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GEOINFORMATICA POLONICA
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TADEUSZ CHROBAK[1]

THE MAP AND GEOINFORMATICS

Key words:

cartography, geoinformatics, computer science, geostatistics

Abstract

The article presents the relationship between cartography and geoinformatics affecting their scientific and socio-economic development.

MAPA A GEOINFORMATYKA

Słowa kluczowe:

kartografia, geoinformatyka, informatyka, geostatystyka

Abstrakt

W artykule przedstawiono wzajemne relacje kartografii i geoinformatyki mające wpływ na ich rozwój naukowy i społeczno-gospodarczy.

1. Introduction

In August 1995 in Barcelona, the General Assembly of the International Cartographic Association (ICA) approved the definition of cartography as a science dealing with the conception, production, dissemination and study of maps.

The development of automation, information technology and telecommunication is the beginning of the new technology at work on the acquisition, processing and visualization. Its beginning dates back to 1963, when the first cadastral system, a computerized system in which maps constituted an integral part, was developed in Canada. The concept of geoinformatics as a science (GI - Science) was first introduced by Goodchild in 1992.

Cartography was formed in three historical periods: from the ancient times to the Renaissance, from the mid-sixteenth to the mid-twentieth century, and since the mid-twentieth century. The map, however, from its inception was the system, despite its analogue form. Changing technologies in cartography to digital resulted in the fact that digital maps are understood as specific models of space

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and are perceived not only as a model, an image, but also as a computer system that supports geoinformatics.

This article aims to demonstrate that the cooperation between the two disciplines is a prerequisite for their further development.

2. The development of cartography

Attempts to isolate an independent science of cartography fall on the beginning of the twentieth century, when the K. Peucker in his article *Drei Thesen der zum Ausbau theoretischen Kartographie* demanded the recognition of cartography as an independent discipline of knowledge. However, it is Max Eckert, who in 1970 published his article *Kartographie als Wissenschaft*, who is commonly considered to be the creator of cartography as a science. This work is recognized as a breakthrough in the history of cartography as a science (Freitag, 1971).

In the 1950s, there were first attempts to develop broader theoretical and methodological principles of cartography, and the growth of publications in this field occurred in the mid-1960s. The precursor of this deepened, scientific approach to cartography was a well known work by A.H. Robinson *The Look of Maps*, published in 1952, which initiated the study of perception of graphics maps, which is one of the main currents of scientific cartography. Besides mathematics, geodesy and Earth sciences, psychology was the first science used by cartographers to improve methods of map production. At the same time in the 20th century, new theories and disciplines developed, such as information theory, semiotics, theory of modelling, theory of knowledge, then science and the theory of scientific visualization, allowing a broader look at the issues related to mapping.

As noticed by D.R.F. Taylor (1991), for many centuries the main problem in the development of maps was to obtain a reliable information source, whereas a new technology of acquisition, processing and sharing information (GIS, remote sensing, the Internet) has led to an explosion of spatial data and the need for their transformation into useful information and ideas. The use of this technology has significantly dominated the research topics of cartography. A number of new concepts and terms, such as digital maps, dynamic maps, hypermaps, interactivity, virtual reality, multimedia technology, databases, mobile cartography, etc. have been created. From the second half of the last century, one can observe a gradual accumulation of various factors, which has been causing on the one hand the increasing demand for maps, and on the other hand the improvement in their development and production.

In the 1970s, Polish cartographer L. Ratajski (1978) proposed the following definition: "Cartography is a scientific and practical human activity, including the establishment and operation of all forms of cartographic communication, where the concept of cartographic communication is to be understood as a form of chorologic communication, which means the transfer of information about the distribution of facts in the geographic space by cartographic communication media." This definition does not limit the subject of cartography to the particular medium or the specific methods of cartographic communication, and it is still valid, regardless of the further development of technology. In the process of cartographic communication the author distinguishes - including cartographic methodology – the following stages:

- preparation of data, i.e. the original information for editing and developing maps;
- mapping, i.e. the creation of cartographic communication;
- perception, i.e. the user's reception of the information contained on the map;
- interpretation, i.e. the reception of information hidden on the map.

The development of cartography as a separate science, according W.Ostrowski (1975), is an effect of taking into account a series of new research directions and theoretical concepts in cartography[2], which was caused by two main reasons for the development:

- cartographic production in various fields, especially in thematic cartography;
- sciences dealing with communication (information theory, epistemology, computer science, psychology,

[2] A.M. Berlant (1992) defines theoretical concepts as a defined system of views on the subject and on the method and interpretation of basic processes of science development and cartographic production.

semiotics, the theory of modelling), which led to making attempts to apply them to the analysis of map functioning.

The results of these sciences stimulated the development of three main theoretical concepts, which are the following:

1. The concept of communication, in which the map is considered as an element of cartographic communication.

A. Moles (1964), widely regarded as a precursor to the communicative approach, considered cartography a special case of the theory of transfer or the theory of information. Information theory makes a basis not only for cybernetics, information technology and telecommunications theory, but it has also been used in such disciplines as linguistics, biology and psychology.

2. The model-cognitive concept, according to which the object of study of cartography is primarily a process of understanding the spatial aspects of reality by means of maps.

This concept has four sources and directions: cartographic method of research, theory of knowledge, theory of modelling and psychological research on map reception.

3. The concept of cartographic semiotics, in which the map is treated as a sign system or as a specific language of the map.

In order to sum up all these concepts A.M. Berlant (1992) states "... Each concept has fully reasonable grounds and contains a rational grain. Cartography is presented by them from one point of view as the science of understanding the world, from the other as a means of communication, and finally as a specific language formation. "

At the turn of the 20th century and the 21st century there were three new theoretical concepts in cartography: geoiconics, geovisualization[3] (cartographic visualization) and geoinformatics. In the mid-1980s A.M. Berlant presented geoiconics, which he developed in the 1990s. Geoiconics covers the synthetic knowledge of theory of geoimages[4], methods of their analysis, and their transformation for the needs of science and practice.

In the concept of geovisualization maps are treated as tools to understand the spatial relationships in order to facilitate the users' process of thinking. The best known representative of the concept of geovisualization (cartographic visualization) is A.M. MacEachren (1995). He proposed a three-dimensional conceptual model in the form of a cube, which shows the basic ways of using maps, also known as a model of cartographic visualization. The model allows for an extensive use of maps and changes in their use, the consequence of which is the emergence of cartographic visualization as a new research direction. One of these changes - from public use maps made by cartographers, to the use by an individual (by experts) - refers to the earlier model of scientific visualization that made use of maps, which was presented by D. DiBiase (1990). The change includes new functions of maps: stimulating thinking and communication. The second change is related to the purpose of using maps: the presentation of known facts to explore the unknown regularity (by testing). The third change in the way the map is used – the one linked to the development of computer technology – is the discriminative ability of low-use interactive maps to its increasingly higher level.

The relationship between the map and geographic information systems at a lower level of generalization is described by A. Głażewski (2006), who orders the commonly used terms. He states that the map is the result of two processes: modelling of geographical reality, which arises as a consequence of geographic databases and visualization that is creating a map image.[5]

Scientific visualization as a new concept is defined as a tool to give opportunities to discern what is invisible and used for interpretation and analysis of digital images, both those that have been introduced to the computer, and those manufactured from complex multidimensional data sets (Bin Jiang, 1996). Scientific visualization is therefore

[3] Geovisualization is a process and an effect of graphic representation using a conventional notation (sign system) on a computer screen or using a projector in order to present a model of space (maps) stored in the database (or as files of the appropriate software, CAD or DTP), in accordance with cartographic rules.

[4] A.M. Berlant (1992) understands the concept of geospace as all time-space, scale and generalized models of objects or processes presented in graphic imaging

[5] This means that the database is a geographic conceptual and logical model of the "geographic reality", and the map is both a model and an image of this reality.

based on computer technology and is a method of integrating the processing capabilities of computer and intellectual capabilities of their users, which allows us to study the causality of phenomena, to formulate conclusions and transfer the information obtained in this way by means of an image.

The differences between scientific visualization and mapping lies in the fact that the former is to analyze information about various types of relationships with graphics, while the latter focuses on visualizing spatial relationships (MJ. Kraak, F. Ormeling, 1996). Worth emphasizing is the role of maps in the intellectual activation of the recipient as well as in the recipient's development of intuition and imagination, which occurs through the use of interactive tools, three-dimensional (visualizing the third dimension) and dynamic (to visualize change over time) presentations (M.-J. Kraak, 1998). The concept of cartographic visualization is thus linked to an extension of the map functions and the ways of its use. Digital maps have become an image of the results or a reflection of a certain stage of research, an indispensable tool to make quick decisions, process simulation and multivariant engineering design.

What appeared in parallel with the concept of cartographic visualization was a closely related concept of geoinformatics.

2.1. Map as a model and an image of reality

In the history of cartography, different approaches to the problem of mapping the model (the concept of cognitive and communication concept) clashed; cartographers have long accepted the general thesis of a "model character of a map."

In Polish literature, these subjects were discussed, for instance, in the late 1970s by Ostrowski (1984) and in the early 1990s by Czerny (1990, 1994). The work by Asłanikaszwili (1974) presents an interesting approach based on the assumption that the modelling of cartographic communication concerns only aspects of what happened, which has met with approval of many cartographers. The advantage of cartographic modelling is a fundamental fact that the map, despite a significant reduction in the dimensions, allows us to show and analyze the distribution of material objects and phenomena, regardless of the size of the modelled area (Ostrowski, 2008).

It can be stated that our understanding of space as a kind of model has been the subject of many studies. An in-depth reflection on the map as a model and the map as a system was presented in recent years by A. Makowski (2001, 2005, 2006). In his proposals the map is a "system model-imaging informational entirety that reproduces space-time practical situations, as the targeted areas in the adopted reference system." It is worth noting that the concept of image is not in this case associated with the graphics. It is all about mental images, the so-called mental images of space. In considering the ontogeny of the map Makowski (2005b) defines, among other things, the following features of the map:

- the map is the entirety of information, targeted space-time concept, the result of systemic thinking, contained in the oneness of three concepts: the system (formation goal, controller of change generating actions), model (targeted information entirety, knowledge), image (psychophysical form of information entirety, communication); thus it is a formation existing thanks to oneness of the triad;
- the map is the product of the psyche and intellect, so it is not assigned to a material form;
- the material form of maps (communication) is formed in a systemic way by means of methodical formalisms and in a psycho-physical way to preserve the explicitness of the information reception;
- physical form of maps (material) is the vehicle of the imagination (mental image) during providing information; the interpretation of the content is a kind of systemic thinking, supported by relevant knowledge. "

A. Makowski treats the concepts of visualization in a non-standard way, but as "awareness that reinforces the firm basis of the relationship as a kind of intellectual interface, acting on reversible directions: cartography - spatial information systems, spatial information systems - cartography" (Makowski 2001).

The above considerations were the source of the definition of the map in the context of mobile mapping, proposed by D. Gotlib (2011):

The map is a model of reality, showing the location and selected attributes of objects and phenomena in relation to the Earth, other celestial body, or other objects, such as a building, of the inside of the human body, as well as spatial relationships between objects and phenomena. This model can cover the state of current, past, future conditions/states or represent changes over time. The model can be communicated to the recipient in various forms: graphics, sound, text and touch. It can also be processed and analyzed only on digital recording. Because this model has been for a long time presented mainly in a graphical form, hence the concept of maps usually has often been equated with the graphic image. Today, however, the transmission of the map contents is often implemented by using non-visual media.

The author of the map definition compares the stages of the use of a classic map and a navigation digital map and presents its results in Table 1.

Table 1. Scripts' comparison of stages of the use of the classic map and the map in the navigation system
Tab. 1. Porównanie scenariuszy korzystania z mapy klasycznej oraz z mapy w systemie nawigacyjnym

Map (according to D. Gotlib, 2011)	
classic	**digital navigation**
Searching on a map where the starting point and the destination point are, on the basis of indexes and directories, of cartographic grid or the knowledge of space	Giving the sought start and destination addresses, and starting the search function for places and objects
Space analysis to select the appropriate route	Choosing the road with several variants provided by the navigation application
Calculating the distance between the starting point and the destination based on the distance tables included in the map or by summing the distance between the markers and their description on the map	Reading the distance between the starting point and the destination as calculated by the application
Based on the analysis of information from the map, calculating estimated time of the arrival at the destination point, finding the successive intermediate locations along the route, reading the name of the street along which the user is moving, checking the number of road on which the user is moving	Reading emerging or permanently visible messages related to the estimated time of the arrival at the destination, successive intermediate destinations along the route (and the distances to them), the current average speed of travel, the street name on which the user is moving, the number of road on which the user is moving
Independent decision making - the choice of routes, changing the route while driving, guided by the marking of roads (e.g., signs of city transit routes, detours signs), reaching for a map and its analyzing in the case of the occurrence of traffic flaws, road obstructions and impediments to mobility	Obeying system commands „turn left, turn, go straight ahead, slow down, keep to the right", etc.
Reading additional content placed outside the map, for example, on its reverse side or on separate pages of the atlas, locating them in relation to the current or anticipated position	Automatically extracting information about events occurring in the immediate vicinity of the route, sights, shopping offers, etc.
Checking the position in relation to the planned route by comparing the names of the passed towns or road junctions with the map, analysing the location of forests, water, railways, etc., checking the approximate distance to the next major town given on signposts and described on the map	A brief look at the map to determine the location of the selected route or orientation in the arrangement of the upcoming intersection and of the route running through it in order to prepare for the precise execution of the system commands and to avoid misinterpretation of voice commands

Two different patterns of cartographic communication: without the use of and using spatial databases are shown in Fig. 1. In both cases, the basis of cartographic communication is the model. By the time when digital technology was being widely used in cartographic production, this model had not been usually recorded in a standardized and formalized form (hence the figure indicated by a broken line). Its material reflection was a ready cartographic product, which was also the only source of cartographic communication that reached the customer (paper map, relief map, etc.). In the most general terms, since the introduction of cartographic spatial database technology to practical use, little has changed in the design process of cartographic communication. Just as before, it is necessary for the process of cartographic modelling to develop an appropriate model of communication (i.e. maps). This process is supported by the modelling of domain (related to the subject of communication) and by the analysis of measurement results using methods of varying accuracy (geodetic, photogrammetric, remote sensing). Thanks to databases technology and GIS technologies, the created model can be materialized by storing it in well-defined structures in a digital form.

In the analogue version of the process (Fig. la), its components are not usually supported by information technology, but it is necessary to support them. In the second version of databases (Fig. 1b), if the cartographic message takes a graphic form, we are dealing with geovisualization (cartographic visualization). In this perspective, spatial database is a database, in which well-defined structures, the location, characteristics of objects and phenomena are saved in relation to the Earth, other celestial body, or other objects, such as a building or the inside the human body. Also spatial relationships between objects and phenomena are saved. This model can relate to the current distribution of facilities and phenomena, past or future states, or it can represent changes over time. In other words, it is a form of saving the map understood as a model of space, which can be presented to the user in many ways. Maps are the best means for immediate verification, sorting, classification and synthetization as well as for data presentation in a review form.

3. Development of geoinformatics

3.1. The history of geoinformatic systems

The first GIS was the Canadian SIP, designed in the mid-twentieth century, in the mid-1960s. In the second half of this period, companies attempted to adapt cartographic GIS programs in order to reduce costs and shorten the preparation of maps. The first automated production of maps emerged in the 1960s, and by the end of the 1970s most of the mapping agencies had already been computerized to a certain extent. However, the first digital map covering the entire country was developed only in 1995 in the UK.

The development of geoinformation systems is also related to remote sensing, which was the source of both technical solutions and data collection. A lot of technical solutions adopted in the geoinformation systems come from the period of the “Cold War”, and the extensive use of GIS dates back to the early 1980s, which was a result of lower prices of computer hardware and software for multiple applications, as well as of the exchange of information and data through the Internet.

Searching maps through the Internet is a very convenient way to access spatial information, which was initiated in 1993. The use of distributed geoinformation systems has become possible thanks to the Internet and several other reasons, such as:

- stationary and portable computer hardware;
- users as clients (“thin” and “fat”) and producers;
- software installed on the user’s hardware and its diversity in terms of complexity and price;
- databases that make up the collection of spatial data stored in a digital form ranging in size from megabytes to petabytes;
- computer networks commonly used in the transmission of various types of data;
- organization and management requiring the development of procedures for the flow of information, verification and sharing.

All these activities require specific skills, which include a basic understanding of spatial data.

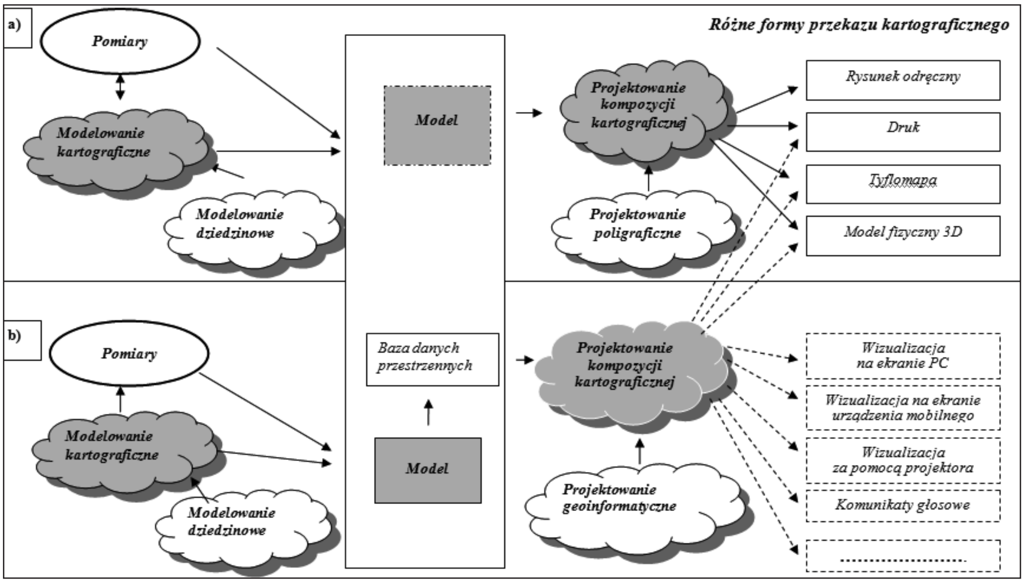

Fig. 1. Two diagrams of cartographic communication
a) without using spatial databases, b) with the application of spatial databases
Elements of the cartographic communication design are marked in grey
Rys. 1. Dwa schematy przekazu kartograficznego (Gotlib, 2011)
a) Bez wykorzystania bazy danych przestrzennych,
b) z wykorzystaniem bazy danych przestrzennych
Elementy procesu projektowania przekazu kartograficznego oznaczono barwą szarą

3.2. Education in geoinformation systems

The development of geoinformation systems is affected by education. There is a difference between training and education of GIS users.

The training usually means teaching how to use specific software. Education is learning the basic principles of geoinformation systems, where during the lectures the theory and general principles are presented, including knowledge of the scientific basis for spatial data processing. Learning specific applications is done during laboratory classes using computers.

3.3. Cartographic sciences and teaching

Geoinformation systems (Fig. 2) are necessary to solve problems by using spatial data.

Geoinformation sciences (called GI - Sciences), is a concept introduced in 1992 by M. Goodchild. Its scope covers basic issues related to data acquisition, processing and exploitation.

Geoinformatics is a set of principles and analytical methods that have been developed for the digital spatial data processing.

Another perspective on geoinformatics as a science is the theory of solving practical tasks occurring in geoinformatics systems (e.g. cartographic mapping - the theory, the 2000 system as a procedure to convert the existing GIS mapping systems to the new system in force in Poland). The basic principle in the field of geoinformatics is the ability to generalize, and thus the transition from detail to the general description of the functioning of the natural process. One should not overlook the great importance of the role played by the theory of perception in editing maps of geographic space and in particular in the creation of road navigation systems (mobile cartography). At this point it is worth noting that rules of mapping, so important for imaging the results with the application of

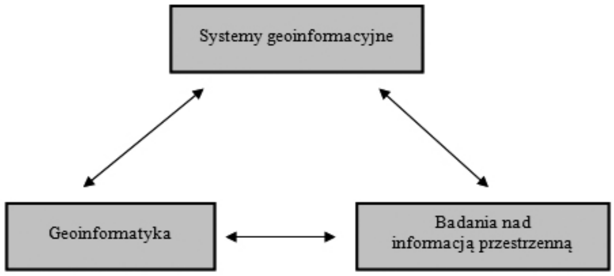

Fig. 2. Connections between geoinformatic systems, geoinformatics and research into the spatial information (GIS Theory and Practice, 2006, p. 492)

Rys. 2. Powiązania pomiędzy systemami geoinformatycznymi, geoinformatyką i badaniami nad informacją przestrzenną (GIS Teoria i praktyka 2006, s. 492)

GIS, emerged long before the introduction of computer technology.

In the time of the development of the Internet and new software solutions, the single GIS structure software based on a "single computer method" is replaced by a multiple number of computers - "a computer network". It is suggested that this conventional term depicting a complex system should replace the abbreviated form "GIS" (geographic information) by the short of "GI" (geointormation), the component part of which would be GISystems (geo-information systems), GISciences (geoinformatics) and GIStudy (studying GIS).

The importance of the social element in the development of geoinformation systems is presented in an interesting way by Chrisman (2003), who stated that "GIS includes the following activities":
- measurement of spatial data;
- conversion of measurement results into the structure of digital data stored in the database;
- execution of data transformations from various sources in order to disclose the spatial relationships and regularities;
- transformations according to the accepted computational models.

3.4. Properties of geospace for the needs of solving and evaluating the problem of localization

Everything that surrounds us has a place in space, and the knowledge of the location of the phenomena is essential in making economic and social decisions. Geospace - a term used in recent years – is a space covering the surface of the Earth and its immediate vicinity. The problem that requires defining the position in space is called the problem of localization. This problem has three main features:
- the scale and level of detail of spatial data;
- orientation towards theoretical or practical issues, which can be settled by the application of by GIS programs;
- validity of spatial data in the time scale.

Information systems can help better operate knowledge, make it easy to organize, store and access the data you need.

There are at least three fundamental differences between knowledge and information (GIS Theory and Practice, 2006):
1) knowledge requires the presence of the person who gathered it, and the information exists independently;
2) sharing knowledge is more difficult than sharing information, which is visible at the stage of the transmission and reception,
3) knowledge requires much greater capacity of absorption, we can accept contradictory information, but we cannot do this with knowledge.

Wisdom is more difficult to define, because usually we talk about it in the case of decision-making or advisory. It is characteristic of the individual and it is the most valued element in the decision making process.

Science gathers a lot of information on the natural environment, its forms and processes therein. For some processes consist of natural phenomena, whereas the others consist of human impacts - anthropogenic factors.

Knowledge of the processes taking place in the environment is more valuable than its forms, as it gives the possibility of predicting phenomena. In science, it is more valuable than a general knowledge of detail; hence the understanding of mechanisms of the phenomenon is more important than the description of their form.

Among scientists involved in defining the place of idiographic geography and form, and scientists interested in nomothetic geography, working on general laws governing the process, numerous debates are being held. Yet, both approaches should not be separated because this is the optimal way to arrive at the correct solution to the problem.

One of the most important features of geo-information systems is the ability to combine the whole and the detail, as well as perceiving the problem as a whole and the ability to solve it. This is possible because GIS allows us to connect general knowledge with detailed information.

The knowledge of the process is represented by GIS software, whereas databases contain a description of the forms.

4. Conclusions

1) The development of theoretical concepts in cartography was based on the following disciplines: mathematics, psychology, computer science, and new theories: information, perception, semiotics, modelling, and visualization of scientific knowledge.
2) Modern cartography created new opportunities in developing and issuing maps, since:
2.1.) maps are often not the final product, but the transitional one, supporting the user in working with spatial data;
2.2.) the map is not the only means of communication, but also a tool to assist the user's process of thinking;
2.3) the map is the best way to immediately verify its contents, arrange, classify, synthesize and present data in a conceptual form;
2.4) the digital map is a key element of modern geoinformation products, as a specific space model for presentation of: geographic reality, reflection of a certain stage of research useful in making quick decisions about space, as well as of process simulations of multivariant engineering designs.
3) The development of geoinformatics as a science is through the development of the theory of processing and data analysis tailored to GIS and cartography, whose basic element is a map.
3.1) Geoinformatics supports the process of scientific knowledge and the gives directions for geoinformatic systems.
3.2) Geoinformation systems support and guide the cognitive process.
3.3) Geographic information systems have significantly increased the number of generated maps.
4) (Cartographic Model) + Geoinformatics = Digital Map
4.1) Cartographic modelling aims at creating a message, which means creating a map.
4.2) The transfer of cartographic information to the user - with the use of the database - is possible in the form of traditional maps and multimedia maps (screen visualization, the composition of sound, text, pictures and video).

Literature

Asłanikaszwili A.F.,1974, *Metakartografia. Osnowy problemy.* Tbilisi. Mecniereba.

Berlant A. M, 1992, Konwiergencyja tieoreticzeskoj informacji w sowriemiennoj kartografii. *Kartosemiotika 3. Mieżdunarodnyj korrespondenc-seminar*: Bratislawa – Drezden.

Bin Jiang, 1996, Cartographic visualisation: anaylytical and communcation tools. *Cartographic,* Vol. 25, no. 2, s. 1-11

Czerny A.,1990, *Struktura i własności mapy, jako model rzeczywistości. Rozprawa doktorska*, IGiPZ PAN, Warszawa.

Czerny A.,1994, Rozwój koncepcji modelowania kartograficznego. *Polski Przegląd Kartograficzny*, Vol.26, no. 4, s.186-202.

DiBiase'a D., 1990, Visualiztion in earth science. *Earth & Mineral Sciences. Bulletin of the College of Earth and Mineral Sciences*, The Pennsylvania State University, Vol. 59, no. 2, s.8-13.

Freitag U., 1971 Semiotik und Kartographie. Über die Anwendung kybernetischer Disziplinen in der therotiscen Kartographie. *Kartogr. Nachr*. Vol. 21, no. 5, s. 171-182.

Gałażewski A., 2006, Modele rzeczywistości geograficznej a modele danych przestrzennych. *Polski Przegląd Kartograficzny,* Vol. 38, no. 3, s. 217-225.

Gotlib D., 2011, *Metodyka prezentacji kartograficznych w mobilnych systemach lokalizacyjnych i nawigacyjnych*, OWPW Warszawa 2011.

Goodchild M., 2005, *Geographic Systems and Science* Tłm. *GIS Teoria i praktyka*, PWN Warszawa.

M-J. Kraak, F. Ormeling, 1996, Cartography: Visualization of Spatial Data. Tłum. Kartografia wizualizacja danych przestrzennych. Warszawa, WN.PWN

M-J. Kraak, 1998, Kartograficzna metoda badań: mapy, jako narzędzia odkryć W: *SIP. VIII Konferencja Naukowo- Techniczna*. Warszawa, s.251-268.

