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Age of Detrital Zircons from Sandstones of the Mesozoic Flysch Formation in the South Anyui Suture Zone (Western Chukotka)

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Abstract—The South Anyui fold zone (western Chukotka) is considered a suture zone related to closure of the South Anyui oceanic basin and collision of Eurasia with the Chukotka–Arctic Alaska microcontinent in the Early Cretaceous. The existence of a compensatory sedimentation basin (foredeep) during folding in the terminal Jurassic–initial Cretaceous remains debatable. This work presents first data on age estimates of detrital zircons from Upper Mesozoic terrigenous sequences of the South Anyui suture zone obtained by the fission-track method. The distal flysch of presumably Late Jurassic age and the proximal flysch of probably Late Triassic age were sampled in the Uyamkanda River basin. The fission-track dating showed that sandstones from the flysch sections contain detrital zircons of two different-age populations. Young zircon populations from sandstones of distal turbidites in the upper course of the Uyamkanda River (two samples) are 149 ± 10.2 and 155.4 ± 9.0 Ma old (Late Jurassic), whereas those from coarse-grained proximal turbidites sampled in the lower course of the Uyamkanda River (one sample) is 131.1 ± 7.5 Ma old (Early Cretaceous). The data obtained indicate that the Late Mesozoic folding in the South Anyui suture zone was accompanied by the formation of a marginal sedimentary basin. Sediments accumulated in this basin compose tectonic nappes that constitute a fold–thrust structure with the northern vergence.

INTRODUCTION

During the last decades, most researchers consider the South Anyui fold zone as a structure related to collision of Eurasia with the Chukotka–Arctic Alaska microcontinent and closure of the South Anyui oceanic basin in the Early Cretaceous (Seslavinskii, 1979; Parfenov, 1984; Noklenberg *et al.*, 1998; Natal'in *et al.*, 1999; Sokolov *et al.*, 2001).

The continental collision and suture development are usually accompanied by the formation of asymmetrical marginal sedimentary basins, whose sediments are thrust toward the smaller collided blocks. The latter are subducted during the collision under larger continental blocks, which can be exemplified by Indostan and the North Slope of Alaska (Grantz *et al.*, 1994; Van der Voo *et al.*, 1999; Chemenda *et al.*, 2000). As a result of unidirectional migration of the folding and thrusting front, sediments of the marginal basins are involved into fold–thrust deformations.

Until recently, data on large-scale thrust structures and the Late Mesozoic marginal sedimentary basin at the fold–thrust front in the South Anyui suture zone were lacking. Recent works of scientists from the Geological Institute of the Russian Academy of Sciences revealed tectonic nappes of northern vergence in the South Anyui suture zone of western Chukotka (Bondarenko *et al.*, 2001a; Sokolov *et al.*, 2001). The nappes are composed of fragments of Paleozoic and Mesozoic ophiolites and Mesozoic island-arc volcanosedimentary rocks typical of the Alazeya–Oloi foldbelt, which borders the South Anyui suture in the south. The autochthon is composed of Paleozoic–Mesozoic rocks of the passive margin of the Chukotka microcontinent (Sokolov *et al.*, 2001; Bondarenko *et al.*, 2001b).

Our studies showed that Upper Jurassic–Lower Cretaceous terrigenous rocks are more widespread within the South Anyui suture zone than it was previously considered. The new data make it possible to outline in general terms a spacious sedimentary paleobasin at the fold–thrust structure front. The Colvill flysch basin (northern Alaska), which accumulated sediments in the Late Jurassic–Paleogene at the Brooks Range fold–thrust structure front (Molenaar *et al.*, 1988; Grantz *et al.*, 1990) is a probable structural and age analogue of the South Anyui basin.

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TECTONIC SETTING OF UPPER JURASSIC–LOWER CRETACEOUS TERRIGENOUS ROCKS

The study area is located in the axial and northern parts of the Anyui suture zone (Anyui Ridge) between the Bol'shoi and Malyi Anyui Rivers in western Chukotka (Fig. 1). This area is characterized by an intricate fold–thrust structure with northern vergence (Figs. 2, 3) that was first described in (Sokolov *et al.*, 2001). Dislocated Upper Paleozoic–Upper Mesozoic island-arc volcanosedimentary complexes of the Alazeya–Oloi foldbelt, which characterize the protractedly developed active Eurasian margin (Fig. 1), are found south of the study area (Til'man, 1973; Parfenov, 1984; Shul'gina *et al.*, 1990; Bogdanov and Til'man, 1992). These complexes are thrust northward over the South Anyui suture zone and Upper Paleozoic–Triassic terrigenous rocks of the passive margin of the Chukotka–Arctic Alaska microcontinent. Structures of the microcontinent are recognized in the Anyui–Chukotka foldbelt (Parfenov, 1984; Noklenberg *et al.*, 1998; Bondarenko *et al.*, 2001b) (Fig. 3). According to (Sokolov *et al.*, 2001), tectonic erosional windows are composed of autochthonous rocks (Triassic flysch of the Anyui–Chukotka belt) in antiforms and fragments of allochthonous volcanosedimentary successions of the Alazeya–Oloi belt and South Anyui suture zone in synforms (Figs. 2, 3) (Sokolov *et al*., 2001). According to (Pinus and Sterligova, 1973; Lychagin *et al.*, 1991; Sokolov *et al.*, 2001), rock complexes of the South Anyui suture zone consist of tectonically dislocated ophiolites, Mesozoic island-arc succession fragments, metamorphosed sequences, and terrigenous accretionary melanges (Figs. 2, 3). Most researchers draw the northern boundary of the South Anyui suture zone along the WNW- to ESE-oriented chain of ophiolitic allochthons (Parfenov, 1984; Bogdanov and Til'man, 1992; Noklenberg *et al.*, 1998).

