GEOCHEMISTRY OF TERRIGENOUS DEPOSITS IN CONNECTION WITH EUSTATIC FLUCTUATIONS OF SEA LEVEL (LOWER AND MIDDLE JURASSIC, NORTHERN CAUCASUS)

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On the example of J_{1-2} deposits of the Northern Caucasus, it was shown that siderite-bearing deposits are usually confined to strata formed in stages of transgressive development of bodies of water, while horizons with Fe-oolites gravitate to intervals corresponding to regressive episodes. This article discusses the reasons for appearance of siderite-bearing deposits and ones enriched with organic matter. The most likely reason for their formation is supposed to be a process of vigorous interaction of the transgressing sea with lake-marsh and lagoon landscapes which arose as a result of a preceding regression on peneplainized coastal spaces.

Eustatic fluctuations of sea level manifested on a global scale could similarly influence the development of sedimentary basins and result in the appearance of certain common features in cross sections separated from each other by considerable distances. Movements of the shoreline affected the structure of cross sections as a whole, as well as accumulation, in a number of cases, of specific chemical elements, which sometimes formed significant concentrations, all the way to ore deposits. B. Brockamp [30], and N. M. Strakhov, in particular detail [18], considered possible reasons for this phenomenon. Subsequently, N. M. Strakhov, analyzing the distribution of various sedimentary mineral resources in connection with transgressive—regressive cycles, outlined the basic tendencies of confinement of particular minerals to certain stages of these cycles' development [19, 20]. Later, in connection with the development of ideas about the nature of eustatic fluctuations of sea level, questions of their effect on the sedimentary process continued to be discussed [31, etc.]. At present, the problem of revealing the connection between deposits of a certain geochemical appearance and different stages of short-period eustatic fluctuations remains quite timely.

In the present communication, we will consider some lithological and geochemical peculiarities of deposits accumulated during periods of transgressive development of the Early- and Middle—Jurassic body of water of the Greater Caucasus on its northern side.

The Jurassic body of water of the Greater Caucasus was part of the system of Tethysic bodies of water and accordingly developed, to a significant extent, in the same direction as other basins of the world. The analysis which was conducted of Jurassic strata of this region showed that the curve of eustatic fluctuations of sea level for the Caucasus largely coincides with analogous curves for other regions of the world [4].

Traces of eustatic fluctuations of sea level recorded in cross sections in one or another form can be found in various structural facial zones* (SFZ) of the Greater Caucasus. However, in the deepest-water, central and adjacent regions of the sedimentary basin, which were characterized by anomalously high rates of sedimentation [9], transgressive and regressive episodes were manifested to the least degree, while in peripheral parts of the body of water traces of them are found quite clearly. Therefore, in the aspect of interest to us, we primarily analyzed Jurassic strata accumulated within the bounds of the shelf part of the body of water and its slope (the Laba-Malka, Eastern Balkar, Digora-Osetia, and Agvali-Khiv SFZ). According to the deposits developed here, we can trace the material expression of eustatic fluctuations, beginning from the Pliensbachian.

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*Structural facial zones are distinguished according to [16].

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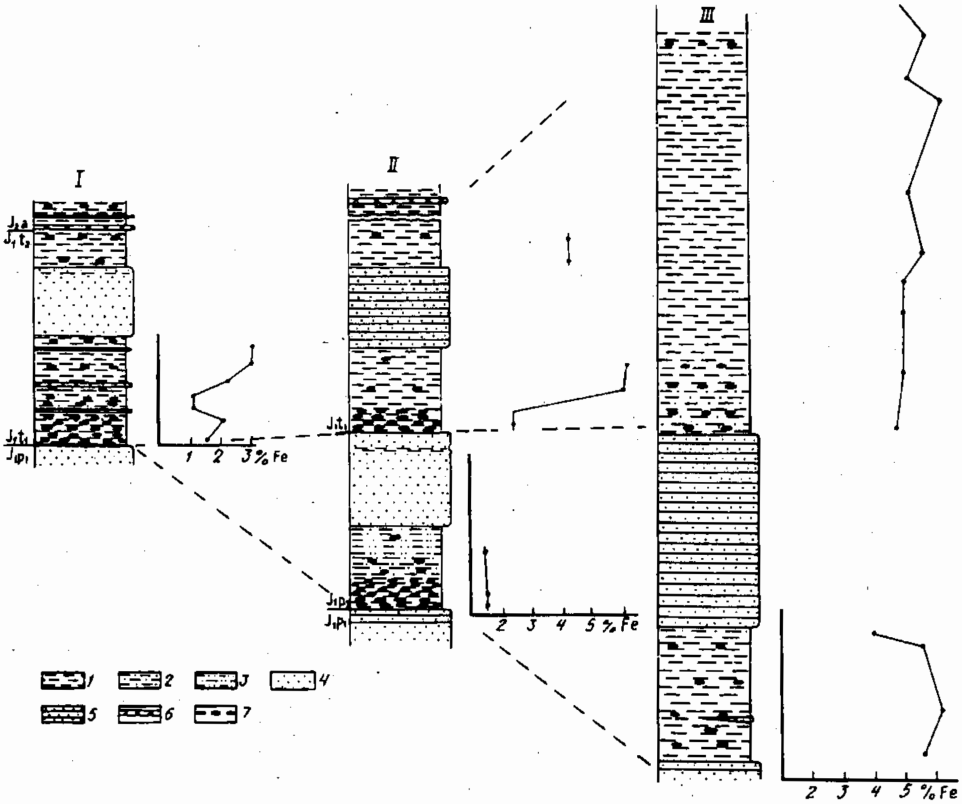

