# Geospatial data integration in rock engineering

**Joanna Pinińska***

*Abstract. Despite the development of measurement methods and the increasing amount of new generation data in rock engineering, many valuable information data are lost together with the locked-out mining archives and associated research institutions. Consequently, a lot of valuable, unique information which could be transformed into new values totally vanishes. Geomechanics, as a relatively new discipline, has so far no tradition of integrated databases. In the European Union, integration attempts are realized through enforcement of the uniform standards; however, the standardization alone will fail to be a successful integration solution until the Digital Terrain Model Data is not implemented into the rock mechanics. Modern information technologies enable to combine and visualize various thematic data, e.g., geological, hydrogeological and mining into a unified digital system with reference to Geographic Information System (GIS). If all the geomechanical data are clearly localized, they can be interpreted, presented, and supplemented with the archival data in a unified format. Visualization of the content of the relational databases by means of digital maps can be done automatically which, as regards rock engineering, will enable the automatic integration of the laboratory data with the geospatial conditions of the environment, including the Spatial Information System (SIP) or Terrain Information System (SIT), i.e., the topographic, geological/environmental and anthropogenic situation (like population, infrastructure, land use plans and prognoses of hazards caused by the land transformation).*

**Key words***: rocks, rock engineering, database, geospatial positioning, GIS, visualization, data management, strength, deformability*

Management of the broad datasets in rock engineering becomes more and more difficult, not only because of the increasing range of the assessed properties, but also due to the natural, descriptive character of many data, influenced spatially by the geological conditions of the rocks massifs (Fig. 1). Requirements of EN-ISO standards on identification and description of rock mass, rock material and rock sample are also very wide-encompassing (EN-ISO, 2003). Due to incorrect management, the obtained data are either not used to their full potential or, as in case of many not archived ones, get lost. The need to change this situation becomes urgent and the decision regarding the scope of field surveys, borehole and laboratory investigations data, their collecting, storage and accessibility is the main topic of many European and global engineering bodies (ISRM, 1978; ISO, 2000; IAEG, 1981; EN-ISO, 2003).

Although there is a number of computerized local registers covering information about the rock media, they are not correlated with one another, which makes them useful only for particular institutions or within a narrowly defined topic. Therefore, it is essential to design and implement an integration system for the diverse but dispersed information, which was collected at great financial cost, and to ensure their broad applicability with an easy *online* access.

As far as rock engineering is concerned, data integration does not seem to be a very demanding task, due to archiving process of the data according to the GIS (Geographic Information System) regulations. Due to the fact that these data pertain to actual rock media (objects), localized clearly in the natural area, it is possible to assign to each of these objects certain geographic location according to the longitude and latitude ($\phi$ and $\lambda$) and the $z$ co-ordinate referring to their elevation relative to the sea level (Fig. 2). Flat geographic co-ordinates can be established with pocket set of global positioning system (GPS) with the cartographic accuracy corresponding to the 1 : 10,000 map scale, and the elevation co-ordinate of the given point can be assessed approximately with help of the elevation data embedded in a Digital Terrain Model (DTM).

Object attributes and data identification, in reference to the generally applied localization system based on geographic co-ordinates, create a relational database which can be

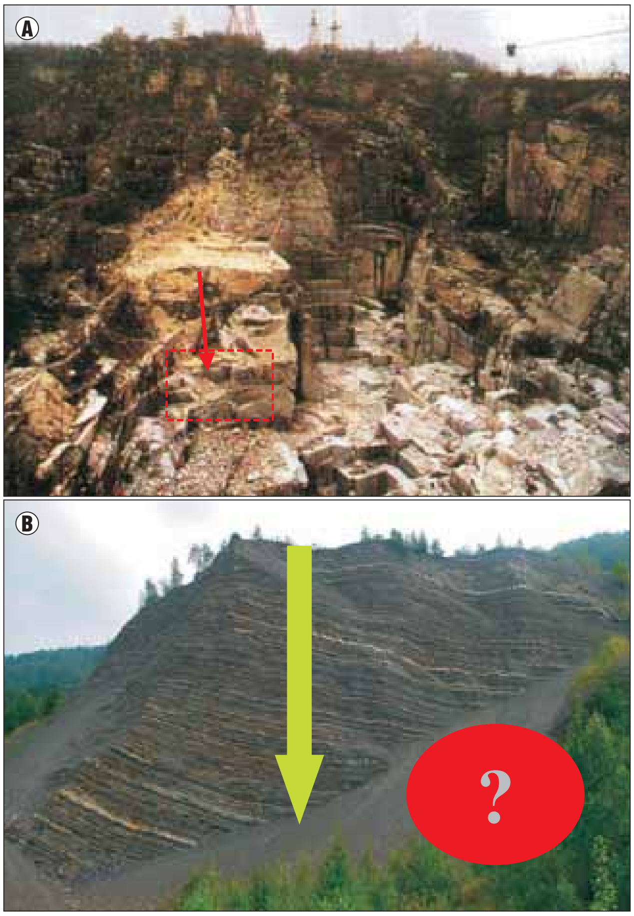


**Fig. 1.** Fissured and schisted rock massif. The term *rock mass* refers to the *in situ* rock together with its discontinuities and weathering profile. The term *rock material* (A) refers to the intact rock within the framework of the discontinuities (EN-ISO, 2003), while the structure of the rock massif (B) is more complex to describe (?)

