ORTHOPHOTO APPLICABILITY TO THEMATIC MAP COMPILATION IN OPEN-PIT MINES

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Increased demand for mineral row materials as well as exhaustion of easy accesible deposits are reasons to undertake exploitation of deposits with worse row material parameters and laying in difficult and worse accesible natural conditions. Therefore in the world, the same as in Poland, large open-pit mines are exploited with deepness from 300 to 900 meters. Work safety, fastness and continuity of surveying information, economy and also necessity of modernization, are the reasons that photogrammetric methods are applied to mining surveying and mapping.

Advantages of orthophotomaps have essential meaning for compilation and revision of mine maps. Orthophotos can be used:
- for compilation and revision of basic, review and special maps of mine surface,
- for volume determination of cap-rock and lignite,
- for planimetric and hight coordinate determination of choosen devices installed at mine,
- for recording of some elements of mine environment.

According to Polish Standards,mining maps are divided into: planimetric maps, excavation maps and geological maps. The orthophoto technique, when applied to mapping of open-pit mines, allows compilation of all kinds of planimetric maps and of some excavation maps.

Each of three kinds of mining maps includes: basic maps /usually 1:5000 or 1:10 000/, review maps /in practice usually in scale 1:1000 or 1:2000/ and the derived or special maps. In cartography, the last ones are called thematic maps.

Considering the applicability of the orthophoto technique to thematic map compilation in open-pit lignite mines, it is necessary to realize what kind of cartographic source of data the orthophoto map is. Orthophoto maps have pictorial qualities of air photos and therefore images of an infinite number of terrain objects can be recognized and identified. The image possesses planimetric correctness, so measurements can be taken directly from an orthophoto just like from a map. The cartographic information from a photographic map is objective and accurate. Images of objects and mining installations are visible with uneven degree of recognition and some of them are hard to identify. But it is important that recognition of such images on orthophoto needs only terrain identification without any additional measurements. The large scale of orthophoto, scale and quality of air photos ensure visibility of numerous minute details. For open-pit lignite mines the 1:2000 review maps are produced. Orthophotomaps of the same scale can be used for compilation of different kinds of thematic maps. Having in mind the two-year revision period of basic and review planimetric maps and every quarter revision of analogous excavation maps - the application of the orthophoto technique for production of these maps seems reasonable. The maps can be prepared faster and at lower cost as compared to other techniques. The orthophotomap can serve as the basic source of planimetric information about the state of works in the mine and can be also used for compilation of line or photographic basic and review excavation maps. In case when an orthophotomap is approved as a source of planimetric information about the mine and its surroundings, it can also be used for compilation of basic and review topographic maps, and of the following thematic /derived/ maps:

1 - map of the mining region /planimetric map showing also boundaries of the mining region/,
2 - map of the industrial district /planimetric map of industrial plants/,
3 - map of the mining plant /planimetric map with objects and surface and underground installations/,
4 - map of the transportation routes /planimetric map showing the network of tracks, roads, conveyer-belts and transportation objects/,
5 - surface energy transfer map /surface map showing power lines and pipe systems of gas, technological steam and compressed air/,
6 - water and sewage system map /surface map showingg drinking and industrial water pipelines and sewage system/,
7 - map of water courses and water basins /surface map showing natural and artificial water basins which could threaten the mining works/,
8 - map of dumps and stockpiles /showing on a planimetric map stockpiles of useful minerals and dumps of spoil/.

Orthophotomaps can be also used for compilation of the following special maps:

9 - maps of terrain displacements /planimetric map with insolines of terrain subsidence/,
10 - maps of terrain development including development of the area after mining exploitation /planimetric maps showing terrain category and usability for building over/,
11 - cadastral maps showing boundaries of land use, soil classification, agricultural complexes and of areas, which can be threatened by mining exploitation, draining of water, dust, gases smoke ect./,
12 - maps of mining protection pillars /planimetric map with outlines of objects demanding protection - and with borders of protection pillars.

