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Practical Application of the Mineralogical Mapping Method for Stratigraphy of the Cretaceous Deposits of Southern Primorye (Russian Far East)

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Abstract: Highly ordered mixed-layer formations of chlorite–smectite (corrensite) and mica–smectite (rectorite) were found in the volcanogenic–sedimentary rocks of Southern Primorye. They have shown a rather narrow "living" time interval (Cretaceous–Paleogene). The associations of corrensite and rectorite with chlorite, mica, kaolinite, and laumontite have great value in labeling. Their study would determine the time and thickness parameters of sedimentation conditions, the nature of the transformation stages, the physicochemical and climatic parameters of the accumulation of the depositional material, and the geological history and stratigraphic construction of Mesozoic–Cenozoic volcanogenic–sedimentary rocks of the Primorye Region.

Keywords: stratigraphy; authigenic minerals; corrensite; rectorite; chlorite; mica; kaolinite; laumontite

1. Introduction

Authigenic minerals are accurate indicators of the paleogeographical conditions of sedimentation and the nature of transformations that take place during epigenetic processes. They have great diagnostic value, and their associations within sedimentary deposits can be benchmark indicators of stratigraphic constructions. Previous studies [1–6] have shown that the formations of the Lower Cretaceous and Paleogene sedimentary rocks in the transition zone between the Asian continent and the Pacific Ocean have similar features. This process probably began in the shallow sea basin on the continental margin (riftogenic stage), often close to evaporites, with frequent changes in the facies condition from the shallow-water to the deep-water depositional regime, episodic supplies of volcanogenic material, and the gradual deepening of sedimentary basins. It was assumed that in the Early Cretaceous and Paleogene periods, sedimentary basins, which form a scattered network on the continental margin of Northeast Asia, developed in a unified mineralogical-tectonic-sedimentological regime that stretched the Earth's crust. The minerals that formed in the accumulated deposits were transformed via epigenesis in the following ways: smectite–rectorite–mica and smectite (palygorskite, sepiolite (?))– corrensite-chlorite. In the sedimentary basins that we studied, three mineralogical phases were distinguished: chlorite-mica (Cretaceous and later); transitional-corrensite (mixed layers of chlorite-smectite and corrensite-like minerals (CLM)) and rectorite (mixed layers of mica-smectite and rectorite-like minerals (RLM)) (Early Cretaceous and Paleocene-Eocene), and smectite (from the Oligocene to the present).

As regards the southern region of Primorye, the most widespread opinion is that, in the Cretaceous period, there were two large sedimentary basins with different sedimentation conditions. In the Razdol'nenskiy Basin, in general, the continental type of deposition prevailed. Meanwhile, in the Partizanskiy Sedimentary Basin, marine conditions sometimes prevailed. Some geologists state that both basins have common sedimentary features [7,8]. Dozens of scientific works concerning the stratigraphy of Cretaceous volcanogenic–sedimentary rocks have recently been published by well-known geologists



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Copyright: © 2021 by the author. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (https:// creativecommons.org/licenses/by/ 4.0/). and paleontologists, such as [9–25] and others. Despite the development of a fairly decent understanding, questions regarding the correlation between certain stratigraphic horizons and the authigenic minerals that they contain remain.

This study aims to clarify the age and context of volcanogenic–sedimentary deposits based on the proposed transformational sequence of authigenic minerals. In combination with the results of traditional biostratigraphic and lithological studies, the obtained data will clarify the history of the formation of the entire Far-Eastern region. An attempt to apply this method to the Posyet Peninsula has been made [26]. Despite some unconventionality in the constructions of the geology and stratigraphy of the Cretaceous deposits in Southern Primorye, the method of mineralogical mapping is valid, although it is limited to a fairly narrow time frame (Cretaceous–Oligocene).

