GEOL. CROAT.	51/1	47 - 58	5 Figs.	5 Tabs.		ZAGREB 1998

Discriminant Analysis as a Tool for the Distinction of Quaternary Sediments in the Region of Đurđevac

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Key words: Discriminant analysis, Modal analysis, Quaternary sediments, Genetic groups, Sedimentary cycle, Drava river depression, Pannonian basin, Croatia.

Abstract

Discriminant analysis of Quaternary sediments in the region of Đurdevac was performed in order to determine the optimum criteria for distinguishing between previously established groups of deposits. Geological properties utilized in the procedure of discrimination are represented by the results of modal analysis. Among the seven groups related to the Quaternary sediments of the Drava river depression, only three proved to be distinctive; Pleistocene alluvial deposits (Q_1), Pleistocene loess (lQ_1), and Holocene deluvium (dQ_2), while others proved to be modally uniform. The close relationship between characteristic minerals and individual genetic groups (Quaternary facies) proved to be useful in labelling the most prominent discriminant functions, thus equipping them with particular sedimentological meaning. Three of the six functions indicated the provenance of the source material, as well as conditions of transport and sedimentation within the Quaternary sedimentary cycle of the studied part of the Drava river depression in the Pannonian basin.

1. INTRODUCTION

The broad area of the Drava river depression is verlain by a variety of prevalent Quaternary deposits which are occasionally, as in the case of the Đurđevac egion, the single stratigraphic member (Fig. 1). Although these sediments were repeatedly the subject of the eological investigations of numerous authors (e.g. RELOGOVIĆ, 1974; MUTIĆ, 1975; BABIĆ et al., 978; PRELOGOVIĆ & VELIĆ, 1988), being surveyed mostly in connection with diverse engineering-geologic and hydrogeologic ventures, as well as oil and gas esearch, no systematic geological field investigations ad been undertaken until the project of the Basic Geologic Map of the area was finally launched. The Quaterary formations on the Đurđevac sheet were divided on e basis of the genetic types of the exposed sediments prompting, for example, some formations of aeolian and alluvial facies to be assigned to the Pleistocene, while the marsh sediments were ascribed to the Holocene (HEĆIMOVIĆ, 1987). Genetic division of the Pleistocene and Holocene sediments was accomplished according to the results of micropalaeontological, palynological and, particularly mineralogical analyses (unpublished reports: MATIČEC, 1984[1]; MIKNIĆ, 1985[2]; NOVOSEL-ŠKORIĆ, 1985[3]). With regard to the relative abundance of numerical data, the latter render the possibility of additional insight into the composition and relationship between particular mapping units. Should any of them be accepted as an *á priori* defined naturally occurring group, then multivariate disriminant analysis will elucidate answers to the following questions: 1) can the clear boundaries among certain genetic types or facies be set in a comprehensible way; 2) what is the relationship between the "natural" and mathematically established groups (facies); 3) which predictor variables in the modal composition of the analyzed sediments best discriminate the investigated groups; and 4) can the given mathematical model indicate the provenance of source material, as well as the character of transport and deposition of the weathered particles within the Quaternary sedimentary cycle of this part of the Drava river depression.

2. MATERIALS

On the basis of geological mapping within the scope of the Basic Geologic Map (HEĆIMOVIĆ, 1986), Quaternary sediments on the Đurđevac sheet were divided into seven genetic groups as follows: I - Pleistocene: the 4th Drava terrace (Q_1); II - Holocene: marsh sediments (bQ_2); III - Pleistocene: loess (lQ_1); IV - Pleistocene-Holocene: Drava alluvium (aQ_{1-2}); V - Holocene: aeolian sediments (pQ_2); VI - Holocene: deluvium; and VII

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[2] MIKNIĆ, M. (1985): Mikropaleontološke analize kvartarnih sedimenata s područja lista Đurđevac za 1984. godinu.- Rep. 121/85, 3 p., Archive of the Institute of Geology, Zagreb.

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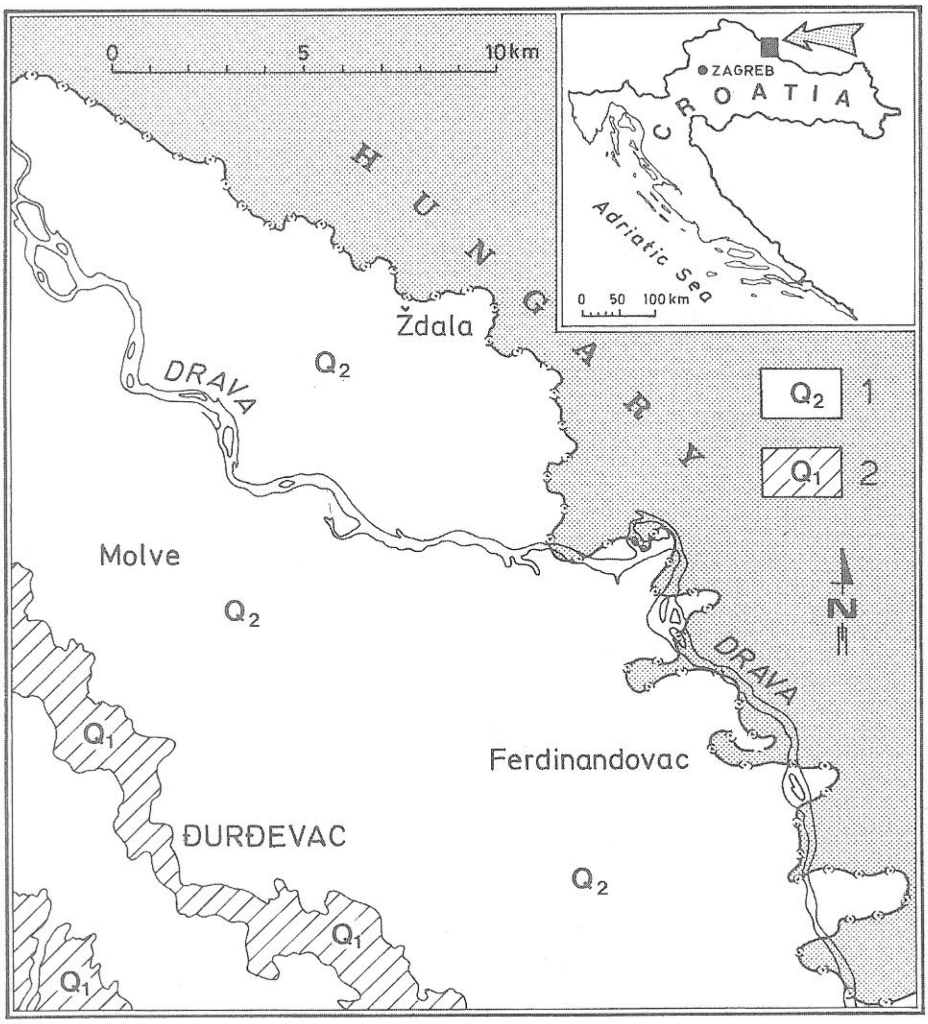

Fig. 1 Simplified geological map showing location of the study area (after HEĆIMOVIĆ, 1986). Legend: 1) Holocene (in general); 2) Pleistocene (in general).

