GeoHyp: an adaptive human interface for geologic maps and their databases

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Abstract

A geologic map is typically a 2D representation of 3D subsurface structures in a given area. It is based on the currently accepted geologists’ model explaining the observed phenomena and the processes that shaped them in the geologic past. For historical reasons, this model is recorded in a geologic map with an explanatory booklet that describes the authors’ conclusions as well as relevant field observations and other data such as tectonic measurements, drill hole logs or fossil records. Today, however, this variety of information can be better handled by converting it into digital and even hypermedial format. This necessitates the prior conception, development and implementation of a suitable geologic “hypermap model”. The main objective of this study is to design models and tools well-suited for the interaction between users and geologic hypermaps. The unique aspect of this family of applications is that users, in general, are both end-users (e.g., engineers) and designers (e.g., mapmakers). Objectives, concepts and methods for developing a human interface to geologic hypermaps have been tested using a prototype (i.e., GeoHyp) within the GIS environment of ArcView from ESRI. Tools to access the underlying background database via hyperlinks have been implemented, as well as functions especially developed to meet specific geologic requirements. Tests with various types of users have shown that the prototype matches their expectations and serves as a good basis for further development. In this article, we report on our design choices for GeoHyp and the current status of our project. © 1999 Elsevier Science B.V. All rights reserved.

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1. Introduction

A geologic map is based on a conceptual model concerning the geologic phenomena and the processes, which shaped them during the Earth’s history. To convey this model to the user, the map must be accompanied by an explanatory booklet containing notes, profiles, pictures etc. Due to technical limitations, only a portion of the information available to the mapping geologist can be shown in a paper map and included in the explanations. For this reason, significant freedom of interpretation remains with the user.

Today, in the era of digital mapping and geographic information systems (GIS) we have the ability to rethink the way of publishing geologic knowledge. It is possible to store all the background infor-
mation about a map in a GIS database. However, there is still no standard regarding geospatial data modelling, storage and query. Assuming such an environment would be compliant with a query language such as the Standard Query Language (SQL), the retrieval of the requested pieces of information would still require experience in formulating SQL-statements. This is often unacceptable as many users are not experienced with SQL (Egenhofer, 1992). In addition, geologic applications require many different types of data that should be handled by a powerful query language.

Therefore, a suitable interface between the map user and the associated data must be found. Hypermedial methods are a solution to this problem as they allow consistent access to many different types of data. Hypermaps, defined as digital maps connected by means of hyperlinks with background information (Laurini and Thompson, 1992), are currently in use for vegetation (Hu, 1999), touristic (Kraak and Driel, 1997) and cartographic (Krygier, 1997) applications. To our knowledge, the potential use of hypermedia in geology has not yet been fully investigated. It should be noted that geologic maps differ from topographic maps in several ways. For example, geologic maps typically depict the spatial distribution of rock types and their relationships as 2D representations of 3D subsurface structures (Powell, 1992). In contrast to topographic maps, geologic maps are not only portrayals of the surface structures but also interpretations of rock-structures under the ground. In addition, topographic maps are based on direct observations while geologic maps also represent phenomena, which elude direct observation. This means that in areas with few outcrops new data can lead to completely new interpretations necessitating geologic map revision (Nickless and Jackson, 1994).

As every hyperdocument, a geologic hypermap is only useful if it is structured in a sensible manner. Because of the various disciplines in geology, a user-specific structuring of the interface and the data is needed. For instance, a hydrogeologist will use the map to solve questions different than those of an economic geologist. In order to spare him or her the need to search the complete set of information, it is necessary to provide specialised geologists with specific tools and data. By means of such tools, querying the map can be partly automated. This would significantly facilitate, for example, the preparation of environmental impact assessments.

A number of national organisations are working on similar user-specified data structuring. Among them, the U.S. Geological Survey is preparing a model for geologic metadata (Raines et al., 1998) and the Geological Survey of Canada has developed a database for geologic field data (Brodaric, 1998). The British Geological Survey is also very active in this field (Nickless and Jackson, 1994; Bain and Giles, 1997).

Requirements of geologic hypermaps go beyond those for traditional hypertext applications (Voisard, 1998). In particular, the various types of semantic relationships, both at a regular and at a metadata level are very important. The underlying database model also must be powerful enough to handle these relationships. Besides spatial dependencies, time dependencies (e.g., paleographic development) have to be considered by the hypermap model.