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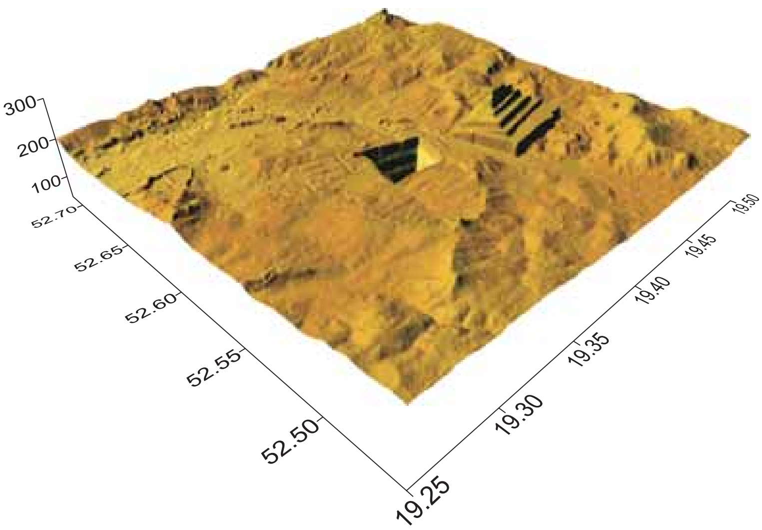
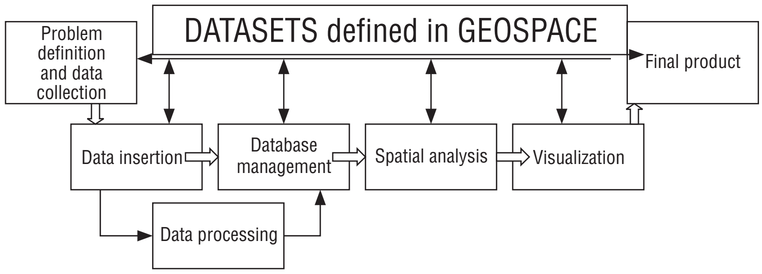



**Fig. 2.** Geological object (excavation) localized according to the geographic situation: longitude and latitude (ö and ë) and the co-ordinate referring to the sea level




**Ryc. 3.** Structure of data localization according to the GIS system regulations (Star & Estes, 1990)

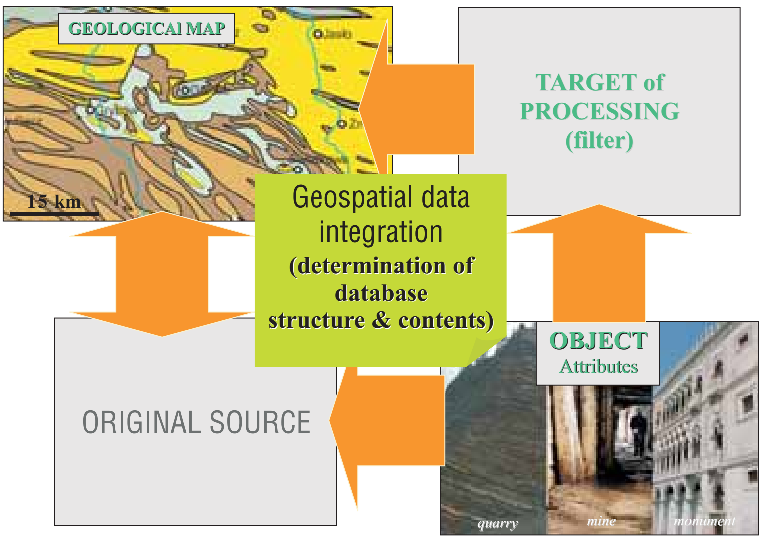



**Fig. 4.** Database functions according to the GIS regulations. Object attributes and data identification, in reference to the generally applied localization system create a relational database which can be mutually integrated and visualized selectively on interactive thematic maps with respect to the key elements of geological situation for a selected engineering problem

mutually integrated and visualized selectively on the interactive thematic maps with respect to the key elements of terrain and geological situation. Data about the objects stored in the relational base can be displayed on a computer screen, whereas supplementation and other changes can be reflected in the content of interactive maps.