In the Uyamkanda River basin, autochthonous rocks of the Anyui–Chukotka belt are exposed in erosional windows as paleontologically substantiated (Bychkov, 1994) Upper Triassic distal turbidites with quartz–feldspar sandstones (Figs. 2, 3). The turbidites consist of rhythmically alternating sandstones, siltstones, and argillites with characteristic cyclic Bouma structures. Detrital material was transported from the northern Chukotka–Arctic Alaska microcontinent (modern coordinates). The Upper Triassic rocks are intensely deformed into stressed asymmetric folds with low-angle axes of mainly northern vergence. Foliated cleavage parallel to axial surfaces of these folds is widespread. The cleavage surface is deformed into asymmetric and differently strained folds. Northern vergence of the structure prevails, but folds of southern vergence are observed in zones of retrothrusts and later strike-slip faults (Bondarenko *et al.*, 2001b).

Ophiolitic allochthons and Triassic complexes of the autochthon sandwich sheets of facies-variable tuffaceous–terrigenous rocks with rare Late Jurassic–Early Cretaceous bivalves (Paraketsov and Paraketsova, 1989). According to geological survey data, these rocks are arbitrarily referred to the Upper Triassic, whereas our field observations indicate their younger, probably Early Cretaceous age. We sampled the presumably Upper Jurassic (lower structural part) and Lower Cretaceous (upper structural part previously attributed to the Triassic) intervals of the section (Fig. 2). The lower interval consists of thin-rhythmic turbidites with a variable admixture of intermediate and acid pyroclastic material (samples 9947 and 9947/1). Proximal turbidites and shelf sediments with more abundant sand interbeds and a higher content of pyroclastic material prevail in the stratigraphically higher interval (sample 9986). The section is crowned by polymictic sandstones and siltstones (Fig. 4) of the Late Triassic age according to the geological survey data.

The studied fold–thrust structure is unconformably overlain by paleontologically substantiated Hauterivian–Barremian coarse-detrital tuffaceous–terrigenous rocks. They are composed of detrital material derived from underlying rocks (volcanics, cherts, ultramafics, gabbro, and Triassic shales) along with quartz, feldspar, and metamorphic schists. Since the Hauterivian–Barremian rocks were partly involved into thrusting, they can be considered the lower deformed neoautochthon. On the right bank of the Uyamkanda River, lithologically similar polymictic terrigenous rocks rest upon Upper Jurassic–Lower Cretaceous strata without apparent unconformity (Fig. 2). Albian–Upper Cretaceous continental volcanics and less common tuffs unconformably overlie all older rocks and show the presence of only brittle strike-slip deformations.

LITHOLOGICAL TYPES OF UPPER JURASSIC–LOWER CRETACEOUS SUCCESSIONS IN THE SOUTH ANYUI SUTURE ZONE AND ADJACENT STRUCTURES

Let us briefly consider variations in the structure and lithology of the paleontologically substantiated Upper Jurassic–Lower Cretaceous succession across the South Anyui suture zone (Fig. 5). According to (Shul'gina *et al.*, 1990), Upper Jurassic–Lower Cretaceous tuffaceous–terrigenous complexes are associated with intermediate and acid rocks (lavas and lava breccias) in the central Alazeya–Oloi foldbelt area south of the suture zone (Fig. 5, I). Volcanics exposed in the northern Yanranai block (eastern part of the Alazeya–Oloi zone) can be considered fragments of an ancient lateral structural succession of the Late Jurassic–Early Cretaceous ensialic island arc (Parfenov, 1984; Bogdanov and Til'man, 1992). Basic and intermediate pillow-lavas registered in the western part of the Alazeya–Oloi foldbelt are interpreted as fragments of the ensimatic island arc (Oksman, 1998).

