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Applied Clay Science 24 (2004) 327–336
Applied CLAY Science
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Upper Cretaceous–Cenozoic clay minerals of the Baikal region (eastern Siberia)

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Received 29 December 2002; received in revised form 13 July 2003; accepted 19 August 2003

Abstract

The Baikal region is located in a single climate zone and includes the Baikal foredeep on the eastern margin of the Siberian craton and the Baikal rift evolving at the western boundary of the Baikal orogenic area. Late Cretaceous–Cenozoic deposition in the two dissimilar tectonic units occurred in different environments, which is recorded in the architecture of sedimentary sequences and in the stratigraphic distribution of clay mineralogy.

Clay minerals are mostly derived from weathered rocks of different ages. The geological ages of the source weathering mantles and their regular changes in different tectonic and climatic conditions can be inferred from the stratigraphic position in the Upper Cretaceous–Cenozoic sedimentary sequences that fill the Baikal foredeep. These inferences agree with data on fossil soils, flora, and fauna. Clay minerals show genetic relationships with stages of postdepositional alteration and processes of soil formation and hydrothermalism.

In general, the Cenozoic history of erosion, deposition, and postdepositional changes of rocks in the Baikal region has been controlled by the interplay of climate and tectonic factors.

Keywords: Weathering; Weathering mantle; Eluvium; Fossil soils; Clay minerals; Baikal foredeep; Baikal rift system; Baikal rift; Baikal basin

1. Introduction

The study region is located in a zone of temperate climate and includes the Baikal foredeep on the eastern margin of the Siberian craton and the Baikal rift (Baikal rift basin bordered by rift ridges) evolving at the western boundary of the Baikal orogenic area (Fig. 1). Late Cretaceous–Cenozoic deposits fill depressions within the foredeep and the Baikal rift system (system of en-echelon rifts with Baikal rift in its center). The general Cenozoic history of erosion, deposition, and postdepositional changes of the sedimentary sequences was controlled by the interplay of climate and tectonic factors. Climate changed cyclically from humid tropic conditions, with optimum in the Eocene, to a temperate and cold climate of the Late Pliocene–Quaternary (Fig. 2). Tectonic activity grew from relative stability in the latest Cretaceous–Paleogene and culminated in Late Pliocene–Quaternary time.

Weathering mantle upon rocks of different ages was the source of autochthon material and, along with deposition environments, controlled the composition of terrigenous deposits and their authigenic compo-

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doi:10.1016/j.clay.2003.08.008

