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## USING GEOGRAPHIC INFORMATION SYSTEM (GIS) TO UPDATE MONTANA GEOLOGY MAPS AND FACILITATE FOSSIL POTENTIAL DATA ANALYSES

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### INTRODUCTION

The Bureau of Land Management (BLM) is one of several federal agencies that manage public lands of the United States. Part of active management includes overseeing the fossil resources. With the passage of the Paleontological Resources Preservation Act (PRPA) agencies were directed to manage and protect paleontological resources using scientific principles and expertise. A tool that the BLM uses to do this is the Potential Fossil Yield Classification (PFYC) system. The PFYC is a numerical rank from 1 (low potential) to 5 (very high potential) applied to geologic units, most often at the formation level. These ranks are assigned by BLM personnel with input from other knowledgeable individuals.

In its practical application, the PFYC is intended to help land managers plan where to focus resources during the planning or execution of ground-disturbing activities. The system can also be used by researchers in helping them to focus attention on fossil-bearing rock units. Perhaps more importantly, it can also highlight formations whose fossil potential is little known, pointing toward gaps in our paleontological knowledge.

### METHODS

Management plans used by the BLM to inform the actions of resource managers include the PFYC. The PFYC is also important for providing guidance to consulting paleontologists who work for project proponents involving public lands. The system can be used to inform the project proponents of areas of high likelihood for fossil resources so adequate planning can be done to mitigate the irreversible destruction of valued heritage resources. For all these reasons the best quality information is sought.

The BLM amassed Geographic Information System (GIS) geology data for the state of Montana from a variety of sources of varying reliability and provenance. The intent of this project was to locate and integrate the best available GIS data from trusted sources in a user-friendly format. It was also critical that sources provided sufficient metadata to allow users to understand the data's intended uses.

Conceptually it seemed that a simple join between a geodatabase geology feature class that contained rock unit codes and a table, text file, or spreadsheet that also contained rock unit codes (and their respective PFYC values) would be effective. Joining these two data sources—one geospatial, one tabular—would enable map representation and geospatial analyses of features in a particular loca-

tion in reference to the PFYC rating of the formation(s) in that area of interest. A similar approach was published by Smeins and Grenard (2009).

In compiling all of the maps into a single data set it quickly became clear that different geologists mapped geologic units in a variety of ways, and that was reflected in non-standard codes for rock units. For example, the standard code on one map might include Kb for a rock unit intending to specify Cretaceous (K) Bearpaw Formation (b), while on another map it may have designated Cretaceous (K) basalt (b). In geological terms, these rock types are significantly different and would be given different PFYC ranks.

The Montana Bureau of Mines and Geology (MBMG) is the primary data provider for digital Montana geology data and related reports. The source data were only available in ArcInfo export (.e00) format downloaded in zip files from <http://www.mbmgs.mtech.edu/gis/gis-datalinks.asp>. This format is an older and somewhat cumbersome GIS product to use, but it contained a wealth of very valuable information. The MBMG website also provided links to United States Geological Survey (USGS) .e00 files for areas not covered by MBMG sources. Complete geology data for the state of Montana was spread over 149 individual ArcInfo map coverages. At the start of this project this appeared to be the only reliable data source available—daunting to integrate, but ultimately worth the effort.

The source maps ranged in scale from 1:24,000 for special focus areas to broad sweep 1:250,000 surveys. There were many gaps and overlaps of GIS features within and between these maps when reviewed individually and side-by-side. Some regions had multiple surveys of different scales that had been completed at different times. From a GIS perspective all these data needed to be integrated into a single, contiguous feature class with consistent geology codes if it was going to be effective.