2. Geological Settings

The Khanka Terrane has been located, according to the tectonic zoning scheme [27], on the Southern Primorye. On its southwestern edge is the Razdol'nenskiy Sedimentary Basin, with outcrops of Cretaceous Nikanskaya and Korkinskaya rocks overlying more ancient deposits, and the Okrainsko–Sergeevskiy complex of the Samarkinskiy Terrane, which contains the Partisansko–Sukhodol'skiy Sedimentary Basin.

The Cretaceous deposits of the Razdol'nenskiy Sedimentary Basin (Figure 1) (Zanadvorovka village, Tavrichanka village and Vladivostok town; see Supplementary Material (Supplementary Figures S1–S3) are representations of the Nikanskaya and Korkinskaya Series. The formations of the Nikanskaya Series are subdivided into the Ussuriyskaya, Lipovetskaya, and Galenkovskaya suites. The ages of the formations are determined from the remains of flora and spore–pollen complexes: the Ussuriyskaya (K₁ us)—Late Neocomian; Barremian—Early Aptian (120–129 Ma); Lipovetskaya (K₁ lp)—Middle–Late Aptian (113–120 Ma); Galenkovskaya (K₁ gl)—Early–Middle Albian (105–113 Ma), and Korkinskaya (K_{1–2}kr)—Late Albian–Cenomanian (95–105 Ma) [9,10,13,16,20–24,27–29].



Figure 1. Geological map of the study area (Southern Primorye, Russia) [30].

The basement of the Partisanskiy Sedimentary Basin is composed of a complex of Early Paleozoic gabbroid and granitoid from the Sergeevskiy Terrane, overlaid by Late Permian,

Triassic, and Jurassic folded terrigenous sedimentary and volcanogenic formations. These complexes, with erosion and angular unconformity, are overlaid with sediments of the Hauterivian–Middle Albian Suchanskaya and Late Albian–Cenomanian Korkinskaya Series. V.A. Krasilov [16] has subdivided the Suchanskaya Series into the Starosuchanskaya, Severosuchanskaya, and Frentsevskaya suites.

Cretaceous deposits of the Partisansko–Sukhodol'skiy Sedimentary Basin (Figure 1) (Suchanskiy or Partizanskiy Coal Basin) are composed of the Suchanskaya ($K_1sč$) Starosuchanskaya (K_1st) and Severosuchanskaya (K_1sv) suites. The correct age of the series is Upper Hauterivian–Middle to Late Albian, and the Frentsevskaya (K_1fr) suite is Middle Albian [16,20,27]. The Korkinskaya Series ($K_{1-2}kr$) (Kangauzskaya and Romanovskaya suites) (Supplementary Figure S4 and S5) [31,32] can be aged to within the Late Albian–Late Cenomanian periods [11,16,18–20,25,27,31,32].

3. Materials and Methods

Samples of Cretaceous sedimentary and volcanic–sedimentary rocks (mostly coarsegrained sandstones and tuffaceous sandstones) in the southern region of Primorskiy (Figure 1) were taken from natural outcrops along roads and the coast (according to a geological map) with a sampling frequency of 5–10 m. They were taken from areas near Zanadvorovka village (Nikanskaya and Korkinskaya Series; Supplementary Figure S1), Tavrichanka village (Nikanskaya Series; Supplementary Figure S2), Vladivostok town (Sadgorod District, Nikanskaya, and Korkinskaya Series; Supplementary Figure S3), Romanovka village (Suchanskaya and Korkinskaya Series), Luk'yanovka village (Korkinskaya Series), Bol'shoi Kamen' town (Suchanskaya Series; Supplementary Figure S4), Zalesye village (Korkinskaya Series; Supplementary Figure S5), and Molchanovka village (Suchanskaya and Korkinskaya Series). In total, approximately 600 samples were taken.

X-ray phase analyses of the samples were carried out on a "Dron-2.0" diffractometer with Cu K α radiation (flat graphite monochromator), an anode voltage of 40 kV, and a current of 30 mA. Samples derived from an aqueous suspension were air-dried and saturated under ethylene glycol conditions. Diagnosis of the mixed-layer formations was carried out according to the models proposed by [33].