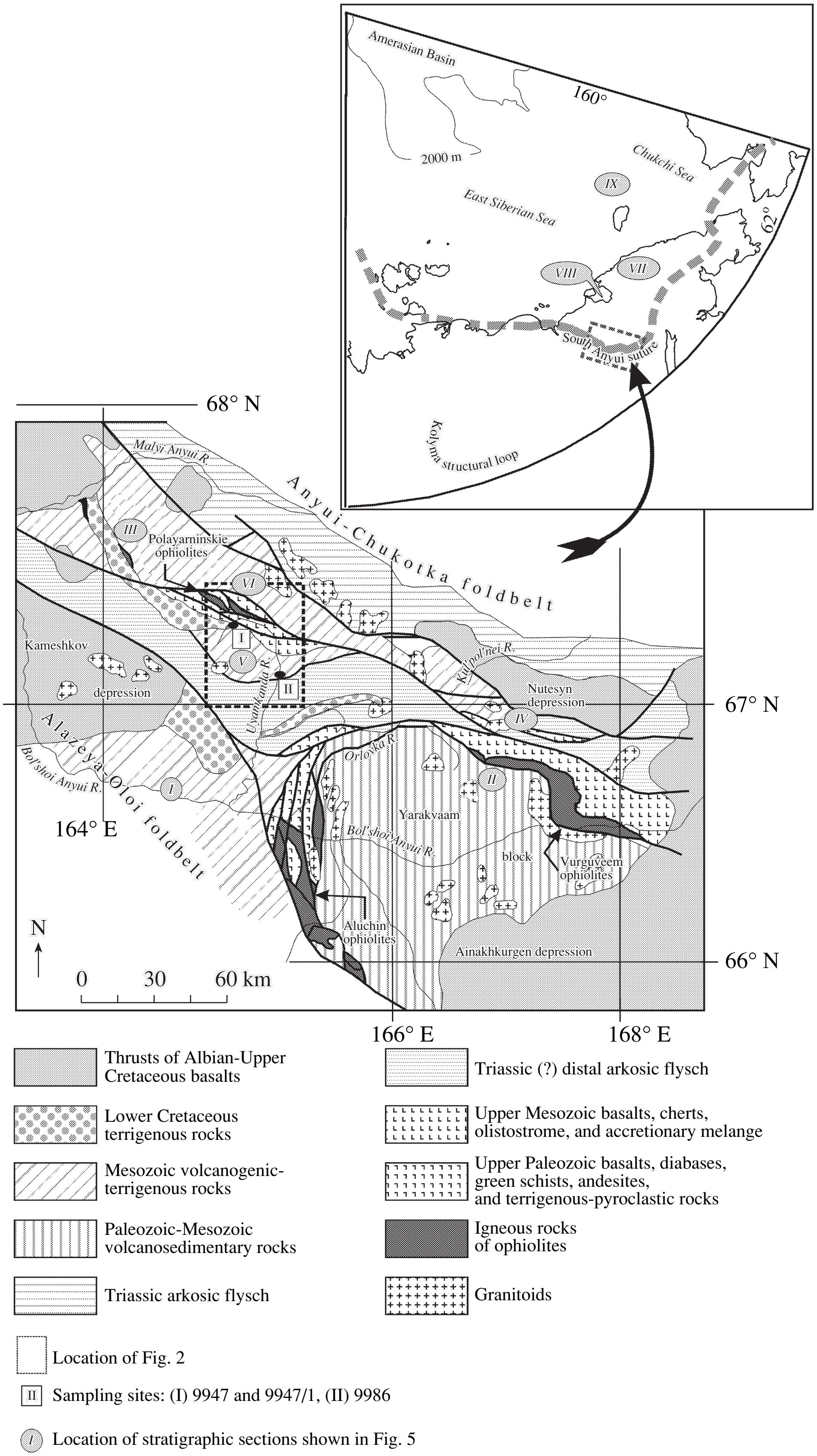


Fig. 1. Tectonic map of the Chukotka segment of the South Anyui suture zone (modified after Lychagin *et al.*, 1991). Inset shows geographic position of the study area.

