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Digital relief intensity map of Pomerania – a concept

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Abstract: The digital relief intensity map of Pomerania based on the digital geomorphology model is a useful tool for the selection of specific work areas. Thanks to the relief intensity coefficient, the image pattern recognition of forms of any sizes of the basic area was possible and independent from the absolute height. This allows comparing the forms, and especially studying their spatial relationships with other morphological units within the marginal zone. The map database is a system both complex, consisting of numerous components adopted from published sources (mainly maps) such as geology, geomorphology or topography, but also open. This means the possibility of its expansion, and the carried out analyses using geostatistical methods are sources of quantitatively new sets of data. As an example may stand the method for determining the area of outwash plain surfaces in Pomerania influenced by extreme glacial water discharges in the late Pleistocene, and the attempt to estimate the scale of this phenomenon. This map, by providing the opportunity to observe the area of morphometric features in both regional and local scales, whether in Pomerania or in contemporary glaciated areas, constitutes an important element in understanding the regularities governing such processes in the past.

Keywords: digital map, digital geomorphology model, relief intensity coefficient, geomorphologic database

Introduction

Geomorphological characteristics of the area have been very often based on a detailed mapping of selected forms or fragments of the terrain as well as on geological punctual studies or profiles. The results extrapolated to the entire area therefore do not reflect fully the nature of the processes that led to the landscape formation. Pomerania (NW Poland) might be an example – here the geomorphological studies on the course and character of the processes during and at the end of the last glaciation, despite the long and richly documented research, still do not give a clear idea of many issues. The main difficulty is the lack of modern continental glaciations covering land with unconsolidated sediments that could provide a model for the Pleistocene ice sheets. The study based mainly on the data from the geological profile records a small portion of events, mostly short-term deposits of the violent phenomena occurring especially during the ice sheet decay (Mojski 1979). In the case of processes and phenomena of such a large-scale as the continental glaciation, it is necessary to understand the wider time-space context. The knowledge of the regularities governing these processes as well as of the conditions in which they occurred – with reference to a larger area – should be the basis of a detailed research. This requires making a working method uniform for any scale of the terrain chosen for analysis.

Field and remote sensing observations, geological, geomorphological and glaciological published data and results, as well as cartographic materials from contemporary glaciated areas (Iceland and Svalbard) helped to draw attention to the special role of the forms spatial distribution within the marginal zone. This feature combined with morphometry in the case of outwash plain surfaces allowed their classification, where the criteria were: the state of dynamic of the ice sheet at the time of the outwash plain forming, the related nature of the glacial water runoff and the dominant type of the area deglaciation (Szafraniec 2009, 2010a, 2010b). The analysis of selected examples of the forms and the search for analogies in contemporary processes (the principle of uniformitarianism) were important elements of the study. They provided the information about the forms distribution and morphometry in the context of the whole large region. The applied relief intensity coefficient enabled this study.

This article aims to present the concept of the digital relief intensity map of Pomerania. The mentioned coefficient, being also the digital geomorphology model (Zhang et al. 2003), became the basis. In contrast to the widely used digital elevation model (DEM), not only does it represent the hypsometric diversity of the area, but also allows the initial recognition of relief pattern (postulated by Szubert 2007, 2008, Szafraniec 2009). The relief intensity map of Pomerania based on geostatistical methods of calculations allowed independence from absolute height, and the final effect – the morphometric pattern of forms – retained its basic features regardless of the freshness of the relief. The information obtained this way is both the initial material and a tool for careful selection of areas for subsequent detailed research, especially sedimentological ones, which is the main role of the digital map of the Pomeranian relief intensity.

Digital geomorphology model of Pomerania

Indicators such as relief intensity or energy of relief (Szczepankiewicz 1948, Szumowski 1967, Grygorenko 1973, Richling 1973, Wyrzykowski 1985, Kozieł 1990, 1993, Brzezińska-Wójcik et al. 2010, Wójcicki & Marynowski 2011), based mainly on the relative heights, slopes, or the number of depressions and hills have already been used in Polish geographical studies (for different purposes). They were focused on smaller regions. A clear distinction between ground moraine and some examples of the sandur surfaces was an important issue in the case of the young-glacial landscape of Pomerania, however the mentioned above factors were insufficient. Hence the relief intensity factor has been enriched with information about sediments associated with various forms.