Longley A., Goodchild M., Maguire D., Rhind D., 2006, *GIS Teoria i praktyka*, PWN, Warszawa

Makowski A. , 2001, Trójdzielna jakość mapy na tle idei systemu informacji przestrzennej, *Polski Przegląd Kartograficzny*, Vol.33, no. 1, s.38-42.

Makowski A., 2005a, Pojęcie mapy. *System informatyczny kraju. Praca zb. pod red. A. Makowskiego*, Warszawa, Oficyna Wydawnicza Politechniki Warszawskiej.

Makowski A., 2005b, Ontogeneza mapy. *System informatyczny kraju. Praca zb. pod red. A. Makowskiego*, Warszawa Oficyna Wydawnicza Politechniki Warszawskiej.

Makowski A., 2005c, Spór o mapę. Wprowadzenie do pojęcia mapy. *System informatyczny kraju. Praca zb. pod red. A. Makowskiego*, Warszawa Oficyna Wydawnicza Politechniki Warszawskiej.

Makowski A., 2006, Definicja kartografii (propozycja). *Świat techniki w kartografii. Monografia pod redakcją W. Pawlaka i W. Spalka*, UW, Wrocław s.40-44.

Moles A. 1964, Teorie de l'information et message cartographique. *Sciences et l'Ensignement des Sciences*, Vol. 32 s.11-16.

Ostrowski W., 1984, Próba klasyfikacji metod kartograficznych. W: Teoretyczne i metodyczne problemy współczesnej kartografii. *Materiały Ogólnopolskich Konferencji Kartograficznych,* Lublin, Vol.10, s. 95-111.

Ostrowski W., 2006, Od nauki o mapie do geowizualizacji. *Projektowanie i redakcja map. „ Główne problemy współczesnej kartografii"*. Wrocław, s.20-32.

Ostrowski W., 2008, *Semiotyczne podstawy projektowania map topograficznych na przykładzie prezentacji zabudowy*, Zakład Graficzny UW Warszawa, Monografia s.209.

Peucker K., 1902, *Drei Thesen zum Ausbau der theoretischen Kartographie. Geogr. Zeitschrift, Bd. 8, H.2, s. 65-80, H. 3, s. 145-160.*

Ratajski L. 1989, *Metodyka kartografii społeczno-gospodarczej*. Wyd.2 Warszawa PPWK

Robinsona A.H., 1952, *The look of maps. An examination of cartographic desing. Madison, University ofWisconsin Press.*

Taylor D.R.F., 1991, A conceptual basis for cartography: new directions for the information era. *Cartogr Journal* Vol. 28, no. 2, s.213-216

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STAGES OF GEOINFORMATION EVOLUTION RELATED TO THE TERRITORIES DESCRIBED IN THE BIBLE – FROM THE 3RD MILLENNIUM B.C. TO MODERN TIMES

Key words:

Bible, geoinformation, geography, cartography, history

Abstract

The paper presents consecutive stages of the evolution of geoinformation related to the territories of the events described in the Bible. Two geoinformation sources are presented: the Bible and non-Bible sources. In the Bible there is much, often some highly detailed information regarding terrain topography. The oldest non-Bible sources are incorporated in the ancient documents, which were discovered in Egypt and Mesopotamia. Some of them are related to the 3rd millennium B.C. The further stages are related to the onomasticons and itineraries written by travellers and pilgrims to the Holy Land. The most famous onomasticons include: onomasticons prepared by bishop Eusebius from Caesarea and those prepared by St. Jerome. One of the oldest maps of Palestine's territory is the so-called mosaic map of Madaba dated to 565. In the 15th century several Bible maps were edited. The most rapid evolution occurred in the 16th and 17th centuries, when the world famous cartographers such as Mercator and Ortelius edited several maps of Palestine's territory. Cartographers from several European countries edited more than 6,000 maps presenting the Biblical territories and Biblical events. Modern maps, based on detailed topographical surveys, were edited in the second half of the 19th and 20th centuries.

ETAPY ROZWOJU GEOINFORMACJI O TERENACH BIBLIJNYCH –
OD III TYSIĄCLECIA PRZED CHR. DO CZASÓW WSPÓŁCZESNYCH

Słowa kluczowe:

Biblia, geoinformacja, geografia, kartografia, historia

Abstrakt

W artykule przedstawiono kolejne etapy rozwoju geoinformacji dotyczącej terenów biblijnych. Omówiono dwa źródła informacji, a mianowicie geoinformacje biblijne i pozabiblijne. W tekstach biblijnych można znaleźć wiele, często bardzo detalicznych informacji topograficznych. Najstarsze źródła pozabiblijne, to starożytne dokumenty odnalezione na

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terenach Egiptu i Mezopotamii. Niektóre z nich pochodzą z trzeciego milenium przed Chr. Kolejnym etapem geoinformacji były onomastikony oraz dzienniki podróży pisane przez podróżników i pielgrzymów do Ziemi Świętej. Do najbardziej znanych należy onomastikon sporządzony przez biskupa Euzebiusza z Cezarei oraz onomastikon św. Hieronima. Do jednych z najstarszych map Palestyny należy mozaikowa mapa odnaleziona na posadzce kościoła w Madabie pochodząca z roku 565. Szybki rozwój kartografii biblijnej nastąpił w wieku XVI i XVI, kiedy to słynni kartografowie Mercator i Ortelius opracowali wiele map Palestyny. Kartografowie z wielu krajów Europy, w ciągu minionych stuleci, opracowali ponad 6 tysięcy map biblijnych przedstawiających terytoria i wydarzenia biblijne. Nowoczesne mapy, oparte na pomiarach topograficznych, zaczęto wydawać w drugiej połowie XIX wieku oraz w wieku XX.

1. Introduction

The area described in the Bible covers all those places where events presented in the Old Testament and in the New Testament occurred. It is, therefore, a vast area stretching from the east to the west of ancient Mesopotamia to Italia, and from the north to the south between the area of modern Turkey and Egypt (Rainey, 2002). The events described in the Old Testament took place within the areas called the Fertile Crescent, whose north-eastern arm was made up by Mesopotamia, lying in the bifurcation of the Euphrates and Tigris Rivers, and its south arm was made up by the territories of modern Israel and Egypt. The central part of the Fertile Crescent is the area of ancient Palestine, where most of the events presented in the Old Testament and in the New Testament occurred (Linsenbarth, 2007). The events described in the New Testament, related mostly to missionary journeys of St. Paul the Apostle, and covered additionally the territories of modern Turkey, Greece and Italy.

The areas covered by Biblical events constitute an ideal example illustrating the development of broadly understood spatial information systems (Linsenbarth, 2008b, Linsenbarth 2010a). It results from both geopolitical and geographic locations of this area, but also from the fact that for many years geographers, historians and cartographers have focused their attention on this exceptional part of our world. It should be noted that although the concept of geoinformation in its literal meaning was unknown in the antiquity, yet the first pieces of information describing geographical space were recorded employing techniques known in those times.

3. The oldest sources of non-Biblicale information

Undoubtedly, maps drawn in ancient Mesopotamia should be counted among the oldest geoinformation sources. They were maps carved in clay, similarly to the majority of Mesopotamian documents. The map drawing was executed on clay tablets with a sharp triangle-end stylus. In Nuzi, located in north-eastern Iraq, a map carved towards the end of the 3rd millennium B.C. was excavated. The map shows an estate belonging to Arzala (Metger, 1997). One of two other maps found in Nippur, in the south of Iraq, shows a drawing of the town itself as well as of nearby canals; the other one presents the boundaries of twelve estates and the names of their owners. These maps may be well considered to be the first cadastral maps. Probably, similar maps existed in other areas of the Middle East.

Many oldest sources of geoinformation are those written down in various kinds of documents that were found in the territories of Egypt (Aharoni et al., 2002). Inscriptions related to the Palestinian territories found on the tombs at Abydos belong to the oldest ones. They give a description of five war expeditions during the reign of Pharaoh Pepi I (2390-2361 B.C.) to the land called “The Land of Sand-Dwellers” (Aharoni et al., 2002). This name was used to refer to the area east of Egypt. In these inscriptions, among other things, campaigns in the coastal belt in the area of Acre in the Jezreel Valley were described. Also, the promontory of (Karmel) Carmel is quite adequately compared to a nose of an antelope. Much information related to the description of Palestine was given in the so-called Execration Texts from the 19th century B.C., written on clay figurines found in Saqqara in Egypt. In the first group of these texts, which date back to the middle of the 20th century B.C., three towns from the region of Palestine are mentioned; they are Jerusalem, Ashkelon and Rehob (Rehov). The second group of the texts, dated to the 19th century B.C., give a list of 64 towns of the region of Palestine (Rainey et al., 2002).

Further geospatial information is included in the description of 17 war expeditions of Pharaoh Tuthmosis III (1504-1400 B.C.). One hundred twenty geographical items located within the areas stretching from Gaza to Kadesh were carved on the temple wall. They included names of towns as well as names of mountain ranges, valleys and rivers. Also the Amarna letters, describing pharaohs' expeditions to the Palestinians terrains, contain many pieces of valuable geographical information.

Few other pieces of historical geoinformation related to the period described in the Old Testament were found in steles and monuments found in Jordan and Iraq. The so-called Mesha Stele, erected by King Mesha of Moab, dated to 880 B.C., is an extremely valuable monument. It lists names of towns that King Omri conquered in the areas north of Moab. The original stele is now in the Louvre Museum, and its copy in the Museum in Amman. The tablets of the Babylonian Chronicles, which relate to the years 605-594 B.C., make another valuable source of information. They describe the victory of Nebuchadnezzar, a son of Nabopolassar, who defeated the Egyptian army led by Pharaoh Necho in the battle of Carchemish in 605 B.C. One more artefact is worth mentioning here, namely a clay cylinder excavated in Babylon and dated to 526 B.C. This clay cylinder is inscribed in Babylonian cuneiform and features an edict by Cyrus the Great, which permits the return (of subjugated peoples) Jews to their homeland (Rainey et al., 2002).

3. Geoinformation in Biblical texts

Biblical texts contain various geoinformation data related both to geographical items, such as localities, mountains, valleys, rivers and to descriptions of boundaries, expeditions routes or war campaigns routes. Genesis includes the Table of Nations (Genesis 10: 1-32) with the description of the rivers and the garden in Eden (Genesis 2: 10-14). In Exodus and in Numbers one can find the description of the Israelites' journey from Egypt to the Promised Land (Numbers 33). The boundaries of lands given to Noah's descendants, including the lists of towns, are described in Genesis (Genesis 10:19) in the following way: "And the border of the Canaanites was from Sidon, as thou comest to Gerar, unto Gaza; as thou goest, unto Sodom, and Gomorrah, and Admah, and Zeboim, even unto Lasha." A very detailed description of boundaries of Canaan, Admah and Zeboim is included in Numbers (Numbers 34:1-12). One can find there also the lists of towns belonging to particular districts. In Joshua, the division of the Promised Land is described (Joshua 13-19); there is also a list of towns on the route of Jews' exodus (Joshua 19) and the list of Levites' towns (Joshua 21).

The descriptions of war expeditions can be found for instance in Kings and Chronicles. The route of Ben Hadad's war campaign from Aram-Damascus to the north of Israel is shown in 1 Chronicles (1 Chronicles 15:20), the war led by Tiglath-Pileser III of Assyria and his invasion of Israel is presented in 2 Kings (2 Kings 15:29). The fights with Philistines, i.e. King Uzziah's conquests and the revenge of Philistines' in Judah in the times of King Ahaz, are described in 2 Chronicles (2 Chronicles 26:6 and 26:18). In many other Books of the Old Testament there are quite numerous, more or less detailed pieces of information related to the geography of the terrain. It should be noted, however, that many localities mentioned on the pages of the Bible, especially those that were destroyed throughout the centuries, have never been located and/or their location can only be roughly determined.

4. Later non-Biblical geoinformation

Data related to geography of the lands described in the Bible included in two works by historian Titus Flavius Josephus (37- d. after 94 A.D.), namely *The Jewish War* and *Jewish Antiquities,* constitute an invaluable source of non-Biblical geoinformation. Frequently they provide very detailed information on the terrain topography. Another valuable source of information was Onomasticon written by Bishop Eusebius of Caesarea (260-340 A.D.) (Linsenbarth, 2009a). It was a list of descriptions of Biblical places

Fig. 1. Gerardus Mercator's map of 1619 depicting the Promised Land, included in the atlas *Atlas soive cosmographicae meditations*, Henricus Hindius ed., Amsterdam 1619. (The map oriented to the east). Reproduction with the consent of the Jewish National and University Library, The Eran Laor Cartographic Collection, Jerusalem

Rys. 1. Mapa Gerarda Mercatora z 1619 roku przedstawiająca Ziemię Obiecaną, zamieszczona w atlasie: „Atlas soive cosmographicae meditationes" Wydawca Henricus Hindius, Amsterdam 1619. (Mapa zorientowana w kierunku wschodnim). Reprodukcja za zgodą: Jewish National and University Library – Eran Laor Cartographic Collection, Jerusalem.

made in an alphabetical order and arranged according to the Books of the Bible. The list covered 600 geographical items, such as towns, mountains, rivers, regions. The description of a particular item often meant merely a repetition of the information from the Bible, yet sometimes was accompanied by some additional information obtained from contemporary sources (e.g. Flavius Josephus's works), or sometimes with contemporary Greek names or, additionally, with distances between important towns.

Eusebius wrote his Onomasticon in Greek in ca. 320 A.D. The translation into Latin was done by St. Jerome in ca. 385 A.D. St. Jerome, known for translating the Bible from Greek into Latin (the so-called Vulgate), before commencing the task of the Bible translation, spent two years travelling and visiting Biblical lands. By doing this he could introduce corrections and comments to the work by Eusebius (Metger et al., 1997). This resulted in a work entitled *Liber locorum.* An example of such a description is worth quoting:

"Ajalon (Joshua 10:12), valley and a ravine, upon which the Moon once stood in response to Joshua's prayer, in the vicinity of a village called Ajalon 'Ailon', east of Betel, at a distance of three miles, close to Gibeah and Ramah, the city of Saul. *Jews, however, claim that Ajalon is a village near Nicopolis (Emmaus) at the second mile stone on the road to Jerusalem"* (St. Jerome's comments are printed in italics). Onomasticon 18:13-16; Liber Locorum 19: 13-17.

An increased interest in pilgrimages to the Holy Land bore fruit in extensive travel journals that frequently included quite detailed descriptions of particular regions or Biblical places (Canetti, 2007). A perfect example of such a travelogue is *Itinerarium Burdiglensis* written by a French traveller before 333 A.D. Also, the descriptions of pilgrimages to the Holy Land in the 6th century written by Archdeacon Theodosius (518-530 A.D) and by an anonymous pilgrim from Piacenza (c.a. 570 A.D) include many pieces of valuable information (Linsenbarth, 2009b).

5. First geographers and cartographers

One of the oldest non-printed maps that were made in Biblical territories is the world map from Sippar (southern Iraq), carved in a clay tablet between 700 and 500 B.C.; now it belongs to the collection of the British Museum in London. Ancient geographers Eratosthenes of Cyrene, Hipparchus and Strabo highly contributed to the development of geographical sciences. Eratosthenes of Cyrene (275-194 B.C.), an eminent astronomer, mathematician and geographer, was the first to calculate the circumference of the earth. He issued a fundamental work devoted to geographical sciences entitled *Geographica*. Starting from 236 he managed the famous Alexandrian Library. Hipparchus (190-125 B.C.), a famous Greek astronomer living in Alexandria and on the Island of Rhodes, defined the relationships between geographical and astronomical coordinates. The works by Strabo make an invaluable source of geoinformation. This outstanding Greek geographer and traveller living at the turn of the old and new eras (ca. 65 B.C.-20 A.D.) was an author of an extensive work *Geographica*, collected in 17 volumes. It was the first work of general geography and it included descriptions of places from different regions of the world known to his era as well as a list of ca. 4 thousand geographical names, i.e. a classical onomasticon (Linsenbarth, 2009a).

Undoubtedly, Ptolemy's maps and works that appeared at the beginning of the first millennium A.D. heralded in a new era of cartography. Claudius Ptolemaeus, a genial astronomer, mathematician, astrologist and geographer was born in c.a. 87 A.D., most probably in Upper Egypt and died in 165. Probably he was an Egyptian of a Greek origin. He was the creator of the geometric model of the universe. One of his most famous works is *Syntaxis Mathematica,* a series of lectures on mathematic astronomy collected in 13 volumes. Ptolemy's other main work is *Geographia*, based on the works by Eratosthenes of Cyrene, Hipparchus and Marinos of Tyre. This work contains mathematical principles to be applied to making maps, as well as a list of geographical names, out of which 6411 are accompanied with geographical coordinates. He worked out a map of the world, where ca. 8 thousand localities are marked. This work, called also *An Introduction to Geography*, comprised in 8 volumes, remained unknown to the Christian world until the late Middle Ages. It was translated from Greek and Syrian by Arabs. The Latin translation was done only in the 15th century. The already mentioned Greek geographer, Marinos of Tyre, dealt with mathematical geography. He was the first to work out and apply cylindrical mapping (Linsenbarth, 2009b).

The first map in the stricter sense is undoubtedly the mosaic map, which is a part of a floor mosaic in the early Byzantine church of St. George in Madaba. It was executed in the second half of the 6th century A.D., most probably before 565, and shows an area of Palestine (Donner, 1992). Based on archaeological and conservation works carried out in 1965 it was found that the original map had the dimensions of 15.60 m by 6.00 m. The mosaic map consisting of ca. 2 million tesserae (mosaic tiles) covered the surface area of 93 square metres. Its current dimensions are 10.5 m by 5 m and its surface area is ca. 30 square meters and comprises ca. 700 to 800 thousand tesserae.

The original church was destroyed probably in the 7th or 8th century. In 1850 the earlier town of Madaba was a village. In 1884 a group of immigrants from Al Karak commenced the reconstruction of the church and having removed the rubble they discovered a beautiful mosaic showing a map of Palestine. The last renovation of the mosaic was carried out in 1965. The map depicts in a very clear

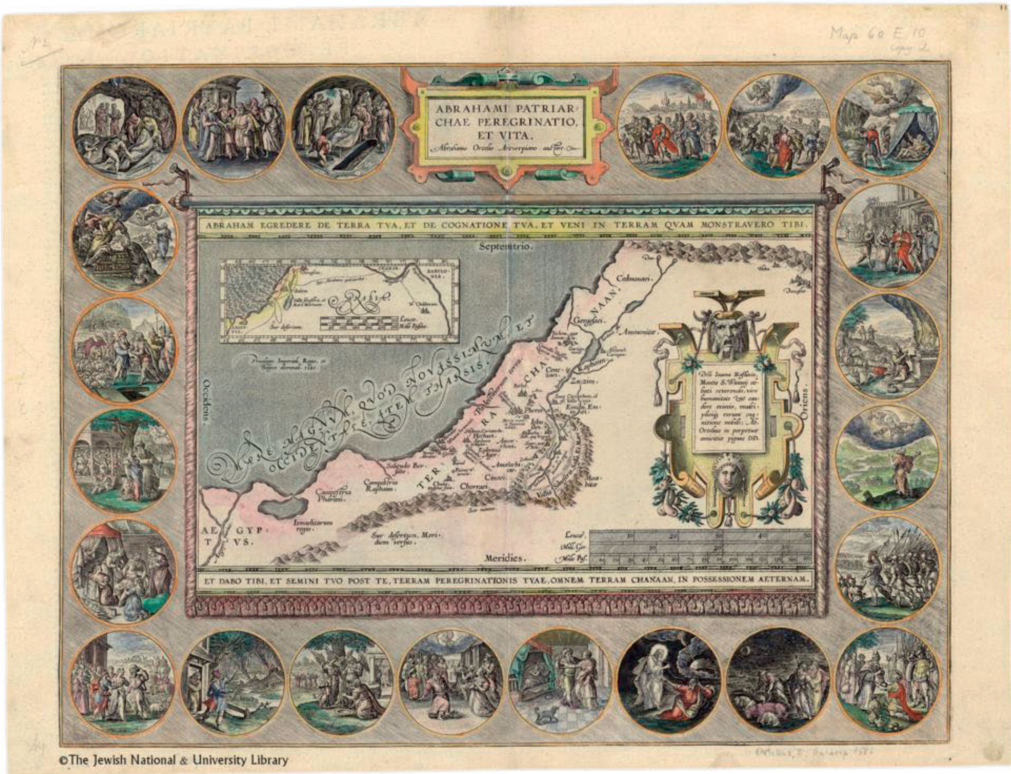

Fig. 2. Abraham Ortelius's map depicting Abraham's journey, included in the 4th edition of the first modern atlas *Theatrum orbis terraum* dated to 1890, published in Antwerp by Plantinian Printing House. Reproduction with the consent of Jewish National and University Library, The Eran Laor Cartographic Collection, Jerusalem

Rys. 2. Mapa Abrahama Orteliusa, obrazująca wędrówkę Abrahama, zamieszczona w IV wydaniu atlasu "Theatri orbis terraum" z roku 1890 opublikowanego w Antwerpii przez oficynę Plantiniana. Reprodukcja za zgodą Jewish National and University Library, The Eran Laor Cartographic Collection, Jerusalem.

way the areas of Palestine and Lower Egypt, and is oriented to the east. The centre of the map shows a magnified plan of Jerusalem together with its building development.

In the 12th century, Arab geographer Muhammad al-Idrisi (1100-1166 A.D.) compiled a map depicting roughly the area of Palestine (Sacerdoti, 2001). One should also note a 13th century map drawn by Mathew Paris, an English monk, showing roads from Europe to the Holy Land, with special attention paid to (Akko) Acre and Jerusalem. In the 14th century, in 1321, Marino Sanudo of Venice worked out a map of the Holy Land for Pope John XXII. In this map, grid squares were introduced for the first time.

6. The period of Biblical cartography development

A rapid development of cartography occurred in the 15th century, when Johannes Gutenberg constructed a printing machine and in 1455 printed the Holy Bible. Towards the end of the 15th century, in 1475, in Lübeck a really original map of Palestine was issued. It was compiled by Brandis de Schass (Linsenbarth, 2009a) and consisted of a great number of irregular fragments representing geographical items in the area of Palestine. Another example from this period is a map worked out in 1483 by German pilgrim Bernhard von Breydenbach. It is oriented to the east and supplemented by a very precise perspective drawing of Jerusalem as seen from Mount of Olives.

At the beginning of the 16th century, in 1507, another interesting map was issued; it was the so-called *Tabula Peutingeriana* (Linsenbarth, 2009b). The history of the map is unclear. It is supposed that a basis for this map was the map of the world by Marcus Vipsanius Agrippa, a friend of Emperor Caesar Augustus. After the Emperor's death, the map was carved on the tomb on Agrippa's portico, near Ara Pacis, in Via Falmina in Rome. The only copy of this Roman map from the 4th century is a medieval copy of 1265 made by an anonymous copyist from Calmar. This copy was found in a museum in Vienna in 1507. It was then worked out by Konrad Peutinger, a councillor of the city of Augsburg, who died before the map was issued. The first print that appeared in Antwerp in 1591 was named after him. The map was a roll of a length of 6.28 m and a width of 32.5 cm. The map covered the areas between Europe and India and was divided into twelve segments. Palestine was depicted in the sixth segment. In principle, it is a road map showing a network of Roman roads, stopping places and distances between these places. The map features ca. 200,000 routes. The map comprises an enormous collection of geoinformation data included in the map contents. It is, however, a very schematic map, of big cartometric distortions. The map shows 555 towns and villages, as well as other geographical items. Beside localities it also presents mountains, rivers, woods and seas. Presently, by applying modern technologies and techniques, extremely valuable data may be obtained from this collection.

In the 16th century an explosion on the European printing market occurred. As far as this period is concerned, special attention should be paid to maps by Gerhard de Jode (1509-1591), Gerardus Mercator (1512-1594) and Abraham Ortelius (1527-1598) (Linsenbarth, 2009a and 2009d). In this time first geographical atlases occur, which contain also maps of Biblical lands. Much attention was paid to include in these maps events described in the Bible. Beside the area of Palestine, the maps depict also places related to Abraham's journey from Ur of the (Chaldees) Chaldeans, with the Exodus of the Israelites from Egypt and with St. Paul's missionary journeys. Frequently, perspective views of towns were added. For example, Gerhard de Jode's map of 1578 shows a very precise view of Jerusalem seen from Mount of Olives. A great artistic value of these maps is worth noting, however in many cases the topography of the terrain was wrong. The 17th century was dominated by (cartographic prints) maps issued by Willem Janszoon Blaeu (1571-1638) and by Nicolas Sanson (1600-1667), which included several maps of Biblical areas. Willem Janszoon Blaeu's maps were known in whole Europe, and their reprints can be found also in Polish bookshops. Nicolas Sanson was the founder of a famous French school of geographic and cartographic sciences (Linsenbarth, 2009b, Linsenbarth, 2010b).

At the beginning of the 18th century a Biblical atlas edited by John Senex came out. It contained six thematic maps, and included a cartographically correct map illustrating St. Paul's journey to Rome. Towards the end of the 18th century, during the French army expedition to Egypt within the years 1798-1799, the first topographic map at a scale of 1:100,000 was worked out. It consisted of 6 sheets and was published in Paris in 1818 (Linsenbarth, 2009b).

In the first half of the 19th century, in 1829, German cartographer Yehoseph Schwarz (1804-1865) worked out a very detailed map of the Holy Land based on his own materials collected during his field reconnaissance in Palestine (Ran, 1989). In the second half of the 19th century Wincenty Pol published a book *Geografja Ziemi Świętej [Geography of the Holy Land]* and a map of these territories (Linsenbarth, 2008a). Maps of Palestine at a scale of 1:63,000, published in (1850) 1880 by the British Palestine Exploration Fund, could be considered a really modern and complex topographic and cartographic work (Linsenbarth, 2009b). In the 20th century many new maps of Palestinian territories were worked out; they were based on updated topographic and geographic materials. Several Biblical atlases were also published. In 2006 the Institute of Geodesy and Cartography launched a new research project related to the system of time-spatial information on historic events on the example of Biblical territories (Linsenbarth, Drachal, 2009; Linsenbarth, 2010b).

7. Conclusions

The article discusses particular stages of geoinformation development related to territories described in the Bible, which can trace their course in the history. Forms of geoinformation were different, starting from information on war expeditions both led by pharaohs from Egypt and rulers of Mesopotamia, through information gathered by travellers and pilgrims and recorded in their travel journals. The next stages included attempts to convey the information by applying cartographic methods, working out onomasticons, compiling and editing maps of lands described in the Bible, and ending in thematic atlases and geoinformation systems. It is worth noting that throughout centuries the attention of cartographic printing houses from various European countries have been focused on the lands described in the Bible and on publishing their maps and atlases. More than 6 thousand maps related to these areas have been published (Ran, 1989). These maps depict various Biblical events. The analysis of these maps allows us to trace the development not only of geographical sciences but also of cartographic technologies. Additionally, it is a valuable material for a comparative analysis of maps published in the same period of history by different printing houses in different countries (Linsenbarth, Brzezińska-Klusek, 2010). Biblical events presented on those maps are generally unchanging; however, over the course of the years, as a result of archaeological research, many geographical items of unknown location have been identified.