- Holocene: facies of the Drava river (aQ_2). The 19 variables used in the analysis of 81 samples represent the modal composition of the investigated sediments (in wt. %) (Table 1). These are: opâque minerals (OP), chlorite (CO), biotite (B), epidote (EP), zoisite (ZT), amphibole (AM), garnet (GR), disthene (CY), staurolite (ST), tourmaline (TU), zircon (ZR), rutile (RU), andalusite (AD), quartz (Q), feldspar (F), muscovite (M), rock particles (CS), carbonate particles (K), and volcanic glass (VS).

2.1. DESCRIPTION OF THE GENETIC GROUPS

The first group of sediments (Q_1) is of Lower to Middle Pleistocene age and belongs to the remnants of the oldest (fourth) Drava terrace (HEĆIMOVIĆ, 1987). Their granulometric composition is diverse. Among coarse-grained sediments the most common are gravelly sands and, subsidiary, silty sands. The gravelly sands consist of 30-50% gravel and 48-66% sand. Their median value (considering the group) may fall within the limits of 0.44-2.10 mm for individual samples. Sorting is poor (4.714-4.830). Particles above the median value prevail. The silty sands contain 45-72% sand and 25-48% silt. Their median is placed within the range of 0.046-0.130. Sorting is also poor (So=2.335-3.823) with a predominance of particles above the median value. The mineral composition is uniform. Quartz prevails among the light minerals (32-34%), accompanied by rock particles (21-35%), feldspars (9-22%) and muscovite (12-22%). Among the heavy minerals, chlorite and biotite dominate with 1-8%, more rarely up to 11%. Opâque minerals are represented with 12-27% limonite - haematite. Transparent minerals include mostly epidote (23-30%) and garnet (18-29%). Less frequent are staurolite (11-17%), tourmaline (1-10%), zircon and rutile (1-6%). Amphibole is also present (4-31%). Andalusite, zoisite and disthene are rare, ranging from 1-4%. The rock fragments are composed of quartzite, protoquartzite, schist and gneiss which rep-

Table 1 Modal composition of the Quaternary sediments in the region of Đurđevac. Legend: No. = sample No., Gr. = group, OP-VS = modal composition, Sample = sample label.

No.	Gr.	OP	CO	B	EP	ZT	AM	GR	CY	ST	TU	ZR	RU	AD	Q	F	M	CS	K	VS	Sample
1	I	12	3	2	23	2	6	29	5	16	6	1	4	1	43	9	12	34	0	0	308
2	I	20	3	1	26	1	16	18	4	15	4	5	5	1	44	13	22	21	0	0	354A
3	I	27	1	11	27	2	14	22	4	11	4	3	5	1	36	22	14	23	4	0	354B
4	I	15	3	1	28	3	8	19	8	17	7	2	4	0	32	23	17	28	0	0	354D
5	II	14	4	1	29	4	6	27	3	12	3	2	3	0	47	14	12	27	0	0	801
6	II	14	4	0	29	3	12	27	4	1	5	6	2	0	38	24	24	12	2	0	113D
7	II	19	6	1	29	4	12	20	7	13	3	3	2	0	45	18	14	20	3	0	500
8	II	18	4	1	39	10	12	8	3	10	4	4	3	0	48	20	21	11	0	0	799
9	II	15	5	3	21	3	15	32	4	4	9	1	2	1	41	22	25	12	0	0	209
10	II	19	7	3	30	6	10	20	6	4	10	3	6	0	38	24	24	12	0	0	211
11	II	17	4	0	26	1	18	36	4	3	6	1	3	0	36	22	15	24	3	0	455
12	II	14	7	1	33	6	20	25	0	1	8	4	2	0	35	23	15	18	9	0	844A
13	II	9	3	1	28	7	16	30	2	2	4	0	2	0	33	26	18	13	10	0	844B
14	II	10	2	1	30	3	11	38	8	2	0	0	0	0	34	26	8	14	18	0	975
15	II	15	3	1	31	15	16	24	0	2	6	4	0	0	40	22	9	5	24	0	1202
16	II	11	2	0	22	0	9	45	8	2	5	1	1	0	42	27	12	10	9	0	1283
17	II	15	3	0	30	0	16	40	1	0	3	1	4	0	39	20	24	10	6	1	1302
18	II	11	4	2	30	3	16	35	0	0	6	2	2	0	37	24	17	8	14	0	1306
19	II	13	1	0	33	2	12	35	1	2	1	0	1	0	38	22	20	17	0	0	1365
20	II	12	4	1	33	6	18	25	0	3	6	1	2	0	39	23	27	4	0	0	1387
21	II	9	5	0	32	2	31	25	1	0	9	0	0	0	40	19	27	11	2	0	1646
22	II	8	3	2	15	6	4	66	0	1	1	1	2	0	47	7	16	30	0	0	1742
23	II	5	0	2	29	3	13	42	1	0	3	0	4	0	58	12	8	21	1	0	1829
24	III	10	2	0	29	4	14	31	1	1	4	5	4	0	39	25	14	1	18	13	3A
25	III	16	3	1	35	2	10	34	3	0	5	5	2	0	41	16	17	4	14	7	21A
26	III	22	1	0	35	2	13	26	2	1	2	11	4	0	42	28	14	3	10	3	38A
27	III	17	1	2	29	3	9	29	4	0	6	12	3	0	41	22	26	11	0	0	56B
28	III	24	2	2	32	4	15	22	3	1	8	3	6	0	40	27	22	11	0	0	90C
29	III	23	3	3	39	5	16	18	1	0	12	3	2	0	37	28	21	9	0	5	113A
30	III	13	5	0	31	5	21	27	1	1	5	2	2	0	41	27	16	8	5	3	113B
31	III	16	11	5	32	4	20	24	3	0	5	5	4	0	36	27	20	5	3	9	113C
32	III	17	4	1	28	5	14	33	2	1	8	3	1	0	41	34	20	4	0	0	181
33	IV	23	1	0	18	0	4	56	3	7	10	1	2	0	57	24	12	5	2	0	181A
34	IV	20	4	1	28	2	13	38	4	3	5	1	1	0	38	23	17	22	0	0	521
35	IV	16	1	1	17	1	11	60	2	2	1	0	2	0	36	26	8	30	0	0	555
36	IV	12	1	0	9	1	8	64	1	2	1	0	0	0	40	10	12	34	4	0	738
37	IV	5	2	0	2	1	7	81	1	1	2	1	2	0	40	5	7	43	5	0	1650
38	IV	6	0	2	11	2	5	71	1	2	3	1	2	0	57	14	8	25	0	0	1893
39	IV	6	3	2	4	1	5	80	2	4	1	0	1	0	46	9	9	32	4	0	1995B
40	IV	8	0	0	16	2	10	60	1	4	1	1	1	0	41	8	13	38	0	0	2046
41	IV	7	2	0	7	3	11	66	3	1	1	0	3	0	52	9	14	23	2	0	2070
42	IV	11	5	1	26	8	18	36	1	2	2	4	0	0	31	26	18	17	8	0	926
43	IV	10	1	1	23	8	15	30	1	2	3	1	10	0	35	23	15	9	18	0	935B
44	IV	15	0	3	44	4	21	20	1	0	7	0	0	0	34	22	14	18	12	0	841C
45	IV	11	2	1	28	6	21	30	0	0	6	0	3	0	34	23	17	12	14	0	942
46	IV	13	1	0	20	3	19	48	0	3	2	1	2	0	36	21	19	14	10	0	1046
47	IV	15	3	2	22	2	26	40	0	0	5	0	1	0	27	14	15	19	25	0	1087
48	IV	14	6	5	34	1	20	23	2	0	5	1	2	0	37	24	20	11	8	0	1471C
49	IV	6	3	0	6	2	14	70	1	0	1	1	1	0	41	5	11	34	9	0	1775
50	IV	4	3	3	20	4	15	46	1	0	1	3	4	0	47	10	14	29	0	0	1819
51	IV	6	4	3	22	1	13	53	2	1	1	3	3	0	49	13	16	17	5	0	2102
52	V	11	3	1	23	5	10	24	1	4	8	8	13	0	43	27	18	12	0	0	188
53	V	14	4	3	28	1	8	30	12	8	1	1	4	0	41	17	34	8	0	0	304
54	V	23	5	1	36	3	13	26	2	10	8	5	2	0	48	21	18	13	0	0	406
55	V	16	3	2	26	1	6	36	3	11	4	2	3	0	43	14	13	30	0	0	490
56	V	13	5	4	19	2	11	43	3	5	4	0	4	1	41	17	18	24	0	0	602
57	V	11	2	1	20	2	12	51	2	4	2	1	2	0	33	13	21	21	12	0	605
58	V	18	5	2	28	3	11	38	3	7	3	1	3	0	35	16	20	27	2	0	605A
59	V	13	17	7	26	0	27	22	6	10	1	1	2	0	36	4	24	36	0	0	687
60	V	12	5	0	18	0	12	50	0	10	7	0	0	0	39	22	10	27	2	0	820
61	V	15	0	0	23	1	10	47	9	4	2	0	0	0	43	27	10	13	7	0	832
62	V	11	5	1	27	8	16	37	7	3	3	0	0	0	31	26	18	17	8	0	921
63	V	10	4	0	34	16	19	17	1	1	4	1	4	0	42	26	22	10	0	0	1422
64	V	15	1	0	17	3	10	48	1	2	7	0	2	0	43	15	17	19	6	0	1536
65	V	14	6	2	20	4	14	35	2	12	0	1	1	0	38	25	13	9	15	0	1116
66	V	12	5	2	22	1	10	46	2	7	1	2	1	0	42	22	15	16	5	0	1233
67	V	12	5	2	23	0	17	42	4	0	5	1	0	0	45	26	15	17	7	0	1265
68	V	23	5	1	21	6	8	39	1	1	10	4	6	0	41	26	14	10	9	0	1297B
69	V	18	5	1	17	3	14	41	0	2	10	2	3	0	43	20	19	15	2	1	1526
70	V	11	6	1	21	3	16	46	1	1	5	1	3	0	40	29	19	12	0	0	1576
71	V	8	2	3	1	1	7	83	3	1	0	0	1	0	48	8	8	36	0	0	1995A
72	V	7	0	0	4	1	4	80	2	3	2	1	1	0	49	14	16	21	0	0	2036
73	VI	16	3	0	31	1	12	32	1	2	10	1	1	0	36	21	7	17	15	4	71
74	VI	16	4	2	25	5	12	24	2	6	11	2	4	0	36	31	8	11	0	2	204
75	VII	8	5	1	13	1	18	50	1	8	4	1	1	0	28	19	14	12	20	7	865
76	VII	8	1	0	15	0	18	48	3	1	0	10	1	0	38	23	18	9	12	0	1135
77	VII	14	3	1	20	3	13	53	3	0	0	0	2	0	37	24	17	8	14	0	1446
78	VII	15	3	1	20	1	10	48	2	1	3	7	2	0	45	24	15	8	10	0	1471D
79	VII	13	3	1	17	1	13	66	0	1	0	0	1	0	36	16	12	14	22	0	1602
80	VII	7	5	2	22	5	11	46	1	1	3	2	0	0	35	10	8	43	4	0	1719
81	VII	12	11	5	35	5	27	17	1	1	3	0	0	0	39	14	34	13	0	0	1586