An orthophotomap, in comparison with other maps has a particular advantage: it presents the direct reflection of real positions of objects taken in real time. It is an objective image of reality shown on accurate cartographic base, and therefore it is excellent as a source material for thematic map compilation of open-pit mines. Metrical quality and the rich content of an orthophotomap are essential for its use as a general base for compilation of thematic maps.

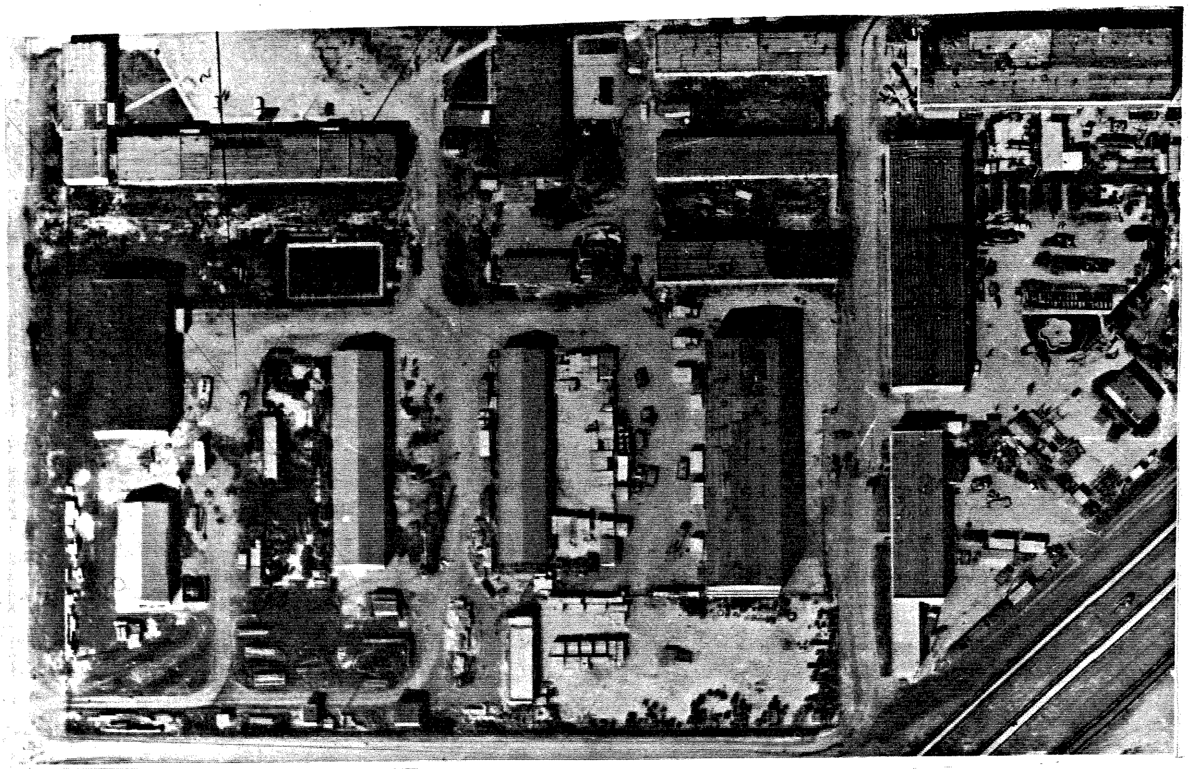

Fig. 1a

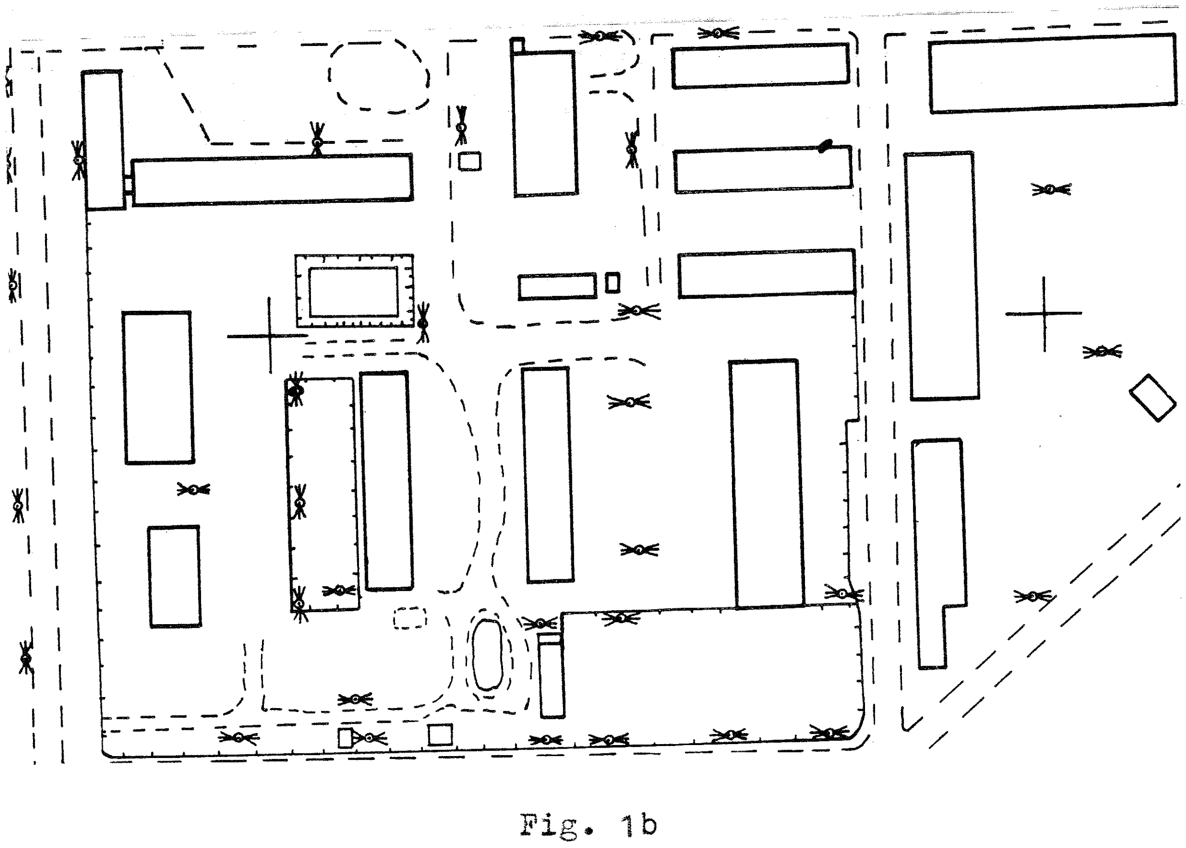

Fig. 1b

The range of utilization of the orthophoto map content is different for various thematic maps. It depends on the degree of recognition of main elements of the thematic map, purpose of the map and also depends on the formulation and presentation of map content. For instance the following derived maps: 1 - the mining region, 2 - the industrial district, 3 - the industrial plant, which shown most of the geographical elements, may be compiled on the basis of full content of an orthophotomap. Derived maps may have the form of a traditional line map or the form of a photographic map with the main elements of the thematic map drafted for better visibility.