Currently, we commonly use the term geoinformation, which was unknown in the antiquity. At each stage of the development of geographical and cartographical sciences the forms of geoinformation data were different. They reflected the then methods of obtaining information on the (terrains) geospace.

8. Literature

Aharoni Y., M. Avi-Yonah , 2002 *The Carta Bible Atlas.* The Israel Map and Publishing Company, Ltd. Jerusalem, Israel

Canetti, H.I., 2007. *Ziemia Święta w Obrazach.* Apogee Press, Herzlia, Israel

Flawiusz, J. 2008. *Wojna Żydowska.* Oficyna Wydawnicza Rytm, Warszawa

Donner H., 1992. *The Mosaic Map of Madaba*. Kok Pharos Publishing House, The Netherlands.

Jewish National and University Library. 2008 Holy Land maps. The Eran Cartographic Collection. Jerusalem.

Linsenbarth A., 2007. *Geoprzestrzeń wydarzeń biblijnych*. Roczniki Geoinformatyki. Vol. V. no 8.

Linsenbarth A., 2008a. *Geografja Ziemi Świętej - Zapomniane dzieło Wincentego Pola.*

Geodeta, Nr 6 (157)

Linsenbartrh A., 2008b *Rola geoinformacji obrazowej w badaniach przestrzeni biblijnej.* Archiwum Fotogrametrii, Kartografii i Teledetekcji, Vol 18

Linsenbarth, A. 2009a. *Old maps of the Holy Land as an example of the world cartographic heritage – evaluation of selected maps.* Proceedings of the Fourth International Workshop of ICA, Venice 6-7 April, 2009

Linsenbarth, A. 2009b. *History of the Bible cartography as an example of the cartography of history.* Proceedings of the 24th International Cartography Conference, Chile, 15-22 Nov.2009

Linsenbarth, A. 2009c. *Exodus Izraela z Egiptu do Ziemi Obiecanej na dawnych mapach. Cz.I – 40 lat na pustyni.* Geodeta nr 11/ 2009

Linsenbarth, A. 2009d. *Exodus Izraela z Egiptu do Ziemi Obiecanej na dawnych mapach. Cz. II – Ładnie ale mało dokładnie",* Geodeta nr 12/2009

Linsenbarth, A., J. Drachal, 2009. *New approach to the Bible cartography. Proceedings of the ICA Symposium in Viena.* Viena 16-17 February, 2009.

Linsenbarth, A. 2010a. *Exodus Izraela z Egiptu do Ziemi Obiecanej na dawnych mapach. Cz. III – Od wyobrażeń do pomiarów.* Geodeta nr 1/2010

Linsenbarth, A. 2010b. *Concept of a Spatio-Temporal Geoinformation System of the Bible Events – Dadabase Approach.* Proceedings of the ISPRS Joint Workshop, Haifa 15-22 March, 2010

Linsenbarth A., M.Brzezińska-Klusek. 2010. *Compatarive analysis of the hydrographic network on the old maps of the Holy Land - digital approach.* Proceedings of the Fifth ICA Cartographic Workshop, Viena, 22-24 February, 2010.

Metger, B.M., M.D.Coogan. 1997. *Słownik wiedzy biblijnej.* Oficyna Wydawnicza „Vocatio" Warszawa

Rainey A. F., Avi-ynoh, M., Safrai, Z., 2002. *The Carta Bible Atlas*. CARTA, Jerusalem.

Ran N., 1989. *Journeys to the Promised Land*. Studio Editions, London.

Sacerdoti, A., 2001. *Izrael – podróże marzeń.* Ars Polona, Warszawa.

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Summary

The Biblical lands cover the territories, where events described in the Old and New Testaments took place. It is an area stretching along parallels from ancient Mesopotamia on the east to Italia on the west, and along meridians from Turkey on the north to Egypt on the south. Thus, these areas covered lands of ancient civilisations originated in the Middle East (Mesopotamia, Babylonia, Assyria) as well as of the civilisation of ancient Egypt. These areas make an ideal example allowing us to trace the development of spatial information in the broad sense.

Undoubtedly, to the oldest geoinformation sources belong maps carved in clay in ancient Mesopotamia. In the locality of Nuzi, located in north-eastern Iraq, a map dated to the end of the 3rd millennium B.C. was excavated. The map depicted an estate.

The areas of ancient Egypt make an inexhaustible source of various kinds of geoinformation included in descriptions of war expeditions led by pharaohs, presented on different kinds of clay tablets or pots. The descriptions of five war campaigns of Pharaoh Pepi I (2390-2361 B.C.) found in Abydos belong to the oldest ones. They depict territories of ancient Palestine.

Texts of the Holy Bible constitute a source of valuable information related to the geography of areas described in the Bible. In particular, in the Books of the Holy Bible, and especially in Genesis, Exodus and Numbers, the character of the lands where the events took place, as well as the routes of the boundaries and lists of localities were given.

The so-called onomasticons, which comprise lists of geographical items, provide another very important source of information. The best known are those written by Bishop Eusebius of Caesarea (260-340 A.D.) and by St. Jerome. The latter, completed in c.a. 385 A.D. and entitled *Liber locorum,* comprised descriptions of more than 600 items located in the area of the Holy Land. Also, numerous travel journals written both by travellers and pilgrims to the Holy Land constitute a good source of information.

Among first geographers and cartographers, in the stricter sense, one may count Eratosthenes of Cyrene (275-194 BC), Hipparchus of Alexandria (190-125 B.C.) and Strabo (ca. 65 B.C.-20 A.D.), who is the author of a 17-volume work entitled *Geographica*. Undoubtedly, Claudius Ptolemaeus (ca. 67-165 A.D.) should be considered as the first cartographer of the modern era. Among other things, he worked out a map of the world, where he marked more than 8 thousand localities. Also, the mosaic map of the Holy Land, which is a part of a floor mosaic in the early Byzantine church of St. George in Madaba (Jordan), is of great importance for the history of cartography.

The development of Biblical cartography, which constitutes the next stage of spatial geoinformation development, occurred towards the end of the 15th century. The first such maps were those compiled by Brandis de Schass, printed in Lübeck in 1475, and the other one by Bernhard von Breydenbach, printed in 1483. At the beginning of the 16th century, in 1507, a really original map, the so-called *Tabula Peutingeriana* was printed. The second half of the 16th century is the time of a very dynamic development of cartography, including Biblical cartography. Within this period many outstanding cartographers were active, such as Gerhard de Jode, Gerardus Mercator, Abraham Ortelius (Linsenbarth, 2008b, 2009a, 2009b, 2009c, 2009d, 2010a). These maps depict consecutive stages of Biblical events, starting from Abraham's journey from Ur of the (Chaldees) Chaldeans, the Exodus of the Israelites from Egypt to the Promised Land, the division of Palestine into twelve tribes of Israel, events related to the life of Jesus Christ and St. Paul's missionary journeys.

Generally, all these maps were characterised by a very nice graphics, but also by not very high cartographic accuracy. It was not until the 18th century, when one can talk about correct maps based on geodetic and topographic measurements. At the beginning of the 18th century John Senex edited a really adequate map depicting St. Paul's journey to Rome. In 1829 German cartographer Yehoseph Schwarz worked out a detailed map of the Holy Land. A book by Wincenty Pol entitled *Geografja Ziemi Świętej [Geography of the Holy Land],* printed in 1862, and a map of Palestine make the Polish contribution to the cartography of the Holy Land. In the second half of the 19th century the British Palestine Exploration Fund edited modern maps of Palestine at a scale of 1:63,000, which constituted a cartographic basis for working out further thematic maps related to the areas described in the Bible and printed towards the end of the 19th century and in the 20th century. Within the years 2006-2008, the researchers from the Institute of Geodesy and Cartography worked out the concept of the system of time-spatial information on historic events on the example of Biblical territories.

The article describes the evolution of the development of geoinformation related to areas described in the Bible, as well as consecutive stages of this development resulting from general development of geographical, historical and cartographical sciences.

Streszczenie

W artykule omówiono poszczególne etapy rozwoju geoinformacji, związanych z obszarami biblijnymi, które pozwalają prześledzić ich historyczny przebieg. Formy tych geoinformacji miały różną postać poczynając od informacji o wyprawach wojennych, zarówno faraonów z Egiptu jak i władców Mezopotamii, poprzez informacje zbierane przez podróżników i pielgrzymów, a utrwalane w ich dziennikach podróży. Kolejne etapy to próby kartograficznego przekazywania tych informacji, opracowywanie onomastikonów, opracowanie i wydawanie map terenów biblijnych, kończąc na atlasach tematycznych oraz systemach geoinformacyjnych. Warto zauważyć, że przez wiele wieków uwaga kartograficznych oficyn wydawniczych z różnych państw Europy skupiona była na terenach biblijnych i wydawaniu map oraz atlasów. Wydanych zostało ponad 6 tysięcy map tych terenów (Ran, 1989). Na mapach tych prezentowano różne wydarzenia biblijne. Analiza tych map pozwala z jednej strony prześledzić zarówno rozwój nauk geograficznych jak i technik oraz technologii kartograficznych. Z drugiej strony jest to bardzo cenny materiał do przeprowadzenia analizy porównawczej map wydawanych w tym samym okresie historii przez różne oficyny wydawnicze w różnych krajach (Linsenbarth, Brzezińska-Klusek, 2010). Wydarzenia biblijne prezentowane na tych mapach są w zasadzie niezmienne, jednak z biegiem lat, w wyniku badań archeologicznych dokonano identyfikacji wielu obiektów geograficznych, których położenie było dotychczas nieznane.

Obecnie powszechnie posługujemy się terminem geoinformacji, który nie był znany w starożytności. Na każdym etapie rozwoju nauk geograficznych i kartograficznych inne były formy danych geoinformacyjnych, które były odzwierciedleniem ówczesnych metod pozyskiwania informacji o terenie.

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EWA KRZYWICKA-BLUM[1]

USABLE FUNCTIONS OF MODERN MAPS

Key words:

map functions, computer maps

Abstract

Modern maps created with the application of GIS technology using special techniques and programmes adequate for spatial information systems are, in comparison to their analogue counterparts, of better model qualities, which is obtained by separating their practical functions. The cognitive function of maps is the main priority. The shape of a map is a result of the applied technology, yet the maps developed using many technical instruments are not always the best ones or graphically correct. There have been many beautiful maps of landscape attempting to show different aspects of landscapes and the results of analyses of multifactorial phenomena and processes.

FUNKCJE UŻYTKOWE WSPÓŁCZESNYCH MAP

Słowa kluczowe:

funkcje map, mapy komputerowe

Abstrakt

Mapy tworzone w warunkach nowoczesnej techniki komputerowej, technologii i organizacji właściwej systemom informacji przestrzennej, cechuje podwyższenie, w stosunku do analogowych, własności modelowych uzyskuje się to dzięki rozdzieleniu funkcji praktycznych. Walory poznawcze mapy stanowią, w całym rozwoju kartografii wartości priorytetowe. Postać mapy jest wynikiem zastosowanej technologii i nie zawsze mapy opracowane w interaktywnym procesie są graficznie poprawne. Pojawiają się nowe ujęcia treści map krajobrazowych i bardzo piękne propozycje ujęć wyników analiz wieloczynnikowych zjawisk i procesów.

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1. Analogue and computer maps

The map usability depends on how the graphic code is adjusted to the human natural visual perception of the surrounding world (Head, 1984; Keats, 1982). A cartographic mode in its historical development is a scene showing relatively positioned markers denoting categories important to people in a given period or situation, and these markers belonging to the separated categories are dimensionally compatible (as to the reduction degree), and the system of markers is compatible with empirically known principles of geometry and topology.

At present two types of relations between a map creator and a map user can be distinguished. In an interactive system "the work is permanently linked to modelling, to transformation and formation of derived images etc. to such a degree that it becomes unclear where the map creation ends and where its using starts" (Berlant, 2000). It is worth noting that the choice of tools is now so rich that the process of map creation in the conditions of an easy access to and knowledge of one given technique, and, which is the result of it, with the application of this particular technique, creates the danger of using non-op-

Fig. 1. Topographic map. Catalonia 1: 10,000 (source: ICC newsletter 32)
Rys. 1. Topograficzna mapa. Catalonia 1:10 000 źr. ICC Newsletter 32

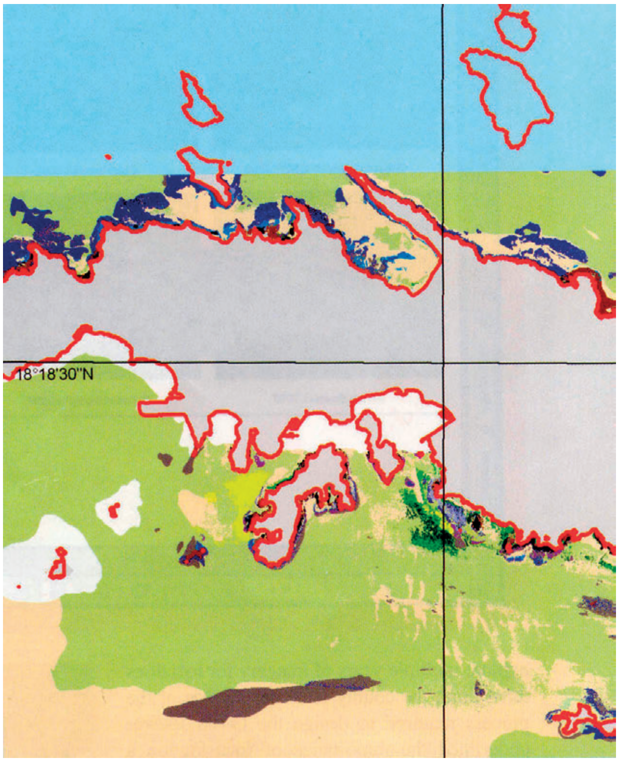

Fig. 2. Coral reefs – threats (source: Arc User, 2006)
Rys. 2. Rafy koralowe – zagrożenia, źr. Arc User, 2006

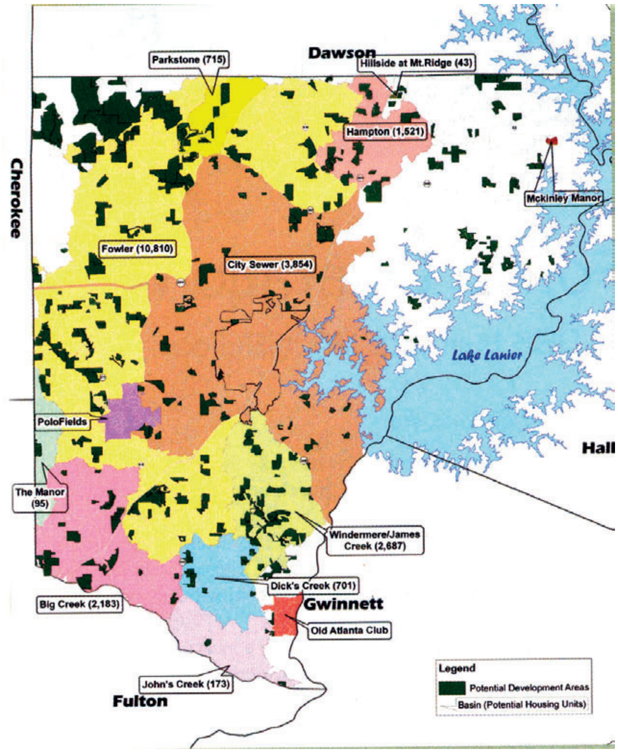

Fig. 3. Forsyth. Availability of infrastructure
Rys 3. Forsyth dostępność infrastruktury, (zaopatrzenie w wodę), źr. Zarc User Winter, 2006

timal models. Most frequently it applies to disregarding rules of using colours in quantitative models.

A completely different situation arises when the user has a map prepared by a given institution or delivered as a work of institutes, professional firms or companies. Maps are developed in adjustment to their purpose, methodically correct and have correctly selected graphic variables.

Obviously, a data set in spatial information systems is not full and the distinguished categories cannot meet the requirement of their compatibility with all possible situations in the man-environment relation. As the development of civilisation changes the contents of the map, so the information resources in the systems are influenced by the changing needs of their users. The life itself always decides which disciplines, and in which external conditions, people put in the highest position. Presently, from the point of view of global assessment, the most important are models, and hence maps, of global threats.

A type of maps illustrating catastrophic phenomena (armed conflicts, epidemics, tectonic shocks, fires, typhoons) has become popular. Analyses of the environment condition, effects of anthropopressure and resources evaluations play an important role in directing economic and social strategies.

On a local scale it is significant that at present people find wealth and convenience important in their life and work. They are interested in land prices, levels of infrastructure, availability of services, job markets, and health care.

A great number of maps that make an inventory of selected elements of the environment or that interpret changes in the environment and which are created in the conditions of the rapid development of methods

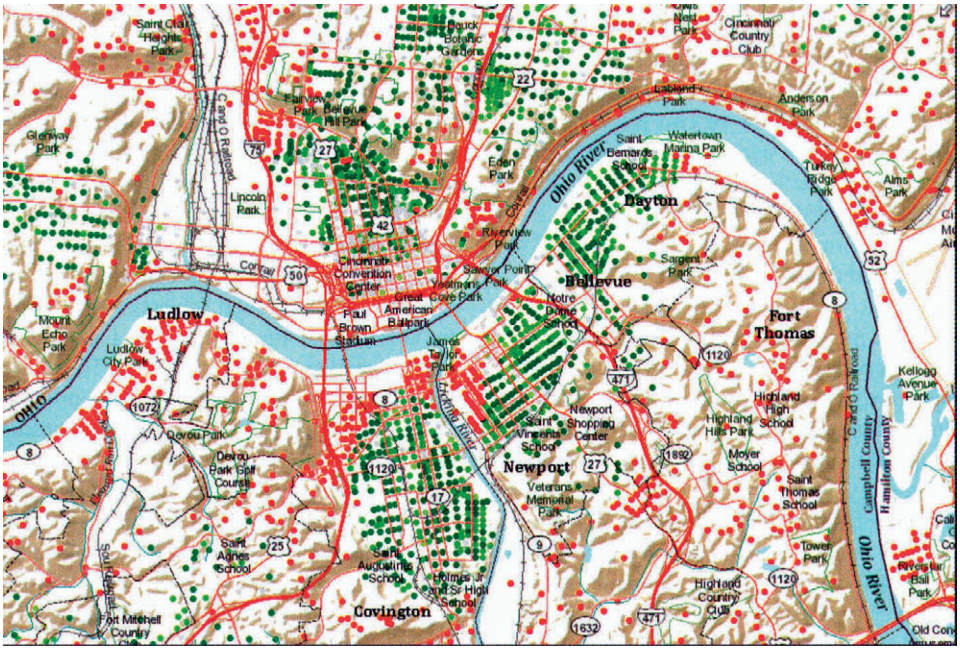

Fig. 4. Chicago. Availability of shops with healthy food (source: Arc User, 2010)

Rys. 4. Chicago. Dostępność do sklepów ze zdrową żywnością źr. Arc User, 2010

Fig. 5. Information of integration – state (source: Arc User Winter 2010)

Rys. 5. Integracja informacji – stan źr. Arc user Winter 2010

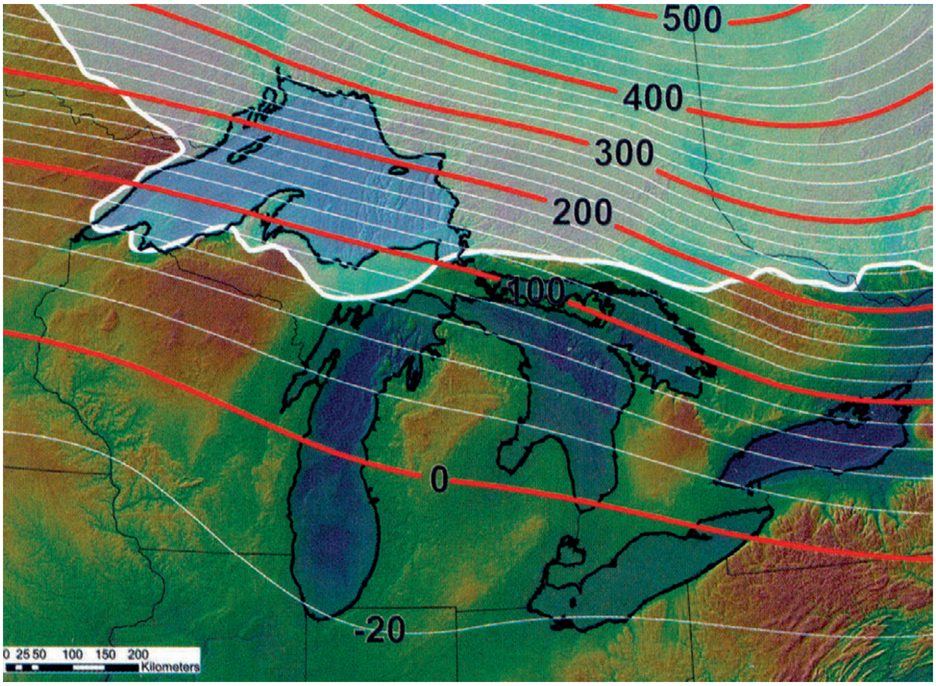

Fig. 6. Information of integration – process (source: Arc User Summer 2009)
Rys. 6. Integracja informacji – proces, źr. Arc User Sumer 2009

of objective recording of natural and anthropologically transformed environment is not balanced with a similar number of population maps. It can be observed that on a global scale the population data still do not satisfy the condition of time or space representativeness, which in view of significant consequences of contemporary migration means the existence of the information gap. All the agreements related to the organisation and range of topics for making lists notwithstanding, lot of important information cannot be spread because of the data protection.

Unlike analogue maps, contemporary computer models are not multifunctional maps; more often they are models clearly adjusted to one selected function: cognitive or practical. At the conference organised by the International Cartographic Association both scholars and practitioners devoted much time to the classification of functions. Finally they established a division into general and specific functions (Freitag, 1980).

2. Usable properties of cartographic models

Visual perception of a map makes a map user able to:

a) create a synthetic image of the object of modelling in the process of partial information compensation;
b) isolate areas differing as to their degree of density of one category items;
c) assess the degree of compliance of the location of items belonging to two different categories;
d) distinguish characteristic properties of a multi-category system.

Referring to (a). The first of the above mentioned properties justifies the usability of maps in school education, but also in widely understood descriptive information with “an addition” of a map. Here one can quote Epictetus’ words: “To see a thing once means more than to hear about it a hundred times”. This wonderful property determined that the term “map” was included in the language of mass media.

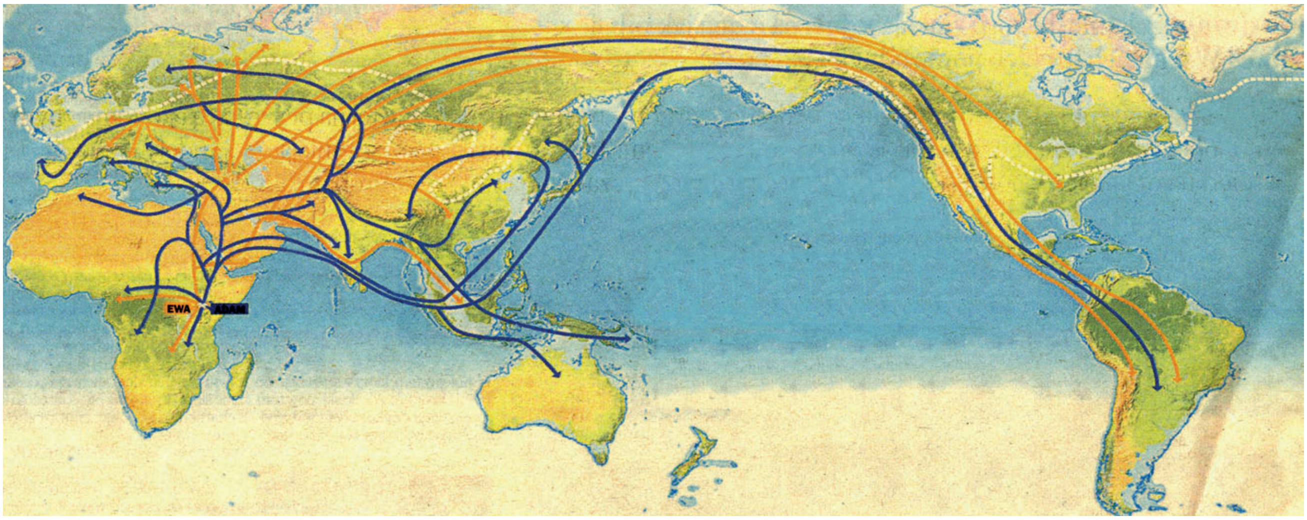

Fig. 7. Genetic mapping of journey (source: Gazeta Wyborcza, Feb. 22, 2008)
Rys. 7. Genetyczny zapis podróży, źr. Gaz. Wyb. 22 luty 2008

It is not only the image of an unknown environment or structure, i.e. the cognitive function, which is important. The ability to create overall associations proves essential in a situation requiring a person's location in the surrounding reality. One's spatial orientation in an unknown or changing environment is supported by tourist maps, city plans, road maps on different media, navigation maps, nautical charts and aerial maps. Evacuation maps and maps of access to fires or accidents, prepared based on many optimisation analyses and used by municipal services, belong to the most important ones in this group.

The remaining three from the above mentioned possibilities of using the properties of a cartographic model require analyses, and the type of analyses corresponds to their various applications.

Referring to (b). The analysis of spatial distribution of markers belonging to one category is a rich source of cognitive information related to environment both natural

Fig. 8. Europe – optimisation of temporary availability; road connections (source: ARC NEW, Autumn 2009)
Rys. 8. Europa – optymalizacja czasowej dostępności, połączenia drogowe, źr. ARC NEWS, Jesień 2009.

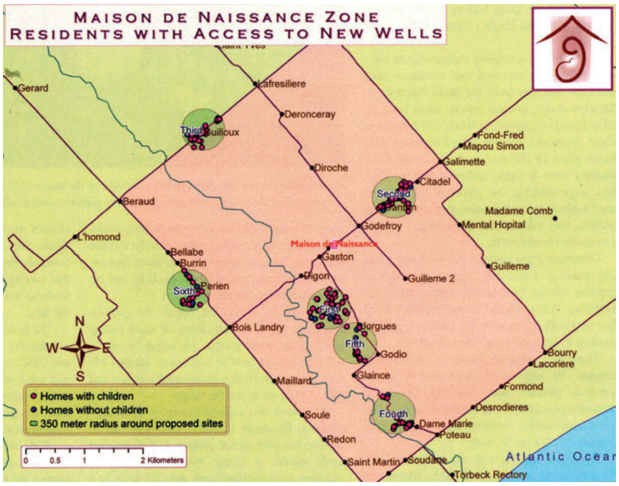

Fig. 9. Location of necessary water intakes (source: Arc User Spring 2009)

Rys. 9. Lokalizacja niezbędnych ujęć wody, żr. Arc User Wiosna, 2009

and that transformed by man (Krzywicka-Blum, 1996). An extraction of a drawing of a river network from a hydrological map, the knowledge about the distribution of an important species of flora, a system of astronomical observation stations or an inventory of historic Renaissance structures in Poland – they are examples of information interesting for the recipient.