resent the rocks of both high and low metamorphic conditions.

The sediments of the second group (bQ_2) originated in the Holocene marsh basins. According to their granulometry they consist of sands, sandy gravels and clayey silts. Their sorting is poor (So=1.638-4.449). The basic mineral components are: quartz (36-58%), feldspar (7-26%), muscovite (8-27%), and rock particles (4-27%). The carbonate particles range from 1-24%. Garnet (8-66%), epidote (15-33%) and amphibole prevail among the transparent heavy minerals. Tourmaline and rutile are rare, as well as zircon (1-10%). Accessory minerals are staurolite and disthene. Limonite, magnetite, and particles with limonite coating form the opâque mineral assembly (5-19%).

The samples in the third group (lQ_1) pertain to Upper Pleistocene loessial fine-grained sediments. The granulometry indicates silt and sandy silt. The particles are rounded and subrounded (median value is within the range of 0.026-0.090 mm). Sorting is medium to poor (So=1.369-2.673). The mineral composition of these sediments is as follows: quartz (36-42%), feldspar (6-34%), muscovite (14-26%), and the rock particles containing quartzite, microquartzite and volcanics (1-8%). Epidote (28-39%) and garnet (18-34%) dominate among the transparent heavy minerals. A significant proportion of amphiboles, brown and green hornblende (9-21%) is also present. Staurolite and disthene are rare. The contents of opâque minerals range between 10-24%. These are limonite, magnetite and limonitized particles. Chlorite (1-11%) and biotite (0-5%) appear among the platy minerals.

The fourth group of samples (aQ_{1-2}) represents the Pleistocene-Holocene alluvial sediments of the Drava river (the first and second Drava terraces). Their granulometry indicates the presence of gravel, sand, gravelly sand, and silty sand. Sorting is medium to poor (So=1.208-8.564). The most frequent mineral component is quartz (30-42%), followed by rock particles (5-38%), feldspar (5-14%), and muscovite (7-16%). Individual samples can contain significant proportion of calcite particles (10-25%). Garnet is dominant among transparent heavy minerals, while epidote (6-26%) and amphibole (4-26%) occur more rarely. Zircon, tourmaline and rutile are accessory (1-10%). Disthene and staurolite are sparse (1-3%). Limonite, haematite and magnetite appear among opâque minerals (6-23%). Platy minerals are represented by chlorite (1-5%).

