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Provenance analysis and tectonic setting of the Triassic clastic deposits in Western Chukotka, Northeast Russia

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Abstract. The study area is part of the Anyui subterrane of the Chukotka microplate, a key element in the evolution of the Amerasia Basin, located in Western Chukotka, Northeast Russia. The subterrane contains variably deformed, folded and cleaved rhythmic Triassic terrigenous deposits which represent the youngest stage of widespread marine deposition which form three different complexes: Lower-Middle Triassic, Upper Triassic (Carnian) and Upper Triassic (Norian). All of the complexes are represented by rhythmic interbeds of sandstone, siltstone and mudstone. Macrofaunas are not numerous, and in some cases deposits are dated by analogy to, or by their relationship with, other units dated with macrofaunas. The deposits are composed of pelagic sediments, low-density flows, high-density flows, and shelf facies associations suggesting that sedimentation was controlled by deltaic progradation on a continental shelf and subsequent submarine fan sedimentation at the base of the continental slope. Petrographic study of the mineral composition indicates that the sandstones are lithic arenites. Although the Triassic sandstones appear similar in outcrop and by classification, the constituent rock fragments are of diverse lithologies, and change in composition from lower grade metamorphic rocks in the Lower-Middle Triassic to higher grade metamorphic rocks in the Upper Triassic. This change suggests that the Triassic deposits represent an unroofing sequence as the source of the clastic material came from more deeply buried rocks with time.

1 Introduction

The main tectonostratigraphic terranes of Western Chukotka are the Chukotka (Anyui and Chaun subterranes), South Anyui, Oloy, and Yarakvaam terranes (Fig. 1; Parfenov et al., 1993; Nokleberg et al., 1994). The Anyui and Chaun subterranes are composed of Paleozoic–Mesozoic sedimentary deposits which form the cover of the Chukotka portion of the Chukotka-Arctic Alaska (hereafter Chukotka) microplate. The South Anyui terrane has a fold-and-thrust structure which has been modified by strike-slip faulting (Sokolov et al., 2001; Bondarenko, 2004). The Oloy and Yarakvaam terranes are chiefly comprised of island-arc rocks of Upper Paleozoic–Mesozoic age, which are thought to have formed along the active margin of the North Asian continent.

The South Anyui terrane is interpreted as a collisional suture resulting from closure of an oceanic basin and collision, in Early Cretaceous time, between Eurasia and the Chukotka microplate (Seslavinsky, 1979; Fujita and Newberry, 1982; Parfenov, 1984; Parfenov et al., 1993; Nokleberg et al., 1998). A rotational model (e.g., Grantz et al., 1990; Embry and Dixon, 1990), in which the Amerasia basin of the Arctic Ocean opened by the rotational detachment of the Chukotka microplate from the North American continent and subsequently the block collided with Eurasia, has been popular. Certain tenets of the rotational hypothesis, however, are debatable, and alternative solutions have been proposed (e.g., Kuzmichev et al., 2006; Miller et al., 2006)

To test the rotational hypothesis, it is critical to establish the initial positions of the terranes and unravel the tectonic history of the Eastern Arctic prior to the time of opening of the Amerasia basin. For this purpose, it is important to study the Triassic deposits of Alaska, Arctic Canada, Chukotka, and Eastern Russian Arctic Islands. Unfortunately, the level of knowledge about these localities is variable, which makes their comparative analysis, and thus the elucidation of sedimentation patterns, paleogeography of ancient basins, and paleotectonic reconstructions, difficult. The level of understanding of the sedimentology of the Triassic deposits is poor. The composition and provenance of clastic material filling the Western Chukotka sedimentary basin during Triassic time has not yet been studied in detail, hence we set out to eliminate this gap in our knowledge. This paper presents the results of a regional study of the Triassic Western Chukotka sedimentary basin; we report on sedimentological, petrographic and chemical data from Triassic clastic sedimentary rocks of the Anyui subterrane.

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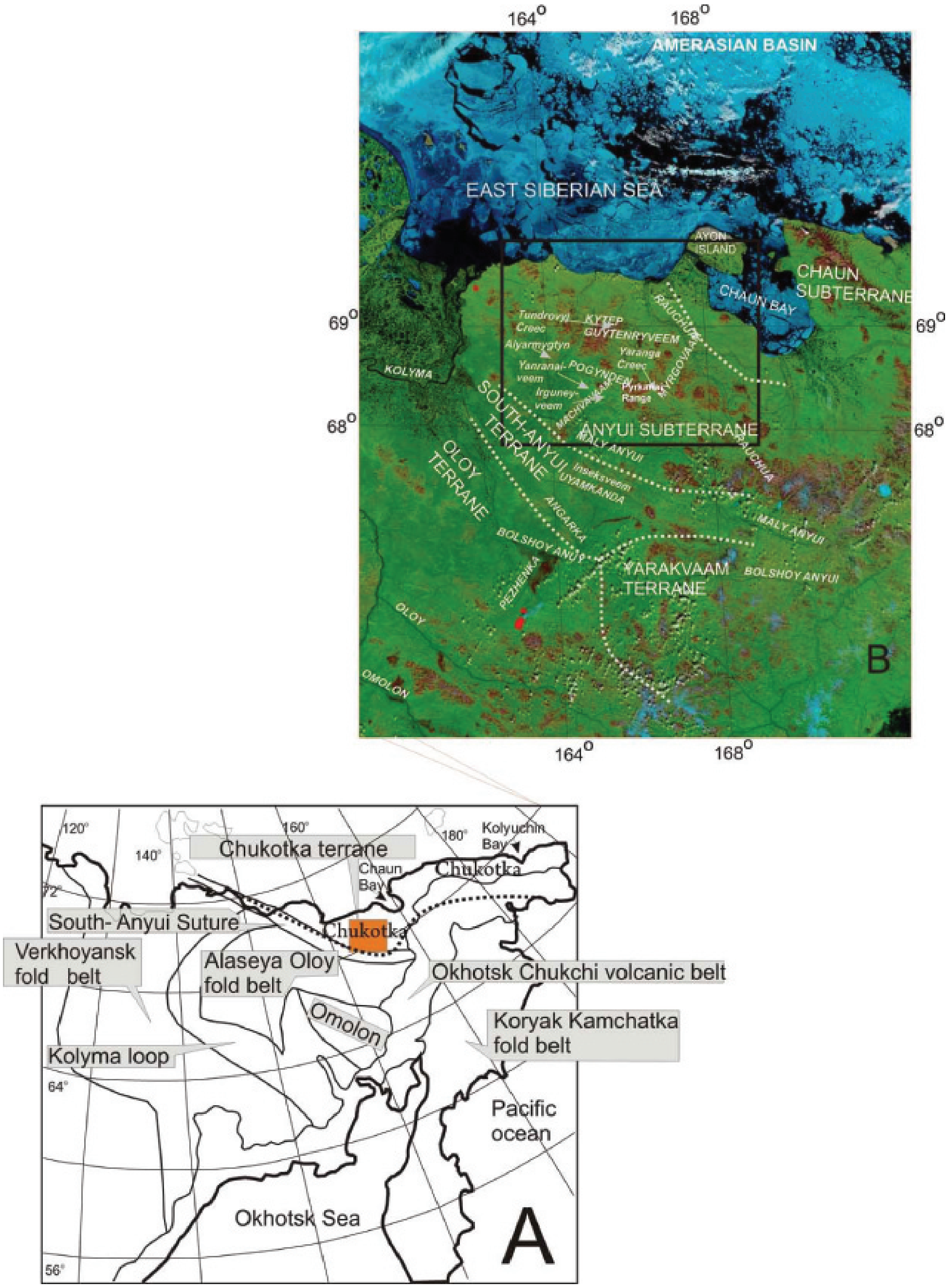

Fig. 1. Location of the study area and the general tectonic framework of northeast Asia. (A) Major structural elements in Northeast Russia; (B) Terranes of Western Chukotka according to Sokolov et al. (2001). The boxes show the study area shown in Figs. 2, 3, 6, and 9.

Triassic terrigenous deposits are known throughout all of the western Chukotkan terranes, but are especially widespread in the Anyui and Chaun subterranes of the Chukotka terrane. These terrigenous deposits are poor in fauna, which are non-uniformly distributed, thus, their dating and stratigraphic subdivisions were high priority objectives. The Triassic geology and paleontological localities in the study area are summarized in Fig. 2.

We studied regional type sections whose sedimentologic, mineralogic, and petrographic characteristics can provide the basis for interpretation and correlation with other sections or fragments thereof. Our sedimentological study was based on the facies analysis method presented in Reading (l978) and Johnson and Baldwin (1986).

Thin sections were point-counted by the petrographic method of Shutov (1967); 200–250 grains per thin section

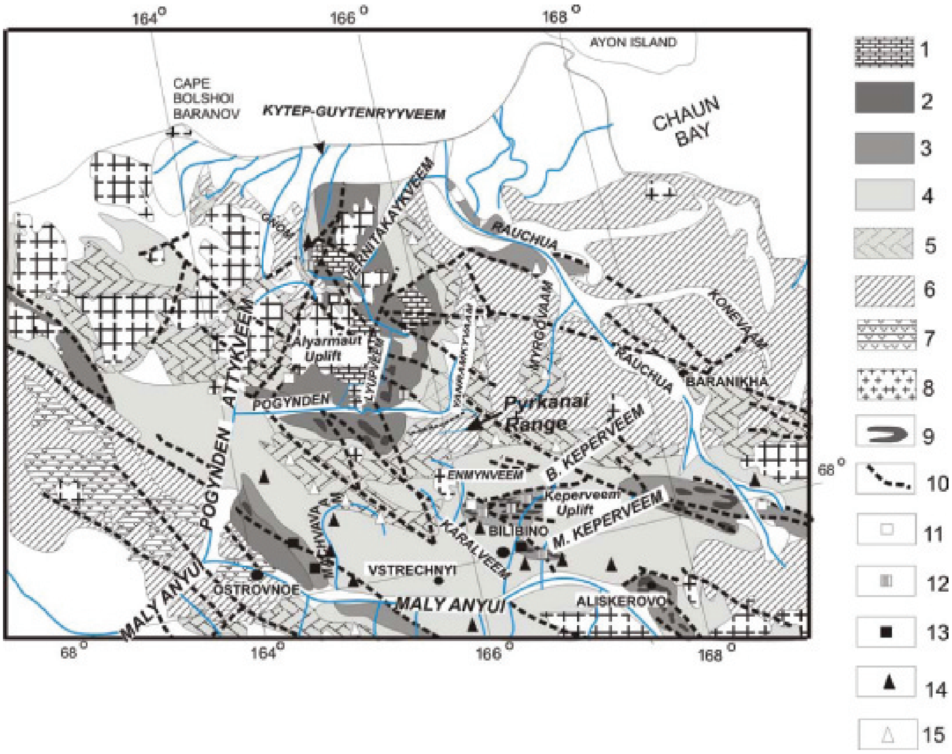

Fig. 2. Map showing the locations of Triassic faunal finds in Western Chukotka; the base map is is constructed on the basis of the Geological map of the Russia, 1:500 000 scale (1995), with minor changes.
1 – Paleozoic rocks, 2-4 – terrigeneous rocks of Triassic age: 2 – Lower Triassic, 3 – Lower–Middle Triassic, 4 – Upper Triassic, Carnian stage, 5 – Upper Triassic, Norian stage, 6-7 – terrigeneous and volcanic rocks of Upper Jurassic-Lower Cretaceous age: 6 – terrigeneous, 7 – volcanics, 8 – granitoids, 9 – diabases, 10 – faults, 11-15 – faunal localities: 11– Indian stage, 12 – Olenekian stage, 13 – Middle Triassic, 14 – Carnian stage, 15 – Norian stage.

were counted. To avoid the problem of grain-size dependent compositional variations, only the medium sand-sized fraction (0.25–0.5 mm) was counted. The geochemical investigations were performed in the Geological Institute of the Russian Academy of Sciences, Moscow, in 2003–2004. Major elements of bulk sample terrigenous rocks (Table 3) were analyzed by classical wet chemistry methods (e.g., Zolotarev and Choporov, 1978) including the determination of H_2O^+, H_2O^-, Fe_2O_3, FeO, and, for several samples, CO_2.

2 Lower-Middle Triassic deposits of Western Chukotka

Lower-Middle Triassic deposits make up the central parts of anticlinal structures or major tectonic blocks in the study area. The orientation of folds and tectonic blocks are controlled by faults of north-northwest and southeast strike. The deposits have been affected by two or three stages of deformation. Their contact with the underlying Paleozoic rocks, where observable, is either faulted or an angular unconformity. However, some data suggest that the Lower-Middle Triassic deposits lie conformably on Upper Permian deposits (Yegorov, 1959; Bychkov, 1959; Til'man and Sosunov, 1960; Gel'man, 1963).

Macrofauna allow the identification of deposits of the Induan and Olenekian stages of the Lower Triassic (*Posidonia cristophori* and *Posidonia olenekensis* Popow, *P*. sp., *Claraia* sp., *Ammonites* gen. indet.; aff. *Ophiceras*), and of the Middle Triassic (Tibilov et al., 1982; Bychkov, 1994a, b). In recent years, the Middle Triassic deposits have also yielded palynological assemblages of *Pinuspollenites* sp., *Callamospora* sp., and *Punetatisporites* sp. (as determined by M. N. Shelekhova and reported by Akimenko, written communication, 1998, and Akimenko and Akimenko, 2000).