Integration of the geomechanical data nationwide will be possible only through implementation of the modern technologies of spatial data in everyday engineering practice. It will be essential to create a habit for registration of the data in reference to the geographic co-ordinate system, according to the regulations of Geographic Information System (GIS) already at the time of collecting the laboratory samples and integrating them with the Digital Terrain Model, e.g., the elevation dataset (DEM) or with the satellite images, geologic maps or any other thematic maps in their digital version.

Visualization of the content of the databases by means of digital maps can be done automatically which, as regards rock engineering, will enable automatic integration of the laboratory data with the geospatial conditions of the environment, including the Spatial Information System (SIP) or Terrain Information System (SIT), i.e., the topographic, geological/environmental and anthropogenic situation (like population, infrastructure, utility plans and prognoses of hazards caused by the land transformation). In consequence, data gathered in the geomechanical database will enable joint management of the environment and the related data.

## GIS principles

The GIS as a computer system which displays data in a spatial geographic co-ordinate system and which concerns all multi-functional datasets, whose location is clearly defined in the geospace (Star & Estes, 1990). The general relation of the databases functions according to the GIS regulations is shown in Fig. 3.

The essential prerequisite for adjusting a geomechanical database to the GIS regulations is the correlation of its content with the spatial model of the terrain already at the stage of gathering data, then storing them in the databases, processing, as well as analyzing them, in a way which will enable cartographic visualization of the final product (Fig. 4).

Geomechanical databases created according to the GIS model will have to employ special programs and procedures enabling the accumulation, management and visualization of its content in relation to the geographic co-ordinate system. Spatial localization of the objects described in a database is easy due to the limited scope of outcrops and mine excava-

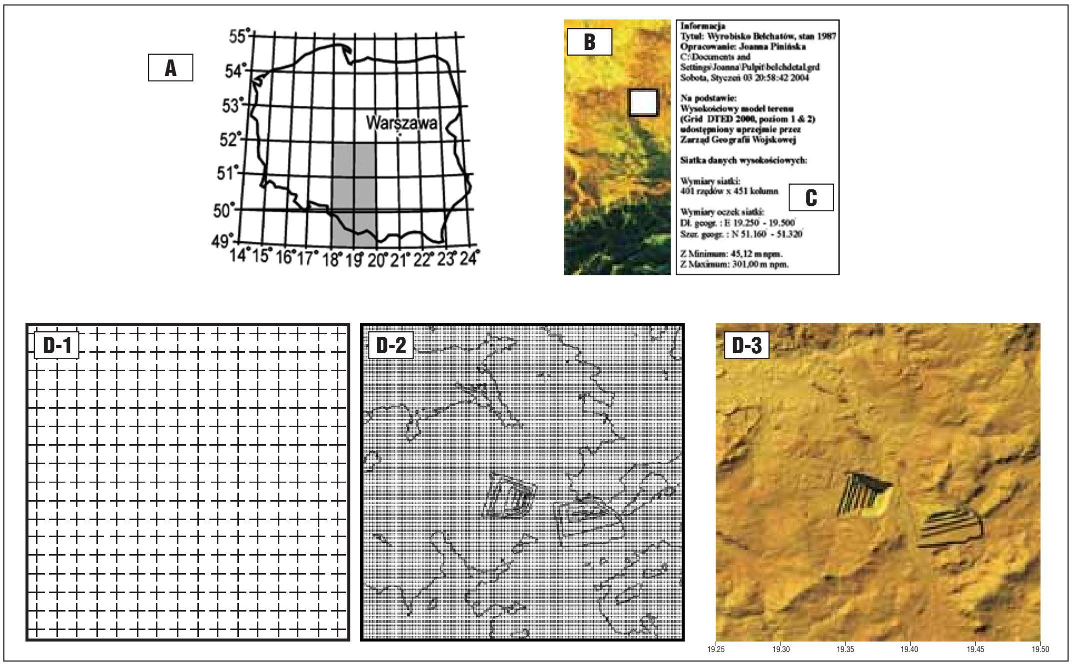



**Fig. 5.** Spatial localization of the object; A — in the geographic co-ordinate system; B — regional, on the elevation terrain model (DTM according to Surfer with colour interpretation); C — legend: Bełchatów excavation (in 1987), Scientific analysis: Joanna Pinińska, Saturday, January 04, Based on Elevation Terrain Model (Grid DTED 2000) provided with kind permission of the Quarters of Military Geography, Size of the grid: 401 rows per 457 columns, Size of the grid squares: geographic longitude: 19.250–19.500; geographic latitude: 51.160–51.320; above sea level: $z$ minimum 42.15, altitude $z$ 301.00; D — detailed with indication of the site of collected monoliths. 1, 2, 3 — different versions of presentation (DEM): 1 — rectangular co-ordinates, 2 — flat grid, 3 — colour-graded model

tions or the spot-like character of drill holes. The idea of the object localization with reference to different digital versions of the terrain model is exemplified in Fig. 5A–C.

