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REGIONAL VARIATION OF THE MEDITERRANEAN RED SOILS OF YUGOSLAVIA

With 9 figures and 4 tables

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Zusammenfassung: Die Regionalität der mediterranen Roterden Es werden die Eigenschaften der mediterranen Roterden verglichen, die aus 48 verschiedenen Orten in Jugoslawien entnommen wurden. Die Orte wurden aus dem slowenischen Inland, der Halbinsel Istrien und der Küstengegend am Adriatischen Meer gewählt, in denen verschiedene Klimate und Vegetationsformen herrschen.

Der Feuchte-Index von C. W. THORNTHWAITE Im(mm) steht in einer negativen Wechselbeziehung zum Basensättigungsgrad V (%). Fe_2O_3 (%) steht mit dem Wasserdefizit (d) in einer starken Wechselbeziehung, schwächer mit P/E, ebenso wie mit Im. Fe_2O_3 (%) steht mit V (%) in einer negativen Wechselbeziehung. Die Regressionsgleichungen, die zwischen V (%) und Fe_2O_3 (%) bestehen, sind im Falle des Inlandes und im Falle der istrischen Halbinsel und der adriatischen Küstengegend verschieden. Der Farbton, der nur mit d korreliert, steht mit Fe_2O_3 (%) in einer positiven Wechselbeziehung. In dieser Beziehung ist die Regressionsgleichung, die für Inland und Istrien besteht, verschieden von der der adriatischen Küstengegend.

Der Hämatit steht zu P/E und Im(mm) in einer starken, und zu d(mm) in einer schwachen Wechselbeziehung. In bezug auf die Beziehung zwischen dem Hämatit, dem Farbton und Fe_2O_3 (%) kann man feststellen, daß der Grad der Röte steigt, wenn der Gehalt von Fe_2O_3 (%) groß und die Spitze des Hämatites hoch ist. In dieser Beziehung ist die Regressionsgleichung, die für Inland und Istrien aufgestellt wurde, verschieden von der für die adriatische Küstengegend. Aber in Hinsicht auf die Beziehung zwischen MnO (%), dem Farbton und Fe_2O_3 (%) ist es klar, daß der Grad der Röte sinkt, wenn MnO (%) über eine bestimmte Quantität zunimmt, auch wenn der Gehalt an Fe_2O_3 (%) hoch ist. In dieser Beziehung ist eine Tendenzkurve, die im Inland und Istrien gilt, verschieden von der, die in der adriatischen Küstengegend gilt.

Die istrische Halbinsel hat dieselbe Regionalität wie das Inland, wenn man unter den Faktoren, die den Grad der Röte beeinflussen, nur solche betrachtet, die von dem heutigen Klima nur wenig oder gar nicht beeinflußt sind. Dies führt zu der Vermutung, daß Istrien im Quartär ein dem Inland sehr ähnliches Klima hatte.

I. Introduction

The properties of Mediterranean red soils have been studied by many pedologists. However, the reasons why the soils are red, and the circumstances that control the degree of redness have yet to be determined.

This paper attempts to clarify the relationship between climatic conditions and the hue of those Mediterranean red soils that develop in the limestone regions of Yugoslavia. In a preliminary study in 1972, the author analyzed samples of red soil that had been collected in the limestone region of coastal Yugoslavia (URUSHIBARA, 1974). In 1974–75, the investigation was extended to include the area from the Inland region in the Slovenia Republic through the Istria Peninsula to the Adriatic coastal region. In this paper, the regional properties controlling the degree of red color are discussed mainly from the basis of the results of chemical and X-ray analyses.

II. Results of Previous Studies of the Mediterranean Red Soils

To the present, red or reddish brown soils in the Mediterranean region have been called "Terra rossa" a term that originates from Latin. According to STACE (1956), the term Terra rossa has been used for (1) the red, shallow and undifferentiated soils that overlie and develop on or from limestone; (2) the corrosional remnants of limestone or dolomite which themselves may become parent material, as well as (3) all of the red and reddish brown soil in the Mediterranean region.

STACE (1956) proposed that Terra rossa and rendzina soils should be called "red-terracal", "brown-terracal" and "black-terracal", because of the many chemical characteristics they have in common. Thus, all are considered members of the same soil group. In Australia, it has been found that when the $(P/E)^{0.7}$ index (PRESCOTT, 1949) is under 0.92, red-brown soils form and when the $(P/E)^{0.7}$ is more than 1.07, a black soil forms. KHAN (1959a, 1959b, 1960), who investigated the characteristics of the Terra rossa, red-brown soils and rendzina in the limestone or chalk region in Europe, showed that SiO_2, Fe_2O_3 and Al_2O_3 increase as the parent materials are transformed into Terra rossa. SiO_2 increases slightly and CaO increases greatly in the development of rendzina. However, he found that there was no significant difference in the translocation of constituents between Terra rossa in the Mediterranean region and red-brown soil on limestone in England, and therefore, concluded that in these two cases similar soilforming process operate.

In many recent articles the term "Mediterranean red soil" has been used instead of "Terra rossa" for the red soils in Yugoslavia. For example, on the soil map of Yugoslavia (NEJGEBAUER et al., 1961) the term "Mediterranean red soil (Terra rossa)" was used to include soils with high amounts of clay and low amounts of P_2O_5 in the B horizon. Although, ŠKORIČ (1962) still used the term "Terra rossa" for soil with great amounts of illite, halloysite and quartz, GREGORIČ (1967) prefered the term "red-brown and brown soil on limestone" for the same soil. GREGORIČ concluded that the red-brown soils in the Slovenia Republic contain more kaolinaite and less chlorite, quartz and mica than brown soil. On the other hand, brown soils have much illite. The Mediterranean red soil of the Slovenia Republic was divided into "Ilovka" and "Kremenica" by Sušin (1964, 1968). Kremenica contains higher amounts of hydrogen ions and lower contents of positive ions in the B horizon than Ilovka. Ilovka has high amounts of exchangeable calcium. Kremenica is very siliceous because the mother rock, which is upper cretaceous calcareous, is slate. Gregorič (1969) discussed the formation of those red brown soils and rendzinas that develop on dolomite. Because of the continuous change in clay minerals, she suggested that rendzina will develop into reddish-brown rendzina *through* thin red-brown soil to thick brown soil.

III. Study Area

Samples of red soil on limestone were collected at 48 locations in (i) the Inland region of Slovenia, (ii) the Istria Peninsula and (iii) the Adriatic coastal region. These three regions differ from each other climatically. In this paper the term "Mediterranean red soil" is used for the red soils formed *from* limestone under the Mediterranean climate.

The Istria Peninsula and the Adriatic coastal region are composed of Cretaceous and Jurassic limestone and dolomite, the Inland region of Triassic limestone and dolomite. These Cretaceous and Jurassic limestone are found mainly in the Adriatic coastal region along the Dinar Alps. Tertiary flysh is also found in the Istria Peninsula and on the southern coast of Zadar (Fig. 1). In the northern Slovenia Republic, Trias limestone occurs zonally from E to W along the Kamnic Alps, and it is especially concentrated in the Inland region of Slovenia.