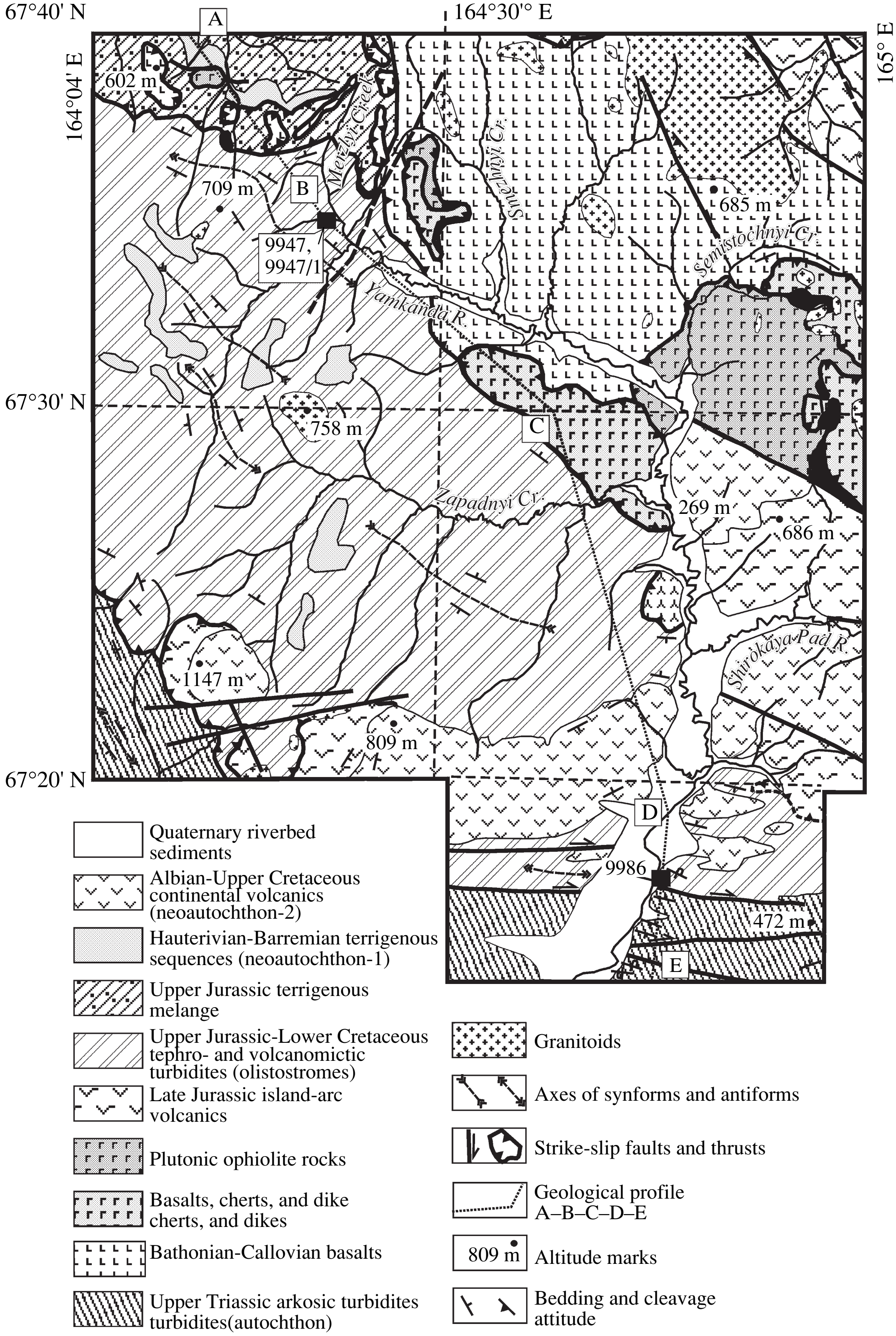


Fig. 2. Geological map of the Uyamkanda River basin based on geological survey data (scale 1 : 200 000) of the Anyui GGGP (Bilibino) with location of sampling points.

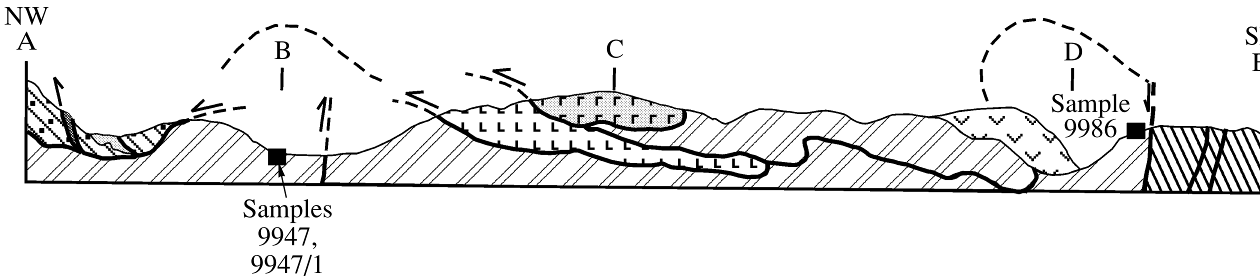


Fig. 3. Schematic geological profile A–B–C–D–E. Legend as in Fig. 2.