### Structure of the Geomechanical Database (BDG)

Experience accumulated during the creation of integrated Geomechanical Databases (BDG) (Pinińska & Dziedzic, 1996; Pinińska & Dziedzic, 1998a, b) in the Department of Geomechanics at the Warsaw University since 1992, serves as the best justification of the purposefulness, necessity and the real opportunity to implement GIS regulations in scientific research on rock mechanics. Presently, the BDG comprise data (nationwide) of 124 objects — 116

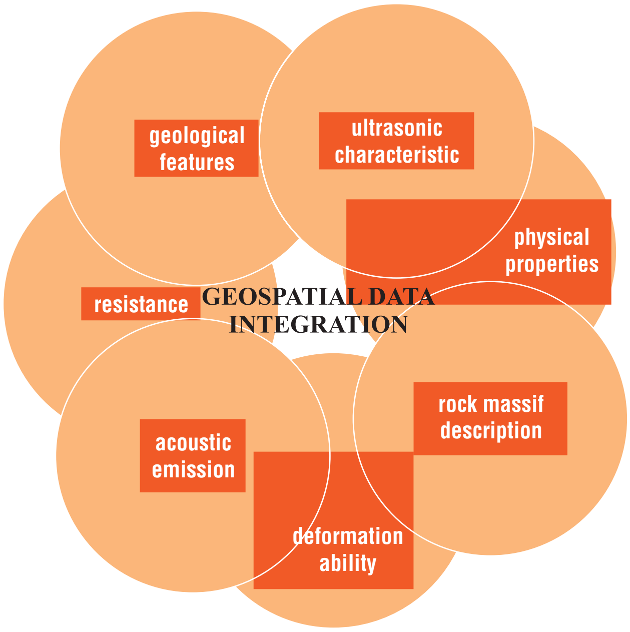



**Fig. 6.** Integrated localization of the objects attributes stored in a databases help with spatial, terrain, cartographic, lithostratigraphic and structural localization of the specific elements of the database

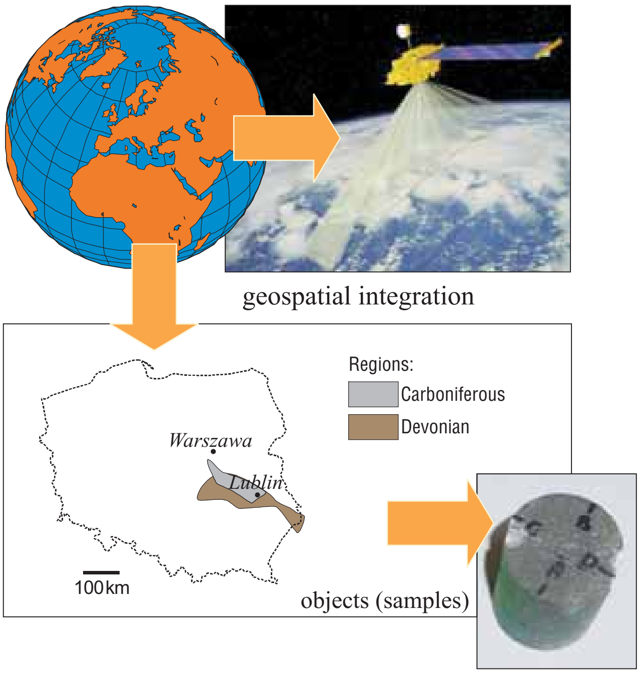



**Fig. 7.** Geomechanical database (BDG) search for data in the broad multi-thematic datasets for compilation of regional catalogues together with the quick selection of the information on each individual sample for particular scientific research

quarries and 8 cored boreholes from six geological regions of Poland, i.e., Świętokrzyskie (Holy Cross) Mountains (Pinińska, 1994, 1995), Sudetes Mountains (Pinińska, 1996, 1997), Przedsudecka (Fore-Sudetic) Monocline, Jura Krakowsko-Czestochowska (Pinińska, 1999, 2000), Lublin Trough (Jarzębski & Pinińska, 2000) and the Outer Flysch Carpathian Mountains (Pinińska, 2003), as well as other objects, e.g., cultural heritage objects (Pinińska & Attia, 2003).