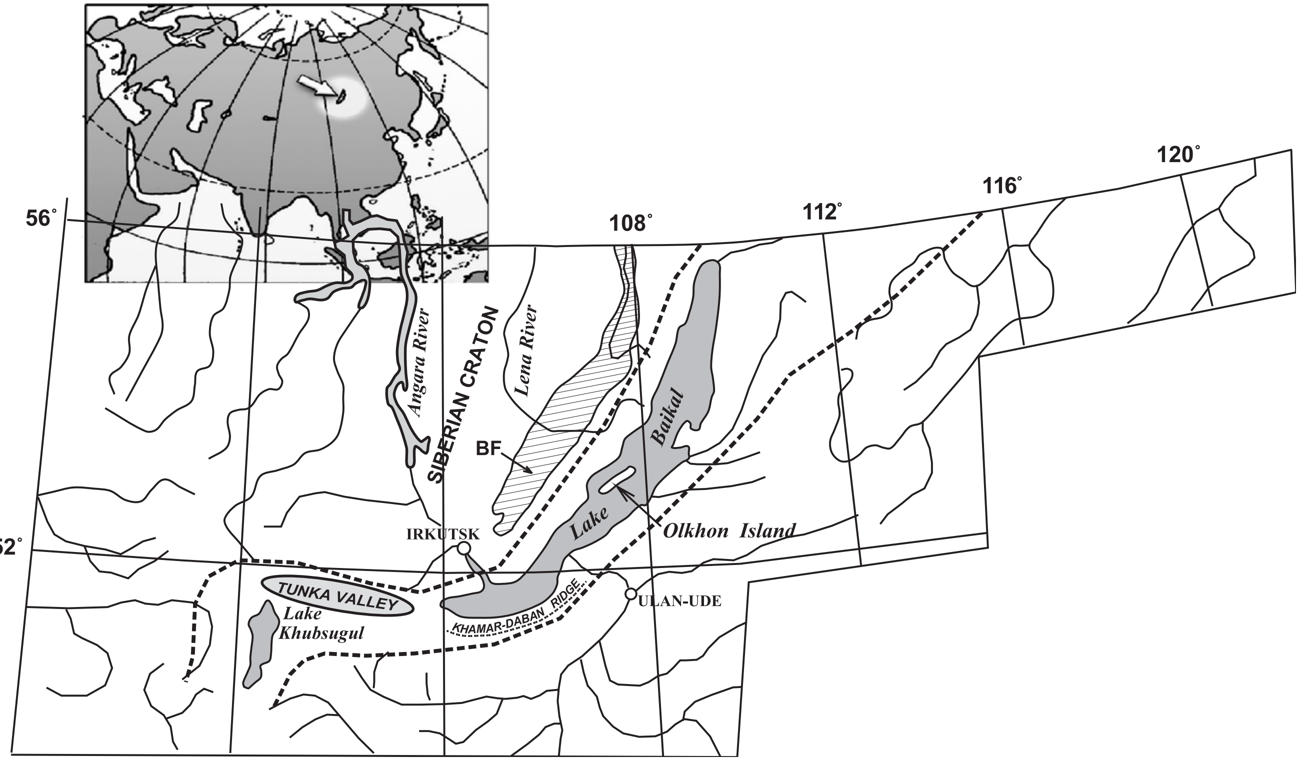

Fig. 1. Location map of the Baikal region. Baikal rift zone is shown by dotted line.

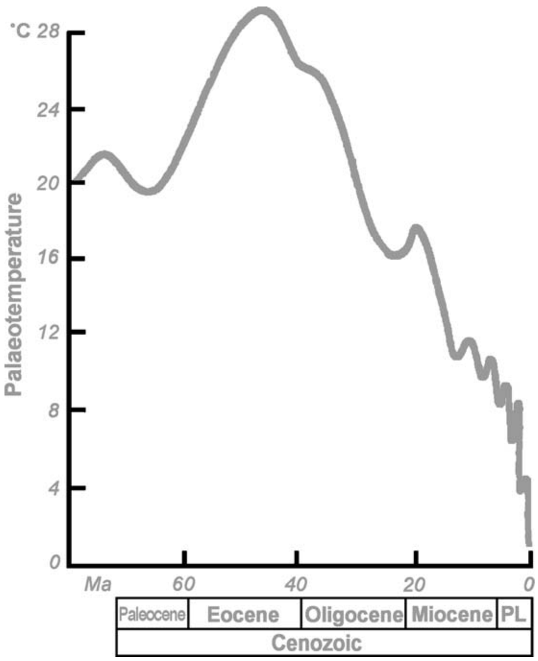

Fig. 2. Global trend of mean annual air paleotemperatures for southern Russian Plain (Budyko, 1984).

nent. The study region includes several lithostratigraphic complexes formed in specific conditions of erosion and deposition recorded in the clay mineralogy of rocks (Logachev et al., 1964; Pavlov et al., 1976; Mats et al., 1988, 2001).

2. Results

2.1. Weathering profiles and related deposits of the Baikal foredeep and Baikal rift

Late Cretaceous–Cenozoic deposition in the two dissimilar tectonic units occurred in different environments, which is recorded in the architecture of sedimentary sequences and in the stratigraphic distribution of clay mineralogy. In the Baikal foredeep, it was deposition of peat in limnic and limnic-bog basins or carbonates, sulfates, and clays in shallow closed saline lakes in which high mineralization was due to evaporation and erosion of abundant pre-Cenozoic carbonates. In the Baikal rift, carbonate-free clays and sands and coarse-grained marginal facies were deposited in large deep overflowing lakes with limited peat accumulation on their periphery.

The Baikal foredeep is a system of basins filled with up to 600-m-thick Late Cretaceous to Holocene sediments. Upper Cretaceous deposits are associated with pre-Maastrichtian weathering profiles and underlie Danian–Paleocene deposits with Late Paleocene–Eocene weathered surfaces upon them overlain by younger Cenozoic sequences (Pavlov et al., 1976).