In the classifications of vegetation in Yugoslavia (1) the Inland region of Slovenia belongs to the Illyrian district of the Euro-Siberian region: (2) most of the Istria Peninsula and the area from the northern Adriatic coast to Zadar belongs to the eastern Adriatic Submediterranean district, and (3) the southern coast of the Istria Peninsula and most of the Adriatic coastal region belong to the eastern Adriatic Mediterranean district (Yoshino, 1974, 1976; Trinajstic, 1976).

The Adriatic coastal region is primarly bare karst with shallow red soil. In contrast, some areas of the Istria Peninsula and of the Inland region of Slovenia have red soils that are more than one meter thick.

The annual precipitation in the Adriatic coastal region is generally less than 1,200 mm with the southern coast of Zadar receiving less than 900 mm. It ranges from 880 to 1,200 mm in the Istria Peninsula, and from 1,300 to 1,500 mm in the Inland region of Slovenia (Table 1). The

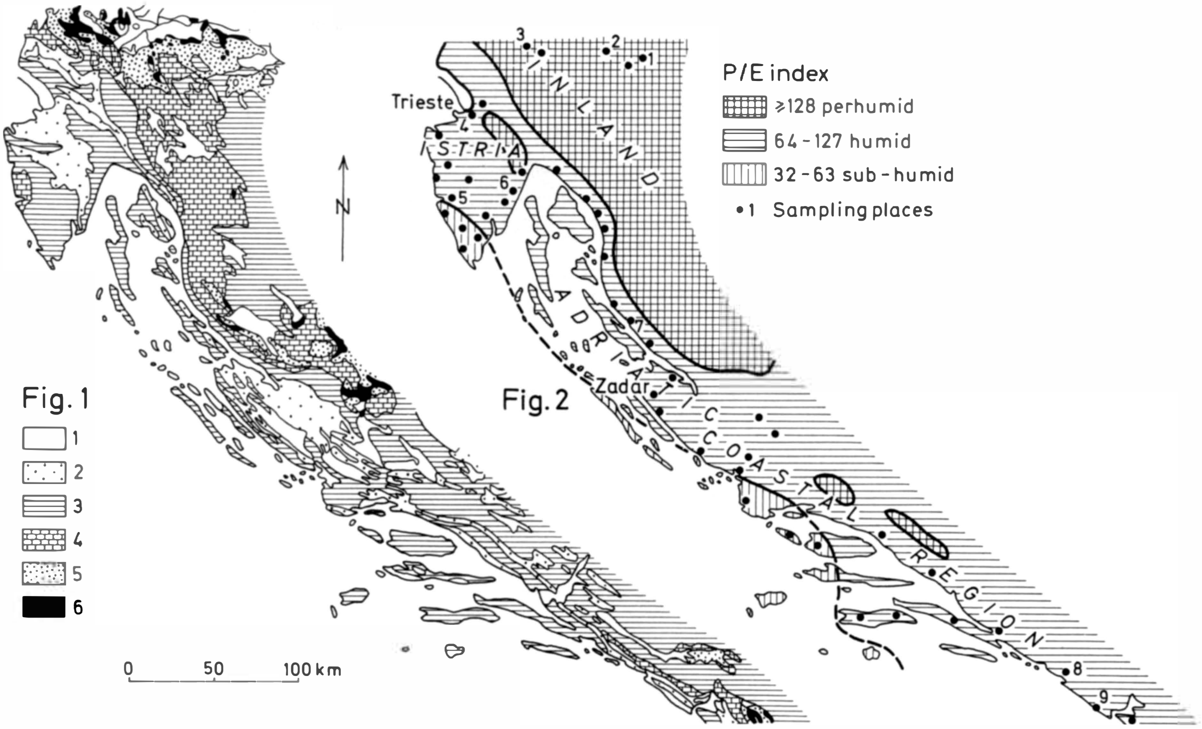


Fig. 1: The generalized geological map of the Yugoslavian karst region.
1. Holocene, Pleistocene and Neogene 2. Paleogenic flysh 3. Cretaceous limestone and dolomite 4. Jurassic limestone and dolomite 5. Upper-middle Triassic limestone and dolomite 6. Lower Triassic limestone and dolomite

Fig. 2: The distribution of P/E index after the Thornthwaite's method
1. Jordankal 2. Perovo 3. Vrhnika 4. Kozina 5. Lovreč 6. Moščenčka Draga 7. Jablanac 8. Dubrovnik 9. Njivice

climate of the Adriatic coastal region is per-mediterranean; the P/E index (Thornthwaite, 1931) ranges between "humid" and "sub-humid" (Fig. 2). In some of the islands on the southern coast, the P/E index is in the "sub-humid" to "semi-arid" range. Most of the Istria Peninsula is in the "humid" range. The Inland region of Slovenia is "perhumid". The climatic-diagram by Walter et al. (1975) also shows that the southern Adriatic coastal region has a drier summer than the other regions, and the northern part of Yugoslavia is humid in all seasons.

be due to the long period of time they have been forming and therefore that clay migration has been occurring (Kundler, 1961; Reuter, 1962; Striter et al., 1967; Janoković, 1967).

The organic matter was determined with the Walkley method (Walkley, 1935; Jackson, 1958). Organic matter decreases from the A to B horizons in all regions. The amount of organic matter in the B horizon in the Adriatic coastal region is greater than in the other regions, a condition that can be attributed to the fact that the organic matter easily penetrates the B horizon of shallow soils.

Table 1: The climatic conditions in the three regions*

	Annual precipitation (mm)	Annual mean temperature (°C)	d (mm) (water deficiency)	Im (mm) (moisture index)	P/E index
Inland region	1300 ~ 1500	8.0 ~ 9.0	0	140 ~ 150	128 ≧
Istria Peninsula	880 ~ 1200	13.0 ~ 14.0	8 ~ 150	30 ~ 60	64 ~ 127
Adriatic coastal region	800 ~ 1200	14.0 ~ 16.5	130 ~ 300	20 ~ 60	16 ~ 127

* Range of the average values at the places where the soil samples were taken.

IV. Properties of the Mediterranean Red Soils

1. *Sampling and analytical procedure*

The red or reddish-brown soils used in this study were obtained from gentle slopes (under 12 degrees) with well developed B_2 horizons. Sample locations were limited to grass fields or fields sparsely dotted with bushes. Sampling was limited to locations where all three regions from A to B_2 horizons were intact despite the fact that many areas in the region lack the A horizon.

Standard procedures were used in the chemical analysis of the soils. X-ray analysis was made after the samples were sterilized under high pressure at 120 °C for 20 minutes.

The soil samples were collected from 48 soil profiles in the three regions mentioned above, and analyzed for free iron oxide, manganese oxide and soil color. Then, the samples from three profiles in each of the three regions were selected for more detailed analysis. The texture, the cation exchange capacity and the exchangeable cations were determined. All samples were air-dried, ground and sieved through a 2 mm sieve before chemical analyses (Table 2).