4. Results

Preliminary mineralogical studies made it possible to identify five mineral associations in the cement of the studied rocks (Figure 2, Table 1, and Supplementary Table S1): 1 kaolinite-mica (mica-kaolinite); 2-mica-chlorite (chlorite-mica); 3-corrensite-chlorite; 4-corrensite-chlorite-laumontite; 5-rectorite. The kaolinite-mica (Figure 3a) association is characterized by 10.0, 5.04, and 3.34 Å reflections for mica and 7.2 and 3.59 Å for kaolinite. The mica-kaolinite group contains insignificant amounts of both highly mixed (rectoritelike; Figure 3e) and low-ordered mixed-layer formations of mica-smectite; their reflexes are 19.2 Å under saturated conditions and 17.7 Å under air-dry conditions (Figure 3b). Chlorite (14.4, 7.2, 4.74, and 3.56 A reflexes) is very rare in this association, and only appears in trace amounts. The mica-chlorite (chlorite-mica) association (Figure 3c) is characterized by mica and chlorite in different ratios, often with a predominance of mica. The corrensitechlorite and corrensite-chlorite-laumontite associations (Figure 3d) are characterized by the presence of corrensite (reflexes 32.4, 14.7, 7.2, and 3.56 Å), chlorite (14.4, 7.2, 4.74, and 3.56 Å) and laumontite (reflexes 9.8, 6.9, and 4.11 Å). The rectorite association (Figure 3e; reflexes 28.5, 12.1, 10.2, 5.04, and 3.34 Å under air-dried conditions and 30.5, 13.6, and 10.2 Å under glycolate conditions) is characterized by rectorite with varying percentages of smectite-mica-type packages, a small amount of mica, and small admixtures of vermiculite layers, with kaolinite sometimes appearing as the pure phase. The transformation of smectite into chlorite ends in Lower Cretaceous rocks. Here, corrensite in association with normal or defective chlorite dominates. In its pure form (without chlorite; Figure 3f), corrensite is found only in Paleogene rocks, which can also be a diagnostic feature.

| Era | Period | Epoch | Age | numerical age (Ma) | l Razdol'nenskiy Basin Suites | Minerals | Partizanskiy Basin Suites | Minerals |
|----------|------------|-------|-------------|-----------------------|---|----------------------------------|---|----------------------------------|
| Mesozoic | Cretaceous | Upper | Turonian | 03.0 | | | | |
| | | | Cenomanian | -100.5- | Korkinskaya Series | Cr+Re+Crl+Dch +Lm+Mi+Chl+Kl?- | Korkinskaya Series (Romanovskaya, | Cr+Re+Crl+Dch _+Lm+Mi+Chl+Kl_ |
| | | Lower | Albian | -110.0- | Galenkovskaya Cr+Re+Crl+Dch +Lm+Mi+Chl Frentsevskaya | | Cr+Re+Crl+Dch +Lm+Mi+Chl | |
| | | | Aptian | -125.0 | Lipovetskaya | Cr+Chl+Mi+Dch+Re +Crl+Kl | Severosvchanskava | Cr+Crl+Dch |
| | | | Barremian | ~120.0= | Ussuriyskaya | Chl+Mi+Crl+Dch +Re | | +Lm+Mi+Chl +Kl |
| | | | Hauterivian | ~132.6 | | | Starosuchanskaya | |
| | | | Valanginian | ~139.8 | | | | |
| | | | Berriasian | ~145.0 | | | | |

Note: Chl - chlorite; Dch - deffective chlorite; Mi - mica; Kl - kaolinite; Cr - corrensite; Re - rectorite; Crl - corrensite-like mineral; Lm - laumontite.

Figure 2. Authigenic minerals identified in Cretaceous volcanogenic-sedimentary rocks of Southern Primorye.

