharing geologic map data is through the database-driven publication process, which results in a formal citation page that typically includes the following products: a report, a pdf map, metadata, and three data products. The data products are provided as: (1) a database package that contains, among other supporting items, a file geodatabase in AK GeMS format; (2) a database package similarly organized but with the more generic GeMS; and (3) shapefiles of the data in GeMS.

We also create, according to USGS specifications, a special database package for delivery to the USGS NGMDB GeMS Repository. The geologic data in this package are the same data that we publish publicly as described above. At times when grant deliverable requirements dictate, preliminary data are provided to the USGS prior to publication.

As a supporting product, we share the cartographic map as a raster map image via an image service, which provides users access to the static map image within their GIS or web map. We directly export the cartographic product from GIS, and the resulting raster images are stored as .tiff files, typically at 300 dpi, which results in an average raster cell size of ~30 meters at 1:63,360 scale. Each raster is added to a mosaic dataset that converts all rasters into the Albers equal-area projection. We maintain two image services, one with the collar information clipped and one with the collar information intact.

Another common method of sharing geologic map data is the AK GeMS multi-map database. The AK GeMS multi-map database is a repository of all AK GeMS single-map databases stored in a single, optimized PostgreSQL Enterprise Geodatabase. The single-map databases can be accessed internally from the enterprise geodatabase via ArcPro; web feature services to allow public access to these data are in development. For additional information, see the AK GeMS Multi-Map Database Repository section.

The final, and most important, component of the AK GeMS Geologic Mapping System is a set of well-defined and documented organizational procedures, the backbone of which is the AK GeMS production workflow. This framework ensures all parties involved with geologic map and data production efficiently complete their assigned tasks. This workflow is a 16-phase process that takes a map and its data from pre-publication though production, quality control, publication, and archiving. In addition, comprehensive production status monitoring is conducted. Underpinning all these processes are well-trained geologists and support staff; to address this critical need, we place a heavy emphasis on training. For details on DGGS's organizational processes see Organizational Procedures section.

Integrated Support Team and Computing Infrastructure

An integrated support team of IT, GIS, and publication staff is critical to ensure DGGS geologists and scientists can efficiently create professional geologic maps; the division's Geologic Information Center (GIC) provides many of these services (Hendricks and Papp, 2018; dggs.alaska.gov/about-us/gic-staff.html).

The AK GeMS Geologic Mapping System relies on a robust IT foundation comprised of a combination Linux- and Windows-based computing architecture. The division's file storage—PostgreSQL geodatabases, Enterprise Portal, and virtual machines—all run-on Linux servers. Our geologists and support personnel primarily operate on Windows desktop or laptop computers, though we have increased the use of virtual desktop machines to support remote workers manipulating large GIS files.

DGGS primarily uses the Esri ArcGIS software stack for most geologic mapping operations. We license the software and support services through an Esri Enterprise Site License managed by the Alaska Department of Natural Resources (DNR): Esri customer number two. In addition, we participate in the Esri Advantage Program, which provides additional training and support. We have successfully leveraged the Advantage Program in several ways while building our mapping system, including building a comprehensive QC process with the Data Reviewer extension, developing our multi-map enterprise geodatabase architecture, and providing instructor-based GIS trainings to DGGS employees.

The current Alaska Geologic Mapping System was originally developed with ArcMap desktop users in mind but has now transitioned to an almost exclusively ArcGIS Pro desktop environment. To store data related to most single-map projects, we use the Esri file geodatabase format. For larger geologic mapping projects, such as USGS-funded Earth Mapping Resources Initiative (Earth MRI) projects and select USGS National Cooperative Geologic Mapping Program's STATEMAP component projects, we stand up a dedicated Enterprise Geodatabase hosted on a PostgreSQL database. We also maintain an Enterprise Geodatabase for general GIS data support, as well as an additional set of PostgreSQL databases for our AK GeMS multi-map data.

Our primary GIS web sharing platform is an on-premises, hosted Enterprise ArcGIS Portal (geoportal.dggs.dnr.alaska.gov/portal/home/). We also maintain content on Alaska DNR's ArcGIS Online (AGOL) organizational site, where a select set of public content from our hosted Enterprise ArcGIS Portal is shared. DGGS is also in very early discussions with USGS Alaska Science Center and Esri on creating a data sharing Hub Site on Esri's cloud architecture for Alaska Geology.

GIS DATA AND SYMBOLOGY STANDARDS
AK GeMS Single-Map Data Standard

As geologists in Alaska began working with NCGMP09 and eventually GeMS standard, several additions to the GeMS schema were identified as important to DGGS. As a result, the decision was made to design an Alaska-specific geologic mapping schema in a way that we could add additional capability while still maintaining our ability to create map database exports in the standard GeMS format for delivery to the USGS.

In our design process, we created a list of key aspects of AK GeMS:

- Increased focus on modeling geologic features
- Capable of exporting to GeMS

- Capable of supporting both single-map geodatabases as well as the DGGS multi-map enterprise geodatabase (PostgreSQL)
- Supports multiple geologic layers (i.e., bedrock, surficial, others)
- Formalized picklists as attribute domains
- Controlled and defined glossary values (currently more than 400 terms)
- Well documented

AK GeMS organizes the feature classes and standalone tables into groups that include map units and boundaries, structure information, other geologic information, thematic points, and cartographic features (fig. 2). These feature classes and standalone tables include the required USGS GeMS classes as well as several custom feature classes and standalone tables to meet DGGS requirements (Hendricks and others, 2021b).

Changes in AK GeMS from the more-generic GeMS are as follows (Athey and others, 2020):

- Changed table and field names from PascalCase to snake_case to better support PostrgeSQL database requirements. For example, MapUnitPolys becomes map_unit_polys.
- Added the requirement to have a bounding polygon feature class product_info to store the boundary of the map as well as numerous product information attribute fields.
- The use of GUID values for nearly all IDs.
- data_sources_id field uses human readable in-line citation format, for example, "Athey, 1999."
- Added numerous fields to store supplementary feature descriptive information. Examples include:
  - product_id: Foreign key to product_info feature class. Unique identifier of the database product. Required for ingestion into the AK GeMS Multi-map Database. This is a GUID value.
  - category: A subdivision of logically associated geologic map features within a feature class; a category is typically further divided into one or more types as defined in the 'type' field. Categories are typically taken from the group heading in the FGDC Symbology Standard (USGS, 2006).
  - layer: An integer value indicating a feature's planar topologic layer. This field allows us to have multi-layered geologic data.
  - modifier: Identifies if this feature is modified in some way, such as hornfelsed, migmatite, etc.
  - distribution_policy: Flag indicating to whom and how this feature can be made available.
  - data_sources_method: The method the data source used in this database. Examples include "New feature based primarily on field mapping", "Feature unmodified from source material."
  - location_confidence_method: Identifies the method by which location confidence is assessed, e.g., "specified" defined as "the feature's location confidence is primarily identified with a numeric value provided by the geologist in the location_confidence_meters field."
  - group_id: Group features, such as faults, folds, map unit, etc., that get split because of attribute changes.
  - assoc_feature_id: The GUID of a feature from a different AK GeMS feature class with