Weathering in the Baikal rift acted upon Cretaceous–Paleogene peneplain and younger landforms. Drilling stripped 3000 m of the basin fill whose total thickness may exceed 7500–11000 m, according to geophysical data (Logachev, 2000).

2.1.1. Late Cretaceous–Paleogene

2.1.1.1. Baikal foredeep. The Upper Cretaceous sedimentary section of the Baikal foredeep includes pre-Maastrichtian and Late Paleocene–Early Eocene weathering profiles stratigraphically alternating with Maastrichtian, Paleogene to Danian–Paleocene, and Eocene–Oligocene deposits.

Pre-Maastrichtian weathering mantle upon Cambrian rocks was found in boreholes from a number of basins within the foredeep. The upper portion of its preserved profile is composed of montmorillonite clays with siliceous debris transient downsection into dolomized limestones with minor high-Mg smectites and hydromicas. Clay minerals also exist as assemblages of smectite (dominant mineral), chlorite, and halloysite. Weathered rocks upon terrigenous carbonate sediments (marls) make up a ∼ 13-m-thick montmorillonite–hydromica zone.

Maastrichtian deposits are up to 30-m-thick lacustrine-bog varicolored clays, sands, and sandstones. Kaolinite is the dominant mineralogy, while hydromica and smectite abundances are minor. Cement in sands and sandstones (up to 70% quartz, minor silica and chalcedony) consists mostly of kaolinite.

Danian–Paleocene deposits are drilled in few basins of the foredeep and are attributed to karst- and tectonic-erosion and karstland deposition basins. Clay minerals in abundant coarse talus are mostly kaolinites, with minor smectites, hydromicas, and halloysite.

Late Paleocene–Early Eocene weathering profiles are preserved upon Cambrian, Jurassic, and Danian–

Paleocene rocks. Kaolin-lateritic profiles formed during the Cenozoic climate optimum and were the source of terrigenous material deposited in a humid climate and supplied into Eocene–Oligocene freshwater lakes.

Cambrian carbonates are overlain by a mantle of quartzitized limestones in marshallite with minor montmorillonite and hydromica. A complete eluvial profile on Cambrian terrigenous carbonate rocks consists of weakly altered kaolinite–hydromica, kaolinite, and goethite–kaolinite–gibbsite zones. The eluvium bears traces of resilicification under the effect of gleying, local leaching, halloysitization, formation of siderite and pyrite, downsection infiltration of gibbsite, and secondary geochemical zonation.

Eocene–Oligocene related deposits are coaliferous, phosphate- and bauxite-bearing continental facies formed in a humid climate and abundant red siliceous-kaolin and kaolin-bauxite rocks with terrigenous kaolinite (Pavlov et al., 1976), mostly of lacustrine and lacustrine-bog freshwater origin. Eutrophic conditions in some deposition basins are recorded in the formation of coal beds and authigenic kaolinite.

The sediments are formed in neutral and acidic, aerobic and anaerobic environments, and contain mostly siderite, chamosite, vivianite, and kaolinite as authigenic minerals.

2.1.1.2. Baikal rift. Upper Cretaceous and Paleogene sediments in the Baikal rift are found in numerous outcrops of weathered rocks and related continental deposits and, being undifferentiated, are considered jointly as Cretaceous–Paleogene rocks.

Kaolin and kaolin-lateritic weathering profiles, 20–30 m thick, are preserved upon Cretaceous–Paleogene peneplain, and linear-type zones penetrate to depths of 100–150 m. Traces of supergenesis recorded in the presence of 36–40 Ma (Dombrovskaya et al., 1984) sericite, alunite, and free-Al mineral inclusions are observed in boreholes to depths of 300–400 m.

The derivatives of weathered pegmatites, granitoids, gabbros, ultramafics, amphibolites, gneisses, schists and shales, limestones, etc. (Logachev et al., 1964; Dombrovskaya, 1973; Mats et al., 2001) include free-Al minerals, karst-metasomatic phosphorites, iron–manganese ore, kaolinite, halloysite, alunite, di- and trioctahedral smectites (montmorillonite, beidellite, nontronite, saponite, palygorskite), magnesite, and silicic rocks and minerals. The rocks and minerals derived from the primary substrate of diverse compositions experienced supergene alteration of different ages.