Table 1. Associations of authigenic minerals in the studied volcanogenic-sedimentary rocks of the

 Southern Primorye.

| | Mineral Associations | | | | | | | | | |
|----------------------------------|----------------------|-------------------|-------------------------|--|-----------|--|--|--|--|--|
| Suite | Mica– Kaolinite | Mica- Chlorite | Corrensite– Chlorite | Corrensite– Chlorite– Laumontite | Rectorite | | | | | |
| Razdol'nenskiy Sedimentary Basin | | | | | | | | | | |
| Ussuriyskaya | | XXX | | | | | | | | |
| Lipovetskaya | XX | XX | XX | | Х | | | | | |
| Galenkovskaya | | XX | XX | XX | Х | | | | | |
| Korkinskaya | | XX | XX | XX | XX | | | | | |
| Partizanskiy Sedimentary Basin | | | | | | | | | | |
| Suchanskaya | XX | XX | ХХ | ХХ | | | | | | |
| Korkinskaya | Х | XX | XX | XX | XX | | | | | |
| Notos: VVV provoile: | VV procent in ag | ual proportions. | | 11 | | | | | | |

Notes: XXX—prevails; XX—present in equal proportions; X—occurs occasionally.

The distribution of associations among the formations (Figure 2, Table 1) requires closer attention. In the Razdol'nenskiy Sedimentary Basin, the *Ussuriyskaya Suite* was only sampled in the Sadgorod area (Vladivostok town; Supplementary Figure S3 [24]), and is represented by a chlorite–mica association. The *Lipovetskaya Suite* was sampled in more detail in Zanadvorovka village, Tavrichanka village, and Vladivostok town. In the area of Zanadvorovka village, in the sandstones, which are lower and higher coal layers, the mica–kaolinite association is dominant. In the other samples, chlorite–mica and chlorite–corrensite associations were found. Somewhat more interesting is the area of Tavrichanka village. Here, in the rocks of Rechnoy Island, the author found intraformational erosion, above which laumontite was found, and below which this was absent, while the chlorite–mica association was predominant.



Figure 3. Typical X-ray diffractograms of the cement of Cretaceous rocks of Southern Primorye. Letter designations: (a) composition of the mineral association—kaolinite, mica, rectorite, quartz, plagioclase; (b) mica, mixed-layer mica-smectite, vermiculite (?), quartz, plagioclase, calcite (?); (c) mica, chlorite, quartz, plagioclase; (d) corrensite, chlorite, laumontite, quartz, plagioclase; (e) rectorite, kaolinite, mica, quartz, plagioclase; (f) corrensite, quartz, plagioclase, calcite (?); I—oriented, air-dried; II—ethylene glycol-saturated. Reflections are in angstroms (Å).

The same situation was noted in the coastal sediments of the Rybachy Peninsula, where, in addition to chlorite-mica, chlorite-corrensite and chlorite-corrensite-laumontite associations were noted. In the area of Vladivostok town (De-Fryz Peninsula and Markovsky Cape), chlorite-mica and chlorite-corrensite associations prevailed, and rectorite associations were sometimes present. The Galenkovskaya Suite in the areas of Zanadvorovka village, the De-Fryz Peninsula, and Markovsky Cape (Vladivostok town) was characterized by chlorite-corrensite-laumontite and, to a lesser extent, chlorite-mica and rectorite associations. The Korkinskaya Series in the area of Vladivostok town (Brazhnikova Bay and Markovsky Cape) was characterized by rectorite, mica-chlorite, and sometimes corrensite-chlorite associations. Deposits of the Korkinskaya Series in Zanadvorovka village were characterized by chlorite-corrensite-laumontite, chlorite-corrensite, and chlorite-mica

associations, whereas the reddish rocks near Kravtsovka village were found to contain rectorite associations.