2. *Texture and organic matter*

The pipette method of Köhn described by Cencelj (1957) was used for the analysis of texture. The soils were classified by the International Method (Kanno, 1963) (Fig. 3 and Table 2). The A horizons in all 9 sets of samples were loamy clays whereas the B_1 and B_2 horizons were mainly clay. The percentage of clay increased markedly from the A to B horizons in the Inland region. This phenomenon is considered to

3. *Cation exchange capacity (CEC)*

The cation exchange capacity (CEC) was calculated as the sum of exchangeable hydrogen. The CEC in soil varies in accordance with the proportion of the quality of organic matter, the percentage of clay, and the kind of clay. The proportion of the organic matter is large in the A horizon than in the B horizon in all regions; it is higher in the Adriatic coastal region than in the Inland region. The CEC of the A horizon is high in the Adriatic coastal region. High CEC values are affected largely by the quality of organic matter. In the Inland region, even though the clay percentages are high in the B horizons, the values of the CEC are low. On the contrary, clay percentages are lower in the B horizons in the Adriatic coastal region than in the Inland region, however the values of CEC are higher. In the Istria Peninsula, the values of the CEC are between those in the Adriatic coastal region and in the Inland region.

The contrasts between the soils of the Adriatic coastal region and the Inland region are caused by the different kind of clay minerals. The peak of sericite is higher for the Adriatic coast samples than for those from Inland region as seen by X-ray analysis. The peak of chlorite, however, is higher for soils of the Inland region. The X-ray analysis shows that soils from each region are composed of different kinds of clay minerals.

4. *Base saturation percentage (V %)*

The base saturation percentages were calculated (Hesse, 1971) as the following expression;

$$V\,(\%) = \frac{\text{the sum of exchangeable cation (S)}}{\text{cation exchange capacity (CEC)}} \times 100$$

The high base saturation percentages in the Adriatic region are explained by dry climate, where no loss of the base saturation percentage by leaching occurs. The author tried to determine the relationships that exist among the base saturation percentage, annual precipitation, Im (moisture index), and d (water deficiency). Im and the d are factors defined by THORNTHWAITE (1948).

The relationship between the base saturation percentages and annual precipitation and between the base saturation percentages and d are not significant at the 5 % level. But the correlation between the base saturation percentages and Im is significant (Fig. 4 and Table 3). The regression equation is:

$$V\ \% = -0.0019 \times (\mathrm{Im})^2\ (\mathrm{mm}) + 87.25$$

When the values of the Im are high, the V % will be small. The variations of annual moisture have stronger influence upon the V % than d in the Istria Peninsula and the Adriatic coastal region. Generally, the degree of d is controlled by the dryness and the high temperature in summer in these regions.

5. *Exchangeable cation (S)*

The exchangeable cations were calculated as the sum of calcium, magnesium, potassium, and sodium which were extracted with 1 N NH_4OH acetate.

The amount of the exchangeable cations in each soil set are highest in the Adriatic region and smallest in the Inland region. The orders of the amounts of cations in the B_2 horizon are as follows: $Ca^{++} > Mg^{++} > Na^+ > K^+$ in the Adriatic coastal region, and $Ca^{++} > Mg^{++} > K^+ > Na^+$ in the Inland region. In the Istria Peninsula, both orders occur.

Sodium is quite readily removed by leaching. The amount of exchangeable sodium in the soils of the humid region is usually very low, and lower than that of potassium. It is suggested that the dry climate in the Adriatic coastal region and the humid climate in the Inland region have some influence on the amount of cations. Sodium can be carried to the

Table 2: The results of chemical analyses at the typical profiles

Location	Depth cm	Horizon	Soil			Texture		pH (KCl)	$CaCO_3$ %	Humus %
			corse sand %	fine sand %	silt %	clay %	texture			
(Inland)										
Jordankal	0– 7	A_1	2.32	26.23	27.35	44.10	loamy clay	4.32	0.00	4.21
(Loc. 1 in Fig. 2*)	7– 21	A_3	1.22	25.98	20.98	51.82	clay	4.11	0.00	1.64
	21–200	B_2	0.59	21.86	15.40	62.15	clay	3.92	0.00	1.20
Perovo	7– 40	A_3	2.18	29.35	36.07	32.40	loamy clay	3.80	0.14	8.20
(Loc. 2)	40– 80	B_1	2.58	26.42	15.17	45.83	clay	3.98	0.00	1.09
	80–160	B_2	0.19	13.56	2.85	83.40	clay	5.72	0.00	1.09
Vrhnika	0– 12	A	1.40	25.40	44.75	28.48	loamy clay	5.41	0.42	6.29
(Loc. 3)	12– 30	B_1	1.05	24.72	32.13	42.10	loamy clay	5.32	1.39	3.28
	30–120	B_2	0.19	17.21	5.85	76.75	clay	5.70	0.28	1.92
(Istria)										
Kozina	0– 15	A_1	0.43	31.32	34.02	34.23	loamy clay	6.62	0.14	4.92
(Loc. 4)	15– 40	B_1	0.17	27.83	27.05	44.95	loamy clay	6.48	0.00	3.12
	40– 85	B_2	0.31	29.44	26.49	43.76	loamy clay	6.48	0.00	1.37
Lovreč	5– 12	A	0.28	31.92	26.60	41.20	loamy clay	6.45	0.63	3.28
(loc. 5)	12– 35	B_1	0.24	23.61	22.25	53.90	clay	6.34	0.00	2.84
	35–105	B_2	0.17	25.11	20.47	54.25	clay	6.18	0.00	1.64
Moščenčka Draga	10– 25	A	0.17	23.23	15.48	61.12	clay	6.42	7.11	3.83
(Loc. 6)	25– 45	B_1	0.39	11.96	10.48	77.17	clay	6.10	0.14	1.48
	45–110	B_2	0.58	13.37	8.70	77.35	clay	5.70	0.00	0.82
(Adria)										
Jablanac	6– 17	A_3	0.26	27.99	16.19	55.56	clay	6.60	5.43	4.10
(Loc. 7)	17– 36	B_1	0.41	24.69	20.75	54.15	clay	6.60	5.60	3.94
	36– 75	B_2	0.45	19.30	19.30	60.95	clay	6.58	5.43	2.74
Dubrovnik	15– 22	A	1.41	41.09	7.35	50.15	clay	7.10	25.08	8.20
(Loc. 8)	22– 31	B_1	0.29	16.21	9.30	74.20	clay	7.07	15.38	3.01
	31– 90	B_2	0.22	15.63	8.53	75.62	clay	6.92	0.28	2.19
Njivice	0– 11	A	5.21	30.19	31.60	33.00	loamy clay	6.58	20.85	8.48
(Loc. 9)	11– 23	B_1	9.50	24.98	32.27	33.25	loamy clay	6.60	4.18	7.12
	23– 50	B_2	3.22	20.63	25.87	50.28	clay	6.93	2.09	4.92

soil by wind, which can transport sea spray. Great amounts of sodium can be attributed to salinization on the Adriatic coast. In the humid and per-humid regions of Yugoslavia, there is no saline soil because of the leaching process in the soils. But, the correlation calculation showed that the distances of sampling places from the coast have no significant relationship with the amounts of exchangeable sodium in the three regions.

