

A classification schema for structural landforms of the Moldavian platform (Romania)

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Abstract—The Moldavian platform (Romania) is dominated by a repetitive pattern of structural landforms, controlled by the monoclinical structure of the sedimentary cover. A supervised landform classification schema, is applied to an SRTM digital elevation model (DEM) to classify these cuesta type landforms (especially cuesta scarps and dip slopes). This issue is important for practical and theoretical geomorphological study of the area. Errors are evaluated and aspects which can improve the classification results are discussed.

I. INTRODUCTION

The Moldavian platform is a geological area east of the Carpathian Mountains (Fig. 1). This geological area, covers the physico-geographical areas of Moldavian tableland and of Moldavian Subcarpathians. The geological structure of the sedimentary cover of the platform is monoclinical, with strata inclined from NNW to SSE at 8-12 m/km and from W to E at 4 m/km [1][2]. The lithology is dominated by clays, marls, sandstones and oolitic limestones [2].

Considering the lithology, structure and paleogeomorphological evolution of the area, the landform system is characterized by structural landforms: cuestas and structural valleys. From this point of view it is of practical and theoretical value to apply a landform classification schema, that could automatically classify cuesta type landforms. The structural landforms are intensively dissected by fluvial erosion.

II. SEMANTIC MODELLING OF CUESTA LANDFORMS

In general, the main aspects of the cuesta type landforms are asymmetry [3], [4] and monoclinical shifting [5]. Asymmetry applies both to valleys and interflues. From this point of view, this should be the base of the landform classification. But because these valleys and interflues have hillslopes in common, a good approach is to divide the landform into catena generic

types: ridges, hillslopes and valley bottoms (could also be named floodplains, which include high order channels). Then the hillslopes, can be divided into cuesta scarps (steep hillslopes corresponding to the up-dip of the strata) and cuesta dip slopes (gentle hillslopes corresponding to the dip of the strata). As a function of the relation between direction of flow and of dip, valleys, valleys bottoms and channels can be consequent (direction of flow the same as dip of strata), subsequent (direction of flow approximately orthogonal to the direction of strata dip) or obsequent (the direction of flow is opposite to the direction of dip).

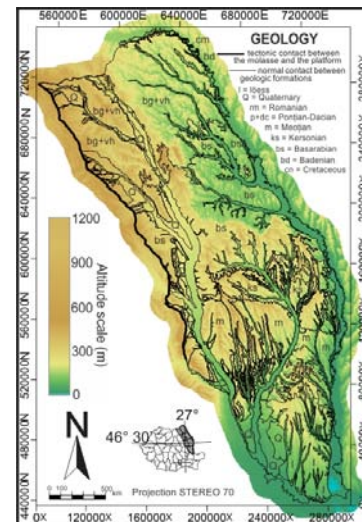


Figure 1 Position and geology of the Moldavian platform (a 600 dpi image is available at <http://www.geomorphologyonline.com/CM.jpg>)

In the Moldavian platform, because of the double inclination of the sedimentary cover, in the cuesta type landforms, [1]

described a double order asymmetry. The first order asymmetry is related to the NNW-SSE inclination, after which:

- N oriented hillslopes are cuesta scarps and are right slopes of subsequent valleys;
- S oriented hillslopes are cuesta dip slopes and are left slopes of subsequent valleys.

The slopes of consequent and obsequent valleys are sculptural landforms on cuesta scarps or dip slopes.

Second order asymmetry is related to the W-E inclination and generates cuesta scarps facing W and cuesta dip slopes facing E: these are on the right and left, respectively, of consequent and obsequent valleys. These aspects provide the semantic component in a priori semantic modeling [6], before our supervised landform classification. The geometric/geomorphometric thresholds are indicated in section III.C.

III. MATERIAL AND METHODS

A. Study area

The study area covers the East European Platform geological zone (delineated using geological maps at 1:200,000 scale) and a buffer zone of 10 km, which was used for the computation of the geomorphometric variables. Quaternary terraces, located only on the valley slopes above floodplains of the major rivers of the area (Siret, Suceava, Moldova, Bârlad), are unrelated to the structural topography. Therefore the terraces were delineated and excluded them from the classification (code Q in Fig. 1). The final conclusions relate only to the initial geological delineation of the area, with the terraces masked.

B. Digital elevation model and geomorphometrical variables

Earth surface altitude in the study area was represented by the SRTM DEM, re-projected to the official projection of Romania (Stereo 70 with the EPSG code 3844). To provide and appropriate resolution for cuesta analysis, the DEM was re-sampled to a cell size of 30 m. We consider that this procedure is equivalent to a median filtering of the digital elevation model, giving a smooth surface and reducing the error generated by the vegetation and man-made features.

The geomorphometric variables were computed using SAGA GIS v. 2.0.6 and Tnt Mips v. 7.3. Slope and aspect were computed using the 2FD algorithm [7-8], implemented with SML in Tnt Mips. Total catchment area (TCA) was computed using the D8 flow algorithm implemented in Tnt Mips. Normalized height was computed with SAGA GIS (Terrain Analysis – Morphometry – Relative Heights and Slope Positions), and focal mean and standard deviation in a 3x3

moving window, were computed with the Tnt Mips SML scripting language.