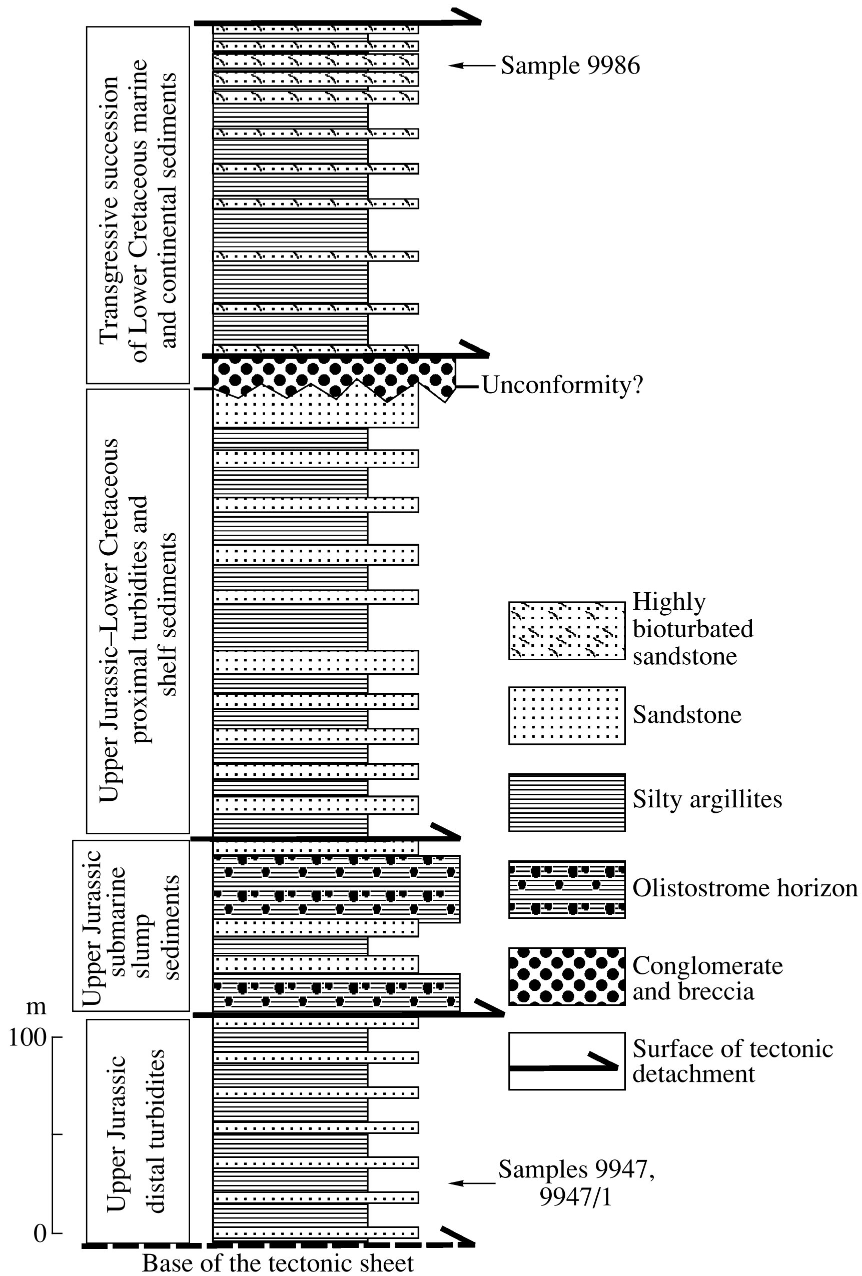


Fig. 4. Schematic integral stratigraphic section of the allochthonous nappe composed of Upper Jurassic–Lower Cretaceous tuffaceous–terrigenous rocks in the watershed area between the Uyamkanda and Angarka rivers.

