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Principal Features of the Chemical Composition of Suspended Load in World Rivers

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The main source of sedimentary rock matter is riverine suspended matter (hereafter, suspension), which exceeds 80% of all the solid and dissolved material transported from continents to seas and oceans. The great body of data available on the composition of suspension in different rivers of the world are inadequately systematized and generalized, impeding the complex geochemical analysis of sedimentation processes, particularly the application of the geochemical balance method. The present paper discusses trends in distribution of the major petrogenic elements (Si, Al, Fe, Mg, Ca, Na, and K), whose oxides accounts for >80–90% of the dry matter of riverine suspension.

We systematized and generalized data on the basic chemical composition of the suspended load from 128 rivers over the observation period from the beginning of the 20th century (the complete source information will be presented in a separate work). Since the direct influence of economic activity on the concentration of the major petrogenic elements in the riverine suspension is negligible, the impact of human factors was not taken into account. We also did not carry out differentiated study of the riverine suspension composition in different hydrogeological (low water, high water, and flood) periods, because of scarcity of the available information. We calculated normal values if two or more analyses were available for a river. To unify the results of chemical analyses, the sum of the major oxides was taken to be equal to 100%.

The statistical treatment of the whole data array yielded no close correlation between the content of the major petrogenic elements. This can be attributed to an intense homogenization of solid erosion products in watersheds. If rivers are grouped by their location in different climatic zones on the basis of information from [2, 8], one can see certain trends (Table 1).

When passing from cold to warmer areas not located in mountain regions, one can see a decrease in the content of SiO_2, which is nearly equal in humid and arid climates. Simultaneously, the Al_2O_3 content shows a nonlinear growth, which is prominent in the minimal SiO_2 concentration area (Fig. 1) confined to the extensive laterization zone in the tropical belt.

The Fe_2O_3 content is minimal in river load of the temperate zone and higher in river suspension of the tundra–taiga and tropical zones. It should be pointed out that the mentioned differences are more prominent in humid climate areas and almost insignificant in low precipitation areas.

Unlike the Fe_2O_3 content, the CaO and MgO contents are high in river load of the temperate zone and low in rivers of the tundra–taiga and tropical zones. The discrepancy is also greater in the humid climate. Maximal contents of CaO and MgO are related to substantial concentrations of carbonates. It is difficult to explain why carbonate accumulation is more intensive in rivers of the temperate zone with humid climate than in rivers of slightly humid areas of the tropical zone. This problem requires detailed study. However, one aspect, which is often overlooked, should be mentioned. Duration of the formation and transportation of suspended load by rivers is much longer than the time during which river water passes the whole path of flow. Therefore, the observed suspension composition most likely reflects past conditions rather than present-day ones.

The Na_2O content in river load decreases from polar to tropical regions regardless of climate humidity that reflects higher mobility of Na, which does not accumulate in products of weathering.

A similar trend is established for K_2O only in areas of insufficient humidity. In contrast, the K_2O concentration increases in humid climates. Potassium shows moderate mobility during weathering and accumulates in clay minerals. Plants probably play an essential role in this process. They extract potassium from soils and give it back in a concentrated form within organic detri-

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Table 1. Average composition of the riverine suspended load in different climatic zones, wt %

Climatic zones	SiO_2	Al_2O_3	Fe_2O_3	MgO	CaO	Na_2O	K_2O
Plains, highlands, and low mountains							
Tundra and taiga, $N = 42$	68.30 ± 5.76	13.84 ± 2.87	8.96 ± 4.31	2.30 ± 1.00	2.73 ± 2.02	1.47 ± 0.72	2.40 ± 0.86
Humid climate of the temperate zone, $N = 18$	62.46 ± 4.66	15.96 ± 3.39	8.66 ± 2.39	2.43 ± 0.98	6.58 ± 6.06	1.24 ± 0.81	2.68 ± 0.78
Arid climate of the temperate zone, $N = 5$	63.71 ± 8.90	14.42 ± 3.45	5.08 ± 1.87	2.90 ± 0.70	10.10 ± 4.14	1.49 ± 0.71	2.30 ± 0.29
Humid climate of the tropical zone, $N = 15$	59.76 ± 3.68	23.33 ± 4.89	9.95 ± 1.90	1.90 ± 0.80	1.34 ± 0.87	0.77 ± 0.50	2.95 ± 1.05
Arid climate of the tropical zone, $N = 8$	58.68 ± 5.51	25.39 ± 8.10	9.24 ± 1.86	2.08 ± 1.32	1.80 ± 2.07	0.99 ± 1.14	1.83 ± 1.10
Mountain regions							
Humid climate, $N = 5$	59.82 ± 4.80	16.58 ± 3.63	9.18 ± 4.99	2.33 ± 0.72	7.45 ± 4.40	1.67 ± 0.34	2.97 ± 0.73
Arid climate, $N = 33$	63.60 ± 4.78	14.19 ± 1.55	4.70 ± 1.40	2.70 ± 1.15	9.84 ± 5.53	2.25 ± 0.62	2.68 ± 0.52