Fig. 1. Lithological columns of Liassic deposits of the Central Caucasus and distribution of Fe in them: I) region of the Baksan River's basin (Laba-Malka SFZ); II) Bezengievskii Cherek River (Eastern Balkar SFZ)) III) region of the Urukh and Aigamuga Rivers' basin (Digora-Osetia SFZ): 1) mudstones; 2, 3) siltstones (2 — clay, 3 — sandy); 4, 5) sandstones (4 — massive, 5 — layered with interlayers of siltstones); 6) beds with ferruginous oolites; 7) concretions.

Within the bounds of the Central Caucasus, Liassic transgressions led to the formation of distinctive sedimentary rhythms (Fig. 1) [4]: in the lower part of them lie clay deposits, which are replaced toward the top by silty and sandy ones. Such a structure of the strata is connected with the high rate of development of transgressions, as a result of which river systems supplying the greater part of the sedimentary material were backed up, and the coarsest sandy material was dumped in estuaries and drowned river valleys, while fine material was removed to the shelf zone and participated in formation of the clay part of the strata. Subsequently, as the encroachment of the sea slowed down or ceased, and the river systems developed, sandy material began to enter the shelf zone, forming the upper part of the rhythm; in this case, clay material from the zone of active hydrodynamics was removed to deeper-water parts of the basin [4]. The reality of this scheme of development of transgressive rhythms (from clay to sandy deposits) is confirmed by data on the geology of young buried river valleys of the Nile, Rhone [27], etc.: they were filled with sediments after very quick flooding of them by the sea, with the lower part of the strata formed as a result of this being composed of clay sediments, which were replaced by coarser ones above.

In considering deposits which arose as a result of transgressions, we are primarily interested in the lower (in this region, clay) parts of strata accumulated precisely during the time of active encroachment of the sea onto dry land.

The noted structure of Liassic strata is traced over rather extensive areas. We carried out lithological and geochemical study of Jurassic deposits in the most complete and representative cross sections belonging to various structural facial zones. The system of cross section studied forms a profile (see Fig. 1) encompassing various parts of the shelf region of the Early—Jurassic body of water: it intersects the zone of the paleoshelf at an angle to its trend. In the northwestern part of the profile, deposits accumulated in relative proximity to the coast are developed; in the southeastern part, more remote from it.

As we can see from cross sections of the profile, the oldest deposits accumulated as a result of transgression are dated in the Upper Pliensbachian. In lower, clay parts of cross sections of the Eastern Balkar SFZ, Domerian ammonites *Amaltheus depressus* Simps. are found [15]. In the J_1 cross section from this SFZ, along the Bezengievskii Cherek River, the lower, clay

TABLE 1. Chemical Composition of Carbonate Concretions

Number of specimen	Al_2O_3	Fe_2O_3	FeO	MnO	CaO	MgO	CO_2	Corg	P_2O_5	MIR *	Total	Age (place taken)
182	None	3,18	40,42	0,91	2,57	7,71	32,2	Нет	2,61	12,84	102,4	Lower Toarcian (Laba-Malka SFZ, Tyzyl R.)
184	"	3,27	40,3	0,57	3,73	8,48	32,7	0,24	0,18	10,22	99,81	
186	"	1,58	43,02	0,36	3,86	7,2	35	0,27	0,09	8,37	99,75	
344	"	2,34	29,9	0,25	3,93	8,53	29,4	0,10	0,08	26,03	100,55	Upper Pliensbachian
359/1**	"	1,68	3,59	0,19	7,25	3,19	9,55	0,30	0,82	72,37	98,94	Lower Toarcian (Eastern-Balkar SFZ, Bezengievskii Cherek R.)
359/2	"	3,76	1,29	0,01	4,35	1,52	1,25	0,63	7,9	57,58	78,27	
359/3	"	2,29	29,45	0,27	3,82	6,01	25,95	0,38	0,32	31,33	99,82	
361	0,81	0,65	38,0	0,67	4,0	7,46	33,10	Нет	0,31	13,77	98,34	
1	0,47	0,89	30,30	0,42	5,40	6,94	29,05	0,42	0,27	22,62	96,78	Aalenian (Agvali-Khiv) SFZ, Kurakh and Samur Rivers
9	None	1,34	30,55	0,47	5,08	6,16	28,20	0,14	0,14	26,68	98,76	
7	0,33	2,31	23,80	0,55	6,80	7,34	28,10	0,45	0,11	26,51	96,30	

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*MIR — mineral insoluble residue.