Given that the rock codes in the various maps could indicate very different rock types, we needed to establish a standardized code for every mapped rock unit. In some cases, the original codes from the source data could be used, but in most cases new codes had to be created in order to maintain consistency across the whole data set. For example, one map may show the Woodside Formation, and another map may combine the Woodside and the Dinwoody formations. Similarly, one geologist may have mapped a single formation, whereas another mapped each of its members separately, and a third mapped the units by lithologic character. For all these cases unique codes for

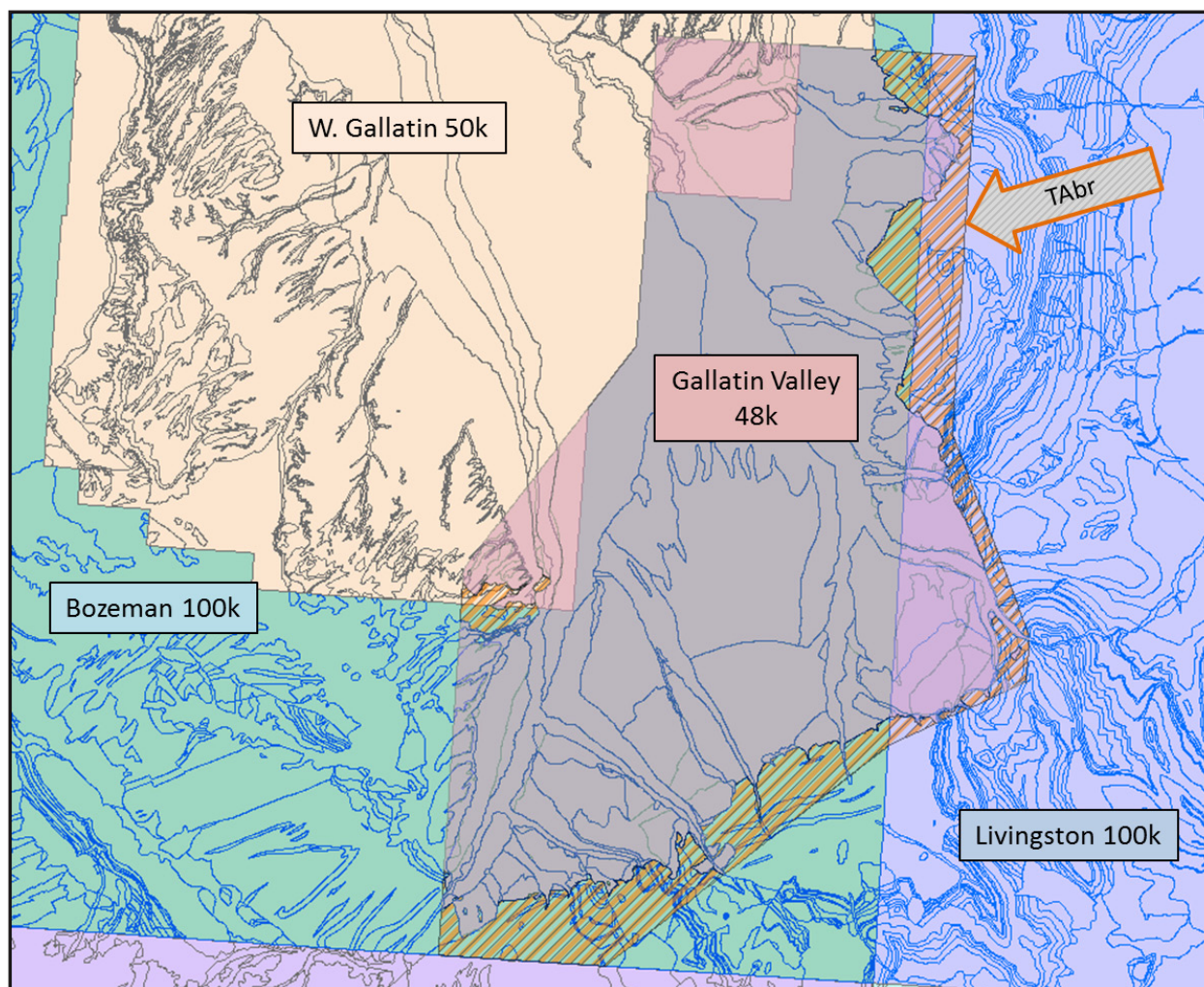


FIGURE 1. Integrating multiple GIS data sources of varying scale and currency required subject matter expert decisions. In this example a preferred 1:48,000 map of Gallatin Valley contained a TAbr (Tertiary to Archean bedrock) polygon that overlapped more detailed information in 1:100,000 scale maps. The TAbr polygon was removed from the overlapping areas.

