2. Atlas of Slope Stability Maps of the Slovak Republic at Scale 1:50,000 – Its Results and Use in Practice

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Abstract. The article presents the main results of the geological project "Atlas of Slope Stability Maps SR at 1:50,000", consisting of maps, inventory sheets (passports) of slope deformations and the final report. The work provides accessibility to detailed regional analysis of slope deformations in Slovakia related to the territorial units of engineering geological regions and areas, geomorphological units and territorial administrative units (districts and regions). The article evaluates practical use of the Atlas and also indicates shortcomings, reflected especially in efforts to transform the area slope deformations shown in the Atlas of the topographic groundwork scale 1:50,000 to detailed scales (1:10,000 and more detailed).

Key words: Atlas of Slope Stability Maps of the Slovak Republic at 1:50,000, slope deformation, inventory of slope deformations.

2.1. Introduction

In the years 1997-2006 in Slovakia the geological project titled "Atlas of Slope Stability Maps SR at 1:50,000" (the Atlas, Šimeková, Martinčeková et al., 2006) was being completed. The project was funded by the Ministry of the Environment, the contractor company was INGEO-ighp Žilina, in cooperation with the Department of Geotechnics SF STU Bratislava, GEOKONZULT Košice, SGIDŠ Bratislava and the Department of Engineering Geology of FNS CU, Bratislava.

The objectives of the project were:

1. Registration of all slope deformation identified from archival materials and field mapping during the project solution at scale 1:50,000, according to an uniform methodology.

2. Creation of data sheet (passport) of each slope deformation, comprising a total of 28 columns with data on territorial integration, exploration, slope deformation characteristics, endangered objects and reasons for generation of slide and existence/absence of remedial measures.

3. Outlining the areas susceptible to slope movement generation in each map sheet.

4. Processing of supplementary maps of small scale to each map sheet (Layout of registered slope deformations, Regional engineering geological division of the territory, Geomorphological division of the territory, Regional engineering geological investigation).

5. Digitization of maps in GIS.

6. Submission of final report.

The methodology was tailor-made and adjusted for the purposes of the project in cooperation among the Principal Investigator, experts from the Faculty of Civil Engineering, Slovak University of Technology, Bratislava (†Assoc. Prof. Malgot, Prof. Baliak) and other professionals involved in the project solution. The final adjustment was based on the knowledge gained from the simultaneous compilation of the pilot map sheets.

The final processing of the geological task resulted in brand new analysis of the occurrence and frequency of slope deformations, and their essential attributes according to geomorphological, engineering geological and administrative division of the territory of the Slovak Republic, as well as the entire territory of the Slovak Republic.

2.2. Groundwork documents for the compilation of the Atlas of Slope Stability Maps SR at scale 1:50,000

The compilation of the Atlas had been preceded by several geological projects focused on, among others, the mapping and registration of landslides and other slope deformations, which represented the input materials for documentation of slope deformations and development of their databases in the Atlas. These included the following documents:

- Results of previous inventories of landslides carried out in three stages (Tab. 2. 1), which were processed in the Landslides register of Geofond.
- Thematic engineering geological maps of scales 1:10,000, 1:25,000, 1:50,000 (multipurpose maps of engineering geological conditions, engineering geological zoning maps, special maps of slope deformations and territory susceptibility to landsliding).
- Geological maps of scales 1:50,000, 1:25,000.
- Passportization of slope deformations in relation to road and rail network and major routes of pipelines of Central Slovakia Region and selected districts of the East Slovakia Region.
- Map documents with data on slope deformations, developed in the scope of geological exploration tasks

Tab. 2.1 Stages of previous inventory of slope deformations

Inventory stage	Period	Provider	Output document	Territory
1st	1962-1964	GIDŠ Bratislava, FCE STU Bratislava, FNS CU Bratislava, ÚÚG Prague	Depiction of landslide contours in map 1:25,000; description on punch cards	Endangered areas along communications and in the vicinity of municipalities
2nd	1974-1978	Department of Geotechnics FCE STU Bratislava	Depiction of landslide contours in map 1:25,000; Monograph (Nemčok, 1982)	High mountain areas, selected areas in flysch and volcanic regions and intramountain depressions
3rd	1981-1988	GIDŠ Bratislava	Depiction of landslide contours in map 1:10,000; inventory sheets designed for computer processing	Flysch regions, volcanic mountains, intramountain depressions

for civil engineering structures, for evaluation and optimal selection of alternative sites and routes.

• Results of engineering surveys of investigated landslides.

In the process of inventory covering different periods, performed by different organizations and authors, the map documents often lacked correlation and acceptance of the results of previous surveys and inventories. This resulted in numerous ambiguous multiple registration of the same slope deformations, at the same time with different interpretation of their borders and characteristics, including the slope deformation type and activity.

The goal of the Atlas was processing and synthesis of existing data obtained from source documents, coherent assessment of disturbed areas, validation of insufficient or contradictory data on slope deformations taken from archival materials. Approximate reconnaissance of unexplored territory in order to detect dangerous slope deformations, posing a threat to the population and existing engineering works was carried out. The project didn't solve a more detailed mapping of unexplored areas nationwide.

2.3. Brief presentation of the Atlas of Slope Stability Maps of the SR at scale 1:50,000

2.3.1. Slope stability zoning maps

Slope stability zoning maps are the most significant results of the project. They were compiled separately for each map of the layout 1:50,000 (in total 132 map sheets) and then "welded" (Fig. 2.1, Fig. 2.2). In order to make the results accessible for the public the slope deformations have been visualized on the map server SGIDŠ (http://mapserver. geology.sk/ zosuvy/).

Each slope failure in the map is marked with digit and contours or point mark (slope deformations of less than 50 m). Estimated slope deformations activity is expressed in color and type of slope failures shows hatch (Fig. 2.3). A simplified classification by Nemčok - Pašek - Rybář (1974) was adopted.

Components of each map sheet 1: 50,000 are also additional maps at scale 1:250,000 (Fig. 2.2), which in transparent manner indicate a complementary information – location of map sheet in the Slovak Republic map layout, distribution of registered slope failures in the respective map sheet, territory geomorphological subdivision, regional engineering geological division of the territory and existing engineering geological maps of regional character.

Territory susceptibility to slope movements generation is expressed in maps dividing the territory into three color-coded zones using heuristic method:

- Zone of unstable area (red area)
- Zone of potentially unstable area (yellow area)
- Zone of stable area (green area).

The main zoning criterion is the stability of slopes defined as the resistance of the geological environment on slopes to form a gravitational deformation, or territory susceptibility to the development of slope deformations.

2.3.2. Inventory sheets (passports) of slope deformations

For each slope deformation registered in the Atlas, an inventory sheet so called passport was drawn. The passport provides more-detailed information about the respective slope deformation (Fig. 2.4). Source information on a slope deformation was retrieved from the old inventories (Baliak et al., 2014) of landslides stored in Geofond. For those slope deformations, which were not registered in the Geofond, or the information in the registry was inadequate or questionable, the data were obtained by study of other existing archival materials and additional field mapping.