Altogether, the database consists of 300,000 pieces of information, including 60,000 geomechanical parameters of Polish rocks determined in the Laboratory of Geomechanics during 1990–2003. Integrated localization of the objects and attributes stored in databases, according to their geographic co-ordinates (Fig. 6) helps with spatial, terrain, cartographic, lihtostratigraphic and structural localization of specific elements of the database, e.g., using MapInfo software.

As the final objective, the BDG shall to be correlated with the serial vectorized maps: The Detailed Geologic Map, Geo-Economic Map or Hydrogeologic Map.

The idea of the complex geomechanical database (BDG) was brought about by the necessity of the quick search for data in broad multi-thematic datasets to enable compilation of regional catalogues, charts and classification diagrams of building stones, together with the quick selection of information on each individual sample for scientific research (Fig. 7). As the base is open, it can accumulate and store new information, as well as archival data (Banna & Pinińska, 1997). The latter seem to be particularly important nowadays while many of the industrial institutions are being locked-out, causing an irrevocable loss of unique data stored in their possession.

As the Institute of Geomechanics specializes in laboratory research, the structure of its Geomechanical Database, shown below, comprises mainly descriptions and mechanical parameters of single rock samples. All the data are assigned to their geospatial localization values.

Inserting the data is done by means of universal editing formulas, according to the thematic modules and attributes (features) of the concerned objects and samples. The applied system of sample identification allows analyzing the research results in many different aspects. Owing to the easy access to the data characterizing either the defined object or the individual sample, it is possible to perform the analysis, according to the needs, either from the general to the specific and the other way round. Data management regarding the lithology of the rock is based on the universal five-grade classification of the lithologic features in the regional division of the strata.

Insertion of the data begins with the launch of laboratory research, with some of the parameters defined automatically according to algorithms and formulas chosen in the spreadsheet of the database. Further processing of the data and their automatic interpretation is done by the original subroutines. The BDG system allows independent insertion of the descriptive data, like, e.g., results of observations of the microscopic images, information about the weathering degree of a given rock, its usefulness or results of the fieldwork.

The content of the base is divided into eight main information modules (Fig. 8) comprising the detailed thematic attributes.

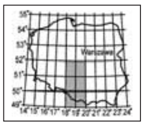
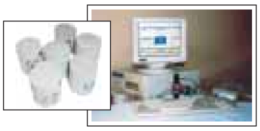
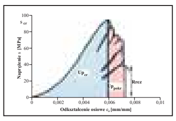
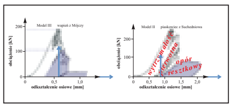
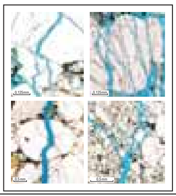
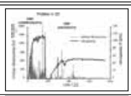
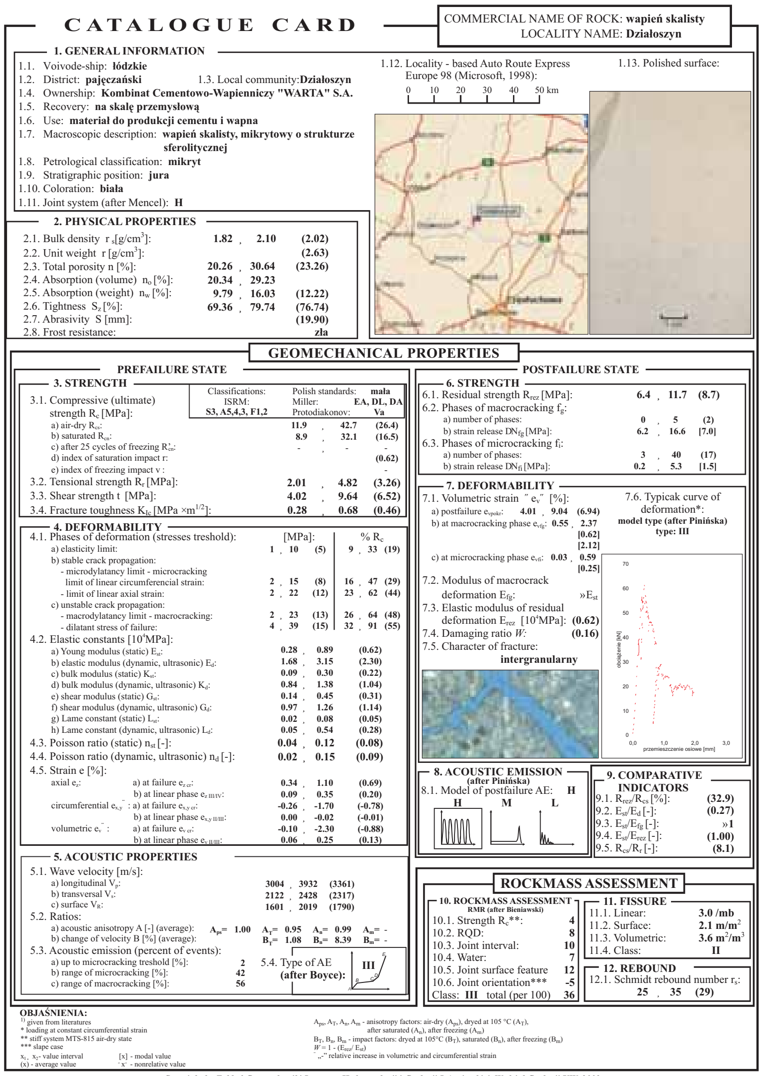
| INFORMATION MODULES | INFORMATIONS MODULUS | | ATTRIBUTES |
|---|---|---|---|
| | 1. Object identification |  | geospatial co-ordinates, administration data, type of the object, type of rock and purpose of research, engineering data, macroscopic description of the rock, technical and identification data of the sample, others |
| | 2. Geological data |  | age, tectonic structures, fracturing system, petrographic description, lithological classification, microscope images, others. |
| | 3. Physical features |  | unit density, volumetric density, porosity, absorbability, permeability, grindability, freeze resistance |
| | 4. Ultrasonic measurement |  | orientated velocity of the longitudinal, transverse and surface waves propagation, index of anisotropy, index of variation of the longitudinal wave velocity under positive temperature, saturation or freezing process |
| | 5. Geomechanical features |  | pre-critical: stress resistance (in air-dry state, after saturation, after 25 cycles of freezing) resistance against extension, shearing and brittle fracturing, index of resistance against freezing and softening; strength classes (e,g., PN-84/B-1080, Miller, ISRM , ISO) |
| | |  | post-critical: residual strength, modules of the main phases of deformation, module of residual deformation, ratio of the damage, fracturing character |
| | 6. Deformability features |  | pre-critical: deformation phases, stress values on the phase contacts, values of deformation (axial, circumferential, volumetric) on the phase contacts, elasticity constants |
| | | | post-critical: number of macro/microfracture phases, and the level of the stress/strain relaxation |
| | 7. Acoustic emission measurement |  | number of signals on the contacts of deformation phases, precritical emission model [Boyce at all1981], post-critical emission model [Pinińska 1992] |
| | 8. Rock mass assessment |  | field research, Schmidt hammer resistance, fissures character and system, RQD, RMR [Bieniawski 1974] |