As an example, several derived maps compiled from an ortho - photomap are presented in fig. 1-3. Fig. 1a shows a fragment of the orthophoto, which was used for line-map compilation /fig.1b/ of a mining region /1-/. Fig. 2a and 2b present fragments of the orthophoto and corresponding line map of transportation routes /4-/. All thematic maps may be compiled directly from orthophoto in form of line-maps as an extraction of some elements or as outline of the same elements directly on the orthophoto base with additional information in the form of conventional signs.
The other derived maps as, for example, surface energy line map - fig. 3b, may be prepared on the basis of orthophoto /fig.3a/ in spite of the fact that main elements of these thematic maps are hardly distingvishable /see the electric poles on the fig.3a/. In such case the orthophotomap may be used for compilation of the thematic map only after interpretation in the terrain. An orthophoto can be also useed as an excellent base for compilation of the terrain displacements map /9-/.
To find out accuracy of the derived maps, their metric quality was determined. The comparison of three kinds of 1:2000 maps was performed on the basis of:
- line map compiled in the C.Zeiss stereoplotter Topocart B using air photos in the scale 1:8000 /f = 150 mm/,
- orthophoto produced in C.Zeiss OrthophotoB /from the same air photos/,
- derived /form the same orthophoto/ line map compiled as an extraction of lines.