Table 2. Suspended load of major rivers [4, 5, 7, 8], for which data on the chemical composition of suspension are available

River	Suspended load	
	10^6 t/yr	%
North America		
Mackenzie	82	12.5
Saint Lawrence	5	0.8
Hudson	36	5.5
Colorado	135	20.5
Mississippi	399	60.7
Total	657	100.0
South America		
Orinoco	210	13.5
Caroni	48	3.1
Amazon	1198	76.7
Parana	92	5.9
Rio Negro	13	0.8
Total	1561	100.0
Africa		
Nile	120	37.4
Senegal	24	7.5
Niger	40	12.5
Congo	48	15.0
Orange	89	27.7
Total	321	100.1
Europe		
Rhine	3	1.6
Seine	1	0.5
Loire	8	4.1
Garonne	6	3.1
Rhone	56	29.0
Danube	68	35.2
Don	5	2.6
Volga	14	7.3
Kuban	8	4.1
Rioni	10	5.2
Northern Dvina	4	2.1
Mezen	1	0.5
Pechora	9	4.7
Total	193	100.0
Asia		
Ob	16	0.5
Yenisei	13	0.4
Lena	20	0.6
Yana	3	0.1
Khatanga	5	0.2
Huan He	1100	35.4
Yangtze	481	15.5
Mekong	160	5.1
Indus	250	8.0
Ganges (Brahmaputra)	1060	34.1
Total	3108	99.9

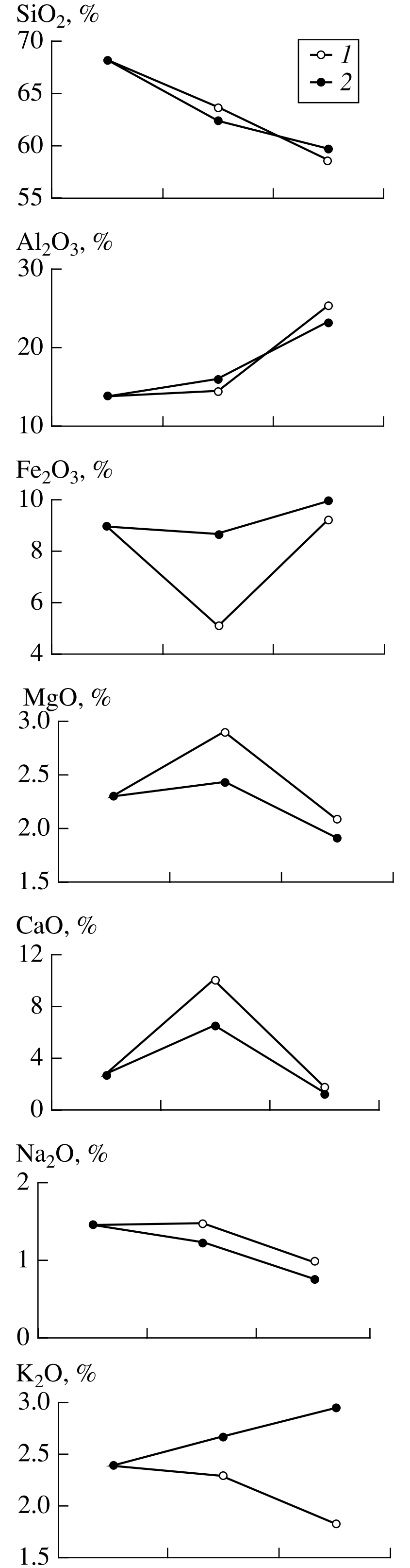

Fig. 1. Contents of the major petrogenic elements in riverine suspensions from different physiographic zones. (*1*) Regions with arid climate; (*2*) regions with humid climate.

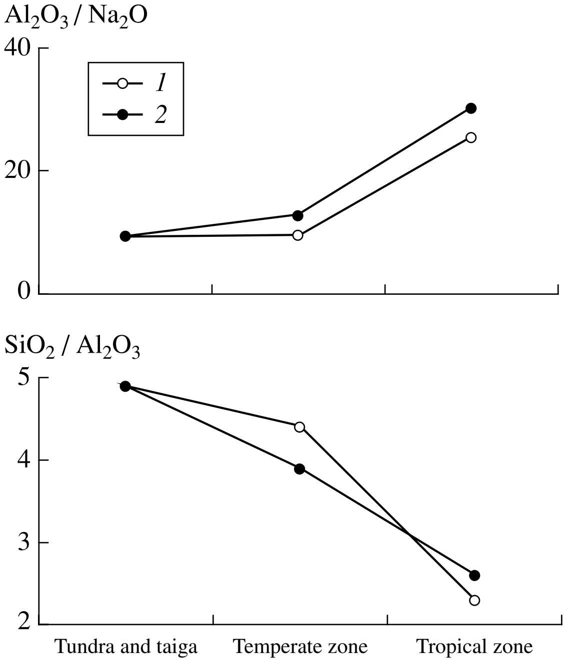

Fig. 2. Al_2O_3/Na_2O vs. SiO_2/Al_2O_3 relationship in riverine suspensions from different physiographic zones. (*1*) Regions with arid climate; (*2*) regions with humid climate.

tus, ash components of which directly participate in the formation of secondary clay minerals. At similar annual mean temperatures, regions with a more humid climate have greater biological productivity. In line with the aforementioned trend, this process should facilitate the accumulation of potassium in products of weathering.

