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Mining Information from Published Geologic Maps (an extractive industry)

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MINING INFORMATION FROM PUBLISHED GEOLOGIC MAPS (AN EXTRACTIVE INDUSTRY)

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Introduction

This paper addresses the development of digital geologic map databases through the extraction of information from existing published geologic maps. As in any mining operation, the objective is an efficient and cost effective method for extracting and processing the ore while (in an environmentally safe way) leaving behind the tailings. The underlying concept of this paper is that information contained in a small scale geologic map can be related to a high quality, larger scale, topographic map in the same manner that the information is commonly related to the real world (which has the ultimate scale of 1:1). The characteristics which are most useful in this process involve the relationships which exist between geologic boundaries (separating distinct and identifiable geologic units) and non-geologic features (cultural or topographic). Although the nature of sedimentary stratigraphy without complicating unconformities makes it the easiest environment for application of these principles, the interactions between geologic boundaries and variations in topography in almost any geologic environment will create patterns and spatial relationships to which the principles of this paper may be usefully applied.

Blowing Up Maps: Terrorism 101

Proverbs are generally the outcome of experience blended with wisdom. People who violate old proverbs may survive the experience, but they do so at their own risk. There is an old proverb among geologists and cartographers:

> ***Don't take a map drawn at a smaller scale and enlarge it for work at a larger scale.***

The fundamental concern addressed by this proverb is map accuracy; more specifically, the accuracy of feature locations on the map. As stated by Robinson et al. (1984), ". . . the accuracy of the source data must always be a matter of primary concern for the map compiler. (p.427)" There are different kinds of accuracy associated with any geologic map. In any case, accuracy is a relative issue, which depends on the intended use of the map. The appropriate accuracy of any source document should be evaluated in relation to its intended use. Three primary factors which Robinson identifies for weighing the probable accuracy of alternative data sources are the age and the scale of the source material, and the level of responsibility that can be associated with the individuals or agencies involved in data collection or mapping.

Regarding age, Robinson notes that newer sources of data are generally preferred to older ones. As examples, in Kansas; 1) the 1962 geologic map of Cowley County by C.K. Bayne would be generally preferred as a data source over the 1926 map by N. W. Bass, and 2) the 1971 map of Johnson County by H. G. O'Connor would be preferred over the 1935 map by N. D. Newell. In these two cases the more recent maps would also be preferred because they were each published at a larger scale than their preceding map, with the implied probability of greater location accuracy. When published maps are used in the compilation of digital geologic map databases, the date when information for the source map was collected and/or last revised, along with the source map's scale and the authors and/or agencies involved in the map production, should be included in metadata to inform the database user. Similar information should also be included on any analog products derived from these databases.

Addressing the current issue of map terrorism via scale changes, Robinson gives his own version of our proverb:

> "The scale of source material must also be carefully weighed. Progressive generalization with smaller scales is an inevitable aspect of the mapping process. For this reason compilation should always be from larger scale sources rather than smaller. The temptation to enlarge a smaller scale map is bad enough. But it would be even worse to **blow up** a smaller-scale map of one feature . . . to be overlaid on a compilation worksheet containing other features . . . that were compiled from larger scales. (p.427-428 emphasis added)"

The first temptation is probably not so much a sin as Robinson suggests, unless the resulting enlargement is used in a way which implies location accuracy possible from original compilation at the larger size (scale). Many geologists past the age of 50, and some younger, have no doubt seen the advantage of using a magnifier of some sort in order to more easily see what is printed on their small scale maps.

Robinson's warning against the second temptation suggests a more specific statement of our first proverb:

> ***Don't enlarge features taken from a smaller scale map in order to overlay those features on a composite map with features that were compiled at a larger scale.***

Violation of this proverb probably generates the worst possible results when it involves features of the same type. Newell's (1935) geologic map of Johnson County includes the outcrop pattern for the base of the Westerville Limestone (now considered a member of the Cherryvale Formation). The map is published at a scale of 1:126,720. O'Connor (1971) did not include this unit in his more recent map, prepared for publication at a scale of 1:48,000 from field work done on 1:24,000 scale topographic maps. Believing that information about the Westerville Limestone Member would improve O'Connor's map, a zealous but poorly trained cartographer might copy the outcrop from Newell's map, enlarge it to a scale of 1:48,000, and overlay the result on O'Connor's map. The superimposed outcrop pattern for the base of the Westerville would probably cut back and forth across outcrops of geologic contacts above and below the Westerville Limestone as mapped by O'Connor. Cartographic transgression (map terrorism) easily leads to violation of a fundamental geologic principle: a sedimentary rock unit, found between other continuous rock units will always remain between those continuous units.