For investigation purposes three 1:2000 maps of the same terrain were analysed. Using a digital plotting table and the mentioned above three kinds of maps, the Y-coordinates of selected points was measured. The points were selected at intersections of grid lines /X=0.0 mm, 100 mm, 200 mm, 300 mm, 400 mm and 500 mm/ with lines of routes, escarps, ditches and other linear objects. Therefore the chosen points have known X-coordinates and only Y-coordinates are to be measured. For comparison purposes the line map compiled in the Zeiss stereoplotter was used as a reference /with planimetric error of 0,3 mm in the map scale/.
Table 1 presents standard errors taken from Y-coordinate differences between the orthophoto and the reference map /A/ and between the derived line map and the reference map /B/. As can be seen from columns 5 and 6, the errors are ± 0,41 mm and ± 0,49 mm respectively. It is noticeable, that the accuracy of the derived line map is lower than of the orthophoto.

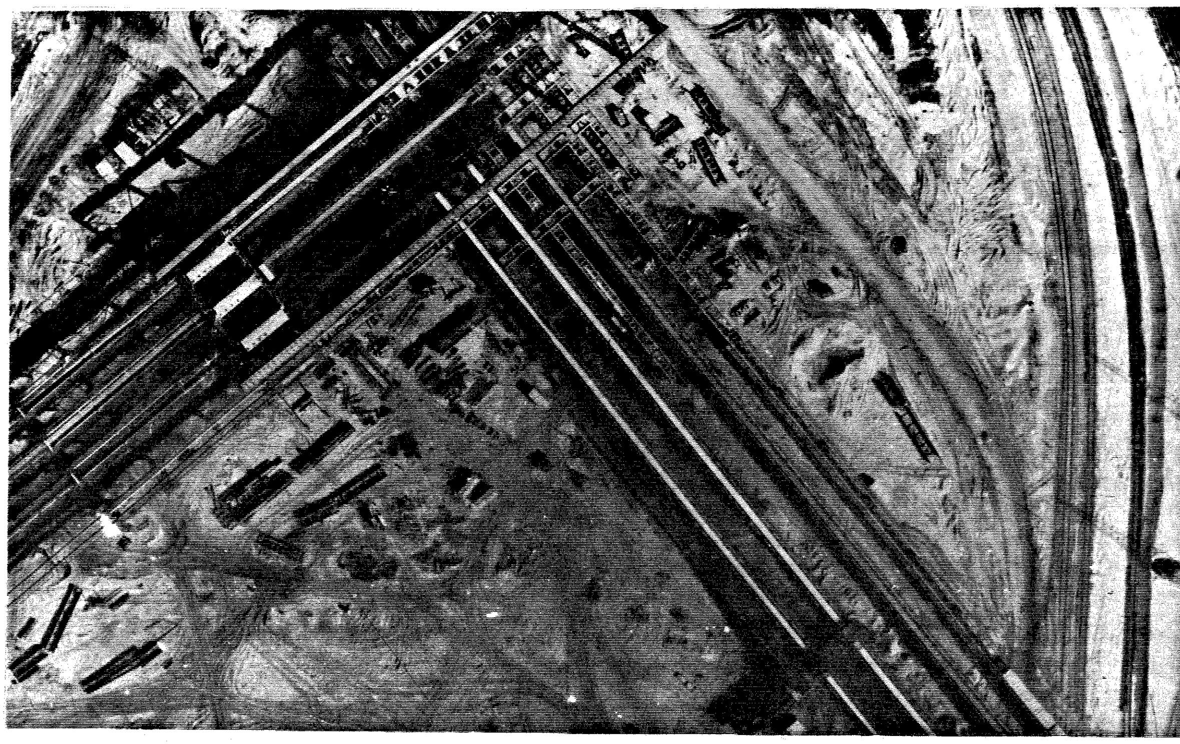

Fig. 2a

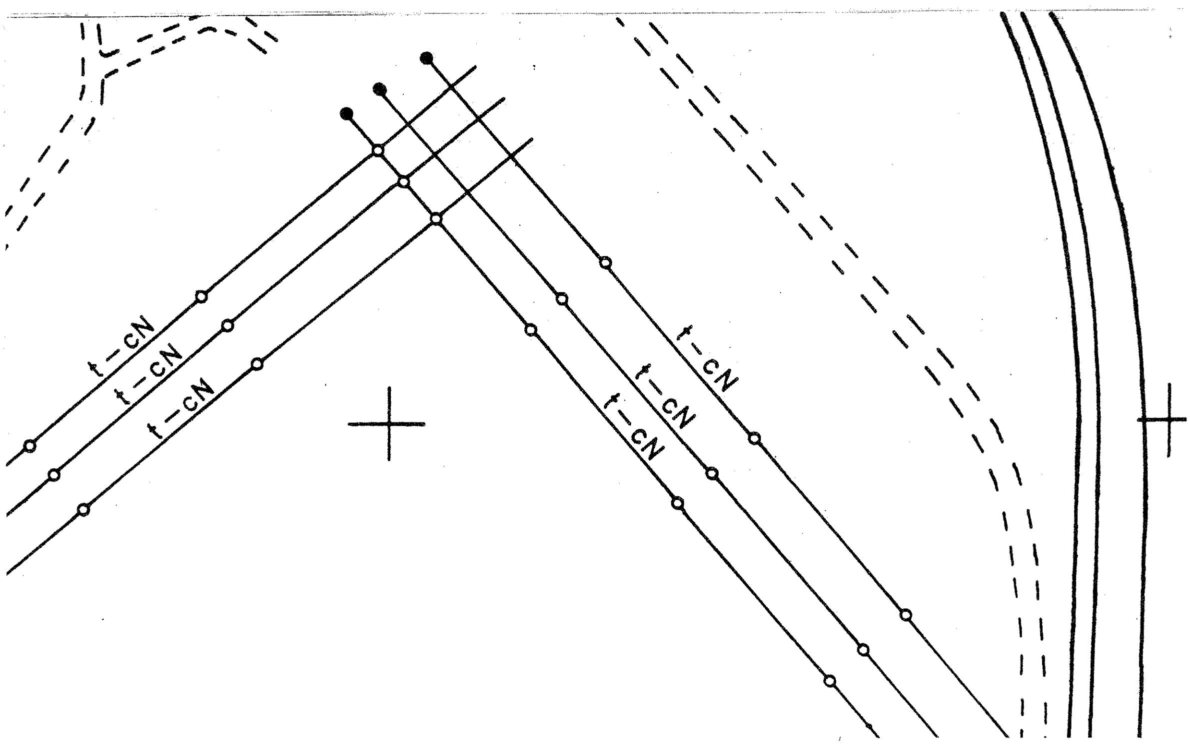

Fig. 2b

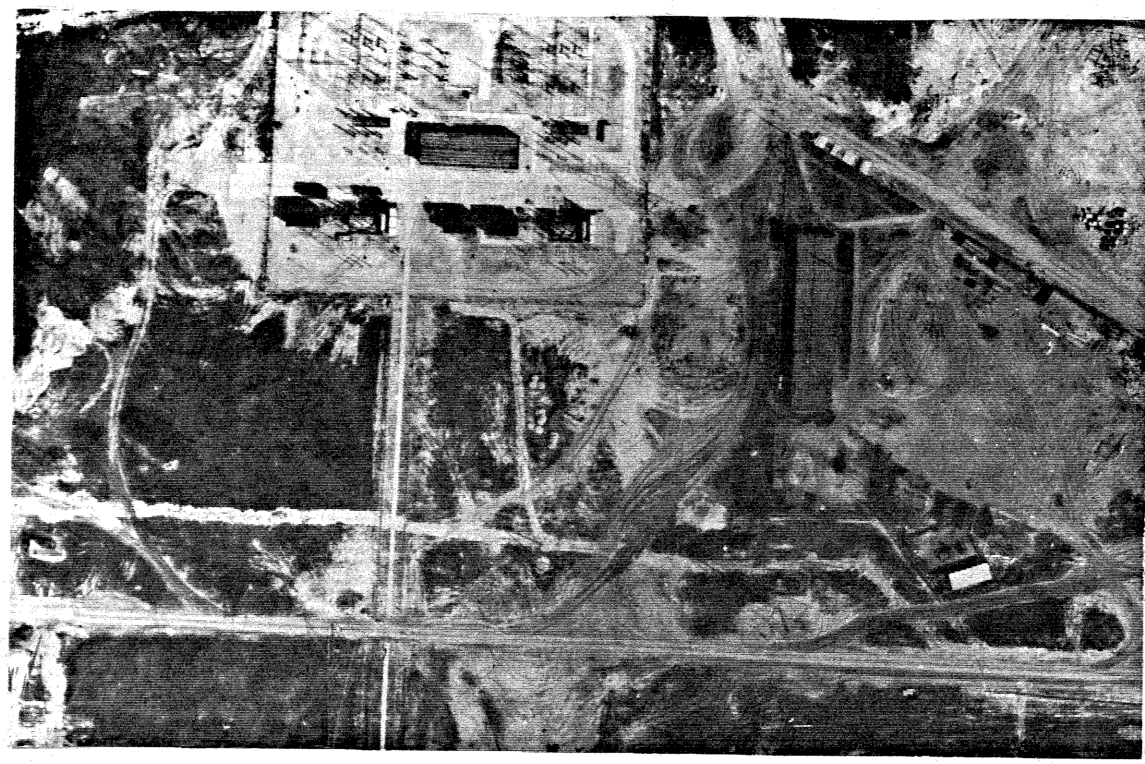