the geologic units needed to be applied for consistency across the data. In the end, over 1,400 unique rock unit codes were assigned.

The first GIS task was to bring the older ArcInfo coverages into a geodatabase for use with the current version of ArcGIS available at the BLM Montana/Dakotas State Office (MTSO), ArcGIS 10.1. The downloaded files contained information on contacts, faults, folds, strikes, dips, other geologic lines, annotation, etc. It also provided metadata in various forms identifying key points of information about each data source, such as publication date, sources, constraints and caveats for use. The contact data became the basis of the new format GIS polygons, in tandem with the very extensive metadata that was provided. All other data in these files are considered useful for future efforts.

An individual geodatabase feature class was created for each of the survey maps using the contact data from the

ArcInfo coverage. These feature classes were named using the map name and the survey scale, i.e. 'alzada\_100k.' All attributes that were included in these data were kept and a new field ("NEW\_POLY") was added and populated to accommodate the standardized rock unit code to be incorporated into all of the maps. All of these features were reprojected into a custom North American Datum (NAD) 1983 Albers projection used for GIS data in the BLM MTSO. Federal Geographic Data Committee (FGCD) metadata was fully populated for some of these feature classes—the effort to finish them all is still ongoing.

In areas where there were multiple sources available, primacy was given to the largest scale (smallest area) map data. For example, if both a 1:24,000 map and a 1:100,000 map were available, the 1:100,000 map data would be copied and the area of the 1:100,000 data would be cut out and replaced by the 1:24,000 polygons. Similarly, if one map