The distortion of the transferred outcrop pattern for the Westerville Limestone Member in relation to surrounding units results from differences in the quality of the base maps and, more significantly, a higher degree of generalization inherent in Newell's smaller scale map. In Maps for America, Thompson (1981) describes the basic nature of cartographic generalization as it relates to topographic contouring. "Generalization is used to some extent in contouring at any map scale, because it is obviously impossible, at any scale, to show every irregularity of the ground surface. The amount of detail omitted varies inversely with the map scale. (p.31)" The same principles apply to representation of surface geology on maps.

Instead of improving the information content of the composite map, violation of the cartographic principles expressed in our first proverb (as revised) would degrade and call into question the information already presented in O'Connor's map.

Making geologic Maps: Field Geology 101

> ***Geologic maps are models of information transferred from a map with the scale of 1:1.***

This is the first axiom of geologic mapping. With new field mapping, geologists follow Robinson's admonition against the use of smaller scale sources in the compilation of maps. Working in the real world they use the largest available source, at the scale of 1:1, where a foot is a foot (and a rose is still a rose).

If previously published, smaller scale geologic maps exist for the area, the geologist may refer to them along with other existing records of field observations to assist in field interpretation. The geologist's primary objective is to compile observations (real world data) about rock units in the mapping area in a way that preserves and communicates their spatial relationship to each other.

Working with the established stratigraphic nomenclature in and around the map area (typically a county in the Kansas Geologic Mapping Program), the geologist does preliminary work to determine which rock units or intervals will be practical to map within the area. In this effort and subsequent collection of field observations, the geologist will examine read cuts, gravel pits and quarries, walk the stream beds and gullies and study cliff exposures in the map area searching for rock units exposed by human activity or the natural effects of weathering and erosion.

Once they identify exposed rock units, geologists search for geologic contacts; where the top of one mapped interval of rock units is in contact with the base of the next mapped interval. Using the best available methods, the geographic location of these geologic contact observation points are carefully determined. This information, along with other descriptive data relating to the geologic contact and associated rock units, is recorded for future use in map compilation. The elevation of geologic contacts at each observation point is determined by direct measurement or by reference to topographic maps; most commonly, the 1:24,000 scale, 7.5 minute, quadrangles of the United States Geological Survey (USGS).

A working concept of the structure of a mapped unit is obtained from an evaluation of the general spatial trends in elevation associated with these observation points. The mapping process then requires interpolation of the outcrop pattern between the observation points. Basically, this pattern is the line of intersection between a model of the mapped unit's structural surface and the model of the topographic surface presented on the 1:24,000 scale base map. The importance of the interpolation process used in compilation of field maps is described by Sawin (1996).

"Geologic maps are compilations of data and inference. Because most bedrock is covered by soil and vegetation, the information gleaned from outcrops are pieced together to build a map. Because outcrops may be a mile or more apart, geologists must use their training and experience to connect the data points by extrapolating and interpreting what happens between the scattered points of information. . . The geologist's job is to visualize the bedrock near the surface without the soil cover and to make a map that reflects this image." (p. 3)

Lines are placed on a geologic map representing the locations where geologic contacts are exposed at the surface or lie close to the surface below a weathered soil cover. However, it is not the precise position of these lines which convey the most important information objective in the map.

Accurate positioning of outcrop patterns is probably the principle concern to the field geologist and the cartographic compiler of geologic maps. As noted previously, generalizations which occur in the production of any map introduce location errors, and increase with reductions in map scale. However, efforts by the geologist and cartographer to achieve limited line position accuracy result in the more important development of information relating the form of outcrop patterns to land forms.

It is the forms of those outcrop lines, their relationship to the forms of the landscape (or the representation of those land forms on topographic maps) and their relationship to cultural features (such as section corners and boundaries in the Public Land Survey System) which provides the most useful information regarding the location and spatial relationship of rock units. Developing the forms of these lines as a source of information is a direct outcome of the field geologist doing his job. This is the most important way in which a geologic map accomplishes the geologist's objective of representing the spatial relationship between rock units. In many cases the scientist is unaware of the distinction between position and form and the primary significance of form to the success of the map making effort.