The correlations between Na^+meq/100 g and the Im (mm), and between Na^+meq/100 g and annual precipitation are not significant. However, Na^+meq/100 g in the B_2 horizons shows significant correlation to the d (mm) (Fig. 5). The correlation coefficient is highest ($r = 0.94$) between Na^+meq/100 g and the d, and its regression equation is:

$$Na^+(\mathrm{meq}/100\ \mathrm{g}) = 0.0000122\ d^2\ (\mathrm{mm}) + 0.07$$

The amount of Na^+meq/100 g increases with d, which is the indicator of the dryness and the high temperature in summer under the Mediterranean climate. If the dryness of the soils in summer increases, the amount of Na^+ meq/100 g will increase also.

6. *Free iron oxide*

Free iron oxide was measured by using the Tamm solution (Tamm, 1934), which was made with 0.1 M oxalic acid and 0.17 M ammonium oxalic acid kept at 3.3 pH. In this acid solution, iron ions are combined by oxalat. An atomic absorption spectrophotometer (Varian 100) was used to detect Fe.

Large amounts of free iron oxide exist in the Inland region, and small amounts in the Adriatic coastal region in every horizon. There are negative significant correlations between free iron oxide and pH, and between free iron and base saturation percentage as shown in Fig. 6. The regression equation for the free iron oxide and pH is:

$$Fe_2O_3(\%) = -1.89(\mathrm{pH}) + 9.83$$

For free iron and base saturation percentage (V %), it can be concluded that the relation is different in the Inland region from that of the Adriatic coast and the Istria Peninsula. For the Inland region, as shown in Table 3, the respective equation is:

$$Fe_2O_3(\%) = -1.74 \log V(\%) + 7.24$$

Exchangeable Cations (meq/100g)					H	CEC	V%	Fe_2O_3 %	MnO %	$\frac{Fe_2O_3}{clay} \times 100\%$	Soil Color (dry)
Ca^{++}	Mg^{++}	K^+	Na^+	S	meq/100g	meq/100g					
4.05	1.70	0.84	0.02	6.61	14.99	21.60	30.60	3.9	1.12	8.8	5YR4/6
3.06	1.18	0.24	0.02	4.50	13.33	17.83	25.23	4.7	0.98	9.1	5YR4/8
1.84	1.00	0.09	0.03	2.96	14.40	17.36	17.05	4.4	0.77	7.1	2.5YR4/6, 5/6
1.06	1.41	0.11	0.03	2.61	15.23	17.84	14.63	4.9	0.56	15.1	10YR4/6
0.92	2.20	0.09	0.03	3.25	14.22	17.47	18.60	6.5	0.63	14.2	7.5YR6/6, 5/6
3.86	3.55	0.07	0.03	7.51	9.19	16.70	44.97	4.4	0.62	5.2	2.5YR4/8, 5YR4/8
16.05	2.43	0.43	0.12	19.03	12.21	31.24	60.91	3.9	0.43	13.7	7.5YR5/4, 4/4
18.82	2.44	0.20	0.11	21.57	9.90	31.47	68.54	3.8	0.33	9.0	7.5YR5/4, 4/4
24.07	4.43	0.24	0.13	28.87	10.55	39.42	73.23	4.5	0.21	5.9	2.5YR4/6, 5YR4/6
36.18	0.82	0.43	0.21	37.64	7.11	44.75	84.11	2.4	0.61	7.0	7.5YR3/2
19.25	0.46	0.20	0.19	20.10	7.05	21.15	74.03	2.5	0.35	5.6	5YR3/6, 2.5YR3/6
29.32	0.23	0.20	0.17	29.92	5.93	35.85	83.45	2.6	0.92	5.9	2.5YR3/4, 5YR3/4
25.96	0.88	0.48	0.13	27.45	6.05	33.50	81.94	3.3	0.76	8.0	5YR4/6
18.23	0.43	0.38	0.22	19.26	6.52	25.78	74.70	2.8	0.50	5.2	5YR4/6
24.21	0.59	0.38	0.19	25.37	7.11	32.48	78.10	3.2	0.40	5.9	2.5YR4/6, 5YR4/6
30.05	3.71	0.61	0.27	34.64	6.87	41.51	83.44	5.5	0.09	9.0	2.5YR3/6
17.65	1.46	0.26	0.32	19.69	9.07	28.76	68.46	7.2	0.08	9.3	2.5YR4/6, 10R4/6
20.71	1.98	0.24	0.32	23.25	10.08	33.33	69.75	7.2	0.08	9.3	2.5YR4/6, 10R4/6
31.07	1.25	0.35	0.25	32.92	6.52	39.44	83.46	1.1	0.55	2.0	2.5YR3/6, 5YR3/6
31.80	0.64	0.32	0.28	33.04	6.52	39.56	83.51	1.0	0.58	1.8	2.5YR4/6, 3/6
34.28	0.43	0.26	0.25	35.22	5.81	41.03	85.83	1.1	0.42	1.8	2.5YR4/6, 3/6
34.43	15.50	0.59	0.58	51.10	4.44	55.54	92.00	1.4	0.46	2.8	5YR3/4
26.40	13.82	0.42	0.76	41.40	5.33	46.73	88.59	2.5	0.35	3.4	2.5YR4/4, 3/6
22.03	11.79	0.45	0.60	34.87	5.75	40.62	85.84	2.6	0.45	3.4	2.5YR3/6, 10R3/6
31.07	2.28	0.48	0.34	34.27	8.89	43.16	79.40	1.6	1.63	4.8	7.5YR4/4
21.30	2.12	0.56	0.49	24.47	9.19	33.66	72.69	1.9	1.54	5.7	7.5YR4/4
3.09	1.24	0.30	0.43	34.06	6.82	40.88	83.31	0.6	0.65	1.2	5YR4/6

For the Istria Peninsula and the Adriatic coastal region, the equation is:

$$Fe_2O_3(\%) = -33.65 \log V(\%) + 66.08$$

The $[Fe_2O_3(\%)/\text{clay}] \times 100\%$ was calculated for each soil set as shown in Table 2. The ratio of those percentages in the A horizons and the B_2 horizons in each soil set, are highest in the Inland region. The ratios in the Istria Peninsula and in the Adriatic coastal region are almost the same except for the set at Njivice, the southern-most part of the Adriatic coastal region studied.