Related deposits are light-colored and red lacustrine and slope-wash clays, lacustrine and alluvial sands and pebbles that fill ravines, river valleys, and gullies or occur as up to 100 m thick cover on older watersheds. Clays have rather kaolinitic compositions, and sands and pebbles are composed mostly of quartz. Fine-grained deposits often contain minerals of free Al (gibbsite, aluminite, allophane, alumohydrocalcite, etc.), Mn, Fe, and P.

2.1.2. Late Oligocene and Early Pliocene

2.1.2.1. Baikal foredeep. Late Oligocene *weathering profiles* are mostly montmorillonitic and are preserved upon rocks of different ages. Remnants of supergenic profile upon Early Cambrian limestones are coarse-blocky eluvial quartzitized limestones grading upsection into 1–3-m-thick waste in marshallite matrix bearing montmorillonite and hydromicas. Cambrian terrigenous-carbonate rocks are mantled by weakly altered deposits and a montmorillonite zone with ferruginous montmorillonite as rock-forming mineral. In some basins, the uppermost Paleogene section is strongly montmorillonitized (Pavlov et al., 1976).

Related deposits (*Upper Oligocene–Lower Pliocene*) are coaliferous polymictic rocks formed in a semiarid climate. Deposition in closed and poorly overflowing saline lakes was accompanied by precipitation of carbonates, gypsum, di- and trioctahedral smectites (palygorskite). The bottom sediments of fresh and low-salinity lakes contain rather montmorillonite–beidellite carbonate clays with minor hydromica and kaolinite (Logachev et al., 1964) and coal beds attaining thicknesses of tens of meters. Red beds appear in the uppermost Miocene section.

2.1.2.2. Baikal rift. Late Oligocene weathered rocks in the Baikal rift rarely can be differentiated from the lowermost Cretaceous–Paleogene profile. Data from lavas in the Khamar–Daban and East Sayan mountains show that Late Oligocene erosion was a single episode in a period of volcanic activity that lasted through the Miocene and Early Pliocene as long as the middle Late Pliocene. Neogene lava flows are separated by weathered surfaces; Lower and Middle Miocene basalts are strongly altered, Upper Miocene volcanics are less changed, and Upper Pliocene–Quaternary basalts are free from traces of weathering (Rasskazov, 1993).

Late Oligocene *weathering profiles* were studied in detail in a section in the southern Baikal shore (Mazilov et al., 1972) and in outcrops in the bottom of Lake Baikal (Goldyrev, 1982; Zonenshain et al., 1995) where they attain thicknesses of many meters and are overlain by Upper Miocene–Pliocene sediments.

Related deposits are found in natural exposures in the inversely uplifted periphery of the Baikal basin and in a number of boreholes, including deep ones. Exposed rocks are known in the southern (Tankhoi) and northern (Sasa) type sections of lacustrine deposits and as subaerial facies (Mats et al., 2001).

The Tankhoi section in the southern Baikal shore is composed of 1000-m-thick carbonate-free polymictic clays alternating with clay–silt and clay–silt–sand layers of limnic facies (of paleobaikalian origin). Graywackes grade on strike into polymictic sands (sandstones) and boulder–pebble conglomerates. Sediments in the Tankhoi section were transported mostly from the active tectonic zone of Khamar–Daban and deposited in the South-Central Baikal basin. The Tankhoi rocks most often have polymineral terrigenous clay compositions. Their authigenic varieties were produced by postdepositional and syndepositional alteration and pre-Late Paleocene weathering. Clay mineralogy in the lower half of the section is clearly dominated by kaolinite (up to 50–80%) and contains significant hydromica abundances and minor smectites; the upper half bears variable contents of hydromicas, kaolinite, smectites, and chlorite.