Representative sections of Lower-Middle Triassic deposits were studied in riverside cliffs of the Enmynveem, Karalveem, Vernitakayveem, Lyupveem and Yanramkyvaam, Maly Anyui and Urguveem rivers (Fig. 3). Based on this, the Lower-Middle Triassic deposits of the Chukotka microcontinent may be subdivided into four units (Fig. 4; Tuchkova et al., 2007) and have varying thicknesses. The thickness of the Lower-Middle Triassic section on the Enmynveem River does not exceed 1000 m, and in some sections it is less (400–600 m in the drainage area of the Vernitakayveem River; 200–400 m in the drainage area of the Lyupveem and Yanramkyvaam rivers; 750–800 m on the right side of the Maly Anyui River near the village of Ostrovnoe; and 150–200 m in riverside cliffs along the Urguveem River). In some cases

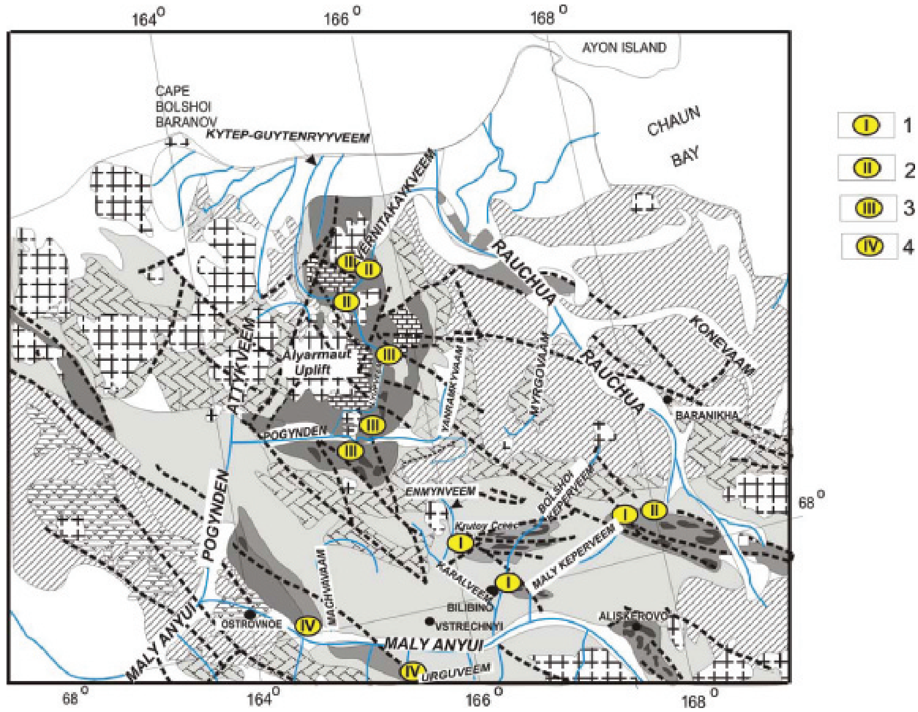

Fig. 3. Map showing the location of Lower–Middle units in Western Chukotka, Sign conventions and base map as in Fig. 2. Lithofacies types denoted by roman numerals in circles.

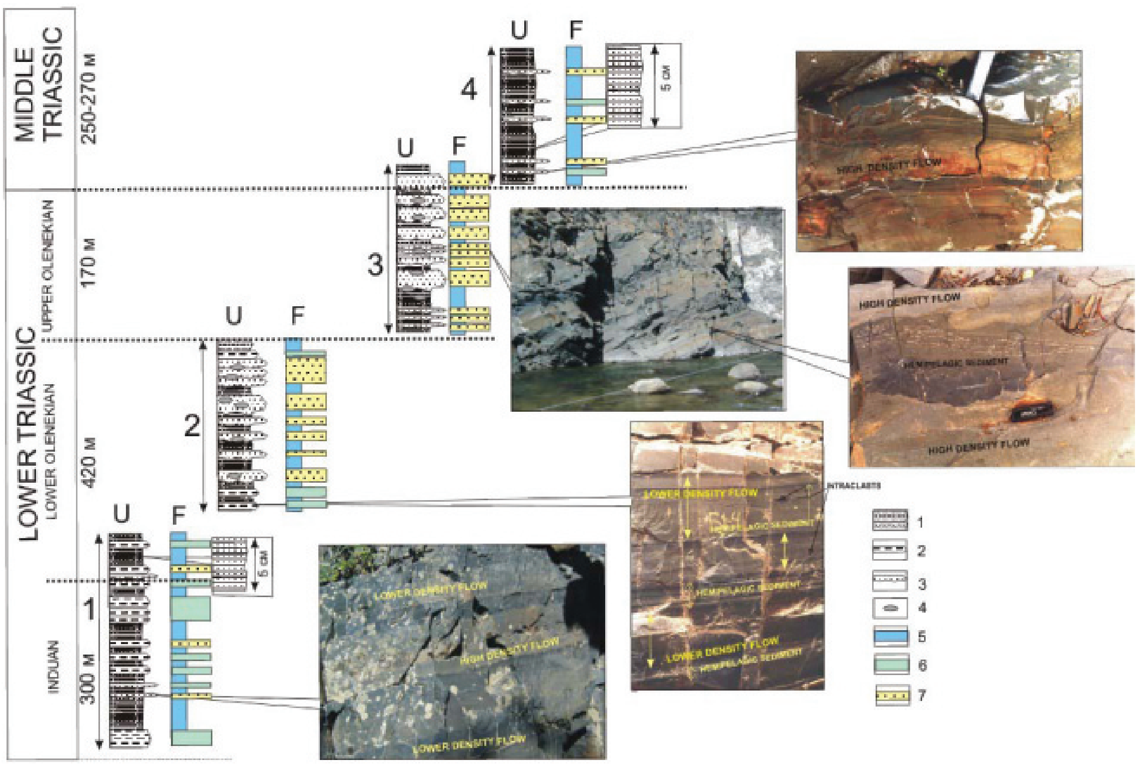

Fig. 4. Lower–Middle Triassic deposits of Enmynveem River. 1, 2, 3, 4 in the left – unit numbers, U – lithological composition of units, F – facial interpretation of deposits, 1 – rhythmic alternation of mudstone and silty sandstone, 2 – silt-sandstone, 3 – sandstone and silty sandstone, 4 – concretions, 5 – hemipelagic sediments, 6 – low-density flows, 7 – high density flows. Black represents hemipelagic background sediments.

it is impossible to assess the total thickness of the section because the rocks are so heavily deformed and folded.

2.1 Types of Lower-Middle Triassic lithofacies

Based on the character of sedimentation, we have defined four types of lithofacies, which accumulated in different depositional environments (Figs. 3, 4, and 5).

Type 1 lithofacies

Type 1 lithofacies are found in the upper reaches of Krutoy Creek, near its confluence with the Enmynveem River (Figs. 3 and 4). Unlike the majority of Lower-Middle Triassic sections in Western Chukotka, deposits of this type section exhibit little structural reworking. Parts of sections of this type (the upper part of unit 2 plus unit 3) are also found in cliffs along the Karalveem River, near the town of Bilibino.

The base (unit 1) of the type 1 section is comprised of a thin, rhythmic alternation of dark gray, occasionally almost black, mudstone and greenish gray or gray siltstone and fine-grained sandstone (Figs. 5 I and 7a). Individual members reach 25–60 m in thickness and individual interbeds do not exceeding 0.01–0.03 m. A few members contain isolated lenticular interbeds of deposits of high-density flows, composed of silty sandstone or sandstone (0.03–0.05 m) with distinctly erosional lower contacts (Fig. 6).

Unit 2 is composed of alternating mudstone and silty sandstone. The thickness of the latter, as compared to unit 1, increases to 0.1–0.15 m (Fig. 5 I, unit 2). Siltstones are not graded and are equigranular and, in a few localities, small, matrix-supported, flat mudstone intraclasts are found in the middle of siltstone layers. The contacts between the layers of different grain size are clear, even, and not erosional. Lenticular, silty sandstones interbeds from high-density flows occur less frequently and are of small length, with distinctly erosional lower contacts and are crossbedded in some cases. Silty sandstones, together with the dominant mudstone make up members 2–5 m thick and alternate with mudstone up to 20–35 m thick.

In unit 3, the mudstone matrix become insignificant in thickness (up to 0.1–0.15 m), while graded sandstones increase in thickness to 0.5–1.2 m (Enmynveem River) to 0.3–0.4 m (Karalveem River). This unit is crowned by unit 4, which is also dominated by matrix deposits. Sandstone interbeds with cross- and cross-wavy bedding are occasionally observed within them.

Based on the sedimentological evidence, type 1 lithofacies are interpreted to represent submarine fan deposition at the base of a continental slope. These strata likely the result of submarine debris flow that originated from a river delta on the continental shelf. Occurrences of clastic strata increased upsection between units 2 and 3.

Type 2 lithofacies

Type 2 lithofacies are observed in riverside cliffs and in talus in the upper reaches of the Vernitakayveem River and Tundrovyj Creek (Figs. 3 and 5 II). This lithofacies type also consists of four units. Unit 1 is composed of matrix deposits, in which thin (no more than 1–3 cm) interbeds of silty sandstone occasionally appear (Fig. 6); in some cases, the interbeds are lenticular and have weakly erosional lower contacts (Fig. 6).

Unit 2 is composed of a non-rhythmic alternation of mudstone and silty sandstone. The thickness of the silty sandstone occasionally reaches 0.08–0.12 m. Siltstone and silty sandstone, along with the dominant mudstone, make up members 2–5 m thick which alternate with massive mudstones that are 20–35,m thick. The siltstone is non-graded and equigranular; rarely, small, matrix-supported flat mudstone intraclasts are found in the middle of siltstone layers. The contacts between the beds are clear and conformable. Less common, lenticular interbeds are of small length, with weakly erosional lower contacts, and exhibit crossbedding in some cases.

Unit 3 typically has a reduced thickness of the mudstone matrix and an elevated amount of sandy components. Sandstones are normally graded, with erosional lower contacts. Rarely, the base of sandstone layers exhibit current marks and small flat mudstone intraclasts. The sandstone members are 12–15 m thick.

Unit 4 is dominated by mudstone. Lenticular interbeds of silty sandstone are sporadic; individual interbeds have graded bedding and weakly erosional lower contacts.

We suggest that the deposition of the type 2 lithofacies probably also occurred at the base of the continental slope, and are interpreted to be more distal than the type 1 lithofacies. Because of this, high-density flows in the middle part of the section have lower erosional capability and are not thick.

Type 3 lithofacies

Type 3 lithofacies are found adjacent to the Alyarmaut uplift, in the upper reaches of the Vernitakayveem River (Figs. 3 and 5 III). Primary sedimentary structures are hard to determine in these rocks. As a rule, this lithofacies is characterized by the predominance of a mudstone matrix, whose members (20–60 m thick) alternate irregularly with thin (5–10 m) members containing interbeds of silty sandstone or sandstone. Interbeds of silty sandstone commonly occur in succession, making up “merged” packages, in which sandstones are no thicker than 3–4 cm.

The deposition of the pelagic background of the type 3 lithofacies was occasionally disturbed. During catastrophic events (storms or gales), great masses of terrigenous material (silt and sand) were delivered into the basin in a suspended form. We suggest that the depositional environment of the matrix was located at the base of continental slope,

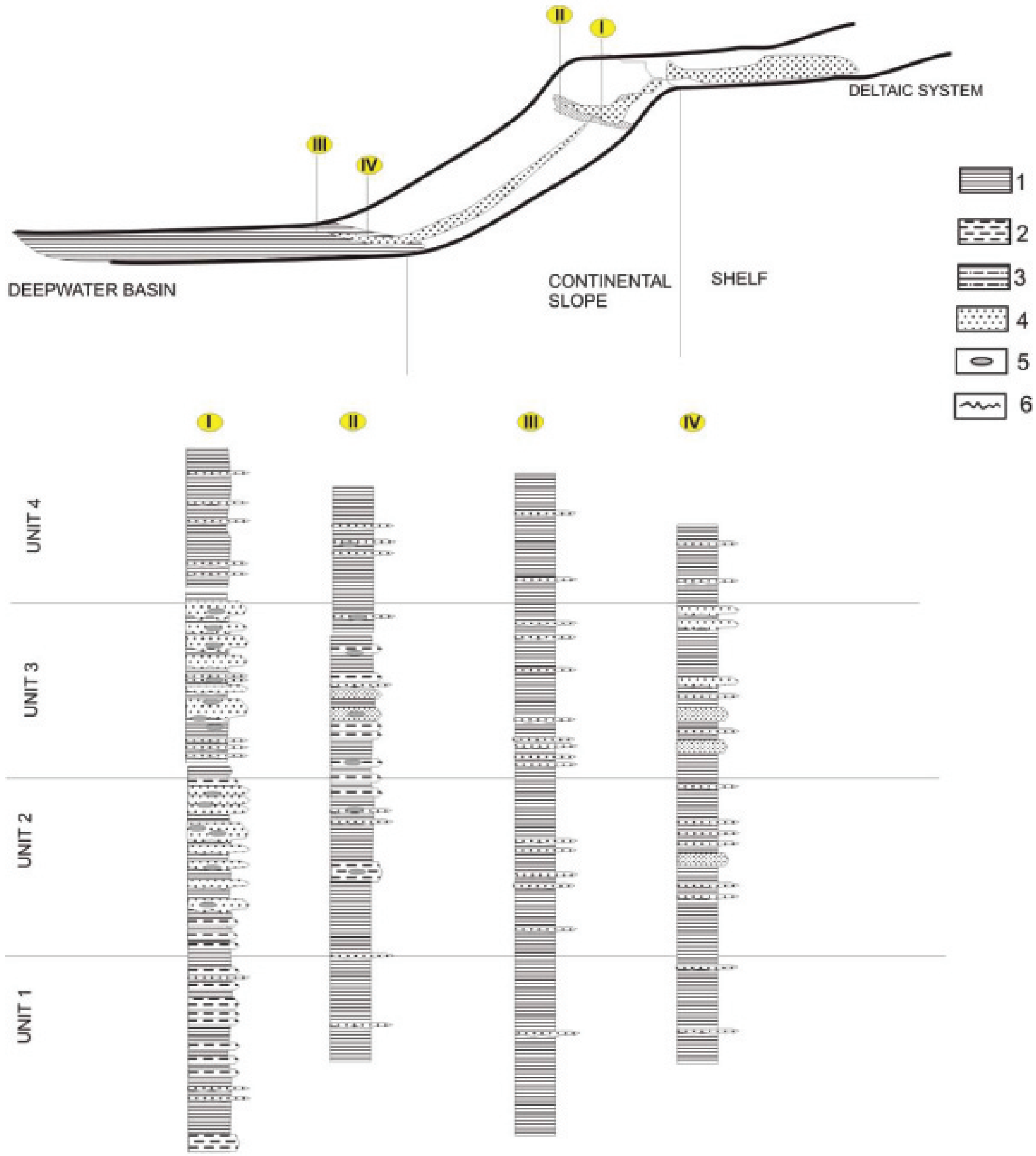

Fig. 5. Correlation of the four lithofacies units of the Lower–Middle Triassic sedimentary basin illustrating the distribution of the four types of depositional lithofacies. 1 – mudstones, 2 – silty sandstones, 3 – mudstones-silty sandstones, 4 – sandstones, 5 – concretions, 6 – erosive contact between different types of rocks. Lithofacies types are shown by roman numerals in circles. Black represents hemipelagic background sediments.

far from deltaic depocenters, in more distal portions of the marine sedimentary basin.