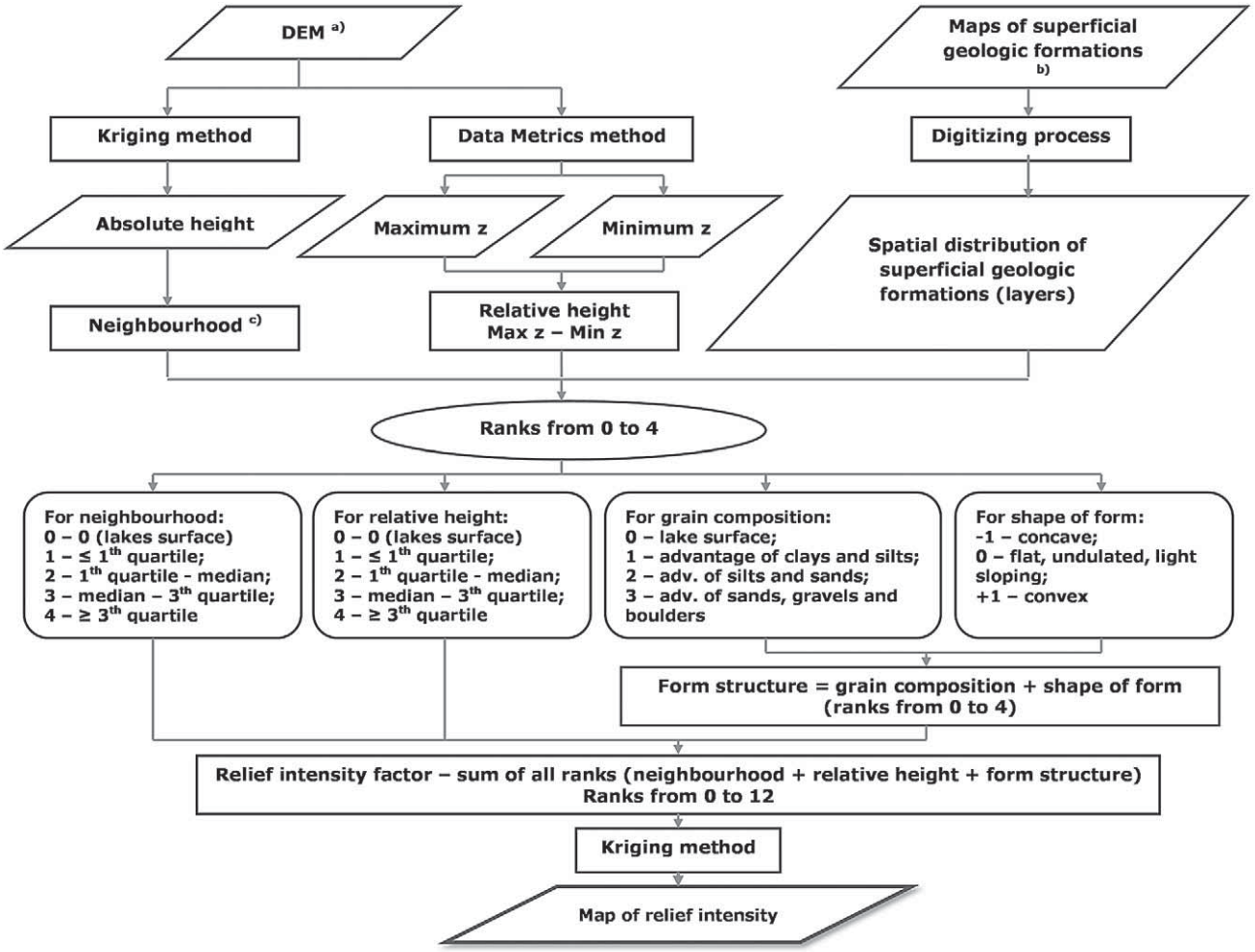

Fig. 1. Stages of the relief intensity coefficient calculations: a) DTED 2, Military Centre for Geodesy and Remote Sensing (for whole Pomerania); b) geological maps edited by Mojski (1974–1981), c) formula for one grid node; $NH = [(AH_{(xn,yn)} - AH_{(xn+1,yn)}) + (AH_{(xn,yn)} - AH_{(xn-1,yn)}) + (AH_{(xn,yn)} - AH_{(xn,yn+1)}) + (AH_{(xn,yn)} - AH_{(xn,yn-1)})]^2$, where NH – neighbourhood, AH – absolute height, x, y – coordinates; the other operations apply to files

The model was developed in several stages. Literature and necessary data were gathered at the beginning. This allowed a comparative morphometric analysis of marginal zones in contemporary glaciated areas in Svalbard and Iceland. The data for Pomerania included: DEM for Pomerania, level 2, Wojskowy Ośrodek Geodezji i Teledetekcji, Warszawa, 2001 and "Geological map of Poland" (Mapa geologiczna Polski) edited by E.J. Mojski, A – Map of superficial formations (1974–1981). The relief intensity database compilation was another step (as an analogy with the geomorphologic database proposed by Minár et al. 2005, Mentlík et al. 2006, Jedlička 2008). It was comprised of the data in tabular form (which also helped to create TIN and grid files), and raster and vector files. The Golden Software programs, Surfer and Didger as well as ArcGIS from ESRI were used for this purpose.

Calculation of the coefficient according to a specific relief intensity algorithm (Szafraniec 2008a, 2010a), presented in Figure 1, was the next stage. Most of the estimations were based on the geostatistical analysis in Surfer. Data obtained from a digital elevation model – the relative height and neighbourhood as well as the superficial formations on the basis of "Geological map of Poland" (ranges, the primary grain size and the nature of the area associated with the type of the formations – convex, flat or wavy and concave) were components of the coefficient. Compiling such information and its respective encoding (ranks) resulted in the relief intensity coefficient that:

- presents in a uniform manner the relief intensity differentiation for the entire area;
- makes the result independent of absolute heights (although they were the basis of the model);
- allows the initial classification of the forms of the marginal zone;
- allows using different sizes of the basic area (up to the size of the average form area).