Aeolian Holocene sands (pQ_2) belong to the fifth group of samples. These are mostly well to medium sorted (So=1.179), while poor sorting appears only sporadically (So=2.480-4.174). All samples are distinguished by the high content of heavy minerals. A high percentage of quartz was determined (39-49%), together with rock particles (9-43%), feldspar (8-20%) and muscovite (12-20%). Garnet prevails among the transparent heavy minerals (17-80%), while epidote is more rare (1-28%). The amphibole portion is significant (green and brown hornblende - 8-18%). The average content of staurolite is 1-4%, but is increased in some samples (10-12%). Platy minerals are also present - chlorite and biotite (1-17%). The prevalence of garnet over epidote, as well as the increased portion of amphibole, are obvious. The characteristic trait of these sediments is both good sorting and roundness.

The sixth group of sediments (dQ_2) is composed of Holocene deluvial sediments. Granulometric analysis reveal medium to poorly sorted sands (So=1.470-1.958). The mineral composition comprises quartz (35-42%), feldspar (21%), rock particles (17%), calcite particles (15%) and volcanic ash (2-4%). Epidote (24-32%) and garnet (25-30%) dominate among the transparent heavy minerals, while tourmaline (11%) and amphibole (12%) are accessories. Zircon, rutile, zoisite, disthene and staurolite are rare. Opâque minerals include limonite and magnetite (16%) together with limonite-coated particles. Platy minerals are represented by chlorite and biotite (0-4%).

The facies of the Drava river (aQ_2) is the seventh group of samples. This comprises Holocene sands, sandy gravels, silt and sandy silt. The samples are medium to poorly sorted (So=1.187-5.180). Morphological characteristics reveal the subrounded to perfectly rounded grains. Quartz prevails (24-48%), followed by rock particles (8-34%) and feldspar (10-24%). The high percentage of carbonate particles (calcite - 22%) is striking. Among the transparent heavy minerals garnet is dominant (6%), accompanied by epidote (13-35%), and amphibole (18-27%). There are also low contents of tourmaline and zircon (7-15%). The content of opâque minerals is 7-15%. Platy minerals, such as chlorite and biotite are present, between 2-11%.

3. METHODS

3.1. DISCRIMINANT ANALYSIS

The modal values are mathematically processed utilizing multivariate discriminant analysis. Linear discriminant functions recently have been widely used to solve various geological problems concerning the classification of samples (objects). Moreover, apart from multivariate regression analysis, it is one of the most commonly applied mathematical methods. Aside from the primary objective common to all multivariate techniques, of highlighting the underlying data structure through the process of the data reduction, discriminant analysis also allows the researcher to distinguish between objects which belong to one of several different groups having the same assemblage of predictor variables. It is applied to *á priori* defined sets of geological observations where for each object is already "known" the group to which it belongs (according to examination of relevant geologic data - DAVIS, 1986). Thus, it helps the researcher to trace any serious errors which may be hidden in the original grouping.

The whole concept of discrimination revolves about finding a linear combination of original variables such

DISCRIMINANT FUNCTION	EIGEN-VALUE	PERCENT OF VARIANCE		CANONICAL CORRELATION
		Relative	Cumulative	
DF1	2.92	44.34	44.34	0.86
DF2	1.82	27.59	71.93	0.80
DF3	0.84	12.80	84.73	0.68
DF4	0.50	7.55	92.28	0.58
DF5	0.27	4.03	96.31	0.46
DF6	0.24	3.69	100.00	0.44

Table 2 Eigen-values and respective functions.

that the difference among previously defined K groups will be at a maximum (DAVIS, 1986). If a linear function can be found which proves that significant difference exists among the groups, then one can calculate the coefficients for each new sample from the investigated area to be classified into either of the known groups. In the case of more than two groups (K>2), a single discriminant function (or single discriminant axis in a K-group space) is insufficient to explain the total variance among the them. Generally, for the K-group case only K-1 discriminant functions (linear composites) can be calculated which form the multidimensional discriminant space. Since the main objective of discrimination analysis is directed to maximize the ratio of between-groups to within groups variability (DILLON & GOLDSTEIN, 1984), the totality of K-1 discriminant function must be mutually independent. Discriminant functions ought to be perpendicular to each other in the reduced discriminant function space, thus producing the greatest possible separation of group centroids which portray the geometrical location of group means.

The clearest distinction between groups is only part of the solution in discriminant analysis. Another is associated with predictor variables and their relationship with the discriminant functions, because discriminant procedure is also aimed at determining the geological properties that account most for the observed differences among groups. This relationship can be detected using various coefficients calculated for this purpose. Discriminant loadings are frequently utilized which are particularly useful when displaying the geometric structure of reduced discriminant function space on 2-D or 3-D plots. Their great advantage is in providing the important information about the geological character of discriminant function as to the identification of specific geological processes for a possible cause of grouping (KLECKA, 1989).

4. RESULTS

Discriminant analysis of Quaternary sediments in he region of Đurđevac, performed on the basis of their nodal composition, is represented as a problem of seven groups (K=7).

Results distinguish among the six available discriminant functions (K-1=6). The first three explain most of the total variability among groups, almost 85%, as can be seen from Table 2. Actually, the discrimination potential of the fourth, fifth and sixth functions offers very low additional information and may be discarded from further consideration.

The first discriminant function accounts for 44.34% or almost half of the total system variance. The 2-D diagrams, which display both the scatterplot of samples between the first two discriminant axes DF1 and DF2 (Fig. 2a), and between the first and third discriminant axes DF1 and DF3 (Fig. 2b) in reduced discriminant space clearly reveal the classification results.

4.1. CLASSIFICATION RESULTS

The first discriminant function is characterized in both cases by its variability, emphasizing the distinctiveness of the first group of samples belonging to the Lower Quaternary. However, it is insufficient to elucidate differences among the remaining groups of which the third and sixth (loess and deluvium) are most prominent. Therefore the attention must be paid to the next two functions DF2 and DF3. Taken together, these two distinctly separate three groups of quaternary sediments:

I - Pleistocene: alluvium Q_1,
III - Pleistocene: loess lQ_1,
VI - Holocene: deluvium dQ_2,

where the first discriminant function DF1 separates group I (the Pleistocene alluvial samples) from both group III (Pleistocene loess) and VI (Holocene deluvium), while the third function DF3 allows group III (loess) to be separated from group VI (deluvium). The second discriminant axis DF2 is very peculiar because its entire discrimination potential is the isolation of groups I, III and VI from the rest. The other groups tend to overlap in reduced discriminant space but a detailed inspection of further discriminant functions, with regard to their low variability (DF4 - 7.55%, DF5 - 4.03%, and DF6 - 3.69%), is without statistical rationale. In other words, it can be shown by the classification results that the following groups: II (Holocene marsh sediments), IV (Pleistocene-Holocene Drava alluvium), V (Holocene aeolian sands) and VII (Holocene facies of the Drava river) can not be clearly outlined on the basis of selected predictor variables. It is easily perceptible from the locations of the respective group centroids (Table 3; Fig. 3a-b).