Fig. 3a

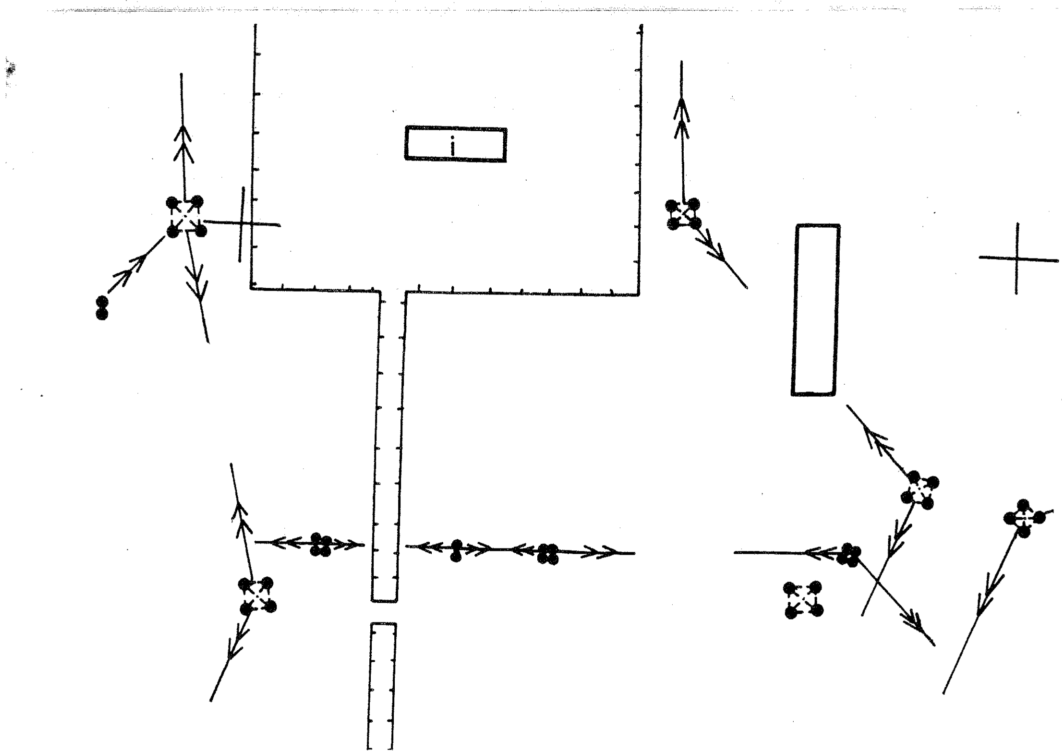

Fig. 3b

List of standard errors of coordinates
/in Y-direction/

A - orthophotomap
B - derivative map compiled from orthophotomap

TABLE 1

Indication	Objects	Number of points	Percentage of all points	Before transformation mm	
				A	B
1	2	3	4	5	6
1	Escarps	60	46,5	0,48	0,55
2	Routes	52	40,3	0,35	0,41
3	Ditches	12	9,3	0,42	0,49
4	Other	5	3,9	0,26	0,33
	Together	129	100,0	0,41	0,49

Indication	Objects	After transformation							
		Isometric mm		Helmert's mm		Affine I mm		Affine II mm	
		A	B	A	B	A	B	A	B
		7	8	9	10	11	12	13	14
1	Escarps	0,48	0,55	0,47	0,54	0,47	0,53	0,47	0,53
2	Routes	0,35	0,40	0,35	0,40	0,35	0,40	0,34	0,39
3	Ditches	0,42	0,49	0,41	0,48	0,41	0,48	0,41	0,48
4	Other	0,26	0,33	0,26	0,33	0,26	0,33	0,26	0,33
	Together	0,41	0,48	0,40	0,47	0,40	0,46	0,40	0,46

Of course it is a result of the technology applied. Both maps exceed the demanded accuracy tolerance /standard planimetric error should be less than $\pm$ 0,4 mm/, although the accuracy of only one coordinate was indicated. But we have to remember, that the presented standard errors are overestimated as