At present, analyses carried out in order to optimise the location of new investments play a very important role.

Referring to (c). The analysis of co-occurrence of items belonging to different categories makes it possible to formulate hypotheses or to make conclusions drawn based on observation more probable; this is an important cognitive property of maps. As an example one may use the confirmation of the relation between effects of deforestation in the Śnieżnik mountain range and the industrial pollution transported from border areas (Krzywicka--Blum, 1999).

Referring to (d). Analyses of spatial distribution of items belonging to several categories make it possible, in cognitive sense, to divide an area into sub-areas qualitatively different, and that actually means creating typology

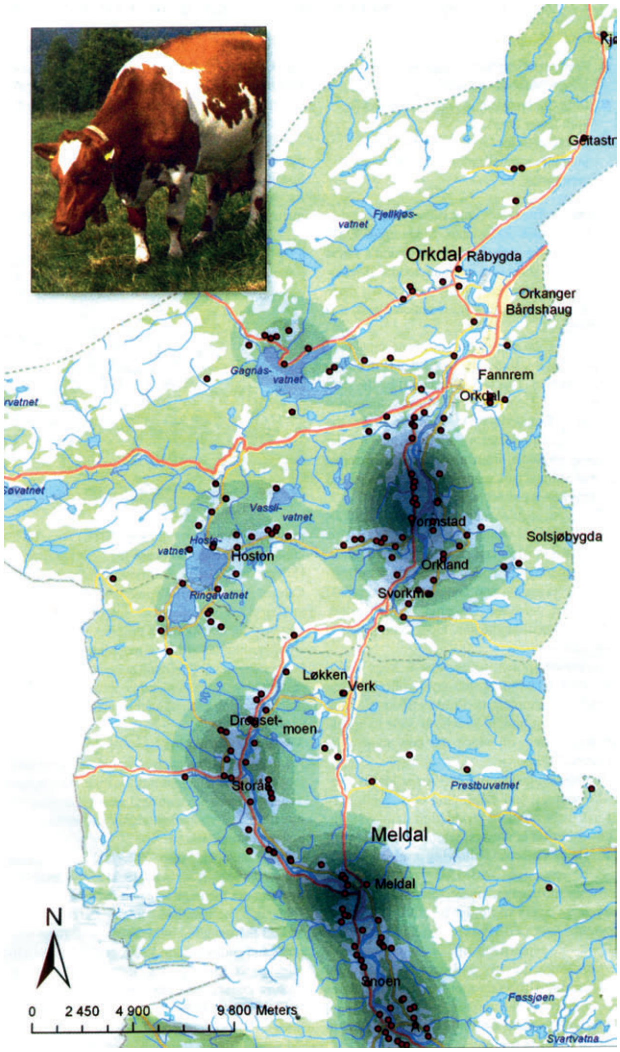

Fig. 10. Potential sources of biogas (source: ARC NEWS Vol. 31 No. 1. 2009)

Rys. 10. Potencjalne źródła biogazu, źr. ARC NEWS Vol. 31 No 1, 2009

together with distinguishing sets of properties that characterize the types.

Valorisation maps, which are prepared based on the assessment of the total level of impact of several components, play an important role in fiscal policy and management.

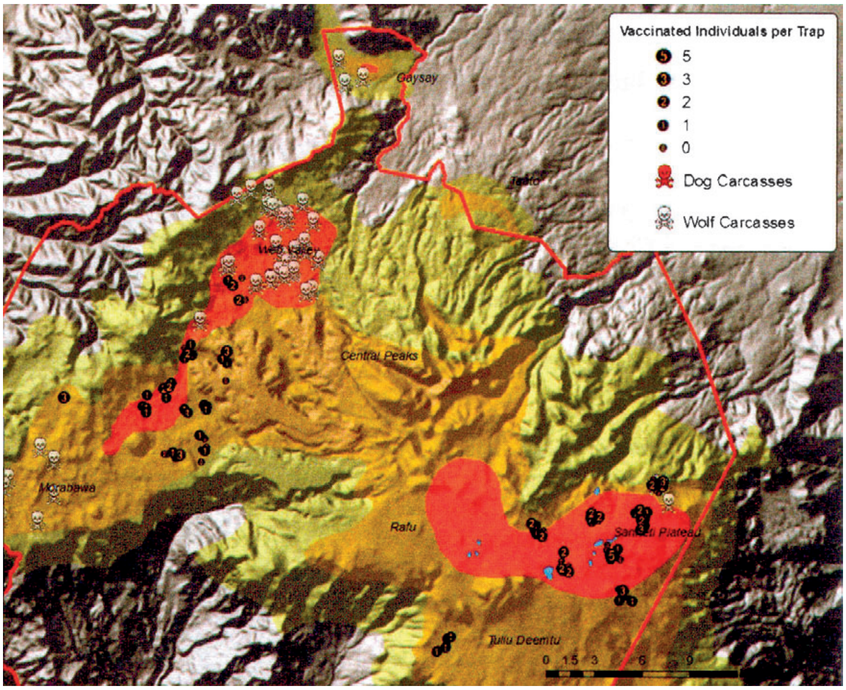

Fig. 11. Ethiopia – threat of wolf rabies transmitted by dogs (source: ARC NEWS 2010, Vol. 32, No. 3)
Rys. 11. Etiopia – zagrożenie wilków wścieklizną przenoszona od psów, źr. ARC NEWS 2010. Vol 32 No. 3

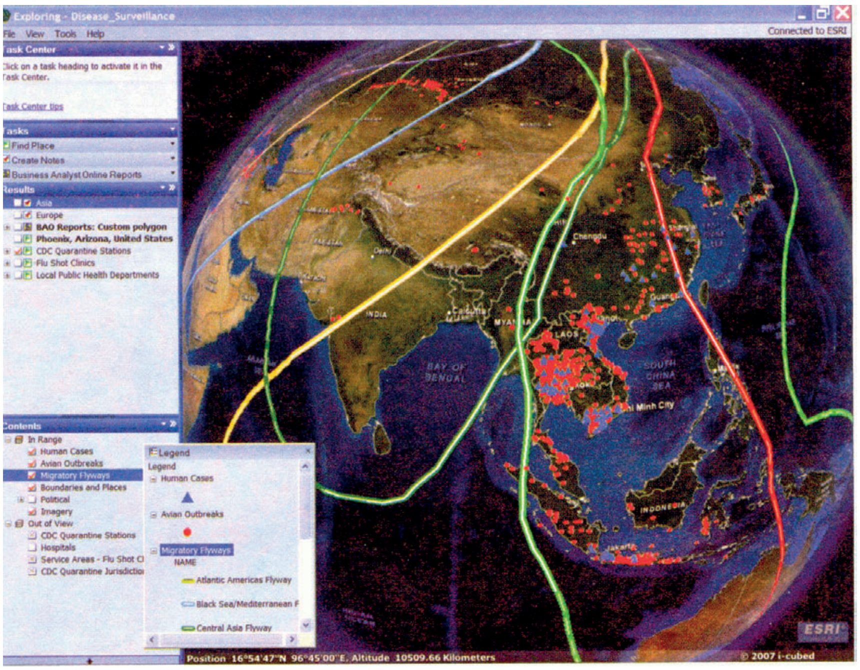

Fig. 12. Birds' migration routes and the diffusion of influenza (source: ARC NEWS 2009, Vol. 31, No. 1)
Rys. 12. Trasy migracji ptaków i dyfuzja grypy, źr. ARC NEWS 2009, Vol. 31 No. 1

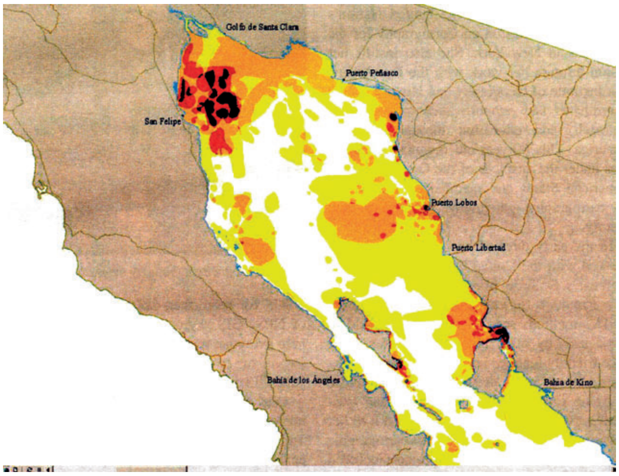

Fig. 13. Assessment of the fishery for amateur fishermen, Mexico (source: ARC NEWS 2009, Vol. 31, No. 3)

Rys. 13. Ocena łowiska dla rybaków amatorów, Mexico, źr. ARC NEW, 2009, Vol. 31 No. 1

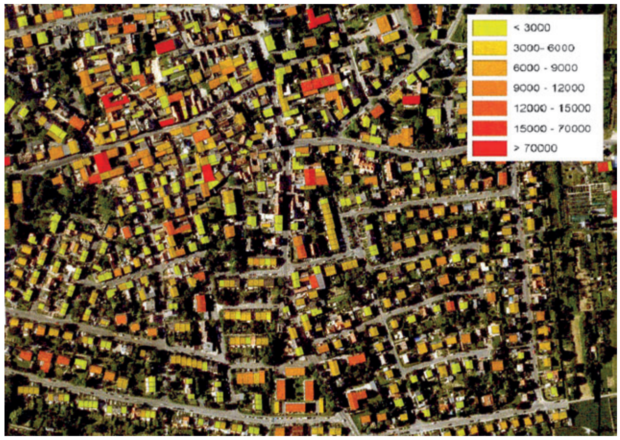

Fig. 14. Osnabruck. Solar energy – reserves (source: ARC NEWS 2009, Vol. 31, No. 3)

Rys. 14. Osnabruck. Energia słoneczna – rezerwy, źr. ARC NEWS 2009 Vol. 31 No. 3

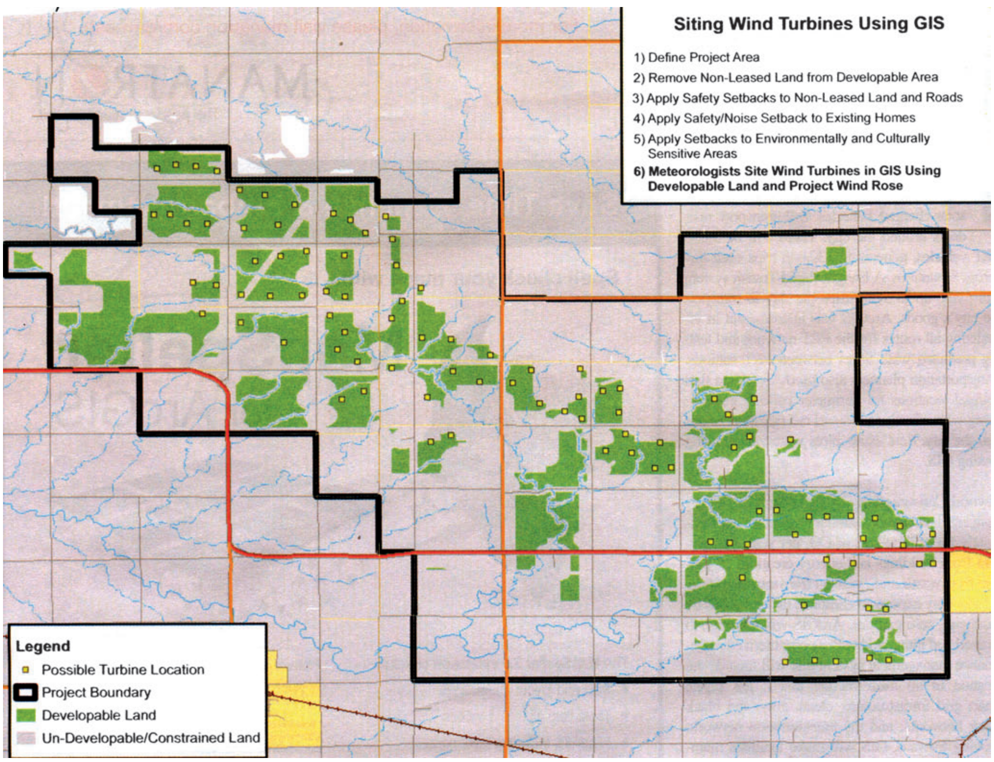

Fig. 15. Location of wind turbines (source: ARC NEWS 2009, Vol. 31, No. 3)

Rys. 15. Lokalizacja wiatrowni, źr. ARC NEWS 2009, Vol. 31 No. 3

Frequently the objective of analyses is to make it easier for the user to decide on the location of structures in privileged or restrictive conditions.

3. Final remarks

A breakthrough in the development of maps using modern techniques and technologies raises hope for great progress in the field of cartography, both in the form of maps and their significance in practice, but also in satisfying the cognitive and aesthetic needs. It is natural that new conditions are characterized by many failures; maps are not always correctly worked out as far as a proper selection of methods and optical order are concerned. Yet, the progress is remarkable and expressive, and reliable kinds of models have already appeared.

4. Literature

1. Berlant, A. 2000. *Kartowanie geoinformatyczne koncepcja i podstawy geograficzne*, Pol. Przegl. Kart. T.32, nr 1, p.6

2. Freitag, U. 1980. *Can communication theory form the basis for cartography*, Nachrichten aus dem Karten-und Vermessungswesen,

3. Head C.G. 1984. *The maps as natural language a paradigm for understanding,* Cartographica 21/1. 1–32.

4. Keates, J.S. 1982. *Understanding Maps*. London and New York: Longman

5. Krzywicka-Blum, E. 1996. *Modelowanie kartograficzne zmian w środowisku przyrodniczym*, [in:] MASYW ŚNIEŻNIKA, P.Ag,Ekol.

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DARIUSZ GOTLIB[1]

MOBILE MAPS – MODELLING OF CARTOGRAPHIC PRESENTATION

Key words:

mobile cartography, mobile maps, mobile GIS, geovisualization, navigation applications, LBS

Abstract

The article focuses on the cartographic design aspects of mobile navigation and location applications. The relationship between the conceptual model of spatial data and the cartographic presentation model is discussed. An example of a formal description of cartographic presentation that uses the concepts: partial geocomposition, cartographic information transmission unit, cartographic event, geovisualization window and elementary geovisualization is presented. The paper shows potential benefits of applying the proposed methodology, primarily the ability to create a description of cartographic presentation, which is independent of specific technologies used by the applications of different manufacturers.

MAPY MOBILNE – MODELOWANIE PREZENTACJI KARTOGRAFICZNEJ

Słowa kluczowe:

kartografia mobilna, mapy mobilne, mobilny GIS, geowizualizacja, aplikacje nawigacyjne. LBS

Abstrakt

W artykule zwrócono uwagę na kartograficzne aspekty projektowania mobilnych aplikacji nawigacyjnych i lokalizacyjnych. Pokazano zależności pomiędzy modelem pojęciowym danych przestrzennych a modelem prezentacji kartograficznej. Przedstawiono przykład formalnego opisu prezentacji kartograficznej wykorzystującego pojęcia: geokompozycja składowa, jednostka przekazu kartograficznego, zdarzenie kartograficzne, okno geowizualizacji, geowizualizacja elementarna. Omówiono potencjalne korzyści wynikające ze stosowania omawianej metodyki, przede wszystkim możliwość tworzenia opisu (definicji) prezentacji kartograficznych niezależnego od konkretnych technologii poszczególnych producentów aplikacji.

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Introduction

Many kinds of mobile applications, including navigation and location applications (e.g. programs for car navigation) have been in constant use for many years already. When they appeared it seemed sufficient (both for their users and manufactures) that they were able to approximately locate a mobile object within the area of a town or country and to show its location in relation to an earlier designed trajectory. Cartographic aspects of the design process and usage of this kind of products were of secondary importance. Nowadays navigation applications carry out a great deal of important tasks, and the question of their correct cartographic message has become crucial. More and more data from many high quality sources, data of dynamic character, increasing functionality as well as an increasing range of devices of various technical parameters extorts optimization of cartographic communication. Simultaneously, users accustomed to precise positioning pay more attention to aesthetic values and, first of all, to the ease of use of this kind of products. In turn, the ease of use depends very much on the correctness of cartographic communication, which begins to be more and more widely discerned.

The complexity of the definition of cartographic presentation is so great that it requires methodical and formal developing. The first works in Poland on that subject were undertaken during the research conducted at Warsaw University of Technology and presented in publications (Gotlib 2008, Gotlib 2009, Gotlib 2011). As a result, a methodology of mobile cartographic communication modelling was suggested and its main assumptions will be presented in the present paper.

Mobile maps

Mobile maps make a fundamental element of mobile navigation and location systems. The concept of mobile maps covers a coherent set of digital spatial data appropriately selected in the process of modelling and, the method of their cartographic presentation.

Cartographic presentation is a transmission of information whose source is a map constituting a spatial model that enables the transmission of ordered information about objects in the context of their spatial location (which particularly allows for a proper interpretation of this location and the relation between the objects) (Gotlib 2008). Cartographic communication process may be realised by different kinds of media, also by using sound or video.

It is not sufficient to satisfy the condition of map movement in order to call a map a mobile one. A mobile map is a map used on a mobile device, adjusted to optimum reading of its content on the move; it is a map reacting to changes of the user's location and characterised by a change of cartographic message in relation to this location and to conditions in which the observation is carried out.

What is worth noting is the diversity and high usability of navigation and location applications. They require specific optimized cartographic communication. Each of the criteria presented in Table 1 influences the way of developing cartographic presentation as well as the selection of suitable data models.

A combination of the qualities specified above in Table 1 allows us to distinguish several tens of various kinds of mobile applications. One can observe that the applications listed for the criterion defined as: "the method of representing reality" may operate in the mode defined as "No visualization" (5.3). The concept of cartographic communication should not be treated as related solely to geovizualization or a graphic picture in a form of a classic map. Many systems may work in the "no map" mode sending only a sound message or direction arrows. It does not change the fact that still it is cartographic message. In the case of navigation systems, relaying geographic information by means of sound is of particular significance. The way of selecting sounds, their substantive characteristics and the selection of places where they are played, belongs also to the field of cartography, which is the science dealing with optimum communication of spatial information.

On the other hand, there has been an increase in user's demands related to the quality and complexity of cartographic visualization. Geovisualizations based on a perspective view have become widely available in car navigation systems. The users expect, among other things, access to advanced 3D models and vector data combined

Table 1. Different classification criteria for navigation and location applications (according to Gotlib 2008) influencing the way of constructing cartographic message

Tab. 1. Różne kryteria klasyfikacji aplikacji nawigacyjnych i lokalizacyjnych wg [1] wpływające na sposób konstrukcji przekazu kartograficznego.

Classification criterion	Purpose and method of use
1. The main function	1.1. Navigation 1.2. Location
2. Place of use	2.1. Outdoor 2.2. Indoor
3. Route type	3.1. Car 3.2. Railway 3.3. Bicycle 3.4. Pedestrian 3.5. Flying 3.6. Sailing 3.7. Mixed
4. User's main goal	4.1. Movement 4.2. Sport and tourism 4.3. Entertainment 4.4. Safety 4.5. Surveing
5. The method of representing reality	5.1. Classic visualization 5.2. Augmented Reality 5.3. No visualization
6. System architecture	6.1. On-line 6.2. Off-line with the possibility of exchanging date with a server 6.3. Off-line
7. User's type	7.1. Professional 7.2. Non-professional
8. Type of production	8.1. Professional 8.2. Consumer community

with aerial photographs. Applications using "augmented reality" technologies[2] are being disseminated. These expectations of geoinformation market make it necessary to further develop theory and practice in cartography.

Fig. 1 presents examples of cartographic visualizations in selected navigation applications.

[2] Augmented reality – methods and techniques where images of real world are combined with data from database

Modeling of data and presentation

Designing cartographic communication process is skilful modelling of data from different sources (selection, combination, generalization) as well as modelling of the cartographic presentation itself in order to ensure effective reading of spatial data by human senses. Cartographic communication modelling in mobile applications mainly applies to two aspects:

– conceptual modelling of source data,
– modelling of geocomposition.

Fig. 1. Examples of cartographic visualizations in selected navigation and location applications (from the left: Auto Mapa, Blaupunkt, IGo; from the top right: MapaMap, NDrive, Google Maps (www.automapa.pl, Blaupunkt promotional materials, www.navngo.com, www.mapamap.pl, www.ndriveweb.com, Google Maps application)

Rys. 1. Przykłady wizualizacji kartograficznych w wybranych aplikacjach nawigacyjnych i lokalizacyjnych (kolejno od góry z lewej: AutoMapa, Blaupunkt, IGo; od góry z prawej: MapaMap, NDrive, Google Maps [7], [8], [9], [10], [11], [12].

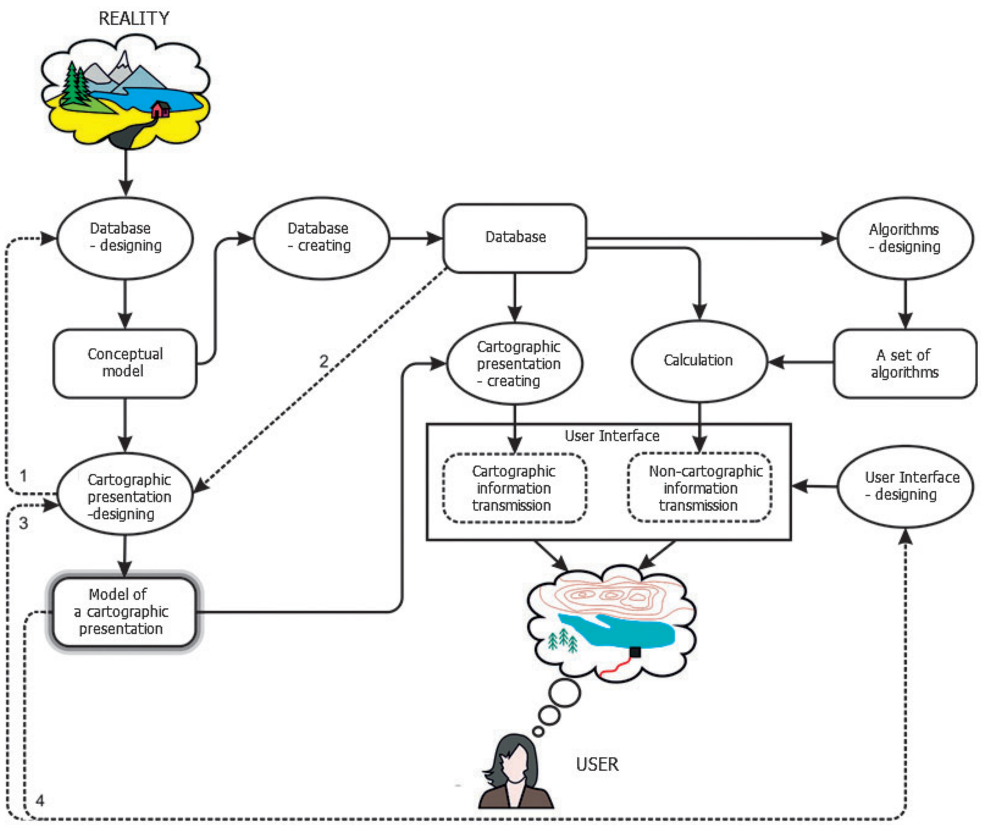

Fig. 2. Location of cartographic presentation model in the context of other processes of creating and using mobile application. Ellipses symbolise processes, whereas rectangles with rounded corners – entities created in the process of creation of mobile cartographic presentation.
Rys. 2. Umiejscowienie modelu prezentacji kartograficznej w kontekście innych procesów tworzenia i użytkowania aplikacji mobilnej. Elipsy symbolizują procesy, natomiast prostokąty z zaokrąglonymi narożnikami – byty wytworzone w procesie tworzenia mobilnego przekazu kartograficznego [1].

Thus, we deal both with a conceptual data model and with a model of cartographic presentation that has characteristics of a metamodel in relation to the first one. We can notice that by analysing a diagram in Fig. 2, where two models are distinguished: a conceptual model of a data base and a model of cartographic presentation. The model of cartographic presentation is a derivative of conceptual models of data and it is not a model of the data itself but of the way of their presentation to the user. The designer of a cartographic presentation model (a cartographer) should perfectly know the model of spatial data available to him/her. It is also important that while designing the cartographer should have access to data (a relation marked as "2" in Fig. 2). The diagram shows also the possibility of an impact of the design process of cartographic presentation on the process of database design (a relation marked as "1" in Fig. 2). The cooperation of these processes may lead to obtaining optimal cartographic communication. Obviously, this is not about constructing a database based on DLM and DCM integrated models[3], but exclusively

[3] Distinguishing between Digital Landscape Model and Digital Cartographic Model is connected with the concept of "separating spatial databases from cartographic studies" (Grün-

about the optimization of its model based on the precise knowledge of the way of spatial communication to the final recipient. According to the diagram shown in Fig. 2, the cartographic presentation model represented by the adequately formalized record (e.g. by using xml), should make a base to control the process of generating cartographic presentation in various mobile navigation and location applications.

It is worth noting that the relations between the design process of cartographic presentation and the design process of an user graphic interface for a mobile application is of great importance. The knowledge about the application interface should be taken into consideration while designing the presentation and vice versa. If there is a possibility of influencing the application appearance, then depending on the choice of the concept of cartographic presentation, attempts should be made in order to adjust them to each other (at least as to their cartographic consistency).

Formalization of design process of mobile cartographic presentations

The concept of formalization in the context of cartographic communication is understood as providing an abstract unequivocal description of cartographic presentation by using specified formal languages (e.g. graphic notations) in order to enable its correct reading by various users and by various IT systems/applications. The formalization of the design process of a mobile cartographic presentation is necessary mainly because of the following reasons:

– the necessity of taking into consideration changing external conditions while the system is being used (e.g. intense sunlight, total absence of light);
– the necessity of matching the content and the form to the requirements of an individual recipients, to the recipient's location in space and to the task carried out at the very moment;
– dynamism of the presented data;
– the necessity of using many changing data sources (e.g. data from on-line services);
– the necessity of making the same presentation available in many mobile devices of various parameters.

One of possible solutions that allows for the formal description of cartographic presentation may be using a discrete Mobile Cartographic Presentation Model suggested by Gotlib (Gotlib 2008). The model primarily employs the following concepts: *geocomposition, partial geocomposition, cartographic communication unit, geovisualization window, elementary geovisualization, cartographic event.* The model was defined both by using UML and also (within the scope of basic concepts) in the language of set theory. The model is based on the following conceptual assumptions:

1. Cartographic presentation consists of a whole sequence of component geovisualizations, and each geovisualization is made of cartographic communication units (elementary components of geocomposition) of seven different types: *geometry, raster, text, label, sound, video, special.*

2. Each user, even moving along the same route, may receive a different image of the same terrain, because the user's speed may be different, the kind of the trip may be different (e.g. business trip, tourist trip), the user may move during the day or during the night (which results in different geocompositions) and the user may chose different system settings. The change in the geovisualization scale (caused directly by the user or indirectly as a result of e.g. the change of speed) increases or decreases its spatial extent, the user's movement causes both imaging of the next fragment of the terrain (partially overlapping the previous one) and turning the presentation towards the direction of the motion. Each time a bit different, dynamically changing "elementary geovisualizations" are generated (Fig. 3).