**Specimen 359: 1 — core, 2 — intermediate zone, 3 — peripheral zone.

member is represented by silty mudstones of dark brownish-gray color; on bedding planes, accumulations of fine plant residues are often found, and petrified (sideritized) fragments of wood (several centimeters) are also noted. The most characteristic feature of these deposits is the presence in them of numerous interlayers and little chains of concretions: the distance between them in intervals of the most frequent alternation is 5-15 cm; the thickness of interlayers and concretions is 3-5 cm. They are composed of magnesian siderite (Table 1, specimen 344). In some sections, the saturation of deposits with concretions is so great that alternation of mudstones and layers of siderite concretions of almost equivalent thickness is observed. The thickness of the member of silty mudstones is about 20 m; above (over the extent of several meters), as the silt content of the rocks increases and they turn into sandy siltstones, the deposits' concretion content decreases.

Within the bounds of Northern Osetia (the Digora-Osetia SFZ), deposits of the same age (their Domerian age is determined by numerous finds of *Amaltheus sp.* [9, 15]) accumulated in more marinelike conditions in comparison with the preceding cross section. The strata are characterized, on the whole, by the same structure of the cross section, but with a somewhat greater total thickness: in particular, the thickness of the clay interval here increases to 50 m. Numerous siderite concretions lie in silty mudstones, but there are far fewer of them in comparison with the preceding cross section.

Geochemical characteristics of these deposits are of special interest: the contents of C_{org} in rocks of the cross section on the Cherek River are insignificant (about 0.3-0.4%); in the cross section on the Urukh River (more marinelike), it is about 1%. The pattern of distribution of iron is quite curious: if in the cross section on the Cherek River mudstones contain about 1.5% Fe, then in the cross section on the Urukh River the content of it reaches 5.5-6% (see Fig. 1). In both cases, the rocks are practically carbonate-free.

It should be noted that in western regions of the Northern Caucasus deposits of the same age as those under consideration (lower subsuite of the Psebai suite), on the whole, have a similar two-member structure: black mudstones with numerous siderite concretions in the lower part of the subsuite and sandstones in the upper part of it; the thickness of the strata is 50-200 m [15].

A structure similar in its general outlines with the strata under consideration is also characteristic of Toarcian deposits (see Fig. 1). Here also, at the base of strata accumulated during the period of transgressive development of the body of water lie black or dark-gray mudstones, or silty varieties of them with a very large number of siderite (see Table 1, specimens 182-186) concretions (Laba-Malka SFZ) [6]. This same interval is also traced in cross sections of Balkaria, which were further from the shore at that time. The degree of the mudstones' saturation with concretions here is also very high: for example, eight concretion interlayers lie in an interval of 1 m. However, if in the preceding cross sections only siderite concretions were noted, then here zonal varieties are found: in the core are calcite and authigenic SiO_2; the outer part is composed of siderite; and an intermediate zone is distinguished between them, which is enriched with phosphate minerals (see Table 1, specimen 359/1-3). The thickness of the interval is ~15 m. The transgressive stage with which the formation of Toarcian strata is connected began in the middle of the Early Toarcian (the ammonite zone of *Harpoceras falciferum* [11]).

In the Digora-Osetia SFZ (Urukh and Ardon Rivers), clay strata corresponding in age to these deposits, which characterize parts of the paleoshelf fairly far from shore, are composed of dark-gray, silty mudstones with nodules of siderite concretions at the base; above, they are replaced by strata of gray mudstones with rhythmically occurring (every 10-20 cm) thin (~0.5-0.7 cm) siderite interlayers, sometimes lenticular. The strata's total thickness is ~150 m.

In cross sections of the Lower Toarcian, clay deposits are characterized by a geochemical pattern similar to that established for Domerian strata. Here, silty mudstones of the cross sections closest to the paleoshore and siderite-bearing to the maximum degree (for example, the cross section on the Tyzyl River [6]) contain C_{org}, 0.25%, Fe 1.75%, and no CO_2; in deposits accumulated in somewhat more marinelike situations (Cherek River), C_{org}, 0.35%, Fe 2.2-2.5%, and CO_2 0.5%; in a cross section relatively far from shore (Urukh River), C_{org} ~ 1%, no CO_2, and Fe 5.5-6%. Thus, for Domerian, and well as for Lower—Toarcian strata, the minimum contents of C_{org} and Fe are characteristic of the maximum siderite-containing deposits (accumulations of siderite sometimes acquire the nature of small ore occurrences), and they increase in deposits further from shore, in which the amount of Fe sometimes exceeds the clarke for clay rocks by 1.5-2%. The pattern of change in Fe content in mudstones depending on the deposit's content of concretions is prominently manifested in Toarcian clay members in cross sections of the Tyzyl and Cherek Bezengievskii rivers. As we can see (see Fig. 1), the minimum contents of Fe are traced in horizons with the maximum content of concretions from lower parts of these intervals, while above in the cross section (where there are noticeably fewer concretions) the contents of Fe in the surrounding rocks increase: in the cross section of the Tyzyl River, from 1.1-2.3 up to 3%; in the cross section of the Cherek River, from 2.4 up to 6%. In the latter case, high contents of Fe are analogous to the amount of Fe in deposits of the same age on the Urukh River. From this, we can draw the conclusion that the initial content of Fe in the sediments when the lower parts of clay members were accumulated was also significant, but subsequently it changed noticeably as a result of diagenetic redistribution of iron.