**Fig. 8.** Contents of the information modules and their attributes in the Geomechanical Database (BDG)

According to the adopted editing structure of the database, data are coded according to the localization of the outcrop, even though its basic content shows the results of complex assessment of the individual rock samples. Each of the sampling sites is characterized by its geographic co-ordinates in the general information section. The basic data, introduced into the database using MS Access interface, cover the primary identification information about the samples and the direct laboratory measurement results. The derivative values are automatically interpolated, estimated and interpreted by means of macros. Hence, the resistance and deformability parameters based on the analysis of the deformation curve are interpreted by






**Ryc. 9.** Documentation Card as an example of presenting data stored in the database (BDG)

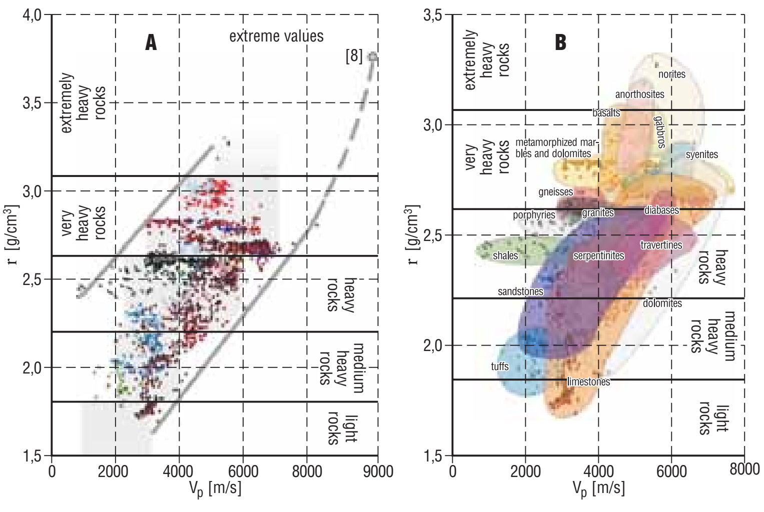



**Fig. 10.** General variation of the longitudinal wave velocity (VP) in the rocks of Poland in relation to the volumetric density classes (ń) according to PN-84/B-01080 and the class of the extremely heavy rocks of ń> 3.2 g/cmł (A) and lithologic variation of the rocks of Poland in relation to the volumetric density variation (ń) and longitudinal wave velocity (VP) (B)

application of custom-made macros created in the MS Excel spreadsheet. Similarly, values of stressing and deformation of the samples and their derivatives in the following deformation phases are processed.