AK GeMS Single-Map Schema Diagram

Cartographic features

cartographic_polys

cartographic_lines

cartographic_points

Thematic points

station_points

geochron_points

fossil_points

Combined 'map unit' and 'other' overlay polys

overlay_polys

iso_lines

includes 'generic points'

Other geologic Info

geologic_polys

geologic_lines

geologic_points

Structure info

structure_polys

structure_lines

orientation_points

☐ = DGGS GeMS addition

product_info

data_sources

data_source_polys

Map Units and their boundaries

contacts_and_faults

map_unit_polys

map_unit_lines

map_unit_points

descr map units table

glossary

Geomaterial dictionary table
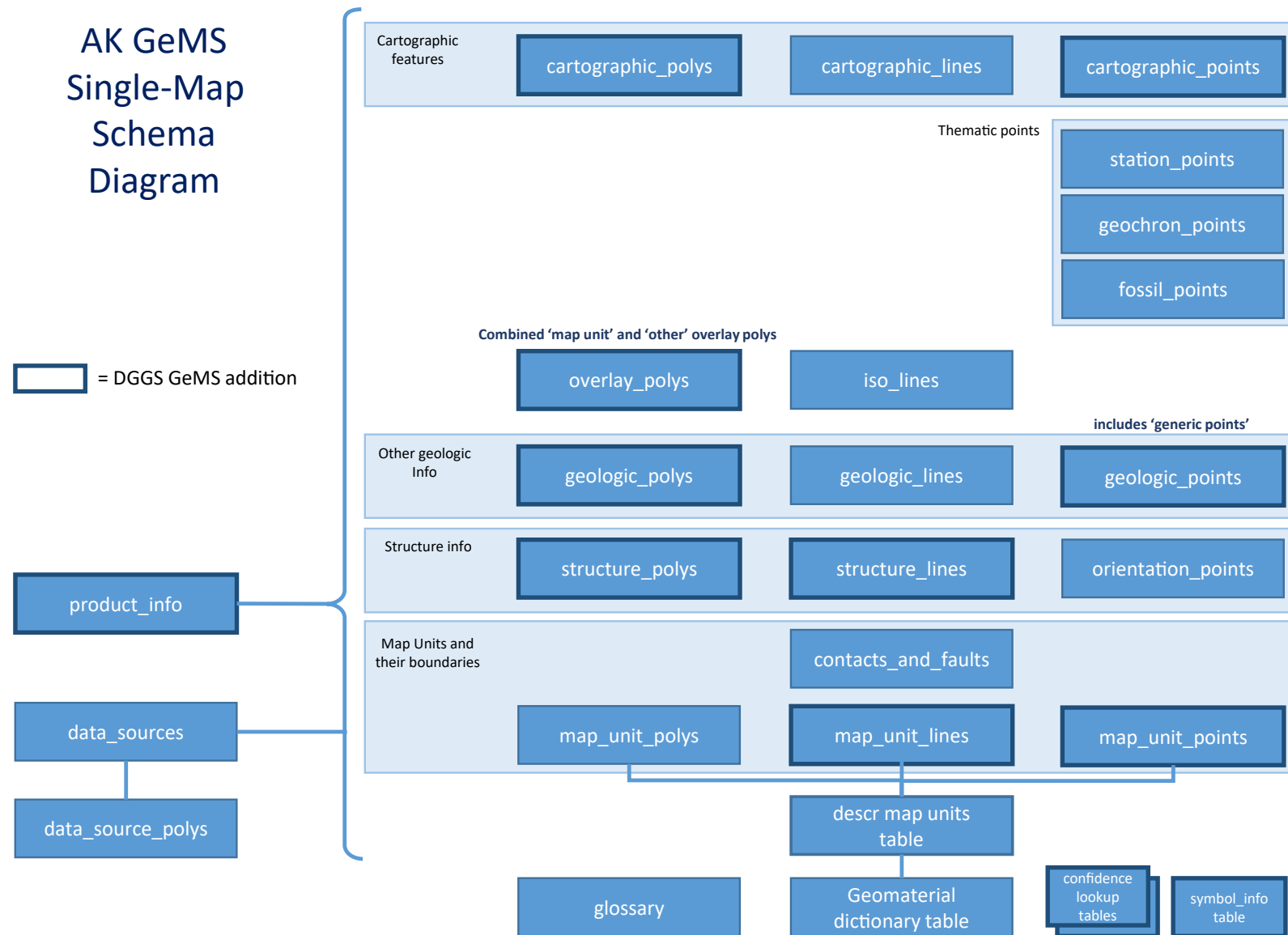
confidence lookup tables

symbol_info table

Figure 2. AK GeMS single-map schema diagram.

which a point feature, such as an orientation point, is associated.

- draw_policy: Controls if the feature is drawn on the map product.

- MapUnit information field split into map_unit_observed and map_unit_associated fields.

  - map_unit_assoc: The map unit in which this feature is located on map. This is typically the topmost map unit in a layered database.

  - map_unit_observed: The map unit observed in the field that is associated with this feature, e.g., an observation of a small igneous body within a larger map unit unmappable at the current map's scale.

Symbology Standards

The Alaska Geologic Mapping System also heavily relies on "AK GeMS Symbology: A Description of the AK GeMS Style File," our published symbology standard (Ekberg and others, 2021). This publication describes the organization and content of the current style file used by DGGS for the Alaska GeMS map production system. In this standard, we have identified the primary and optional FGDC symbols (USGS, 2006) for specific feature type values found within our established attribute domains. In addition, we have established procedures for requesting, creating, coding, and documenting custom symbols added to our style.

The AK GeMS symbolization philosophy is as follows:

- A feature's symbol code, stored in the symbol field, is part of a feature's representation hierarchy.

- Alaska DGGS phased out the use of "Esri representations."

- We do not use repurposed symbols—we make custom symbols with a new symbol code.

- We formalize and document the process of requesting, creating, and storing custom symbols.

- We attempt to always consider symbolization for single maps as well as online interactive multi-map representations.

The idea that a feature's symbol code is a part of the feature's representation hierarchy is a central concept for AK GeMS. The most-generalized level is the feature class that is chosen for storage, e.g., contacts_and_faults. The next level of detail is the category field that stores a subdivision of logically associated geologic map features, e.g., a feature in the contacts_and_faults feature class might be a *fault*. These category values are typically further divided into one or more types as defined in the type field, e.g., *fault, low angle.* Note that the category and type field for all feature classes have well-described attribute domains within AK GeMS. The next level of detail within a feature's representation hierarchy is the symbol field itself, e.g., a feature of type *fault, low angle* has a symbol value of 02.03.01 if its identity and existence is certain and its location is accurate. The final level of detail in our hierarchy is the symbol description for each symbol; a description such as "Low-angle fault (unknown or unspecified sense of slip)—Identity and existence certain, location accurate" is taken, when possible, directly from the FGDC symbol documentation (USGS, 2006).

Additional symbol related schema implementation components are:

- All feature classes have a symbol field, and the symbol code value must be found in our style file.