Type 4 lithofacies

Type 4 lithofacies are found in small, isolated, erosional windows along the Urguveem River and on the right side of the Maly Anyui River (opposite the village of Ostrovnoe) (Figs. 3 and 5 IV). This lithofacies type lacks faunal dating and is assigned to the Lower-Middle Triassic by analogy with deposits in more northern sections.

A reassembled, composite section consists of four units with a total thickness of 500–600 m primarily of pelagic matrix. Unit 3, the sandiest one, is composed of a member some 50–70 m thick, dominated by sandstone interbeds 0.3–0.5 m thick (Figs. 5 IV unit 3, and Fig. 6).

We infer that the deposition of the type 4 lithofacies occurred at the base of the continental slope, but close to a deltaic depocenter.

The Lower-Middle Triassic deposits contain ubiquitous carbonate concretions (2×4 cm; Fig. 6), whose number and size increase (7×10 cm) in the middle of the section. The most concretion rich interbeds are found in a section along the Enmynveem River. In addition to carbonate concretions, isolated, small and flat sulfide concretions are rarely found. The sulfide concretions, as individual pyrite grains, are found in the mudstones and the low-density turbidites.

2.2 The depositional setting in Early-Middle Triassic time

Comparison of the sections studied suggests that the Lower-Middle Triassic lithofacies types have similar evolutionary patterns of sedimentation. Unit 1 is composed of low-density turbidites with sporadic interbeds of high-density flows. Units 2 and 3 are dominated by deposits of high-density flows, alternating with a mudstone matrix, and Unit 4 is composed of dominantly of mudstones with sporadic thin deposits of high-density flows. Units 1 and 2 are customarily dated by some people as Late Permian–Earliest Triassic, unit 3 is dated as Early Triassic (Olenekian), and unit 4, as Middle Triassic (Yegorov, 1959; Bychkov, 1994a, b; Akimenko and Akimenko, 2000).

Analysis of the mode of sedimentation indicates the extensive supply of clastics into a marine basin. It is well known that the accumulation of thick sedimentary complexes in marine basins occurs near mouths of large rivers (Reineck and Singh, 1975; Selley, 1985; Reading, l978). Of the sections studied, only one contains a small-pebble conglomerate (Nomnunkuveem River; the section was reassembled from hillside talus). In the rest of the Lower–Middle Triassic deposits studied, only finer sediments are observed. These circumstances may indicate that there existed a single paleodeltaic system, probably located in the eastern part of the study area.

Sedimentological features of the terrigenous units suggest two stages of development of the deltaic system. The first stage (the deposition of units 1 and 2) was characterized by an extensive supply of terrigenous material from the continent and its delivery to the deepwater zone of the basin. Weak coastal currents and the presence of a narrow shelf prevented the redistribution of this material across the basin. As a result, the delta prograded across the shelf and abundant sediments were able to reach and incise the continental slope. Meanwhile, in the deepwater zone, a debris cone marking the extension of the delta formed.

By the time of the second stage (the deposition of units 3 and 4), the terrigenous material filled in the feeder channels, and the frequency of high-energy flows decreased. Low-density flows, alternating with deposition of the mudstone matrix, once again started flowing into the basin. This was probably the terminal stage of the functioning of the feeder channel and the development of the debris cone ceased by the end of Middle Triassic time.

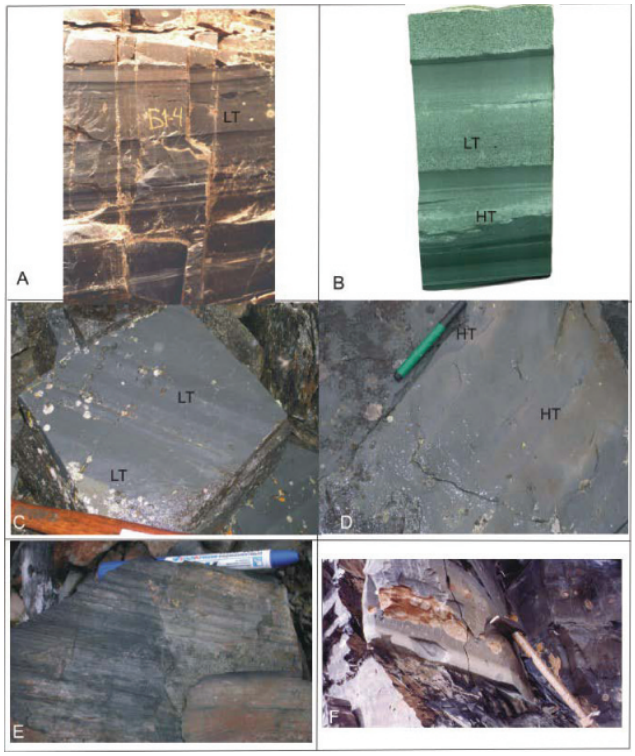

Fig. 6. (A) Alteration of low-density (LT) and high density (HT) flow (turbidite) along the Enmynveem River, Lower–Middle Triassic formation. Photos by O. L. Morozov. (B) Low-density turbidite with intraclastes on the upper part of flow, Lower–Middle Triassic formation. Photo by O. L. Morozov. (C) Low-density turbidites, Vernitakayveem River, Lower–Middle Triassic formation. (D) High density turbidites with erosive contact, Vernitakayveem River, Lower–Middle Triassic formation. (E) Rhythmic alteration of sandstones - silt-sandstones and mudstones, Maly Anyui River, Lower–Middle Triassic formation. (F) Concretion in sandstone, Enmynveem River, Lower–Middle Triassic formation. Photo by M. I. Tuchkova.

3 Upper Triassic (Carnian stage) deposits of Western Chukotka

Terrigenous deposits of the Carnian Stage make up large domains of northwest-southeast strike and exhibit deformation at different levels. A number of researchers believe that Upper Triassic deposits lie conformably on the Lower–Middle Triassic sequence (Til'man and Yegorov, 1957; Sadovsky, 1962; Natal'in, 1984). However, according to Solovyev et al. (1981), the contact between the Lower-Middle Triassic formations and the overlying Carnian strata is typically faulted (the drainage areas of the Urguveem, Mchvavaam, and Yanranaiveem rivers), and only in the drainage area of one of the left tributaries to the Maly Anyui River is a stratigraphic contact with the underlying formations confirmed.

Deposits of the Carnian Stage are faunally well dated. In the upper reaches of the Rauchua, Kytep-Guitenryveem, Maly Anyui, Maly Keperveem, Bolshoi Keperveem, Pogynden, Pyrkanaivaam, and Nomnunkuveem rivers, abundant casts of *Halobia* and ammonites of the genus *Sirenites*, as well as *Anaucella ussuriensis* (Vor.), *Gervilia* sp. indet., *Pecten* (*Eupecten*) aff. *subhiemalis* Kipar., *Oxytoma* sp. indet., *Nucula* sp., and *Isocrinus* sp. were collected; also tubular *Dentalium* bodies, fucoids, fragments of *Pentacrinus* sp., casts of foraminifers *Flagrina* sp. indet., and unidentifiable plant remains are found (after Yegorov, 1962, and G. I. Solovyev et al., written communication, 1979).

Representative sections of Carnian deposits were studied in riverside cliffs of the Maly Anyui, Maly Keperveem, Mchvavaam, Urguveem, Karalveem, and Inseksveem rivers, in the middle reaches of the Vernitakayveem River, along left-side tributaries of the Yanramkyvaam River, and in the upper reaches of the Lyupveem and Kytep-Guitenryveem rivers (Fig. 7). They are composed of rhythmically alternating interbeds of sandstone, siltstone, and mudstone, whose proportions are rather variable. These deposits consist of two units: a lower shale, and an upper sandstone and silty sandstone. Some researchers (e.g., Yegorov, 1962) subdivide the deposits of the Carnian Stage into three units. The middle unit then consists of alternating sandstone, siltstone, and shale, and the lower and upper ones are similar to those described above.

The thickness of the Carnian deposits is hard to assess because the rocks are heavily deformed. Based on data of different workers (Til'man and Yegorov, 1957; Til'man and Sosunov, 1960; Gorodinsky and Paraketsov, 1960; Yegorov, 1962; Gel'man, 1963; Akimenko and Akimenko, 2000, etc.), the Carnian deposits range from 700 to 2000–2500 m in thickness.

3.1 Lithofacies of the Carnian stage

We can identify three types of lithofacies based on the mode of sedimentation in the Carnian (Fig. 8).

Type 1 lithofacies or fragments thereof, are described from riverside cliffs of the Maly Anyui, Maly Keperveem, and Karalveem rivers (Figs. 6 and 8 I). The lower unit is composed of mudstone with sporadic lenticular interbeds of siltstone. Mudstones are parallel-bedded and contain some amount of millimeter-scale lenticular interbeds of more lightly colored siltstone. Subordinate interbeds of medium platy silty sandstone, 5–15 cm thick, are found. Some sandstone interbeds contain small lenses of mudstone, oriented parallel to the bedding, weakly developed gentle crossbedding and, rarely, elongated siderite concretions (1×2 cm). Alternating mudstones and sandstones are represented by two different types of members. Type 1 members are 5–6 m thick and composed of alternating interbeds of mudstone (2–10 cm) and sandstone. Type 2 members are 7–10 m thick and consist of thicker (0.8–1.1 m) mudstones and sandstones, alternating with millimeter-scale mudstone interbeds, that occur in successions that form sandstones-siltstones packages 0.25–0.35 m thick (Fig. 9a and b). The transitions between the lithologies are sharp but with no erosional contacts.

The upper unit consists of an alternation of rhythmic strata 10 to 15 m thick; each stratum consists of an alternation of mudstones (1.0–1.5 m thick) with rare interbeds of sandstone (0.35–0.45 m thick), with members (3.5–6.5 m) of rhythmic silty sandstone (0.1–0.4 m thick) and mudstone units of equal or somewhat smaller thickness. The mudstone units are typically parallel-bedded, but occasionally they contain thin (no more than 1–1.5 cm) lenticular interbeds of siltstone. Sandstone units exhibit cross-, cross-wavy, and lenticular bedding, passing into parallel bedding; occasional signs of convoluted bedding within layers are observed. In some cases, sandstones interbeds have erosive lower boundaries with small, chaotically oriented oval mudstone intraclasts (2×3×1 cm). At the base of interbeds of this type, ripple marks are occasionally recorded. Silty sandstones are typically massive and exhibit parallel, occasionally weakly developed cross-, and cross-wavy, bedding and less frequently, graded bedding.

The observations suggest that the type 1 lithofacies of Carnian age were deposited in an outer shelf environment, away from deltaic depocenters, to which sandy material was supplied periodically after having been delivered by the delta to the shelf of the marine basin. The increase in the amount of clastics in the upper horizon, most likely, indicates a progradation of the deltaic system that supplied the clastic material.

Type 2 lithofacies or its fragments are form riverside cliffs along the Maly Keperveem and Bolshoi Keperveem rivers (Figs. 6 and 8 II). The lower unit is dominated by mudstone members alternating with occasional thin platy interbeds of pure or silty sandstone. This kind of alternation typically includes members 5–6 m, sporadically up to 10 m, thick. Siltstone interbeds have tabular bedding, although occasionally, weakly developed lenticular bedding occurs. Siltstone interbeds are 0.05–0.15 m thick while mudstone interbeds are 0.5–1.0 m thick. The upper unit has an elevated proportion of silty sandstone. The deposits consist of two types of rhythmic alternation of mudstones and sandstones with one or the other dominating. The first type, dominated by mudstones, form members 3–5 m to 15–20 m thick. The mudstones are dark and laminated; they are separated by thinly bedded silt and fine sandstone layers. The sandstones have variable grain sizes and commonly display cross- and cross-wavy bedding; sporadically, the thinner interbeds exhibit microslumping structures and signs of contour currents. The base of the sand interbeds commonly show evidence of invasive, or flame structures; ripple marks on the soles of layers or signs of erosive action are also observed. The second type of alteration is represented by units dominated by sandstone interbeds 0.1–0.3 m, occasionally 0.5–0.8 m thick, and sporadically more.

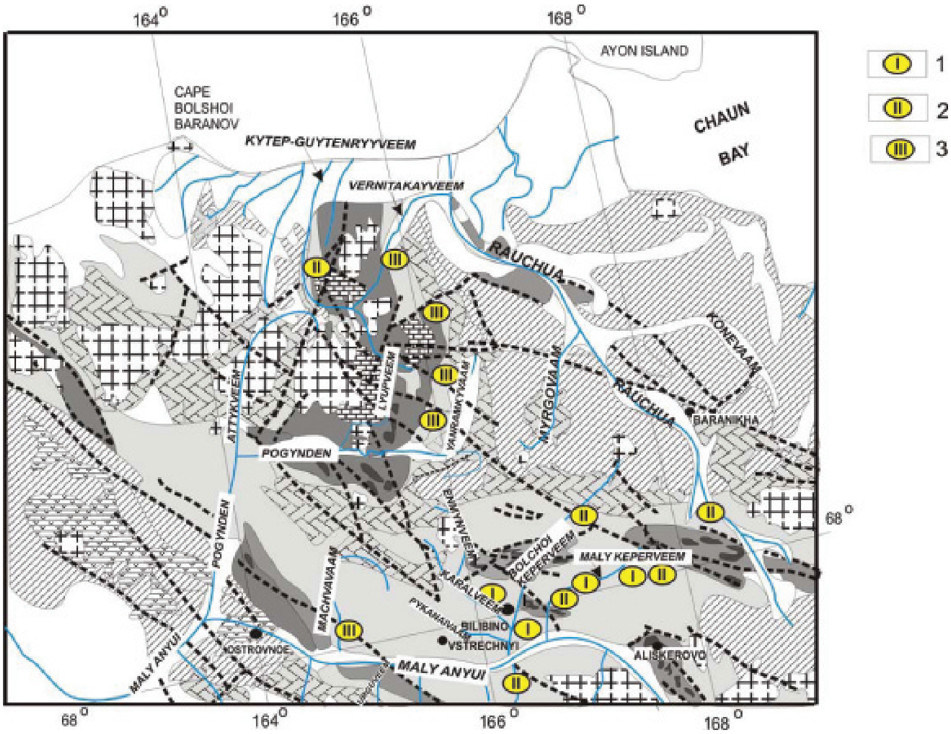

Fig. 7. Map showing the location of Carnian units in Western Chukotka. Sign conventions and base map as in Fig. 2. Lithofacies types are denoted by roman numerals in circles.