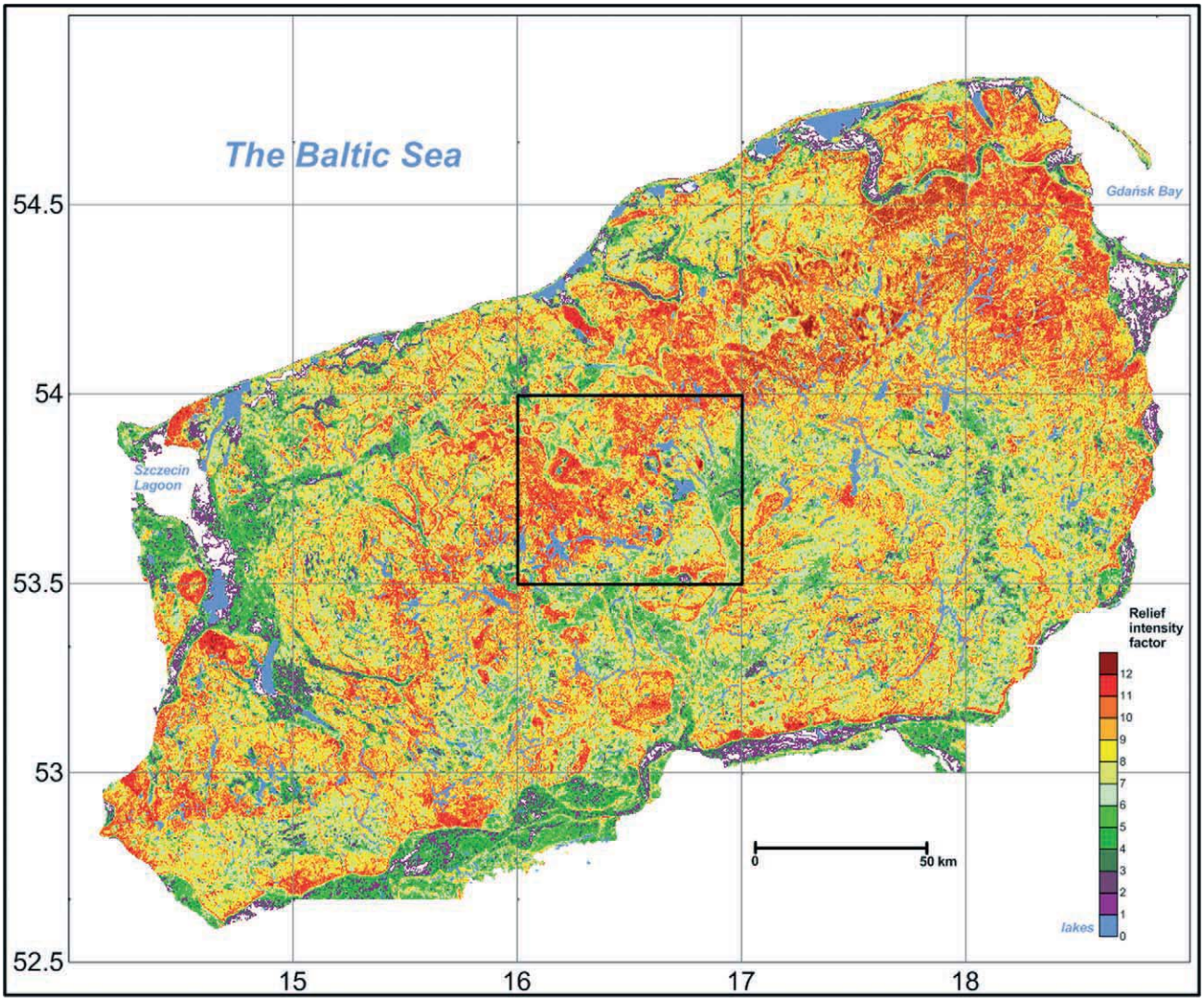

Fig. 2. Relief intensity map of Pomerania (worked out on the basis of the DEM from Wojskowy Ośrodek Geodezji i Teledetekcji and geological maps edited by Mojski, 1974–1981). Area in black box is presented on Fig. 3 as a visualization of exemplary thematic layers in geomorphological database. Geographical coordinates are presented in the decimal degrees format

