The application of GIS in geological cartography

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A b s t r a c t. Paper contains a description of uses of Geographic Information System (GIS) in the field of geological cartography, mainly at the Polish Geological Institute (PGI). The PGI uses GIS, since a dozen years, in several mapping projects to produce databases and state-of-the-art maps: Detailed Geological Map of Poland, Hydrogeological Map of Poland, Geoenvironmental Map of Poland (all in the scale 1 : 50,000, although maps in other scales are also created). Cartographic databases are used to solve practical and scientific problems; examples are provided. Thanks to the digital maps production, aided by GIS, the spatial geological data are made available and published as maps in digital formats like raster files or vector GIS data or as online map services. Spatial geological data are the crucial part of Spatial Data Infrastructure on every level, therefore, the data should be used to create corporate (geological) SDI and should be integrated with existing SDIs, like the national SDI (www.geo-portal.pl) and the European SDI (INSPIRE).

Key words: *GIS, geological cartography, map service, database, geospatial data portal, Spatial Data Infrastructure*

The PGI fulfils the tasks of the national geological survey and is the main coordinator of geological mapping in Poland and conducts methodic works according to the Polish Geological and Mining Law. Thus, the Polish Geological Institute (PGI) is predestined to create and manage the nation's biggest resources of geological maps and databases.

Access to information is very important at present times and GIS aided discovering, processing and visualizing of information digitally, in its spatial and sometimes temporal aspect. GIS is used in many fields, not necessarily within the Earth sciences, that is geography or geology, but also quite different, like business management, decision making in local administration and self-government, transport, public security, health protection, tourism, telecommunication etc.

GIS is defined in many ways. Search for definition of GIS in Google returns hundreds of references in Polish language and hundred thousands of references in other languages, mainly in English. Some definitions stress that the components of GIS are software tools and databases which are operated by user possessing skills of selecting and using tools from GIS toolbox to process the real world data to achieve expected results (Fig. 1).

All GIS definitions emphasize that GIS is a system which groups together several functions for spatial referenced data (databases). These functions are as follows:

1. Collecting (capturing) and updating data;
2. Storing and managing data;
3. Searching data;
4. Processing data, that is integrating, manipulating, analyzing and modeling;
5. Visualizing (displaying) data.

Some definitions emphasize the aims, which can be achieved by using GIS: solving organizational and planning problems and decision making. When GIS is used in geological cartography, its most important applications are: map editing, as well as solving and visualizing scientific problems.

GIS is described not only by formal definitions. GIS can be also charcterized by its ability to carry out spatial operations; there are five generic questions GIS can answer (Understanding GIS, The Arc/Info Method, 1997):

1. Location — What is at …?
2. Condition — Where is it?
3. Trends — What has changed since …?
4. Patterns — What spatial patterns exists?
5. Modeling — What if …?

GIS systems are developed since about 40 years and the history of GIS usage in PGI is similar to its evolution during this 40 years history. It can be divided into three stages: the first one was the time of data collecting and map editing, however, GIS is not simply a system for making maps (Understanding GIS, The Arc/Info Method, 1997); the second one involved mailny analyzing of data and the third one is managing and solving scientific problems. This order results from the need of collecting data for the next stages of analyzing and visualizing.

Collecting data in databases

The first professional GIS software was bought for the PGI in 1993. It was the ArcInfo system developed by the Environmental Systems Research Institute (ESRI). Several years later another system appeared, the Intergraph.

Since 1994, the ArcInfo system has been used for a big GIS project: computer-aided production of the *Detailed Geological Map of Poland in the scale 1 : 50,000* (*DGMP*). The project involved testing and development of the *DGMP* database itself, dedicated applications for map and database production and preparing the map sheets for offset printing. Offset printing was then replaced by plotter printing on demand after years. Additionally, the *DGMP* became available digitally as raster images in PNG format and vector data in export files of ArcInfo or shape files. Several applications, which were prepared with the Neokart GIS, are used by map authors, database operators and technical editors up to now. These applications facilitate administration of the database, as well as preparing and verifying data for database and technical edition of the map sheets. By now, 52% of the planned 1069 *DGMP* sheets have been digitized and loaded to the database; each sheet covers abo-