The deposition of type 2 lithofacies is suggested to have occurred at the base of the continental slope. Two different genetic styles of sedimentation can be identified: the first – a mudstone matrix, within which deposits of distal gravity flows and bottom currents occasionally accumulated. The second consists of turbidity currents, alternating with a mudstone matrix. The sedimentation rate was high, as indicated by invasion structures at the base of sandstones.

Type 3 lithofacies were identified in riverside cliffs of the Mchvavaam River, left tributaries to the Yanramkyvaam River, in the upper reaches of the Lyupveem River, and on the Kytep-Guitenryveem and Vernitakayveem rivers (Figs. 6 and 8 III). The deposits are composed of tabular bedded mudstone with sporadic, small (1–1.5 cm long) lenses of siltstone (Fig. 9). It is hard to divide type 3 lithofacies into units due to their similarity. In some cases one finds an alternation of 5–9 m thick members composed of mudstone, and 1.5–2.0 m thick members composed of alternating mudstone with thin (2–3 cm) silty interbeds (Fig. 9). The siltstones sporadically show weakly developed lenticular or normal graded bedding, and occasionally, weakly developed erosional contacts.

The deposition of type 3 lithofacies occurred either in the most distal deepwater parts of the basin, at the base of the continental slope, away from deltaic depocenters. This lithofacies is chiefly composed of a mudstone or siltstone matrix. The sedimentation was periodically disturbed by the delivery of coarser clastics supplied by bottom currents.

All types of the Carnian lithofacies also exhibit carbonate concretions: medium size concretions (10×7×7 cm) are confined to the middle part of sandstone interbeds, whereas small concretions (1.5×2×1.5 cm) occur in various parts of sandstone and siltstone interbeds.

3.2 Depositional setting in Carnian time

By the end of Middle Triassic time, the continental slope became gentler, and sediments that accumulated in the basin were mostly clays, with minor mixture of silty material. At the end of Carnian time, however, the hydrodynamic energy of deposition became higher. Note that the thickest turbidity flows are found in the upper part of the Carnian deposits. This suggests that the activity of the deltaic system, which had virtually terminated by the end of the Middle Triassic, resumed in the middle of the Carnian stage. In the southern part of the Keperveem uplift, there likely existed a deltaic depocenter, in which flow deposits were widespread. South of it, there accumulated continental slope base deposits, including both distal turbidites and deposits of contour currents. Conditions on the continental shelf and slope again allowed for sediments to pass into more deepwater zones.

The Carnian Deposits are characterized by sedimentary structures typical of different parts of the base of continental slope, at varying distances from major deltaic depocenters. The sedimentological features of the deposits suggests the presence of one sand-rich fan system.

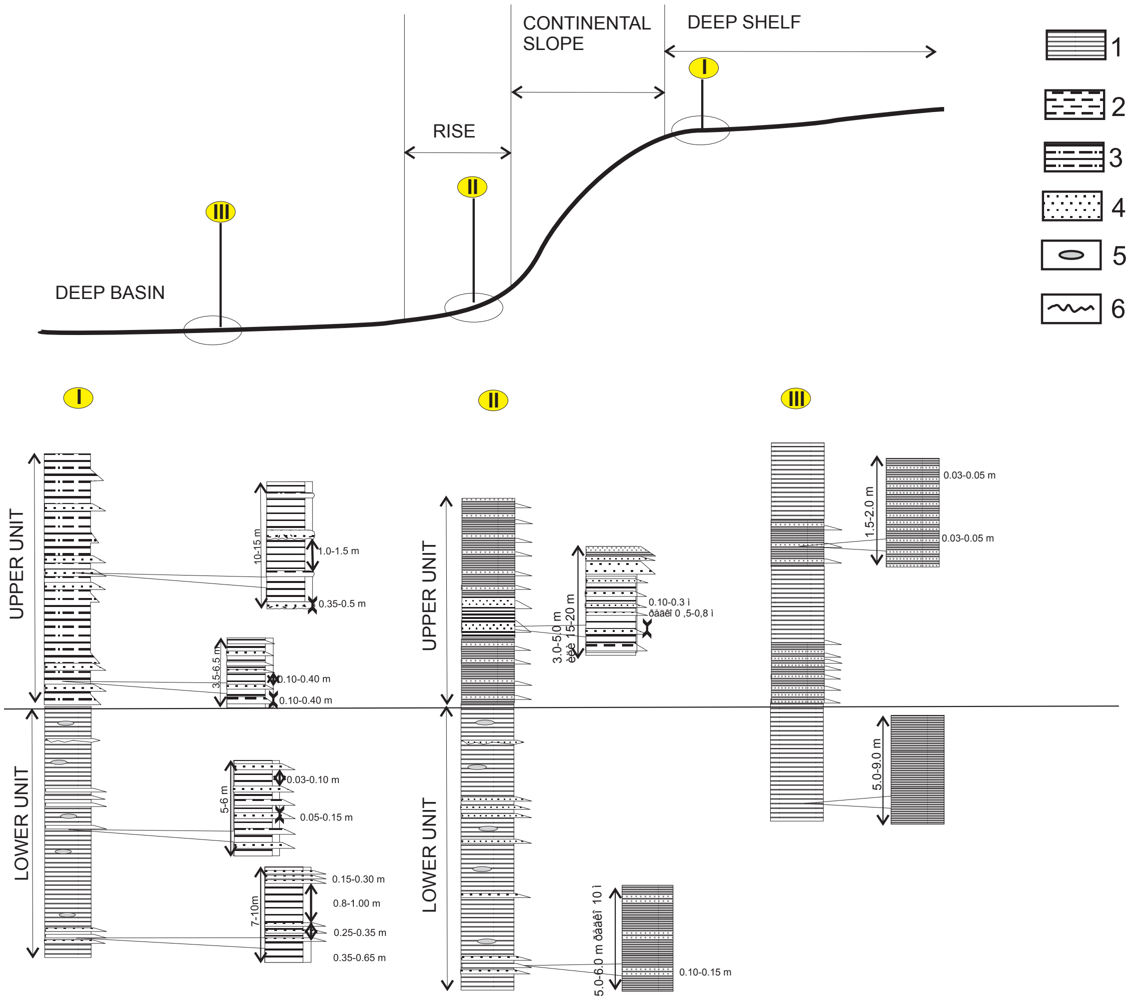

Fig. 8. Correlation of the three lithofacies units of the Upper Triassic (Carnian) sedimentary basin, illustrating the distribution of types of lithofacies. 1 – mudstones, 2 – silty sandstones, 3 – mudstones-silty sandstones, 4 – sandstones, 5 – concretions, 6 – erosive contact between different types of rocks. Lithofacies type denoted by roman numerals in circles. Black represents hemipelagic background sediments.

4 Upper Triassic (Norian stage) deposits of Western Chukotka

Terrigenous deposits of Late Triassic (Carnian-Norian age) also make up areas of NW-SE strike and are affected by deformation at various levels. Deposits of the Norian Stage, based on data of many researchers, occur conformably on Carnian strata (Bychkov, 1994a, b; Gorodinsky and Paraketsov, 1960; Sadovsky, 1962). However, there is evidence of tectonic contact between Norian and Carnian deposits along some of the left tributaries of the Maly Anyui River (Solovyev et al., 1981).

In the Norian deposits, faunal finds are abundant and ubiquitous; worm burrows and crawling trails are widespread. The most abundant macrofaunal finds were made in the lower reaches of the Rauchua River, on the Pogynden River, on the left bank of the Alyarmygtyn River and in the drainage areas of the Pogynden and Mchvavaam rivers. Typical faunas in the Norian deposits are *Monotis*, represented by *Monotis ochotica* (Keys.), *M. planicostata* Efim., *M. scutiformis* Tell., *M. scutiformis* var. *typica* Kipar., *M. eurhachis* Tell., *M. pachypleura* Tell., *M. jakutica* Tell., *M. aequicostata* Kipar. The other commonly encountered faunas are *Otapiria ussuriensis*, *Halobia* sp., *Flagrina* sp., *Halobia aotii* Kob. at Ich., *Halobia* et. Ich., *Halobia kawadai*Ich., *Flagrina* sp., *Oxytoma czekanowskii* Tell., *O. mojsisovicsi* Tell., *O. zitteli* Tell., *Pecten (Eupecten) subniemalis* Kipar., *Pecten (Eupecten)* ex gr. *hiemalis* Tell., *Pecten (Eupecten)* ex gr. *suzukij* Kob., *Pecten (Eupecten) suzukij* var. *fujimoto* Kob., *Palaeopharus buriji* Kipar., *Modiola* sp., *Nucula* sp. indet., *Lima* sp. indet., *Pleuromya* sp., and many others.

Representative sections of Norian deposits were studied in riverside cliffs in the Pyrkanai Range, along the upper reaches of Mchvavaam River, the Pogynden River, and along left tributaries to the Kytep-Guitenryveem River (Fig. 10).

Sedimentologically, the Norian deposits are almost indistinguishable from the Carnian, but they contain greater amounts of sand-silt material. Deposits of the Norian stage form two units: the lower consists of shale or mudstones and siltstone, while the upper is dominated by siltstone and sandstone or sandstone alone (D. F. Yegorov and A. I. Afitsky, written communication, 1966). Various authors (Til'man and Yegorov, 1957; Til'man and Sosunov, 1960; Gorodinsky and Paraketsov, 1960; Yegorov, 1962; Gel'man, 1963; Akimenko and Akimenko, 2000; etc.) have all estimated the thickness of the Norian deposits to be about 1000 m.

4.1 Lithofacies types of the Norian Stage

Deposits of the Norian Stage exhibit three lithofacies types (Figs. 9 and 11).

Type 1 lithofacies (Fig. 11 I) are the least typical; they are encountered in isolated exposures on southern and western spurs of the Pyrkanai Range, in the upper reaches of Mchvavaam River, on the Irguneyveem River, and on left-side tributaries to the Kytep-Guitenryveem River. They are typically composed of the alternation of two kinds of members. One is composed of a matrix composed of a thin rhythmic alternation of silty sandstone (up to 1–3 cm thick) and mudstone (1.5–2.0 m to 5–7 m thick). In the lower unit, members of this type are dominant. The second kind of member, found mostly in the upper unit, is composed of medium, platy sandstone (0.2–0.4 m thick) with convolute, cross-, cross-wavy, and lenticular bedding (Fig. 9e and f). Sandstone layers commonly have erosional lower boundaries, tool marks, and soft sediment deformation. The sandstone is fine-grained and virtually not graded. Isolated measurements yield a NW–SE current direction. Mudstone intercalations commonly display ichnofossils. The most abundant concretions occur in the mudstone matrix ($1\times1.5\times0.5$ cm), but also in some sand interbeds.

The deposition of type 1 lithofacies occurred in distal parts of the delta, with gentle slopes and the periodical deposition of gravity flows. No signs of a large deltaic system have been discovered, thus, it is likely that clastics were supplied into the marine basin by a few small deltas. Traces of one of the inferred deltaic systems are established in the sections along the upper reaches of the Mchvavaam River and on southern spurs of the Pyrkanai Range. Another system is inferred from sections in the northern edge of the Alyarmaut uplift, in the Gnom Creek section.

Type 2 lithofacies (Fig. 11 II) are observed in riverside cliffs of right tributaries of the Pogynden River, in the upper reaches of the Machvavaam River, on southern spurs of the Pyrkanai Range, along a left tributary to the Vernitakayveem River, and Yaranga Creek. Deposits of this type commonly show thin rhythmically alternating mudstones and siltstones or fine silty sandstones (Fig. 9g). In the upper unit, the content of the silty-sand component increases. Silty sandstones have laminate or weakly developed cross-bedding. Interbeds

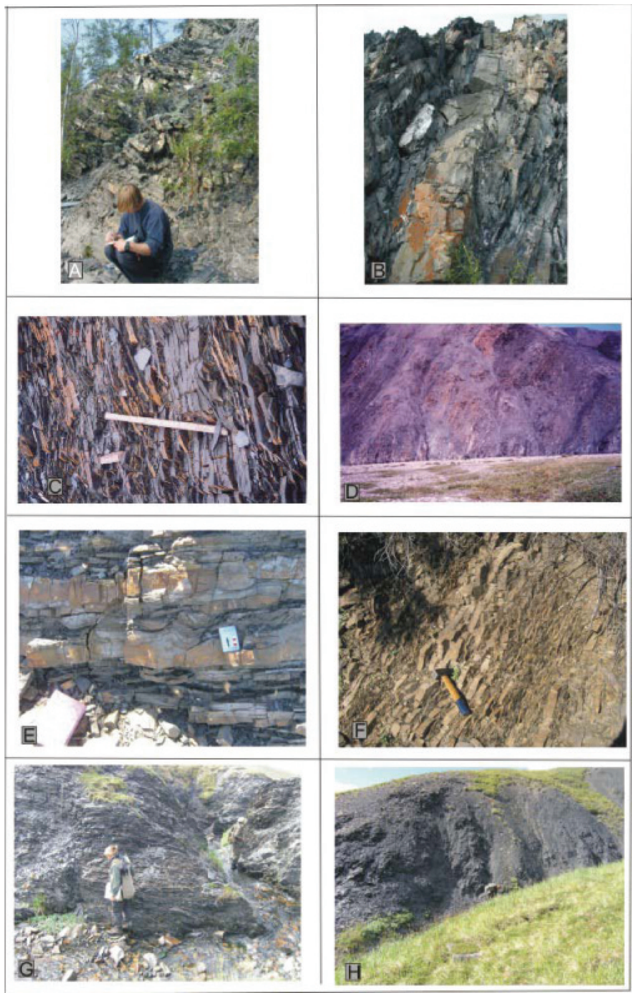

Fig. 9. (A) Interlayered fine-grained sandstone-siltstone and mudstone, Maly Anyui River, Upper Triassic (Carnian) formation; (B) Interlayered fine-grained sandstone and turbidite, type 1 lithofacies, Maly Anyui River, Upper Triassic (Carnian) formation; (C) Monotone alternating siltstone and mudstone, type 3 lithofacies Mchvavaam R., Upper Triassic (Carnian) formation; (D) alternating mudstone and thin silty sandstone, type 3 lithofacies, Kytep-Guitenryveem River, Upper Triassic (Carnian) formation; (E) Interlayered fine-grained sandstone/mudstone and medium-grained sandstone with convolute bedding, sandstone have erosive lower boundary, type 1 lithofacies, Irguneyveem River, Upper Triassic (Norian) formation; (F) Alternating fine-grained sandstone with silty mudstone, type 1 lithofacies, Irguneyveem River, Upper Triassic (Norian) formation; (G) Thin rhythmically alternating mudstones and siltstones, type 2 lithofacies, Yaranga Creek, Upper Triassic (Norian) formation; (H) Alternating mudstone and rhitmic siltstone, type 3 lithofacies, Yaranga Creek, Upper Triassic (Norian) formation.

of sandstone or silty sandstone with erosional lower contacts are sporadic and thin (no more than 10–15 cm). Ichnofossils are common, but they are smaller than in type 1 lithofacies. Individual small siderite concretions ($1\times0.5\times1$ cm) are common.