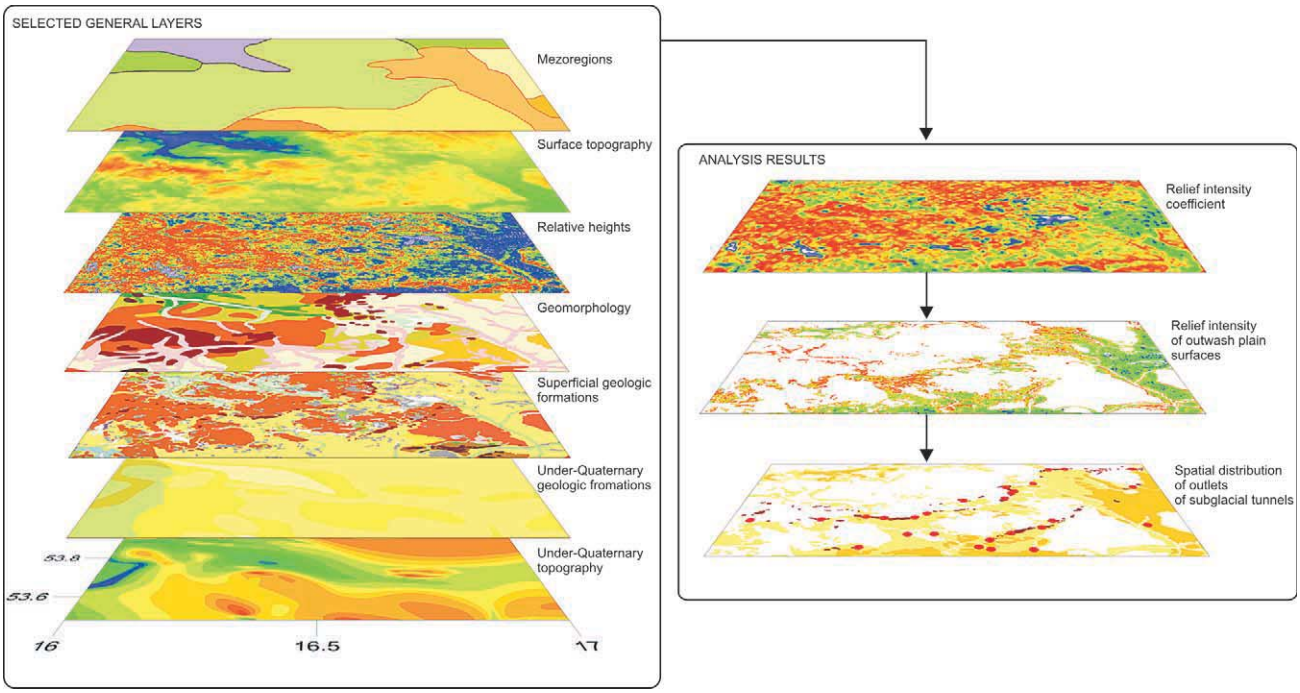

Fig. 3. Selected thematic layers used to develop and analyze the digital relief intensity map of Pomerania (fragment of the central part of the region in the vicinity of Szczecinek). Geographical coordinates are presented in the decimal degrees format

A visualization of the coefficient in the form of the relief intensity map of Pomerania (Fig. 2) was the final stage of the study. The coefficient ranged from 0 to 12, where 0 refers to flat surfaces situated in the lowest areas in comparison to the neighbouring ones, and 12 – the most diverse in terms of relief with the highest values of relative and the absolute height in comparison to their surroundings.

Concept of the digital relief intensity map of Pomerania

Data and study area boundaries

The fact that visualization facilitates a uniform presentation of the degree of the relief diversification characteristic for the entire area representing a specific type of landscape makes it vitally advantageous (Szafraniec 2008a). This feature has contributed to developing the concept of the digital relief intensity map of Pomerania. It might be a useful tool for selecting specific areas of research. In addition to the previously mentioned data, there were also used: "Reference geomorphological map of Poland" (Przeglądowa mapa geomorfologiczna Polski) edited by L. Starkel (1980), "Geological map of Poland" (Mapa geologiczna Polski) edited by E.J. Mojski, B – Map of under-Quaternary formations (1974–1981), topographic maps in the 1965 system in scale 1:10,000 (selected sheets), Główny Urząd Geodezji i Kartografii, Państwowe Przedsiębiorstwo Geodezyjno-Kartograficzne, Kraków, data from the boreholes to the "Hydrogeological map of Poland" (Mapa hydrogeologiczna Polski) on a scale 1:50,000 (selected sheets), made available by Zakład Hydrogeologii i Geologii Inżynierskiej, Państwowy Instytut Geologiczny, Warszawa, data from hand drillings within the outwash fan in the vicinity of Borne Sulinowo, obtained by courtesy of Prof. K. Klimek (University of Silesia).

Pomerania in this study is considered as the area between the valleys of the lower Vistula and lower Oder River to the east and west and between the Baltic Sea in the north and the Toruń-Eberswald proglacial stream valley in the south (see Fig. 2).

Structure of the Pomeranian relief intensity database

The collected data were used to build the relief intensity database of Pomerania, which is part of a larger one – the relief intensity database of contemporary marginal zones (from Svalbard and Iceland) and the Pleistocene ones. This Pomeranian consists of two main parts (comp. Fig. 3 and 4): 1) general layers for the whole of Pomerania, and 2) relating to the relief intensity coefficient and the results of the spatial and morphometric analysis.