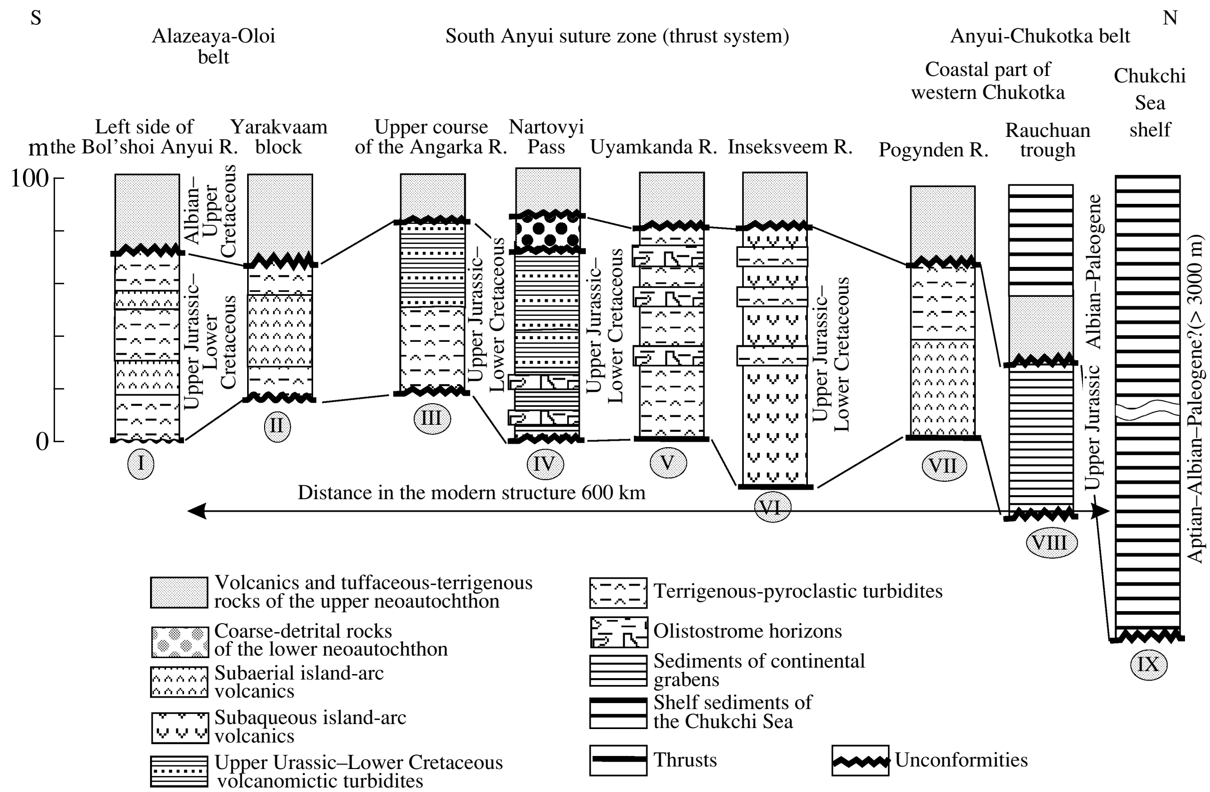


Fig. 5. Lateral succession of Upper Jurassic–Lower Cretaceous sequences of the South Anyui suture zone and adjacent structural elements in the modern structure. Roman numbers of columns correspond to numbers in Fig. 9.

Upper Jurassic successions in the South Anyi suture zone are composed of the following lithological varieties:

(1) Rhythmic-bedded volcanomictic turbidites and tephroturbidites that almost lack the background sediments and can be considered distal varieties of deep-sea sediments (Fig. 5, III).

(2) Volcanomictic turbidites with horizons of carbonate–terrigenous background sediments and submarine slump sediments that can be interpreted as proximal flysch (Fig. 5, IV). These sediments are unconformably overlain by the Hauterivian–Barremian polymictic coarse-detrital rocks (Dovgal *et al.*, 1975).

(3) Tephroturbidites with olistostrome horizons with fragments and blocks of subaqueous basaltic and andesitic lavas alternating with members of finer rhythmic flysch (Fig. 5, V). These rocks can be viewed as slope sediments accumulated in the frontal (or rear) part of the island arc.

(4) Subaqueous basaltic and andesitic lavas with tuffaceous–terrigenous flysch members whose share increases upward the section (Fig. 5, VI). These rocks could form in the back-arc or fore-arc basin of the ensimatic island arc.

According to (Ivanov, 1985), marine terrigenous and subcontinental coal-bearing rocks (Kukeveem Formation) are confined to grabens in the Anyui–Chukotka foldbelt in the north (Fig. 5, VIII). Their age remains debatable. Basal layers of the section have the latest Early Cretaceous age (Ivanov, 1985). The section can also include Lower Cretaceous and probably Upper Jurassic rocks (Paraketsov and Paraketsova, 1989).

Exposures of subaqueous and subaerial basaltic lavas associated with siliceous–clayey and flysch sediments are known in the Rauchuan depression in the east (I.V. Tibilov, pers. commun.). We observed similar rocks at the western flank of the Alyarmaut uplift located on the right bank of the Pogynden River (Fig. 5, VIII) (Bondarenko *et al.*, 2001a). The age of these sediments is unknown so far, but we detected their similarity with Upper Jurassic–Lower Cretaceous sections of the South Anyui suture zone and Alazeya–Oloi belt. Therefore, these rocks can represent a fragment of the allochthonous nappe thrust over the margin of the Chukotka microcontinent from the south.

According to (Grantz *et al.*, 1994), lower layers of the sedimentary cover on the Chukchi Sea shelf are composed of Aptian–Albian marine sediments accumulated in the Colvill foredeep that appeared at later stages of the Anyui–Chukotka–Brooks (Grants *et al.*, 1988) foldbelt development (Fig. 5, IX).

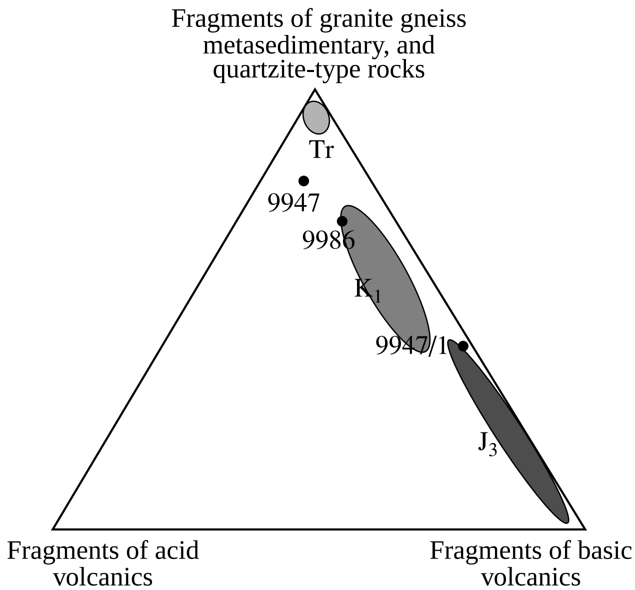


Fig. 6. Classification diagram by Shutov (1972) for the examined Upper Jurassic–Lower Cretaceous sandstones from the South Anyui suture zone. Compositional fields for Upper Triassic sandstones are compiled using preliminary results for four samples. Compositional fields for Upper Jurassic and Lower Cretaceous sandstones are compiled using 18 samples.