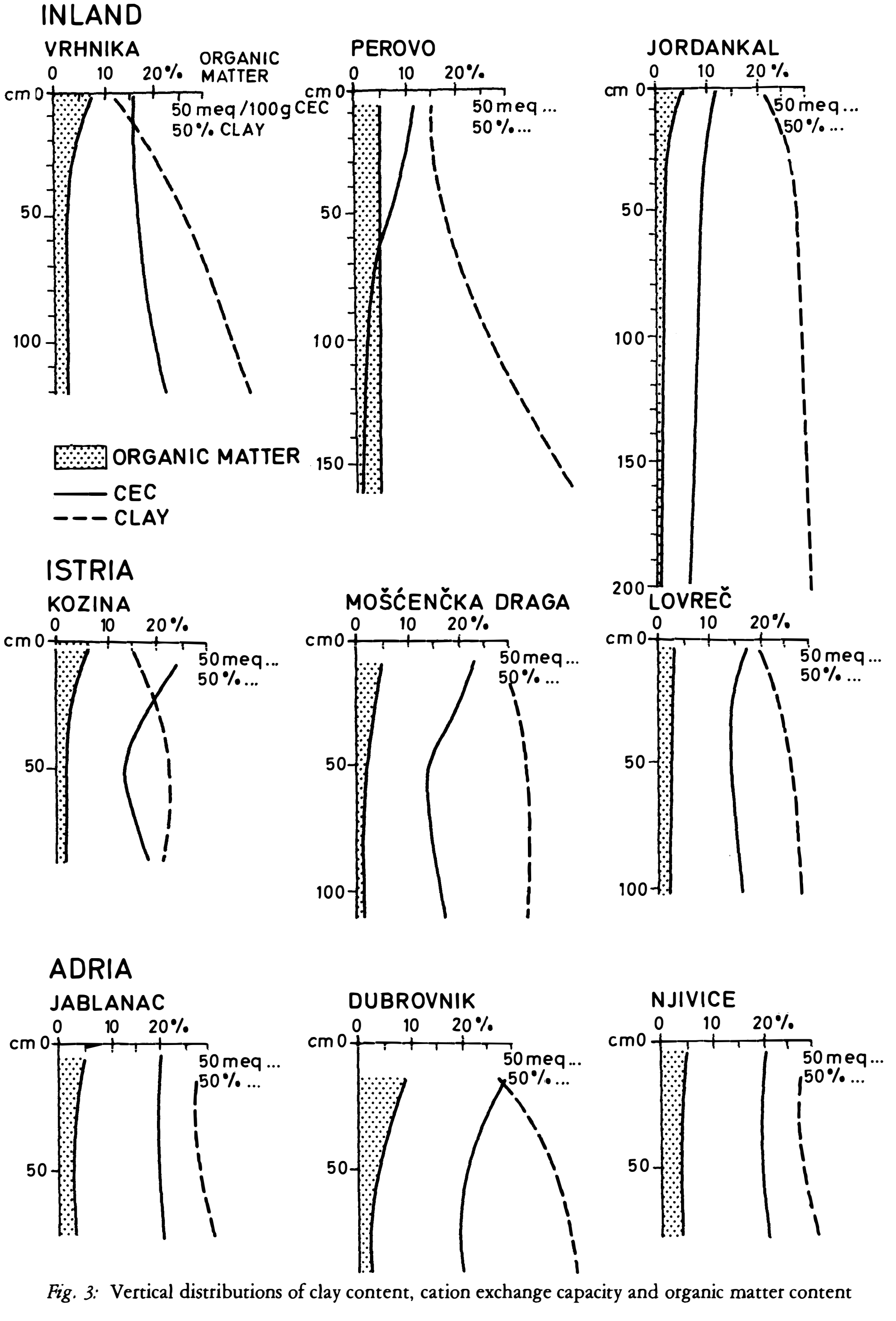


Fig. 3: Vertical distributions of clay content, cation exchange capacity and organic matter content

When only the B_2 horizons are considered it is found that the values of iron oxides and of clay percentages are higher in the Inland region than the other regions. These facts suggest that the migration of free iron oxide and clay is easier and their accumulation greater in the soils of the Inland region under the humid climate than the other regions.

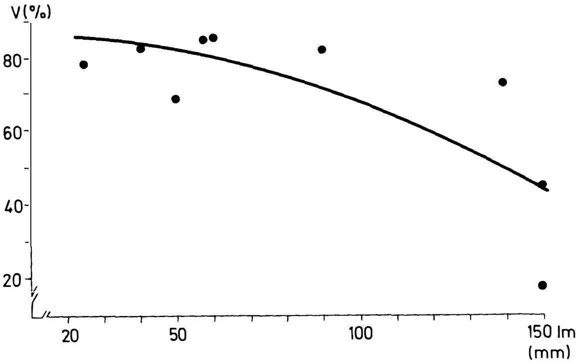


Fig. 4: The relationship between degree of base saturation (percentage) and Im (mm) (moisture index) in B_2 horizon
$V(\%) = -0.00194\ Im^2(mm) + 87.25;\ r = -0.78$

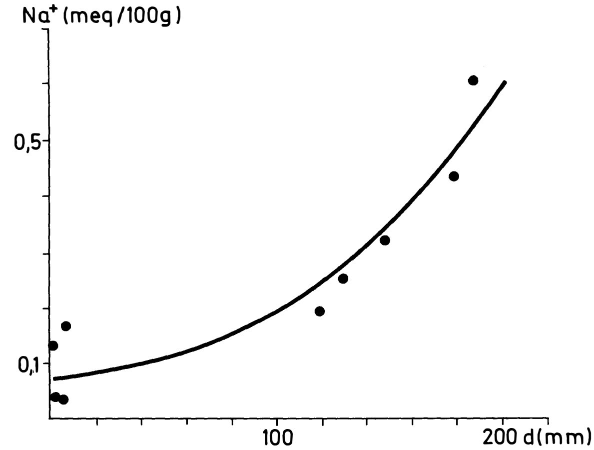


Fig. 5: The relationship between exchangeable Na^+ (meq/100 g) and d (mm) (water deficiency) in B_2 horizon
$Na^+(meq/100\ g) = 0.0000122\ d^2(mm) + 0.074;\ r = 0.94$

Table 3: The correlation coefficients between V(%) and Im (mm), Na^+ (meq/100 g) and d (mm), and Fe_2O_3 (%) and V(%) at the three cases

	y = ax + b	y = ax² + b	y = a log x + b
V(%), Im(mm)	r = −0.73	r = −0.78	r = −0.64
Na^+(meq/100 g), d(mm)	r = 0.98	r = 0.95	r = 0.81
Fe_2O_3(%), V(%)			
Inland	r = −0.04	r = −0.48	r = −0.57
Istria and Adria	r = −0.67	r = −0.61	r = −0.61

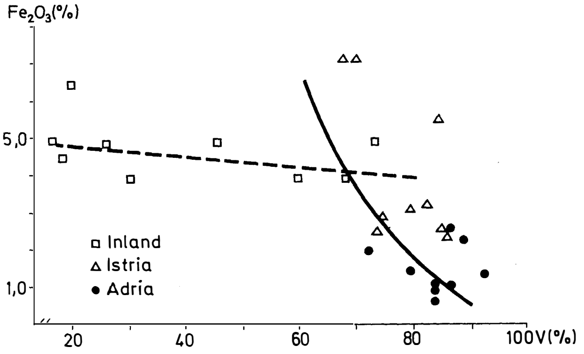


Fig. 6: The relationship between free iron oxide content and degree of base saturation
Inland $Fe_2O_3(\%) = -\ 1.74 \log V(\%) + 7.24;\ r = -0.57$
Istria + Adria $Fe_2O_3(\%) = -33.65 \log V(\%) + 66.08;\ r = -0.61$

V. The Hue of the Red Soils

1. *Free iron oxides and hue*

The color of the soils in the Yugoslavia limestone area has been discussed by URUSHIBARA (1974), and URUSHIBARA and KOJIMA (1974). It was concluded that the hue of the red soils is controlled positively by the amount of Fe_2O_3 (%), analysed by the Mehra-Jackson method, and negatively by the C (%) in the A horizon. But the amount of Fe_2O_3(%) can be an index of hue only in the B_2 horizon.