Several parameters can characterize the intensity of weathering. One of them is the Al_2O_3/Na_2O ratio. Both components occur in host rocks mainly in the silicate fraction and exhibit clear distinctions in migration capacity: aluminum belongs to the group of inert components, whereas sodium belongs to more mobile ones. It is apparent that the Al_2O_3/Na_2O ratio should directly correlate with the degree of weathering of the lithogenic base of watersheds. Another parameter is the SiO_2/Al_2O_3 ratio, which involves components of the silicate fraction with different migration capacities. Since the mobility of silicon is higher than that of aluminum, the SiO_2/Al_2O_3 ratio should negatively correlate with the degree of weathering. Indeed, Fig. 2 demonstrates that the lowest degree of weathering of river load is observed in rivers of the tundra and taiga zones, whereas the highest degree is observed in the tropical zone. Rivers of the temperate zone occupy an intermediate position and tend to the tundra and taiga zones.

There is no question that it is necessary to use weighted average values for a correct geochemical interpretation of the global river load. However, realization of this procedure is hampered by scarcity of the available data. Nevertheless, as a first approximation, we can calculate weighted average values of suspended

Table 3. Chemical composition of riverine suspended load from different continents

Continent	River load [3]		Content, wt %							
	10^6 t/yr	%	SiO_2	Al_2O_3	Fe_2O_3	MgO	CaO	Na_2O	K_2O	Total
North America	1080	7.0	71.14	14.22	5.92	1.92	3.23	1.05	2.53	100.01
South America	1238	8.0	60.00	23.19	9.67	1.95	1.33	1.12	2.75	100.01
Africa	1043	6.7	62.02	20.31	8.82	2.61	2.75	1.55	1.96	100.02
Europe	580	3.7	61.21	13.99	7.60	2.84	10.02	1.64	2.70	100.00
Asia	9137	59.1	62.28	17.20	7.77	3.11	5.11	1.37	3.16	100.00
Oceania	2231	14.4	59.76	23.33	9.95	1.90	1.34	0.77	2.95	100.00
Australia	165	1.1	58.68	25.39	9.24	2.08	1.80	0.99	1.83	100.01
Total for continents	15474	100.0	62.26	18.53	8.19	2.70	4.12	1.26	2.94	100.00

Table 4. Comparison of the chemical composition of suspended load and clayey rocks of the continental crust, wt % (difference is given in parentheses, rel %)

Component	Suspended load			Clays and shales [6]
	[1]	[9]	This work	
SiO_2	63.37 (+2.2)	64.49 (+4.03)	62.26 (+0.4)	61.99
Al_2O_3	18.10 (–0.4)	18.24 (+0.4)	18.53 (+1.9)	18.17
Fe_2O_3	8.42 (+6.6)	7.90 (0.0)	8.19 (+3.4)	7.90
MgO	2.39 (–15.5)	1.95 (–31.1)	2.70 (–4.2)	2.83
CaO	4.07 (–10.9)	3.68 (–19.5)	4.12 (–9.4)	4.57
Na_2O	1.56 (+32.2)	1.03 (–12.7)	1.26 (+6.8)	1.18
K_2O	2.09 (–37.8)	2.71 (–19.35)	2.94 (–12.5)	3.36

load of the major rivers (with correction for the unaccounted portion of the total flow) for individual continents. Table 2 gives necessary information on suspended load of major rivers. Owing to the lack of information, let us also assume that the composition of river load from Australia and Oceania is similar to that from arid and humid tropical regions, respectively (Table 1). Then, considering that the weighted average composition of suspension in large rivers of a certain continent characterizes the composition of sediment load and knowing the values of the sediment load for all continents, we can estimate the average chemical composition of river suspension from land in general (Table 3).

Table 4 presents the results obtained and previous data on the average chemical composition of the suspended load in world rivers, as compared to the average composition of clayey rocks from the sedimentary cover of the continental crust. It is evident that average compositions of clayey rocks and the suspended load of rivers in the world differ insignificantly, and our calculations yield the best matching. Maximal discrepancies were observed for K_2O (–12.5%) and CaO (–9.4%), which can be accounted for by transition of these components from seawater to bottom sediments during the formation of biogenic (chemogenic) carbonates and diagenetic silicates, respectively.

Thus, our results show that the main chemical composition of the suspended load of rivers shows a variation trend in different climatic zones. However, the composition generally corresponds to the average composition of clayey rocks of the continental crust. This can be regarded as indirect evidence in favor of the following fact: present-day conditions of sedimentary rock formation differ slightly from the average Phanerozoic setting, which accumulated the main mass of sedimentary rocks of the continental crust.

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