UPPER JURASSIC–LOWER CRETACEOUS SEDIMENTARY SUCCESSIONS

Sandstone samples 9947 and 9947/1 were taken from the exposure on the right bank of the Uyamkanda River approximately 1 km upstream of the Merzlyi Creek mouth (right tributary of the Uyamkanda River) (Figs. 1, 2). Late Jurassic (Kimmeridgian–Volgian) *Buchia* shells are found in lower layers of the volcanogenic–terrigenous sequence exposed several kilometers upstream of the Uyamkanda River (Paraketsov and Paraketsova, 1989). The studied part of the section is composed of intensely cleaved thin-rhythmic turbidites. Sandstone beds with graphitized plant detritus form boudines with argillite pebbles flattened parallel to cleavage planes in their basal layers. In clayey turbidite beds, bedding is poorly expressed and sometimes recognized only in detached hinges of isoclinal folds overturned in the NNW direction. The apparent thickness of the sampled section without regard for deformations is about 100 m.

Sample 9986 was taken from the fine-grained sandstone bed exposed on the left bank of the Uyamkanda River 5 km downstream of the Shirokaya Pad River mouth (Fig. 2). The bed is confined to the central part of the ~15-m-thick coarse-grained rock member containing graphitized plant detritus. The bedding here is steeply inclined to the SSE. The sandstone is intensely bioturbated and characterized by coarse ripple marks at the base. The brittle deformation zone with signs of strike-slip displacements is followed in the south by paleontologically substantiated Upper Triassic thin-rhythmic turbidites (Figs. 2, 3). The sandstone bed is stratigraphically underlain in the north by shallow-water marine siltstones with volcanomictic sandstone interbeds showing the presence of roiling and reworking structures. The sandstone member was arbitrarily attributed to the Upper Triassic based on geological survey data. According to our observations, the sampled sandstone member occupies the highest stratigraphic position in the Upper Jurassic terrigenous and tuffaceous–terrigenous succession of the Uyamkanda River basin (Fig. 4).

LITHOLOGY OF TERRIGENOUS ROCKS FROM THE UYAMKANDA RIVER BASIN

The sampled sandstones are divided into medium (samples 9947/1 and 9986) and coarse-grained (Sample 9947) varieties. They are usually inaequigranular and poorly sorted rocks with variably rounded, mostly angular fragments. Based on the composition of major components, Shutov *et al.* (1972) referred the sandstones to as graywackes with an insignificant (5–13%) cement (Fig. 6). Clasts are composed of granite gneisses, micaceous schists, aleuropelites, cherts, acid volcanics, tuffs, and presumably acid tuffaceous–terrigenous rocks (Table 1). Basic volcanics with relicts of intersertal and vitrophyric textures and occasional devitrified volcanic glass are subordinate.

The irregular granite gneiss fragments have granolepidoblastic, blastogranitic, and micropegmatitic textures. Quartz and feldspar crystals are characterized by palmate contours and the presence of muscovite-type mica flakes and cataclastic granite gneiss clasts.

Quartz in fragments is observed as differently rounded (angular, subrounded, or well-rounded) mono- and polycrystalline grains with wavy extinction. They contain different (mainly small) fluid inclusions, rutile, and mica (probably muscovite) flakes. Inclusion-free grains are also observed. The quartz grains are subjected to ductile deformation.

Feldspars most commonly occur in intergrowths with quartz, whereas separate grains are relatively rare. They include potassic varieties with the characteristic (sometimes intensely perthitized) microcline lattice and grains with rounded perthitic ingrowths. Fragments of acid plagioclases of two types are also present. Grains of the first type are dominated by platy (usually thin-twinned) albites or acid oligoclases. Intensely perthitized grains are also found. The oval or elongated perthite ingrowths are developed along twin sutures. Plagioclase of the second type is also represented by the tabular albite or acid oligoclase grains, but their edges are smoothed. Twinned crystals are rare and, when present, the boundaries between them are characterized by fuzzy contours. These plagioclases are intensely replaced by chaotically arranged hydromica

Table 1. Composition of detrital components in Upper Jurassic–Lower Cretaceous sandstones from the South Anyui suture zone

Mineral, rock	Sample		
	9986	9947	9947/1
	Number of grains in thin section		
Quartz	60	30	36
Acid plagioclase (<no. 20)	16	4	
Intermediate plagioclase Na–Ca (nos. 20–45)		4	10
Basic plagioclase (no. 45 and higher)			
Microcline			16
Undifferentiated feldspar	14	26	16
Microperthite intergrowths	24		
Acid volcanics	6	6	
Unaltered basic volcanics		2	
Albitized basalt	12	2	10
Slightly altered basaltic andesite			
Pelitic tuffite	28	10	14
Granite gneiss	26	32	4
Siliceous rock			
Quartzite		8	
Metasedimentary rock			4
Micaceous shale	4	2	
Unidentified rock		4	
Biotite			
Cement (% of the observable area)	5	4.25	13.3
Carbonate cement (% of the observable area)			5.3
Grains in total	190	130	110

flakes with an averages size of 0.02 mm (sometimes up to 0.04–0.05 mm along *C* axis. Some plagioclase grains are dislocated. Their twins are displaced relative to each other. Less commonly, the twin sutures have sinuous forms.