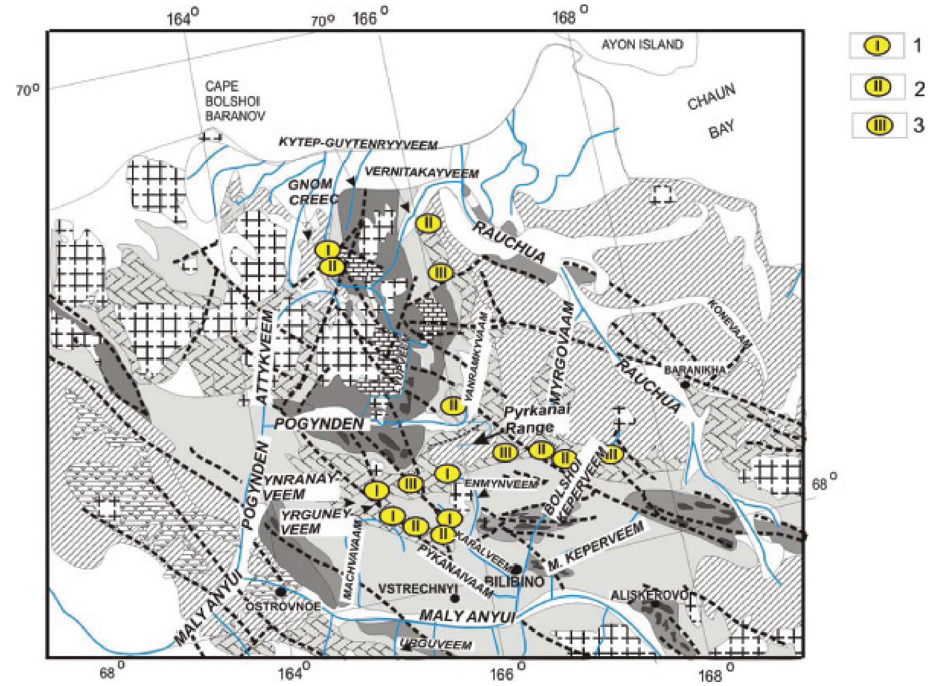

Fig. 10. Map showing the location of Norian units in Western Chukotka. Sign conventions and base map as in Fig. 2. Lithofacies types are shown by roman numerals in circles.

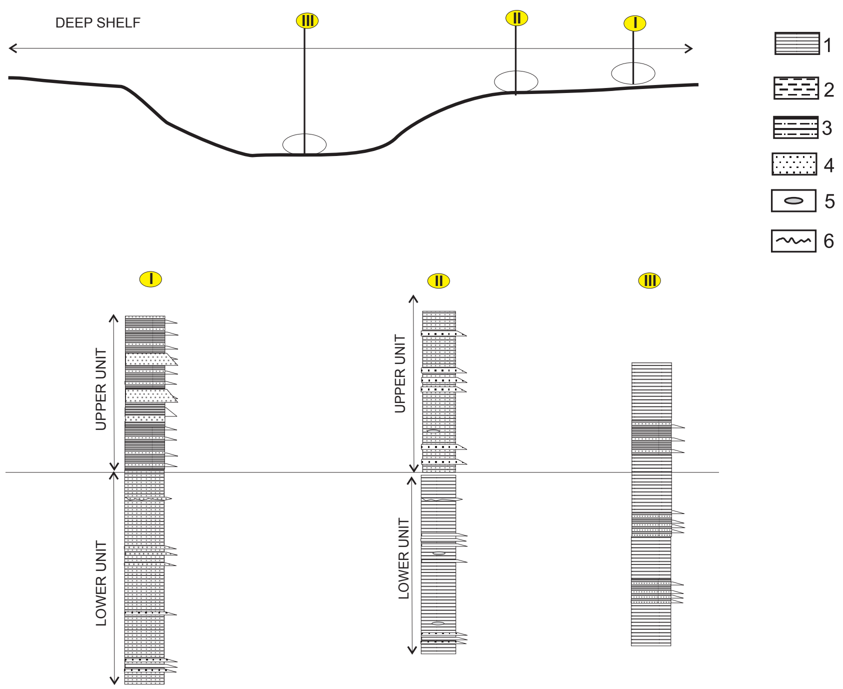

Fig. 11. Correlation of the three lithofacies units of the Upper Triassic (Norian) sedimentary basin. 1 – mudstones, 2 – silty sandstones, 3 – mudstones-silty sandstones, 4 – sandstones, 5 – concretions, 6 – erosive contact between different types of rocks. Lithofacies types are given by roman numerals in circles. Black represents hemipelagic background sediments.

The deposition of type 2 lithofacies occurred in zones more distal from the prodelta, probably on shelf portions with low hydrodynamic energy, allowing for the accumulation of sediments supplied by deltaic flows and dispersed by bottom currents.

Type 3 lithofacies are composed of a mudstone matrix without the addition of silty material. This type is found in sections along the Kytep-Guitenryveem River, Yaranga Creek, and in the upper reaches of the Enmynveem River (Figs. 9 and 11 III). The deposits consist of mudstone, with sporadic, thin (no more than 1.5–3.0 m) members containing silty sandstones interbeds which are occasionally lenticular (Fig. 9). The mudstones contain trace fossils and remains of macrofauna, commonly both.

The deposition of type 3 lithofacies also probably occurred in shelf areas with very low hydrodynamic energy. The supply of siltstone or silt-sandstone material occurred very rarely; siltstones forming the matrix were predominant.

4.2 Depositional settings in Upper Triassic (Norian) time

By the end of the Late Triassic, in Norian time, two types of sediment, non-uniformly distributed, became widespread in the region. The influence of deltaic systems is recorded throughout the entire shelf zone; only a few deeper portions were dominated by pelagic background sedimentation. Sedimentation in the Norian occurred in a shallow shelf basin judging from the abundant trace fossils and various macrofaunas. By the end of Triassic time, the amount of clastic material in the basin increased, and the predominant sediments accumulating in the basin were rhythmic silty mudstones. Generally, the basin was dominated by sedimentation of lithofacies types 2 and 3. Type 1 lithofacies formed within zones influenced by deltas, where sedimentation was controlled by flow currents. We conjecture that deltas were situated in two localities: one in the upper reaches of the Mchvavaam River and on southwestern spurs of the Pyrkanai Range, and the other in the northwestern edges of the Alyarmaut uplift, in the middle reaches of the Kytep-Guitenryveem River.

5 Stages of sedimentation

The principal stages in the geological evolution of the Western Chukotkan passive margin in the Triassic have been repeatedly addressed in the literature, but in different sources, the age boundaries between the stages are somewhat different. Some workers propose that the Triassic was a single sedimentary stage, from the Early Triassic to Late Norian, during which the territory of Western Chukotka evolved as part of a large basin (Gorodinsky and Paraketsov, 1960; Bondarenko, 2004; Bondarenko and Luchitskaya, 2003). Others divide the sedimentary history of Western Chukotka into two major sedimentary stages: Early–Middle Triassic and Late Triassic (Sadovsky 1962; Gel'man, 1963; Seslavinsky, 1970). Bychkov (1991, 1994a, b) also advocates two major stages in the evolution of the Verkhoyansk-Chukotka fold belt, but the time boundaries of the stages in his scenario are different: stage 1 terminated in middle Norian time, and stage 2 continued until the Jurassic. Based on the structure of the Triassic sections we studied, three sedimentary cycles are identified in the region (Table 1): Lower–Middle Triassic, Carnian, and Norian.

The same sedimentary cycles can be traced throughout the study area, suggesting that there existed a continuous depositional basin in Western Chukotka. Based on the facies distributions, shallow-water domains prograded into deeper water zones of the basin during the Triassic. The progradation of the delta and shallow shelf resulted from the vast amount of clastic material supplied both from the continent. The deeper water facies may have been deposited in the most distal parts of the basin, regions away from deltaic depocenters, or in areas where clastic influx was reduced due to tectonic movements on the shelf; these cannot be resolved with the data at hand.

Clastic material was delivered by a deltaic system that may have been located in the northeast of the study area, but whose position changed during the Triassic. The supply of clastic material was not steady; at the end of Middle Triassic and in the beginning of the Carnian and Norian stages, this supply dropped so low that the basin was dominated by pelagic sedimentation. In the periods when the delta was active (Induan–Olenekian, Late Carnian, and Late Norian), a variety of voluminous flow deposits composed of sandstones, were formed.

A characteristic feature of the Triassic basin is that sedimentation appears to have been controlled by proximity of deltaic depocenters and/or the width of the shelf. In Early–Middle Triassic time, the shelf zone was narrow. Due to this, sediments accumulated on the continental slope, which most likely had an overall gentle gradient and numerous sediment traps. In Carnian time the shelf zone considerably widened, so that the shelf provided the site for accumulation of thick units of prodeltaic deposits. The continental slope became sufficiently steep and with little relief, enabling sediments to pass into deeper water zones and accumulate at its base.

The southern boundary of the Western Chukotka sedimentary basin is marked by the collisional suture resulting from closure of an oceanic basin in Early Cretaceous time. The first pre-collisional deformation were recognized by sedimentary and geochronological investigations and occurred at about 200 m.y (K-Ar and Rb-Sr methods; Tuchkova et al., 2007).

6 Mineralogy and chemistry of the rocks

Sandstone samples for petrographic analysis were collected from all the studied Triassic deposits. The compositions of the sandstones were determined by analyzing 49 thin sections of typical, medium grain-size (0.25–0.5 mm) sandstones. Because the samples were very different in grain-size, grains of 0.25–0.35 mm were counted to obtain average

Table 1. Correlation of Triassic cycles of sedimentation in Western Chukotka by different authors.

AGE		Gorodinsky and Paraketsov (1960), Bondarenko and Luchitskaya (2003), Bondarenko (2004)	Sadovsky (1962), Gel'man (1963), Seslavinsky (1970)	Bychkov (1991, 1994a)	This paper
JURASSIC					
	Rhaetian				**?**
UPPER TRIASSIC	Norian				
	Carnian				
MIDDLE TRIASSIC	Ladinian Anisian				
LOWER TRIASSIC	Olenekian Induan				

data. The modal composition of the sandstone was determined by point-counting. For each thin section, 100–200 grains were counted and the grain type was identified according to the following scheme (Table 2): 1. Monocrystalline quartz (Qm); 2. Polycrystalline quartz (Qp); 3. Clasts with micro- and crypto-crystalline quartz aggregates were counted as quartzo-lithic (chert-like) grains; 4. Potassium feldspar including perthite, myrmekite, orthoclase, microcline (K); 5. Plagioclases (P); 6. Total feldspar (Ft), including grains of potassium feldspar, or plagioclase feldspar, etc.; 7. Volcanic rock fragments (Lv), including clasts of quartz + feldspar and quartz + feldspar + mica; 8. Fragments of sedimentary rocks as such as siltstone, sandstone and coal (Ls); 10. Metamorphic rocks fragments (Lm), including metasedimentary fragments (because the cement of the fragments is white mica with long mica flakes).

The Triassic sandstone and siltstone are very uniform. Macroscopically, these are compact, strong rocks of gray or greenish gray color. Fine-, medium-, and coarse-grained varieties are found. The modal composition of sandstones (Table 2 and Fig. 12) corresponds to a lithic arenite according to the classification of Pettijohn (1975). Depending on the origin and age of the sandstone, they have different proportions of matrix material.

Clayey rocks are represented by dark gray or gray varieties. Structurally, they are thinly bedded and, where mudstone alternates with silt laminae, lenticular or lenticular-bedded. Silt is found in mudstones of shallow-water provenance. All Triassic rocks ubiquitously contain carbonate minerals, forming microlaminae or aggregates of irregular shape. Rocks of the Norian Stage contain more carbonate, commonly in the form of diagenetic calcite cement.

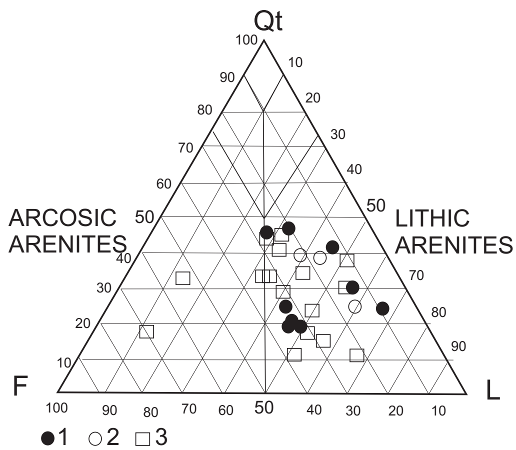

Fig. 12. Mineral composition of Triassic sandstones in the Western Chukotka. Mode diagrams according to the Pettijohn (1981) classification diagrams. Q – total quartz, F – total feldspar, L – total lithic fragments.
1 – Lower–Middle Triassic sandstone, 2 – Carnian sandstone, 3 – Norian sandstone.