The passport of a slope failure includes: serial number of slope failure (column 1), territory administrative division (district, geomorphological unit, engineering geological region, columns 2-4), data on exploration and visualization scale (columns 5-8), slope deformation description (columns 9-14), slope failure dimensions (columns 15-18), endangered objects (columns 19-25), causes of slope failure generation (columns 26-27) and corrective measures (column 28).

Statistical processing of an extensive set of data contained in individual passports of slope deformations provided groundwork for comprehensive analysis of the project results.

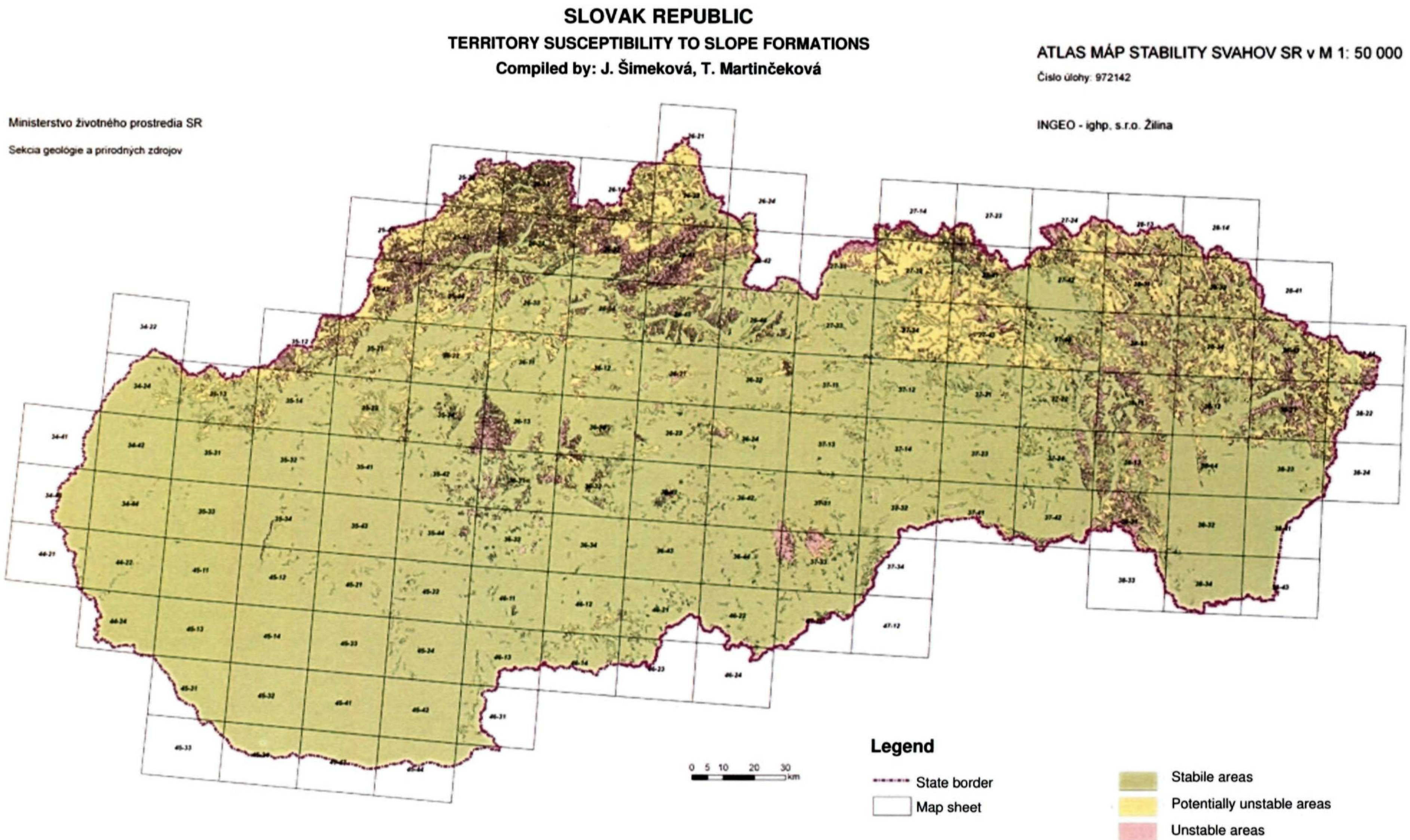

Fig. 2.1 Landslide susceptibility map of the SR with depiction of map sheet layout at scale 1:50,000 (The map is available in Slovak at the Map Server of SGIDŠ)