Our attention is also drawn to the circumstance that clay rocks with presently low content of C_{org} are characterized by a very dark color, the intensity of which can decrease in deposits of more marinelike parts of the body of water, against a background of a certain increase in the amount of C_{org}.

Thus, summarizing what has been set forth, we will note the following points: 1) the lower parts of clay—silt members accumulated during the time of rapid transgressions are enriched with diagenetic concretions of siderite or mixed, but with the obligatory participation of siderite, composition; the degree of the deposits' saturation with siderite concretions and interlayers is anomalously high, decreasing further from the paleoshore toward more marinelike parts of the body of water; 2) deposits surrounding the concretions are impoverished of Fe, and also a number of other components, while clay rocks from those parts of the members (usually upper) in which concretions are present in a small number or entirely absent are characterized by higher contents of iron, in a number of cases exceeding its clarke for mudstones by 1-2%.

In reconstructing the conditions of formation of the established lateral and vertical zonality in clay strata formed during transgressions, we have to take into account the overall paleogeographic and climatic situation at that time. At least during the Upper Liassic, the climate in the territory of the Northern Caucasus was subtropical and humid. In territories of dry land adjacent to the body of water, coal-bearing deposits were sometimes accumulated (the Khumara suite, J_1p_1). Data from spore and pollen analysis [28] indicate the existence here of fairly diverse and abundant vegetation. Therefore, in the favorable conditions here, lake-marsh systems could always have arisen. But, as is known [21, 26], they are often connected with formation of marine, siderite-bearing deposits, since marsh landscapes are a supplier of Fe and organic matter (OM) to marine sediments, where siderites form during diagenesis. However, a complicating point for establishing a direct correlation between lake—marsh landscapes and siderite formation in marine conditions is the fact that, in seemingly favorable conditions, siderites were far from always formed. In our view, the development of this process was largely determined by how the sea's interaction with the coastal landscape was accomplished. So, for example, simultaneously with accumulation of continental, coal-bearing deposits of the coal-bearing Khumara suite, marine deposits of the Veriyut suite were forming: the suites replace each other facially. However, there is no noticeable enrichment of deposits of the Veriyut suite with OM and siderite concretions in the region close to the zone of facial transition. There are no mass accumulations of siderites even in marine deposits of the Kyrtyk depression of the same age as the Khumara suite, i.e., with the sea and its shoreline standing more or less stably, there could be no energetic interaction with a coastal lake—marsh landscape. The situation was different with noticeable fluctuations of the sea's level. It is important to emphasize that stages of rapid transgressions, as a rule, were preceded by comparatively brief regressive episodes. They led to release from the sea of a band of the sea's bottom in the shelf region, which, in the case under consideration, is a gently sloping terrain leveled by marine erosion and subsequent accumulation of sediments. This newly formed coastal plain was an ideal place for development of lake—marsh landscapes, the more so as climatic conditions were very favorable for this; on the side of the sea, shallow-water bays and lagoons were adjacent to it. These landscapes were formed very quickly. The length of their existence was apparently no more than several tens of thousands of years. The transgression that followed comparatively soon after the regression led to a situation in which the encroaching sea began to vigorously interact with the coastal landscape: the direct contact of these two systems led to destruction of accumulated plant material and removal of a significant amount of reactive OM into the sea. Moreover, the distance, reduced to a minimum, between lakes and marshes, on the one hand, and the sea, on the other, resulted in easy transfer of OM, Fe, and certain other elements. N. M. Strakhov [21], considering the question of supply of Fe to a body of water, noted that with sufficiently large length of rivers, i.e., paths from the region of mobilization of Fe to the place of its burial, oxidation of the Fe being transferred occurs, and it is frequently already deposited within the bounds of river valleys. In those cases when the marsh terrain was very close to the runoff's final body of water, iron mobilized in marshes reached the marine basin. Part of the iron was brought in the form of a true solution; and another part, as oxidized forms. According to data given in [12, 29, etc.], an important role in the transfer of Fe into marine bodies of water was played by iron—organic complex compounds, in particular, with humic and fluvic acids.

In Late-Liassic time, OM and Fe entering the body of water were accumulated primarily in regions relatively close to the shoreline. Here, diagenetic processes took place especially intensively in sediments, which led to formation of siderite accumulations. Judging from the numerous plant residues in clay—silt Domerian deposits of the cross section on the Cherek River and of the Lower Toarcian on the Tyzyl River (see Fig. 1), OM brought in from dry land also largely determined the nature and intensity of diagenesis here.

But not only allothigenic OM enriched silts. As analysis of the structure of the Toarcian part of the cross section on the Cherek River shows, accumulation of clay sediments in the Early Toarcian was accompanied by high biological productivity of the body of water itself, and marine organisms made an appreciable contribution to enrichment of the sediments with OM. The flourishing of organisms requires an increase in the concentrations in the water, first of all, of such biophilic elements as C, P, N, etc. As was noted, C_{org} in a dissolved form entered from the shore in sufficient amounts. Entry of phosphorus into the body of water may have been connected with the same source. V. A. Kovalev [12] pointed out that peat bogs and the bog process as a whole can be considered one of the characteristic types of manifestation of geochemical migration of phosphorus in the zone of hypergenesis.