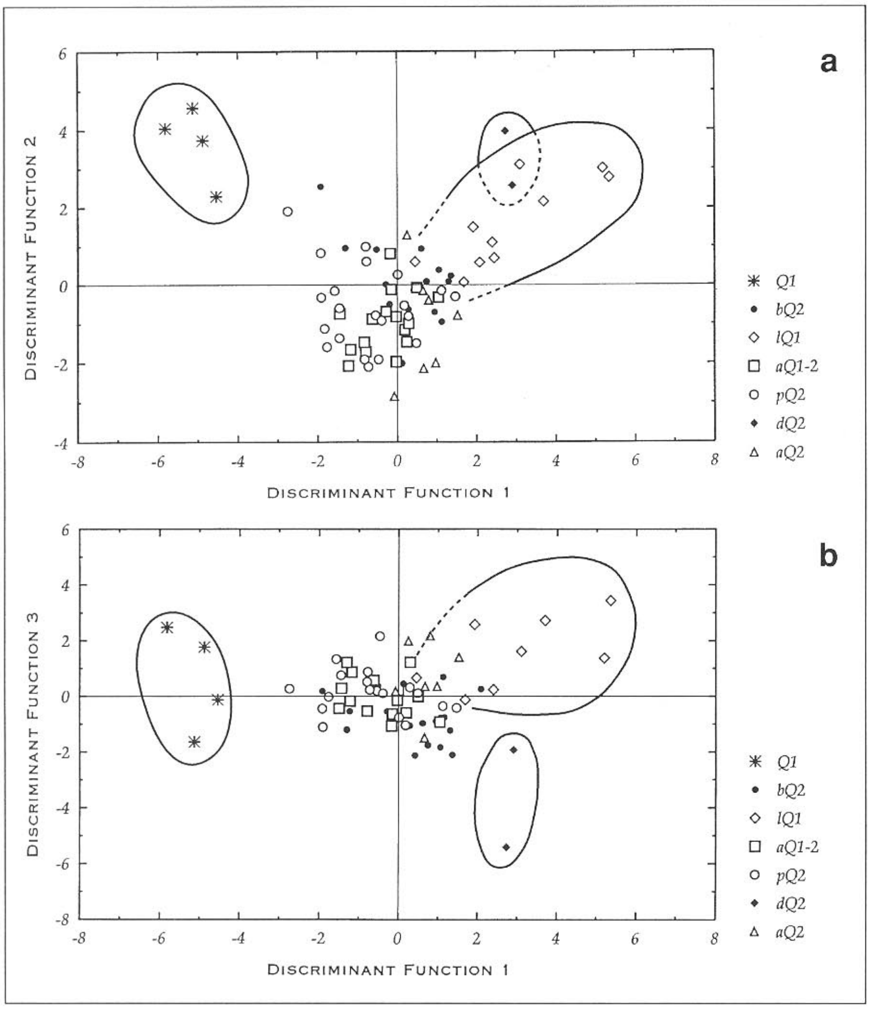

Fig. 2a-b Scatterplot of group samples in reduced discriminant space. Legend: Q_1) Pleistocene: the 4th Drava terrace; bQ_2) Holocene: marsh sediments; lQ_1) Pleistocene: loess; aQ_{1-2}) Pleistocene-Holocene: Drava alluvium; pQ_2) Holocene: aeolian sediments; dQ_2) Holocene: deluvium; aQ_2) Holocene: facies of the Drava river.

Although inspection of Table 3 makes it obvious that the centroids of groups I, III and VI are distinguished by their high discriminant coefficients concerning the first three functions, Fig. 2 also shows a slight overlay of the group-III samples by the objects of other groups, the centroids of which are gathered around the central point due to their insignificant discriminant potential. This is caused by the impact of two samples having a modal composition only slightly different from the average for all seven groups. The arrangement of group centroids of groups II, IV, V and VII around the zero point (Fig. 3) can also be explained by the modal composition of related samples having essentially the same values as average for the whole population. Classification results (Table 4) aid the understanding of how accurately the samples have been systematized into the *á priori* groups. The samples belonging to the groups I (Q_1) and VI (dQ_2) were classified correctly indicating that no significant difference exists among actual and mathematically predisposed groups. As for group III (lQ_1), it was found by the analysis that out of the total of 9 samples, 7 were correctly classified, while only two were misclassified - into groups II (bQ_2), or IV (aQ_{1-2}), respectively. There is a remarkable overlap among the remaining groups, which have their centroids closely packed around the axis intersection as can be seen from Figs. 2 & 3. It is obvious that the first three axes with the greatest discrimination potential can not satisfactorily distinguish among these.

	DISCRIMINANT FUNCTION					
centroid	DF1	DF2	DF3	DF4	DF5	DF6
I (Q_1)	**-5.09**	**3.66**	0.62	0.39	0.02	0.38
II (bQ_2)	0.36	0.12	-0.77	-0.76	0.35	0.38
III (lQ_1)	**2.92**	**1.67**	**1.42**	0.09	0.28	-0.21
IV (aQ_{1-2})	-0.39	-1.05	-0.14	0.89	0.42	-0.07
V (pQ_2)	-0.75	-0.55	0.20	-0.48	-0.37	-0.55
VI (dQ_2)	**2.82**	**3.27**	**-3.67**	1.44	-1.25	-0.59
VII (aQ_2)	0.68	-1.00	0.72	0.34	-1.02	1.01

Table 3 Group centroids.

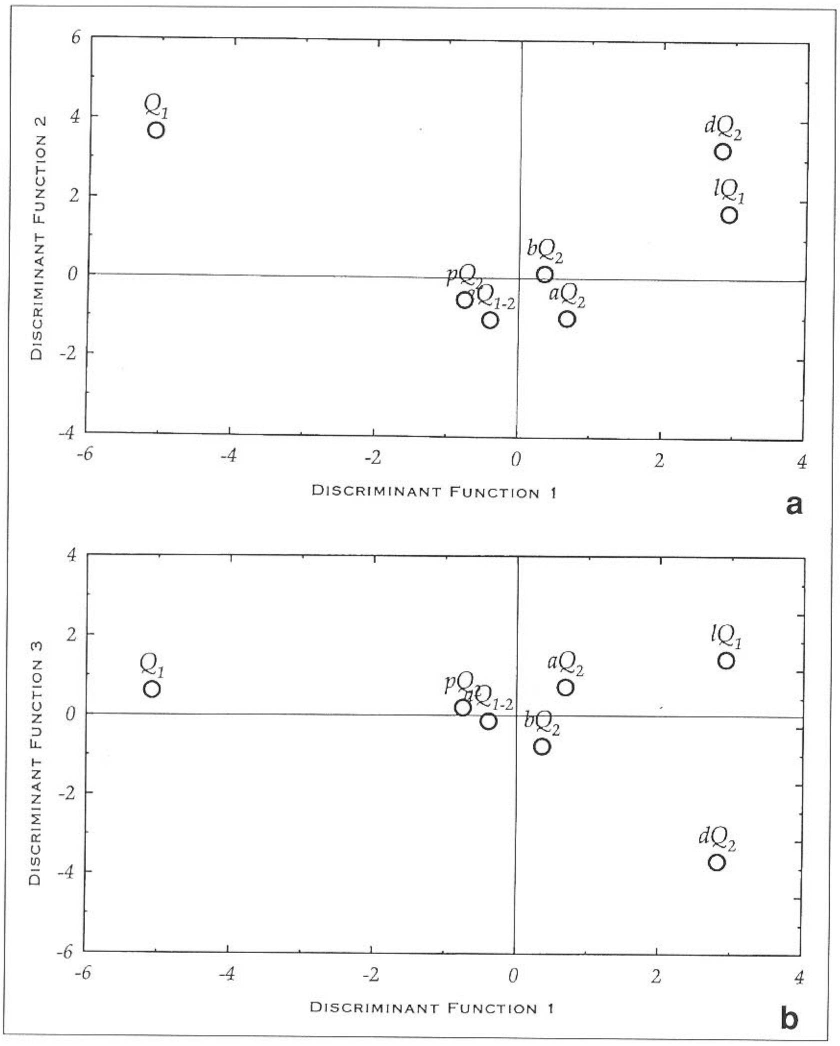

Fig. 3a-b Scatterplot of group centroids in reduced discriminant space. For legend see Fig. 2a-b.