- All feature classes have a binary draw_policy field that controls if the feature is drawn on the

map product. PlotAtScale field is not included in AK GeMS. We assume a value of 0 (draw at all scales) for this field in GeMS submissions.

- A symbol_rotation field is included with feature classes geologic_points and cartographic_points. This field will be included in all point feature classes in future versions of AK GeMS.

- A symbol_alt field with select feature classes: orientation_points, contacts_and_faults. This allows better symbolization for multiple orientation observations at one locality and the ability to symbolize faults with custom point decorations.

- In the description_of_map_units table, the area_fill_pattern_description field is populated with, and only with, the FGDC pattern code: 101-K, 116-C, etc., that can be found in our style.

- A style field in the project_info table to store the version of style file used for the database when created.

AK GEMS SINGLE-MAP PRODUCTION

All geologic mapping at DGGS is now using the standard AK GeMS as defined by Hendricks and others (2021b). Currently, DGGS creates and converts geologic maps using the single-map geodatabase structure. This decision was made over five years ago for several reasons—the data schema was not firmly established at that time, and the ability to stand up a central GIS Enterprise geodatabase and train geologists in its use was unknown. Experiments with the use of a centralized geologic map production database are being conducted but will not be addressed in this report.

For each new geologic map in production or data conversion project, a separate AK GeMS geodatabase is created and used. In most cases this database is a File Geodatabase, stored in a well-defined network location. If it is determined that a map will be edited by more than one or two geologists, we create a project-based PostgreSQL geodatabase for that map to support multi-user editing.

For each geologic map starting its production process, a production meeting identifies three key roles: Lead Geologist, Data Lead, and Cartographer. These key responsibilities can all be handled by one experienced geologist, or more likely, GIC GIS staff take on the Data Lead and (or) Cartography responsibility. This flexibility allows the process to adjust to different experience levels and expectations.

To increase efficiency and decrease confusion, AK GeMS identifies when, who, and how each field within the database is populated. When: A field's value should be obtained and (or) filled out during fieldwork, interpretation, or publication preparation. Who: Either the geologist or data lead is identified as responsible for filling out each field. How: A field may be filled out by manually entering the data, picking from an attribute domain, or calculating it from another field.

When a geologic map is ready to move from production to the review phase, the geologist coordinates with GIC to formally begin the review process. GIC personnel coordinate peer reviews and oversee document revisions. The report, geologic map, and supporting data are then sent to the section chief and then division director for approval. When the map and report are approved, GIC staff archive the map production data, copy the data to the gems_pub_prep folder, and begin the data QC process. When QC is completed, metadata are created and the map and data are packaged, published, and shared (Hendricks and Macpherson, 2023).

AK GEMS MULTI-MAP DATABASE REPOSITORY

The AK GeMS multi-map database is a repository of AK GeMS single-map databases stored in a

single optimized PostgreSQL Enterprise Geodatabase. The DGGS AK GeMS multi-map database is just one of the many distribution methods of single-map AK GeMS data (fig. 1). The one aspect of the AK GeMS multi-map database that differs from these other data-release methods is that the database is not static, which allows DGGS to make future changes to ensure the best quality data are represented.

Differences between the Single-Map and Multi-Map AK GeMS Databases

The AK GeMS multi-map design is based on the AK GeMS single-map design but is optimized for large volumes of data as well as handling multiple geologic map products. The key differences from the AK GeMS single-map schema are as follows:

- The AK GeMS multi-map database is an Enterprise PostgreSQL Geodatabase hosted in a Linux environment.
- Attribute fields with defined attribute domains are integer-based to decrease storage and improve performance. AK GeMS single-map databases, on the other hand, employ string-based attribute domains, which geologists find to be easier to use during map production.
- The ID fields for each feature class and standalone table are true GUID type fields, as opposed to the AK GeMS single-map's string-based approach of using GUIDs.
- There is a single projection used for all data: Alaska Albers equal-area, NAD 83.
- Numerous relationship classes are built into the database.
- The product_info polygon feature class plays a much bigger role than in the single-map schema since by design there are many database products in the database.
- Several supporting standalone tables are created and maintained.
  - We have a standalone table named *nicknames* to store the geologic map's nickname, which is a short name associated with a database product. The concept of a nickname is currently not implemented in version 1.1 of AK GeMS, and as a result, to use this capability for map organization, this table is joined to the product_info feature class.
  - A *product_status* standalone table stores attributes describing the number of features/records each product has in each of the schema's tables and feature classes. This is used for internal analysis. A web feature service and associated dashboard showing this information are in development.
  - Multiple tables to support the many-to-many data sources relationship using the method pioneered by the USGS for the Seamless Integrated Geologic Mapping (SIGMa) Extension to GeMS (Turner and others, 2022).

AK GeMS Multi-Map Conceptual Architecture

The AK GeMS Mapping System developed, maintains, and continues to test and improve upon a robust conceptual architecture to support the system's multi-map database operations (fig. 3). The multi-map geodatabase's primary implementations are hosted on a Linux-based ArcGIS Enterprise PostgreSQL database. The primary components consist of the following databases:

- Test Multi-Map Database: This database is used for testing.
- Development (Dev) Multi-Map Database: Though this database is named Dev, it functions as the primary working multi-map database and stores both public and non-public (as defined in the distribution_policy field) data. Geologic map databases are loaded into this database
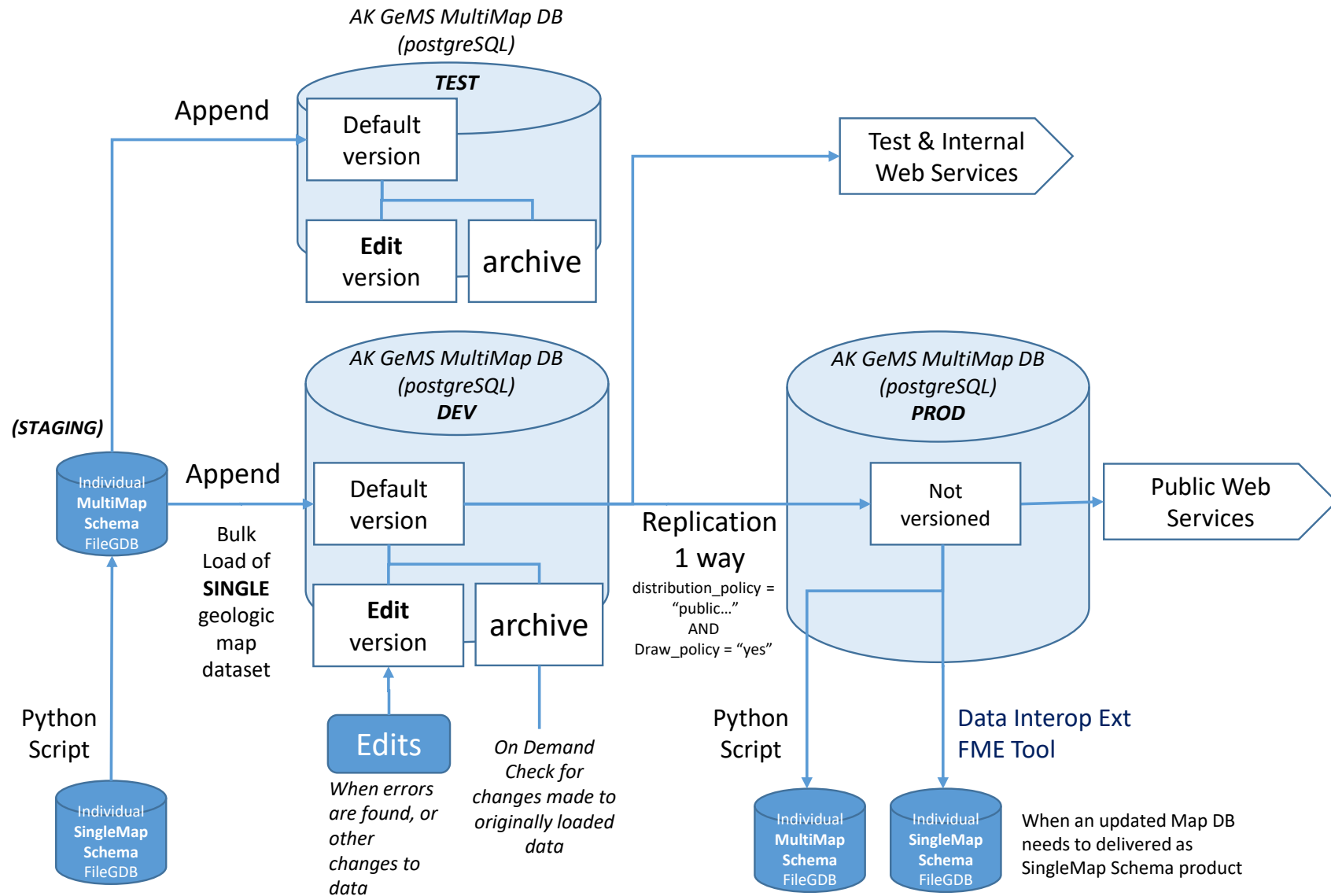
AK GeMS Multi-Map Database Architecture

Figure 3. AK GeMS multi-map database architecture.

towards the end the production process (fig. 1).

- Production (Prod) Multi-Map Database: This database is a replica of the development database but only includes public data and those features with draw_policy set to yes. It is not used for editing and is optimized for display.

Database Settings

The AK GeMS multi-map Test and Dev geodatabases are versioned. Versioning allows data managers to edit data and have those edits reviewed and approved before being committed to the default (official) version of the database. Currently these changes are not scientific error fixes but data format issues that were missed in QC or created when expected values were changed (e.g., a database product may have inadvertently not been coded as public data, or map_unit_poly field labeling features included incorrect font tags). In the future, we expect to make global changes to all the products in the database based on changes to the schema or changes in suggested values.

The versioned Dev multi-map geodatabase takes advantage of Esri's active archiving capability, which allows data managers to view previous states of the database and the ability to calculate changes to one or more database products over time.

DGGS also worked with Esri support to design and build a one-way replication between the Dev and Prod geodatabases. The replication allows us to filter only public data and data that has a draw_policy of true and then programmatically replicate database changes from the Dev database to the public-facing Prod database.

Loading a Single Map into the Multi-Map Geodatabase

Loading individual geologic map data after publication or conversion is one of the fundamental workflows associated with the multi-map database; below are the key tasks in this workflow.

1. Convert the single-map database schema file geodatabase into a multi-map database schema file geodatabase. This step is performed with a custom-built Python script.

2. Load/append the multi-map database schema file geodatabase into the Test PostgreSQL multi-map database. This allows us to verify a correct data load before loading into the Dev geodatabase. If loading errors occur, determine error, fix single-map geodatabase, and return to step 1.

3. Load/append the multi-map database schema file geodatabase into the default version of the Dev PostgreSQL multi-map database.

4. Create an edit version in Dev PostgreSQL multi-map database and complete the following steps:
   - Update nicknames table. Add record to nicknames table and populate with the product's nickname.
   - Update the data sources many-to-many relationship classes. Run the custom Python Data_sources tool.
   - Update the product_status table (truncate and repopulate).
   - Make manual custom edits if required.

5. When updates are complete and verified, reconcile and post edit version to default. Then delete edit version, which allows database to compress.

6. Run maintenance on Dev database.

7. Create backup.
8. Synchronize Dev to Prod

Exporting Data from the AK GeMS Multi-Map Database

We expect scenarios where individual geologic map databases will need to be exported from the multi-map geodatabase. There are two scenarios that we currently support. The first is a simple export of a single geologic map in the stored multi-map schema into a file geodatabase; a Python tool creates this geologic map geodatabase with the AK GeMS multi-map schema.

The more complicated scenario is exporting an AK GeMS single-map schema database. To support this scenario, we worked with Esri technical support to develop an Interoperability Extension - Feature Manipulation Engine (FME) tool to convert a map database stored in the multi-map geodatabase's schema into an exported single-map-schema file geodatabase. We recently implemented this scenario with Interoperability Extension to test the viability of using this technology for data schema conversions as opposed to building custom Python tools.

ORGANIZATIONAL PROCEDURES

A critical component of the AK GeMS Geologic Mapping System is well-defined and documented set of organizational procedures. To develop these procedures, we established a working group named the Geologic Data Inquiry (GEDI) council, which consists of GIC production staff and geologist representatives from within DGGS. The GEDI council meets weekly to review geologic map production status; discuss, decide, and document questions related to schema implementation; develop updated schema versions; and enforce organizational procedures. In addition, we hold a bi-weekly general publications meeting with additional GIC staff, as well as a quarterly leadership-focused publications meeting.

Workflow Documentation

To ensure that all parties involved with moving geologic maps and data through the system complete their assigned tasks requires well-defined organizational procedures. The backbone of these procedures is the AK GeMS production workflow graphic, which illustrates the 16-phase process that takes a map and its data from pre-publication though production, quality control, publication, and archiving (fig. 4).

The workflow identifies the following items through the entire process: workflow, responsibilities, location of data, production meetings, and products. An AK GeMS production workflow tasks document describes in more detail key aspects of each of the 16 phases of the production flow.

One of the fundamental organizational decisions is that peer review and DGGS leadership approvals occur early in the process (phase 3). Only after the map and report are approved for scientific accuracy is the geologic map's data finalized and QC'd and metadata created (phases 5–8).

In addition to this specific workflow documentation, we maintain several other AK GeMS procedural documentation products, including weekly AK GeMS GEDI meeting notes, an AK GeMS Frequently Asked Questions (FAQ) document, AK GeMS multi-map key task list, suggestions for future versions of AK GeMS, and QC rules descriptions, as well as documents related to AK GeMS geodatabase packages supporting files.