In addition, the identification or deduction of geologic features is an iterative and evolutionary process. This means that geologic map making is often an incremental process. Based on initial observations, hypotheses are formulated which might be supported or refuted by further evidence. It is an analytical process where the collected data can lead to re-classification or re-interpretation (Brodaric, 1998). This evolutionary classification may radically affect geologic map making. Hence such geologic hypermaps also have to take into account the possibility of updating multidimensional data in terms of time, space and assumptions.

Geological Surveys benefit considerably from the results of such applications. Within the framework of the geologic hypermap project we have worked closely with the Geological Survey of Northrhine-Westfalia, Germany (GLA NRW) since the beginning of the project in 1996. Our hypermap approach, known as GeoHyp, was tested in a pilot study using the 1:25,000-scale geologic map set of Brilon. This area was surveyed between 1987 and 1992 by Steuerwald (GLA NRW).

This article is organised as follows. Section 2 reports on human-computer interaction with geologic hypermaps. In Section 3 our developed tools are illustrated and Section 4 draws our conclusions.
2. Human-computer interaction with geologic maps

A geologic map set is composed of several thematic maps, which are made for different purposes (e.g., geologic structure map, hydrogeologic map and soil map). These data can be combined in an hypermedial organisation. Depending on the objective of the study, this is done in different ways.

Converting geologic paper maps into digital maps offers new possibilities for the representation of the underlying model. On the one hand, it enables the analytical process of geologic mapping, where the model and with it the geologic map may change dramatically if new data become available (Nickless and Jackson, 1994). On the other hand, geologic maps are used for different purposes depending on the specialisation of the user.

These two points show the needs for efficient database support (see Section 4). However, the best database is useless if it does not provide the end user with an easy-to-use interface to the available information. A common way to obtain an appropriate interface is to conduct interviews with specialists (Linton et al., 1989). Hence, we asked geologists from different disciplines (e.g., hydrogeologists, research geologists, soil scientists and structure geologists) about their specific way of working and their wishes for the interaction with digital geologic maps. The following points emerged clearly from the interviews.

- The need to design tools that handle geologic hypermaps was confirmed. The geologists wanted to interact with digital maps in the same uncomplicated way they do with hypertexts. They requested to be guided through the system and retrieve all the available information by clicking the mouse.

- Depending on the specialisation, each geologist needed different data and tools to handle them. He or she did not want to waste time by searching the entire set of information. It would be desirable to immediately retrieve a user-specific data selection.

- In the explanatory text of traditional geologic maps, it is difficult to follow the author’s steps of work leading to the resulting map. Due to technical limitations, only the final results of the interpretations are plotted and many of the true features of the map are lost, e.g., the uncertainty of borders between geologic units or the hypothetical nature of indicated geologic objects.

This study showed that, according to the level of specialisation of the geologist, different data and methods for interpretation have to be provided. For the development of the user interface, a flexible expert solution is adopted, where the layouts are fixed by the dialogue author (Wetzenstein-Ollenschläger and Wandke, 1990). To implement a first prototype, we selected the GIS development environment ArcView 3.0 (Environmental Systems Research Institute, 1998). This system offers a graphical user interface which can be expanded by user-defined methods. Additionally, the layer-oriented concept of a GIS database has the advantage that the graphical data can be stored and displayed as desired allowing separate layers to be related to each other in different ways.

A hypermedial map set was built which can be used in a straightforward manner. If the user selects one part of the map (region query), he or she receives a pull-down menu, which offers a choice of background information and interpretation methods. In addition, the user is guided through the system by a number of dialogue boxes.

The prototype has been evaluated by various test users during the development phase. The results were used to improve the user-friendliness of the prototype, which is of prime importance (Khoshafian et al., 1992; Carey, 1994). The hypermedial structure of our prototype is described in detail in Kübler et al. (1998). We focus here on the background ideas of our project and the experiences and insights we gained in its development.

3. User-specific tools

Based on the results of the interviews with different specialised geologists, a requirement list for accessing and analysing geologic hypermaps was compiled. It became clear that the standard tools of ArcView were not adequate to satisfy all of the geologists’ needs. For this reason, many specific tools were developed with the script language of ArcView, AVENUE (Environmental Systems Research Institute, 1996).
One important result of the interviews was the need for different data and tools depending on the question geologists want to solve with the map. In the prototype, therefore, a number of interfaces for different user groups, such as general geology, hydrogeology, soil science and structural geology, are provided. They all can be invoked from a popup menu.

According to the choice of the user, he or she obtains tools and data matching the specific requirements. For example, by selecting the option “Research Geology” the user retrieves the geologic map and the respective cross sections. The geologic map includes the geologic units, the position of the cross sections and the locations of outcrops, fossil records and drillings. This map then serves as a hypermedia interface to additional information. Via hyperlinks, the map symbols are connected with their background data. For example, the text explanations about a geologic unit are shown by selecting the corresponding symbol on the map. By clicking on a profile line, the full profile can be invoked. Location points of outcrops, photos, drill hole logs, sketches or video sequences can also be viewed.