The warm sea and the presence of necessary amounts of biophilic elements resulted in favorable conditions for fairly high bioproductivity of these parts of the body of water. Further from shore, the portion of basin OM in the sediments rose, replacing plant OM, which was dominant in the coastal part. But the rate of terrigenous sediment accumulation increased in the same direction, and the amount of OM in the sediments decreased accordingly. The part of OM which was made up of allothigenic OM was oxidized during transfer in this part of the body of water and lost its reactivity. In connection with these factors, diagenetic processes took place much less intensively here, and no significant accumulations of siderite arose.

Since, in the process of encroachment onto dry land, the sea fairly quickly "won back" the territory it had previously abandoned and moved further to the north, the most vigorous interaction between the sea and lake—marsh landscapes was mostly realized in initial stages of the transgression, and, accordingly, it was precisely the lower parts of clay members accumulated at that time which were enriched with siderite accumulations. Subsequently, the sea occupied territories where marsh landscapes were developed to a lesser degree; removal of OM and other components was reduced in comparison with that which occurred previously; and, following this, siderite deposits also disappeared from the cross section.

We should especially note the nature of diagenetic processes in the strata under consideration. Their intensity during periods of formation of clay deposits accumulated at the time of transgression was extremely high, reaching its maximum manifestation in the whole J_{1-2} cross section of the Central Caucasus. In sediments initially somewhat enriched with OM and Fe, active redistribution of iron and formation of siderite interlayers took place according to the scheme of diagenetic carbonate layer formation [3]. This process involved not only Fe found in the silts in a relatively free state (sorbed, in the form of metal-organic compounds, etc.), but also that which entered into the composition of clay and other terrigenous minerals. As a result, the content of Fe in surrounding clay deposits was sharply reduced (to 1-2%), although if one evaluates the total iron content in the whole clay-siderite member, then it is fairly high. Certain other elements behaved analogously to iron. Thus, manganese is present in mudstones in trace amounts, but is concentrated, at least slightly, in concretions (see Table 1). Reworking of the sediments was very deep, with destruction not only of calcareous inclusions ($CaCO_3$ is absent in these rocks), but also of silicate minerals such as chlorite and, partly, hydromica. Clay deposits were enriched with kaolinite, which not only has an allothigenic origin, being partially brought in from continental bogged regions, but also an authigenic one, since it was formed directly in siderite-bearing horizons.

As a result of intensive reduction and other processes, by the time diagenesis subsided the content of C_{org} in the sediments was also significantly reduced. At present, it is hard to reconstruct its initial amount in the sediments, but it is thought that they exceeded the background contents, reaching several percent.

In Middle—Jurassic time, transgressive episodes of the Central Caucasus were lithologically less clearly expressed in cross sections in comparison with Early—Jurassic ones, which is connected with further movement of the shoreline to the north — into regions presently covered by younger deposits. Accordingly, in contemporary outcrops, deposits accumulated in sections of the Jurassic body of water's shelf relatively far from shore mostly emerge to the ground surface. A much clearer lithological reflection of transgressions can be observed in eastern regions of the Northern Caucasus — in Dagestan.

In the Middle Jurassic, transgressions occurred in the middle of the Aalenian, and the beginning and middle of the Bajocian. In the cross section of Jurassic strata, the Aalenian transgression is especially prominently expressed by its lithological and geochemical manifestations. It was preceded by a regression at the boundary of the Toarcian and Aalenian, which led to the appearance in the cross section of marine deposits of a set of continental facies, coal-bearing in places (Middle-Karakh [24] and Upper-Batlukh [7] suites), connected with the development here of a large river's delta. These strata are mostly represented by sandstones (Fig. 2). With the beginning of the transgression's development, interstratification of sandy and clay deposits appears, with the ratio of them changing in favor of clay ones upward through the cross section (the Upper-Karakh suite and lower part of the Khiv suite [24], and the Datun suite [7]). In the stage when the shoreline and, accordingly, the river delta, had moved sufficiently far to the north, the supply of sandy material was sharply reduced, and mostly clay deposits accumulated, which are replaced upward through the cross section by a flyschoid, sandy—clay member and enter into the composition of the Khiv, Igatla, Geptsai, and other suites distinguished by various authors [17, 24, etc.]. In deposits formed during the transgression lie a multitude of carbonate concretions, with the number of them differing at various levels. V. T. Frolov, evaluating the quantitative