Production Status Tracking

Keeping track of the status of maps in production is an important component of an efficient production system. We maintain a digital production status board in the Microsoft Teams Planner App. Each
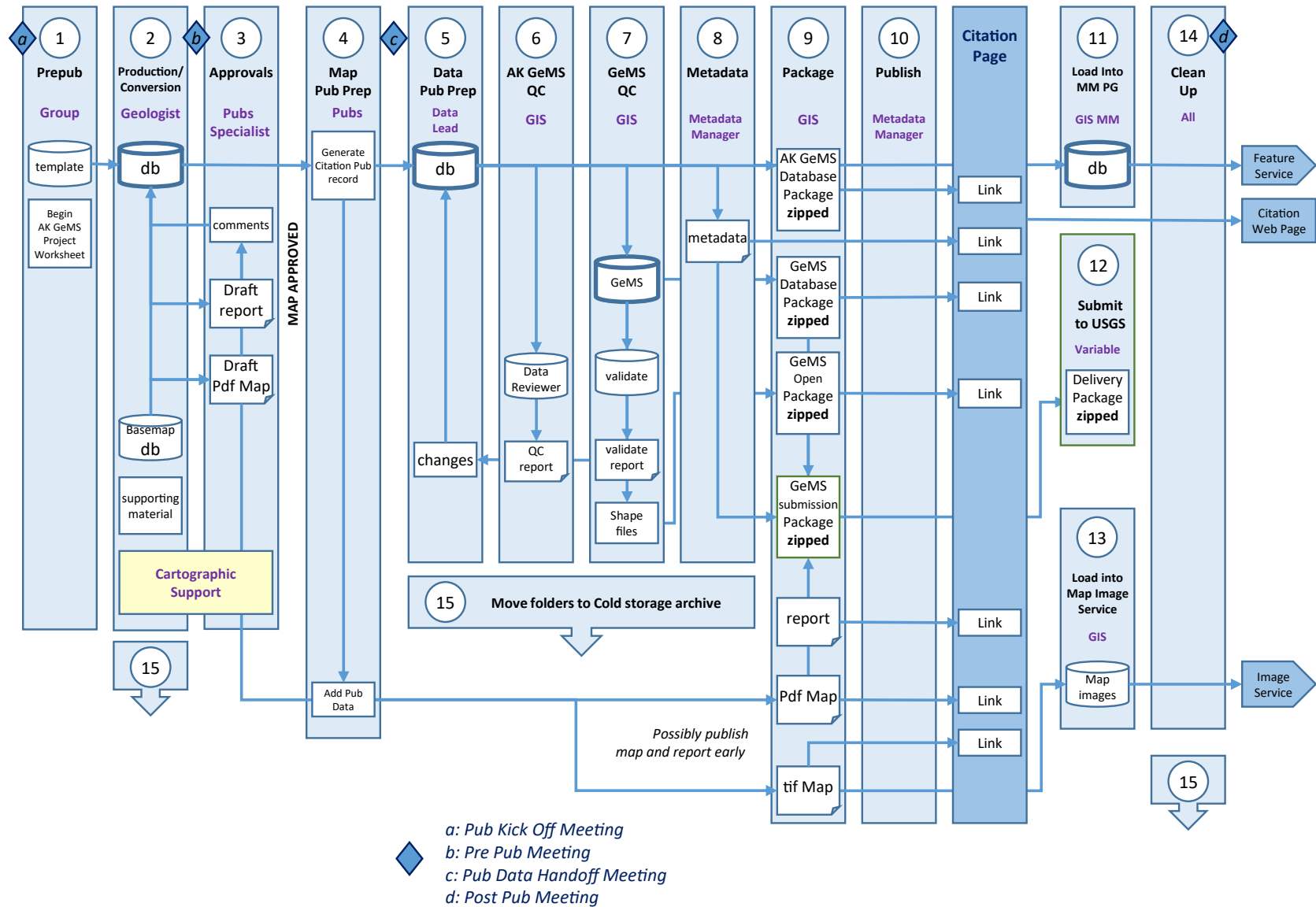
Figure 4. AK GeMS production workflow.

map in production includes critical information fields, is assigned to the appropriate personnel, and is tracked through the production workflow. During the weekly GEDI meeting, the production status board is reviewed; this weekly check on the status of production has increased productivity and ensured processes are not skipped or projects forgotten.

Aside from regularly scheduled coordination meetings mentioned above, other meetings related to the Alaska Geologic Mapping System include pre-publication meetings for each product before it enters the mapping system process, weekly GeMS multi-map database meetings, individual product production status meetings, and numerous map-specific meetings.

Training

In addition to the established organizational procedures, GIS and AK GeMS training is a vital component of the AK GeMS Geologic Mapping System. Along with the geologic training and hands-on experience our mappers receive, DGGS places a high priority on cartography, GIS, and graphics training. The weekly hour-long "GIS Tips & Tricks" training session for GIS and AK GeMS-specific instruction is well-attended by DGGS and other DNR staff. DGGS also heavily leverages Esri's educational opportunities available through the Enterprise Site License and Advantage Program.

QUALITY ASSURANCE (QA) AND QUALITY CONTROL (QC) PROCEDURES

We have placed an emphasis in the past few years on developing robust and efficient QA and QC procedures. We have heavily leveraged the Esri Data Reviewer capability, as well as developed Python-based scripts and tools as part of our QC. Efforts to improve QC procedures have dramatically increased the quality of DGGS's published geologic map data (Hendricks and others, 2022).

When DGGS first implemented NCGMP09, and then GeMS, there was not a well-defined set of quality control rules and procedures, or automated tools to conduct QC. As a result, QC was minimal, inconsistent, and very time consuming. Further, QC occurred in an ad hoc manner during metadata creation, late in the mapping production process.

In 2019, as we were developing both AK GeMS and the overarching Alaska Geologic Mapping System, we determined that a well-defined QC process was critical. We decided to implement Esri's Data Reviewer technology to drive much of the process. In the spring of 2020 and winter of 2021, DGGS used dedicated Esri Advantage Program credits to help develop Data Reviewer rules and procedures. With input from DGGS geologists, we developed a list of QC rules based on the AK GeMS data standard. Some of those rules are:

Attribute Centric Rules:

- All values must meet database domain constraints.
- The symbol code for a map unit must match that same map unit's symbol in the description_of_ map_units table.
- The feature label must match the correct value in the identity_confidence field and vice versa.
- Contacts_and_faults features must only be split when key attributes change.
- Map_units_polys features must only be split when key attributes change.

Geometric Centric Rules:

- All features must have valid geometries.
- Line features must not self-intersect.

- Contacts, faults, and map unit polygons must be single-part features.
- Curved segments for lines and polygons are not allowed.
- Point feature classes that reference a station feature must be collated with that feature in the stations feature class.
- Contacts and faults must be on the boundary of map unit polygons.
- Line features must be longer than 10 meters.
- Polygon features must be larger than 100 square meters.

Based on these rules, we built Data Reviewer rule files for ArcMap, developed organizational procedures, and developed several Python scripts to supplement the Data Reviewer capability. In addition to the Data Reviewer QC procedures, we run all converted GeMS databases through the GeMS validation scripts provided by the USGS.