C. Landform classification schema

The landform classification flowchart is represented in Fig. 2. The classification is realized in four steps as a supervised classification [9].

In the first step, a channel network is extracted using Tnt Mips (Process/Raster/Elevation/Watershed procedure). Using a depression-filled digital elevation model, this procedure applies a D8 flow routing algorithm to obtain flow direction and flow accumulation.

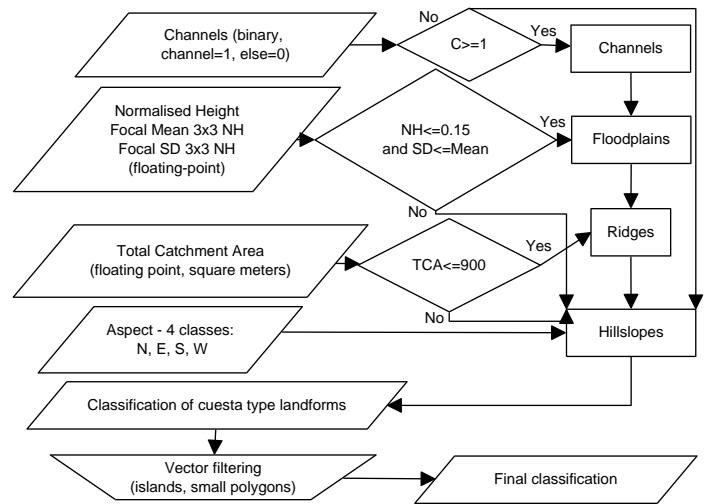


Figure 2 Flowchart of the landform classification procedure

Using user-supplied thresholds, the program then traces flow channels and basins. Thresholds are set for outlet, inlet, branch and basin parameters. Inlet specifies the value of flow accumulation from which a flow route starts, but for such a route to be traced the branch criteria must be fulfilled. Outlet and branch are parameters used for basin delineation. After several exploratory runs we used as thresholds the values of 0.45 km² for inlet and 0.9 km² for branch.

In the second step, a catena classification is performed using as inputs TCA, Normalised Height (NH), focal mean and standard deviation of NH using a 3x3 pixel window and a binary raster for channel network (value 1 assigned to channels). The following thresholds are used:

- channels are taken as extracted (value 1);
- floodplains are areas other than channels, with NH <= 0.15 and focal SD <= focal mean;

- ridges are areas other than channels or floodplains, and with TCA < 900 m²;
- hillslopes are all other areas.

In the third step, hillslopes alone are divided into 4 classes of slope aspect, defined as azimuth clockwise from N in degrees: N (315 ° - 45 °), E (45 ° - 135 °), S (135 ° - 225 °) and W (225 ° - 315°).

In the final step the raster is transformed to a vector format, for performing island, bubble polygons, area and dangling-line filters (in Tnt Mips), to generalize the supervised classification results. The minimum threshold area of a polygon in the filtered vector, was set to 5 km², but there are in the final vector polygons with smaller values, because they are in situations which cannot be resolved by the topology, in the case of their removing.

IV. RESULTS

The results of the produced classification schema are represented in Fig. 3, for a typical first order asymmetry, and in Fig. 4 for a typical double asymmetry (the result for the hole area are available at <http://www.geomorphologyonline.com/CM.jpg>).

We obtained 60 278 polygons, with an area of 28,439.7 km². From this area 2.66% represents channels, 32.13% floodplains, 51.04% hillslopes (47 311 polygons) and 14.17% ridges (12 967 polygons). From these data, result a mean area of hillslope polygons of 31.12 km² and a mean area of ridge polygons of 31.08 km².

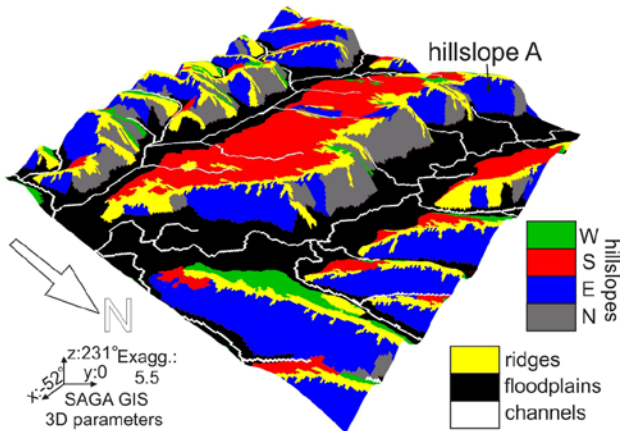


Figure. 3 Results of the landform classification procedure for a first order asymmetry (Sârca dip slope, in Bahlui basin)