To handle these data, various tools were implemented. In the following section specific tools for geologists and soil scientists are described.

3.1. Specific tools for geologic requirements

For geologic requirements, special tools can be called from the graphical user interface (GUI) by buttons or a menu, which appears if the user selects one part of the digital map. These tools can be grouped into the themes ‘Flexible attribute display’, ‘Information for a given area’ and ‘Call for additional information’. Additional tools (‘querying for background data’, ‘database views’, ‘selection of map objects’) are described in Kübler et al. (1998).

3.1.1. Flexible attribute display

Many of the interviewed users complained about the fact that geologic paper maps are overfilled with symbols. For instance, the colour of the geologic units illustrates their stratigraphic age while the texture defines their lithology. These two symbols also are often overprinted with textual abbreviations, which additionally display the stratigraphic age and the lithology of the geologic units. Much time can be lost trying to extract the required information from the map. To solve this problem, we decided to implement the method of “flexible attribute display” (Lin et al., 1995).

The resulting tool enables the user to re-classify geologic units by their attributes. The user can choose the attributes of interest from a pull-down menu. Available attributes of the geologic units are, for example, their stratigraphic age, lithology, genesis, thickness, engineering properties or permeability for groundwater.

The selection of the desired attribute results in a re-drawn map with a new colouring. The respective legend also is modified according to the chosen classification attribute. In Fig. 1 the geologic units are re-classified according to their thickness (note that in the figure the geologic units are written in German on the left-hand side). This was accomplished using the data classification functionality of ArcView (Environmental Systems Research Institute, 1998).

3.1.2. Information for a given area

Another result of the interviews was noting that users of traditional geologic maps require excessive time to find the relevant information just for one part of the map. When using an analogue map set, the geologist must compare the region in different specialised maps (e.g., a hydrogeologic and soil map), search for the corresponding textual explanations and finally draw a conclusion.

This tedious way of working is facilitated by a method that readily displays the attribute values for a given area of the hypermap. The user has the ability to define a search radius and to choose one attribute of the database from a menu, thereupon the database entries for that attribute and within the search radius are presented in a window. This might be, for example, the lithology of the geologic units within a given area (Fig. 2).

3.1.3. Call for additional data

Our approach of providing the different users with domain-specific data saves considerable time. But for some purposes, additional data or maps may be necessary. Therefore, the user can select additional GIS layers or maps from a pull-down menu. These might be tectonic structures, tectonic values, con-
tours of height, topography, climate data, borders of administration areas, nature units, the map of soils, the map of hydrogeology, the map of engineering properties or the geologic overview map. Each belongs to data sets associated with various user groups.

3.1.4. 3D visualisation aspects

So far, there is no 3-dimensional model of the prototype area incorporated into the GeoHyp interface. We have, however, built a digital elevation model (DEM) and draped it with the geologic units
Fig. 2. Database entries of one attribute in a given area.
using the Virtual Reality Modeling Language (VRML) (WEB3D Consortium, 1999) to visualise the geologic structures on a 3D surface. Our hypermap model can be mapped into that VRML model as well as to a possible future 3D model in GeoHyp.

3.2. Specific tools for soil scientists

According to the results of our interviews, one important task of geologists who work at a Geological Survey or in an engineering company is the preparation of data for environmental impact assessments. Another important task is to decide whether an area is planned for different competitive uses (e.g., the use of a site either for agriculture or to be protected). In this context, the properties of soils have to be evaluated. Therefore, we prepared several tools that support the analysis of the soil map in a semi-automatic manner. The term ‘semi-automatic’ is used here to emphasise that these tools must not be used in a black-box approach. It is always sensible that the expert should check the computer’s decisions.

In our prototype we integrated the 1:50,000-scale soil map of the Brilon area into the GeoHyp database. In the same way as for the GUI of the geologic map, all tools are available through a pull-down menu, which appears if the user selects by mouse one part of the digital map. In that menu, the tools are grouped into themes such as ‘Protected soils’, ‘Functionality’, ‘Background values’, ‘Flexible attribute display’ and ‘Information for a given area’.

3.2.1. Protected soils

In the case of planned construction, the aim of environmental impact assessments is to identify soils that have to be protected. Schraps and Schrey (1997) defined criteria to protect soils in Northrhine-Westfalia where our test area Brilon is located. These include the natural water and nutrient content, the

Fig. 3. Soils protected because of their natural fertility.
natural fertility and the local and regional importance or rarity of the soils.