The Sasa section consists of lacustrine sands and clays and is the most complete in the Olkhon block where it reaches a thickness of 120–150 m. Lower–Middle carbonate and gypsum-bearing montmorillonite clays and sands of small and medium closed lakes, locally with thin partings of brown coal, occur at the base of the section and are overlain by carbonate-free oligomictic deposits of relatively large Late Miocene–Early Pliocene freshwater Sasa lake. Numerous lagoons, in which carbonate clays gave way to red subaerial facies, surrounded the lake. The greatest portion of the Sasa section is composed of green clayey siltstones and kaolinite–hydromica–montmorillonite clays.

2.1.3. Red rocks

Abundant Upper Miocene–Pliocene *red rocks* (laterite, red earth, and stratified products of local redeposition) in the Baikal foredeep and in the rift are subaerial facies, rapidly grading into submarine deposits. They are encountered at the Upper Miocene–Lower Pliocene and Upper Pliocene stratigraphic levels (Mats et al., 1982, 2001).

Polymineral red rocks are most often carbonate and contain up to 13% iron oxides (goethite, hydrogoethite) and iron–manganese nodules. The pelitic fraction consists of smectites, hydromicas with different iron contents, and chlorites. The related deposits bear high percentages of kaolinite if red rocks are derived from kaoline weathering profiles and Jurassic or Paleogene deposits.

Soils in the Baikal region were of Mediterranean type long through Miocene–Pliocene time (Voroboyva et al., 1987, 1995). Red and cinnamonic soils predominated on slopes and graded into vertisols in depressions. Red color is due to iron oxides that pigment clay matter and make thin coating on grains of some minerals or exist as 0.02–0.03-mm nodules concentrated mostly near cracks and pores. The shades of red fade from Miocene to Pliocene soils to disappear in latest Pliocene (forest gray soils and gley gelisols) and in the Quaternary. The stratigraphic sequence is from Fe–Si–Al red earths of latest Miocene, to Early Pliocene vertisols and red-cinnamonic earths (with desiccation cracks), and on to dark-cinnamonic, cinnamonic, cryogenic-gley, and gray forest soils in the Late Pliocene (Table 1). Meadow and marsh chestnut soils replace red earths in depressed landforms where their red color is masked by humus organic matter.

Soils acquired red color through two-stage evolution. First, in a humid warm climate, iron was evacuated from iron–manganese silicates and impregnated the clay matter of soils with hydroxides. At the following stage, when climate was strongly arid, hydroxides changed into oxides (possibly, into goethite and hematite) by dehydration. Aridization caused rapid mineralization of organic matter and was favor-

Table 1
Clay mineralogy in Late Cenozoic soils

Age	Soils	Clay minerals
Holocene	Sod-podzolic soils, sod forest soils, gray forest soils, chernozem (black earth), sod carbonate (humic carbonated) soils, chestnut soils	Hydromica, chlorite, smectite↔mixed-layer, kaolin
Upper Pleistocene (warming within glacial)	Weakly developed soils: carbonate-gley soils, sod-gley soils, non-gley primitive soils	Hydromica, kaolin↔smectite↔chlorite, mixed-layer
Pleistocene (glacials)	Subaerial deposits	Hydromica↔chlorite, kaolin↔smectite, mixed-layer
Pleistocene (interglacials)	Sod forest soils, brown forest soils, gray forest soils, chernozem, sod carbonate (humic carbonated) soils	Hydromica↔chlorite, smectite, kaolin, mixed-layer
Upper Eopleistocene	Chestnut soils	Hydromica, chlorite, kaolin
	Weakly developed soils	
	Podbur (ferrimorphic cryomorphic taiga soils)	
Lower Eopleistocene	Chestnut soils	Hydromica, kaolin
	Chernozem and chernozem-like soils	
	Chestnut soils	
	Brown semi-desert soils	Hydromica, chlorite, kaolin
		Montmorillonite, (chlorite), hydromica, kaolin
	Pedosediments of chestnut soils and chernozem	Hydromica, kaolin
	Humic aggradation soils	Montmorillonite, hydromica, kaolin
Upper Pliocene	Gray forest soils	Hydromica, metahalloysite
		Kaolin, smectite, hydromica
	Cryogenic gley soils	Smectite, kaolin, minor hydromica and chlorite
	Cinnamonic soils	Chlorite, hydromica, kaolin, smectite
		Chlorite, hydromica, kaolin
		Hydromica, kaolin
		Hydromica, chlorite↔kaolin
		Hydromica, smectite, kaolin, chlorite
		Smectite, kaolin↔hydromica
	Dark cinnamonic soils and compacted cinnamonic soils	Montmorillonite, hydromica,kaolin
		Montmorillonite
		Smectite, kaolin, hydromica
Lower Pliocene	Red-cinnamonic soils (with desiccation drying)	Hydromica, kaolin, montmorillonite, (chlorite)
	Dark cinnamonic soils	Smectite, kaolin, hydromica
	Slitozem-vertisols (= tirs, smolnitza, smolnitza)	Montmorillonite, kaolin
		Montmorillonite, hydromica
		Montmorillonite
		Smectite, kaolin, hydromica
Lower Pliocene–Upper Miocene	Red Fe–Si–Al (= mediterranean) soils	Hydromica, kaolin, smectite