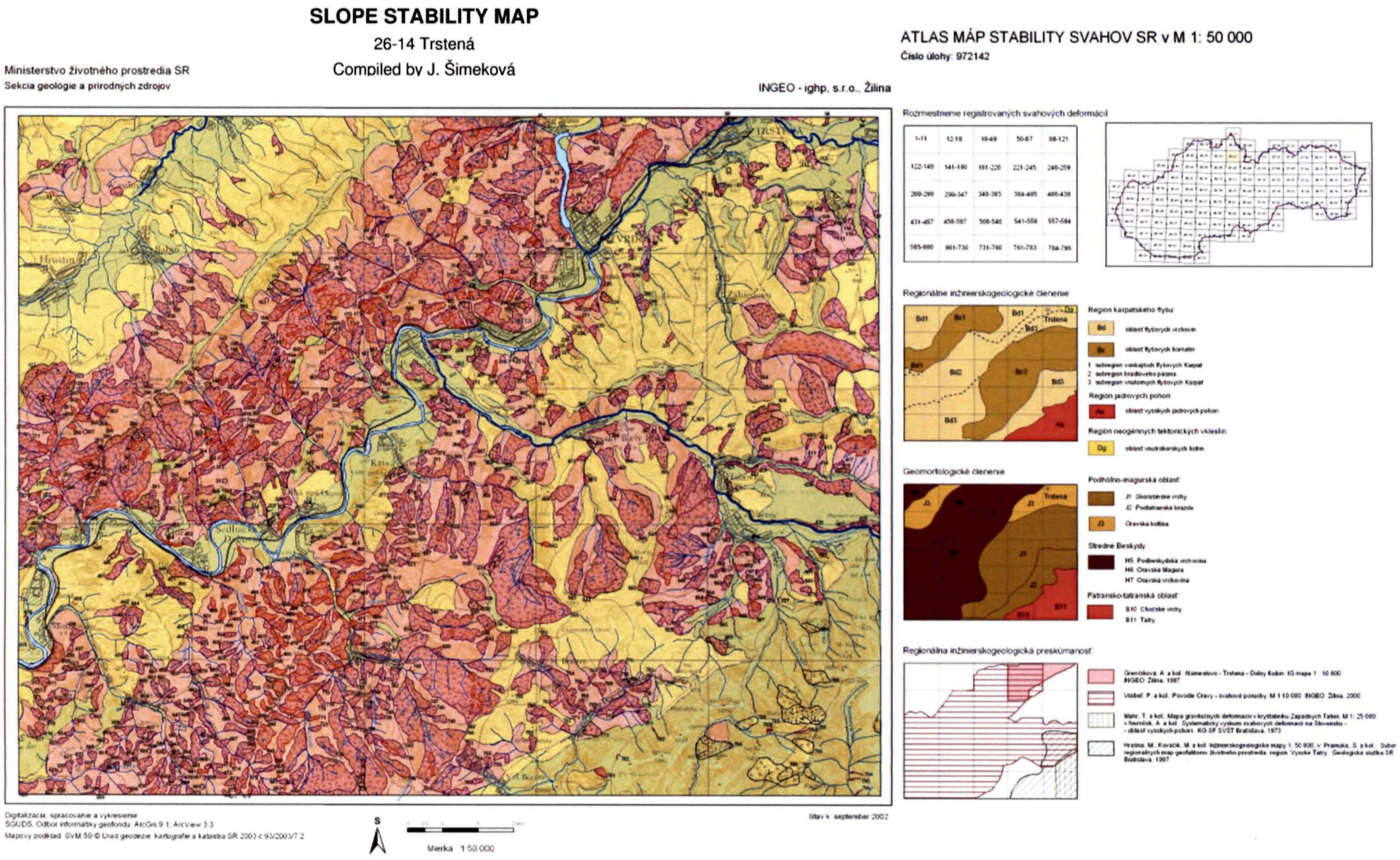

Fig. 2.2 Example of slope stability zoning map, map sheet 26-41 Trstená (to the right are complementary maps of small scale)

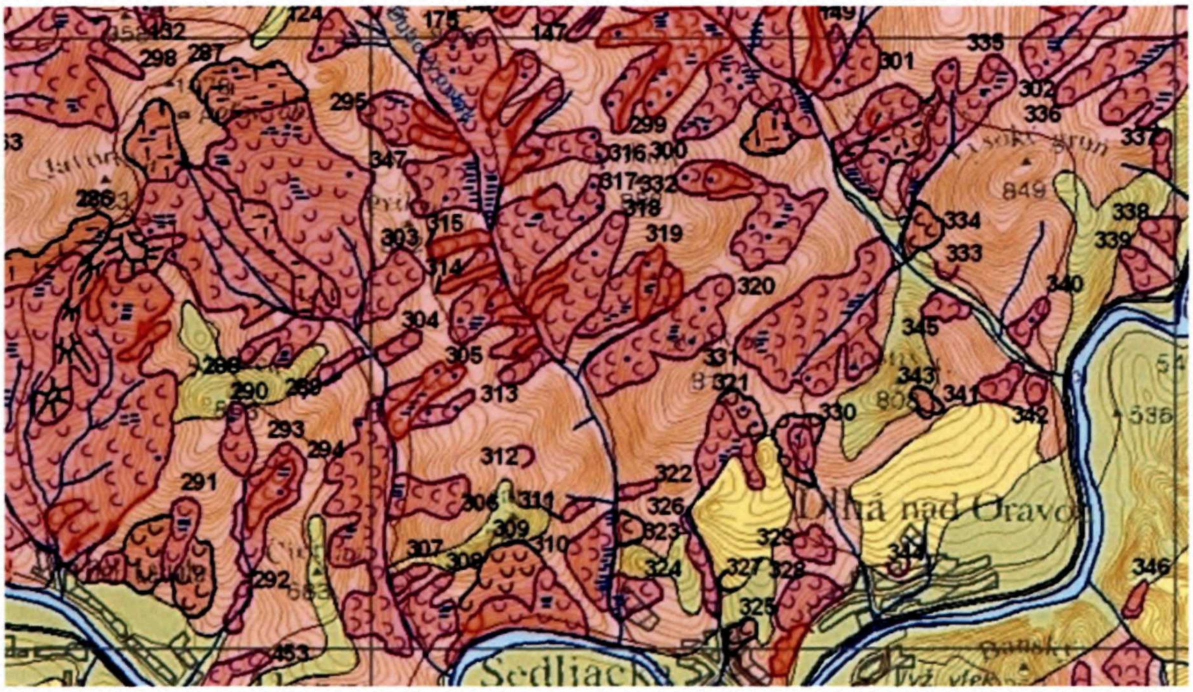

Fig. 2.3 Detail of the map sheet 26-41 Trstená

2.3.3. Statistical processing of data on slope deformations registered in the Atlas

2.3.3.1. Slope deformations occurrence

In the scope of the Atlas of Slope Stability Maps SR at 1:50,000, **21,190 slope deformations** were registered by the end of the project in 2006. Of the total number of slope deformations registered in the Atlas:

- 13,012 (61.4%) slope deformations were retrieved from archival documents without their field validation;
- Due to nonconformity of archival documents, 6,076 (28.7%) slope deformations were validated in the field (determination of the type, extent, activity, additional data on the endangered objects, etc.);
- 2,102 (9.9%) slope deformations were discovered and registered in the scope of the field work. Most of them were randomly identified during field reconnaissance of the archived landslides, in rare cases they were detected by targeted mapping of the territories with potential threats to infrastructure based on various indications, e.g. topographic studies.

The number of registered slope deformations gives only indication of the overall territory of Slovakia affected by slope failures. The actual number of slope deformations is significantly higher. Due to the output scale maps 1:50,000 it was often necessary to combine complex and interlinked slope deformations in intensively disturbed areas. Thus, such clusters of individual failures were recorded under one label.

Fair idea of the territory of Slovakia affected by slope failures gives Table 2.2; the final figure of the Atlas equals to 257,591.2 ha, representing **5.25% of the total land area of the Slovak Republic**. For comparison, in the scope of the former registration, which preceded the compilation of the Atlas, there were estimated 9,194 slope deformations in Slovakia affecting 3.06% of the total territory (Nemčok, 1982).

From the data in Tab. 2.2, which outlines the land-use of affected areas (built-up areas, playgrounds, cemeteries), it indicates that agricultural and forest lands are disturbed about equally (50.6% and 46.7%). The share of the other lands amounts to mere 2.7%. Some areas of agricultural land disturbed by slope failures have been abandoned because of difficult farming conditions, and are now overgrown with wild grassy, bushy or forest stands. This is confirmed by the results of the analysis by Liščák et al., (2009), according to which directly affected by slope failures are 120,855 ha of the forest stands (the analysis was based on Corine Land Cover 2000 input data).