Since the adoption of the AK GeMS Data Reviewer QC and GeMS validation tools, the completeness and quality of DGGS's geologic map data are greatly improved; as a result, QC has become highly valued at DGGS. Currently the senior GIS analyst and Chief of the Geologic Information Center conducts QC of all geologic map databases. However, a newly hired, dedicated AK GeMS Data QC GIS position will take QC at DGGS even further in the future.

QC procedures are moving from ArcMap to ArcGIS Pro (Hendricks and others, 2022). This is a fundamental shift of methodology and brings a host of improvements. ArcGIS Pro gives us the opportunity to embed data constraints and checks into the database, expanding the data quality focus from primarily QC to QA—this will prevent introduction of data errors from the outset.

PACKAGING, PUBLISHING, AND SHARING

After a geologic map and its data are produced, scientifically reviewed, organizationally approved, quality controlled, and finalized, the map and data move into packaging, publishing, and sharing. The first step in the packaging process is the creation of standards-based FGDC–CSDGM metadata. Although it is typically assumed that authors are best qualified to write metadata, to do so requires them to fully understand the FGDC standard. In the past, this author-centric approach caused confusion, inefficiencies, and publication delays. As a result, we now maintain a centralized metadata production process with a single DGGS geologist responsible for the creation of metadata. We create database-level metadata that heavily references our published database schema. This metadata record is provided as standalone files as well as embedded into the product's file geodatabase. This workflow ensures that authors capture key metadata in their reports and data, without requiring them to maintain currency on metadata standards, tinker with an application, or write XML.

Upon completion of metadata, packages are created for distribution and sharing. The primary distribution method shares the geologic map's .pdf file, report, and data products as a formal citation. The data products that we share for all publications are: (1) an AK GeMS geodatabase package; (2) a GeMS geodatabase package; and (3) a shapefile representation of the GeMS database. As required by the USGS for grant deliverables, we also upload a GeMS version of the publication's map database to the USGS NGMDB in their prescribed package format.

To allow users to easily view the cartographic representation of the map in a web browser or within GIS, we share the map via two image services.

Alaska Geologic Map Images: geoportal.dggs.dnr.alaska.gov/portal/home/item.html?id=3240b5b3f9d34d3582258b1ec684f1e7

Alaska Geologic Map Images with collars: geoportal.dggs.dnr.alaska.gov/portal/home/item.html?id=9fe9167898324243832cb91594a1803d

Each single-map publication and map conversion is loaded into the AK GeMS multi-map PostgreSQL geodatabase and will eventually be made available to the public. As of June 2023, over 50 map databases are loaded into the multi-map geodatabase.

ASSESSMENTS AND FUTURE PLANS

The Alaska Geologic Mapping System is an ever-evolving system, continuously being assessed and adjusted as we strive to make it as efficient as possible. The publication of our data and symbology standards, as well as establishing formal processes and procedures has dramatically increased DGGS's efficiency of production and quality of geologic map data over the past few years.

CDEFG-Identified Specifications for a system supporting a Multi-Map Database

Early in the development process, CDEFG group members identified key specifications for a multi-map database. These specifications helped develop the multi-map database component of the Alaska Geologic Mapping System, as well as drive development of all aspects of the Alaska Geologic Mapping System. Appendix A shows these specifications along with our self-assessment grade for each specification. Overall, we rate the Alaska Geologic Mapping System with a current score of 2 out of 3 based on these specifications.

Strengths of the Alaska Geologic Mapping System

Establishing a more standardized and documented system based on published data and symbology standards is a success. DGGS now produces higher quality standards-based map products at a significantly faster rate than in the past. For example, between 2013 and 2020 we published 19 new geologic maps (in various data formats) at a production rate of 2.4 per year. With the Alaska Geologic Mapping System operational we have published, since 2021, 7 new maps and converted 45 maps into our AK GeMS data standard, at a production rate of 18 per year. This is greater than a seven-fold increase in productivity! Users can view the over 50 AK GeMS geologic map databases that have been created or converted into the AK GeMS Schema with our Map Index Web App (fig. 5). Additionally, over 60 new maps and conversions are in our much-more-efficient production queue.

In addition to production efficiencies, the Alaska Geologic Map System has a significant number of further advantages:

- Having a single system that meets the data needs of both the DGGS and USGS helps ensure compatibility and future-proof State of Alaska and national data management scenarios over the long term.

- A comprehensive, well-established geologic mapping system ensures that all aspects of production are considered and addressed, which increases efficiency and decreases confusion.

- A standardized, published database schema with established, defined domain values dramatically improves efficiency, data assurance, and data quality.

- Metadata production is more efficient and comprehensive. What used to take sometimes a week per map to create metadata can now easily be accomplished in an hour.

- Extending GeMS to include Alaska requirements allows DGGS to implement additional

Figure 5. Map Index Web App, displaying only modern GeMS databases, v1.+, filtered to see details of these maps; maps.dggs.alaska.gov/mapindex

capability while still retaining the ability to deliver GeMS-compliant data.

- Having a managed multi-map repository geodatabase provides DGGS an single location to find authoritative geologic map data in a standard schema.

- A comprehensive and well-documented style file customized for Alaska geology enhances cartographic standardization across DGGS products.

- A well-established and documented workflow dramatically increases organizational efficiency.

- The establishment of automated and semi-automated quality assurance and quality control procedures has improved data quality.

- Customized geoprocessing tools have increased efficiency.

- Moving toward a more database-focused product that has value beyond the cartographic product is important for future access to information.

- The division's emphasis on training is a critical strength of the overall system.

Weaknesses of the Alaska Geologic Mapping System

There are aspects that are not optimal and have been identified as weaknesses that need to be addressed.

- The system can be complicated for both the general user and administrators. We have strived to document the system to ensure all involved understand their roles, but there are elements that are still vague and need additional documentation.

- The extension of the GeMS into AK GeMS adds tables and a significant number of new fields to the schema that must be populated. Thus, Alaska maps in GeMS format cannot be added directly into the multi-map database but require scripting.

- Converting between AK GeMS and GeMS is supported but requires tools to make this efficient.

- Handling layered units (surficial/bedrock) has been a challenge. We have added a field named layer and documented processes to employ its use, but we still have not come up with a well-defined process or tool to support working in a multi-layered environment.

- Workflows for compilation databases are not yet established (however, they are being discussed).

AK GeMS Multi-Map Scalability Testing

As of June 26, 2023, the AK GeMS multi-map database held 51 geologic map database products. To test the scalability of the multi-map database, we loaded a very large database, the "Geologic Map of Alaska" (GMA; Wilson and others, 2015), into the Test environment. Adding the GMA increased the number of contacts and faults by 780 percent and map unit polygons by 913 percent (table 1).

Test results showed a marked slowdown in display speed. The slowdown is a result of the large number of linear and polygon features. We discussed these performance challenges with Esri, who indicated that the nearly 300,000 map unit polygons and over 600,000 contacts and faults represent a very large database. Accordingly, Esri expected performance to be slow given the number of features, without employing procedures such as scale-dependent drawing. This finding may be significant for the NGMDB implementation of the national "Phase Three" database.