The GeoHyp prototype automates all necessary selections from the database. For example, if the user desires to display the soils that should be protected according to their natural fertility, soils with a high usable field capacity and a high cation exchange capacity are selected (Fig. 3).

As the defined selection criteria are quite general, this tool can also be used to analyse soil maps of other regions. If any special rules have to be considered, the selection process can be easily modified.

3.2.2. Soil functionality

Another factor for environmental impact assessments is the evaluation of the soil functionality. This is necessary in order to find the best solution if competitive uses are planned for an area. We implemented three tools to support the classification of the soils according to their site importance based on natural vegetation, agricultural use and water storage.

The database is queried automatically. For example, to find the important sites for agriculture all soil units with high soil moisture and a high cation exchange capacity are chosen. The respective soil units are marked in a special colour in the map and a window displaying the selected part of the database appears. Additionally, for each soil unit, the database views are accessible by mouse click. In a report window, the actual use, suitability for agricultural use and the agricultural yield potential of the chosen soil unit are summarised.

3.2.3. Background values

In the framework of environmental impact assessments, the contaminant content of the soil often must
be investigated. To assess the results of chemical sample analysis, it is important to understand the natural background values of the soil, especially because the contents of chemical elements differ depending on the geologic substrate from which the soils originate.

For the soils of Northrhine-Westfalia, Liebe et al. (1997) proposed a set of substrate specific background values. They are based on several samples of different sites. We converted these values into a GIS-layer, which can be called up from the general tool-menu (described in Section 3.2). With ArcView’s Info-Button, the user is able to explore the background chemical content values of a soil unit by mouse click (Fig. 4). This approach can be transferred to other regions than Northrhine-Westfalia if the specific chemical background values are known.

3.2.4. Flexible attribute display / information for a given area

For the soil map, as for the geologic map, flexible views of the underlying database are provided. The soil units can be classified according to various attributes such as field capacity, cation exchange capacity, water permeability, yield potential, geologic substrate, soil moisture, clay content or effective root depth. The results can be stored in thematic maps. Additionally, the values of one attribute for a given area can be displayed in a message window (see Section 3.1.2).

4. Conclusions and perspectives

In this article we described the basic concepts of GeoHyp, the hypermedia interface for geologic maps. A recently revised geologic map of the Brilon area in Northrhine-Westfalia was used as a test application. The underlying hypermap model was developed on the basis of the results of interviews with different specialised geologists.

GeoHyp is an easy-to-use, flexible, expert solution-type interface. From a start menu, various task-specific tools may be invoked. These tools enable the user to access and analyse the available data and map objects. An evaluation by a number of test users has shown that the prototype is a good solution for the interaction between geologists and digital geologic information. Furthermore, it revealed that it matches the users’ expectations. These results indicate that we have solved the first two of the three points we have drawn from the interviews. The final point can only be accomplished by the development of a model for geologic metadata.

It is necessary, therefore, to develop a data model, which enables the storage of background information (e.g., description) for each single geologic object of the layer. These background data consist, on the one hand, of measurements and observations made in the field and, on the other hand, of interpretations and classifications that summarise the collected data to a geologic object. Additionally, it would be desirable to consider metadata concerning the measurements, interpretations and classifications. This could be the declaration of the fault intervals of a measurement method or the listing of the involved theories.

Such a data model, which is based on geologic concepts and the rules of interaction of geologic objects, is an abstraction of the geologic mapping process (Brodaric, 1998). Certainly, at the beginning, the construction of a metadatabase requires considerable time — more time than is usually available for the traditional mapping process where only the results of the interpretations are present in the explanation text. The more geologic maps are linked with the incremental steps of their origin, however, the more likely it is that common principles of the mapping process will be found. This enables new possibilities for standardisation in geology. Although geologic interpretations are subjective, they are often based on rules stemming from the similar education of all geologists. For example, field observations are often summarised into a geologic object, which is a member of a defined classification schema. In this case, it is sensible to hold the different types of geologic units and classes, and their relationships, in a set of database-defined classifications (Giles et al., 1997; Power et al., 1997; Richard, 1998). Storing metadata that includes the assumptions and the individual procedures of a map’s author improves the comparability of neighbouring map sheets. In addition, updating maps becomes easier.

We are currently working on a geologic data model that supports theories and assumptions under various interpretations. First studies on the reasoning of the geologists and the consequences for data
representation and manipulation can be found in Abu-Khalil et al. (1999) and Voisard (1999).

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