6.1 Lower–Middle Triassic sediments

Lower–Middle Triassic sandstone is mostly fine-grained, with a considerable component of silt and a very small amount of coarse clasts (Fig. 13a). The proportion of matrix to clasts is, as a rule, quite high, 15–40% (Fig. 13b). The sandstones are poorly sorted and contain grains with variable degrees of rounding. Organic plant fragments are distributed chaotically or along microlaminae in the rocks. The sandstones are uniform. Quartz accounts for 20–50%, feldspars for 5–40%, and rock fragments for 30–70%. Feldspar includes albite, untwinned potassic feldspar, and occasionally zoned oligoclase grains.

Table 2. Mineral composition of Triassic sandstones of Western Chukotka.

No		1	2	3	4	5	6	7	8	9	10
Sample Number		B1-3/1	B1-4	B1-4-2	329/3-3	B1-1/3	B1/5-1	B1/6	230/6	9913	421/1
Qm		14	15	15	5		14	22	65	26	21
Qp		6	2	4	2		1	3		4	7
Qt		**20**	**17**	**19**	**7**	**21**	**15**	**25**	**65**	**30**	**28**
Plagioclase	albite-oligoclase		6	2		3	13	2	7	7	
	oligoclase-andesine		13	17	1		3	1	1	2	8
K-feldspar		8	9	12	2	1	7	4	9	9	17
Ft		**8**	**28**	**31**	**3**	**4**	**23**	**7**	**18**	**16**	**35**
Lv	andesite -basalts	24	36	13	2		8		6		30
	acid effusive	1	3			7	5	5	15	4	2
Ls	silty sandstone	3	1	24	1	7	10	22	8		
	sandstone	1									
	coaly rashings	1						9	7		3
Lm	mica schist	4	4				10	13		4	
	quartz-sericite schist			4		4	1	5	5		6
	gneiss	6		9	2	11	3	2	31	11	4
	meta-sedimentary										5
	chert					1	2		3		
Lt		**40**	**44**	**50**	**5**	**30**	**39**	**70**	**75**	**19**	**50**
mica	biotite	3	3								
	muscovite	3	3	1				11	2		
other						3					
Total		**74**	**89**	**101**	**15**	**55**	**77**	**103**	**160**	**65**	**113**
matrix,%		20	5	15	25	25	30	13	5	3	15
No		11	12	13	14	15	16	17	18	19	20
Sample number		9991/2	200/6a	200/9	GBZ-1	GBZ-2	201/5	9992/1	230/1	230/5-1	230/5-2
Qm	quartz		27	26	36	16	48		36	34	38
Qp			3	8	8	1	4		5	4	10
Qt		**59**	**30**	**34**	**44**	**17**	**52**	**35**	**41**	**38**	**48**
	albite-oligoclase	5	3	18	3		6	3	7	8	12
	oligoclase-andesine	2	2		2					4	
K-feldspar		7	14	14	22	18	6	11	16	28	30
Ft		**14**	**19**	**32**	**27**	**28**	**12**	**14**	**23**	**40**	**42**
Lv	andesite-basalt	11			2			3		12	8
	acidic extrusives	14	5	6	2	10			3	4	4
Ls	silty sandstone										
	sandstone										
	coaly rashings	1					2				
Lm	mica schist	8	1	12	4	6	4	7	9		
	quartz-sericite schist					2				4	8
	meta-edimentary	6	8	4	8	10	2		1	14	12
	chert	5						22			
	gneiss	20	23	12	21	22	66	33	14	20	38
	microquartzite										
Lt		**54**	**37**	**34**	**37**	**50**	**74**	**65**	**28**	**54**	**50**
mica	biotite		3	5			2	2	10	6	8
	muscovite	4	6		1		7	4	5	4	4
other					11	3					
Total		**142**	**95**	**100**	**120**	**95**	**147**	**120**	**107**	**132**	**152**
matrix, %		5					5		3	3	2
secondary carbonate cement, %		20					3		25	2	

Table 2. Continued.

No		21	22	23	24	25	26	27	28	29
Sample number		328/3	328/7	203/1	203/4	203/6	207/7	207/9	456/4	453/4
Qm	quartz	50	10	12	12	70	42	41	17	69
Qp		8	2	2	4	10	13	7	29	11
Qt		**58**	**12**	**14**	**16**	**80**	**55**	**48**	**46**	**80**
Plagioclase	albite-oligoclase	6	2	2	2	12	6	15	3	7
	oligoclase-andesine		14	10	14	4	3			
K-feldspar		20	21	12	12	22	16	10	8	18
Ft		**30**	**37**	**24**	**28**	**38**	**29**	**25**	**26**	**34**
Lv	andesite-basalts*	24	28	31	28	4	5	5	6	31
	acidic extrusives	8		10		6		4		
	QF								60	36
Ls	Silty sandstone								1	4
	coaly rashings						1	2		
Lm	mica schist	2		6		10	3	6	18	
	quartz-sericite schist	10	22		22	2				20
	meta-sedimentary	6	4		8	10	5	8		
	chert		1	2	2					4
	microquartzite									
	gneiss	26		32		26	42	24	23	15
Lt		**76**	**55**	**81**	**60**	**58**	**56**	**49**	**108**	**95**
mica	biotite	4	4		2	10		5	1	
	muscovite	8	1			2	3	4	12	8
other		2		4		2			8	11
Total		**178**	**109**	**106**	**130**	**190**	**143**	**131**	**201**	**228**
matrix, %						5	2	3	2	3
secondary carbonate cement, %		5						20	7	3

Qm – monocrystalline quartz, Qp – polycrystalline quartz, Qt – total quartz=Qm+Qp, P – plagioclase, K – K-feldspar, Ft – total feldspar, total of plagioclase, K-feldspar and very altered feldspar grains, Lv – volcanic rock fragments, andesite-basalts appear mostly in very altered rocks fragments, Ls – sedimentary rock fragments, Lm – metamorphic rock fragments, QF – Casts of quartz + feldspar and quartz + feldspar + mica; Mtx – matrix.

1–11 – Lower-Middle Triassic sandstones: 1–7 – Enmynveem River; 8 – Urguveem River; 9 – Karalveem River, near Bilibino; 10 – Enmynveem River; 11–25 – Upper Triassic (Carnian) rocks: 11 – Urguveem River; 12-15 – Karalveem River, near Bilibino; 16–17 – Maly Anyui River; 18–22 – Urguveem River; 23–24 Ynseksveem river; 25 – 30 Upper Triassic (Norian) rocks: 25 – Ynseksveem river; 26–27 – Glubokaya River; 28 – Pyrkanay Range; 29 – Irguneyveem River.

In terms of rock fragments, the sandstones fall into two groups by composition (Fig. 14). Group 1 (in low-density turbidite deposits; Fig. 13b) is dominated by quartz and fragments of metamorphic rocks, and group 2 (in high-density turbidite deposits; Fig. 13a) by clasts of altered volcanics of mafic or mafic-intermediate composition with quartz not being a significant portion. Sand-size volcanic clasts consist of fine- to very fine-grained groundmass aggregates; clasts of chloritized and non-crystallized volcanic glass are found as well. All volcanic rock fragments, such as andesite-basalt, are altered and usually consist of stable minerals with chloritized glass. In one sample (B1-3/1), sand-size grains of tuff (?) with chaotically arranged recrystallized ash particles were found. The mica content is different in sandstones of different provenance. Up to 8% mica is found in deposits of high-density flows. In low-density turbidites, the mica content ranges from 0–1.5%.

Mudstones from Lower–Middle Triassic deposits are, as a rule, chlorite- and mica shales, occasionally with silty material. Clastic grains are supported by the matrix. Among silt-size grains, quartz, feldspars, heavily deformed micas, and clasts of metasedimentary rocks and microquartzites are

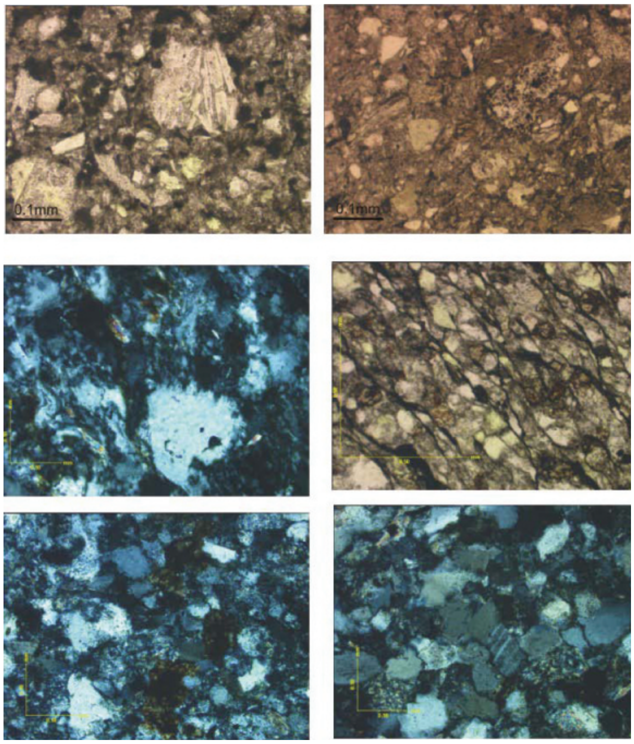

Fig. 13. Photomicrographs of typical Triassic lithic arenites. (A) Lower–Middle Triassic volcanoclastic sandstone, type 1 lithofacies, high-density turbidite, Enmynveem River. Detrital volcanic fragments with a plagioclase phenocryst in plain polarized light; (B) Lower–Middle Triassic lithic arenite, low-density turbidite, Enmynveem River. Detrital grains are in the clay matrix. The contacts between grains are degraded, plain polarized light. (C) Carnian lithic arenite, detrital quartz grain at the center showing small laths of authigenic mica. A clay matrix is lacking, Maly Anyui River, crossed nichols. (D) Cleavaged Carnian sandstone, Maly Anyui River, plain polarized light. (E) Typical Norian sandstone, Machvavaam River, (F) Cleavaged organic-rich Norian mudstone and siltstone, Enmynveem River.

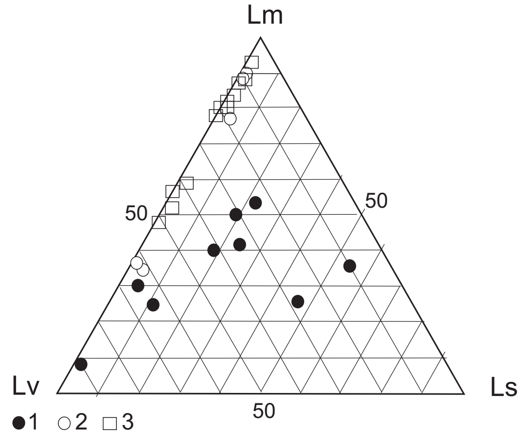

Fig. 14. Ternary diagram Lv-Lm-Ls, showing rock fragment composition of Triassic sandstones of the Anyui subterrane. Apex components are explained in Table 2. The data suggest two groups of Triassic sandstones as discussed in the text.

found. In two samples from sections on the Maly Anyui and Urguveem rivers, the mudstone contains recrystallized ash particles forming microlaminae thicker than 0.5 mm within the mudstone matrix. Compositionally, the clay mineral assemblage is uniform; it consists of illite and chlorite in variable proportions.

6.2 Carnian stage sediments

Sandstone of the Carnian Stage includes fine-, medium-, and coarse-grained varieties. A clay matrix is lacking or its content is insignificant, and only in interbeds in flow deposits at the base of continental slope does the clay content increase to 5–10%. The detrital material is, as a rule, well sorted or, less commonly, moderately sorted and cleaved (Fig. 13c and d). The degree of rounding of the clastic grains ranges from poor to medium. In terms of composition, the sandstones are rather uniform with quartz accounting for 30–45%, and feldspar (albitic plagioclases) for 5–10%. Plagioclases are commonly monocrystalline, although they are also found intergrown with quartz (~20–30% of the total plagioclase). Mica (muscovite and biotite) flakes are ubiquitous. Among rock fragments (55–60% of the total counted grains) in the sandstones, clasts of gneiss, schist, mica schist, and metasedimentary rocks are found. The greatest variety of rock fragments is observed in sandstones of type 1 lithofacies.

As a rule, pure mudstone interbeds in the Carnian deposits from shelf and continental slope base settings are sporadic; they ubiquitously contain 5–10% of fine silt, consisting of poly- and monocrystalline quartz and albite. In other deposits, the silt content is insignificant. The clay fraction consists of a micaceous mineral with 2–5% of mixed-layer sheets. In same cases micaceous minerals and chlorite with defects are observed.

6.3 Norian stage sediments

Sandstones and siltstones of Norian age are mostly fine-grained, with a high content of silt. The clay matrix accounts for 10 to 25%, occasionally more. Clastic material is well sorted or, less commonly, moderately sorted. The rock-forming components are typically subangular and, less commonly, semi-rounded (Fig. 13e). Clasts are composed mainly of quartz (30–45%) and rock fragments (35–55%). The feldspar content is roughly the same (15–20%) in all samples counted. Predominant rock fragments are granite-gneiss, schist, chert, metasedimentary rocks, and volcanic clasts of intermediate and mafic-intermediate composition. More mica is present than in the Carnian and Lower–Middle Triassic deposits.

Mudstones of Norian age are equigranular; only mudstones from prodeltaic facies are have a high content of structure-less organic matter, which in some cases is the cement for the clastic grains (Fig. 13f). The larger clasts consist of quartz, sporadically albite, and stable rock fragments (cherts, aggregates of quartz or felsic microquartzite), and abundant grains of micas.

6.4 Source areas and geochemistry

Chemically, the Triassic sandstones are quite uniform; they are not very high in SiO_2 and Al_2O_3, which indicates a polymictic composition of the rocks (Table 3). On classification diagrams, the sandstones and siltstones are divided into two groups, one of which is close to the average sandstone composition (Mason, 1971), and the other to the average composition of intraplate basalts (Beus, 1972) (Fig. 15). In the mineral composition discrimination diagram of Dickinson and Suczek (1979) for sediment sources, almost all the data plot in the dissected magmatic arc and recycled orogen fields (Fig. 16a). Thus, the clastic material of the Lower–Middle Triassic units has two origins, a local volcanic province and a metamorphic province.