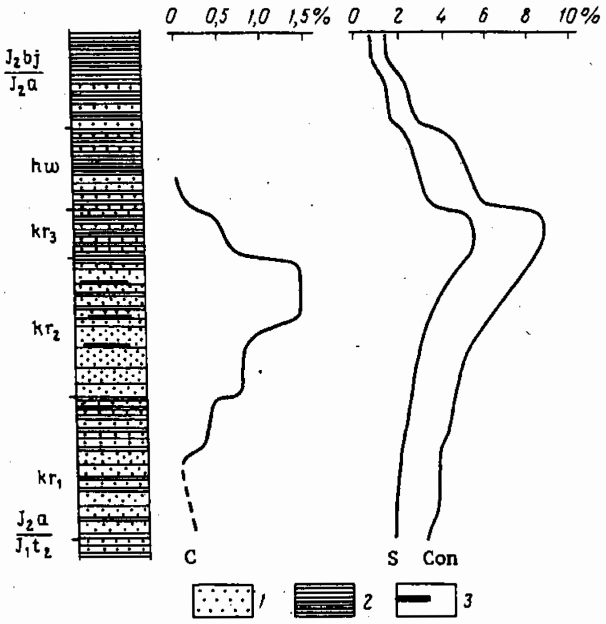

Fig. 2. Lithological column of Toarcian-Bajocian deposits of Dagestan, and their contents of coal and concretions [24]: 1) sandstones; 2) clay rocks; 3) coal seams; C coal content; Con — total content of concretions; S — siderite content; kr — Karakh suite; hw — Khiv suite.

distribution of concretions in the cross section, came to the conclusion that the maximum content of concretions (and siderite content, in particular) was characteristic of the Upper-Karakh suite (see Fig. 2) and does not coincide with the maximum coal content [24], which is characteristic of lower-lying Middle-Karakh strata. Such a pattern is not random: it is precisely the transgression which had begun that led to vigorous interaction of the marine basin with marsh landscapes widely developed here, which resulted in a sharp intensification of siderite formation. Thus, in Dagestan, a pattern is observed which is quite similar with respect to the conditions of its formation to that which occurred in the Central Caucasus at the beginning of the Late Pliensbachian and in the Early Toarcian. In the Dagestan cross section, accumulations of concretions of iron minerals (ankerite, siderite) lie in sandstones, as well as in clay deposits, which indicates constant inflow of Fe and OM from the shore (in the form of various compounds). At the same time, active hydrodynamics and the high rate of sediment accumulation for these strata [5] somewhat restrained processes of diagenetic formation and redistribution of ferruginous carbonates. V. N. Kholodov [26] noted that high hydrodynamic activity of the medium was an unfavorable factor for formation of concretions.

Subsequently, as the seashore and region of delta sedimentation moved to the north, over the greater part of the Eastern Caucasus (within the bounds of Dagestan), in hydrodynamically much calmer conditions in comparison with the preceding period, and with significantly lower rates of accumulation of deposits, formation of clay strata began (the uppermost part of the zone of *murchisonia* — lower part of the zone of *Concava*). In their lower part, the clay strata are also characterized by fairly high content of concretions. In this case, the paleogeographic situation at that time was such that, in individual sections, the size of which reached several kilometers (possibly, depressions in the relief, calm sections surrounded by islands or shoals), special conditions were created for accumulation of OM and Fe brought in, and most importantly, for successful passage of diagenetic transformations. Here, processes of diagenetic siderite formation were realized in the sediments to the maximum degree, as a result of which large accumulations of siderite concretions and interlayers arose (see Table 1, specimens 1, 7, and 9). In places, the amount of siderite interlayers reaches 20% or more of the corresponding members' thickness. In the territory of Dagestan, several such ore accumulations of siderites are known. The thicknesses of these siderite-bearing strata vary from several tens up to a few hundreds of meters. Questions of the structure, mineralogy, and geochemistry of siderite deposits have been considered in a number of works [23-25]; the conditions of formation of siderite deposits of the Eastern Caucasus were discussed in detail by V. N. Kholodov and Z. R. Kikadze [26], taking into account contemporary data on the paleogeographic and facial conditions of accumulation of siderite-bearing deposits and the geochemistry of the process of siderite formation.

After the shoreline moved far to the north, the entry of reactive complexes for siderite formation decreased, and the concretion content of the deposits dropped noticeably.

As V. T. Frolov notes [24], in Northern Dagestan there are intervals of strong siderite enrichment of clay—silt deposits of the Lower and Middle Bajocian, which are also apparently connected with the corresponding transgressive episodes.

Thus, we can see that, fairly often, accumulations of siderite concretions are confined to deposits accumulated during transgressive stages of a body of water's development. Their appearance is connected with the inflow into sediments of necessary reactive components, which subsequently result in intensive occurrence of diagenetic processes. Accumulations of siderites gravitate to deposits of peripheral parts of the basin.

In connection with this, we should note the following. A. Hallam and M. Bradshaw [31], considering the relation of brief eustatic fluctuations of sea level with formation of oolitic iron-ore horizons, came to the conclusion that this type of ore can be considered an indicator of regressive stages of basins' development. In the cases which we have described, deposits of transgressive episodes were enriched with siderite accumulations, i.e., ore manifestations of various mineral forms of Fe are confined to deposits formed in different stages of regressive—transgressive cycles. In the Northern Caucasus, the clearest example illustrating this tendency is Aalenian deposits. Thus, the regressive stage manifested at the very end of the Toarcian-beginning of the Aalenian coincides with the appearance in the region of the Central Caucasus of oolitic iron-ore horizons [1, 6, 22]; and transgressive development of the body of water is connected with the development of siderite ore occurrences of Dagestan. Of course, accumulations of ferruginous minerals approaching ore concentrations only formed in favorable sedimentation conditions, as happened in the Aalenian. Other regressive and transgressive episodes in Lower- and Middle—Jurassic deposits of the Northern Caucasus are connected with local occurrences of less significant concentrations of Fe minerals, which are sometimes only of mineralogical interest (Fig. 3), i.e., more or less significant accumulations of Fe minerals arose at corresponding stratigraphic levels not everywhere, but only in sedimentation traps in favorable facial situations.