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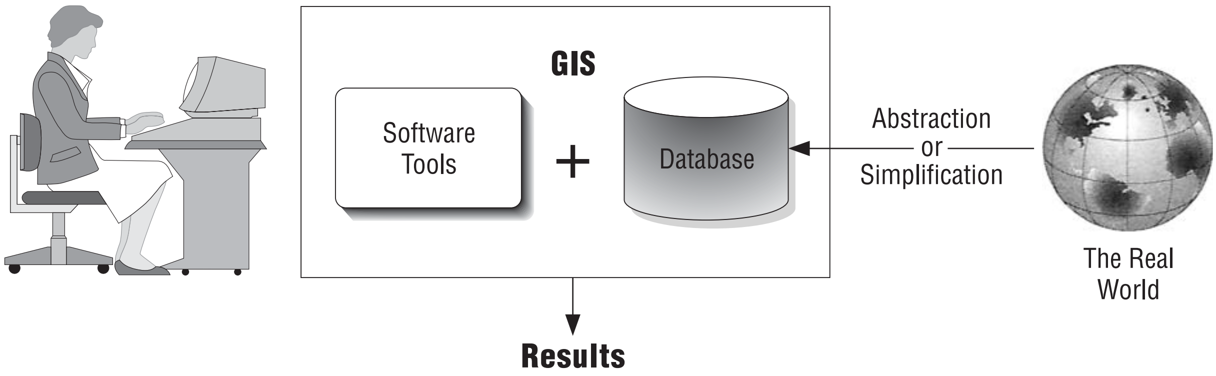

Fig. 1. Components of a GIS (after Understanding GIS, the Arc/Info Method, 1997)

ut 300 square kilometers. The remaining map sheets should be digitized within the next 10 years. It is due to the time consuming process of map digitization and map editing – every sheet is composed of up to several thousands of polygon, line and point objects, representing different geological structures and phenomena. Additionally, map production in the field is not finished and will continue until 2010.

The next two cartographic projects of nationwide maps began in the second half of the 1990s: the *Hydrogeological Map of Poland* (*HMP*) and the *Geological-Economic Map of Poland* (*G-EMP*), both in the scale 1 : 50,000 with the same map index as the *DGMP*.

The *DGMP* project used GIS as a computerized tool for continuation of a map that was originally started in the 1950s. The *HMP* and *G-EMP* were digital projects from the beginning. The *HMP* was finished in 2004. Database updating and modernizing its structure, converting to seamless GIS database and development by adding new coverages are the current tasks. The *G-EMP* project will be finished in 2007, because several hundred sheets remain to be compiled and digitized. This map is updated by adding new coverage before completing the map edition. The *G-EMP* with new information layers is called *Geoenvironmental Map of Poland in the scale 1 : 50,000* (*GMP*).

The Central Geological DataBase (CGDB) is administering significant resources of GIS data, which are collected in spatial subsystem as coverages of borehole location (five layers), archival documentation (three layers), research points, raw minerals deposits (two layers), three countrywide maps (*DGMP, HMP, G-EMP*) indexes and source vector data, topographic background (nine layers). The newest technology, that is server of spatial data ArcSDE, is used for data storage in the CGDB.

Many maps and atlases (geological, tectonic, geochemical, etc.) are produced at the PGI, but they are not produced in GIS format and none of them possesses associated databases. These maps are produced and edited with graphic software like CorelDraw. It is an easy way for map production but without the benefits of GIS and database use. Graphic programs have impressive tools for technical map editing but GIS with its topological relationships provides more powerful and universal toolbox (Bedell, 1995).

New GIS projects are under way and will be continued in the future: new editions of geological maps of Poland in the scales 1 : 500,000 and 1 : 200,000, new edition of the *Tatra Mountains Map in scale 1 : 10,000*, new *Litho-genetic Map of Poland in the scale 1 : 50,000*, *Geoenvironmental Map of Degraded Areas and Increased Natural Hazard Risk in the scale 1 : 10,000.*

Processing data in GIS

GIS is an analytical tool for processing data. Analytical functions can be used efficiently thanks to the ability of GIS to create and store topological (spatial) relationships of map features. Points, lines and polygons represent map features. Other important factor is the ability of GIS to join geometric and descriptive data.