By rock fragment composition, Lower–Middle Triassic sandstones also fall into two groups: one is dominated by clasts of volcanic and the other by clasts of metamorphic, rocks. Lower–Middle Triassic sandstones typically contain fragments of weakly metamorphosed rocks (carbonaceous shale, phyllite) indicating that they were derived from the erosion of metamorphic complexes. The clastic source for Lower–Middle Triassic sandstones also had a contribution from the erosion of altered intermediate to mafic volcanics. Upper Triassic sandstones exhibit an increased contribution from highly metamorphosed rocks; they have an elevated amount of crystalline schist, microquartzite, and schists, and in some cases gneiss is dominant (Fig. 14).

X-ray diffraction study of the clay fraction of these sandstones has detected the presence of a uniform assemblage consisting of illite and chlorite. Both sandstone groups exhibit high proportions of matrix. The matrix is a fine-grained brownish structureless mixture of clay minerals, ore dust, and in places limonitized and unidentifiable clasts. The greatest proportion of matrix is found in sandstones of high-density turbidity currents.

The Ti module (TiO_2/Al_2O_3), reflecting the degree of maturity of sedimentary material, remained almost the same throughout the Triassic: 0.05–0.08 in Lower–Middle Triassic rocks and 0.04–0.07 in the Upper Triassic. The only exception is the rocks in the drainage of the Vernitakayveem River, where the Ti module is considerably higher: 0.11–0.15 in Lower Triassic deposits and 0.11 in Carnian ones. Consequently, the relative location of the sediment source is inferred to have remained virtually unchanged during all of the Triassic, and only in the drainage area of the Vernitakayveem River was the sediment source was much more proximal.

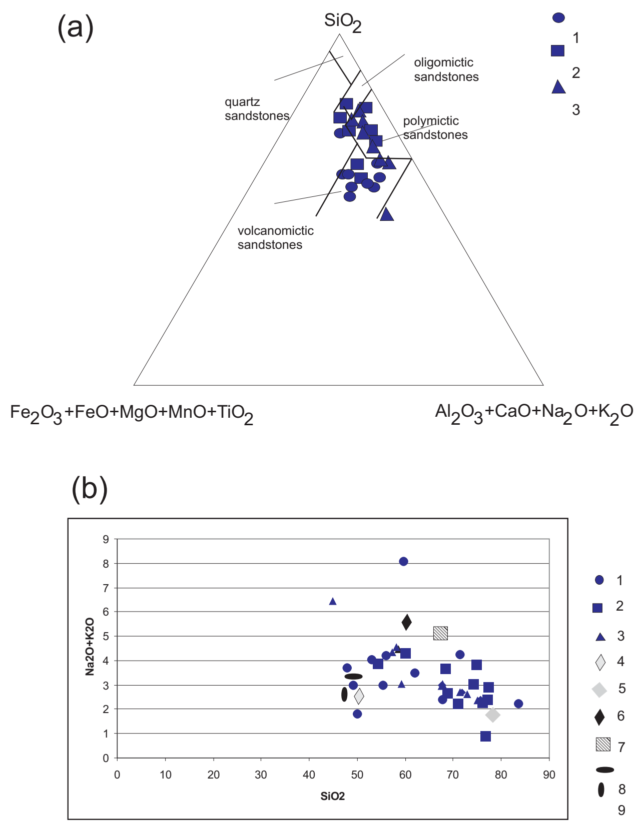

Fig. 15. (a) Triangular discrimination diagram for the sandstones after Kossovskaya and Tuchkova (1988). Chemical composition of: 1 – Lower–Middle Triassic sandstones; 2 – Carnian sandstones; 3 – Norian sandstones.
(b) (Na_2O+K_2O) – SiO_2 diagram showing chemical compositions: 1 – Lower–Middle Triassic sandstones; 2 – Carnian sandstones; 3 – Norian sandstones. For comparison, the average composition of: 4 – intraplate basalts (Beus, 1972); 5 – sandstone (Mason, 1971); 6 – continental crust (Lentz, 2003); 7 – greywacke (Lentz, 2003); 8 – Anyui zone diabase (Gel'man, 1963); 9 – Tunguska basin traps (Gel'man, 1963).

Provenance classification diagrams after Bhatia (1983), using major element chemistry, show a wide distribution for the Triassic formations and thus can not be used to uniquely interpret the tectonic setting (Fig. 16b). However, two fields can be discriminated here as well; one has $K_2O/Na_2O<1$ and $Al_2O_3/CaO+Na_2O<5$. These ratios are considerably higher ($K_2O/Na_2O\sim1$–3.2 and $Al_2O_3/CaO+Na_2O\sim5$–15) in sandstones of the other field. Many sandstone samples with high K_2O content (1.5–5.43%) contain abundant authigenic micas. Generally, from Early Triassic to Norian time, the silicate component increases, and the mafic and Ti components decreases.

The compositional evolution of Triassic rock fragments in the sandstones points to the erosion of a large metamorphic complex composed of metasedimentary, metavolcanic, and granite-gneiss rocks. The metamorphic rock fragment

Table 3. Chemical composition of the Triassic rocks of Western Chukotka.

No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
	T_{1-2}	T_{1-2}	T_{1-2}	T_{1-2}	T_{1-2}	T_{1-2}	T_{1-2}	T_{1-2}	T_{1-2}	T_{1-2}	T_{1-2}	T_{1-2}	T_{1-2}	T_3c	T_3c	T_3c
	Type 1 lithofacies			Type 2 lithofacies			Type 3 lithofacies					Type 4 lithofacies		Type 1 lithofacies		
Sample Number	329/1	329/2	329/3	460/7	460/8sh	409/2	404/3	405/4	406/3	407/6	459/7-1	230/6	Av (12)	201/1	201/5-1	201/5
SiO_2	55.32	55.92	49.12	50.04	53.12	71.33	67.55	47.81	67.68	59.67	83.64	75.7	61.4	54.16	77.18	75.94
TiO_2	1.54	1.25	1.19	2	1.33	0.99	0.98	1.71	1.27	0.98	0.82	0.74	1.13	0.99	0.77	0.59
Al_2O_3	13.42	15.58	12.03	13.53	15.21	12.07	13.46	16.6	11.13	17.92	5.4	8.66	12.91	19.83	9.51	8.68
Fe_2O_3	2.72	3.54	2.32	3.47	1.77	1.74	3.19	4.1	1.64	2.39	1.84	3.9	2.72	3.27	1.9	1.76
FeO	7.87	6.89	5.39	9.7	8.73	4.19	3.62	8.83	6.4	3.96	1.29	1.84	5.73	6.11	2.52	2.95
MnO	0.11	0.08	0.11	0.17	0.24	0.04	0.05	0.11	0.06	0.07	0.02	0.09	0.096	0.08	0.07	0.1
CaO	3.45	1.97	11.8	5.84	3.67	0.61	0.96	4.29	1.07	1.4	1.06	<0.10	3.28	0.45	0.26	1.06
MgO	5.4	3.82	2.81	7.23	4.41	1.84	1.76	4.49	3.63	2.61	1.17	1.16	3.36	3.72	2.58	2.34
Na_2O	2.36	2.17	2.32	1.74	2.67	3.55	0.49	2.47	2.17	7.67	1.56	1.3	2.54	1.04	1.9	1.42
K_2O	0.64	2.05	0.67	0.07	1.38	0.7	2.51	1.24	0.22	0.42	0.69	1.11	0.98	2.87	1.06	0.9
P_2O_5	0.18	0.25	0.18	0.19	0.19	0.15	0.2	0.23	0.17	0.18	0.34	0.13	0.20	0.28	0.14	0.13
loss on ignition	6.48	6.12	11.91	5.4	6.55	2.47	4.67	7.38	3.95	2.04	1.62	4.77	5.28	6.74	2.2	3.49
Total	99.49	99.64	99.85	99.38	99.27	99.68	99.44	99.26	99.39	99.31	99.45	99.4	99.46	99.54	100.09	99.36
CO_2	1.54	1.04	9.31	0.83	2.17	0.27	0.24	2.08	0.34	<0.2	0.48	2.58	n.d.	<0.2	0.46	1.33
H_2O-	n.d.	n.d.	n.d.	0.16	0.22	n.d.	n.d.	n.d.	n.d.	n.d.	0.1	n.d.	n.d.	0.42	0.17	0.22
H_2O+	n.d.	n.d.	n.d.	3.89	3.8	n.d.	n.d.	n.d.	n.d.	n.d.	1.02	n.d.	n.d.	n.d.	n.d.	n.d.

No.	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
	T_3c	T_3c	T_3c	T_3c	T_3c	T_3c	T_3c	T_3c	T_3c	T_3c	T_3n	T_3n	T_3n	T_3n	T_3n
	Type 1 lithofacies		Type 2 lithofacies		Type 1 lithofacies						Type 1 lithofacies				
Sample Number	422/z	400-3-2	328/zr	200/9	411/1-1	414/3	414/7	417/4	417/6	Av (11)	454/3	454/2sh	K-04-43	453/1	453/2a
SiO_2	67.72	70.85	74.7	68.53	59.96	76.46	76.97	73.9	68.18	70.38	71.82	62.04	67.68	71.3	57.23
TiO_2	0.73	0.55	0.67	0.77	1.19	0.56	0.6	0.58	0.68	0.72	0.82	0.93	0.82	0.63	0.91
Al_2O_3	12.68	9.29	10.8	11.9	18.66	5.23	9.67	9.43	11.46	11.43	10.9	16.5	13.08	10.42	20.24
Fe_2O_3	1.04	4.12	2.14	2.06	1.47	1.73	2.54	1.93	2.35	2.19	2.63	4.07	1.67	0.63	2.82
FeO	3.88	3.97	2.2	6.36	6.12	4.35	2.69	2.47	4.25	3.99	2.52	1.94	3.9	6.48	4.05
MnO	0.07	0.13	0.09	0.13	0.06	0.06	0.04	0.03	0.03	0.074	0.05	0.05	0.15	0.13	0.08
CaO	1.98	1.25	0.56	1.2	0.37	1.82	0.23	1.31	0.82	0.94	0.56	0.56	0.56	0.87	0.31
MgO	2.18	1.69	1.3	1.94	2.23	1.62	1.15	1.1	1.36	1.93	1.21	1.41	1.38	1.56	2.13
Na_2O	1.05	1.52	2.52	1.52	0.7	0.27	0.97	2.1	2.34	1.45	1.17	1.02	1.19	1.71	1.03
K2O	1.93	0.77	1.33	1.16	3.64	0.65	1.48	0.99	1.35	1.51	1.51	2.49	1.78	0.97	3.3
P_2O_5	0.13	0.15	0.15	0.17	0.2	0.11	0.14	0.15	0.14	0.16	0.08	0.09	0.11	0.17	0.23
loss on ignition	6.16	5.13	3.09	3.92	5.03	6.57	2.99	5.54	6.73	4.80	6.3	8.2	7.55	4.51	7.15
Total	99.55	99.42	99.55	99.66	99.63	99.43	99.47	99.53	99.69	99.58	99.57	99.3	99.87	99.38	99.48
CO_2	3.05	1.76	0.29	0.29	0.25	5.43	0.35	4.14	4.56	n.d.	2.95	2.91	3.45	1.68	0.22
H_2O-	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	0.57	0.88	0.8	0.6	1.74
H_2O+	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	2.37	4	3.31	2.15	5.01

No.	32	33	34	35	36
	T_3n	T_3n	T_3n	T_3n	T_3n
	Type 2 lithofacies		Type 3 lithofacies		
Sample Number	454/8-2	456/4	474/1sh	451/9sh	Av (9)
SiO_2	72.8	75.08	59.19	44.95	67.14
TiO_2	0.59	0.4	0.94	1.28	0.76
Al_2O_3	10.44	8.23	18.57	26.7	13.55
Fe_2O_3	1.37	2.88	0.91	2.38	2.13
FeO	4.86	1.72	6.77	6.41	4.03
MnO	0.17	0.3	0.18	0.15	0.14
CaO	0.74	2.41	0.74	0.2	0.84
MgO	1.72	1.41	2.44	3.06	1.66
Na_2O	1.54	1.42	0.74	1.01	1.23
K_2O	1.05	0.93	2.28	5.43	1.79
P_2O_5	0.1	0.11	0.21	0.12	0.14
loss on ignition	4.15	5.04	6.11	7.4	6.13
Total	99.53	99.93	99.03	99.09	99.51
CO_2	0.92	2.99	0.21	0.28	n.d.
H_2O-	0.52	0.39	0.49	0.49	n.d.
H_2O+	2.58	1.68	4.32	5.44	n.d.

Major element abundances are given in weight %. Major element content was measured by the wet chemistry method. Analyses were obtained at the chemical-analytical center of Geological Institute of the Russian Academy of Sciences, Moscow. n.d. – no data, T_{1-2} – Chemical composition of Lower-Middle Triassic rocks, T_3c Chemical composition of Carnian rocks, T_3n – Chemical composition of Norian rocks.

Analyses 1-3 – Enmynveem River, sandstones; 4 – Vernitakayveem River, sandstone; 5 – Vernitakayveem River, schist; 6 – Tundrovyj Creek; 7-8 – Yanramkyvaam River, silt-sandstones; 9 – Lyupveem River, sandstone; 10 – Lyupveem River, silt-sandstone; 11 – Yagelnyj Creek; 12 – Urguveem River, sandstones; 13 – Average of 12 samples of T_{1-2}; 14 – Maly Anyui River, schist; 15-17 – Maly Anyui River, sandstones; 18 – Bolshoy Keperveem River, silt-sandstone; 19 – Urguveem River, sandstone; 20 – Keperveem River, near Bilibino, sandstone; 21 – Tayny Creek, silt-sandstone; 22-23 – Kytep-Guytenryveem River,sandstones; 24-25 – Ugol Creek, sandstone; 26 – Average of 11 samples of Carnian rocks. 27-29 – Machvavaam River, silt-sandstones; 30-31 – Irguneyveem River, sandstone; 32 – Machvavaam River, schist; 33 – Pyrkanay Ridge (southern part), sandstone; 34 – Machvavaam River, silt-sandstone; 35 – Enmynveem Ryver, schist; 36 – Average of 9 samples of Norian rocks.