As we see, in Jurassic deposits of the Northern Caucasus, transgressions had a significant effect on the geochemistry of iron. But, as was already noted, the same stages of development of transgressions are connected with a widespread process of formation of strata enriched with OM. In the deposits which we have discussed, the contents of residual C_{org} are comparatively low, but initially the amount of it in the sediments' upper layer was significant, and subsequently, as a result of postsedimentation processes (especially, diagenetic ones), it decreased sharply. Since transgressions went through two phases, as it were (flooding of coastal dry lands abandoned as a result of preceding regression, and appropriation of new territories), we can expect that removal and accumulation of OM in the marine body of water was characterized by certain particular features in different stages of a transgression. However, it is hard to reconstruct and evaluate the initial state of OM in sediments, since intensive diagenetic processes in Jurassic deposits of the Northern Caucasus led to considerable reworking of the sediments' components, including OM. To a certain extent, data on the geochemistry of OM in certain deposits from other regions of the same age as those that we studied, in which diagenetic processes were not so actively manifested, help to evaluate possible variations in the nature of OM. In spite of differences in the facial situations of their formation, such a comparison seems quite correct, since we are primarily interested not in the quantitative or qualitative parameters of OM by themselves, but in the dynamics of their change in the process of the sea's encroachment onto dry land.

So, in the Early Toarcian in Western Europe, in conditions of an epicontinental sea, against the background of a transgression which developed, sediments enriched with OM were accumulated. These deposits are known as Jet Rock (Yorkshire), Posidonia Shales (Germany), or schistes cartons (France). The thickness of these deposits is not great (a few tens of meters), but a similar structure of their cross sections, down to details, is traced over very large territories. Lower—Toarcian shales have been repeatedly studied by geologists [32, etc.]. Interesting geochemical data characterizing the conditions of sediment accumulation in the Early—Toarcian body of water are given in Küspert 's work [14]. He showed that bituminous shales from lower horizons of the strata, which contain jet inclusions in places, are characterized by a geochemical anomaly expressed in a change in the value of $\delta^{13}C$ in the direction of a decrease in comparison with corresponding values for the rest of the cross section: lightening of organic carbon is observed in OM, as well as in carbonate material (Fig. 4). This anomaly is traced everywhere: in cross sections of Yorkshire, Southern France, and Germany [14]. On the basis of data from chemical analysis and petrographic study of rocks, W. Küspert came to the conclusion that the source of the greater part of the organic matter was water microorganisms. However, in this case, he noted that, in comparison with contemporary plankton of tropical and moderate seas ($\delta^{13}C$ close to —20‰), the organic carbon of Posidonia Shales (from —27 to —33‰) is significantly lightened, and the values of $\delta^{13}C$ are close to terrestrial plants. Of a number of possible reasons for the parallel variations of $\delta^{13}C$ (of organic matter and carbonate material), W. Küspert singles out as the most likely an "environmental effect" connected with dissolved inorganic carbon in the local seawater.

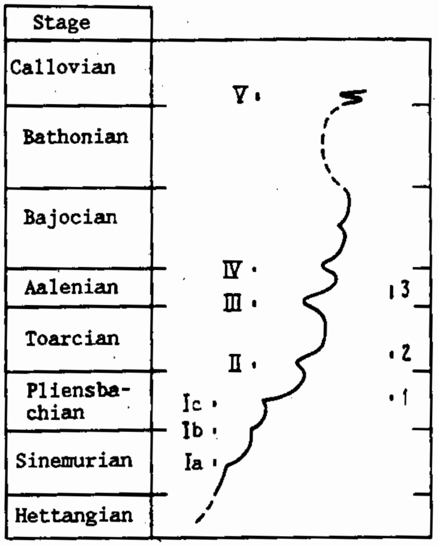

Fig. 3. Curve of eustatic fluctuations of Early- and Middle—Jurassic body of water of the Greater Caucasus [4] and distribution of siderite-bearing deposits and horizons with ferruginous oolites in J_{1-2} strata. I-V) horizons with Fe-oolites: I) Veriyut suite (Western Caucasus): a) at the base of the suite, b) inside the suite, c) limestones with oolites at the roof of the suite; II) beds with oolites in Lower-Toarcian deposits of the Digora-Osetia SFZ [9, etc.]; III) iron-ore horizons of the Central Caucasus [1, 6, 22]; IV) horizons with Fe-oolites at the boundary of Aalenian and Bajocian deposits [2, 10]; V) horizon with Fe-oolites in Ingushetia [8]; 1-3) siderite-bearing deposits: at the base of Domerian (1) and Toarcian (2) deposits of the Central and Western Caucasus, 3) Aalenian deposits of Dagestan.