Several projects were prepared using of spatial geological data to answer questions about location, condition and modeling of flood risk in some regions: Warta and Odra River Valleys (Kocyła, 1997).

The extent of the last glaciation is being verified and re-traced on-line with the use of database of the *Detailed Geological Map of Poland* (Fig. 2). The database is 55% complete and will be filled in within the next few years. The database of the *DGMP,* together with the data from other Peri-Baltic countries, was used in 2003 to create the Map of Weichselian directional ice-flow features of Central and Eastern Europe (Marks et al., 2003). Ice-flow directions were detected from linear glacial landforms mapped and recorded in the *DGMP* database; they are direct (streamlined landforms) and indirect ice-flow features (glacial tunnel valleys, eskers, kame chains, end moraines).

Visualizing and making available data: maps and map services

A lot of people used to make traditional use of the paper maps. GIS development allows to re-evaluate map concept and map usage. GIS was inaccessible, difficult to use and expensive years ago but this has changed and digital maps are becoming common now. More people have access to the Internet and commercial GIS companies offer not only expensive professional systems, but also free GIS explorers. These GIS explorers allow users to read cartographic databases, maps composed on demand and to connect to map services.

PGI follows users expectations in making available its cartographic databases in many formats and forms: offset and plotter prints, raster maps, vector data. Three map services deliver cartographic data to end-users. The first one is the Internet map service of the Central Geological DataBase (Fig. 3), the second one is the Intranet Map Service of the CGDB and the third and newest one is the Internet map service of the *Geoenvironmental Map of Poland in the scale 1 : 50,000* (http://mgp.pgi.gov.pl).

GIS, geological cartography and Spatial Data Infrastructure (SDI)

Geospatial portals are mushrooming. They are on-line and easy to use access points to collections of geospatial data and services. Geospatial portals are tools for data discovery, access, integration and application of geospatial data and services, view geospatial data as maps (Harrison, 2003). A geospatial portal delivers spatial data in accordance with the OGC specifications like Web Map Service (WMS) and Web Feature Service (WFS). Simplified structure of a corporate (geological) geospatial data portal of the Geological Survey of the South Africa (Council for Geoscience) is shown in Fig. 4.

New geo-portals are the effect of the ongoing process of construction of the Spatial Data Infrastructure. The SDIs are being built thanks to increase of digital cartographic resources and development of GIS. SDIs are being developed in many countries and on many levels: local, corporate, national, European and international. Polish country-wide portal (www.geo-portal.pl) was established several months ago commissioned by the State Geodesist with a cooperation of Centre of Geodesy and Cartographic Documentation.

A definition of SDI according to Ryghaug (2005) is worth quoting here. "... SDI is:

- ❑ metadata, spatial data sets and spatial data services;
- ❑ network services and technologies;
- ❑ agreements on sharing, access and use;

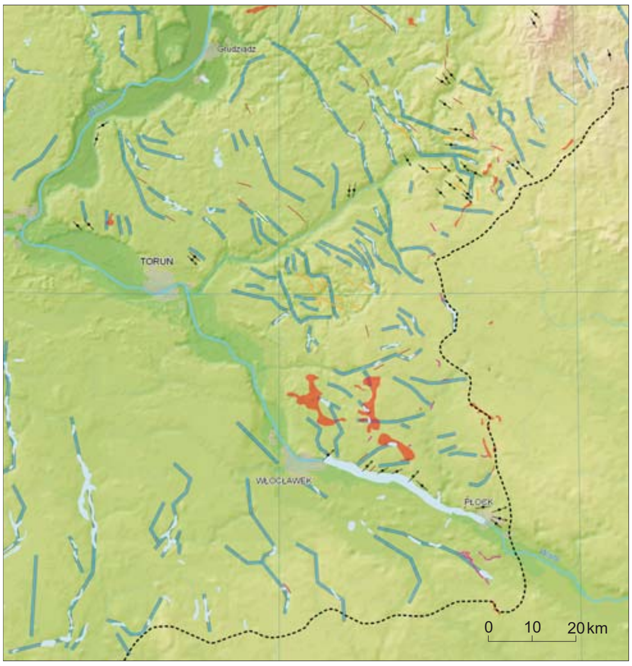

Fig. 2. Fragment of the *Map of Weichselian Directional Ice-flow Features of Poland in 1 : 500,000 scale* (Marks et al., 2003)