Tab. 2.2 Acreage of area disturbed by slope failures (Šimeková, Martinčeková et al., 2006)

Acreage	Acreage in total	Acreage of slope failures	Disturbance by slope failures [%]	
	[ha]	[ha]	vs acreage in total	vs land use
Slovak Republic	4,903,347	257,591.2	5.25	-
Agricultural land use	2,436,876	130,289.9	2.66	50.6
Forest land use	2,004,100	120,243.3	2.45	46.7
Other land use	462,371	7,058.1	0.14	2.7

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Label	District	Geomorphologic unit	Engineering geological area	Investigation Level				Slope failure type	Activity	Bedrock	Geological complex	Hydrogeol. cond.	Slope angle (°)	Acreage				Endangered objects							Causes		Corrective measures
																		Roads			Buildings		Eng. Netw.				
				Geofond - Landslides register (Nr.)	Geofond - report (Nr.)	Present state	Scale							In total (ha)	Agricultural land (ha)	Forest (ha)	Other landuse (ha)	Motorway and Ist class (m)	II. and III. class (m)	Railway (m)	Housing estates (number)	Others (number)	Above ground (m)	Underground (m)	Natural	Anthropogenic	
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
267	DK	H6	Bc1	-	83646	-	B	Z	P	Pg	ZF	S	13	1,2		1,2									KE		N
268	DK	H6	Bc1	x	83646	-	B	Z	A	Pg	ZF	P	17	3,5	1,5	2,0									WE		N
269	DK	H6	Bc1	-	83646+	-	B	Z	P	Pg	ZF	P	12	3,5		3,5			200				150		KE		K
270	DK	H6	Bc1	56372	83646	-	B	Z	P	Pg	ZF	P	13	24,2	4,0	20,2			300						KE		N
				54385	58280+				A	Pg	Z	Z	13	4,4		4,4									K		N
271	DK	H7	Bd1	54385	83646	-	B	Z	P	Pg	ZF	P	13	10,0	3,0	7,0									KE		N
					46025+				A	Pg	Z	Z	14	5,2	2,0	3,2									KE		N
272	DK	H7	Bd1	54385	83646+	-	B	Z	P	Pg	ZF	Z	11	11,7		11,7									KE		N
273	DK	H7	Bd2	54384	83646+	-	B	Z	P	K	ZF	Z	13	7,6		7,6									KE		N
274	DK	H7	Bd2	54384	83646+	-	B	Z	P	KJ	ZS	P	12	13,3		13,3									KE		N
275	DK	H7	Bd2	-	83646	-	B	Z	P	JPg	ZF	Z	18	9,9		9,9									KE		N
									A	Pg	Z	Z	11	2,3		2,3									KE		N
276	DK	H7	Bd2	-	83646	-	B	Z	P	K	ZF	P	15	5,4		5,4									KE		N
								P	A	K	Z	P	13	0,8		0,8									KW		N
277	DK	H7	Bd2	54383	83646	-	B	Z	P	Pg	ZF	Z	18	5,1		5,1									KE		N
					46025				A	Pg	Z	Z	13	1,6		1,6									KE		N
					58280			P	P	Pg	ZF	Z	17	2,0		2,0									KE		N
278	DK	H7	Bd2	54382	83646	-	B	Z	P	Pg	ZF	Z	15	11,5	3,0	8,5									KE		N
					46025+				A	Pg	Z	Z	16	0,9		0,9									KE		N
279	DK	H7	Bd2	54378	83646+	-	B	Z	P	K	F	P	15	56,2		56,2									KE		N
280	DK	H7	Bd2	-	83646	-	B	B	S	Pg	F	S		21,4	6,4	15,0									P		N
281	DK	H7	Bd1	54417	83646	-	B	Z	P	Pg	F	P	11	66,0	46,0	20,0			550		7	1	900		WE		N
					58280+				A	Pg	Z	P	13	12,8	4,4	8,3	0,1		45						KW	GM	N
282	DK	H7	Bd2	51943	83646	-	B	L	P	Pg	F	P	17	7,4		7,4									PW		N
				54393	58280			Z	P	PgK	F	P	11	55,5	15,6	39,9			650		6	1			EW		N

Fig. 2.4 Passport of slope deformations 267-282 from the map sheet 26-412 Trstená

The sloping agricultural land areas are the most affected by landslides, or by their combinations with other types of slope deformations (about 90%). In the devastation of the forest land landslides are the most abundant (67.4%), but also important (32.6%) are slope deformations of the creep, fall and flow types. Other areas, particularly built-up areas (2.7%), are particularly susceptible to landslides. The areas above the tree line are dominantly susceptible to failures of the creep, fall and flow types.

Of the total number of registered slope deformations (21,190 units) 90.15% are landslides; other types of slope deformations account for less than 10%. In terms of the assessment of disturbed areas acreage (Fig. 2.5), which is more representative than the above account, the share of landslides is also significantly higher (78.12%) than block fields (15.31%) and other types of slope failures, including the combined ones (total 6.57%).

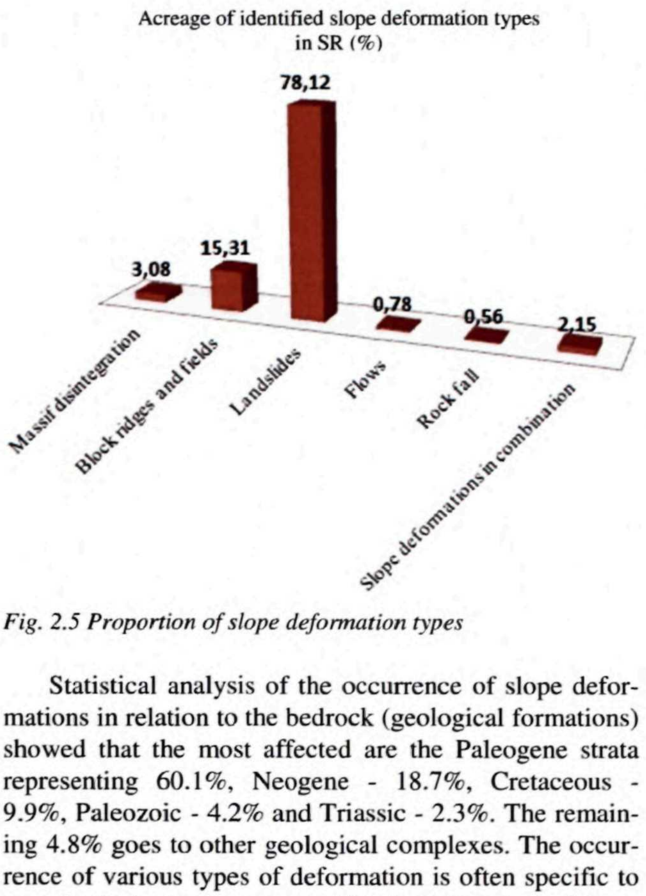

Fig. 2.5 Proportion of slope deformation types

Statistical analysis of the occurrence of slope deformations in relation to the bedrock (geological formations) showed that the most affected are the Paleogene strata representing 60.1%, Neogene - 18.7%, Cretaceous - 9.9%, Paleozoic - 4.2% and Triassic - 2.3%. The remaining 4.8% goes to other geological complexes. The occurrence of various types of deformation is often specific to a particular bedrock, or a combination of geological complexes, for example, disintegrating massif - Paleozoic (75.0%), block ridges - Neogene volcanites (68.0%), block fields – Neogene volcanites (61.2%), landslides - Paleogene (65.9%), debris flows - Paleozoic (55.6%), rock fall – Neogene volcanites (40.7%). For creep deformations of the block movements group, besides Neogene volcanites, typical is a combination of several complexes which are generally characterized by a favorable structure of rock complexes differing in strength properties. Most often combinations are: Triassic - Cretaceous, Neogene - Paleogene, less Jurassic - Cretaceous and Jurassic - Triassic.