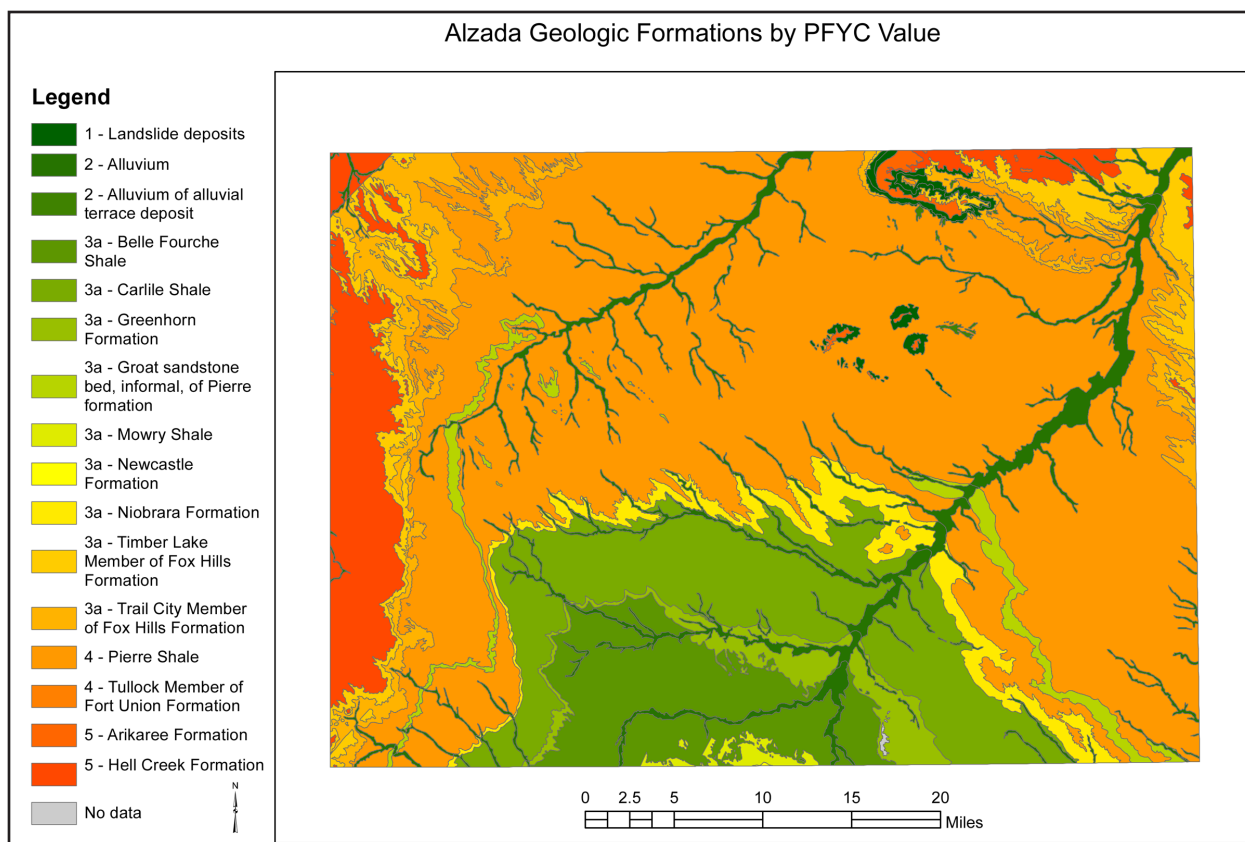


FIGURE 2. The Alzada 1:100,000 scale geology mapped with the Potential Fossil Yield Classification (PFYC) values as an example of visualizing the new composite data set.

of an area included blank or 'no data' areas that were identified with a geology code in an overlapping source, the blank areas were removed regardless of the mapping scale preference. In certain rare circumstances polygons with geology codes from larger scale surveys were removed in favor of more detailed data in overlapping sources (Fig. 1).

The 'jigsaw' of the individual maps of differing scales that had been cut out to fit together were merged into a single feature class. Only the NEW\_POLY, original map scale, and calculated acreage attributes were included in this new feature class. This feature class contains approximately 126,500 individual polygons.

After merging the individual maps into a single feature class, a map topology was set up to identify the areas of gaps and overlaps in the feature class. For these data to be most effective in geospatial queries it needs to be continuous. The initial topological error count was somewhere over 31,000; at present it is under 20,000, so edits are ongoing. Most of these gaps or overlaps are very small and do not significantly affect the visual or analytical utility of the data as they are generally used.

The merged data were then dissolved into another data set so that there is only one polygon for each NEW\_POLY-CODE (geologic code) value. A version which dissolved the features on both the geologic code and the map scale

was initially created but the scale attribute was later considered to be unnecessary. The current dissolved feature class contains the NEW\_POLY attribute and calculated acreage to facilitate area calculations and contains 1,226 polygons, approximately one-tenth the number of the merged polygon feature class. As the topology errors are corrected in the merged feature class the dissolved feature class will be regenerated for improved overall data quality.

A GIS layer was created showing the boundaries of the individual data sources that were going to be combined into a single feature class. This was done to preserve the ability of a user to go back to the original source to answer any questions about the information presented in the combined data. This will also facilitate ongoing maintenance and updates of this feature class as new maps become available and need to be integrated into the whole.

Metadata has been populated for all of these feature classes and will continue to be updated as the data are maintained and improved.