In the Partizanskiy Sedimentary Basin, the Suchanskaya Series contains mica–kaolinite (central part of the Severosuchanskaya suite), corrensite–chlorite (upper part of the Severosuchanskaya and Frentsevskaya suites) associations (Table 1, Supplementary Table S1, Figure S4). The deposits of the lower parts of the Korkinskaya Series (Luk'yanovka, Romanovka, Molchanovka, and Zalesye villages) are characterized by chlorite–mica, corrensite–chlorite, and corrensite–chlorite associations (Kangauzskaya Suite). Associations of rectorite, mica, and kaolinite were found in the reddish-colored sediments of the upper part of the Romanovskaya suite (Zalesye and Molchanovka villages) (Table 1, Supplementary Table S1, Figure S5).

5. Discussion

In general, the Razdol'nenskiy and Partizanskiy sedimentary basins have similar features as regards the distribution of authigenic minerals contained in the rock cement. The presence of mica-kaolinite in the Lipovetskaya suite and Suchanskaya Series, corrensitechlorite-laumontite in the Suchanskaya and Korkinskaya Series and the Galenkovskaya suite, as well as the persistent presence of rectorite associations in the reddish-colored sediments of the Korkinskaya Series (upper part of the Romanovskaya suite), are noted. The presence of the kaolinite-mica association (often in sandstones in the lower and upper parts of coal layers) is logically associated with the proximity of the continent and the humid climate on the nearby land. Some of the sediments of the Lipovetskaya suite and the Suchanskaya Series correspond to these conditions. Sedimentary environments are likely to change to arid conditions, or to conditions favorable for the evaporation of seawater. As a result, deposits with elevated magnesium concentrations are sedimented, in which corrensite is subsequently formed. These conditions were observed for some of the sediments of the Suchanskaya Series (Frentsevskaya suite), the upper part of the Lipovetskaya suite, the lower part of the Galenkovskaya suite, and the Korkinskaya (Kangauzskaya Suite) Series. This was followed by an event ("Galenkovskoe") common to the formations of both of the sedimentary basins, which is characterized by the presence of a corrensite-chlorite-laumontite association in the Galenkovskaya suite, and in the upper part of the Suchanskaya (Frentsevskaya suite) and Korkinskaya (Kangauzskaya suite) Series.

The early presence of laumontite in the Lower Cretaceous rocks was noted only in the area of the Yamato Upland (Sea of Japan) [1,3,4], and its presence has been confirmed in the sediments of the south of the Far East. The conditions for its formation are not yet clear. In Primorye, laumontite was found for the first time in Paleogene rocks [26] in association with corrensite (Posyet Peninsular, Khasansky District) and corrensite-like mineral (CLM) formations (initial corrensitization near Romashka village, Khasansky District), and then in the Galenkovskaya suite, and the Suchanskaya and Korkinskaya Series ("Galenkovskoe" event), in association with corrensite and chlorite. Since laumontite is a calcium zeolite, its formation may be associated with increased calcium contents in sediments, and therefore, it is assumed that increases in its quantity could supply the sedimentary basin. The identification of laumontite, kaolinite, corrensite, mica, and chlorite in the Lower Cretaceous deposits of the Yamato Upland (Sea of Japan) and South Primorye suggests the proximity of sedimentary environments, and the possible existence of a united sedimentary basin or several neighboring ones, formed during the destruction of the Earth's crust [34]. At first, this probably gave rise to humid epicontinental (presence of kaolinite) sedimentation conditions, which were replaced by coastal marine conditions, establishing the possibility of the evaporation of seawater (corrensite) and increased supplies of calcium (laumontite). Then, the deposits formed in a humid subtropical climate, as confirmed by the reddish colors (increased ferruginization, rectorite association, sometimes the presence

of kaolinite—signs of weathering on the nearby land) in the upper parts of the Korkinskaya Series (Romanovskaya suite).