4.2. LABELING DISCRIMINANT FUNCTIONS

The location of centroids *per se* cannot account satisfactorily for the differences among groups. Equally, one cannot assign plausible geological (mineralogical) identity to discriminant functions. Geological determinants of the reduced discriminant space may, however, be deduced from the discriminant loadings of variables which represent the mineral composition of the investigated groups (Table 5; Fig. 4).

The first function DF1 is of a bipolar nature owing to its key variables being oppositely polarized. Transparent heavy minerals, characteristic of the high grade metamorphic rocks, namely andalusite (AD), and staurolite (ST), can be found on the negative pole together with the rock particles (CS), while the positive pole is distinguished by volcanic glass (VS) (feldspar (F) and zircon (ZR) are much less pointed). Accordingly, information conveyed by the first discriminant function emphasizes the difference among the respective groups

ACTUAL GROUP	PREDICTED GROUP							TOTAL	miss-classified samples
	I	II	III	IV	V	VI	VII		
I (Q_1)	4	0	0	0	0	0	0	4	0
II (bQ_2)	0	16	0	2	1	0	0	19	3
III (lQ_1)	0	1	7	1	0	0	0	9	2
IV (aQ1-2)	0	2	0	14	2	0	1	19	5
V (pQ_2)	1	2	0	3	15	0	0	21	6
VI (dQ_2)	0	0	0	0	0	2	0	2	0
VII (aQ_2)	0	1	0	0	0	0	6	7	1
TOTAL	**5**	**22**	**7**	**20**	**18**	**2**	**7**	**81**	**17**

Table 4 Classification matrix. Total correctly classified (79.01%).

	DISCRIMINANT FUNCTION					
variable	DF1	DF2	DF3	DF4	DF5	DF6
OP	0.08	**0.69**	0.28	-0.19	-0.01	-0.31
CO	0.19	-0.07	0.04	-0.44	-0.49	-0.05
B	-0.40	0.28	0.22	0.15	-0.16	-0.02
EP	0.37	**0.58**	0.13	-0.47	0.32	0.10
ZT	0.14	-0.01	0.00	-0.36	0.30	-0.02
AM	0.12	-0.18	0.20	0.06	0.05	0.29
GR	-0.09	**-0.75**	-0.11	0.46	-0.15	-0.04
CY	-0.30	0.38	0.04	-0.44	-0.05	-0.11
ST	**-0.85**	**0.60**	-0.18	-0.22	-0.28	-0.09
TU	0.29	**0.69**	-0.22	-0.13	0.05	-0.43
ZR	0.46	0.48	**0.64**	-0.11	0.00	0.08
RU	-0.26	0.41	0.17	-0.04	0.20	-0.37
AD	**-0.80**	**0.72**	0.09	0.06	0.02	0.18
Q	-0.06	-0.16	0.05	-0.21	0.38	-0.30
F	0.47	0.36	0.21	-0.31	-0.07	-0.23
M	-0.01	-0.02	**0.56**	**-0.59**	0.08	0.05
CS	**-0.63**	-0.17	-0.44	0.42	0.00	-0.02
K	0.21	-0.27	0.04	0.30	-0.23	0.50
VS	**0.87**	**0.59**	0.27	0.21	-0.24	-0.05

Table 5 Discriminant function matrix.

of samples, as disclosed on the ground of both enrichment of the Quaternary sediments in the variables AD, ST and CS, and, contrarily, their depletion in variable VS (and, to the lesser extent, ZR and F). Sedimentologically, it is most probably that the origin of mineral grains in the Quaternary sediments of the investigated area is directly reflected in DF1 - indicating the possible distribution area and composition of primary rocks.

The second function DF2 is loaded with a considerably higher number of variables. That alone, regardless of its significant variability, can render interpretation difficult, particularly due to the influence of variables specific for the first discriminant function DF1 (ST, AD, and VS). However, the basic information related to the function DF2 is manifested in the relationship of garnet (-GR) against other variables located on the positive pole of the discriminant axis (+OP, +TU, +EP), showing its dependence upon the variability of the garnet content within certain groups of sediments. Since GR is loaded insignificantly on the first function, suggesting that the primary material may be of various origins, DF2 can easily indicate some prominent physical property of that mineral in interaction with its environment. The increased content of garnet in the sediment is usually considered as indicating the high energy conditions during transportation (ROTHWELL, 1989).

The third discriminant function DF3 is the simplest for explanation in view of its accentuated non-polarity, while the main discriminatory potential is carried by the variables M and ZR. It implies differentiation among respective groups on the ground of increased or decreased content of muscovite and zircon. Sedimentologically, this function can also indicate granitic rocks and, particularly, pegmatites as a parent material. Nonetheless, concerning the stability of muscovite and zircon to physical and chemical weathering (PETTIJOHN, 1975; TIŠLJAR, 1994), it probably indicates a distant source and long-lasting transportation of weathered material (M) and/or the possibility of its sedimentary reworking (ZR) (ROTHWELL, 1989).

5. DISCUSSION

When compared, the scatterplots of samples and group centroids (Figs. 2 & 3) on the one hand, and the scatterplot of variables (Fig. 4) on the other, afford clear insight into the relationship between the groups and variables. One must take into account that the diagrams can not be compared directly by reason of the different scales being exercised (discriminant axes on the scatterplot of variables are drawn as normalized vectors) so that the interdependence between samples and groups should not be considered as absolute.