#### **Establish Connectivity Between PFYC Data and GIS Data**

ArcGIS offers multiple options for connecting to non-GIS data sources, as well as for importing such sources into a geodatabase table for use and maintenance wholly

within the ArcGIS interface. In this instance, the PFYC ratings per rock unit table exists in an ArcSDE geodatabase which is edited and updated using MS Access through an open database connectivity (ODBC) connection. GIS users can access the table for joins and queries, but cannot modify its contents. Changes made to the table by approved users in Access will be immediately available to the GIS community.

### RESULTS

The geospatial end product of most interest from this process is the dissolved feature class carrying standardized rock unit assignments which can be joined to the PFYC table for mapping and analysis. The merged geology polygon feature class will be used when updating the geology data to accommodate new map information. The source boundary polygon feature class provides a tie to specific details about the original map information incorporated into this dataset.

Each of the more than 1,400 uniquely identified geologic units needed to be given a PFYC rank. A related project was undertaken to make an extensive review of all the geologic units from Montana, North Dakota, and South Dakota. The PFYC for each formation was determined from a review of the literature and known fossil localities and occurrences, and for each unit a short summary justification of the assigned rank was provided. As a rule, the BLM assigns 1 rank to a formation for the entire state. However, on a case-by-case basis a formation may be ranked differently in another state if it is justified by fossil occurrence. This formation by formation review will be published separately.

The standardized table of geologic unit codes and PFYC ranks can easily be joined to the GIS polygon data, creating the most up-to-date PFYC map. This information is invaluable to anyone involved in potential surface-disturbing undertakings, land use plans, and research.

### FUTURE EFFORTS

There are still GIS 'housekeeping' tasks to be completed for all of the data that support this process. This includes completing the topology error cleanup in the merged dataset, fully populating metadata for the original 149 converted coverage files, finding sources for any remaining 'no data' areas, and so on.

Another area of improvement will provide users with an easy way to access key reports about each of the original map surveys. Access methods may include hyperlinks in the metadata, a searchable online library, or a document management application. At a minimum we are looking to provide a comprehensive citations list for the maps used.

An ArcGIS layer file (.lyr) allows GIS users to create a consistent look and feel of the mapped data, including the source, symbology, definition queries, and so on, that can be shared with other GIS users who have access to

the same data. A layer package (.lpx) can be made that includes both the layer and the supporting data so that other GIS users that do not have access to the primary data source can also use them (Fig. 2). Having users add a layer file to a map document (.mxd) instead of just adding the feature class saves them the effort of setting the specific parameters again when collaborating with others or in generating consistent map products, or of having to apply a data style to the feature class.

Presently, we are also exploring the best way to make the full dataset publicly available. After more refinement of the data we will post them on the Montana BLM website. Web based map access through an internet browser is also under consideration.

### CONCLUSIONS

Creating a standardized geospatial geology data set and PFYC ratings table for the State of Montana was both a specific project and a process pilot. While there is still some work to be done the next logical step is to expand the area of incorporated geology maps using similar steps. Recently we found a USGS website that may modify and simplify the geology GIS data gathering and standardization part of this effort. Starting in 1997 the USGS Mineral Resources Program set out to create "Digital geologic maps of the US states with consistent lithology, age, GIS database structure, and format" as described on the USGS data access page for this project (<http://tin.er.usgs.gov/geology/state/>). Shape files for all 50 states and Puerto Rico, as well as a combined dataset for the continental US, are available, as is extensive documentation of the project approach, data sources, and so forth. Google Earth compatible files are also provided, as are ArcMap style sheets and csv files listing references, unit descriptions, age categories, and other parameters. It includes standardized data for faults, dikes, and the other geologic features that have not yet been addressed in the BLM project. We are hopeful that much of the groundwork in expanding this effort may already have been accomplished. The USGS data may serve as the basis of a national standardized GIS geology layer and PFYC rating tool which could be available relatively quickly. Research into how these data were created, what rationale was used to create standardized rock unit codes and integrate different map scale sources, how new data are/are not added, and so on needs to be completed, but the outlook is encouraging.

### LITERATURE CITED

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