In this paper, only the hue of the soil color will be dealt with, because the value and the chroma change easily by the contents of water in the soil. 48 soil profiles were sampled in the three regions as mentioned already. They were air dried until the water content was less than 5%. Then the hue was determined by using the Munsell soil color chart.

The relations between Fe_2O_3(%) and the hue in the B_2 horizons, which are almost independent from the amount of C (%), are shown in Table 4. When the correlation coefficients were calculated for each region, high coefficients were obtained for the Istria Peninsula (r = 0.72) and for the Adriatic coastal region (r = 0.50 which is significant at 1% level). However, significant correlation were not found for the Inland region. When the correlation coefficient is calculated by the combined values of the Inland region and the Istria Peninsula, a significant correlation (r = 0.57) was obtained at the 2% level. The regression equation, as shown in Fig. 7, is:

$$Fe_2O_3\% = 0.59\ \text{hue} + 1.08$$

When the contents of free iron oxide become higher, the hue changes from YR (Yellow Red) to R (Red). The correlation coefficient between Fe_2O_3(%) and hue of the Istria Peninsula and in the Inland regions combined is significant. The content of Fe_2O_3(%) in the Adriatic coastal region is half of that in the Inland and in the Istria Peninsula for the same values of hue. Generally speaking, the contents of Fe_2O_3(%) in the Inland regions are bigger than in the Istria Peninsula for the same hue.

The correlation coefficients between Fe_2O_3(%) and the climate were examined as shown in Table 4. In all the regions, the correlation between Fe_2O_3(%) and d is significant (r = 0.44) at the 5% level. The correlation between Fe_2O_3(%) and P/E index is significant (r = 0.24) at the 10% level, and the correlation between Fe_2O_3(%) and the Im is also significant (r = 0.26) at the 10% level. For instance, in the case of significance at 10% level, the standard deviation of Fe_2O_3(%) for the Im value was about ±1.2%. Therefore, it can be concluded that the contents of free iron are influenced by the P/E and Im, and strongly by the d. But, when the correlations were calculated in each region separately, significance could be found between (Fe_2O_3(%) and at the 10% level only of the Istria Peninsula.

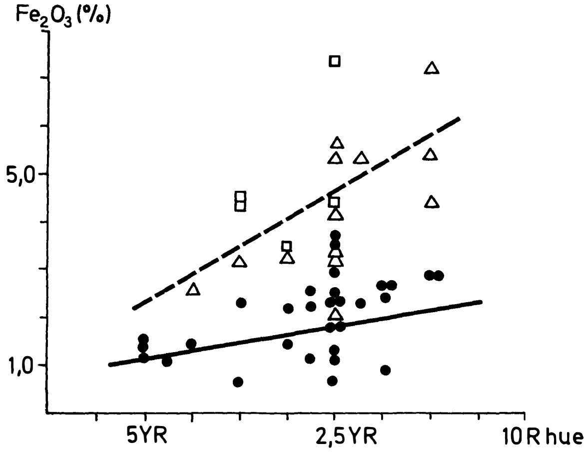


Fig. 7: The relationship between free iron oxide content and hue
Inland + Istria $Fe_2O_3(\%) = 0.59$ hue $+ 1.08$; r = 0.57
Adria $Fe_2O_3(\%) = 0.23$ hue $+ 0.76$; r = 0.50

Table 4: The correlation matrix of the B_2 horizons

All regions (n = 48, *n = 36)

	Fe_2O_3 %	MnO %	hue	P/E	Im	d	Hem*
Fe_2O_3 %		0.0133	0.4032	0.2448	0.2582	0.4366	0.3223
MnO %			0.2003	0.1344	0.1356	0.0648	0.0179
hue				0.1473	0.1475	0.2873	0.1732
P/E					0.9997	0.6249	0.3583
Im						0.6373	0.3463
d							0.2834

Inland region (n = 5)

	Fe_2O_3 %	MnO %	hue	P/E	Im	d	Hem
Fe_2O_3 %		0.3270	0.5018	0.6521	0.6507	–	0.0760
MnO %			0.2581	0.8628	0.8674	–	0.3494
hue				0.1122	0.1136	–	0.2458
P/E					0.9996	–	0.0080
Im						–	0.0042
d							–

Istria region (n = 13, *n = 11)

	Fe_2O_3 %	MnO %	hue	P/E	Im	d	Hem*
Fe_2O_3 %		0.5862	0.7180	0.0700	0.0361	0.4859	0.3373
MnO %			0.4378	0.3647	0.3659	0.3121	0.1120
hue				0.4828	0.4854	0.6943	0.5101
P/E					0.9999	0.6807	0.1283
Im						0.6796	0.1320
d							0.4921

Adriatic coastal region (n = 30, *n = 20)

	Fe_2O_3 %	MnO %	hue	P/E	Im	d	Hem*
Fe_2O_3 %		0.2909	0.5036	0.0316	0.0424	0.0203	0.0431
MnO %			0.1420	0.1440	0.1412	0.3957	0.3175
hue				0.0603	0.0596	0.3379	0.1092
P/E					0.9995	0.6291	0.3666
Im						0.6306	0.3024
d							0.1856

2. *Free iron oxide and free manganese oxide and hue*

At some places in the field, the soil corticated with manganese in the B_2 horizon was observed. Therefore, the free manganese oxide and the hue were analyzed. The free manganese oxide was extracted by the Tamm solution like the free iron oxide, and the atomic absorption spectrophotometer was used to detect iron and manganese. The correlation between MnO(%) and hue in the B_2 horizon is not significant for the samples of any of the three regions, nor for all samples considered together (Table 3). However, a significant correlation between MnO (%) and Fe_2O_3 (%) (r = 0.59) was found at the 5 % level in the Istria Peninsula samples.

The relationship between MnO (%), Fe_2O_3 (%) and the hue in the B_2 horizon was obtained as in Fig. 8. The hue of the soil color is controlled strongly by the contents of free iron oxide and manganese oxide. When the amount of free manganese oxide exceeds a certain value, soil color becomes nearer to the YR (Yellow Red) side than the R (Red) side of the color scale. But, the trend curve between Fe_2O_3 (%) and MnO (%) and the hue for the Adriatic coastal region differs from that for the Inland region plus the Istria Peninsula.

The correlation between the MnO (%) and the indices of climate (P/E, Im and d) were calculated for all regions, but they are not significant. The correlation coefficient calculated for each region separately is significant only between the MnO (%) and d at the 5% level.