The first discriminant function has already been explained as separating facies Q_1 from facies lQ_1 and dQ_2 taken together. Comparing variable (Fig. 4) to group positions (Fig. 2) one can easily find DF1 separating Q_1 from lQ_1 and dQ_2 owing to the polarized association between two groups of predictor variables. The position Q_1 at the negative pole of DF1 complies with the variable AD, ST and CS plots, whereas the placement of lQ_1 and dQ_2 at the negative pole corresponds to the variable VS (and to a lesser extent F and ZR). In other words, Q_1 is enriched in andalusite, staurolite and rock particles, but depleted with regard to volcanic glass, whereas lQ_1 and dQ_2, on the contrary, is distinguished by increased quantity of volcanic glass with insignificant contents of staurolite, andalusite and rock particles. In accordance with sedimentological identification of the axis DF1, a premise cannot be rejected that the parent material for sedimentation of Q_1 were predominantly high grade metamorphites, while the parent material for sedimentation of lQ_1 and dQ_2 origi-

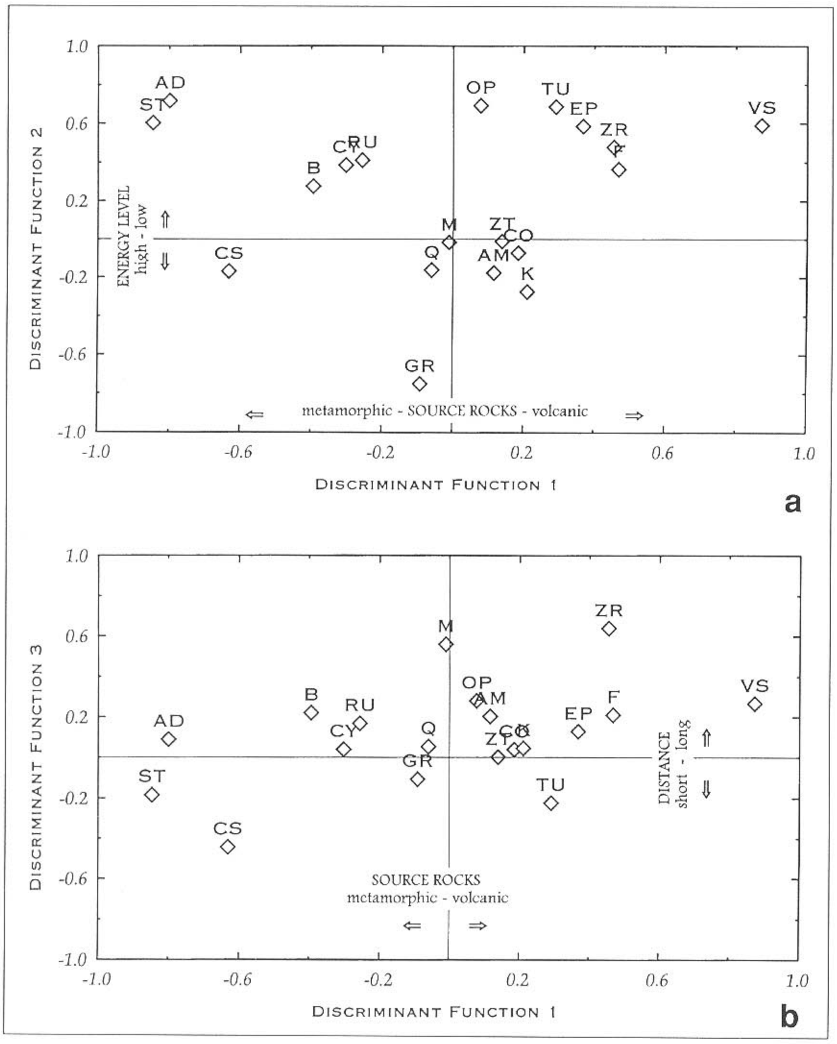

Fig. 4a-b Scatterplot of discriminant loadings in reduced discriminant space. Legend: OP) opâque minerals; CO) chlorite; B) biotite; EP) epidote; ZT) zoisite; AM) amphibole; GR) garnet; CY) disthene; ST) staurolite; TU) tourmaline; ZR) zircon; RU) rutile; AD) andalusite; Q) quartz; F) feldspar; MU) muscovite; CS) rock particles; K) carbonate particles; VS) volcanic glass.

nated for the most part from more acid types of igneous rocks, particularly extrusives.

In the former case the distribution area of the characteristic minerals is most probably the zone of high-grade metamorphic rocks (gneiss in particular) of the Pohorje Mt. (Slovenia) (MUTIĆ, 1975). Another possible source area, the Papuk Mt., is situated farther eastward in the Drava depression and thus not taken into consideration. The Q_1 deposits represent the remnants of the oldest 4th Drava terrace being mostly overlain by Holocene deposits except for the outermost southwestern part of the research area (Fig. 5) where they outcrop as a result of the rapid Quaternary uplift and denudation (PRELOGOVIĆ & VELIĆ, 1988). In the latter case the source area is more contrasted, giving material for the two different types of sediments - loess which originated by the aeolian transport of silt during the Upper Pleistocene thus indicating distant areas, probably the Alps (HEĆIMOVIĆ, 1987), and deluvium which is a typical sediment of short distance transportation.

Similarly, one can explain the affinity between minerals and groups with the other two discriminant functions, namely DF2 and DF3. In the case of DF2 the large number of loaded variables may turn out to have some unfavorable effects concerning interpretation, particularly if the groups gather around the same pole of discriminant function. All three distinct groups are placed on the positive pole being distinguished by their increased content of opâque minerals (OP), tourmaline (TU), epidote (EP), as well as minerals typical for the first function DF1. Thus, the distinction of the three indicated facies relative to the other, less prominent ones, is not determined clearly enough. However, the negative polarity of garnet (-GR) on DF2 endows it with special significance which, in regard to its particularly high loading, push it into the role of a sole discriminator variable for Q_1, lQ_1 and dQ_2. Clearly, it is easy to decide the variance among these and other Quaternary facies as being dependent on the decreased content of garnet. According to the sedimentological identification of DF2, these are sediments which originated in sedimentary environments of relatively low energy levels.

Figures 3 & 4 aid clarification of the difference between lQ_1 and dQ_2. The third discriminant function DF3 mirrors the increase in the content of muscovite (M) and zircon (ZR) in loess sediments (lQ_1). On the other side, due to the very prominent placement of the