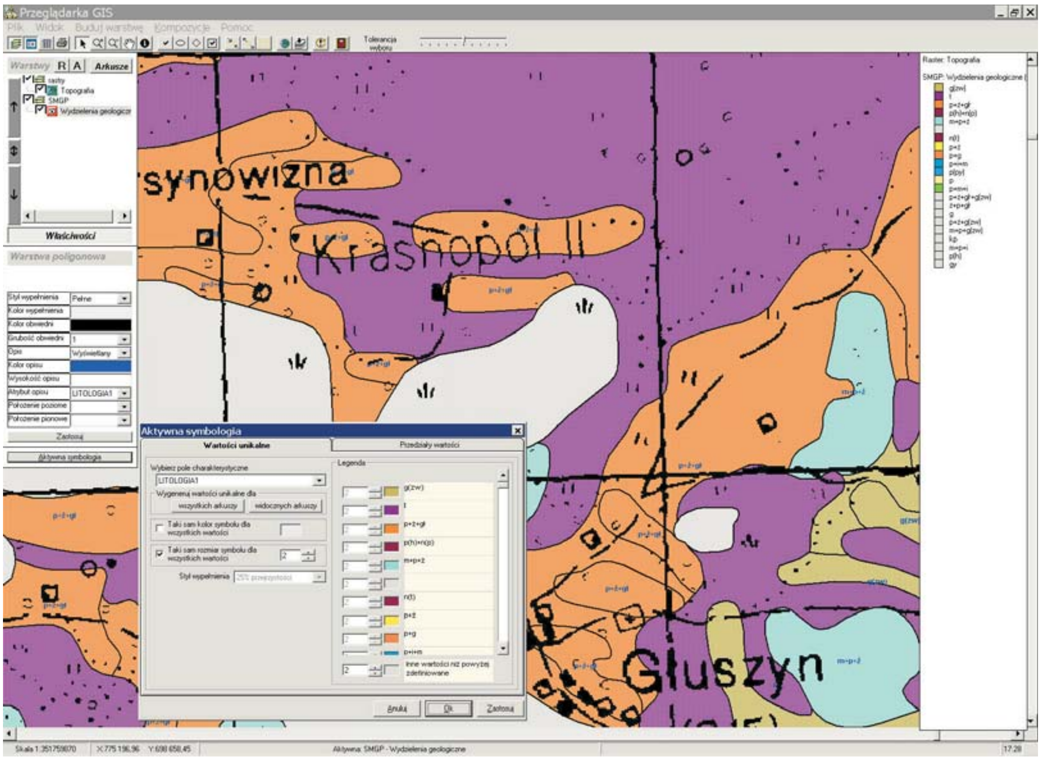

Fig. 3. Fragment of the Krasnopol Sheet of the *Detailed Geological Map of Poland in 1 : 50,000 scale* in Intranet GIS explorer of CGDB: lithological map was created with use of selected coverages

