TABLE III
PROPERTIES OF TOPOGRAPHIC LANDFORM CLASSES AS GIVEN BY DIFFERENT CLASSIFIERS APPLIED TO THE TISIA SITE. FOR EACH CLASSIFICATION SOLUTION (MAP) AND TERRAIN ATTRIBUTE A COLUMN GIVES AVERAGE MAGNITUDE OF THIS ATTRIBUTE IN A GIVEN CLASS (RANGING FROM ± 100 TO 0). **NB** – NAIVE BAYES, **B** – BAGGING WITH C4.5, **SVM** – SUPPORT VECTOR MACHINES.

watershed based segmentation															
class	**segments**			**area**			**slope**			**curvature**			**flood**		
	NB	**B**	**SVM**	**NB**	**B**	**SVM**	**NB**	**B**	**SVM**	**NB**	**B**	**SVM**	**NB**	**B**	**SVM**
plateau	5588	5354	5809	100	100	100	1	3	3	-1	-1	-1	1	2	3
floor	569	464	476	15	14	15	1	1	1	10	6	6	100	100	100
cvx. wall	384	687	573	3	10	9	100	100	100	79	66	68	92	92	94
con. wall	324	675	572	4	10	8	83	79	80	-84	-100	-100	38	7	11
cvx. ridge	210	258	136	1	1	1	46	35	41	100	46	54	79	2	6
con. ridge	616	270	142	7	1	2	36	40	41	-70	-35	-49	1	1	1
K**-means based segmentation**															
class	**segments**			**area**			**slope**			**curvature**			**flood**		
	NB	**B**	**SVM**	**NB**	**B**	**SVM**	**NB**	**B**	**SVM**	**NB**	**B**	**SVM**	**NB**	**B**	**SVM**
plateau	2660	3811	3613	100	100	100	3	1	3	-1	-1	1	1	1	2
floor	463	614	519	14	15	15	1	1	1	7	6	3	100	100	100
cvx. wall	793	739	754	13	9	11	100	100	100	100	52	82	97	91	95
con. wall	1846	739	1305	30	7	18	58	70	62	-70	-100	-100	8	4	8
cvx. ridge	238	272	254	1	1	1	20	25	36	10	43	55	7	8	7
con. ridge	593	355	148	11	2	1	23	29	31	-5	-16	-2	1	1	1

TABLE IV
PERFORMANCE MEASUREMENTS FOR MAPS OF THE TISIA SITE GENERATED BY DIFFERENT CLASSIFIERS. THE ENTRIES FOR INDIVIDUAL LANDFORMS ARE (PRECISION / RECALL). **NB** – NAIVE BAYES, **B** – BAGGING WITH C4.5, **SVM** – SUPPORT VECTOR MACHINES.

watershed based segmentation							
classifier	**overall accuracy**	**plateau**	**floor**	**cvx. wall**	**con. wall**	**cvx. ridge**	**con ridge**
NB	84.67	0.94 / 0.97	0.93 / 0.93	0.87 / 0.39	0.57 / 0.37	0.12 / 0.12	0.20 / 0.51
B	89.31	0.95 / 0.96	0.97 / 0.87	0.80 / 0.83	0.65 / 0.75	0.51 / 0.45	0.38 / 0.37
SVM	89.71	0.92 / 0.98	0.96 / 0.90	0.87 / 0.75	0.72 / 0.70	0.62 / 0.29	0.48 / 0.29
K**-means based segmentation**							
classifier	**overall accuracy**	**plateau**	**floor**	**cvx. wall**	**con. wall**	**cvx. ridge**	**con ridge**
NB	74.11	0.99 / 0.76	0.99 / 0.80	0.70 / 0.78	0.32 / 0.83	0.14 / 0.19	0.08 / 0.25
B	87.42	0.96 / 0.92	0.94 / 0.92	0.80 / 0.85	0.67 / 0.72	0.34 / 0.47	0.25 / 0.40
SVM	86.10	0.97 / 0.91	0.98 / 0.87	0.77 / 0.79	0.46 / 0.83	0.46 / 0.54	0.18 / 0.12

are above 86%. Note that maps based on the watershed segmentation have slightly higher rates than maps based on the K-means segmentation. This reflects the watershed segmentation simpler character, more in line with the analyst drawing. The table also shows precision and recall rates for six landform classes. Results show that inter-crater plateau, crater floor, and convex crater walls landforms are designated with high accuracy. Concave crater walls are detected with less accuracy, and ridges are essentially difficult to identify correctly. This is because local ridges look like crater walls, even though they are different landforms in the context of the entire landscape.

B. Other sites

The remaining five test sites, Vichada, Al-Qahira, Dawes, Evros, and Margaritifer, represent the same type of Martian surface as the Tisia site. The same six landform classes are present; one would then expect that models generated from the Tisia site would be able to map these sites accurately. In general, maps of these sites have the same relative character as maps from Tisia site. Fig. 5 shows a sample of the results. The top row in this figure shows the topography of each site. The topography helps to visualize the landscape and serves as a guide for a visual assessment of map quality. The middle row shows maps generated by the SVM classifier applied to the watershed segmentation, and the bottom row shows maps generated by the SVM classifier applied to the K-means segmentation. As in the case of the Tisia site, maps originating from the watershed segmentation lack small-scale details, whereas maps originating from the K-means segmentation show more details, but tend to generate more misclassifications.

The Vichada site was hand-labeled by an analyst. Table V shows accuracy performance for maps of this site. Maps corresponding to watershed segmentation have accuracy rates only slightly lower than those of Tisia site. However, these maps are much less useful than Tisia because they miss most ridges. The Vichada site is dominated by the plateau class, identified correctly during prediction (which explains the high accuracy rates). One gains more insight when evaluating precision/recall rates for individual landforms; such evaluation shows poor performance on all classes except the plateau class. Maps originating from the K-means segmentation have precision/recall rates similar to those recorded for the Tisia site.

VI. SUMMARY AND CONCLUSIONS

In this paper we have proposed a machine learning-based method for annotating planetary surfaces with geomorphic