3. The content and the form of the presentation changes depending on the enlargement or reduction of the map size as well as on the occurrence of specified user's activities (e.g. movement) or the occurrence of specified situations (e.g. entering an urban area).

reich 1995, Grünreich et al. 1992). From one DLM database many DCMs can be developed; they may be diverse in terms of their purpose, scale and method of presentation. The essence of this diversification is the variety of purposes. DLMs supply analysis-oriented GISs, whereas data from DCM supply display-oriented maps.

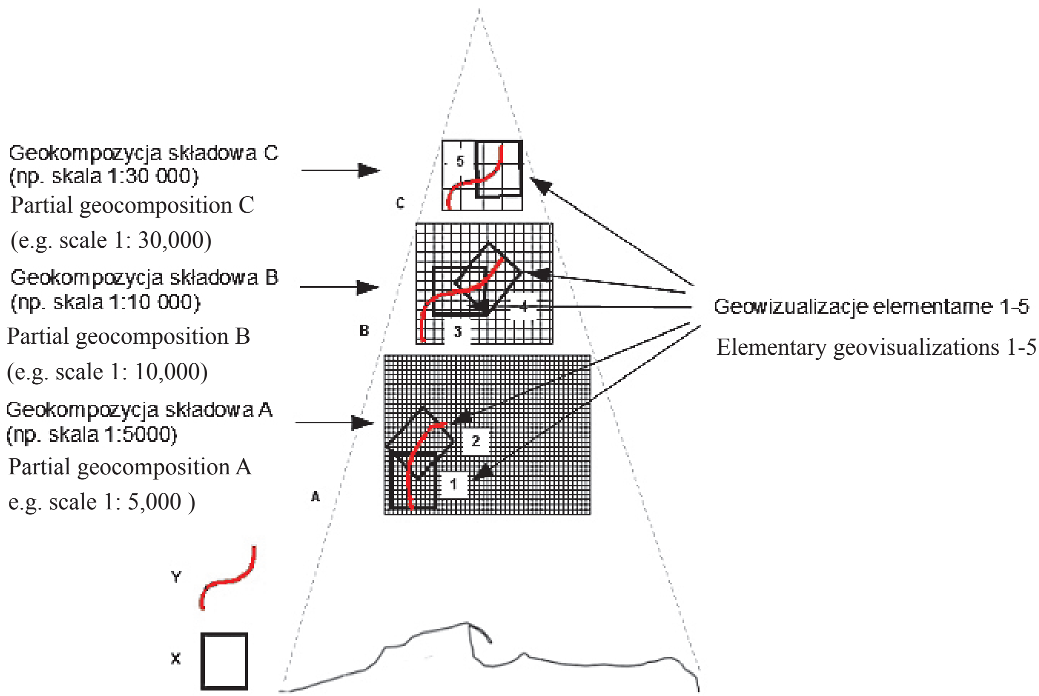

Fig. 3. Geocomposition as a set of partial geovisualizations "caused" by the user's movement with changeable speed (increasing speed); A, B, C – partial geocompositions, Y – the user's route, X – geovisualization window, 1, 2, 3, 4, 5 – elementary geovisualizations

Rys. 3. Geokompozycja jako zestaw geokompozycji składowych „wywołanych" na skutek ruchu użytkownika ze zmienną prędkością (zwiększanie prędkości); A, B, C – geokompozycje składowe, Y – trasa użytkownika, X – okno geowizualizacji, 1, 2, 3, 4, 5 – geowizualizacje elementarne

4. The same cartographic presentation may be used in many devices of various parameters (resolution, display size, colour depth) and should include geocomposition sets optimized for various classes of these devices.

5. The same cartographic presentation may be used in different utility and cartographic modes: navigation, location, 2D, 3D, etc.

Example of mobile cartographic presentation

The Mobile Cartographic Presentation Model may be implemented in various ways, e.g. in a relational database or in a form of XML files. An example (fictitious) of a definition of the mobile cartographic presentation implemented in a relational database will be discussed below.

From the description of the designed cartographic presentation presented in Fig. 4 we may notice that it is composed of several geocompositions (of conventional names), including (among others):

– "Nawigacja Standard" with ID=1 ("Standard Navigation");
– "Nawigacja Słoneczny Dzień" with ID=2 ("Sunny Day Navigation");
– "Nawigacja Nocna" with ID=3 ("Night Navigation");
– "Lokalizacja Standard" with ID=4 ("Standard Location");
– "Narciarstwo" with ID=10 ("Skiing").

Thus we may deduce that this is a project prepared for use both during navigation and location in conditions

PozycjeLegendy

Id_JednostkaKarto	Id_GeoKompozycjiSk	Id_ZnakuKarto	KolejnoscWyswietlania	Priorytet
1	1	1	10	1
1	2	1	10	1
1	9	52	10	1
1	10	52	10	1
1	11	51	10	1
2	1	2	10	2
2	9	53	10	2
2	2	2	10	2
3	1	3	10	2
3	9	16	10	2
4	1	4	10	3
40	1	82	11	1

GeokompozycjeSkladowe

Id	Skala	Id_GeoKompozycji
1	2000	1
2	5000	1
3	10000	1
4	20000	1
5	50000	1
6	100000	1
7	200000	1
8	500000	1
9	1000000	1
10	2000000	1
11	10000000	1
12	2000	3
13	5000	3
14	10000	3
15	2000	4
16	5000	4
17	10000	4
18	2000	2
19	5000	2
20	10000	2
21	2000	10
22	5000	10
23	50000	10

Geokompozycje

ID	Nazwa	TypUzycia
1	Nawigacja Standard	1
2	Nawigacja Słoneczny Dzień	1
3	Nawigacja Nocna	1
4	Lokalizacja Standard	2
5	Lokalizacja Słoneczny Dzień	2
6	Pomiary	2
7	Turystyka	2
9	Loty samolotowe	2
10	Narciarstwo	2
11	Nawigacja Kontrast	1
12	Nawigacja Wesołe Kolory	1
13	Nawigacja Pastele	1
14	Nawigacja Barwy Google	1
15	Nawigacja Minimum Treści	1
16	Szybownictwo	1
19	Żeglarstwo rekreacyjne sródlądowe	2
20	Żeglarstwo regatowe śródlądowe	1
21	Nawigacja Maksimum Treści	1
22	Niewidomi Nawigacja Użytkowa	1
23	Niewidomi Nawigacja Krajoznawcza	1
24	ENC standard	1
26	Nawigacja samochodowa - tryb bez geowizualizacji	1
27	ENC widok podwodny	1

JednostkiPrzekazuKartograficznego

ID	Nazwa	Typ	ID_JednostkiKartoNadrzednej
1	Jezdnia autostrady	Geometryczna	10
2	Jezdnia drogi ekspresowej dwujezdniowej	Geometryczna	10
3	Jezdnia dróg ekspresowych jednojezdniowych	Geometryczna	10
4	Jezdnia dróg głównych dwujezdniowych	Geometryczna	10
5	Jezdnia drogi głównej jednojezdniowej z poboczem twardym	Geometryczna	10
6	Jezdnia drogi głównej jednojezdniowej bez pobocza twardego	Geometryczna	10
7	Jezdnia drogi drugorzędnej dwujezdniowej	Geometryczna	10
8	Jezdnia drogi drugorzędnej jednojezdniowej	Geometryczna	10
40	Obliczona trasa samochodowa	Geometryczna	110

ZnakiKartograficzne

ID	TypZnaku	Definicja	Nazwa
82	1		
1002	4		
1001	4		
1000	4		
600	1		
500	3		
52	1		
51	1		
50	1		
5	1		
4	1		
3	1		
2	1		
1	1		

Fig. 4. Example (fictitious) of fragment definition the mobile cartographic presentation stored in the relational database structure (Gotlib 2008).

Rys. 4. Przykład (fikcyjny) fragmentu definicji mobilnego przekazu kartograficznego zapisany w postaci relacyjnej bazy danych [1].

of changeable light. An additional property of this cartographic presentation is access to a geocomposition adjusted to use while skiing. From the presented records we may conclude that for the geocomposition called "Nawigacja Standard" the following scale sequence was assigned: 1 : 2,000; 1 : 5,000; 1 : 10,000; 1 : 20,000; 1 : 50,000; 1 : 100,000, 1 : 200,000; 1 : 500,000; 1 : 1,000,000; 1 : 2,000,000; 1 : 10,000,000. It means that a change is the presented content of the map and a change in the level of generalization, a change of cartographic signs will occur after these (and only these) scale thresholds are exceeded. For such scales the appropriate cartographic set of information was defined. Hence it is of discrete character. Therefore, launching the "zoom" function in the navigation application within the range between the thresholds will be connected only with technical reducing or enlarging of the image. A proper change in the cartographic presentation will occur exclusively in the given concrete scales. As can be seen in the discussed example, for each geocomposition we may assign different scale sequence which is characteristic of it and that guarantees the flexibility in creating presentations. And so, for instance, for the geocomposition called "Skiing" only three scales are designed: 1: 2,000; 1: 5,000 and 1 : 50,000, assuming that they are sufficient for skiers when they are on the slopes.

When defining component geocompositions it is crucial to assign them the so-called cartographic communication units (CCU), i.e. elementary elements constituting the geocomposition. For the geocomposition called "Nawigacja Standard", for the scale of 1:2,000 there are units of the following identifiers: 1, 2, 3, 4, 40 (fig. 4). One can read it by analysing relations between the first record in the table *GeokompozycjeSkladowe* (partial geocompositions) and column *Id_GeoKompozycjiSk* (identifiers of partial geocompositions) from the table *PozycjeLegendy* (legend positions), in which the value of "1" occurs 5 times. As can be easily checked in the table *JednostkiPrzekazuKartograficznego* (cartographic communication units) individual identifiers have the following descriptions:
– "Jezdnia autostrady" (motorway roadway);
– "Jezdnia drogi ekspresowej dwujezdniowej" (dual carriageway expressway roadway);
– "Jezdnia drogi ekspresowej jednojezdniowej" (single carriageway expressway roadway);
– "Jezdnia drogi głównej dwujezdniowej" (dual carriageway main road roadway);
– "Obliczona trasa samochodowa" (calculated car route).

The type assigned to each of the CCUs listed above is *"Geometryczna"* (geometric), which means that it has a vector representation. These units also have defined hierarchic relations. In this case a higher unit "Jezdnia" (roadway) with ID=10 is assigned to the first four CCUs and unit "Trasa" (route) with ID=110 for the last one.

In the table *PozycjeLegendy* (legend positions) is defined the way of presenting objects by assigning cartographic symbol identifier to individual cartographic communication units: for CCU with ID=1 is assigned the symbol with ID=1, for ID=2 the symbol with ID=2, for ID=3 the symbol with ID=3, for ID=4 the symbol with ID=4 and for ID=40 the symbol with ID=82. The symbols definition can be included in the table *ZnakiKartograficzne* (cartographic symbols) by using a selected formal language, as a value of attribute *Definicja* (definition). It is sufficient to refer to the symbol identifier from the externally defined symbol library, which guarantees abstractness of the solution and makes possible the implementation by different manufacturers. In the table *PozycjeLegendy* the order of displaying the object during geovisualisation is defined – for the listed road classes the same value ("10") is assumed, because in this case the order of displaying depends on the object classification, which results from the database content (a road segment in a tunnel, on an overpass, on the ground). The assigned value of attribute "KolejnoscWyswietlania" (order of displaying) for CCU "Obliczona trasa samochodowa" (calculated car route) is higher, which means that the route should be presented above the roadway sign. Other display priorities are assigned to individual cartographic communication units (attribute *Priorytet*), which in the case of graphic conflicts occurrence allows for the decision on the geovisualization priority. By analysing the table *Pozycje Legendy* one can remark that the cartographic presentation of CCU's varies depending on changes in the scale. And thus, e.g. in the presented example for geocomposition "Nawigacja Standard" motorway roadways are shown by means of:
– cartographic symbol with ID=1 at scales of 1:2,000 and 1:5,000 (partial geocompositions with ID=1 and 2);

– cartographic symbol with ID=52 at a scale of 1:1,000,000 (partial geocompositions with ID=9 and 10);
– cartographic symbol with ID=51 at a scale of 1:10,000,000 (partial geocomposition with ID=11).

The table *ZmianyJednostekPrzekazu_INT* (changes in communication units) contains information related to the dynamics of cartographic presentation. This shows that in the case of partial geocomposition with ID=1, at a mobile device speed decreased to the value not exceeding 60 kph (cartographic event with ID=3), CCU with ID=37 (PoI labels[4]) should be activated during visualization (value "1" in column *Id_typZmiany* (the type of changes identifier), which corresponds with the value "Aktywacja" (activation) in the table *TypZmianJednostekKarto (types of change of CCUs*). In other words, for low speeds, labels of selected objects, e.g. "Central Station" should be automatically displayed. In turn, e.g. CCU with ID=33 due to the so-called "cartographic event" recorded in line with ID=13 should be deactivated (which means turned off). For CCU with ID=45, as a result of the occurrence of event with ID=18 (e.g. "approaching an object of a specified category to a distance less than 50m"), its cartographic sign should be changed to symbol with ID=601 (no matter what sign was previously active).

The presented description of the model (or in fact of its fragment) is only an example of possibilities of this method. There is also possibility, among other things, of defining the way of "inducing" sounds (e.g. voice navigation messages, for instance: "in front of you Palace of Culture and Science") or video (e.g. a film presenting the interior of a castle during the journey by car next to him), defining contextual changes in the cartographic communication content (e.g. excluding signatures of closed shops while travelling at night), defining the way of obtaining individual CCU's from the source database, controlling context generalization, defining parameters of the displays, which could be used during geovisualization. More examples and a full description of the method together with theoretical basis can be found in Gotlib (2008).

[4] PoI (Point of Interest) – object important to the user stored in the navigation system database and used in navigation as travel destination points or travel intermediate points, represented most frequently by point e.g petrol stations, shopping centres, cinemas, offices, railway stations

Conclusions

The presented approach to the designing of mobile cartographic presentation modelling may bring many benefits to authors of mobile navigation and location applications. Among the most important ones the following should be listed:
– standardized documentation of cartographic presentation, which allows for its development in the future;
– possibility of an easy modification of the developed cartographic presentation;
– possibility of convenient collaboration in developing complex cartographic presentations by big teams of cartographers;
– easiness of use for mobile application programmers;
– possibility of automated processing;
– possibility of using by different applications.

That last aspect is especially worth noting. The formalization of the design process may allow to develop cartographic presentations in such a way that they should be independent of specific technologies of particular navigation or location applications manufactures. It is not a specific geovisualization for a specific manufacturer, but that may become a new product: the cartographic presentation ready for use in different mobile applications.

At the same time it must be remembered that cartographic communication modelling begins already at the stage of developing a conceptual model of spatial database. Whereas the methods of developing conceptual models are commonly known, the formalization of cartographic presentation modelling is a new proposal. However, the popularization of this idea is not possible unless suitable cartographic software supporting this process is designed.

Designing cartographic communication for the needs of mobile navigation applications demonstrates the necessity of a broader view of the map definition and forces us to formalize the process of cartographic presentation development, especially that the number of kinds and ways of using navigation and location applications is constantly increasing. Therefore, in subsequent years a speciality called by Reichenbacher "mobile cartography" will develop (Reichenbacher 2001, Reichenbacher 2004).

Bibliography

Gotlib D. 2008. „Nowe oblicza kartografii – kartografia mobilna" [in:] Polski Przegląd Kartograficzny, t. 40, nr 2

Gotlib D. 2009. „Selected methodological aspects of creation of cartographic presentation for the needs of mobile systems" [in:] Proc. of the 24th Int. Cartographic Conf., Santiago, Chile, November 15-21, ICA

Gotlib D. 2001 „Metodyka prezentacji kartograficznych w mobilnych systemach lokalizacyjnych i nawigacyjnych" [in:] Prace naukowe Politechniki Warszawskiej – Geodezja, z. 48

Grünreich D., Powitz B.M., Schmidt C. 1992. *Research and Development in Computer-Assisted Generalization of Topographic Information at the Institute of Cartography.* Hanover University, Mat. Konferencji GIS, vol. 1, Monachium

Grünreich D. 1995 "Development of Computer-Assisted Generalization on the Basis of Cartographic Model Theory" [in:] *GIS and Generalization – Methodology and Practice*. pp. 47-55, Taylor & Francis, London

Reichenbacher T. 2001. "The world in your pocket – Towards a mobile cartography" [in:] Proc. of the 20th Int. Cartographic Conf., Beijing, China

Reichenbacher T. 2004. *Mobile Cartography – Adaptive Visualization of Geographic Information on Mobile Devices*. PhD Thesis, Der Technischen Universität München, 2004

Other sources:

www.automapa.pl

Blaupunkt, promotional mateirals

www.navngo.com

www.mapamap.pl

www.ndriveweb.com

Google Maps

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GEOLOGICAL AND MINING CONDITIONS OF DISTURBANCES IN THE GEOID COURSE ON THE EXAMPLE OF THE REGION OF INOWROCŁAW[2]

Abstract

Problems of modelling of geoid and quasi-geoid course are usually considered in Polish literature in the context of the expected accuracy, which enables the implementation of satellite techniques for altitude measurements with accuracy comparable to the geometric levelling. The difficulties that are associated with this modelling are usually referenced to the mountainous areas, i.e. where given the significant denivelation of the terrain, the course of geoid or quasi-geoid surface is varied. It appears that the landform features are not the only factors disturbing the course of the above mentioned surface.

This paper shows the difficulties in modelling the quasi-geoid in the area of Inowrocław, where considering the large changes in the gravitational field, land survey results may give a false picture of its course. The cause for these changes is geological (deposit of salt domes) and mining (high concentration of voids) conditions. In this case, knowledge of the geological situation is important in terms of how to implement surveying for precise, centimetre course of geoid or quasi-geoid. On the basis of the work of surveying, a quasi-geoid model for the region of Inowrocław was presented.

GEOLOGICZNE I GÓRNICZE UWARUNKOWANIA ZABURZEŃ PRZEBIEGU GEOIDY NA PRZYKŁADZIE REJONU INOWROCŁAWIA

Abstrakt

Problematyka modelowania przebiegu geoidy lub quasi-geoidy rozpatrywana jest zwykle w literaturze krajowej w kontekście oczekiwanych dokładności, które umożliwiłyby realizację pomiarów wysokościowych technikami satelitarnymi o dokładnościach porównywalnych z niwelacją geometryczną. Trudności, jakie związane są z tym modelowaniem odnoszone są zwykle do obszarów górzystych, tj. takich gdzie z uwagi na znaczną deniwelację terenu przebieg powierzchni geoidy lub quasi-geoidy jest zróżnicowany. Okazuje się, że ukształtowanie terenu nie jest jednym czynnikiem zaburzającym przebieg ww. powierzchni.

W przedstawionej pracy wskazano na trudności w modelowaniu quasi-geoidy w rejonie Inowrocławia, gdzie z uwagi na duże zmiany w polu siły ciężkości wyniki pomiarów geodezyjnych mogą dawać nieprawdziwy obraz jej przebiegu. Przyczyną tych zmian są uwarunkowania geologiczne (wysadowe złoże soli) i górnicze (duża koncentracja pustek poeksploatacyjnych). W tym przypadku wiedza o sytuacji geologicznej jest istotna z punktu widzenia sposobu realizacji prac geodezyjnych dla uzyskania precyzyjnego, centymetrowego przebiegu geoidy lub quasi-geoidy. Na podstawie wykonanych prac geodezyjnych przedstawiony został model quasi-geoidy dla rejonu Inowrocławia.

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Introduction

The issue of designation of the figure of the Earth, the representation of which is the surface of constant potential of gravity force – the geoid, is still one of the fundamental tasks of surveying. In the era of satellite missions, this research task gets a new meaning. At the same time, there are new requirements for the accuracy of geoid models. Despite substantial progress in this field, the accuracy of these is still insufficient to solve a wide range of surveying tasks. These include, among others, replacing the classical geometric or trigonometric levelling measurements by satellite technology measurements (Góral and Szewczyk 2004). The issue involves the creation of accurate local levelling geoid models that take into account geological and geomorphological characteristics of the area. Such accurate geoid models used as reference surfaces in altitude systems would allow wider use of satellite technology in levelling (Banasik 2001).

The aim of this paper is to point to the importance of geological structure as a factor locally disturbing the geoid or quasi-geoid course. Large amplitude of gravity force anomaly occurring in a relatively small area of Inowrocław is not unique in Poland. The area of our country lies at the crossroads of major tectonic units of Europe and consists of a large number of tectonic structures, which are related to the occurrence of significant gradients of gravity anomaly.

It should be noted that the factors described do not exhaust the long list. Today it seems impossible to take into consideration all disturbances in the global or in many cases regional models.

The course of geoid and quasi-geoid and the accuracy of the model are usually considered in the context of changes in topography (Kryński 2007). The research works devoted to the problems related to the plumb line frequently overlook the issue of the mass distribution of the rock mass. This approximate modelling is based on the assumption that within a small flat area changes in geological mass distribution are minor in terms of undulation of the examined surface. The subject of this paper is to demonstrate the illegitimacy of this assumption.

The present work is a continuation of earlier publications, focusing on the issue of combining measurements performed using the classical technique of precise levelling and GPS (Szczerbowski et al. 2007, Szczerbowski et al. 2011). The first of these works presents the results of altitude references of measurement matrices in the area of Inowrocław, as an example to confirm the advisability of the use of GPS technology practise of surveys, also in financial terms. Simultaneously, the model showed high accuracy of "Levelling Geoid 2001" model for the analyzed area. The second work presents the results of similar measurements, but realized within the structure of the gravitational interaction of salt structure. The result of the presence of salt masses is, among other things, the disturbance of the rock density distribution and changes in the distribution of the direction of the plumb line. The amplitude of changes in this direction can be up to 1.5" on a relatively short section of 2-3 km (Szczerbowski 2010). These changes result from the gravitational effect of the salt structure, and the maximum amplitude of the gravity anomaly detected on the basis of field measurements is about 7 mGal (Łąka et al. 1980). This value corresponds to a change in the Earth's gravitational field (free-air reduction) for the difference of approximately 20 m.

The national model of quasi-geoid levelling called "Levelling Geoid 2001" was approved by the Surveyor General of the Land to practice of surveying (GUGiK, 2000). The characteristics of the model given in literature suggest accuracy comparable to the accuracy of precise levelling Class II - 2 mm / km at a distance of several kilometres, which is of considerable practical importance (Pażus R. et al., 2002). This model has a discrete character and was set in a grid of nodes 1' × 1'. This means that for such a model resolution the Inowrocław diapir area would be represented by 1-2 points. In this situation, due to geological conditions, it is impossible to determine a realistic course of the geoid surface for engineering needs.

The issue of adopting an appropriate resolution of the model for the designation of quasi-centimetre geoid for the area resembles the problem of creating a model of any other surface - such as topographic, where the adequate representation of points is fitted to the shape of the surface. The criteria for the model's accuracy and variability of the modelled surface determine the number of required points. For the old technical instruction K-1 (before 1995), the required density of measurement points (pickets) was associated with the decline in the land surface. Its course is described based on the field measurements: situational and altitude. In the case of quasi-geoid levelling it is necessary to determine the location of a point in space and determine the parameter describing the surface – in this case the altitude difference in terrestrial and satellite levelling measurements. These issues having, until recently, purely academic character, in recent years have become increasingly important in practice, as evidenced, among others, by the developed Information Technology ISO standard, related to the spatial reference issues, including geoid and its spacing from the ellipsoid.

Short characteristics of the area

From the point of view of geoid and quasi-geoid in the analyzed area it is important to know the distribution of gravity anomaly, which is induced by the disorder in the distribution of rock masses. The latter in turn is related to the structural characteristics of geological layers and physico-mechanical properties. The Zechstein salt deposit in Inowrocław is of diapiric character. A general picture of the structure goes through the Mesozoic salt formations and presents itself as a pole, which in plan view has the shape of an ellipse with a c.a. 3 km long axis running more or less meridionally and a shorter axis of a length of 1 km. The salt surface is covered with the co-called dome cap, which was created through the leaching by circulating groundwater (eluvial formation). The cap, whose thickness varies from 30 m to 180 m, is covered with Quaternary formations of a thickness typically up to several metres.