The presence in the cement of Lower Cretaceous rocks (corrensite-chlorite and corrensite-chlorite-laumontite associations) can potentially act as the benchmark, and thus help to more precisely distinguish the deposits of the Galenkovskaya suite ("Galenkovskoe" event) among similar deposits of the Lipovetskaya suite (Tavrichanka village, Rechnoy Peninsula, Rechnoy Island; Supplementary Figure S3, samples 404-406, Table S1). Furthermore, this is probably synchronous with the "Galenkovskimi" sediments of the Suchanskaya and Korkinskaya series, and could help to distinguish Cretaceous deposits from Jurassic and Triassic (area near town Bol'shoi Kamen'; Supplementary Figure S4, samples 516–520, Table S1). Laumontite in association with corrensite in the sedimentary deposits of the Primorye Region was first noted [26] in the Paleogenic volcanic-sedimentary rocks of the Posyet Peninsula (Khankaisky District), and in association with a CLM in Paleogenic volcanic-sedimentary rocks near Romashka village (Khasansky District). Therefore, the appearance of laumontite in the sedimentary rocks cannot serve as a diagnostic sign [35], but in association with corrensite and chlorite, it can at least mark the beginning of the Galenkovskoe event, since it is most widespread in the Galenkovskaya suite and Suchanskaya and Korkinskaya Series. Moreover, such events (as the "Galenkovskoe" period, corrensite-chlorite-laumontite association) may happen more often, because there seem to have been warming periods in this area in the Early–Middle and Late Albian [20].

The Suchanskaya Series includes four associations: mica–kaolinite, chlorite–mica, corrensite–chlorite, and corrensite–chlorite–laumontite, i.e., it mirrors the Nikanskaya Series [7,8]. Corrensite was found in some samples of Triassic rock (in the area near Bol'shoy Kamen' town; Supplementary Figure S4, samples 516–520, Table S1), which may allocate this part of the region to the Early Cretaceous. The kaolinite–mica association may relate part of the deposits of the Lipovetskaya Suite and Suchanskaya Series to coal accumulation, the presence of nearby land, and a warm and humid climate. As already noted [1,3,4], in the Yamato Upland, Japan Sea, kaolinite and mica are found in the rectorite association, but are antagonistic to chlorite, corrensite, and laumontite. The existence of corrensite in the absence of chlorite helps to easily distinguish Cretaceous sediments from Paleogenic ones (Figure 3e,f; Supplementary Figure S4, samples 521, 543–544, Table S1).

Thus, in both sedimentation basins (Razdol'nenskiy and Partizanskiy), we can observe five identical stages of sedimentation, reflected in the cement rock's mineral composition:

- 1. Coastal marine ("normal" marine) conditions were noted in all the formations (chloritemica association);
- 2. Epicontinental conditions were noted in the Lipovetskaya suite and the Suchanskaya Series (kaolinite–mica association, coal-bearing conditions);
- 3. Coastal marine conditions (with the possibility of evaporation of seawater) are characteristic of the Lipovetskaya and Galenkovskayay suites, and the Suchanskaya and Korkinskaya Series (corrensite–chlorite association);
- 4. Coastal marine conditions, with the possibility of the evaporation of seawater and an increased supply of calcium to the sedimentary basin, were found in the Galenkovskaya suite ("Galenkovskoe" time or event) and in the Suchanskaya and Korkinskaya series (corrensite–chlorite–laumontite association);
- 5. Epicontinental deposits under conditions of chemical weathering in a humid subtropical climate, noted in the upper part of the Korkinskaya Series (reddish-colored deposits, rectorite association, Romanovskaya suite).

Mineralogy and vegetation. Changing flora and fauna are determined by variations in climatic, physicochemical, and tectonic parameters, which, in turn, are reflected in the deposition conditions and mineral associations of sedimentary rocks. It is very important to study this connection. For the Lower Cretaceous deposits of South Primorye, according to V.P. Konovalov, two main transgressions can be distinguished: Aptian–Middle Albian and Middle–Late Albian, separated by the Middle Albian regression [19].