Minerals are listed from higher to lower abundances. Arrows show dominance changes.
Minerals in parentheses are of irregular occurrence.

able for migration of carbonates into the upper section where clay mineralogy is dominated by hydromica, and the abundances of kaolinite, montmorillonite, and chlorite are minor. Increase in hydromica contents up the section indicates that a part of hydromicas is authigenic. Silt- and sand-size grains of unstable minerals are strongly weathered, and the degree of weathering decreases sequentially from vertisols to chestnut and cinnamonic soils, and to red earths, i.e., from more humid to drier varieties.

Soils in Miocene–Pliocene sections are separated and underlain by *subaerial facies* of yellowish talus, often banded due to bright red-earth interlayers, which makes it different from Quaternary slope wash.

2.1.4. Latest Pliocene–Quaternary

Late Pliocene–Quaternary deposits are described jointly for the Baikal foredeep and the Baikal rift. The conditions of weathering and soil formation changed abruptly at the Neogene–Quaternary boundary. Quaternary weathering profiles differ dramatically from older products but have equivalents in the modern eluvium (Chernyakhovsky, 1991).

(1) *Pre-Quaternary–Early Quaternary weathering profiles* are composed of eluvium beds, tens of centimeters thick, or occasionally, up to 10–12 m (Mats et al., 2001), formed by mechanical shattering of rocks almost without changes in chemistry and mineralogy. It is the main source of broadly distributed polymictic sands in the lower portion of the Quaternary section in the Baikal region. Redeposited polymictic sands and loamy sands contain 80–90% hydromica, 10–30% chlorite, and 1–5% kaolinite.

(2) *Pre-Quaternary–Early Quaternary soils* are forest soils of warm periods and ferrimorphic and cryomorphic varieties, with highly mobile iron and organic matter (Voroboyva et al., 1995) that formed in a humid glacial climate and are typical of northern taiga and tundra (Table 1). Clay minerals in ferrimorphic, cryomorphic, and forest soils have polymictic compositions (allogenic hydromicas, smectites, and kaolinite). Soils typical of arid and semiarid landscapes (steppe, dry steppe, and semidesert zones), as well as drift soils, formed in moderately cold and arid conditions through the greatest portion of Early Quaternary time (Voroboyva et al., 1987, 1995). Clay minerals in them are mostly allogenic, and hydromica abundances increase upsection (Table 1).

(3) *Pleistocene weathering profiles*. Primitive profiles of debris-blocky eluvium formed during glacials, and immature varieties originated in interglacial periods. Weathering profiles demonstrate almost no migration of components but fine-grained varieties contain significant amounts of exotic aeolian material. Glacial eluvium in the Baikal foredeep is fine-grained and glacially deformed. Cold arid climate precluded leaching and was favorable for carbonatization, while freezing–thawing processes provided vertical redistribution of carbonates.

(4) *Pleistocene subaerial deposits* include loessy loam, aeolian sands, talus, and products of solifluction. Clay minerals in them make three- or four-component assemblages where any component may predominate (hydromica, chlorite, montmorillonite, or rarely kaolinite).