The database can store information processed in form of reports, charts, diagrams and statistical data of the given parameters theme or localization. The search for any of the defined information can be done according to the following criteria: *quantity* criterion, i.e., how many outcrops or rock types of the defined characteristics are there in the region; *quality* criterion, i.e., which of the rocks in the region agree with the defined parameters; *valorizing* criterion, i.e., accessibility of the outcrop, conditions of exploitation, localization within the country.

Since the Geomechanical Database is environmentally and regionally conditioned, the synthetic product of GIS may involve the valorizing, local or regional maps.

## Application examples

One of the most important forms of presenting the data stored in the database is the Documentation Card (Pinińska & Dziedzic, 1996; Pinińska & Dziedzic, 1998a, b) which in its present form contains around 150 unified pieces of information about rock from each object (Fig. 9). It can be generated as a report in the MS Access programme and is therefore an integrated part of the whole database, which enables the cards to be updated and modified in the course of the research progress.

Another form of data presentation employs summary diagrams (Fig. 10) which present the trends of geomechanical parameters variation, like, e.g., the general variation trend of longitudinal wave velocity in rocks according to their volumetric density (Fig. 10A) or visualization of the volumetric density and longitudinal wave velocity variation classes in the rocks with different lithology (Fig. 10B).

The subject of interest or presentation can be as well the single data concerning deformation or fracturing processes according to the size of grains or mineral composition of a rock (Fig. 11A–D) which helps to assess post-damage behaviour of a rock, e.g., as a factor of the assessment of the rock weakening in the defined state of extension useful in building engineering or in assessment of the susceptibility to the harmful migration of dissolved agents in the valuable stone elements which is of interest for the conservation practice.

An example of application of the Geomechanical Database (BDG) in conservation works concerns the data about historic buildings, e.g., construction elements of Maadi Town Temple in Egypt (Fig. 12A– E) made of marly Paleogene and Neogene limestone, who-

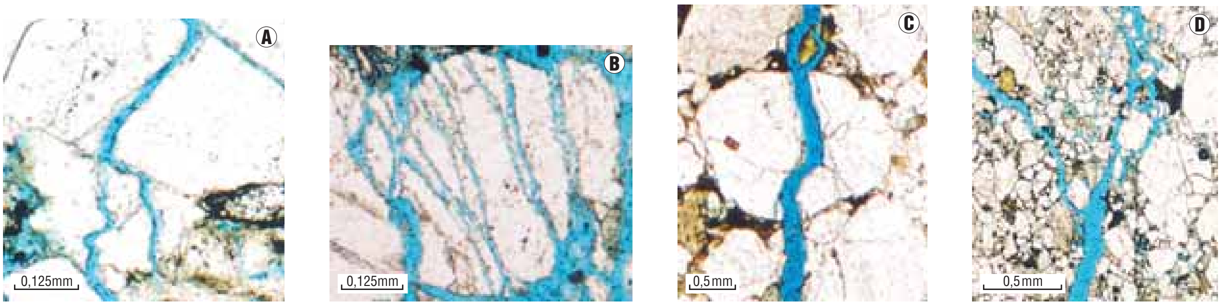



**Fig. 11.** Diversified character of the fracturing process in flysch sandstones; A– D micro-scale: A — intragranular fracturing (flysch sandstone with siliceous cementation); B — concentration of local intragranular defects; C — development of transgranular fissure (flysch sandstone of compact structure and carbonaceus cementation); D — wedging of the fragments in the fissure; average-grain sandstone with carbonate cementation


**Fig. 12.** Examples of the damages in the valuable stone elements of monumental objects: A — macroscale fracturing of the walls, B — efflorescence on pillars, C — closeup of the efflorescence (SEM), D — microfissure (SEM), E — salt crystallization (SEM), F — location of the described monuments

se samples were analyzed in the Laboratory of the Geomechanics Institute. One of the causes of their degradation was the cyclic twenty-four hour migration of the salt solutions in microfissures, intensified by the recrystallization of the salt crystals during the day. Complex revealing other degradation agents, with the help of BDG data, will aid in choosing the optimal conservation intervention.

Geomechanical Data can be also cartographically visualized on a geological background, in a regional or local system. Owing to the transfer of the object's co-ordinates, the object or its selected attributes can be localized with help of MapInfo programme on vectorized geological image of any theme and in any scale (Fig. 13A, B).

Information data are supplied to the MapInfo programme through the search command of the suitable recordsfrom the chart of geographic co-ordinate of the object in the given localization. Importing of the chart to the MapInfo programme allows visualization of the found records on the map background.