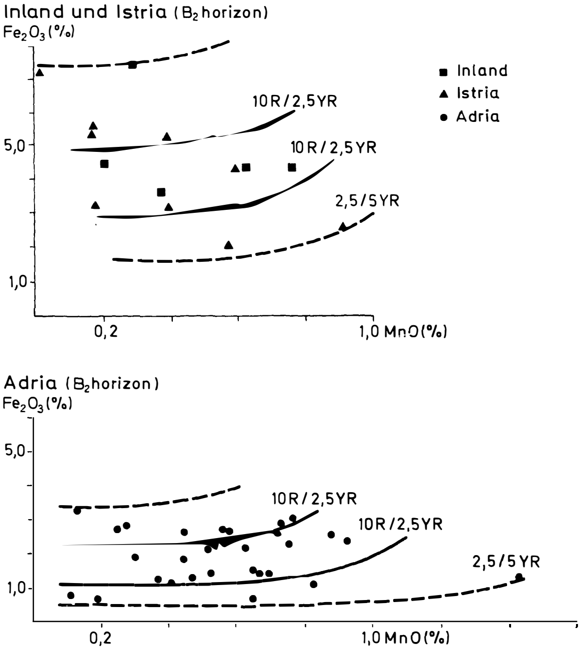
3. *Free iron oxide and hematite and hue*

The amounts of free iron oxide strongly influence the hue, as mentioned above. In this part of the study, the crystalline structures of iron were examined qualitatively with X-ray analysis by the Rigakudenki 40011B2 X-ray instrument mounted with an Fe target and a Mn filter. The recorded condition was 30 KV, 15 mA, count range 25 c.p.s., time constant 2 seconds, slit 1°−0.3−1°, scanning speed 2°/min, and chart speed 2 cm/min.

Hematite was analysed by considering the sum of the highest (2.69 Å) and the second highest (1.63 Å) peak intensity as a rough standards of crystallinity.

The correlation coefficient between hematite and hue is not significant for samples of all regions combined nor for any of the three regions taken separately (Table 4). However, that between hematite and Fe_2O_3 (%) is significant in all the regions at the 10% level. It can be said, therefore, that the hematite influences the hue of the soil color through the content of Fe_2O_3 (%).

The investigation of the relationship among hue, iron oxide and hematite in the three regions demonstrated a general tendency. When the peak intensities of hematite are higher and the amount of Fe_2O_3 (%) is greater, the hue of the soil color changes from YR (Yellow Red) toward R (Red). However, the difference between the values of those in each of the three regions is great. There was no difference between the horizons in the Inland region and in the Istria Peninsula (Fig. 9). However relatively greater differences were found between the horizons in the Adriatic coastal region. Even though the tendency is similar, the figures show differences from horizon to horizon.


Inland und Istria (B_2 horizon)

Adria (B_2 horizon)

Fig. 8: The relationship between free iron oxide, manganese oxide and hue in B_2 horizon

The lower limit of the values of free iron oxide and hematite taken from the same hue of soil color in the B_2 horizon is highest in the Inland region, and lowest in the Adriatic coastal region (Fig. 9). In the Adriatic coastal region, in spite of the low amount of Fe_2O_3 (%), the peak intensities of the hematite are higher than those in the other regions. Regionality of such relationships among the free iron oxide, the hue of soil color and the hematite is demonstrated. The values from the Adriatic coastal region to the Istria Peninsula differ from those in the Inland region.

The following relationships were found between the hematite and the climatic conditions in the three regions. The correlation coefficients are not significant between the hematite and the P/E, between the hematite and the Im, or between hematite and the d. However, a significant correlation was obtained between hematite and the P/E (r = 0.36), and between hematite and the Im (r = 0.35) calculating them for all three regions at the 5% level. But, the peak intensities of the hematite have a weak correlation with the d (r = 0.28) for all three regions. The climatic conditions expressed by P/E and the Im influence the hematite values strongly.

A correlation coefficient was significant with hue and d in all the regions at the 5% level. On the other hand, the correlation coefficient calculated in each of the three regions separately, was quite high (r = 0.69) in the Istria Peninsula at the 5% level. The correlation coefficients between the hue and the P/E were significant (r = 0.48), and between the hue and the Im (r = 0.49) at the 10% level in the Istria Penin-

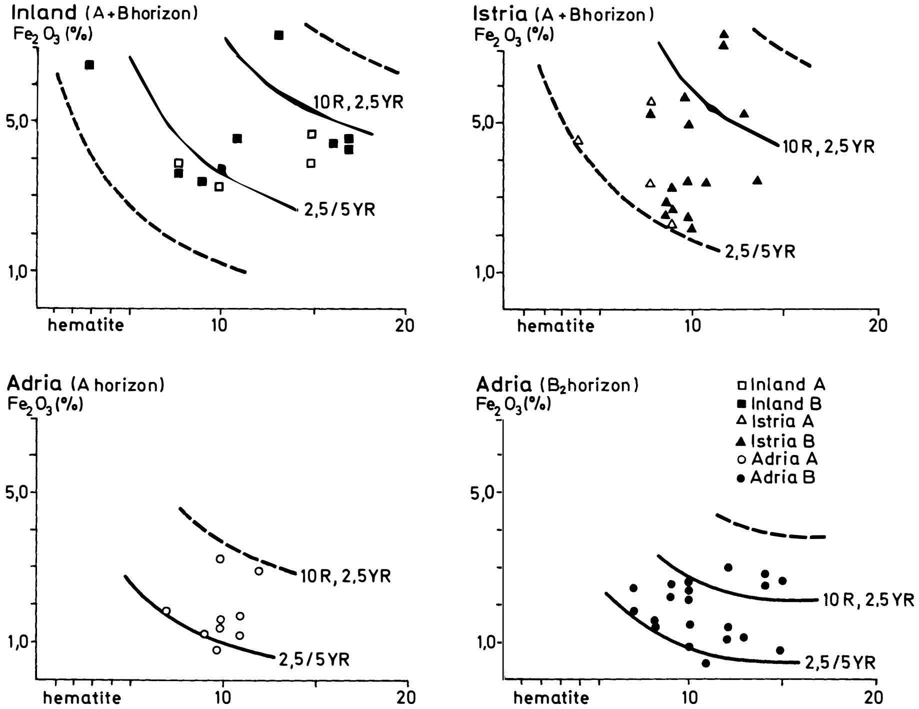


Fig. 9: The relationship between free iron oxide, hematite and hue in the three regions

sula. In the Adriatic coastal region, however, the hue has significant correlation only with the d (r = 0.34) at the 10% level. From these results, it can be concluded that hue has a closer relation to d than to P/E, or to Im in the Istria Peninsula and in the Adriatic coastal region. But, it must be noted that these conclusions are not appliciable to the Inland region, because d is 0 everywhere.

VI. Summary and Discussion

The results mentioned above can be summarized as follows;

1. The properties of Mediterranean red soils, which were determined for three different climatic regions (i) Inland region, (ii) Istria Peninsula and (iii) Adriatic coastal region, have regionality. Particularly, the clay percentage increases markedly from the A to B_2 horizons in the Inland region. The distribution of the cation exchange capacity can be attributed to the kinds of clay minerals in the Inland region differ from those in the Adriatic coastal region. The amounts of the CEC and the clay (%) in the Istria Peninsula take a middle position in the Inland region and the Adriatic coastal region. This range suggests that the climate of Istria region is also the middle of the two other regions.