The western side the dome borders sandstone-slate formations of Lower Jurassic, while its east side borders limestone and marl limestone of Upper Jurassic. The gravity anomaly that occurs in the region of Inowrocław is an effect of the density contrast in the cap formations (gypsum) and rock-salt, which are lighter in relation to the Jurassic rocks that surround the dome. Another cause of this anomaly is the size of the disturbing body, i.e. the

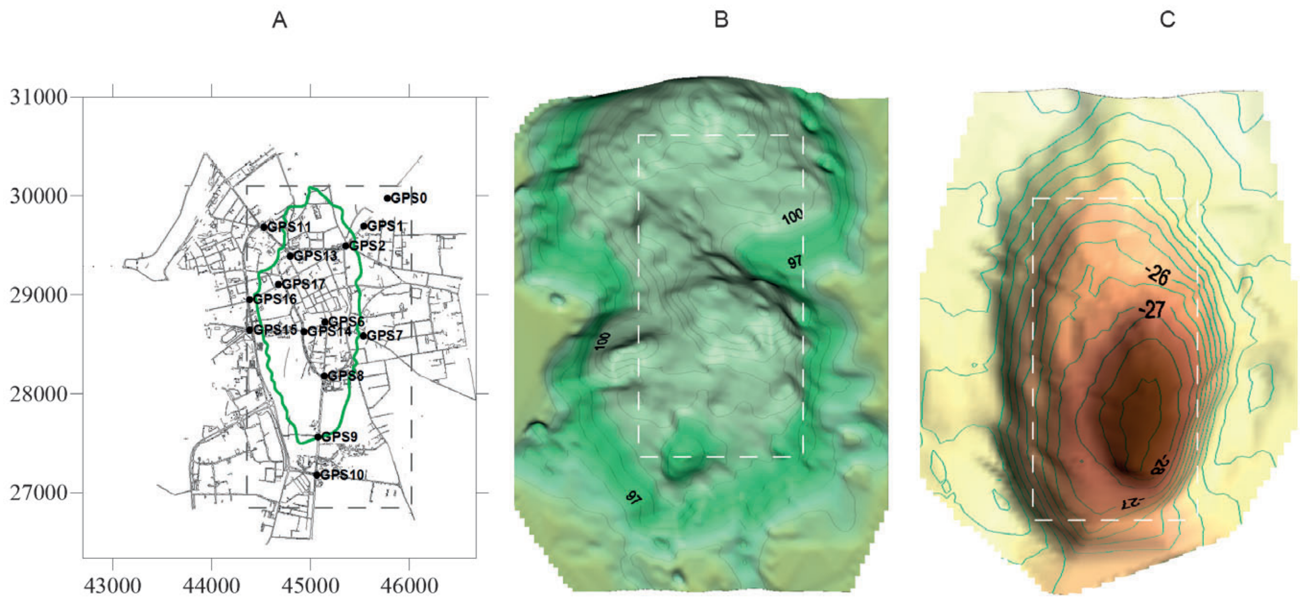

Fig. 1. Inowrocław. Location of the examined area:

A situational map and location of test points including the boundaries of the deposit at a depth of 470 m

B. model of land surface in the salt dome area [m asl]

C. distribution of gravity anomaly in the Bouger reduction [mGal], according to Łąka et al. (1980).

Rys. 1. Inowrocław. Lokalizacja rejonu badań:

A. mapa sytuacyjna oraz lokalizacja punktów badawczych wraz z granicą złoża na głębokości 470 m

B. model powierzchni terenu rejonu wysadu soli [m npm]

C. rozkład anomalii siły ciężkości w redukcji Bougera [mGal] wg Łąki M. i in., (1980).

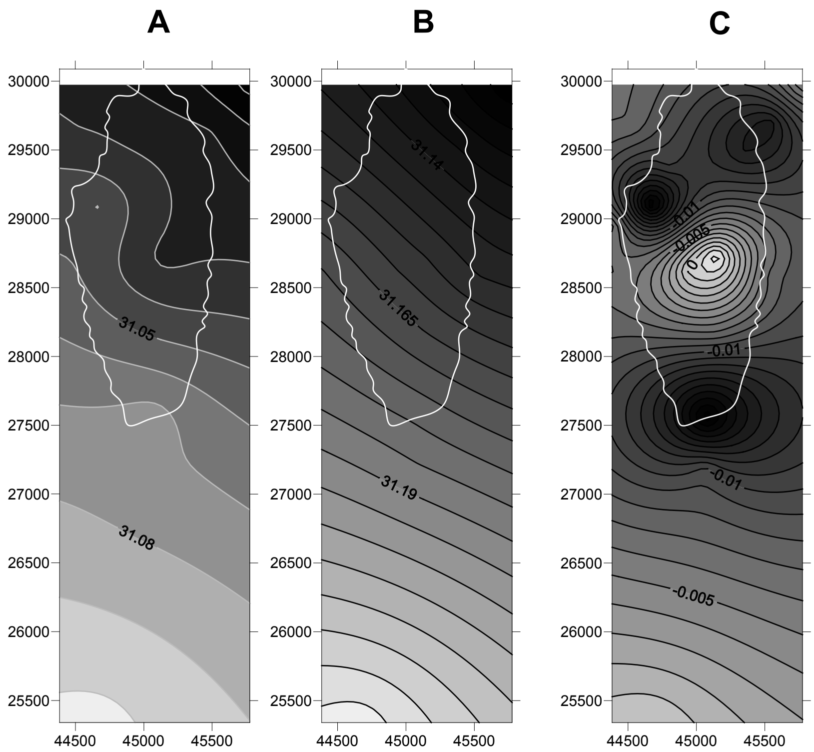

Fig. 2. Inowrocław. Results of the spacing distribution of the quasi-geoid against the border of the bed [m].
A. designated spacing in the measuring way
B. spacing determined from the model of „Levelling Geoid 2001"
C. distribution of differences between model values and measured spacing.

Rys. 2. Inowrocław. Wyniki badań rozkładu odstępów quasi-geoidy na tle granicy złoża [m].
A. odstępy wyznaczone na drodze pomiarowej
B. odstępy wyznaczone z modelu „geoida niwelacyjna 2001"
C. rozkład różnic pomiędzy wartościami modelowymi i pomierzonymi odstępów.

dome. Although the horizontal projection of the salt structure covers a relatively small area, its height is estimated at about 5 km. And although the topographic effect of the dome motion is small, a dozen or so meters of elevation, the gravimetric effect is a significant "discount" in the distribution of gravity anomaly (Fig. 1).

Another cause of disturbances in the distribution of gravity anomaly within the area of Inowrocław was mining activities conducted on the salt dome. Their effect was, among other things, the increase of the amplitude of gravity anomalies caused by the exploitation of rock-salt and by leaving voids of a volume of more than 15 million m^3 (now eliminated by backfilling with waste sodium liquor). The maximum value of the gravity anomaly induced by mining factors amounted to about 0.3 mGal (Szczerbowski 2010). Land development is also important when analyzing the course of quasi-geoid in the area in question. Although in Inowrocław mining activities are no longer carried out, in this part of the Kujawy region salt mines are still operating as well as strategic storage places for hydrocarbons. The need for maintaining current geodetic services in mines and other enterprises is connected with problems arising from occurance of large-area farms. They pose a difficulty in the stabilization and maintenance of geodetic control points and implementation of surveys carried out based on level circuit datum points. However, natural conditions -

the plains of low level of afforestation - help to carry out satellite measurements. These conditions may be important in engineering applications of the local quasi-geoid model on a larger scale.

More detailed information on the geology and mining situation of the area, relevant to geological structure and mining situation in the area in question, which is important from the point of view of geodetic and gravimetric works carried out there, as well as the information about these works can be found in Szczerbowski (2007), Szczerbowski et al. (2007), Szczerbowski (2010).

Geodetic research in the area of the diapir

The analysis of quasi-geoid undulation was based on the measurements made within the area of Inowrocław in the years 2004-2007 by the team of workers from the Faculty of Mining Surveying and Environmental Engineering, AGH University of Science and Technology in Kraków. This work was carried out in parallel with precise levelling measurements and observations employing GPS technology. The results of these measurements, in the context of assessing the usefulness of GPS technology in altitude references of measurement matrices and determining vertical displacements of datum points, were presented in the works by Szczerbowski (Szczerbowski 2007; Szczerbowski et al., 2007). Ellipsoidal coordinates φ, λ, h of the determined 14 points of a research network are defined with reference to the point of the national matrix POLREF - 3403, located in the southern part of Inowrocław. GPS observations were made by the static method of measuring in three-hour sessions. The average error of the datum points altitude determined in 2004-2007 with the application of the GPS network adjustment does not exceed 3 mm. At the same time the altitudes determined using the classical precise levelling were determined with an average error of about 2 mm.

In this paper the results of ground and satellite measurements of levelling have been analyzed in the context of issues related to the quasi-geoid course. Gravimetric and levelling measurements enable to calculate normal altitudes (H^n) of datum points in the analyzed research network. On the basis of the ellipsoid (h), measured using the GPS technique, the spacing between quasi-geoid and the ellipsoid (N) was determined in the network points, using the following formula:

$$N = h - H^n$$

The results were compared with the “Levelling Geoid 2001”. At the same time these results were referenced to the results of previous studies on changes in the direction of the plumb line in the area Inowrocław (Szczerbowski 2010). On the basis of measurements and GPS levelling, deviations of plumb lines were determined at points of research. These points were located along the meridionally running line (3403-GPS11) passing through points 3403, GPS10, GPS9, GPS8, GPS6, GPS13, GPS11. As shown in Figure 1, these points are located adjacent to the long axis of the ellipse, which is the horizontal projection of the structure of the salt. The average double amplitude deviation change of the plumb line in the fragment of the analyzed line running over the area for which a model of local changes in direction of the line was 1.7". The value of double amplitude of the modelled changes in the direction of the above mentioned fragment was 0.97" (Szczerbowski 2010). The modelling was done using existing geological and gravimetric data that allowed us to determine changes in component values of the plumb line deviation at different points in relation to the POLREF network point (3403). These results were not compared with the values of model deviations, i.e. those that would be derived from the national model of quasi-geoid. Figure 1 presents the location of test points, the border of the deposit, the land surface model and the distribution of Bouguer anomalies, which are based on measurements made in 1980 (Łąka et al., 1980).

Discussion of Results

Although the analyzed area is influenced by geological factors (underground erosion, deposit diapiric movements) and by mining factors (limited surface area of subsidence caused by the influence of shallow excavations from the late nineteenth and early twentieth centuries), yet the changes in datum points altitude in the period 2004-2007 were not significant. Thus the spacing (N) values obtained from surveying in individual years are similar. Figure 2 presents a distribution of spacing designated in

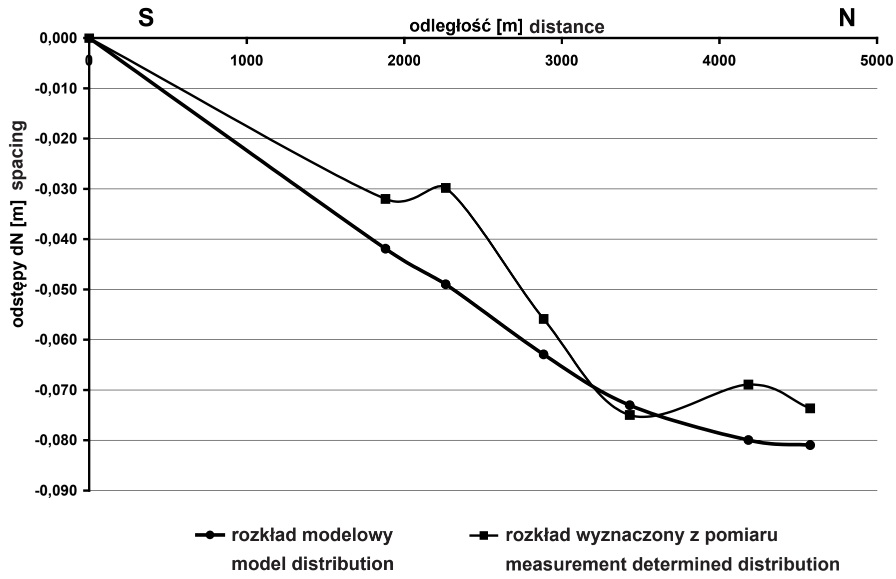

Fig. 3. Distribution of relative mode spacing (dN) and spacing measured in meridionally running line 3403-GPS11
Rys. 3. Rozkład względnych odstępów (dN) modelowych i pomierzonych na południkowo przebiegającej linii 3403-GPS11

the measurement campaign in 2004. The area shown on the map is limited to the range of the distribution of test points, most of which are located within the limits of the occurrence of salt deposits, deposited at a depth of 470 m. The distribution of isolines describing the course of the spacing is characteristic. Despite being relatively small, the area is characterized by large gradients and changes in their orientation. The map presented in the same drawing illustrates the distribution of spacing determined from the model "Levelling Geoid 2001". Very similar results were obtained using a different national model of quasi-geoid – Quasi08c (Łyszkowicz 2010).

Visible depression and elevation of the surface describing the differential value between the measured and the model spacing (N) result from disturbances in the distribution of rock masses in the area. The centre of concentrically arranged isolines describing the maximum divergence between the analyzed spacing is located in the border area of the bed. The maximum value of the discrepancy is about 2 cm and corresponds to the values of the standard error reported by the authors and designated under the control of the model (Pażus et al., 2002). The numerical values of these differences are more visible in the graph (Fig. 3), which shows the distributions of the analyzed relative spacing in line 3403-GPS11. Relative spacing dN was determined relative to point 3403 for subsequent points of that line. Visible oscillations of the latter are the result of the impact of the salt in Inowrocław. Thus the distribution model is a kind of approximation to the distribution determined from the measurement, and the differences between the distributions do not exceed 2 cm. This value may be taken as indicatory geoid model error. In the case of measurements with the application of satellite technology the error in designating points using the national geoid model for the Polish territory may be too significant for engineering applications.

Conclusions

In a more detailed description of the distribution of spacing for the quasi-geoid in a given area an appropriate amount of data is necessary, especially if it is an area of high gradient of gravity anomaly. Then it will be possible to more precisely determine the quasi-geoid model, which is associated with the introduction of next, i.e., higher degree polynomials approximating the values of its spacing in the area. But the most important is the number of points, which should correspond to the variability of the surface. In the analyzed case the course of the quasi-geoid is disturbed due to geological conditions, which is related to the gravity anomaly of relatively high amplitude. This large gradient of gravity anomaly occurs on a small surface area, but it is a built up area and, as mentioned earlier, its character particularly justifies the use of satellite technology in the measurement of altitude. Low density or uneven distribution of points affects the results of the interpolation of the quasi-geoid course, especially in areas with heterogeneous geological structure. Inowrocław example shows that, for geologically diverse areas the geoid or quasi-geoid model resolution should be considerably higher than in other Polish regions.

Literature

Banasik P. 2001: Wykorzystanie quasi-geoidy w pomiarach niwelacyjnych. Geodezja, UWND AGH, T. 7, Z. 2, Kraków.

Góral W., Szewczyk J. 2004: Zastosowanie technologii GPS w precyzyjnych pomiarach deformacji. Uczelniane Wydawnictwa Naukowo-Dydaktyczne AGH, Kraków.

ISO/IEC 18026:2009. Information technology – Spatial Reference Model (SRM), Edition: 2, Stage: 90.92, JTC 1/SC 24 ICS: 35.140, 2009.

Kryński J. 2007: Precyzyjne modelowanie quasigeoidy na obszarze Polski – wyniki i ocena dokładności. Seria Monograficzna nr 13, 2007. Instytut Geodezji i Kartografii, Warszawa.

Łąka M. i in. 1981: Dokumentacja szczegółowych badań grawimetrycznych. Temat: wysad solny Inowrocław, 1981 r. Przedsiębiorstwo Badań Geofizycznych. Warszawa. Archiwum Przedsiębiorstwa Badań Geofizycznych w Warszawie.

Łyszkowicz A. 2010: Quasigeoid for the area of Poland computed by least squares collocation, Technical Sciences, No. 13.

Pażus R., Osada E., Olejnik S. 2002: Geoida Niwelacyjna 2001. Magazyn Geoinformacyjny Geodeta Nr 5 (84), Warszawa.

GUGiK, 2000: Regulation by the Council of Ministers of 8 Aug. 2000 on the national spatial reference system. Dz. U. Nr 70, poz. 821.

Szczerbowski Z. 2007: The evaluation of salt dome vertical movements in Inowrocław detected by classical precise levelling and GPS surveying techniques. Acta geodynamica et geodynamica. Vol. 4, No. 4 (148), ss. 1-10, Praga.

Szczerbowski Z. 2010: Wpływ uwarunkowań geologicznych i górniczych na lokalne zmiany kierunku linii pionu. Wydawnictwa AGH.

Szczerbowski Z., Banasik P., Kudrys J. 2007: Przykład wykorzystania techniki GPS w pomiarach wysokościowych na obszarach górniczych. Geomatics and Environmental Engineering. Kwartalnik AGH. Kraków. Vol. 1, No. 1/1.

Szczerbowski Z., Banasik P., Kudrys J. 2011: Geological conditions and local changes of plumb line direction. Acta geodynamica et geomaterialia. Praga (in print).

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THE ROLE AND PLACE OF CARTOGRAPHY IN THE DEVELOPMENT OF THE SPATIAL INFORMATION INFRASTRUCTURE

Key words:

cartographic modelling, spatial information infrastructure

Abstract

Hundreds of various spatial databases and maps developed using those databases were created in Poland and abroad in the past decade. The majority of them were created ad hoc, in relation to implementation of current demands of particular institutions or organisations. Thus, the side effect of rapid development of geoinformation was increasing organisational, methodological and conceptual chaos. Adoption and successive implementation of resolutions of the EU INSPIRE Directive, as well as the Polish Act on the Spatial Information Infrastructure was the partial solution of the discussed issues.

However, the legal acts of high grade specify only general rules of creation of the geoinformation infrastructure. The development of modern and functional spatial, reference and thematic databases requires detailed determination of a conceptual model of particular databases, the ways of their population, utilisation and processing of data stored in those databases. However, legislative activity is not the most important part of that process; appropriate understanding of surrounding geographic reality, resulting in the development of correct cartographic models, implemented in the form of spatial databases, is far more important. Therefore, after the period of rapid technological development and fascination of modern information solutions, the deep methodological reflection is necessary.

ROLA I MIEJSCE KARTOGRAFII W KSZTAŁTOWANIU INFRASTRUKTURY INFORMACJI PRZESTRZENNEJ

Słowa kluczowe:

modelowanie kartograficzne, infrastruktura informacji przestrzennej

Abstrakt

W minionym dziesięcioleciu powstało, zarówno na świecie, jak i w Polsce, setki różnego rodzaju baz danych przestrzennych i opracowywanych na ich podstawie map. Większość z nich była tworzona *ad hoc* w związku z realizacją bieżących potrzeb danej instytucji czy organizacji. Skutkiem ubocznym gwałtownego rozwoju geoinformacji stał się zatem narastający chaos organizacyjny, metodyczny i koncepcyjny. Częściowym rozwiązaniem tego problemu stało się

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przyjęcie i sukcesywne wdrażanie zapisów unijnej dyrektywy INSPIRE i polskiej ustawy o infrastrukturze informacji przestrzennej.

Akty prawne wysokiej rangi określają jednak tylko ogólne zasady tworzenia infrastruktury geoinformacyjnej. Do budowy nowoczesnych i funkcjonalnych baz danych przestrzennych o charakterze referencyjnym i tematycznym niezbędne jest bowiem szczegółowe określenie modelu koncepcyjnego poszczególnych baz, sposobu ich zasilania, wykorzystania oraz przetwarzania zgromadzonych w nich danych. Najistotniejszym elementem tego procesu nie jest zatem działanie legislacyjne, lecz właściwe zrozumienie otaczającej nas rzeczywistości geograficznej, przekładające się na utworzenie poprawnego modelu kartograficznego realizowanego w postaci bazy danych przestrzennych. Po okresie gwałtownego rozwoju technologicznego i fascynacji nowoczesnymi rozwiązaniami informacyjnymi, niezbędna jest zatem głęboka refleksja metodyczna i koncepcyjna poprzedzająca dalsze działania wdrożeniowe.

1. Introduction

When in the 1960s the term “global village” was used for the first time to describe cross-border economic, demographic and political processes it was hard to believe that half a century later, in the era of the ubiquitous Internet, this metaphor is no longer merely a means of literary expression and has become a true illustration of globalization (McLuhan, 1962). One of the essential elements of a global process of informatization is to build regional and intercontinental geoinformation infrastructures. One component of this process is the creation of spatial databases and visualization of their data. Thus modelling of geographic information in a supraregional scale has become a subject of not only cartographic but also legal, social and information technology works. In this context, Prof. Michael Wood’s message *“The 21st century world - no future without cartography”* (2001), delivered at a conference of the International Cartographic Association in Beijing is particularly important. Former President of ICA notes that although the name itself was a relatively recent discipline, cartography is an expression of one of the oldest impulses shaping the humanity - efforts to map the surrounding world. Wood argues that the traditional “cartographic dichotomy” - the classic division between creators and users of cartographic work - is now being replaced by ‘linguistic analogy’ denoting the full use of the language of cartography by the general public. Just as knowledge of a language does not only allow us to read existing studies but also to write them, so a basic knowledge of cartographic methods not only allows the use of maps, but also their co-creation and sharing for instance in the form of websites. It should be noted that in the process of universal “mapping of the world” understood in this way, the role of professional cartographers would be not so much to create the resulting map compositions but rather widespread education on methods of presentation and the correct modelling of the reference information in spatial databases, which are canvas for thematic and trade studies.

2. Cartographic modelling

Modelling and imaging of the surrounding geographic area has a tradition much older than the formal cartographic techniques (Peters, 1978). Dated at tens of thousands years old totemic paintings on the walls of the cave of Lascaux (French Aquitaine), a product of Palaeolithic art, indicate the significance of spatial relationships in learning and exploration of the world. The development of forms of human communication through shared learning of space was for our ancestors not so much religious art or applied art as just a prosaic visual art of survival. According to Peters (1978) cognitive maps can be an important factor in the intellectual evolution of hominids. Throughout human history, our external conditions of life have undergone significant change, however, what has not changed is the way the mind works, the way we become involved in our interpretations of reality, how we identify ourselves with limited aspects of ourselves, and how our commitment and fears determine our actions. It can therefore be concluded that the development of the ability of the mapping of the sur-

rounding reality as developed by the species of homo sapiens (Lewis, 1987) is affected by:
• delay in providing an instinctive response, which provides analysis and exploration of spatial data,
• storing the collected information,
• ability to abstract and generalize,
• ability to process information and respond appropriately.

Therefore, at the dawn of our history sharing information about known space and cooperation on the one hand was decisive for the survival of *homo sapiens* as a species, on the other, shaped the foundation for cartographic modelling, understood as abstraction features of reality and its imaging. Obviously, the technical means of expression or a physical medium for cartographic information used to consolidate the conceptual model evolved over the centuries, changing from a drawing on a rock or a clay tablet through printed maps to multiresolution spatial databases (Weibel, Dutton, 1999). This does not change the nature of the problem, which is the understanding of the surrounding space, and such its display, which allows the recipient to understand the work of mapping and - indirectly – to understand the world. This aspect of cartography is emphasized by Imhof (1982), who states that “a good cartographer must be both a scholar and an artist. He/she must have deep knowledge about the object of their interest - the Earth. He/she must have the ability to intelligently generalize, properly select details and create the model. (...) This requires truly artistic abilities.” Thus, cartography is not only “science and technology, but also art.” The artistic aspect can be interpreted as characteristic of individual cartographers’ way of modelling and presentation of geographical space that goes beyond the established framework of the convention or the technical guidelines.

As noted by Ostrowski (2008) in the 1960s, as a result of interdisciplinary research at the interface of cartography, information theory, semiotics, the theory of modelling, and computer science, three basic theoretical concepts (problem orientation) emerged, shaping the further development of cartography as a self-study:
– communication concept, which treats the map as an element of information transfer;
– semiotic mapping concept, identifying a map with specific language or sign system;
– model-cognitive concept, which plays a special role in the era of geo-information technologies, creation of spatial databases and data analysis.

A great achievement of cognitive orientation is the creation of the concept of the model and of cartographic modelling in the 1960s. What contributed to this was the fact that cartography came closer to natural sciences (especially geography) and tried to explain the nature of the spatial distribution and characteristics of phenomena by means of maps taken as models of reality. Cartographic model is associated with a generalized representation of a fragment of geographical space. The modelling process is carried out through subjective selection of the important components of geographical space and “their intelligent generalizations” (Imhof, 1982).

Map editing – as an image-sign model – was thus equated with the process of modelling a particular state of reality or, more broadly, with the description of the state and changes over time and geographical space. In this perspective, the model is defined as a specific representation of the real beings without irrelevant attributes and relationships. This model is the appearance of characteristic aspects of a given fragment of reality to the extent required for cognition (Makowski, 1997).

The basic idea of model-cognitive orientation is to say that the process of creating a map (as well as spatial databases) must be preceded by a process of understanding the spatial aspects of reality (Ostrowski, 2008). Model-cognitive orientation in cartography is based on the assumption that the mapping is identical with the knowledge of some aspect of objective reality – space of objects and phenomena (Żyszkowska, 2000). This concept is also present in Weibel (1991, 1995), who states that not only the primary development of map or reference spatial data base, but also developing a full scale range of derivative maps (or generalized conceptually and geometrically databases) is the process of cartographic modelling that requires “understanding”. The sense of this understanding is not only a mastery of methods and algorithms for spatial data transformation, but above all the geographical knowledge of reality, understanding the spatial distribution of objects and phenomena and their interactions, and processes that shape the geographic space and that manifest different intensity depending on the present scale of observation. Only this knowledge allows the modelling of higher levels of conceptual generalization and application of algorithms for geometric reduction and simplification. The subject of cartographic modelling therefore is not geometric operations carried out on various graphic elements representing the topography, but those bringing objects and phenomena significant in a given observation scale from understanding geographical space (Olszewski, 2009).

This approach is consistent with the idea of Makowski (2001, 2005), who proposed the concept of the triad mapping (Latin: *trio iuncta in uno*), according to which the map is a system, model and image. The concept of cartographic modelling process is based on the deliberate selection and generalization appropriate to the scale and purpose of the study. This can not therefore be identified with geometric simplification. The essence of this generalization is Weibel's understanding of reality and the construction of an adequate model, not the geometric operations on graphical objects treated individually - points, lines and polygons, conducted in isolation from their semantic content of the information.

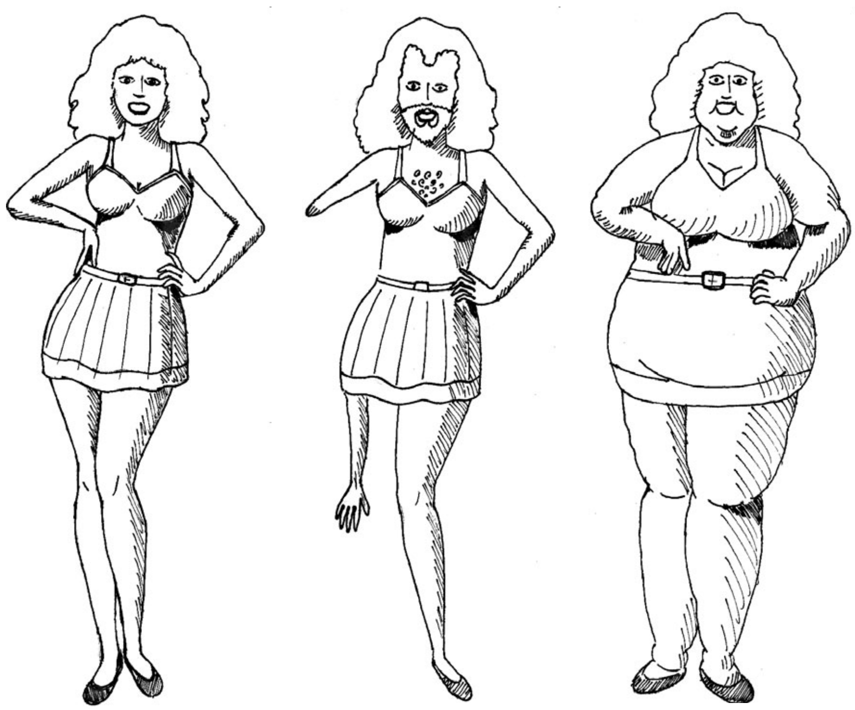
In this sense, the map considered spatially is a superior concept, and all activities within the scope of spatial information are "mapping" in relation to objects, phenomena and real events. This is consistent with the psychological determinants of the man who in all spatial activities uses images (figurative or abstract information, conceptual information as equivalent to the perceived reality). The utility of basic concepts in the form of a structural triad first of all merges maps into one of so far freely understood terms: a topographic database, a topographic map, a geographical information system, pointing also to misconceptions about the map understood only as a form printed on paper (Makowski, 1997).

In light of the foregoing, modern cartography cannot be reduced to the role of a science dealing with the development of formal theory and methods of graphic communication of information about the spatial distribution of objects and phenomena. Cartography is the science of methodical modelling and spatio-temporal imaging of the information structures in the form of maps describing the multi-dimensional reality (Makowski, 2005). The very essence and a fundamental advantage of cartographic modelling is that the map, despite a significant reduction in the spatial dimensions in comparison with reality, allows us to show and analyze the mutual arrangement of relevant objects and phenomena, regardless of the size of the modelled area (Ostrowski, 2008).