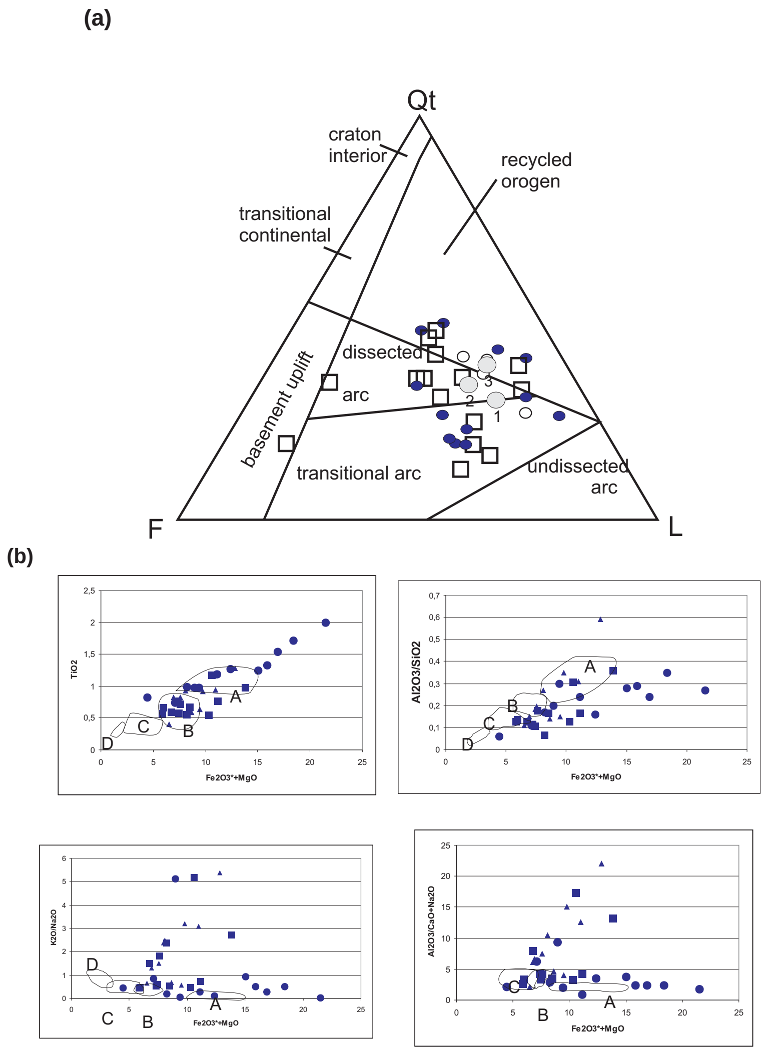

Fig. 16. (a) – Tectonic discrimination diagrams for mineral composition of sandstones after Dickinson (1985). The grey circles are average sandstone compositions: 1 – Lower–Middle Triassic, 2 – Carnian stage, 3 – Norian stage; **(b)** – Tectonic discrimination diagrams after Bhatia and Crook (1986): A – Oceanic Island Arc, B – Continental Island Arc, C – active continental margins, D – Passive continental margins.

assemblage suggests that low to medium grade metamorphic rocks were located in the source area. The marginal zones of this complex experienced erosion during the regressive sedimentation cycle (in Early and Middle Triassic times), and its central zones suffered erosion in Late Triassic time, during two transgressive cycles. The evolution of the mineral composition of Triassic sandstones was likely due to the increasingly deeper level of erosion of the metamorphic complex as a result of either its exhumation or progressively deeper incision of the draining rivers.

6.5 Nature of the volcanic source material

Lower–Middle Triassic sandstones exhibit a predominance of volcanic rock clasts of mafic to intermediate composition. The inferred sediment source area for these sandstones was located in the nearshore- or shallow-water zone of the paleobasin and did not have synchronous volcanism (see below); rocks were lithified and deformed prior to the beginning of sedimentation (Tuchkova et al., 2007). Decomposition and erosion of volcanic rocks led to the formation of loose, easy eroding sediments and gel-like material on the bottom of the shallow-water zone of the marine basin. In the period of voluminous clastic supply from the direction of the continent, deltaic flows entrained this altered volcanic material and carried it into deeper domains of the basin.

The low alkali values in the sandstones (no higher than 4.3%) are notable and suggest the lack of coeval volcanic material in them. However, some of the Triassic (mostly Lower–Middle) sandstones plot in or near the field linked to oceanic island arcs in the Bhatia (1983) plots. Lower-Middle Triassic sandstones have higher Ti content, which become considerably lower in Upper Triassic sandstones. So, the mafic source existed only in Early Triassic time. Gel'man (1963, 2000)

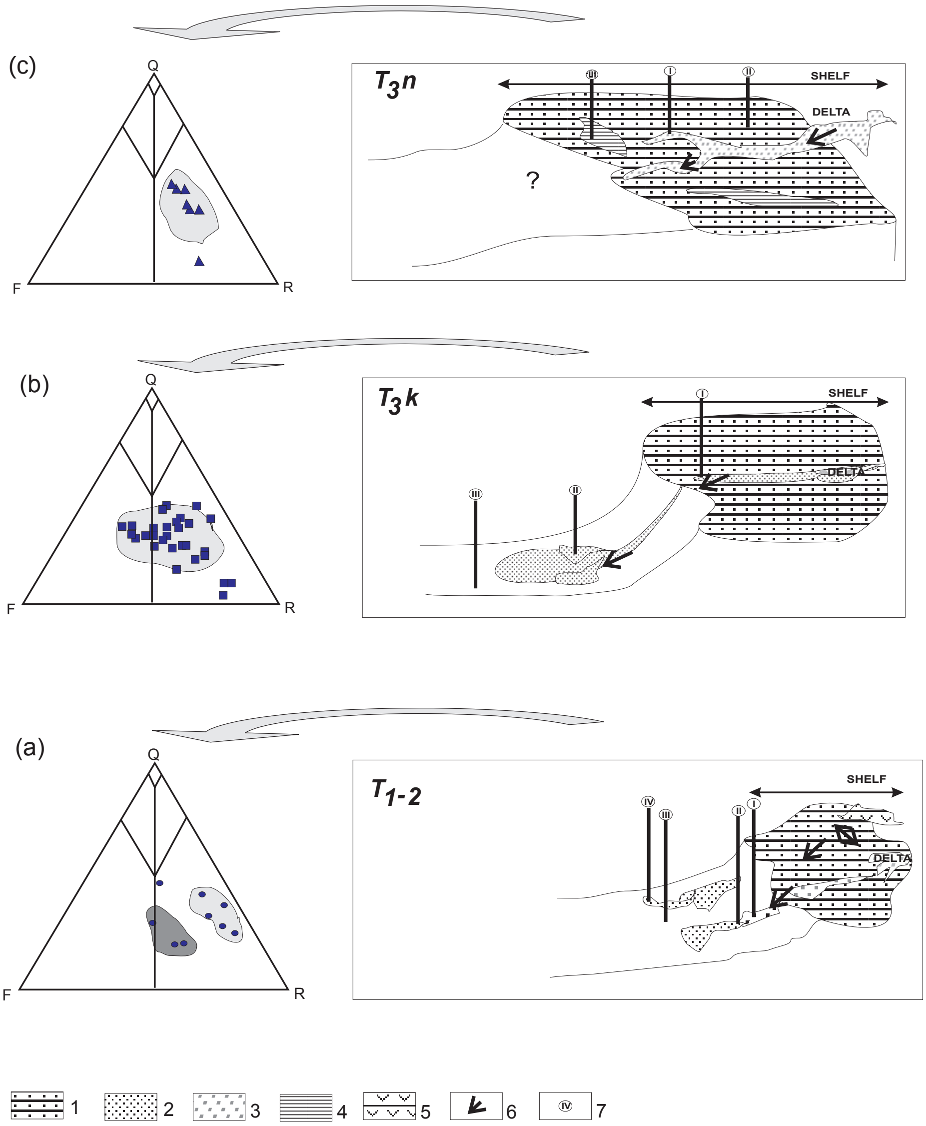

Fig. 17. Model of the paleogeography of the Triassic continental margin of the Chukotka microcontinent **(a)** – In the Early-Middle Triassic; **(b)** – In the Late Triassic, Carnian interval; and **(c)** – In the Late Triassic, Norian interval. The shelf area increases from Early to Late Triassic. At left – mineral composition diagrams for all Triassic sandstone formations, data from Fig. 12.
1 – mudstones-sandstones, 2 – silty sandstones, 3 – sandstones, 4 – mudstones-silty sandstones, 5 – areas of volcanic deposits, 6 – flow direction of clastic material, 7 – types of lithofacies from Figs. 5, 9, and 11 are given in roman numerals in the circles.

also points out the high content of detrital ilmenite in sandstones of the upper unit of the Lower–Middle Triassic and invokes the erosion of diabases or extrusive complexes, without specifying their location, as a possible source (Gel'man, 1963, 2000).

Based on published data, western Chukotkan Triassic deposits contain no pyroclastic material (Til'man, 1958; Til'man and Sosunov, 1960; Seslavinsky, 1970; Bychkov, 1994a, b). At the same time, regional studies show that a considerable part of the Early–Middle Triassic stratigraphy consisted of tuffs. In the course of mapping, tuffs were identified by the green color of isolated interbeds that stand out in terrigenous units of gray or greenish gray color. As noted above, petrographic studies of these rocks, however, reveal no evidence of coeval volcanism. The clay fraction of sandstones lacks any fraction of pyroclastic material, volcanic glass, and smectites or their traces. Only in a few isolated samples from Lower–Middle Triassic deposits from the Urguveem and Maly Anyui rivers, did we establish tuffites, containing ash particles. However, the age of these deposits is not constrained faunally.

Therefore, the results of petrographic studies in Triassic rocks of the region to date do not support a coeval volcanic source. It is possible that the volcanic sources are poorly recorded in the deposits or that a volcanic source was far from sedimentary basin. This issue, however, calls for additional studies: dating of ash-bearing rocks and identification of sediments attributable to tuff intercalations is especially vital in view of the U-Pb age data (Miller et al, 2006) which indicate that Upper Triassic sandstones contain some detrital zircons with ages of 236–255 Ma.

7 Geodynamic setting and conclusions

Our reconstruction of the paleogeography in the Chukotka region is divided into three phases (Fig. 17), and we suggest that the lateral facies patterns are more proximal in the northeast and more distal in the southwest.

Western Chukotkan Triassic deposits originated on the continental margin of the Chukotka microcontinent and are composed of thick terrigenous units accumulated in a large oceanic basin on a passive continental margin. The sedimentation history of the basin in Triassic time falls into three stages: a regressive Lower–Middle Triassic and transgressive Carnian and Norian stages (Fig. 17). During the Lower–Middle Triassic stage, the sedimentation rate was high, and very thick sediments accumulated in depositional traps on and at the base of the continental slope. In Carnian time, sediments were deposited mostly at its base. Deposits of the Norian basin accumulated on the shelf, which provided habitats for abundant faunal communities. Analysis of the distribution of facies across the region indicates that the depth of the paleobasin increased from northeast to southwest in modern reference frame.

The mode of deposition in the basin and the supply of sediments into it were controlled by a deltaic system whose depocenters and size experienced changes throughout Triassic time. A large system existed in Early–Middle Triassic and Carnian times, and possibly, two smaller ones existed in Norian time. This suggests that a large catchment area existed in the source region; hence, petrographic, mineralalogic, and chemical compositions of the Triassic rocks provide only an averaged characterization of the source region. From Early to Late Triassic, the shelf zone grew progressively wider, prograding into deepwater zones. A proximal source area for the Triassic clastics is situated only in the drainage area of the Nomnunkuveem River.

Many authors have speculated on the exact source areas for the terrigenous Triassic units. It was initially proposed that clastic material was supplied to the Triassic Western Chukotka sedimentary basin from a now subsided Hyperborean craton in the north (Til'man, 1962; Gusev, 1964; Seslavinsky, 1970). Subsequently the source was proposed to be the erosion of rocks of the Canadian Arctic margin (e.g., Grantz et al., 1979). Recently it has been suggested that the Chukotkan Triassic deposits were derived from erosion of rocks of the fold belt in Siberia (Miller et al., 2006). Our data show proximal source area for the Triassic clastics only in the drainage area of the Nomnunkuveem River, thus more distal sources, such as Canadian, are more preferable. The location of sources is unknown and still debatable; however, we can now determine the composition of the erosional sources by petrographical and chemical investigations (see Sect. 6).

The Triassic sandstones have a uniform mineral composition and are classed as lithic arenites. Geochemically the sandstones can be subdivided into two groups, both of polymictic composition; one group corresponds to normal sandstones and the other is close to intraplate basalts. The main sediment source is suggested to have been a metamorphic complex whose marginal portions suffered erosion in Lower–Middle Triassic time, and whose central portions eroded in Late Triassic time. The Triassic basin was dominated by a single source province. It is quite possible, however, that we are dealing with averaged mineral compositions of sandstones originating from different sources, resulting from the large size of the catchments area and protracted transportation of clastic material.

Sandstones of the Lower–Middle Triassic stage of sedimentation have an additional sediment source composed of deformed volcanic rocks of mafic to intermediate composition. Recently in the Kolyuchin Bay subvolcanic mafic rocks with a U-Th-Pb zircon age of 252±4 Ma and associated with terrigenous sediments (V. Pease et al., personnal communication, 2007; Sokolov et al., 2009) have been found. It is therefore possible to suggest a local source for zircon population with a 236–255 m.y. age (Miller et al., 2006).

8 Further study

The analysis presented in this paper is an initial study in the sedimentary history of the Chukotkan paleobasin. A number of issues remain unresolved; these include (i) the exact source area for the Triassic paleobasin; (ii) reliable correlation of coeval parts of Triassic sedimentary complexes; (iii) exhaustive paleogeographic analysis of the paleobasin, involving biostratigraphic data; etc. Future studies need to acquire more sedimentologic and zircon data on the Lower–Middle Triassic and Norian deposits. In addition, future studies and reconstructions need to make use of the data obtained to correlate Triassic deposits of the Anyui subterrane (Chukotka microcontinent) and the South Anyui terrane (suture) to eventually select a model for Triassic sedimentation and evolution of Mesozoic basins of the Eastern Arctic.

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