Using Geologic Maps: Visualizing Spatial Data

> ***When a geologic map is used in the field, the information content of the smaller scale map is related back to a topographic relief map with the larger scale of 1:1.***

This is the first axiom of map use. Significant errors between the map coordinates of points along a line representing the outcrop pattern of a geologic contact and the corresponding geographic location of the outcrop occur as the result of generalization, and increase with decreases in scale. Despite this obvious fact, geologic maps published at small scales (ranging from 1:24,000 down to 1:320,000 for county maps and 1:500,000 for the state geologic map in Kansas) maintain a high degree of usefulness in a wide variety of applications.

Why is it that a product replete with position inaccuracies can remain highly useful in a multitude of real word applications? The explanation lies in the fact that the user derives most of the available information from map characteristics other than the precise position of outcrop lines on the map.

The most significant, information loaded, element of virtually any geologic map is not the precise coordinate location of points along lines on the map but rather the form of the lines and their relative association with other features of the map. That is to say, topology is more important than absolute position. "Topology," as it is used in mathematics and in cartographic applications, refers to those properties of geometric configurations which are invariant under transformation by continuous mappings. As such, the topological accuracy of a geologic map is independent of scale over a broad range of scales. The topological characteristics of geologic outcrops are the constants which maintain the information content of geologic maps as they decrease in scale even though location accuracy may steadily deteriorate in the process.

What are the topological characteristics of a geologic map? As indicated in the discussion of map terrorism, one characteristic totally independent of scale is the local stratigraphic sequence of sedimentary rock units: one formation, found between other continuous formations will always remain between those continuous formations. This characteristic is particularly valuable when integrating unique formation mappings from multiple sources. Another important characteristic of geologic maps is the topology of intersections and points of close proximity between geologic and non-geologic features. More accurate representation of these points and features than others on the map is largely due to the strong correlation between these points and points in the field where the geologist actually observed (as opposed to inferred) the geologic features. It is a fundamental result of the interaction between the cartographer and the geologist whose observations are being drawn on the map. In addition to the intersection or close proximity of outcrops to roads, streams, ponds or other landmarks, this principle applies to the response of outcrop patterns to topographic features such as saddle points on ridges or isolated outcrops around local topographic highs. These points and topologic features are identified as critical locations for transfer of geologic map information from smaller scale maps to 1:24,000 scale base maps.

Consulting geologists, highway engineers, civil engineers, zoning boards and a multitude of other users of the end product of the field geologist's efforts take advantage of the topological characteristics of geologic maps when they use their training and experience to relate the forms of outcrops on geologic maps to the corresponding topographic form of the real world where knowledge of near surface geology is crucial for success in performance of their jobs.

Recognizing the inevitable generalization which occurs in representation of outcrop locations and, as Sawin notes, that ". . . most bedrock is covered by soil and vegetation," geologic maps should never be interpreted or used as conveyors of information regarding the absolute position of geologic contact outcrops. Such information is only available for the sparse locations where geologists have actually found surface exposures of rock units and their contacts with other units. Only when these locations have been carefully surveyed and recorded as map notes or included in an associated report can those few locations be taken as precise measurements. Despite this minor shortcoming, geologic maps provide a valuable timesaving source of information in many real world, site specific, applications.

Development of Digital Databases from Published Geologic Maps: Advanced Topics in Cartography

> ***The information content of all geologic maps can also be related to models of the large 1:1 scale topographic relief map.***

This is an important corollary to the first axiom of map use. With emphasis on the information content of maps, it is a concept which must be adequately conveyed to technicians and program managers responsible for geologic database development. Confronted with the task of developing digital geologic databases from existing published maps, the typical response of computer mapping technicians has been distinct from the typical response of program managers and "field" geologists. Both responses, based on a misunderstanding of the nature of the information content of geologic maps, pose roadblocks to development of quality databases from these maps.

Computer mapping technicians generally see the task of data compilation from published maps as a challenge to find the best technology for capturing the precise location of each and every relevant line on the map or maps in question. Unconcerned by issues on source evaluation raised by Robinson, et al., they focus on resolutions of scanning equipment, repeatability of point location measurement on specific digitizing tables, the medium on which the source map is printed, possible distortions in the medium, and the quality and clarity of lines on the map. Technicians generally fail to recognize that the most important and most accurate geologic information presented by a published map is in the topology of the map features, not the absolute position of the lines. Their efforts for accurate reproduction of the lines on the map will result in accurate reproduction of the cartographic generalizations (i.e., the position errors) built into the particular scale at which the map was drafted.