The average angles of the slope deformation types are as follows: disintegrating massif - 26.7°, block fields - 15.2°, landslides - 13.3°, debris flows - 25.2°, rock fall - 27.6°. On the steepest slopes disintegrating massifs, flows and rock falls are frequently present. Artificial slopes affected by slope failures have an average slope of 21°. The landslides, which make up 90% of all slope deformations, have a mean inclination of 13.3°; to be more accurate 65.5% of landslides are formed on slopes of 7° to 17° (Kopecký et al., 2008).

2.3.3.2. Slope deformation distribution in the enginee ring geological regions and areas

The evolution and forms of slope movements have their own characteristics depending on the geological setting and geomorphological evolution. For the purpose of this assessment an engineering geological division of the territory of Slovakia according to Matula (Matula, Pašek, 1986) was adopted in the Atlas, which takes into account the criteria of geological structures uniformity and macro-relief. This division was later modified and updated by the authors Hrašna, Klukanová in the Atlas of Landscape SR (2002). The territory of Slovakia is divided into 4 engineering geological regions and 8 engineering geological areas as follows:

1. **A** – Region of Core Mountains:
   - **Aa** – Area of High Core Mountains
   - **Ab** – Area of Core Highlands
2. **B** – Region of Carpathian Flysch:
   - **Bc** – Area of Flysch Highlands
   - **Bd** – Area of Flysch Uplands
3. **C** – Region of Neogene Volcanites:
   - **Ce** – Area of Volcanic Highlands
   - **Cf** – Area of Volcanic Uplands
4. **D** – Region of Neotectonic Depressions:
   - **Dg** – Area of Inner-Carpathian Depressions
   - **Dh** – Area of Inner-Carpathian Lowlands

The Region of Carpathian Flysch (B) is dominated by various types of landslides. In the Region of Core Mountains (A) occur most frequently creep deformations of a character of massifs disintegration. In the Region of Neogene volcanites (C) deformations of block type are significant and in the Region of Neoectonic Depressions (D) landslides prevail over block deformations (Tables 2.3, 2.4, Figs. 2.6, 2.7).

In summary presentation of slope deformations acreage in various engineering geological areas (Tab. 2.5) the most disturbed is the Area of Flysch Uplands followed by areas of Volcanic Highlands and Flysch Highlands. In relation to the total area of the Slovak Republic the first place is occupied by the Area of Flysch Uplands followed by the areas of Volcanic Highlands and Inner-Carpathian Depressions.

2.3.3.3. Slope deformations distribution in territorial-administrative units (regions)

In terms of territorial-administrative division of the Slovak Republic (8 regions, 79 districts) relatively high-

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Tab. 2.3 Occurrence of the main types of slope deformations in the engineering geological regions and areas of Slovakia

EG Region	EG Area	Massif disintegration	Block ridges and fields	Landslides	Flows	Rock fall	Slope deformations in combination	Total EG Area	Total EG Region
		[ha]	[ha]	[ha]	[ha]	[ha]	[ha]	[ha]	[ha]
A	Aa	6,355.5	2,726.7	5,291.1	862.9	975.0	1,442.2	17,653.4	23,741.9
	Ab	1,301.1	579.5	3,934.1	9.8	75.5	188.6	6,088.5	
B	Bc	134.8	2,266.8	24,732.2	153.8	9.1	231.8	27,528.5	138,169.7
	Bd	25.3	2,150.4	105,956.2	568.7	1.3	1,939.3	110,641.2	
C	Ce	61.0	19,085.4	17,737.7	263.1	373.3	1,045.6	38,566.1	52,214.3
	Cf		10,311.4	3,167.3	14.7	13.2	14.6	13,648.2	
D	Dg	50.6	2,207.0	33,449.7	97.5	3.9	538.8	36,347.5	43,465.5
	Dh		113.1	6,969.7	35.2			7,118.0	
IN TOTAL		7,928.3	39,440.3	201,238.0	2,005.7	1,451.3	5,527.9	257,591.4	257,591.4

Tab. 2.4 Frequency and acreage of main types of slope deformations in the engineering geological regions of Slovakia

EG Region	Massif disintegration		Block ridges and fields		Landslides		Flows		Rock fall		Slope deformations in combination		TOTAL	
	No	area [ha]	No	area [ha]	No	area [ha]	No	area [ha]	No	area [ha]	No	area [ha]	No	area [ha]
A	114	7,656.6	88	3,306.2	1,260	9,225.2	672	872.7	84	1,050.5	41	1,630.8	2,259	23,741.9
B	5	160.1	147	4,417.2	12,624	130,688.4	156	722.5	4	10.4	28	2,171.1	12,964	138,169.7
C	6	61.0	518	29,396.8	1,708	20,905.0	46	277.8	61	386.5	22	1,187.2	2,361	52,214.3
D	3	50.6	51	2,320.1	3,513	40,419.4	34	132.7	3	3.9	4	538.8	3,608	43,465.5
TOTAL	128	7,928.3	804	39,440.3	19,105	201,238.0	908	2,005.7	152	1,451.3	95	5,527.9	21,192	257,591.4

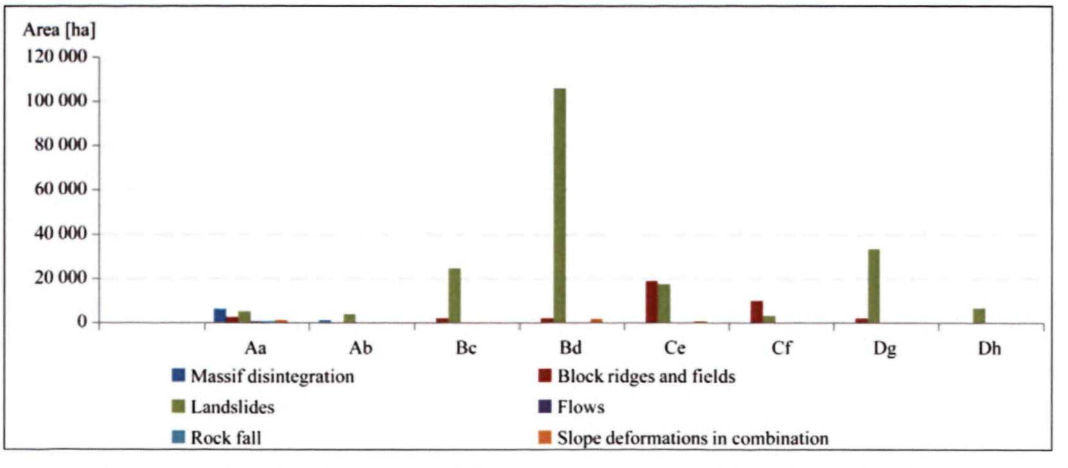

Fig. 2.6 Diagram of acreage of the main types of slope deformations in the engineering geological regions and areas of Slovakia