we have assumed errorlessness of the reference map, what is certainly a simplication. Therefore, having in mind the rules of this analysis we should estimate the metric quality of both maps as satisfactory though on the border of demanded accuracy.
The same coordinate measurements were used in the quest of possible systematic errors. The following transformations were used for computations of new coordinates: a/ isometric, b/ two-dimensional conformal /Helmert's/ and two types of two-dimensional affine c/ and d/.
In general form these transformation can be writen as:

$$\begin{bmatrix} X \\ Y \end{bmatrix} = \begin{bmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \end{bmatrix} \cdot \begin{bmatrix} x \\ y \end{bmatrix} + \begin{bmatrix} Tx \\ Ty \end{bmatrix}$$

where: x,y - coordinates measured on the investigated map,
X,Y - coordinates measured on the reference map,
Tx,Ty - translation coefficients,
$a_{11} \ldots a_{22}$ - elements of the rotation matrix.

for a/ isometric transformation

$a_{11} = \cos\varphi$, $a_{12} = -\sin\varphi$, $a_{21} = \sin\varphi$, $a_{22} = \cos\varphi$

φ - rotation angle between the two coordinate systems

for b/ Helmert's transformation:

$a_{11} = k \cos\varphi$, $a_{12} = -k \sin\varphi$, $a_{21} = k \sin\varphi$, $a_{22} = k \cos\varphi$

k - scale factor

for c/ affine transformation I

$a_{11} = k_x\cos\varphi$, $a_{12} = -k\sin\varphi$, $a_{21} = k_y\sin\varphi$, $a_{22} = k_y\cos\varphi$

k_x, k_y - scale factors in x and y directions,

for d/ affine transformation II

a_{11}, a_{12}, a_{13}, a_{14} - line transformation factors.

The computations gave following results:

- rotation angle: from $0{,}0075^G$ to $0{,}0100^G$
- scale factor k: from 1,000290 to 1.000300
- scale factor k_x: from 0,999990 to 0,999996
- scale factor k_y: from 1,000305 to 1.000350
- component of translation Tx: from 0,1 mm to 0,15 mm
- component of translation Ty: from 0,3 mm to 0,4 mm.

All these values indicate, that the systematic errors do not exist in the analized maps /their values are within the limits of tolerance/. This is confirmed also by standard errors computed after coordinate transformations /columns 7-14, table1/, they differ only slightly from standard errors computed without any filtering.