Project managers, on the other hand, will tend to respond immediately to Robinson's concerns. They are the ultimate anti-terrorist SWAT teams of computer mapping. They intuitively recognize the merits of Robinson's admonition against blowing up a small-scale geologic map and printing it as an overlay on base map data derived from larger scale sources. They know the result is going to be ugly, painful, downright bloody. As a consequence, large programs such as development of state or national databases are established in relation to a "standard" scale (e.g., 1:100,000 for the National Digital Geologic Map Database). It is easily presumed that no maps published at a scale smaller than the "standard" can be an acceptable sources of information for the program. The scales at which existing geologic maps were actually published becomes a constraint on the selection of a target scale for database development. As a practical matter, the goal of a national database referenced to a 1:24,000 base is rejected a priori as impractical or infeasible. This rejection is based on the assumption that maps do not generally exist at this large scale and that resulting compilation efforts would be extremely expensive. The target scale of 1:100,000 was undoubtedly influenced by an expectation that most areas of the country have already been mapped at that scale. The result is an unfortunate restriction in the use of information available from many published maps. Even among geologists, who are perfectly comfortable taking a small scale map to the field, there is strong resistance to the idea of taking information from the smaller scale map and placing it on a larger scale map. Failing to recognize that they use the information in (and on) the largest scale map, geologists commonly believe (incorrectly) that map information is determined by the position of the lines rather than their topology. The result is a failure to consider the possibilities for capture of this important information from almost any geologic maps and the relate that information in useful ways to larger scale models of the local topography.

Procedures for capture of geologic information from published geologic maps which have been tested and found highly effective at the Kansas Geological Survey include the transfer of information from published maps to a common, 1:24,000 scale, topographic base (USGS). Some topological interpretation is required. The tasks involved in this process, and the cartographic principles on which they are based, are described by Ross (1996) and by Ross and Collins (1997).

As Ross explains, the idea of transferring the map information to larger (1:24,000) scale topographic maps is not a matter of "trying" to make the data more accurate than the existing maps. Nor is it a violation of Robinson's principles of map compilation. Using the topologic, stratigraphic and geologic information presented in the smaller scale map and the more accurate representation of real world topography on the 1:24,000 base map, it is possible to develop geologic data which more accurately represent what the geologists intended to map than could be done on the existing smaller scale maps. Obviously, if a geologist makes the wrong identification of a formation, there is no way a cartographer (isolated from the actual geology) can correct the error and re-map the formation in its correct location. But, using the recommended procedures, the cartographer can more accurately describe where the geologist who was wrong thought the formation was located. This also holds for the work of the geologists (presumably in the overwhelming majority) who were right!

Rather than representing flagrant 'cartographic license,' the process described here represent a redrafting of available information while eliminating much (but not all) of the 'cartographic license' taken in the process of generalization which occurred when results of field mapping were prepared for publication at small scale. That process of generalization typically smoothes the outcrop pattern by cutting across small valleys or small protrusions in ridge lines. Cartographers are not the only ones who take this license. Many geologists, in the process of completing outcrop patterns on their field maps, will fail to follow the structure implied by their field observations (often made at sparse critical points) when interpolating between actual mapped locations of a formation.

Conclusion

There is a new proverb among geocartographers:

> ***Don't let an old proverb keep you from using the information content of a smaller scale map when you want to make a map at a larger scale.***

Scanned images of old maps can still be important historic resources in geologic literature. They provide an efficient, cost-effective means of preserving past geologic research and make possible electronic re-publication of the old maps, now generally out of print. Scanning is the only method recommended for this purpose because it replicates the original document in all its detail with far greater fidelity and much lower cost than any digitizing technique. Digitizing or scanning geologic formation boundaries and outcrop patterns directly from existing smaller scale maps or from bases prepared at a small scale such as 1:100,000 for the purpose of database development would simply perpetuate the errors introduced by cartographic generalization. Using these images, or elements vectorized from the images, in conjunction with databases derived from more accurate, larger scale maps would be a return to map terrorism, violating the wisdom of old proverbs and basic principles of cartography. This a constant concern in other geographic information systems applications as well as in automated cartography. The databases derived from published maps through transfer of map information to a common larger scale base provide an appropriate alternative to this violence.

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