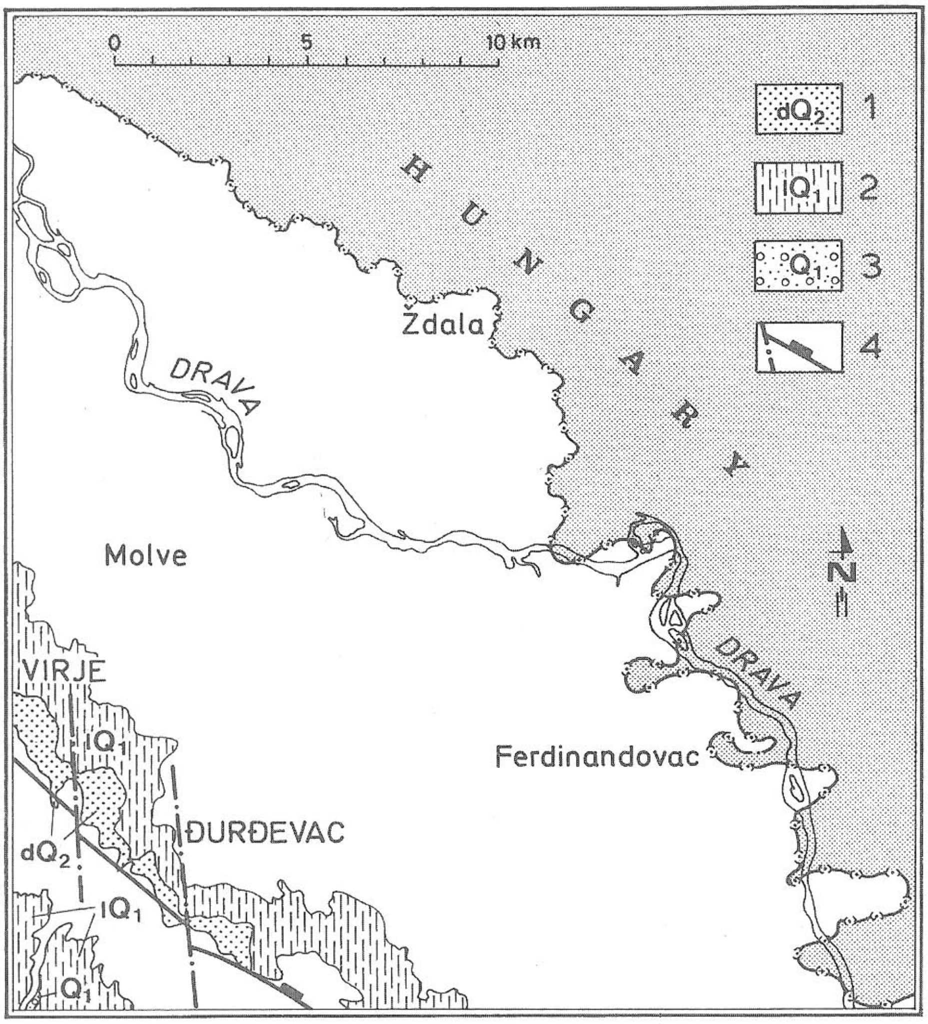

Fig. 5 Simplified geological map with modally differentiated genetic types of Quaternary sediments. Legend: 1) Group VI (dQ_2) - Holocene: deluvial sediments; 2) Group III (lQ_1) - Pleistocene: loess and loessial sediments; 3) Group I (Q_1) - Pleistocene: gravel and sand (4th Drava terrace); 4) Virje fault (after PRELOGOVIĆ & VELIĆ, 1988).

dQ_2 centroid on the negative pole, the very low content of these minerals in the deluvial facies is more accentuated. Taking into account the sedimentological identification of the DF3, one can profess a significant portion of long-term and distant aeolian transport (muscovite in loess), together with filtering of the fine fraction, the latter being an important process during sedimentation (non-existence of muscovite and more accented appearance of rock particles in deluvium) (ROTHWELL, 1989; EINSELE, 1992). As for the latter, dQ_2 was deposited as a result of denudation, wash-off and subsequent resedimentation of aeolian sands and weathered loess from the northern slopes of Bilogora Mt. (HEĆIMOVIĆ, 1987). The extension of these sediments markedly conforms to the strike of the Virje fault (Fig. 5), one of the more important faults parallel to the Drava river depression, obviously very active during the Quaternary era (PRELOGOVIĆ & VELIĆ, 1988).

Illustrative is the placement of certain minerals occurring profusely in Quaternary sediments, such as quartz (Q). These acquire markedly low discriminant loadings on all discriminant functions indicating their position very close to the axis intersection. Such minerals are represented regularly across all groups of Quaternary sediments which render their discriminant potential useless. Similarly the carbonate grains (K) have the discriminant loading (>0.5) only slightly increased on the DF6 (Table 5) as this is the indicator of increased content of carbonates in the facies of the Drava river aQ_2 (Table 3). However, owing to the very low variability of the function, such observation is more or less of speculative character.

6. CONCLUSIONS

Discriminant analysis applied to Quaternary sediments of the region of Đurđevac, proved that the distribution of light and heavy minerals among the various genetic types can be considerably different from that shown by a routine table display of data (Table 1). The results of the investigation convincingly and plausibly relate particular mineral associations to quite distinctive Quaternary facies. The appearance of such relationships allows some definite conclusions to be made about specific stages of the sedimentary cycle, or conditions prevailing during weathering, transport and sedimentation within the study area.

Pursuing assumptions introduced earlier in the text about the nature of genetic groups and their mineral composition, some clear conclusions may be drawn:

- Utilizing the modal composition as the predictor variables, discriminant analysis failed to establish clear boundaries among all previously defined "natural" groups of Quaternary sediments. Only three consistent groups can be distinguished - Pleistocene alluvium (the 4th Drava terrace) (Q_1), Pleistocene loess (lQ_1), and Holocene deluvium (dQ_2) - whereas other groups tend to cluster together (Figs. 2 & 3) and therefore can be considered as modally undifferentiated regardless of their extent and stratigraphic position (Fig. 5). Aeolian sediments (pQ_2) and the Drava alluvium are particularly inconsistent groups showing the greatest discrepancy between mapped and mathematically predicted units. These, and to a lesser degree both the marsh sediments (bQ_2) and the facies of the Drava river (aQ_2), are characterized by such an extensive compounding of light and heavy minerals that their composition clearly reflects the average of all seven groups.
- Certain variables in modal composition of the analyzed sediments not only help to discriminate actual groups but also point at the sedimentological meaning of discriminant functions. The strong discriminant potential associated with the first function is placed on andalusite and staurolite, as well as on the rock particles and volcanic glass. These variables point at the origin of parent material: high grade metamorphic rocks mostly participated in forming the fluvial Pleistocene sediments (Q_1), while Pleistocene loess (lQ_1) and Holocene deluvium (dQ_2) prevailingly contain material derived from more silica-rich types of igneous rocks, mostly volcanics. Garnet characterizes the second discriminant function. A distinctly low percentage of this highly stable mineral in all three mentioned facies indicates a comparatively low energy potential having predominated during the process of their accumulation. Eventually, the third discriminant function is characterized by muscovite and zircon which indicate long-distance transport and possibility of subsequent resedimentation of loess (lQ_1). Moreover the latter process most probably participated in forming the youngest, deluvial sediments (dQ_2).

Although the results of discriminant analysis prove that the modal composition can be a reliable tool in distinguishing *á priori* defined Quaternary formations in the investigated area, a main problem involving group coherence is not quite resolved. Regardless of the strong discriminant potential of certain light and heavy minerals, modal composition accompanied with other geological data such as, for instance, the granulometry, would assuredly help establishing clearer boundaries among various genetic types. This, owing to increasing variability among facies, and taking account of intrafacies variability, would reduce differences between "natural" and predicted groups. Also, the number of misclassified samples would be reduced to a minimum. Certainly, the range of data relevant for discrimination among the youngest stratigraphic units is not exhausted exclusively on the results of sedimentological analyses.

Acknowledgements

The authors wish to express their gratitude to Dr. Ivan HEĆIMOVIĆ (Institute of Geology, Zagreb) who was especially kind in providing them with necessary data. During preparation of this paper we greatly benefited from the counsel and critical comments by Prof. Josipa VELIĆ (Faculty of Mining, Geology and Petroleum Engineering, University of Zagreb). We also like to address a word of special thank to Prof. Simon PIRC (Institute of Geology, University of Ljubljana, Slovenia) for reading the earlier version of the manuscript and offering many suggestions for its improvement.

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Manuscript received November 13, 1997.
Revised manuscript accepted May 18, 1998.