Tab. 2.5 Summary disturbance of engineering geological areas of Slovakia

EG Area	Share of EG Area in the area of SR	Acreage of EG Area disturbed by slope deformations		Share of slope deformations of EG Area in the area of SR	Share of slope deformations of EG Area to disturbed area of SR
	%	[km^2]	%	%	%
Aa	7.70	176.53	4.79	0.36	6.85
Ab	17.90	60.89	0,71	0.12	2.36
Bc	5.40	275.28	10,58	0.56	10.69
Bd	15.30	1,106.41	15.13	2.26	42.95
Ce	6.90	385.66	11.78	0.79	14.97
Cf	4.00	136.48	7.19	0.28	5.30
Dg	14.40	363.48	5.27	0.74	14.11
Dh	28.40	71.18	0.52	0.15	2.76
TOTAL	100.00	2,575.91		5.25	100.00

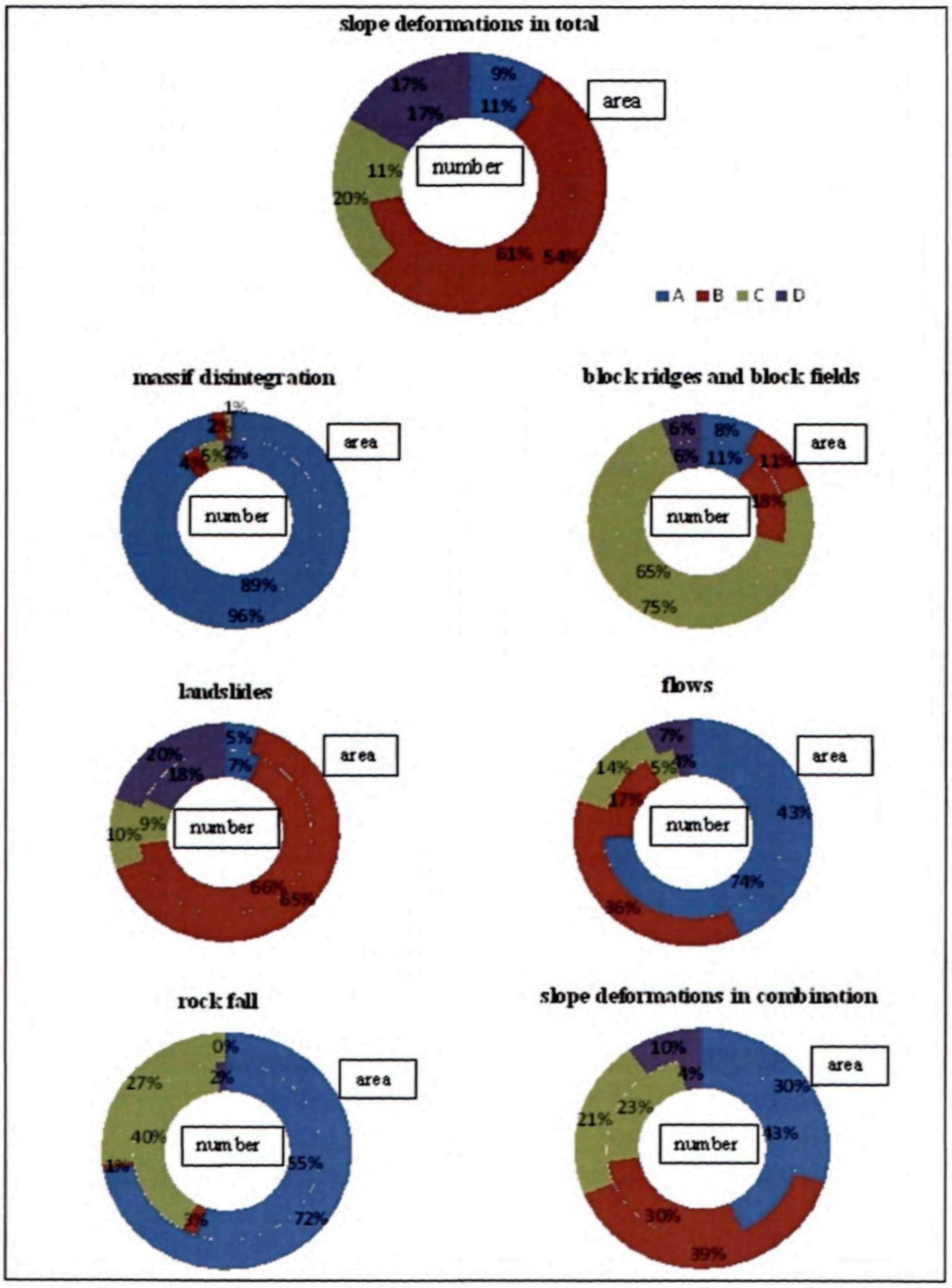

*Fig. 2.7 Frequency and acreage of the main types of slope deformations in the engineering geological regions of Slovakia in %. **Legend:** A - Region of Core Mountains, **B** - Region of Carpathian Flysch, **C** - Region of Neogene Volcanites, **D** - Region of Neotectonic Depressions*

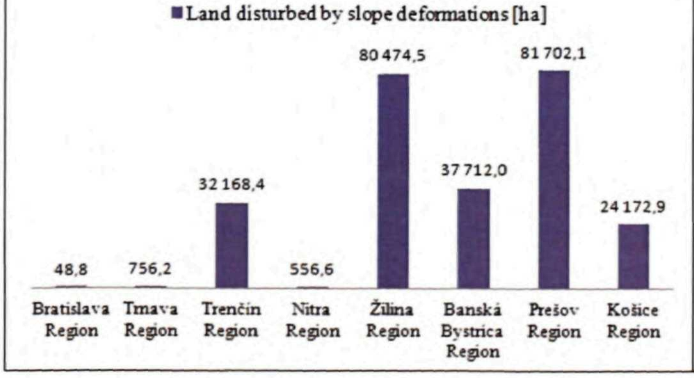

Fig. 2.8 Acreage of slope deformations in the regions of the Slovak Republic

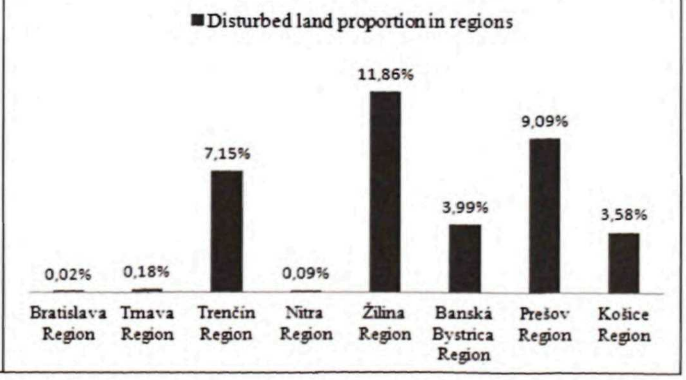

Fig. 2.9 Disturbance of the regions of the Slovak Republic by slope deformations in %

est disturbance by slope failures is documented in the Prešov region followed by Žilina and Banská Bystrica regions (Fig. 2.8).