Among laypersons there is often a tendency to limit the role of cartography to "composing maps based on data from the GIS system." Even among professionals, you can see the tendency to marginalize cartography aspect of the model for "vectorization of spatial data and visualize them in a certain stylistic conventions." According to the concept of Imhof (1982), cartography is not only a field of science and technology, but also art. It is therefore a question about the durability of the idea of a leading role of cartographic model with a simultaneous development of technology, as well as the question of the sense of that modelling.

To visualize the role and nature of this process one can make a kind of personification of the digital topographic (landscape) model and its visualization (Fig. 1). The basis for the discussion is a topographical model. This model has a clear space-time location resulting from the adoption of the national spatial reference system and the natural reference system. This model is implemented in the form of a structurally integrated multifunctional topographical database, containing the appropriate generalized representations of field objects (situational objects and forms of the relief) and time-space relationships that describe them (Fig. 1a).

Cartographic modelling is a process whose essential element is adequate to the purpose and use of the product, abstraction of features of geographical space. Thoughtless reduction of the process, e.g. by the omission of relevant classes of objects and by the so-called layered acquisition of topographic data, leads to the deformation of the database (Fig. 1b). Similarly, excessive and inappropriate to the needs of the user spatial databases overloaded with hundreds of sub-attributes, makes the reference database model lose its simplicity and functionality (Fig. 1c).



a) b) c)

Fig. 1. Personification of digital topographic (landscape) model in the process of cartographic modelling of geographic information – stage 1 - conceptual modelling (Figures: Daniel Urbanowicz - 2011)
Rys. 1. Personifikacja topograficznego modelu terenu w procesie modelowania kartograficznego informacji geograficznej – etap1 – modelowanie pojęciowe (rysunki: Daniel Urbanowicz – 2011)

The personified cartographic approach to the modelling process used by the author makes easier the falsification of the hypothesis that "the role of cartography is merely aesthetic visualization of data." Any graphics of thematic topographic map fails to compensate for modelling errors committed in the conceptual design stage of the reference database structure (Fig. 2). Due to the critical role of the official topographical database, which is the canvas for the creation of the reference infrastructure for spatial information, accurate cartographic modelling is crucial.

Just to make an additional point to the above considerations, it should be noted that in the non-professional cartography methodological errors occur not only at the initial stage of conceptual modelling, but also in the resulting visualization of spatial data stored in the database. Mismatched artwork can significantly contribute to the formation of graphical presentation which is defective, unsightly and / or inconsistent with the cartographic convention, but errors in the map graphics are usually quite apparent even to the layperson. Errors made during the conceptual modelling of geographic information, although harder discernible, are equally important and have far-reaching consequences, for example for the analytical usefulness of spatial databases.

3. Cartography and spatial information infrastructure

As shown in the previous chapter, cartography is a field of knowledge that deals with the modelling of spatial information and its imagery – geovizualization. Therefore cartography aims at the description of the real world, the

Fig. 2. Personification of digital topographic (landscape) model in the process of cartographic modelling of geographic information – stage 2- visualization (imaging) of data (Figures: Daniel Urbanowicz - 2011)
Rys. 2. Personifikacja topograficznego modelu terenu w procesie modelowania kartograficznego informacji geograficznej – etap2 – wizualizacja (obrazowanie) danych (rysunki: Daniel Urbanowicz – 2011)

organization of information related to this description in spatial databases, and the formulation of principles of geographic data visualization and provision (Gotlib, Iwaniak, Olszewski, 2006, 2007). The achievements of cartography, covering areas such as: mapping, test methods, geostatistics, cartographic generalization and methods of presentation, have stimulated the development of information systems based on information technology, without which the systemic imaging of geoinformation is currently impossible. Cartographic methodology allows for supplying geographic information systems with concepts (e.g. the way of the organization of spatial information storage), which were born long before the advent of computer science and that allow us to organize information and also lead to create models of geographical space. Thus it can be concluded that centuries of cartographic methodology are fundamental for geographic modelling of surrounding reality, both in a form of classical analogue maps and reference databases, which is essential for the development of infrastructure for spatial information. Despite the technological development, basic ways of cartographic modelling of geographical space remain the same. The development of information systems contribute to the improvement of the method for processing digital geographic information. The legacy of cartographic knowledge, however, determines the methodology both of the method of space modelling and the visualization of the collected data (Olszewski, 2009).

The strength of the maps is the possibility of abstraction of geographical space. In the modelling process it is essential to take into account the operational scale – a scale in which object forming processes and events in this space are observable. This allows us to maintain connectivity between the scale of the study and the system of spatial patterns. Layered recording method for spatial data in GIS databases often results in independent processing of particular classes of objects, such as road network and settlement pattern, of the lie of the land and hydrographic network. This approach is clearly erroneous due to the fact that holistic process of geographic information modelling should reflect and highlight the relationships between various components of the natural environment (Harrie, Weibel, 2007).

This confirms the validity of the ideas presented by Olszewski (2009), under which the proper way to model cartographic generalization of geographical information developed through centuries of experience is independent of the used tools and it makes a "heritage of modern cartography, not its burden." This heritage can also be used to create the foundations of spatial information infrastructure (SII), because, as noted by Gaździcki (2011), the construction of SII in Poland is not a technological but civilization challenge. This finding is of great importance for the development of cartography and highlights its both important roles: modelling and imaging. On the one hand it requires development of the continous for whole country, logically coherent and structurally correct basic reference database and a number of sderivative products, and on the other hand it calls for the development of visualization methods of multiscale thematic data and their consistent placement in the official geoportal.

Analyzing the contemporary legislative (Law on the Spatial Information Infrastructure and a number of executory provisions), organizational and financial conditions (advanced phase of the GBDOT project), it should be considered that the target conceptual model of reference source database for the Polish geodetic and cartographic services determined has been, but the way of use and transformation of the data to be stored in the database still requires appropriate conceptual studies. Developed models, reference and thematic databases and spatial data gathered in a national geodetic and cartographic resources are to be in fact used by many people and institutions interested in implementing the INSPIRE Directive.

Data collected in these databases allow us to create any thematic studies using reference topographic content. It is therefore a task consistent with the requirements of commonly created transnational infrastructures for spatial information, which in this respect points to the INSPIRE Directive and the Act on the Spatial Information Infrastructure implementing this directive. For more than thirty data themes and twelve leading authorities, and for dozens of other institutions related to the implementation of INSPIRE, cartography thus becomes not only a tool visualizing the output concept of environmental management and spatial regularity in the distribution of the population, but above all, the primary source of knowledge about the surrounding space. For cartography both imaging and modelling of geographic information in a form of functional databases of thematic and referential character is of utmost importance.

Spatial information infrastructure in Poland is created, maintained and developed as a result of cooperation of creating it leading authorities, other administration bodies and third parties. Creating, maintaining and developing infrastructure are coordinated by the Minister of Public Administration, who performs the tasks with the help of the Surveyor General of the Country. Interoperability of particular spatial databases and services created and provided by leading authorities and other institutions involved in the creation of spatial information infrastructure in Poland requires harmonization, i.e. developing a form coherent and adapted to its common and joint use. The easiest, and most economic and effective measure to this harmonization is to use a common reference database for all industry developments. Spatial data themes such as "Energy resources" (for which Geologist General of the Country is responsible), "Land management" (under the management of the Minister of Infrastructure) or "Protected Areas" (carried out jointly by the Minister of the Environment and the Minister of Culture and National Heritage) require a unified reference data. The role of cartography is therefore to provide both properly balanced, multi-dimensional conceptual model of geographic space as well as the development of reference topographic maps and basic general geographic maps for multiple users.

4. Conclusions

Harley and Woodward (1987) state that the map features have evolved over time from identifying a location in space and finding the way through the inventory of the surrounding space, the representation of places of worship, to decorative and functional art. Currently, the fundamental role of cartography should be modelling of geographic information, which allows it to be explored in the geo-information systems (Mackaness, 2007). A properly set up database of topographical data is thus a kind of reference canvas for freely defined spatial analysis and thematic mapping products. Cartography by its inherent characteristic, which is the ability to model arbitrarily defined abstraction of the conceptual level of generalization, is therefore well placed to take the lead in creating the infrastructure for spatial information.

The process of globalization redefines the way we perceive both socio-cultural and economic relations. It also contributes to the evolution of information society, based on technical knowledge and aiming at the formation of an open society, characterized according to Popper (1945) by equilibrium of followers of various theories related to historicism. An open society is able to discuss all the relevant facts of political and economic life and accept different points of view, and adapt new ideas coming both from outside the community as well as being its own making. An important element of such a discussion can be public participation for sustainable development understood as a free exchange of views on the development of the surrounding space – spatial management, environmental protection, economic development, etc. The carrier of such a discussion might be, for example social network geo-portal, in which against the background of reliable reference data various spatial concepts are presented and discussed, for instance course variants for the Augustów bypass taking into account or ignoring the environmental qualities of the Rospuda Valley. The role of cartography, however, remains a reliable modelling of geographic reality and its imaging. Only a true conceptual model and current spatial data stored in a functional database as well as high quality cartographic presentation can guarantee social success in the discussion conducted on the basis of reference data and understood in this way; the success interpreted both in the context of creating infrastructure for spatial information and of shaping the open information society.

5. Literature

Gaździcki J., 2011, Nietechniczne aspekty infrastruktury informacji przestrzennej, seminarium „Nauka polska na rzecz europejskiej polityki geoinformacyjnej", Główny urząd Geodezji i Kartografii, 14.10.2011

Gotlib D., Iwaniak A., Olszewski R., 2006, Budowa Krajowej Infrastruktury Danych Przestrzennych w Polsce. Harmonizacja baz danych referencyjnych. Wrocław: Wydawnictwo Akademii Rolniczej we Wrocławiu.

Gotlib D., Iwaniak A., Olszewski R., 2007, GIS. Obszary zastosowań, Wydawnictwo Naukowe PWN, Warszawa

Harley J.B., Woodward D., Eds. 1987, The History of Cartography, University of Chicago Press, London

Harrie L, Weibel R., 2007, Modelling the overall process of generalisation, w: Mackaness W., Ruas A., Sarjakoski T., 2007, Generalisation of geographic information: cartographic modelling and application, Elsevier

Imhof E., 1982, Cartographic Relief Presentation, Edited by H. J. Steward, Berlin: de Gruyter

Lewis G.M., 1987, The Origins of Cartography, w: Harley J.B., Woodward D., Eds. 1987, The History of Cartography, University of Chicago Press, London

Mackaness W., Ruas A., Sarjakoski T., 2007, Generalisation of geographic information: cartographic modelling and application, Elsevier

Mackaness W., 2007, Understanding geographic space, w: Mackaness W., Ruas A., Sarjakoski T., 2007, Generalisation of geographic information: cartographic modelling and application, Elsevier

Makowski A., 1997, Cartography versus spatial information systems, Geodezja i Kartografia, t, XLVI, z. 3, Warszawa

Makowski A., 2001, Na obrzeżach cybernetyki, w: Mapa w systemach komputerowych, Materiały XXVIII Ogólnopolskiej Konferencji Kartograficznej, Szczecin

Makowski A., 2005, System informacji topograficznej kraju. Teoretyczne i metodyczne opracowanie koncepcyjne. Warszawa: Oficyna Wydawnicza Politechniki Warszawskiej

McLuhan H. M., 1962, The Gutenberg Galaxy, University of Toronto Press

Olszewski R., 2009, Kartograficzne modelowanie rzeźby terenu metodami inteligencji obliczeniowej, Prace Naukowe – Geodezja, z. 46, Oficyna Wydawnicza Politechniki Warszawskiej, Warszawa

Ostrowski W., 2008, Semiotyczne podstawy projektowania map topograficznych na przykładzie zabudowy, praca habilitacyjna, Uniwersytet Warszawski

Peters R., 1978, Communication, Cognitive Mapping and Strategy, w: Wolves and Hominids, in Wolf and Man Evolution in Parallel, Hall R. Sharp H., Academic Press, London

Popper K., 1945, Open Society and Its Enemies, udostępnione na stronie internetowej: http://www.scribd.com/doc/11920263/Karl-Popper-Open-Society-and-Its-Enemies

Weibel R., 1995, Map generalization in the context of digital systems, Cartography and GIS, vol. 22, no. 4

Weibel R., 1995, Map generalization in the context of digital systems, Cartography and GIS, vol. 22, no. 4

Weibel R., Dutton G., 1999, Generalizing spatial data and dealing with multiple representations, w: Longley P., Geographical Information Systems: Principles, Techniques, Management and Applications

Wood M., 2001, The 21st century world – no future without cartography, Proceedings of International Cartographic Association Conference, Beijing, http://icaci.org/documents/ICC_proceedings/ICC2001/icc2001/file/f00001.doc

Żyszkowska W., 2000, Semiotyczne aspekty wizualizacji kartograficznej, Studia Geograficzne LXXIII, Wydawnictwo Uniwersytetu Wrocławskiego

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THE ANALYSIS OF THE EFFECTIVENESS OF SIMULTANEOUS INVERSION OF TURNING AND HEAD WAVES FIRST BREAKS – MODEL STUDY[2]

Key words:

geophysics, seismic methods, refraction tomography, traveltime tomography

Abstract

In the presented paper the model data were used to analyse the effectiveness of simultaneous inversion of the turning and head waves first breaks in comparison with the effectiveness of the inversion of only first breaks of turning waves or head waves. The analysis was undertaken for the gradient velocity models of the near surface layer with the low velocity anomaly and for the CDP aquisition. The effect of the numerical ray tracing on the traveltime calculations and inversion results was estimated taking into account the wave equation modeling of seismic records. The effect of the errors of the starting velocity field in the process of inversion as well as the effect of spatial smothing of resulting velocity fields were considered too. The analysis confirmed some improvement in the imaging of the near surface velocity anomalies when we use simultaneous inversion of the turning and head waves first breaks.

ANALIZA EFEKTYWNOŚCI JEDNOCZESNEJ INWERSJI PIERWSZYCH WSTĄPIEŃ FALI REFRAGOWANEJ I CZOŁOWEJ – STUDIUM MODELOWE

Słowa kluczowe

geofizyka, metody sejsmiczne, tomografia refrakcyjna, tomografia czasów przebiegu

Abstrakt

W przedstawionej pracy wykorzystano dane modelowe do analizy efektywności jednoczesnej inwersji pierwszych wstąpień fal czołowych i refragowanych w porównaniu do efektywności inwersji tylko pierwszych wstąpień fali refragowanej lub czołowej. Analizę podjęto dla gradientowych modeli strefy przypowierzchniowej z niskoprędkościową anomalią dla

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akwizycji metody pokryć wielokrotnych. Oszacowano wpływ numerycznego trasowania promieni na wyniki obliczeń czasów przebiegu i inwersji uwzględniając wyniki modelowania rekordów sejsmicznych z równania falowego. Rozważano także wpływ błędów startowego pola prędkości w procesie inwersji, jak również wpływ przestrzennego wygładzania wynikowych pól prędkości. Analiza potwierdziła pewną poprawę w odwzorowaniu anomalii prędkościowych strefy przypowierzchniowej, gdy wykorzystujemy jednoczesną inwersję pierwszych wstąpień fal czołowych i refragowanych.

Introduction

Defining the velocity fields in the near surface layer is an essential stage of seismic data processing. Its results determine the accuracy of the field static corrections calculations and the good quality of resulting seismic sections. The correct imaging of velocity fields in the near surface layer is very also important when we construct the shallow velocity part of migration velocity model.

The problem of the static corrections estimation comes into special prominence in the commonly used vibrator method of land seismic acquisition when often the only source of the information about low velocity layer are the traveltimes of first breaks on seismic records. Three approaches are used in this case. In the first approach the times of first breaks are treated as the arrival times of head waves connected with the succeding refractors of low velocity layer. These traveltimes (head waves hodographes) are interpreted using refraction, well known methods yielding an approximate layered velocity model of the near surface medium. To improve the results of refraction interpretation we can apply the generalized linear inversion (GLI) using the well known Hampson-Russell program (Hampson, Russell 1984). The second approach treats the traveltimes of the first breaks as the arrival times of turning waves propagating in the gradient medium of low velocity layer. The velocity fields are estimated by means of tomographic inversion in this case (Zhu et al. 1992, Stefani 1995, Lanz et al. 1998, Zhu 2002). In the third approach we use in the process of inversion the first breaks of head waves generated by the refractor in the bottom of low velocity layer.

Each of the above described approaches has its own limitations. In the first case we can estimate only layered model with constant velocites in each layer. It is difficult to recover the local velocity heterogeneities in the individual layers. In the second case the tomographic inversion of the traveltimes of turning wave with dominating ray trajectories deviated from vertical and horizonal directions yields in many cases the relative weaker horizontal resolution. In the third case the tomographic inversion of the traveltimes of head waves with dominating vertical ray trajectories characterizes of weak vertical resolution manifesting in smearing velocity anomalies in vertical direction toward surface.

In the case of the gradient medium with local velocity anomalies placed above the strong refractor none of the described solutions create the possiblity of the optimal estimation of the velocity fields. The solution may be the simultaneous inversion of the turning wave first breaks connected with gradient low velocity layer and head wave first breaks connected with the strong refractor in the bottom of near surface layer. The analysis of the effectiveness of such a approach based on the model data was undertaken in the presented paper.

1. Construction of the seismogeological models of low velocity models and the generation of theoretical traveltimes of the turning and head waves

For the purpose of the model calculations realized for the case of turning waves, the gradient models (with positive vertical velocity gradient) without anomalies and with low velocity shallow anomaly were constructed. For the purpose of the model calculations realized for the case of head waves the refractor was placed in the bottom of the gradient medium. The gradient model is presented in Fig. 1. The velocity anomaly had the dimensions: width 300 m, height 20 m. The depth of the top of anomaly was 10 m and the velocity inside anomaly was 600 m/s. The velocity outside the anomaly was increasing from the

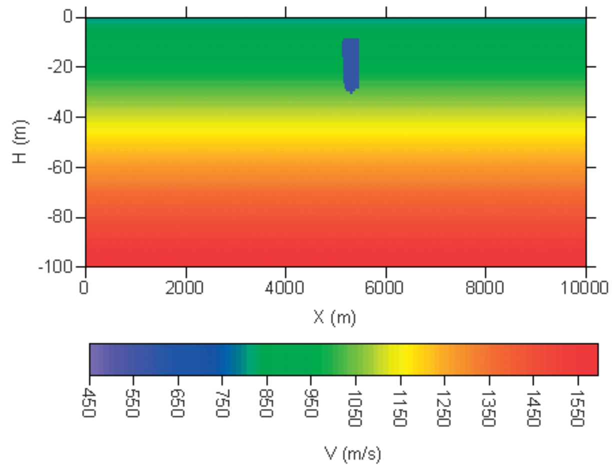

Fig. 1. Assumed gradient model of the medium with low velocity, shallow anomaly

Fig. 1. Założony model gradientowy ośrodka z niskoprędkościową, płytko położoną anomalią

value 800 m/s near the surface to the value of 1600 m/s in the bottom of the gradient layer. The assumed depth of the refractor was 100 m with refractor velocity 2100 m/s.

In the case of tomographic inversion of turning wave first breaks the starting velocity models were modified doubly: changing the velocities in the nodes of velocity grid in the range of +15% to -15% or varying the value of velocity gradient in the same range.

The process of ray tracing was realized by means of solving the set of differential equations resulting from Fermat's principle (Kasina 2001):

$$d\alpha = \frac{1}{v}\left(\frac{\partial v}{\partial x}\sin\alpha - \frac{\partial \alpha}{\partial z}\cos\alpha\right) ds$$

$$dx = ds\cos\alpha$$

$$dz = ds\sin\alpha$$

$$dt = \frac{ds}{v}$$

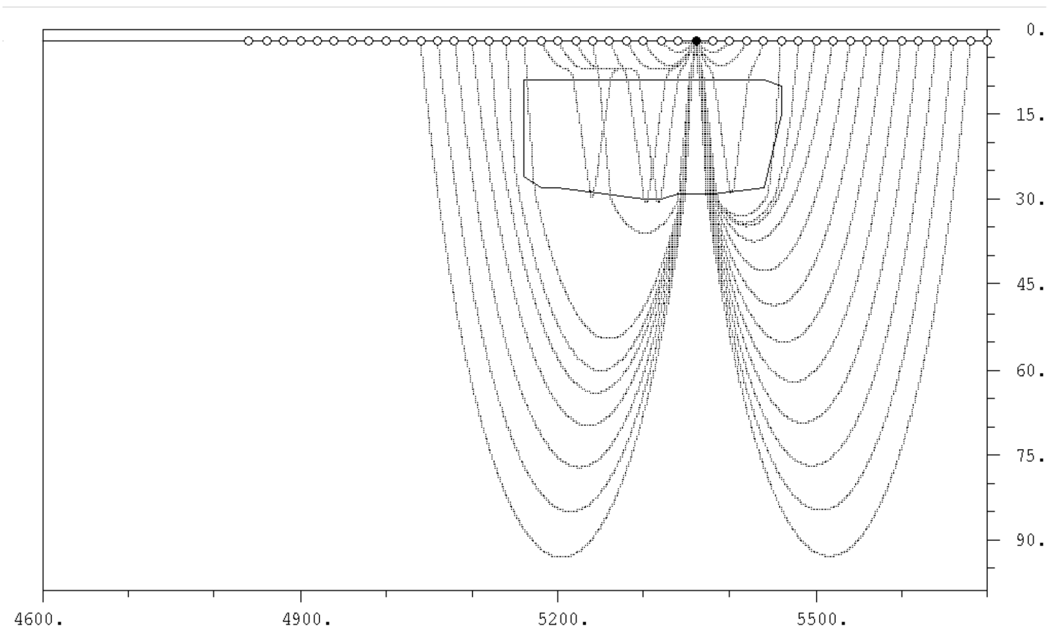

Fig. 2. Graph of ray trajectories for the selected shot point (SP. 5)

Fig. 2. Wykres trajektorii promieni dla wybranego punktu strzałowego (PS. 5)

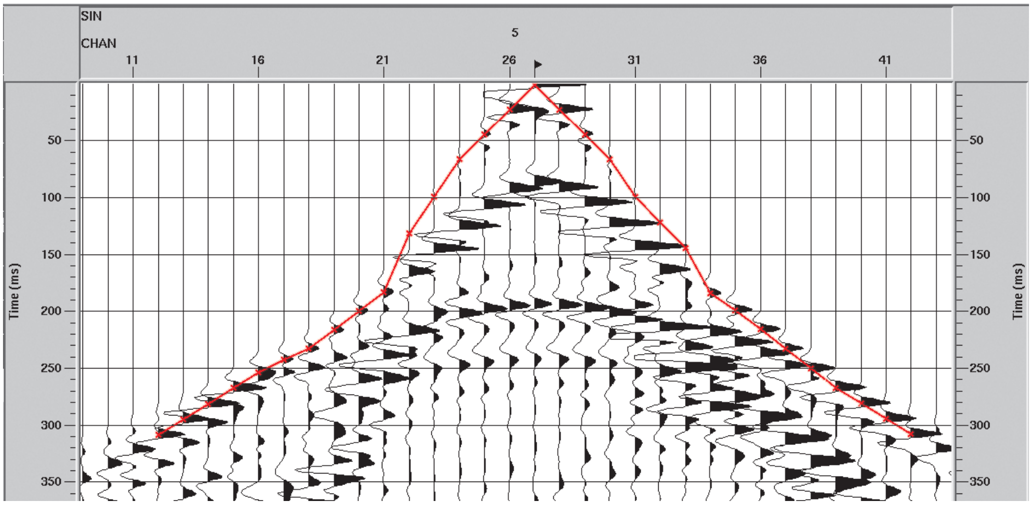

Fig. 3. Wave picture of the selected record (SP. 5) from modeling by means of the finite difference method (FDM)
Fig. 3. Obraz falowy wybranego rekordu (PS. 5) z modelowania metodą różnic skończonych (FDM)

where an angle α defines the slope of the tangent to ray trajectory, *ds* is the element of the ray trajectory, *v* - velocity defined along the ray trajectory. In the process of ray tracing we solve the above set of differential equations using numerical Runge-Kutta method of fourth order. The program #RAYEDT elaborated by the author was used for the calculations.

Because part of the defined ray trajectories for the assumed aquisition parameters were far from real trajectories (oscillation caused by the numerical calculations on the grid including numerical velocity interpolation) for each shot position the modeling was performed based on the wave approach with the application of FDM program (*Finite Difference Modeling*) from the system of data processing PROMAX® with additional first breaks picking. Such a double approach created possibility to assess the effect of ray approach on the tomographic inversion errors.

The modeling of ray trajectories and the traveltimes was realized for the discrete velocity model with dimensions 10000 m x 100 m with the step of the discretization in the horizontal direction Δx = 20 m and Δz = 1m in the vertical direction. The points of ray trajectories were calculated with the step ds = 0.3 m. The following parameters of the CDP aquisition were simulated: split spread, the channel number 52, the number of shot points 9, receiver interval 20 m, shot interval 40 m, the distance from the shot to the nearest receiver 20 m. The shot points were placed in the range 5200 m - 5520 m and the receiver positions in the range 4680 m - 6040 m. In the FDM modeling the zerophase Ricker signal was applied with the dominate frequency 60 Hz. The example of the results of ray trajectories calculations for selected SP. 5 is presented in Fig. 2 and the results of record modeling with the help of FDM program for the same shot are illustrated in Fig. 3 with picked first breaks. Fig. 4 includes the comparison of the traveltimes from ray tracing and FDM's record picking.