It seems to us possible to link the occurrence of this carbon anomaly with the mechanism discussed above of vigorous interaction of a marine body of water with coastal landscapes during the regressive—transgressive cycle of the basin's development. The emergence of a lake-marsh landscape on the coastal plain, and of lagoons and bays in the zone near the shore, as a result of the sea's regression led to accumulation of a significant amount of OM here, which was characterized by a lightened composition of $\delta^{13}C$. During the subsequent transgression, which destroyed this landscape, removal of OM (in various forms) into the marine body of water occurred. The OM (and primarily dissolved OM) was utilized by marine organisms for formation of soft tissues, as well as carbonate shell skeletons. Hence the appearance of a parallel anomaly of $\delta^{13}C$ for OM, as well as for carbonate material. This process should take place most actively precisely in the transgression's initial stages, when the sea encroached onto the territory previously abandoned by it, destroying the coastal landscape. Later, the transgression, appropriating new territories, also resulted in the entry into the body of water of substances removed from the shore, which maintained the sea's fairly high productivity in relation to OM. However, the amount of carbon in the material brought in from dry land (and of lightened C, in particular) decreased, and the clearly expressed carbon anomaly disappeared accordingly.

In connection with the problem of the source of OM for formation of horizons with increased contents of C_{org}, we will note that A. I. Konyukhov, discussing the question of accumulation of OM in sedimentary strata of the Atlantic Ocean, also expressed a hypothesis that, in a number of cases, "black" clays in the ocean arose as a result of redistribution of sediments from continental margins of the Atlantic type in the mature period of their development, i.e., on the margins of peneplainized cratons. The redistribution process was promoted by large marine transgressions, resulting in erosion of coastal-marine and delta deposits containing significant amounts of OM [13]. In comparing Toarcian deposits of the same age in the Northern Caucasus and Western Europe, we can see that in different facial situations clay strata were formed which differ in a number of traits:

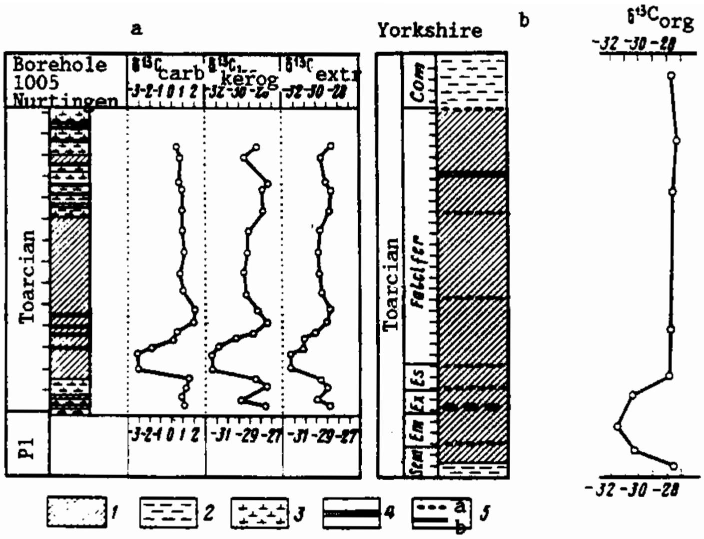

Fig. 4. Isotopic composition of carbon in carbonate and organic matter in Toarcian deposits of West Germany (a) and England (b) [14]: 1, 2) bituminous and nonbituminous shales, respectively; 3) gray marls; 4) siderite interlayer; 5) limestone concretions (a) and interlayers (b). Pl—Pliensbachian; subzones: Sem — Semicelatum, Em — Elegantulum, Ex — Exaratum, Es — Elegans, Com — Commune.

carbonate content, degree of enrichment with OM, and the mineral composition of concretions. But, in this case, the changes noted in both cases in certain lithological and geochemical parameters from the bottom up through the cross section agree well with the general direction of the sedimentary basins' development, which was manifested in a regressive—transgressive cycle. The two-stage cycle of development (regression, during which formation of a corresponding marsh—lake landscape on a coastal plain occurred, and then transgression, which resulted in this landscape's vigorous interaction with the croaching sea), it seems to us, best promoted the appearance of specific lithological and mineralogical features of the accumulated deposits.

In this case, the climatic factor undoubtedly played a quite significant role, promoting or preventing the appearance on coastal plains of landscapes with hygrophilous vegetation. Temperature and humidity were important factors determining the nature of weathering on catchment areas and, consequently, the supply of mineral substances to the body of water. An important circumstance in the formation of Posidonia shales and others of the same age may be the fact that the Toarcian was a time of increasing temperature (the Toarcian optimum), while the Pliensbachian and Aalenian transgressions did not lead to formation of deposits significantly enriched with OM. As we see, not all transgressions find their clear lithological and geochemical reflection in cross sections. We should note that, in general, more or less significant iron-ore accumulations are, directly or indirectly, paragenetically connected, first of all, with terrigenous strata, while accumulation of OM in the Mesozoic—Cenozoic occurred regardless of background sediment accumulation (be it carbonate or terrigenous), i.e., the process of formation of horizons enriched with OM was of a more universal nature.

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