Palynological data confirm that changing stages in the Cretaceous vegetation of the Primorye Region fit with types of sedimentary change [15,17,20,21,36–40]. V.V. Golozubov [14] states that the pre-Albian plant communities of the two basins differ in both structure and taxonomic composition; then, at the beginning of the Albian, these differences were erased as the paleoenvironments became similar. V.S. Markevich [20] believes that the mosaicity and heterogeneity of the Cretaceous sedimentary rocks in Southern Primorye probably determined the high rates of plant diversification and the dynamics of their diversity. The Barremian of the Razdol'nenskiy Sedimentary Basin (Ussuriyskaya Suite) is dominated by pine and schizaean ferns. In flora of the same age in the Partizanskiy (Starosuchanskaya Suite) basin, the taxodia and various ferns species are different: gleichenium and schizoid. In the Aptian (Lipovetskaya suite and upper part of the Starosuchanskaya and Severosuchanskaya suites, kaolinite-mica mineral association), under a warm and humid climate, in the plant communities of the Razdol'nenskiy basin, there was a sharp change in the dominant group, with sudden increases in the abundance and diversity of gleicheniaceae, and in the role of rare angiosperms. The Partizanskiy basin is also dominated by ferns, mainly close to gleicheniums. Among gymnosperms, the number of taxodiaceae remained high, but the variety of pine increased. The middle of the Cretaceous period, in addition to the formation of angiosperms, was the time of active geological and tectonic events, and sharp fluctuations in climate. The rates of extinction and diversification of flora in the Albian in the south of Primorye were very high. In the Early Albian, with some cooling and aridization of the climate, coal accumulation stopped and the Early Cretaceous plant communities were replaced by forests of a new type.

The Early Albian flora of the Razdol'nenskiy (lower part of the Galenkovskaya suite, the corrensite–chlorite–laumontite mineral association) and the Partizanskiy Basin (the upper part of the Severosuchanskaya suite, the same mineral association) were similar. They were dominated by species close to cyateaceae and schizaeidae amongst ferns, as well as pines and taxodiaceae. The participation of angiosperms increased. In the Middle Albian period in the Razdol'nenskiy Basin, under continental conditions (the upper part of the Galenkovskaya suite, corrensite–chlorite–laumontite mineral association), the vegetation remained the same, but the diversity and participation of angiosperms increased.

At the same time, in the Partizanskiy Basin (the Frentsevskaya suite with remnants of trigonium, corrensite-chlorite-laumontite mineral association), species closely related to the ophioglossales became dominant, and taxodiaceae were still abundant. The Late Albian flora (the lower part of the Korkinskaya series, corrensite-chlorite-laumontite mineral association) in the Razdol'nenskiy basin were characterized by an abundance of ophioglossales, a reduction in the participation of thermophilic gleicheniaceae and schiziaceae, and the disappearance of ferns and gymnosperms typical of Jurassic and Cretaceous floras. As regards the composition of gymnosperms, in addition to the still-abundant taxodiaceae, girmeriella and more oppressive varieties appeared. The variety of magnoliophyta increased in prevalence. In the coeval flora of the Partizanskiy Basin (Korkinskaya Series, Kangauzskaya suite, corrensite-chlorite-laumontite mineral association), the diversity of spore species reduced. The main plant associations included thermophilic gleicheniums, cyateaceans, dixoniaceans, schizaeans, and pure-mouths. The gymnosperms were dominated by taxodiaceae, rare girmeriella, and oppressive varieties. Magnoliophyta were very rare. Some warming and drying of the climate in the Late Albian is evidenced by the prevalence in the vegetation of girmeriella and oppressive plants. The increase in the participation and diversity of angiosperms is an undeniable indication of a change in the paleo relief—early angiosperms were the first settlers on cooled volcanic lavas and vacant ecological niches after the extinction of the Jurassic and Early Cretaceous taxa that previously dominated [20].