2.2. Clay minerals in Baikal bottom sediments

The age of Baikal bottom sediments in the drilled section on the submerged Akademichesky Ridge reaches the middle Miocene (Kuzmin et al., 2001). BDP-93, BDP-96, and BDP-98 long drill cores as well as shorter piston cores show polymineral systems at different stratigraphic levels (Holocene, Pleistocene, Pliocene, and Miocene). Clay minerals in Baikal bottom sediments are of terrigenous (majority) and authigenic origin (Kashik et al., 2001) and are predominantly hydromicas and smectites; mixed-layer hydromica–smectite and chlorite–smectite, as well as kaolinite, vermiculite, and chlorites are less abundant (Knyazeva, 1954; Rateev, 1954; Kazenkina, 1960; Goldyrev, 1982; BDP Members, 1997; Melles et al., 1995; Kashik and Mazilov, 1997; Kashik et al., 2001; Yuretich et al., 1999; Solotchina et al., 2001; Fagel et al., 2003). Percentages of chlorites and mixed-layer minerals are occasionally high (Muller et al., 2001). Clay mineral assemblages in sections spanning glacials and interglacials are considered a useful climate proxy (BDP Members, 1997; Solotchina et al., 2001; Fagel et al., 2003).

2.3. Clay minerals in hydrothermally altered rocks

Cenozoic deposition in the Baikal region was associated with low-temperature hydrothermal metasomatism involving rocks of different ages and compositions. In the Baikal rift, metasomatites are encountered within the Akademichesky Ridge. Two-phase metasomatites in Precambrian granites were studied from *Pisces* submersibles (Kudryavtsev and Nikolaev, 1989). The higher-temperature phase (200–210 °C) formed in Jurassic time (albite, epidote, laumontite), and the Paleogene lower-temperature phase is superposed upon the argillized zone of smectites and kaolinite. A thin crust of hydrothermal neoforms (smectite, hydromica, chlorite, calcite, zeolite, iron–manganese nodules) was found to locally cover plagiogranites on submerged slopes of the B.

Ushkanyi Island at water depths below 400 m (Bukharov and Fialkov, 1996).

Weakly eroded amphibole–biotite gneisses in Olkhon Island in central Baikal rift (gulf of Ulan–Irgi) include partings of hydrothermal Zn–Ni–Cu bearing montmorillonite and halloysite.

3. Discussion

Regular changes in clay and silt-sand-size minerals in Cenozoic sediments of the Baikal region record changing environments. Kaolin-lateritic mantles formed during the Eocene climate optimum (humid tropics), revealed in regional Cenozoic sections (Pavlov et al., 1976), whereas all previous and following climate cycles produced less mature eluvial profiles.

The existence of Cretaceous–Paleogene peneplain and the composition dependence of Late Cretaceous–Paleogene deposits on related weathered rocks, despite the small thickness of the latter (20–30 m), imply very low tectonic activity. The latest Cretaceous through middle Oligocene was the time of tectonic stability in the Baikal region and in large territories of Eurasia (King, 1967; Nikolaev, 1984).

The climate trend turned toward cooling since the Oligocene: The Eocene optimum gave way to subtropic conditions in the Late Oligocene–Early Miocene, temperate semiarid climate of Early–Middle Miocene, and then to sub-tropic arid environments with intermittent wetting in the Late Miocene–Early Pliocene (Pavlov et al., 1976; Belova, 1985; Voroboyva et al., 1995). The climate changes produced different conditions of pre- and syndepositional chemical weathering as long as the middle Late Pliocene. Accelerated vertical crustal movements and the related surface dissection in the Baikal region since the Late Oligocene deformed the Cretaceous–Paleogene weathering profiles, whereby rocks, weathered to different degrees, were supplied into the area of deposition. The formation of rather polymictic sediments (Tankhoi type section) was caused by deep fluvial erosion in the source area, and predominance of sheet erosion in the Olkhon block resulted into oligo- and monomictic deposition.

Mineral formation of carbonates, carbonate–sulfate sediments and chemical smectites deposited in shallow closed saline lakes or bogs in the Baikal foredeep was strongly influenced by the hot arid climate, whereas this influence was very weak in the Baikal rift, with its large overflowing lakes, which favored carbonate-free deposition.