In terms of percentage disturbance to the total area of the region, Žilina is the most affected region followed by Prešov and Trenčín regions (Fig. 2.9).

Bratislava, Nitra and Trnava regions are less affected by slope failures.

2.3.3.4. Threat for buildings and other objects

The high disturbance of the SR territory by landslides also implies a high extent of the threat to buildings and other structures (Tab. 2.6). The given data have to be considered as guidelines. In common, they were denominated from the basic topographic maps of scale 1:10,000, with the last update 10 to 20 years prior to the Atlas issuance. In numerical terms in the table are included the objects which had been damaged or set out of operation, as well as the objects that were stabilized by remediation works (during the construction of an object or as a result its emergency state).

Tab. 2.6 Objects jeopardized by slope deformations (Šimeková, Martinčeková et al, 2006)

Type of object	Extent
Buildings (housing estates and other buildings)	27,920 objects
Other structures (water-supply tanks, cemeteries, playgrounds, bridges and others)	600 objects
Sites with more than 50 objects endangered*	168 sites
Motorways and roads of the Ist class	98 816 m
Roads of the IInd and IIIrd classes	571,408 m
Railway	67,210 m
Above-ground engineering networks	1,116,056 m
Gas pipelines	101,180 m
Oil pipelines	3,500 m
Water pipelines	290,925 m

**endangered municipalities, urban suburbs, recreation and garden areas, which are fully or partially located in the territories affected by slope deformations*

The most frequently threatened other buildings include water-supply tanks (38.5%) and cemeteries (32%). Degree of threat to objects is dependent on several factors, but mainly on the type and activity of slope failure, its extent and depth course, relative position of an object threatened to a slope deformation, etc.

2.4. Application of the results of the Atlas of Slope Stability Maps SR at scale 1:50,000 in practice

Given that Atlas is the first complete digital map depicting slope deformation throughout the territory of the Slovak Republic, freely available on the Internet through the map server SGIDŠ (http:// mapserver.geology.sk/zosuvy/), it has been often used for various purposes. During almost one decade of its use there have been identified a number of shortcomings and examples of its misuse for the purposes of which the map scale and the related generalization of landslide areas has not been intended. The insufficient scale of the Atlas is evident especially in experiments, or efforts extrapolating the landslide area in the Atlas into documents of larger scales, e.g. in the development of spatial plans and the evaluation of specific building sites.

The deficiencies of the Atlas of Slope Stability Maps SR at 1:50,000 can be divided into several groups.

1. Deficiencies arising from the scale:

- generalization and distortion of mapped boundaries of slope deformations during the transformation of the detailed documentation for the scale 1:50,000 (Fig. 2.10a, b, c, d);
- joining together (welding) of composite disturbed areas and landslides directly interlinked or lying in close proximity and their registration as single slope failure (one label) (Fig. 2.10e, f);
- visualisation of smaller slope deformations (with dimensions <250 m) only by icons (e.g., Fig. 2.10e, f - landslide Nr 216);
- inequalities (distortion) among topographic documents of different scales.

2. Deficiencies arising from the lack of nation-wide mapping:

- we can not exclude the existence of previously unregistered slope deformations, even in relatively stable areas (green areas in the zoning map).

3. Deficiencies arising from the aging of map documents (completion in 2006):

- there is no systematic update of the status on newly registered, newly formed and reactivated slope deformations (e.g. in 2010 after massive activation of landslides, especially in eastern Slovakia, SGIDŠ registered 551 new active slope failures using precise GNSS measurements (Liščák et al. 2010).

4. Deficiencies resulting from inaccuracies of the source documents:

Objective errors:

- field mapping performed only by validating the facts with available topographic document of appropriate scale (usually 1:10,000), without accurate registration of contours and morphological elements of slope deformations by modern geodetic GPS devices;
- inaccurate or outdated topographical maps used in the course of mapping work;
- slope deformations without significant morphological manifestations facilitating their unambiguous identification and delineation (disguised by secondary modeling through erosion-denudation and weathering processes or anthropogenic activity - agriculture, construction activities);
- vegetation cover during the field mapping (dense vegetation, growing wild and lush vegetation, incapacitating especially in summer and spring seasons motion of mapping staff and veiled morphological shapes of slope deformations);