The general data layers have been adapted from existing publications such as maps and data from field measurements. They reflect all the ways of the field representation (Longley et al. 2006) however

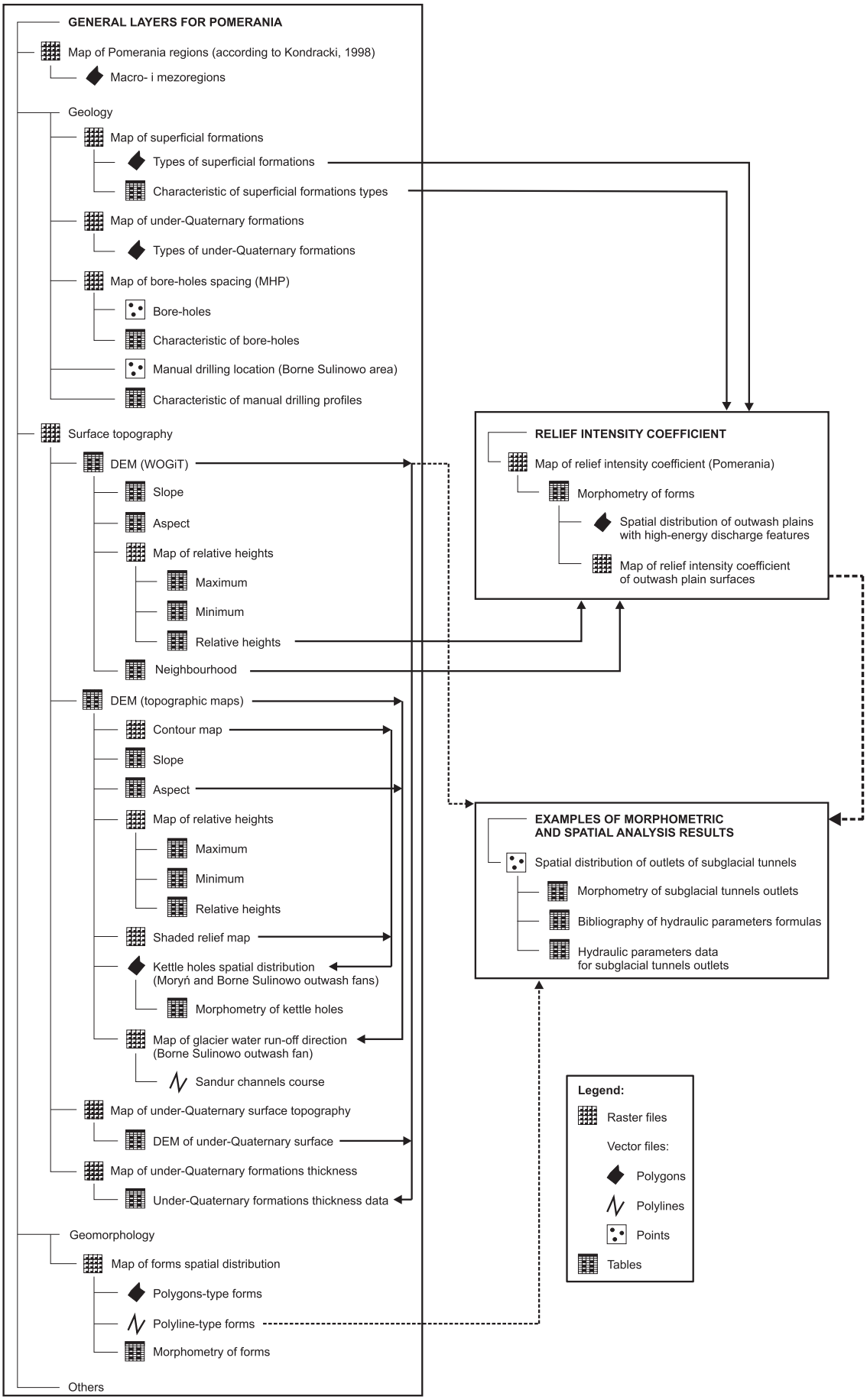

Fig. 4. Scheme of the Pomeranian relief intensity database

in the structure schema they have been converted into raster and/or vector files and tables. The data refer to:
- physical-geographical macro- and mezoregions of Pomerania (according to Kondracki, 1998);
- geology;
- topography (surface and under-Quaternary);
- geomorphology;
- and others (such as hydrology, glacial ranges etc.).