The compositions of subaerial deposits are intimately related with those of the surrounding rocks and are controlled by climate. Carbonate-rich red rocks were derived from laterite and red earth and experienced subaerial postdepositional changes. Clay mineralogy in Miocene–Early Pliocene red rocks, formed in a hotter and drier climate, is dominated by hydromica, montmorillonite, and kaolinite, whereas dominant hydromicas, smectites, and chlorite were typical of Late Pliocene deposition in colder and wetter conditions.

Cooling in the latest Pliocene dramatically changed the conditions of weathering and soil formation. Formation of red soils ceased and the clay component of sediments consisted mostly of terrigenous hydromica with minor smectites, halloysite, and kaolinite. The climate trend since the latest Pliocene included repeated cold spells with formation of permafrost and glaciation in the mountains around the Baikal basin. Climate rhythms caused alternation of primitive-glacial, primitive, and immature weathering profiles, in which claying was impossible or very weak. The pelitic fraction of subaerial deposits and soils was dominated by allogenic hydromicas, chlorite, kaolinite, and montmorillonite. At the same time, processes of clay formation may continue in the modern soils of the Baikal region (Gradusov and Voroboyva, 1969). Some clay minerals are associated with low-temperature hydrothermal metasomatism.

4. Conclusion

Clay minerals are a useful climate proxy bearing record of environments in which they form. Most of clay minerals are derived from weathered rocks. The Upper Cretaceous–Cenozoic sedimentary section of the Baikal region includes several stratigraphic levels of weathering with their specific clay mineralogy: kaolin pre-Maastrichtian–Maastrichtian and Danian–Paleocene, kaolin–laterite Late Paleocene–Early Eocene, montmorillonite Late Oligocene–Early Miocene, red montmorillonite–hydromica Late Miocene–Late Pliocene, and primitive, mostly hydromica Late

Pliocene–pre-Quaternary–Early Quaternary and Quaternary profiles.

These mineralogy changes reflect cyclic cold spells within the general cooling trend from the Eocene climate optimum (wet tropic conditions) to subtropics with different humidity levels and a temperate climate in the Neogene, and finally to a temperate and cold climates in Late Pliocene–Quaternary time. The global climate cycles (Budyko, 1984) agree with regional data on lithology, palynology, and fauna and with the existing views of Cenozoic climate change in the Northern hemisphere.

Cretaceous–Paleogene deposition occurred in a wet tropic climate in the conditions of tectonic stability and surface planation. Cooling and vertical crustal movements since the Late Oligocene became especially intense in the middle Pliocene and at the Neogene–Quaternary boundary. Tectonically controlled proportion changes between channel and sheet erosion strongly influenced the abundances of clay and other terrigenous minerals and the composition dependence of weathering-derived sediments on the source substrate.

Deposition in the two major tectonics units occurred in different environments. Water in Neogene small closed lakes and bogs in the Baikal foredeep had high carbonate–sulfate mineralization, which caused the dominance of montmorillonite in rocks deposited in an ever-drying climate. The terrigenous component in deposits within the Baikal rift, with its large overflowing freshwater lakes, was supplied from zones of fluvial erosion. Therefore, polymictic terrigenous sediments bearing polymineral clay assemblages formed in the South-Baikalian basin, whereas montmorillonite clays, and oligomictic and monomictic sediments with hydromica and kaolinite as dominant clay minerals were typical of the Olkhon block in the Baikal rift basin.

From the middle Miocene through Pliocene, lateritic weathering profiles and subaerial red rocks and soils formed in a drying climate. Since the latest Pliocene, climate abruptly became temperate, punctuated by intermittent cold spells (climate of glacials), and the conditions of weathering and the composition of related sediments changed correspondingly. Tectonic activity since the middle Pliocene, and especially since the middle Quaternary, strongly deformed remnant peneplain within the rift uplifts, and coarse clastics were supplied into the deposition basins to become predominant in piedmont and marginal facies of Lake Baikal since the Middle/Late Pleistocene boundary. Uplift growth was accompanied by lake deepening and accumulation of glacial and interglacial clays and silts. Hydrothermal alteration also influenced clay mineralogy in rift structures.

Thus, in the Baikal region, the Cenozoic evolution of weathering, deposition, and post-depositional changes recorded in clay mineralogy was controlled by the interplay of climate and tectonism.

Acknowledgements

This work was partly supported by RFBR grant 03-05-65255.

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