Future work

We are currently working on several items to improve the AK GeMS Geologic Mapping System and have identified other needed improvements. As this is an in-production, fully maintained system, we will continue to improve and grow the system as DGGS's needs change and technology advances.

- Publication of AK GeMS version 2.0 along with AK GeMS Symbology 2.0 (in progress).

- Continue development and documentation of field data collection steps and best practices in the use of Esri's Field Maps (in progress).

- Adjust the schema to better support compilations and create documentation of compilation workflows (in progress).

- Public and internal access to a multi-map database (in progress).

- Dashboard to display operational multi-map database statistics to increase management awareness and monitoring (in progress).

- Develop and implement web-friendly symbolization for geologic map feature services and map services.

- Incorporate future added GeMS tables (e.g., geologic materials, etc.).

- Continue cartographic support and evolution (e.g., workflows for the generation of cross sections and legends).

- Improve support for 3D data.

- Fully leverage ArcGIS Pro's ability to embed QA checks into the schema.

Table 1. Multi-map database basic feature content as of June 26, 2023.

Content (number of maps)	# Contact and faults features	# Map unit polys features
All other data products (51)	75,535	26,887
GMA (1)	588,811 (780 percent increase)	245,557 (913 percent increase)

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APPENDIX A. CDEFG-IDENTIFIED SPECIFICATIONS FOR A MULTI-MAP DATABASE

The table below shows the specifications vetted by the CDEFG group, along with our self-assessment grade with values of 0–3, where 3=fully implemented, 2=mostly implemented, 1=minimally implemented, and 0=not implemented. Importance values from the original assessment range from 1 to 3, with lower numbers showing greater importance to the committee. Specifications that were not accepted are not shown in this list. Original list is available at dggs.alaska.gov/oldgemswiki/en/Database_Specifications.html.

Importance	Acceptance	Specification	Category	Grade	Notes
1.08	accepted	Topologic consistency	DB model	3	All data are checked for topologic consistency with both AK GeMS QC and GeMS Validation scripts and tools. In addition, we ensure all contacts and faults are planarized.
1.15	accepted	Data are query-able across multiple maps	DB model	3	Yes, when contained within the multi-map database.
1.23	accepted	Flexible model	DB model	2	Our AK GeMS data model allows for flexibility in a number of ways.
1.31	accepted	Manage multi-scale, multi-temporal data sets.	DB model	2	We have numerous scaled data of different ages included in our geodatabase. We have not addressed temporal changes beyond tracking the data of publication. However, our archiving-enabled, multi-map geodatabase has the ability to track changes in the database over time.
1.31	accepted	Ease of use for staff	General	2	The Alaska Geologic Mapping System is well documented. However, to address all aspects of these specifications, the system has a lot of components and as a result is not overly simple to use. Robust staff training helps ameliorate this issue.
1.31	accepted	Tool to check data sets/structure for errors	Tools	3	We have a robust set of technologies and scripts to check for errors.
1.31	accepted	Schema, scripts, and other reusable components will be made available through Github (or some other commonly used open source code host) and the NGMDB website as appropriate	workflows	1	Major documentation is published. We have set up a Github site but have not yet implemented the sharing of components pending creation of comprehensive user documentation. Tools and scripts were shared directly with STATEMAP and NGMDB as grant and cooperative agreement deliverables.
1.38	accepted	Scalable – some data sets will be huge.	DB model	2	Our system on an Enterprise Geodatabase is scalable. However, testing is not complete and optimizations will be necessary.
1.38	accepted	Have the database structure and/or scripts enforce QA/QC	DB model	3	Our QA/QC process enforces quality. The ArcGIS Pro implementation in our next schema version will embed QA into the database much more than the ArcMap capability.
1.38	accepted	Reasonable speed of access to data	Technical	2	Our system on an Enterprise Geodatabase is scalable. Data access speed is currently reasonable, but as the database grows, optimizations will be necessary.
1.42	accepted	Allow single and multi-map unit descriptions	DB model	3	The DMU table stores unit descriptions. In addition, we employ a DMU_GUID field with the map unit poly, line, and point features classes to ensure we relate to the correct unit description within our multi-map database.

Importance	Acceptance	Specification	Category	Grade	Notes
1.46	accepted	Manage bibliographic information and metadata	DB model	2	Bibliographic data are stored in the product_info table. The data model facilitates metadata creation, but full metadata creation and storage is not embedded in or managed by the database.
1.46	accepted	Common vocabularies stored as tables in the database	DB model	3	Our glossary table defines all domain values, as well as other required values. We currently have 375 defined items in the glossary.
1.46	accepted	Ability to integrate with data in other databases	DB model	3	The use of GUIDs and key fields and well-documented procedures facilitates data integration with other databases.
1.54	optional	Tool to create FGDC or ISO metadata	Tools	2	Metadata creation for GeMS databases is semi-automated.
1.62	accepted	Reuse the NCGMP09 Glossary, DataSources, DescriptionOfMapUnits, GeologicEvents, and StandardLithology tables for multiple maps	DB model	2	We have a standard Glossary and manage global data sources in AK GeMS, and StandardLithology values are a domain. Description of Map Units values are not yet shared among multiple maps.
1.62	accepted	Create compilation maps more efficiently	General	2	Having more and more of our geologic map data in a single database with a single schema is conducive to creating compilation maps. Procedures and schema changes are not yet implemented for compilation creation.
1.62	accepted	Low administrative and technical overhead	Technical	2	Though we have automated and semi-automated procedures to work with the AK Gems Single-map database, the GeMS Multi-map database requires considerable technical expertise.
1.62	accepted	Facilitate data services	Technical	2	The Esri environment that we employ makes creating services from the data stored in our enterprise multi-map database relatively straightforward. Symbology is challenging for feature services.
1.69	accepted	Common unit descriptions	DB model	1	We do not yet have a common unit description list at DGGS, but this could be constructed by joining a new compilation map units table to the description_of_map_ units table in a one-to-many relationship.
1.69	accepted	Provide standardization across geologic data sets in multiple organizations	General	2	Having an established map database standard at the national level is helpful for data sharing. However, this national standard does not always meet the needs of state geologic surveys. Our extension to GeMS, the AK GeMS, is specific to the Alaska DGGS but maintains the ability to convert between the two.
1.69	accepted	Allow for tools and scripts to be built to increase efficiency	General	3	Building the system within the Esri environment allows multiple levels of user to create and use tools to increase efficiency.
1.69	accepted	Enable metadata to be harvested by other data portals.	Technical	3	Our embedded and standalone .xml metadata files are easily harvested.

Importance	Acceptance	Specification	Category	Grade	Notes
1.69	optional	Manage multi-scale, multi-temporal, and multi-dimensional (3D mapping) data sets.	DB model	2	The AK GeMS database schema does not address true 3D data.
1.77	optional	Manage original data – either in the same database or a relatable database.	DB model	2	Our Alaska Geologic Mapping System has organizational procedures to store original field and production data. The AK GeMS schema and resulting geodatabase, however, does not store original data beyond Esri's versioning capability.
1.85	optional	Manage analytical data	DB model	0	Our system does not manage analytical data. Via GUIDs and documented procedures, DGGS manages analytical data in parallel, relatable databases and makes the basic data available in the multi-map database as required by GeMS.
1.92	accepted	Manage unpublished data	DB model	3	All feature classes can contain managed unpublished data. We have a distribution policy field in all tables to store how each record can be shared.
2.08	optional	Manage field data	DB model	0	Our system does not dictate a field collection schema.
2.38	optional	Manage ephemeral interim products and processes, such as unpublished interpretations etc.	DB model	0	Our system does not explicitly manage this.