6. Practical Application

Taking into account all of the above, it becomes possible to determine the time frame in the Cretaceous period of sedimentation in the studied sedimentary basins. Chlorite–mica (mica-chlorite) association was found in all formations, and so cannot be determinative by itself. For the kaolinite-mica association, the time of formation can be established as Aptian—the beginning of the Early Albian—113–120 Ma (coal accumulation, "Lipovet-skoe", is noted in the Lipovetskaya suite and Suchanskaya Series). The corrensite-chlorite association marks the beginning of the Early Albian period—110–113 Ma (noted in the Lipovetskaya and Galenkovskaya suites and the Suchanskaya and Korkinskaya Series); the corrensite-chlorite-laumontite marks the second half of the Albian—105–110 Ma ("Galenkovskoe", which is recorded in the Galenkovskaya suite and Suchanskaya and Korkinskaya Series), and the rectorite marks the Late Cenomanian—93–95 Ma ("Korkinskoe" time, reddish-colored sediments of the Korkinskaya Series (Romanovskaya suite)).

Therefore, "Lipovetskoe" marks two events, the kaolinite–mica association (113–120 Ma (coal accumulation epoch)) and corrensite–chlorite association (110–113 Ma), the times of which are comparable to the Early Albian event (Paquier event, OAE 1b, 111 Ma, [41–43]). For "Galenkovskoe" (the presence of laumontite), the interval can be defined as 105–110 Ma. The nearest global events involving a significant supplied of calcium in their sedimentary deposits are recorded at the boundaries of 103, 105, and Urbino–107.5 Ma, OAE1c and OAE1d [41,44,45]. Such multiplicity can be explained by the recurrence of events of increased calcium supply to the sea basin, i.e., there may be several supply periods, and these have not yet been sufficiently studied in these deposits.

It should be assumed that some of the Lower Cretaceous rocks of the Yamato Upland (Sea of Japan) may also have been through similar sedimentation stages, since similar mineral associations have been identified there [1,3,4]. The formation interval of the reddish-colored sediments of the Korkinskaya Series (upper part of the Romanovskaya suite) is 93–95 Ma (the epoch of lateritic weathering), which coincides with the Cenomanian–Turonian events (OAEs—Bonarelli event, C/T OAE, OAE2, ~93 Ma, [41,42,46]). Similar stratification was also noted for the Cretaceous deposits of Europe [47–49], Venezuela [45], Northern Iraq [50], Japan [51–54], Polynesia [55], Tibet [56,57], the Arctic [58], and other regions of the world [59–64].

The sediments of the OAE1a–OAE 1d events, identified in the Shatskiy Rise [59] and in Japan [54], can also be found in Primorye. The author found black shales with pyrite on Shikotan Island. The same rocks were found in samples from roads in the Southern Primorye Region. The black shale marker horizon (layer/layers) was noted in the Partizanskiy Sedimentary Basin. Its exact age has not been determined but is presumed to be between Barremian and Albian [7,8,19].

7. Conclusions

It is assumed that the further study of authigenic minerals in the Cretaceous deposits of the Primorye Region will provide an opportunity to use the identified stages (benchmarks) in the history of the geological development of the region to clarify stratigraphic constructions. It will become possible to identify periods in the Cretaceous sedimentation of the Primorye Region, which may be associated with global biotic and abiotic events in the history of the Earth—113–115, 110–112, 103, 105, 107.5, and 93–95 Ma, referred to as OAEs and characterized by certain climatic changes.

Undoubtedly, with further in-depth studies of authigenic minerals in the rocks of this region, the assumptions of the author can be confirmed.

Supplementary Materials: The following are available online at https://www.mdpi.com/article/10 .3390/min11080840/s1, Figure S1: Simplified geological scheme of the Zanadvorovka Village [65,66]; Figure S2: Simplified geological map of the Tavrichanka Village [65–67]; Figure S3. Simplified geological scheme of the area of Sadgorod (Vladivostok) [24,65]; Figure S4. Simplified geological map of the area of Romanovka Village [68]; Figure S5. Simplified geological map of the area of Molchanovka Village [68]; Table S1: Authigenic minerals in studied rocks of the Southern Primorye (Russian Far East). **Funding:** This work was supported by the Ministry of Science and Education of Russia (project 121021700342-9).

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