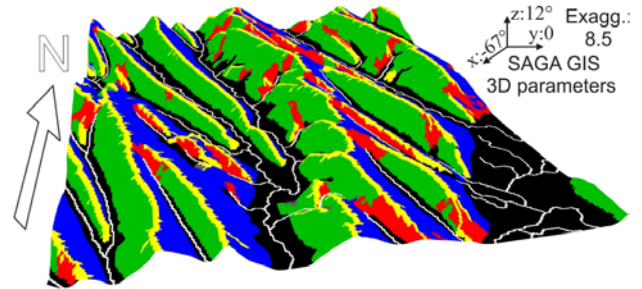


Figure. 4 Results of the landform classification procedure for a second order asymmetry (Tutova basin); the colors are the same as those in Figure. 3

Regarding hillslopes aspect: N is represented by 7.07% of the area (8 131 polygons), E by 19.80% (11 905 polygons), S by 9.29% (15 219 polygons) and W by 14.88% (12 056 polygons). The corresponding mean areas of hillslopes polygons are: N 24.74 km², E 47.31 km², S 17.36 km² and W 35.09 km².

The distribution of hillslopes polygon areas is exponential, the biggest hillslope polygon having 179.44 km², but the majority less than 20 km². Descriptive statistics of mean slope and mean normalized height for hillslope polygons are given in Table I.

TABLE I. DESCRIPTIVE STATISTICS FOR MEAN SLOPE AND MEAN NORMALIZED HEIGHT OF HILLSLOPES POLYGONS, FOR N, E, S AND W ASPECTS

	Slope (degrees)				Normalized height (dimensionless)			
	N	E	S	W	N	E	S	W
Min	2.18	1.01	1.27	1.23	0.16	0.14	0.077	0.13
1 st Qu.	13.91	11.24	9.23	13.88	0.45	0.45	0.50	0.53
Median	19.91	16.66	13.84	19.62	0.50	0.50	0.55	0.56
Mean	19.71	16.96	14.59	19.60	0.50	0.51	0.56	0.56
3 rd Qu.	25.42	22.01	19.16	25.30	0.55	0.56	0.62	0.60
Max	43.33	42.99	42.50	48.14	0.94	0.95	0.95	0.94

V. DISCUSSIONS AND CONCLUSIONS

From analysis of the descriptive statistics of the hillslope polygons, we can see that the degree of the dispersion of data is big, and we cannot define a mean slope or mean normalized height value, that can help us to classify the cuesta scarps and dip slopes. This may be due several reasons:

- by generalization we obtained some polygons which have great extension in altitude (being possible that cuesta scarps to have slope smaller than cuesta dip

slopes) and horizontal space, or small dimensions (north- and south facing hillslopes in Fig. 4);

- generalization of aspect into four classes generates the overlapping of the classic eight classes of aspect (N, NE, E, SE, S, SW, W, NW), and produce errors in applying the semantic modeling rule for scarps and dip slopes (e.g. hillslope A from Fig. 3);
- the channel network has flow directions intermediate those indicated in the semantic modeling of valleys from section II, and can give erosional hillslopes which don't follow necessary the rules: the most typical cuesta landforms appearing at a direction of channel flow of 60°, as shown by [1].

For classifying the cuesta scarps and dip slopes, aspect remains the best geomorphometric variable which can be used, jointly with the semantic modelling rules. But these rules don't apply to all the hillslopes, especially for hillslopes with small areas which cannot be filtered because of topological restrictions of the vector format. In this direction additional rules, such as fuzzy membership functions or probabilistic functions, can be applied for scarp/ dip slopes classification, in relation with the area, for e.g.

Our analysis show that the semantic modeling rule, that the north and west oriented hillslopes should be cuesta scarps and those oriented south and east should be cuesta dip slopes, does not necessarily apply in practice. To apply this rule, there is need for great generalization, and queries on the topology and area of polygons.

Concerning the errors of this approach, the global error of the classification is formed by conceptual error, DEM error, computation error, error of generalization and random error.

Errors in SRTM data, remaining present after the re-sampling, can influence the final classification results especially in floodplain areas. The majority of these errors (vegetation and man-made features) were removed in the generalization step, mainly by polygon island filtering.

Slope and aspect were computed using the second order finite difference algorithm, based on four neighbours, which is reported to be the best estimator [8]. The D8 flow algorithm creates unrealistic channels in floodplain areas, and some rectilinear courses on hillslopes (Fig. 3 and 4), otherwise it produces good agreement with the channels represented as blue lines on 1:25,000 topographic maps.

The generalization procedure, introduces the biggest error, but we consider that vector filtering has an error smaller than the raster filtering performed by other authors [10]. The main problem of the filtering is moving the boundary between two

polygons when a bubble polygon or a polygon with the area smaller than the threshold, is removed. This applies especially for boundaries between catena classes; for hillslopes with different aspects, the error is smaller. From visual inspection we can say that generally this boundary was moved only by one or two pixels, but the error can be bigger where a line is removed or a polygon broken. To minimize these errors, filters with other spatial queries can be used.

In conclusion, utilization of a supervised classification schema can help us to delineate the structural landform of the Moldavian platform. There is need, however for additional rules to deal with the classification of cuesta scarp hillslopes as opposed to dip slopes. Further, unsupervised statistical landform classification methods might be tested.

VI. ACKNOWLEDGMENT

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