APPENDIX B. GEOPROCESSING TOOLS SUPPORTING THE ALASKA GEOLOGIC MAPPING SYSTEM

The tool, scripts, and models described below are available upon request from DGGS. Please note that we are still working on comprehensive user documentation for most of the tools and, therefore, items are only available in an "as-is" state.

1. Model Builder toolboxes with tools:

GeMS_production_tools.tbx
Tools for Production of AK GeMS Data

Unsplit and Planarize contacts_and_faults
It is suggested that this tool should be run early in the production or conversion process. The tool will generate NEW contact_and_fault_id values. This tool WILL NOT transfer the product_id value to the output. This tool assumes an AK GeMS ver 1.1 GeoDB.

Rebuild Map Unit Polys
Given contacts_and_faults and map_unit_polys, this tool will create a NEW map_unit feature class based on contact and fault boundaries using the original map unit polys attributes. This tool assumes an AK GeMS ver 1.1 GeoDB.

Find Changed Map Unit Polys
This tool generates a polygon feature class that shows the changes between two map_unit_polys feature classes. This tool assumes an AK GeMS ver 1.1 GeoDB.

Generate Map Unit Polys from CF and synthetic MU points
Given contacts_and_faults and synthetic map_unit_points (category = 'synthetic'), this tool will create a map_unit_polys feature class. This tool assumes an AK GeMS ver 1.1 GeoDB.
Note: this tool needs an update to ensure map_unit_points fields are not saved

2. Python toolboxes tools:

GeMS_production_tools_python_ArcMap.pyt
Tools for Production of AK GeMS Data

Toolset: Phase 2 Production/Conversion

Change Source Value
Change a source value in the sources field from an old value to a new value in all tables and features classes. This tool assumes an AK GeMS ver 1.1 GeoDB.

Disable Editor Tracking
Disable Editor Tracking for all Tables and Feature Classes in a GeoDatabase.

Enable Editor Tracking
Enable Editor Tracking for all Tables and Feature Classes in a GeoDatabase.

Toolset: Phase 5 Data Pub Prep

Build a Pub Prep Folder
Builds a folder in the pub_prep folder to house an AK GeMS map that is going into Quality Control phases. This tool assumes an AK GeMS ver 1.1 GeoDB.

GeMS_production_tools_python_ArcMap.pyt
Tools for Production of AK GeMS Data

Remove Empty Tables
Remove Empty Tables in a GeoDatabase.

Remove Leading and Trailing Spaces from ALL string fields
Remove Leading and Trailing Spaces from ALL string fields in DB.

Update Feature Extents
Update feature extents of all feature classes in DB.

Update geo_material_dict_id field in the DMU
Update geo_material_dict_id field in the DMU. This tool assumes an AK GeMS ver 1.1 GeoDB.

Update Location Confidence Fields
Update location confidence fields based on the value of the location_confidence_method and the lookup tables. This is for all feature classes that have these fields.

Update map unit dmu_guid value
This tool updates the MUpoly|line|point FC dmu_guid value from the DMU_id. Ensures that the description_of_map_units_id has a guid value.

Update map unit dmu_guid value for cross section
This tool updates the MUpoly|line|point FC dmu_guid value from the DMU_id. Ensures that the description_of_map_units_id has a guid value.

Update map_unit_assoc field value
Update the map_unit_assoc field for orientation_points, geochron_points, geologic_points, stations, and fossil_points. This tool assumes an AK GeMS ver 1.1 GeoDB.

Update Product id
Update Product id. Changes ALL records in the database to the Product_ID value in the product_info table.

Toolset: Phase 6 QC

Check orientation_confidence_meters field Values
Check orientation_confidence_meters field Values.

Toolset: Phase 9 Packaging

Remove Editor Tracking Fields
Remove Editor Tracking Fields prior to publication.

Save all layers in map
Save all layers in in map layer files to a folder.

Update Distribution Policy
Update Distribution Policy. Changes ALL records in the database to 7 = Public. This tool assumes an AK GeMS ver 1.1 GeoDB.

3. Available python scripts:

convert_akgems_to_fedgems_11_with_functions
converts AK GeMS schema data to GemS Schema and loads into a GeMS database.

empty_Single_fed_GeMS_Geodatabase_of_all_values
Empties all tables in a GeMS geodatabase.

convert_RGB_to_usgs_color_code
Function to convert RGB string into USGS 4-digit color code.

gems_RGB_to_usgs_color_code_wo_K
Function to convert RGB string into USGS 3-digit color code.

gems_color_4_digit_code_to_3_digit_ref_num
Function to convert a USGS 4-digit color code to a 3-digit reference number.

gems_color_3_digit_ref_num_to_4_digit_code
Function to convert a USGS 3-digit reference number to a 4-digit color code.

gems_color_code_to_RGB.py
Function to convert a USGS 4-digit color code to RGB.

group_selected_features_with_New_GUID
Populates with a GUID all selected record's group_id field.

4. Available calculations:

convert_usgs_color_3_digit_ref_num_to_4_digit_code.cal
Converts a USGS 3-digit reference number to the 4-digit reference number.

gems_cmyk_to_rgb.cal
Converts the cmyk value to rgb value. CMYK format, ##,##,##,##, RGB format YYY,YYY,YYY.

gems_color_code_to_rgb.cal
Converts 4-digit color code to RGB triplet YYY,YYY,YYY.

gems_rgb_to_cmyk.cal
Converts RGB triplet to CMYK value with a K value of 0.

gems_rgb_to_color_code.cal
Converts RGB Triplet to generalized USGS -digit color code. Note: K value always 0.

Generate_GUID.cal
Generates a GUID value.

Remove_leading_and_trailing_spaces.cal
Removed leading and trailing spaces from a string field.

string_rgb_to_hex.cal
Converts RGB triplet to hex value.

5. Multi-map Admin Tools
Tools for the conversion of single-map databases to the multi-map PostgreSQL database.

GeMS_MM_Admin_tools.pyt
Tools for populating the multi-map database

1.1: Convert SM to MM
Converts single map database to multi-map. This tool copies and transforms features to an intermediate database where the fields will be updated to match the multi-map PostgreSQL schema. NOTE: Currently only supports NAD 27 and NAD 83 datums.

1.2: Append MM to PostgreSQL
Appends data from the intermediate database to the multi-map PostgreSQL database.

1.3: Update Datasources
Creates a M2M relationship with USGS logic.

1.4: Update Multi-map Stats Table
Creates statistics table for all products.

Database Maintenance
Runs ESRI prescribed maintenance of a PostGreSQL database.

Delete product from Multi-map Database
Delete a product from the multi-map database.