## Summary

Scientific analysis of the rock strength is expensive, time-consuming and sometimes possible to perform only in the highly specialized laboratories. Only proper gathering of research results and their *online* accessibility in the unified archiving system will enable to use them to their full potential in any demanded configuration.

In the process of closing the production of mining and geological companies or transformation of the research institutions, a lot of archival, often unique data get lost, even though they could have been stored in modern datasets, broade-

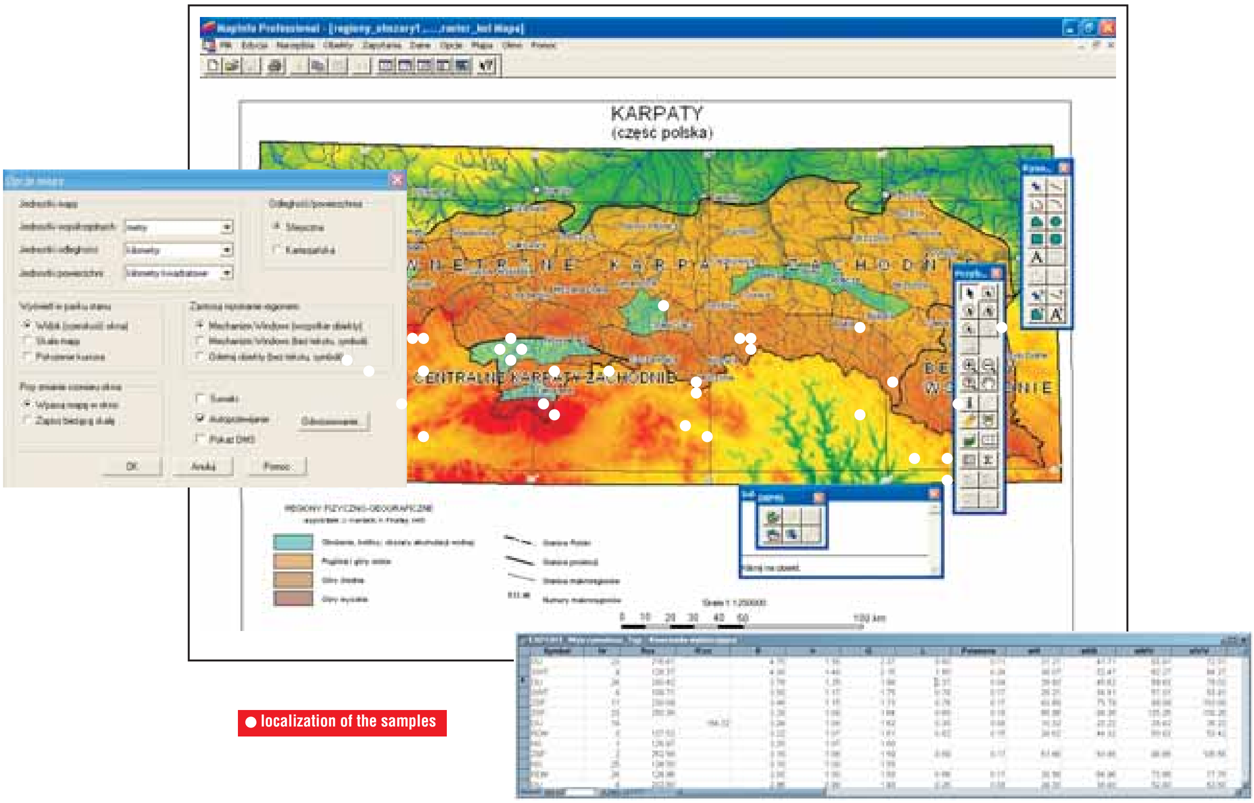



**Fig. 13.** Cartographic visualization of the objects on the geological background (according to MapInfo), regional localization: Outer Flysch Carpathians: localization of the samples

ning the scope of available knowledge and reducing the costs of the basic research.

Creating open, integrated databases, allowing easy flow of specialized information, directly connected with the Digital Terrain Model is the only way to economize data management in rock engineering.

The above analyzed examples show that the broad applicable character of the Geomechanical Database (BDG) makes them a multi-level carrier of information, ranging from the detailed scientific data about individual samples to the regional data concerning the rock formations. The BDG can eventually become a source of universal information about active, valorized or degraded quarries, their accessibility, and their legal or property status in relation to geomechanical parameters. It can as well serve as a source of information about the original materials in restoration of the valuable stone buildings, regionalization of the rock properties, and therefore be applicable in the comparative research on rock mechanics and in seismic studies.

Management of broad datasets within the integrated, geospatial relational databases is the only way of introducing regional diagnostic strength indices of the rock masses in rock engineering making use of the archival data.

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