The analysis of the ray trajectories for all the shots makes it possible to formulate several essential conclusions important for the realization of the tomographic inversion of turning wave first breaks with the application of ray approach commonly used in the system processing of seismic data:

- in the case when the split spread is recording the waves propagating from the shot point placed above the

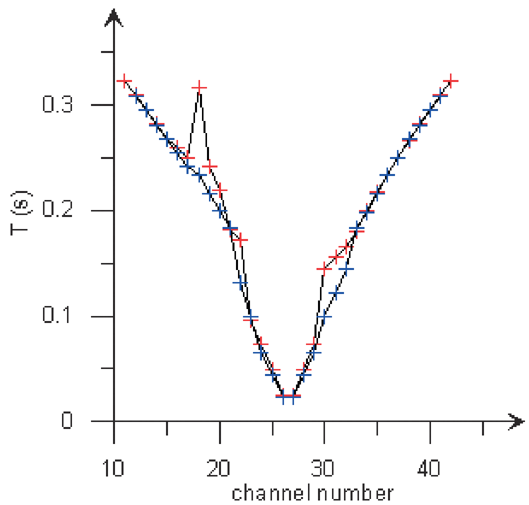

Fig. 4a. Results of first breaks traveltimes calculations using program RAYEDT (red color) and results of FB picking on the record from FDM (blue color)

Fig. 4a. Wyniki obliczeń czasów pierwszych wstąpień za pomocą programu RAYEDT (kolor czerwony) oraz wyniki punktowania FB na sejsmogramie z FDM (kolor niebieski)

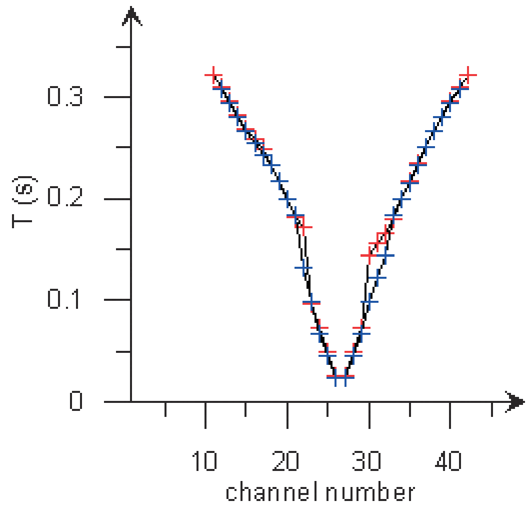

Fig. 4b. Results of first breaks traveltimes calculations using program RAYEDT (red color) after removing non reliable traveltimes and results of FB picking on the record from FDM (blue color)

Fig. 4b. Wyniki obliczeń czasów pierwszych wstąpień za pomocą programu RAYEDT (kolor czerwony) po usunięciu niewiarygodnych czasów oraz wyniki punktowania FB na sejsmogramie z FDM (kolor niebieski)

middle of the velocity anomaly we observe reliable ray trajectories without any oscillations confirmed by the concordance of calculated traveltimes with the results of FDM's picks;

- as the shot point is moving far from the anomaly the oscillations of ray trajectories appear and the calculated traveltimes are very often quite different from (much greater then FDM's picks);
- in the last case the identification of the less reliable traveltimes is not so difficult and the effective removing such traveltimes before inversion is possible. In Fig. 5 the graphs of theoretical traveltimes from all 9 shots are presented after removing less reliable first breaks. These traveltimes create the input data to the tomographic inversion of turning wave first breaks. Additionaly, in Fig. 6 the set of all reliable trajectories is displayed confirming, very good coverage of the anomaly and its surroundings by the rays. That means that the main condition of the effective tomographic

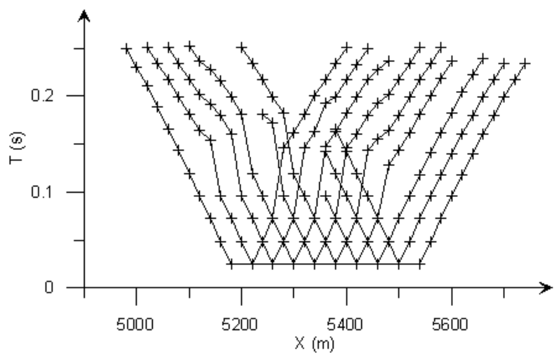

Fig. 5. Presentation of theoretical traveltimes from program RAYEDT for all the shot points after removing non reliable times

Fig. 5. Zestawienie czasów teoretycznych z programu RAYEDT dla wszystkich PS-ów po usunięciu czasów niewiarygodnych

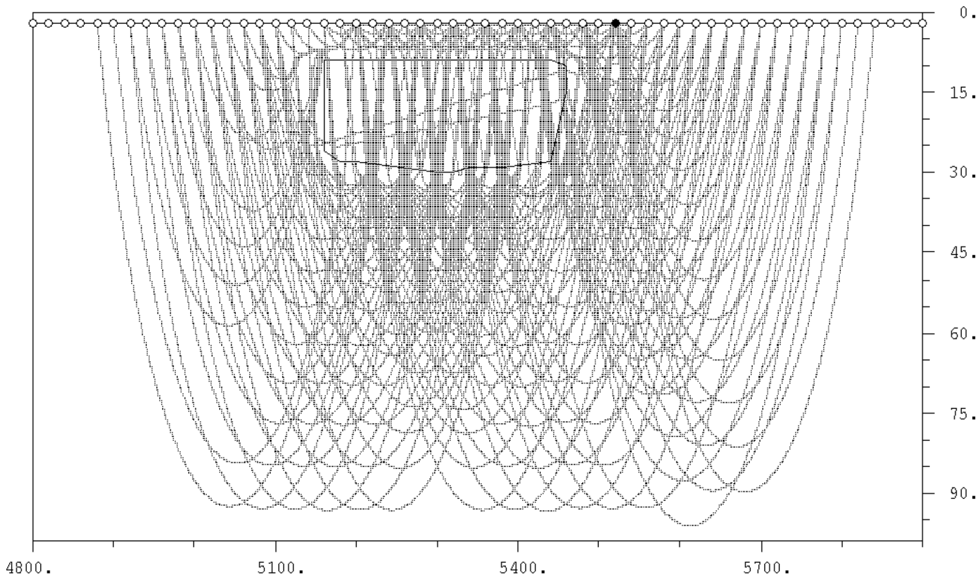

Fig. 6. Presentation of all ray trajectories from nine shot points after removing non reliable rays

Fig. 6. Zestawienie wszystkich trajektorii promieni z dziewięciu PS-ów po wykluczeniu promieni niewiarygodnych

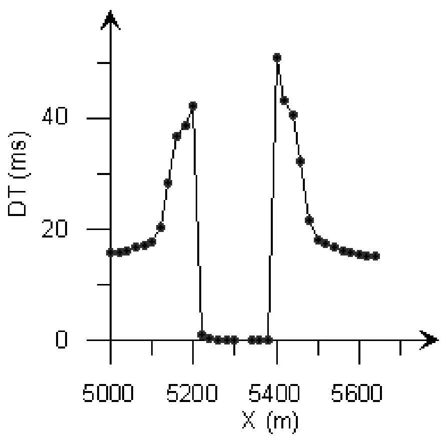

Fig. 7. Differencies of traveltimes defined using program RAYEDT for SP. 4 for the medium with velocity anomaly and for the model without anomaly

Fig. 7. Różnice czasów przebiegu, określonych za pomocą programu RAYEDT dla PS. 4 dla ośrodka z anomalią prędkościową oraz dla modelu bez anomalii

inversion is satisfied. The graph of differences between the traveltimes calculated for the gradient model with and without anomaly for the selected SP. 4 is presented in Fig. 7.

The calculations of the ray trajectories and the traveltimes for the case of the head wave were performed for the aquisition parameters (two split spreads) simulating the recording for two shot points yielding data to construction two long hodographes with reciprocal times. The coordinates of the shot points have the value 4600 m (SP. 1) and 6000 m (SP. 2). The receivers (138) were placed with the interval 20 m on the base 3220 m - 5980 m for SP.1 and 4620 m - 7380 for SP. 2. The resulted ray trajectories for the model with anomaly are displayed in Fig. 8 and the seismic record generated using FDM program is illustrated in Fig. 9. The resulting hodographes are presented in Fig. 10 and the graph of the differences between traveltimes calculated for the model with and without anomaly is presented in Fig. 11.

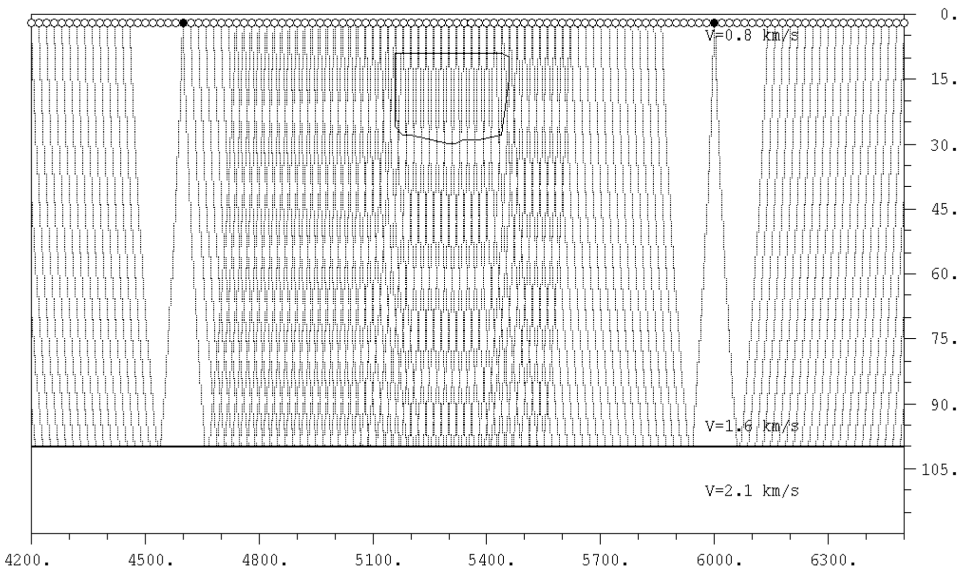

Fig. 8. Graphs of seismic ray trajectories of head waves for the gradient model with velocity anomaly

Fig. 8. Wykresy trajektorii promieni sejsmicznych fal czołowych dla modelu gradientowego z anomalią prędkościową

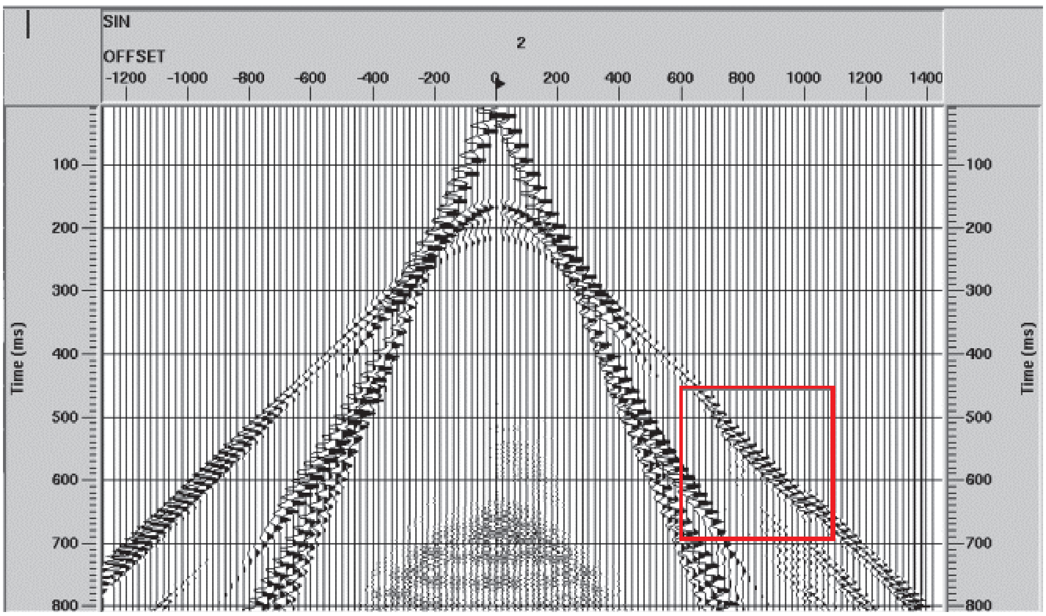

Fig. 9. Wave picture of the seismogram from the modeling using program FDM; red rectangle defines the zone of head wave first breaks in which the influence of the velocity anomaly is marked as traveltimes increasing

Fig. 9. Obraz falowy sejsmogram z modelowania zrealizowanego za pomocą programu FDM; czerwonym prostokątem zaznaczono strefę pierwszych wstąpień fali czołowej, w której anomalia prędkościowa odwzorowała się zwiększeniem czasów rejestracji

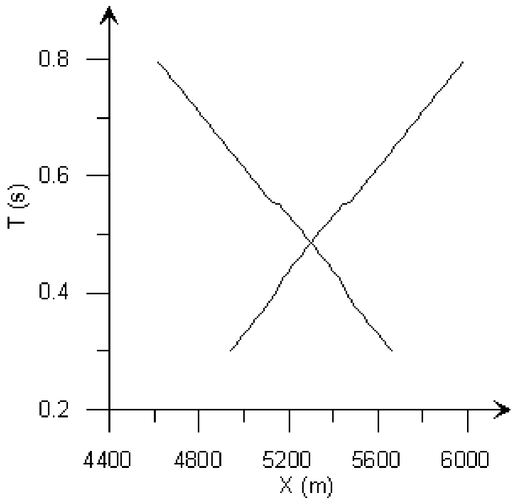

Fig. 10. Theoretical traveltimes of head wave (ray approach) for two shot points and gradient model of the medium with velocity anomaly above refractor

Fig. 10. Teoretyczne czasy przebiegu fali czołowej (podejście promieniowe) dla dwóch PS-ów i gradientowego modelu ośrodka z anomalią prędkościową w nadkładzie refraktora

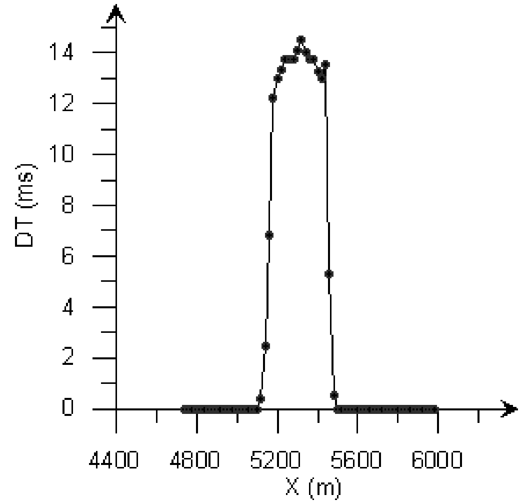

Fig. 11. The differences between head wave traveltimes for the model with velocity anomaly and without anomaly

Fig. 11. Różnice czasów przebiegu fali czołowej dla modelu z anomalią prędkościową i dla modelu bez anomalii

2. Analysis of results of the turning wave first breaks inversion

The inversion of the turning wave first breaks was executed using the program INVERST elaborated by the author. The algorithm of the program is based on the expression of the differences Δt_r between the observed traveltimes (picked data from records) and theoretical traveltimes calculated for the starting velocity field as the function of velocity corrections in the nodes of the calculation velocity grid:

$$\Delta t_r = -\Delta s \sum_{P_k} \frac{\Delta v(P_k)}{v^2(P_k)}$$

where

$$\Delta v(P_k) = \sum_m c_m \, \Delta V_m$$

$\Delta v(P_k)$ is the error of the starting velocity field at the point P_k, ΔV_m - the velocity error at the m - the nearby node.

The above relation may be expressed for all R rays as the equation set:

$$\sum_{m=1}^{M} a_{r,m} \, \Delta V_m = \Delta t_r, \quad r = 1,2,\ldots,R$$

In the above set of equation the corrections ΔV_m are treated as the unknowns.

To avoid serious irregularities in the solution the constraints are introduced on the estimated corrections ΔV_m. Finally, we minimize the norm:

$$S = \sum_{r=1}^{R} \left(\sum_{m=1}^{M} a_{r,m} \, \Delta V_m - \Delta t_r \right)^2 + \lambda \sum_i \left(\Delta V_m - \Delta V_i \right)^2$$

where i is the index of the nodes close to the m node, λ is the constraint coefficient (damping). If we introduce matrix notation:

$$\underset{(R,M)}{\hat{A}} = a_{r,m}, \quad \underset{(M,1)}{\Delta\hat{V}} = \Delta V_m, \quad \underset{(R,1)}{\Delta\hat{t}} = \Delta t_r$$

and we shall realize the minimization of S:

$$\frac{\partial S}{\partial \Delta V_k} = 0, \quad k = 1,2,\ldots,M$$

then we obtain the final set equation in the matrix form:

$$\left(\hat{A}^T A + \lambda\, \hat{\Omega}\right) \Delta\hat{V} = \hat{A}^T\, \Delta\hat{t}$$

where $\hat{\Omega}$ is the constraint matrix, $\hat{A}^T$ is the transposition of matrix $\hat{A}$.

In the algorithm of the program the procedure of convolution smoothing named seismic quelling (Meyerholtz et al. 1989, Kasina 2001) was included. The procedure is equivalent to replacing the seismic ray trajectory into band including greater number of grid nodes in the procedure of ray tracing. That means introducing strong correlation between the velocities in the close nodes on the way of seismic ray. Taking into account the comparison of the effectiveness of different kinds of tomographic inversions (Philips, Fehler 1991) we can classify the described algorithm as close to the solution based on first difference regularization.

The inversion of turning wave first breaks from nine shots was realized with constraint parameter λ = 10 and 30 - 100 iterations during solution the set of equation by means of iterative conjugate gradient method. The resulting velocity fields were smoothed using 2-D operators. The root mean square error of estimated velocity field was calculated taking into account the known assumed velocity model of the medium with anomaly. The starting velocities field (constant gradient medium) was modified introducing constant errors of velocities or constant errors of the gradient value within the range +15% to -15%.

Selected results of turning wave first breaks inversion are illustrated in Figures 12 i 13. The comparison of the root mean square errors RMSDV of estimated velocity fields for different errors of starting gradient medium is presented in Tab. 1 and Tab. 2. The analysis of the inversion results allows to formulate the following conclusions:

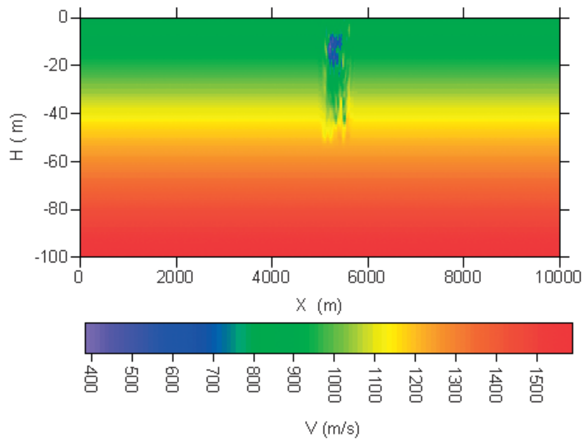

Fig. 12. Results of the inversion of the turning wave first breaks after first iteration for 30 iterations in the conjugate gradient method after smoothing the velocity field using 2-D operator: a) 2 x 2 (80 m x 4 m), b) 1 x 2 (40 m x 4 m)

Fig. 12. Wyniki inwersji pierwszych wstąpień fali refragowanej po pierwszej iteracji dla 30 iteracji w metodzie gradientów sprzężonych po wygładzeniu pola prędkości operatorem dwuwymiarowym: a) 2 x 2 (80 m x 4 m), b) 1 x 2 (40 m x 4 m)

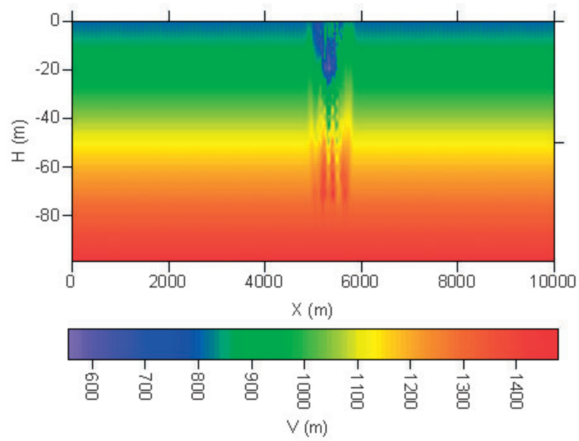

Fig. 13. Results of the inversion of the turning wave first breaks for the value of constant gradient error (-10%) of starting velocity field

Fig. 13. Wyniki inwersji tomograficznej pierwszych wstąpień fali refragowanej dla wartości stałego błędu gradientu (-10%) startowego pola prędkości

error of starting velocity field	RMSDV (m/s)
- 15%	181,5
-10%	121,8
-5%	63,1
0%	18,7
+5%	62,9
+10%	121,6
+15%	181,3

Tab. 1. Root mean square error RMSDV of the velocity field defined for different values of the constant error of starting velocity field

Tab. 1. Średni kwadratowy błąd pola prędkości RMSDV, określony dla różnych wartości stałego błędu startowego pola prędkosci

error of velocity gradient	RMSDV (m/s)
+ 15%	140,6
+ 10%	97,1
+5%	54,5
0%	18,74
-5 %	46
- 10 %	87,2
- 15%	134,8

Tab. 2. Root mean square error RMSDV of the velocity field defined for different values of the error of starting field gradient

Tab. 2. Średni kwadratowy błąd pola prędkości RMSDV, określony dla różnych wartości błędu gradientu pola startowego

- when we use the exact model of the gradient medium without anomaly as the starting model then we can obtain a satisfactory image of the anomaly in the process of inversion using only one iteration assuming the application of the well chosen operator of 2-D smoothing;
- increasing of the number of iteration in the gradient conjugate method from 30 to 100 does not introduce serious changes into resulting velocity fields;
- in the second iteration of the inversion performed with the application of resulting velocity field from the first iteration as the starting field the obtained results were much worse then in the first iteration; it was caused by taking into account not reliable trajectories of seismic rays in the process of automatic generation the equation coefficients during ray tracing;
- the errors of starting gradient velocity field essentially decrease the quality of imaging specially for the errors reaching the value ± 10%;
- the decreasing of the quality of imaging is greater when we introduce the error of gradient value then in the case of constant error of velocity field;
- in the case of the gradient errors we can observe somewhat greater values of root mean square error when the gradient value is overestimated in comparison when it is underestimated.

3. Analysis of results of the head waves first breaks inversion and of the simultaneous inversion of the turning and head waves first breaks

The inversion of the head waves first breaks for the case of two shot points and long spreads were performed for 69 receivers arranged on the base 4620 - 5980 m with the receiver interval of 20 m. The resulting velocity field is presented in Fig. 14. We can observe a very good horizontal resolution (correct position of the anomaly on the horizontal axis and correct anomaly width) but a much worse vertical resolution manifesting as the smearing of the velocity anomaly towards the surface.

The simultaneous inversion of the turning and head waves first breaks were acomplished using program INVERSTH developed by the author. The program includes procedures of calculations of ray trajectories of head waves and turning waves. During ray tracing the coefficients of much larger set of equations are generated. The traveltimes observed only in first breaks were used as input data after the elimination of not reliable traveltimes of turning waves. The result of the inversion is presented in Fig. 15. The RMS errors of the velocity fields resulting from all the three types of tomographic inversion (head wave inversion, turning wave inversion and simultaneous inversion of head and turning waves) were compared in the Tab. 3.

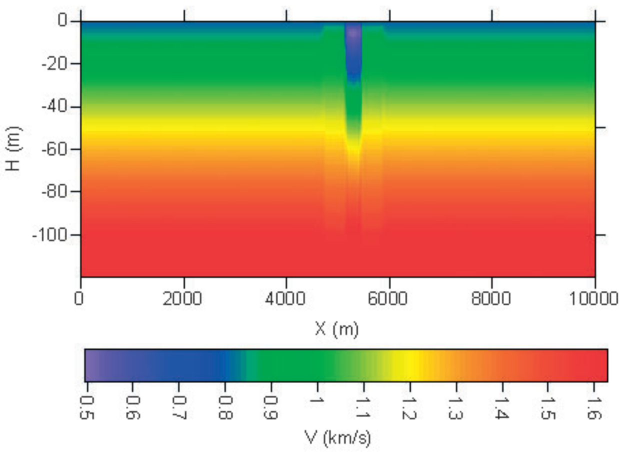

Fig. 14. Results of the inversion of the head wave first breaks after first iteration for 30 iterations in the conjugate gradient method

Fig. 14. Wyniki inwersji pierwszych wstąpień fali czołowej po pierwszej iteracji dla 30 iteracji w metodzie gradientów sprzężonych

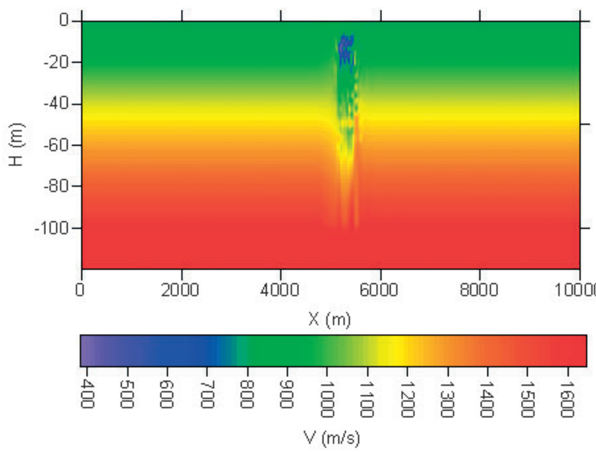

Fig. 15. Results of the simultaneous inversion of the head and turning wave first breaks after first iteration for 30 iterations in the conjugate gradient method after after smoothing the velocity field using 2-D operator 1 x 2 (40m x 4 m)

Fig. 15. Wyniki jednoczesnej inwersji pierwszych wstąpień fali czołowej i refragowanej po pierwszej iteracji dla 30 iteracji w metodzie gradientów sprzężonych po wygładzeniu operatorem 1 x 2 (40m x 4 m)

The analysis of the results of the inversion makes it possible to draw the following conclusions:

- the simultaneous inversion of the turning and head waves first breaks yields the anomaly image with much better vertical resolution then in the case of the inversion of head waves first breaks;
- the resulting image of anomaly is also somewhat better then the results of turning wave first breaks inversion (a much proper position of the bottom boundary of the anomaly and a better horizontal resolution);
- the advantage of the simultaneous inversion marked distinctly smaller RMSDV error (73.9 m/s) in comparison with the error of turning wave inversion (96.5 m/s) when the errors are calculated in the velocity field window including the anomaly and its immediate surroundings (X = 4500 - 6000 m, HMAX = 40 m).

type of inversion	RMSDV (m/s)
head wave + turning wave	25,2
head wave + turning wave, X = 4500-6000 m, HMAX = 40 m	73,9
turning wave, X = 4500 - 6000m, HMAX = 40 m	96,5
turning wave	18,7
head wave	24,7

Tab. 3. Comparison of the inversion errors RMSDV calculated for the fool velocity field or for the selected window defined by the range of X coordinates and maximum depth HMAX

Tab. 3. Porównanie błędów inwersji RMSDV, obliczonych dla pełnego pola prędkości lub dla wybranego okna, zdefiniowanego zakresem współrzędnych X oraz maksymalną głębokością HMAX

Bibliography

Hampson, D., and Russell B., 1984 - *First-break interpretation using generalized linear inversion*. J. Can. Soc. Expl. Geophys., vol. 20, 40-54

Kasina Z., 2001 – *Tomografia sejsmiczna*. Wydawnictwo Instytutu GSMiE PAN, Kraków, 211 stron

Lanz E., Maurer H., Green A. G., 1998 - *Refraction tomography over a buried waste disposal site*. Geophysics, vol. 63, 1414-1433

Meyerholtz K. A., Pavlis G. L., Szpakowski S. A., 1989 - *Convolutional quelling in seismic tomography*. Geophysics, vol. 54, 570-580

Philips W., Fehler M., 1991 - *Traveltime tomography: a comparison of popular methods*. Geophysics vol. 56, 1639-1649

Stefani J. P., 1995 - *Turning-ray tomography*. Geophysics, vol. 60, no. 6, 1917-1929

Zhu X., Sixta, D. P., Angstman, B. G., 1992 - *Tomostatics: Turning-ray tomography + static corrections*. The Leading Edge, 11, no. 12, 1

Zhu X., 2002 - *Velocity imaging through complex near-surface structures by tomography*. E37, EAGE 64th Conference & Exhibition — Florence, Italy, 27 - 30 May 2002

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