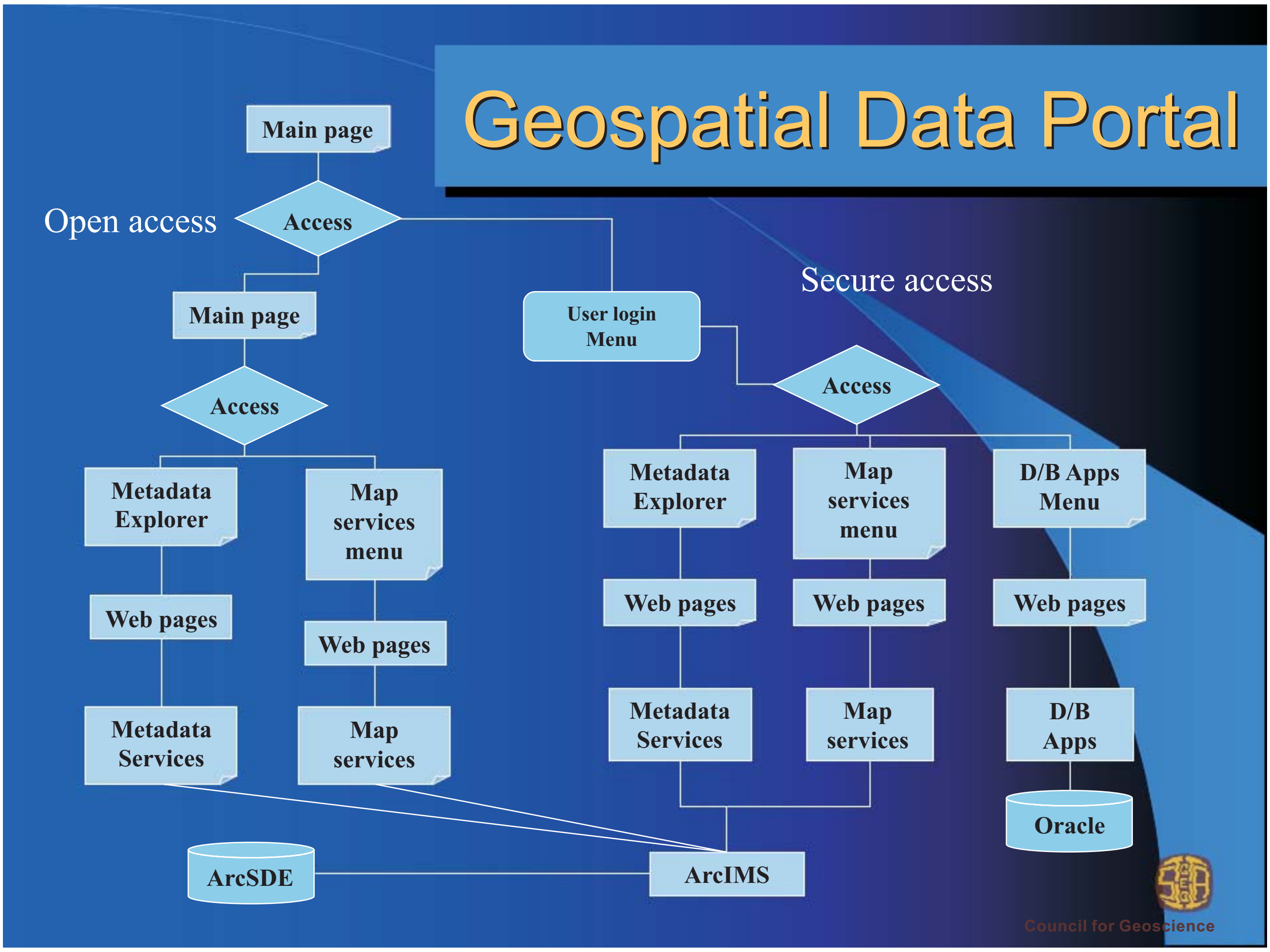

Fig. 4. Model of the Geospatial Data Portal of the Council for Geoscience — Geological Survey of South Africa (after Brynard, 2005)

❏ coordination and monitoring mechanism, processes and procedures established, operated or made available in an interoperable manner.

SDI in his context constitutes a platform and implementation-neutral technological infrastructure for geospatial data and services, based upon standards and specifications (ISO, OGC etc.)… ”.

Geological cartography is the crucial part of spatial data infrastructure on national and other levels. Geological data are a part of initiative of Infrastructure for Spatial Information in Europe (INSPIRE).

Conclusions

Geological cartography provides basic data about geological structure of the country and GIS is a powerful tool aiding in collecting, processing, visualizing, discovering and sharing these data. Polish spatial databases, especially databases of maps in detailed scales (1 : 50,000) accumulated very rich data during the past decade.

The people involved in digital, GIS-aided geological cartography, have to cooperate in creating corporate, national and European Spatial Infrastructure.

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