The layers associated with the relief intensity coefficient are both the derivatives of those adopted data and the result of a further analysis, mainly morphometric and the spatial distribution of the forms within the marginal zone (see Fig. 4; Szafraniec 2008a, 2010a).

The concept of the relief intensity database, presented in a simplified scheme (Fig. 4), takes into account the content, type of data and relations between them. It is an open system that allows both conducting analyses basing on existing data and their updating.

Application of the digital relief intensity map

The advantage of the digital relief intensity map is its independence from the absolute height which allows comparing the same landforms situated at different altitudes. At the same time, comparing them with similar forms in modern marginal zones indicates that the pattern of forms recognition was retained regardless of their age (Szafraniec 2008a, 2009).

These features were used to distinguish types of outwash plain surfaces in Pomerania (Szafraniec, 2009, 2010a). Detailed analyses allowed formulating the conclusion that morphometry and location of the form in the marginal zone in relation to other forms is important information on the conditions in which it was built and transformed. Therefore, if the form relief intensity deviates from the standard, the form is expected to remain under the influence of other morphogenetic factors.

Distinguishing these fragments of outwash plain surfaces which at some stage were transformed by extreme discharges was the consequence of this approach (Szafraniec 2008b, 2009, 2010a). Their morphometry (relief intensity coefficient below 6) is similar to those forms whose formation is strictly dependent on the action of water flowing freely, as in the case of proglacial stream valleys. This led to reflect on the causes of glacier water runoff of such extreme nature. Geological and geomorphological conditions give grounds to consider the water outburst flood during the active phase of the glacier surge as an important cause. Tunnels of the subglacial drainage system were unblocked rapidly in this way. Many tunnel valleys deep-rooted in proximal slopes of the end moraine ridge are typical for the Pomerania region. They are accompanied by gorges incised in the moraines at the mouth of which there are extensive outwash fans covering the distal slopes of the end moraines with fluvioglacial sediments. Morphometry of parts of their surface indicates the impact of flows of high energy. The gorges within the end moraine ridge were considered as outlets of subglacial channels (Szafraniec 2010b). Paleohydraulic parameters were calculated and estimated on the basis of their morphometry and using the published formula. It is worth mentioning that the average size of the outlets of the subglacial tunnels in Pomerania and the average maximum values of hydraulic parameters are similar to the analogous ones observed in the Gígjukvísl gorge (Iceland) after jökulhlaup in 1996 (see Russell et al. 1999).

Conclusions

The described example of utilising the digital relief intensity map of Pomerania indicates how vital is the possibility of referring to the whole of the region – the general trends resulting from the pattern of recognition of forms and their local differentiation. The applied algorithm taking into account the absolute height allows including the two main features – structure and randomness (Namysłowska-Wilczyńska, 2006).

Features of the relief intensity coefficient such as the unification of the marginal zone surface, the location of the study area in relation to a larger subdivision, the possibility of applying different sizes of the basic area, emphasize its universality, and therefore the possibility of using it both for the surface formed during the Pleistocene and today, and consequently – a comparative analysis allowing better understanding of the impact of various processes on the relief morphology.

The concept of the digital relief intensity map of Pomerania and an example of the geomorphological database structure indicate the necessity of gathering the fullest possible information about the study area. The digital map is the open system, where it is possible to add new data and carry out analysis on the basis of existing ones.

This map thus becomes a source of information not only about the forms (morphometry, spatial distribution), but also by using the potential of the work in the geoinformation system environment and the knowledge of the regularities that govern the evolution of these forms it allows drawing conclusions about the processes and their dynamics.

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