2. The exchangeable sodium contents show a significant positive correlation with the d in all three regions. The amount of exchangeable sodium has no relation to distance from the coast, but it is determined by the d values. Furthermore, high negative correlation was found between the base saturation and the Im in the B_2 horizon in the three regions. These facts suggest that present climatic conditions are important to base saturation and exchangeable sodium.

3. The relation curve between the base saturation and the free iron oxide in the Inland region is different from that in the Istria Peninsula and the Adriatic coastal region. This difference is a reflection of the annual humidity.

4. There are relations between the properties controlling the red color and the climatic factors. Fe_2O_3 (%) has a close relation to d and a weak relation to P/E and Im. Hematite has a strong relation to P/E and Im, and a weak relation to d. The correlation coefficients between MnO (%) and P/E, Im, and d are not significant. The hue has a strong relation to P/E and Im. From these results, it can be concluded that the amounts of Fe_2O_3 (%), and hematite have a close relation to the present humid and dry climatic conditions, but the hue is influenced more strongly by the dry condition. The MnO (%) has no relation with the conditions of the present climate.

5. A positive significant correlation if found between the free iron oxides and hue. The relation can be expressed by one tendency curve fitted to the values in the Inland region and in the Istria Peninsula. But, a different tendency curve was found for the values on the Adriatic coast (Adria). It can be said, therefore, that the regionality, (Inland + Istria versus Adria) is demonstrated between the free iron oxides and the hue.

6. Concerning the relation between the hue, the free iron oxide and the free manganese oxide, the following reference

was revealed. When the amount of free manganese oxide reaches a certain limit, the hue takes closer values to the YR (Yellow Red) than to the R (Red). This relation reveals also the same regionality as mentioned above, (Inland + Istria versus Adria).

7. The hematite and free iron oxides in the soils control mainly the hue of the soil color. The higher the amount of free iron oxides and the higher the peak intensity of the hematite, the nearer will the hue approach R (Red). This general tendency is true of soils from all regions, but the absolute values of each factor are different. When the hue is the same in the three regions, the amounts of free iron oxide and the values of hematite are lower in the Adriatic coastal region than in the Istria Peninsula and the Inland region.

8. The results mentioned above suggest that two types of region occur, as follows: 1. the regional differences in the relationship between the base saturation and the amount of free iron oxide, which have a close relation to the present climatic conditions, show that the Inland is separate from the Istria + Adria, and, 2. the relationship between the amounts of free manganese oxide and free iron oxide, which have no significant relations to the present climatic conditions, and the hue, which has a relation only to the dry condition, show that the Inland + Istria differ from the Adria.

9. Therefore, when we consider the properties which have no relation to the present climate or have a weak relationship to certain factors of present climatic conditions, the soils of the Istria Peninsula are similar to those of the Inland region. This regionality suggests that the Istria Peninsula and Inland region shared common climatic conditions during the Quaternary ice age. On the other hand, the Istria Peninsula and the Adriatic coastal region have been situated under climatic conditions similar to those at present.

During the Quaternary ice ages, the Adriatic coastal line was located near Zadar (Roglič, 1963). The Palaeo-air pressure pattern in summer during the Quaternary (Wright & Lamb, 1974) shows that the low air pressure in Europe expanded to the south. These studies suggest that the Istria Peninsula during the Quaternary ice ages was wetter than at present and climatic conditions were almost the same as in the Inland region.

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KLIMAGEGENSÄTZE IN SÜDPERU UND IHRE AUSWIRKUNGEN AUF DIE VEGETATION

Mit 10 Abbildungen, 2 Photos, 2 Tabellen und 2 Beilagen (I + II)

Michael Richter

Summary: Climatic contrasts in southern Peru and their effects on the vegetation

In southern Peru the climate is subject to several gross changes from the Pacific to the Highlands. The relatively cool coastal area, with small diurnal fluctuations of temperature and atmospheric humidity, is followed above the 800 m contour by the dry and warm Atacama Desert. From 2,000 m. above sea-level precipitation increases while temperatures decrease over very short distances. In the Highland east of the volcanic cordilleras diurnal amplitudes are particularly high (30 °C. in August), but decrease again in the direction of Lake Titicaca (Fig. 3 a, b). A hygro-thermal climatic typology according to W. Lauer/P. Frankenberg (1978, slightly altered) with balancing of the hydrological cycle elucidates the rapid change of the climatic circumstances (Map 1). Results of microclimatic measurements at different altitudes above sea-level show (Figs. 6–8) that further marked accentuation of extreme values of the individual climatic factors occurs, especially at great altitudes. Particularly noteworthy are the diurnal fluctuations of the surface temperature above the 4,000 m. contour, which, thanks to the special radiation conditions, may rise to well over 60 °C.

Since the plants are predominantly confronted with the surrounding microclimate (e.g. during the germination phase at the soil surface, in their adult state at the plant surface), the signs of adaptation vary greatly at the different stages of adaptation (Map 2). Xerophytes and lichen characterize the temperate climate of the coastal zone, succulents and dwarf shrubs the semi-desert above the largely barren Atacama. Hard and ericaceous foliage are typical phenomena in the tola heath of the western cordilleras. The xeromorphic characteristics of the puna grasses and the polster plants in the highland are evidence of the need for protection against extreme diurnal fluctuations of the surface temperatures and against high rates of evaporation. In the Titicaca region, however, the growth forms of the plants are less unusual; hemicryptophytes predominate here.

This study attempts to elucidate the significantly more abrupt change in the climatic and plant-geographical change of forms at high altitudes on the fringe of the tropics than in mountains of middle and higher latitudes.

Von den extremen Klimaverhältnissen in Südperu fanden bislang insbesondere die hohen Tagesschwankungen der Lufttemperatur sowie die Frostwechselhäufigkeit Berücksichtigung (s. z. B. C. Troll, 1966). Ausführliche Beschreibungen der Pflanzen-Verbreitung und -Wuchsformen durch A. Weberbauer (1911) bildeten zudem eine Grundlage für ökologische Betrachtungen durch H.-W. Koepcke (1961).

Für eine eingehendere Untersuchung der Beziehungen zwischen Klima, Wasserhaushalt und Vegetation stehen jedoch erst seit kurzem Meßdaten zur Verfügung. Dies betrifft vor allem die relativ dicht besiedelte Region von der südperuanischen Küstenwüste über den Kordilleren-Westabfall und die Altiplano-Hochfläche bis zum Titicaca-Becken. Das in Abb. 1 vorgestellte Arbeitsgebiet umfaßt die Departementos Tacna, Moquegua sowie jeweils die südlichen und mittleren Provinzen der Dep. Puno und Arequipa.

Hier wurde zum einen während der letzten Jahrzehnte das Stationsnetz des peruanischen Wetterdienstes (SENAMHI)1) erheblich ausgebaut, zum anderen liegt seit wenigen Jahren mit den Informations- und Tabellenbänden eines nationa-