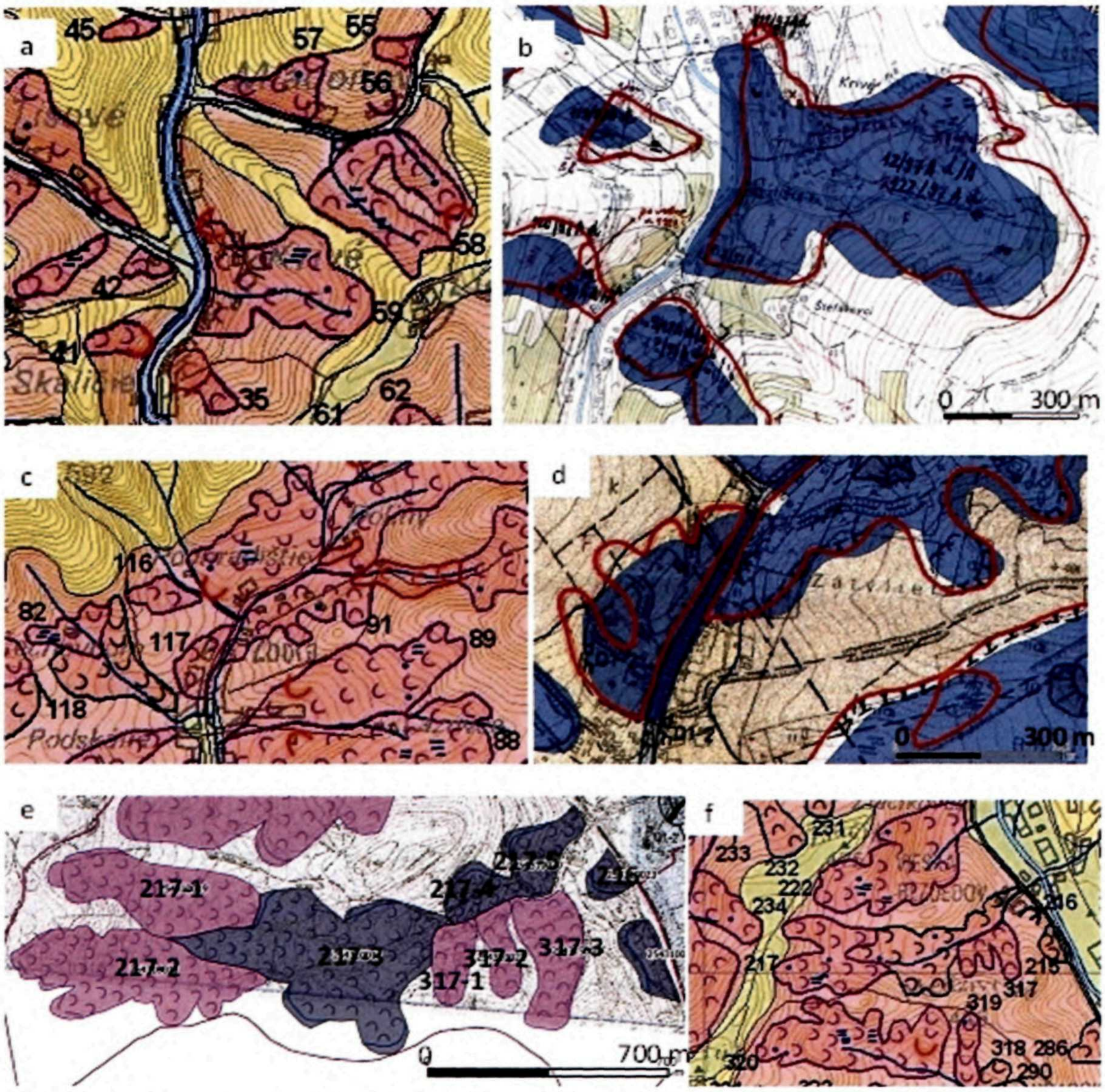

Fig. 2.10 Depiction of deficiencies of the Slope Stability Atlas SR 1:50,000 due to map scale
Explanations: a, c, f - detail from Atlas' zoning map; b, d - detail from working groundwork map Atlas' at scale 1:10,000, with highlighted landslides boundaries (red line) and area in colour, representing landslides areas transformed from Atlas into opography ZM 10; e - complex sliding area with 8 partial landslides (217 - 1 to 5, 317 - 1 to 3) mapped on topography at scale 1:10,000 and f - its final depiction in the Atlas at scale 1:50,000 (landslides 217 and 317)

• inaccessibility of the terrain in terms of build-up land or other land use (fenced private facilities, military facilities, etc.).

Subjective errors:

• inaccurate mapping and incorrect information due to lack of experience and knowledge of the mapping geologist;

• inaccurate and incorrect mapping information due to inconsistency of the mapping geologists;

• subjective approach of a mapping geologist in harder identifiable slope failures;

• miscalculation of distance.

Despite the above outlined shortages the Atlas of Slope Stability Maps SR at scale 1:50,000 has many advantages and benefits:

• The Atlas of Slope Stability Maps of the SR is a single clear map series, processed in digital form in a GIS environment, showing the occurrence of slope deformations, distinguished by type and activity throughout the territory of the Slovak Republic. This work can be continuously updated, refined and used in practice.

• For each slope failure registered in the Atlas a passport (database) of a slope failure was drawn with its detailed characteristics, territorial-administrative affiliation, level of investigation, figures on geometric characteristics and objects at risk, and eventual corrective measures, which form the basis of extensive statistical file.

• The data on level of investigation listed in passports of slope failures include a link to the source map documents provided they are available. Most of these documents are available at Geofond SGIDŠ Bratislava. Previous multiple registrations of the same landslide area led to a variety of records with different interpretations. Provided, they were not validated in the scope of the

Atlas field work, the most preferred records were those with a more detailed scale mapping and actual time-date).

• Compilation of the Atlas supplemented existing Landslides Register of Geofond on new slope deformations. Contradictory data on slope deformations produced during the previous multiple registrations were eliminated.

• Newly registered, validated in the field and spatially corrected slope deformations of the Atlas were plotted on the primary working topographic maps at scale 1:10,000.

• All figures in the passports (acreage of slope deformation, the extent of endangered objects) were derived from existing documents or detailed working maps of the input documentation of the Atlas.

As was already mentioned the usefulness of the output maps of the Atlas is partially limited due to the used scale 1:50,000. The Atlas is suitable for the following applications:

• As a primary source of information on the occurrence of landslides in the area of interest in various geological projects and land use planning;

• For the indicative assessment of major investment plans, for example, assessment of variant communications routes, water works and other constructions (in the stage of engineering geological study and preliminary engineering geological survey);

• As basis for assessing the suitability of the construction area for structures foundation, or other land use on a wider scale and its optimization;

• For designing engineering works at the stages of technical study, environmental impact assessment and documentation of building plan.

The Atlas is conditionally suitable only as a primary source of information - study of more detailed documents, or the assessment of the territory by a professional geologist is necessary. The input map should not be superior to specific approach of the professional geologist in the territory assessed:

• For the formulation of the statements of the Ministry of Environment of the SR in compilation of land-use planning documentation from the viewpoint of geological hazards;

• For the creation of spatial plans in medium and small scales;

• For physical and legal entities when buying land;

• For building committees of local authorities in building proceedings and issuing a building permit;

• For the need of insurance companies in terms of property insurance.

2.5. Conclusions

The Atlas of Slope Stability Maps of the SR at 1:50,000 presents an overview of digital map developed by unified methodology for the whole territory of the Slovak Republic. In the scope of this work there were registered 21,190 slope deformation of the total area of 257,591.2 ha, which constitutes 5.25% of the total area of Slovakia.

The majority of the registered slope deformations belong to the group of potential sliding activity. In some regions of Slovakia (mainly the flysch areas of north-western and eastern Slovakia - Region of Carpathian Flysch, but also in the territories made of volcanic rocks in the central and eastern part of Slovakia - Region of Neogene Volcanites) the share of affected land is often greater than 10%. In terms of territorial-administrative division of Slovakia, dominantly affected are the Žilina and Prešov regions. This aspect is reflected in the high number of endangered objects, number of emergency situations due to activation of slope movements and considerable financial resources expended for corrective measures.

The Atlas provides a wide range of uses, however, with certain limitations. The most important issues are too small scale 1:50,000 and related incompatibility of the used topography ZM-50 with topography of larger scales, causing relatively large distortions in the transformation of slope deformations boundaries from the Atlas into more detailed map documents.

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