Rare grains of colored minerals are represented by sphene, tourmaline, and zircon.

Results of the calculation of major minerals in sandstones were plotted on the diagram “metamorphic rocks–acid volcanics–basic volcanics” with characteristic Triassic, Upper Jurassic, and Lower Cretaceous sandstone fields (Fig. 6). These fields were empirically obtained when studying the composition of paleontologically substantiated Upper Jurassic–Lower Cretaceous successions of the South Anyui suture zone (18 samples) and Upper Triassic sandstones from the northern Anyui–Chukotka foldbelt (4 samples). The identified field should be considered preliminary ones that need further confirmation. It is evident from the plot that sandstones of sample 9947/1 compositionally gravitate to the field of Upper Jurassic sandstones, whereas sandstones of samples 9986 and 9947 are close to Lower Cretaceous counterpart (Fig. 6).

Sialic metamorphic rocks, quartz, and feldspars prevail in the detrital material of samples 9986 and 9947 (Table 1). Sample 9947/1 is dominated by quartz and feldspar grains. This sample contains reworked products of basic volcanics accumulated after their prolonged transportation, which is evident from the absence of volcanic clasts with mineral inclusions in sandstones (Table 1). In the case of provenance proximity, the sandstones would preserve pyroxene, olivine, and other minerals that are less resistant to mechanical destruction and characteristic of basic volcanics.

All examined sandstones have the rim-type micaceous cement. The spinuous texture locally developed in Sample 9947 is related to the ingrowth of authigenic micas into edges of regenerated quartz grains. This sample also contains newly formed (more or less isometric) quartz crystals along veinlets. The quartz bears signs of *in situ* ductile deformation observed as Boehm lamellae and deformation bands of fluid inclusions.

The sandstones differ in the intensity of secondary alteration. Sample 9986 is referred to the sericite–chlorite facies of the early metagenesis stage according to the classification by Shutov (1972), whereas samples 9947 and 9947/1 can be attributed to the hydromica–chlorite facies of deep epigenesis.

METHOD AND RESULTS OF FISSION-TRACK DATING

The **fission-track dating** is based on estimation of the density of tracks left by particles during the spontaneous fission of uranium (^{238}U) nuclei that accumulate in minerals in the course of geological history (Price and Parker, 1963). Essential physical principles of the method and its application for the solution of geological problems are described in (Fleischer *et al.*, 1975; Shukolyukov *et al.*, 1965; Faure, 1986; Wagner and Van den Haute, 1992). The track accumulation in minerals with time is a process similar to the accumulation of radiogenic isotopes during radioactive decay. The stability of tracks primarily depends on temperature, i.e., tracks are formed and preserved in crystals that are cooled below closure temperature of the track system. For instance, if the zircon grain is gradually cooled under conditions typical of geological processes (cooling rate 1–30 K/Ma), closure temperature of the track system is 215–240°C (Brandon and Vance, 1992).

The **detrital fission-track geochronology** is based on track dating of separate zircon grains from terrigenous and tuffaceous rocks (Garver *et al.*, 1999). The method allows one to reveal the relationship between endogenic (magmatism, volcanism, and orogeny) and exogenic (erosion and sedimentation) processes. First works in this field were published approximately 15 years ago (Hurford *et al.*, 1984; Baldwin *et al.*, 1986; Hurford and Carter, 1991). Recently, the detrital fission-track geochronology became a popular tool in the study of sedimentation and tectonic processes worldwide (Brandon and Vance, 1992; Garver and Brandon, 1994; Garver *et al.*, 2000; Soloviev *et al.*, 2001; Shapiro *et al.*, 2001).

Inasmuch as the fission-track age is determined for separate mineral grains, this makes it possible to discriminate different-age populations related to various provenances. According to (Brandon and Vance, 1992), the term “fission-track age” designates the age of zircon grain cooling below the effective temperature of track system closure in zircon (215–240°C). Rock cooling in provenance depends on different geological settings. In the case of volcanism and near-surface intrusions, cooling of newly formed minerals can occur simultaneously with their origination. In the case of rock exhumation from deeper levels, the fission-track age of minerals may be significantly younger relative to the formation age of minerals and host rocks.

Researchers have shown that the unreset fission-track age of detrital zircons can be used for estimating the accumulation age of terrigenous sequences. The age of the youngest zircon population is close to that of sedimentation if the latter is associated with synchronous volcanism in the immediate vicinity (Brandon and Vance, 1992; Garver and Brandon, 1994; Garver *et al.*, 2000; Soloviev *et al.*, 2001; Shapiro *et al.*, 2001). The near-surface intrusions are exhumed and eroded during a sufficiently short time in mountainous belts that experienced rapid rise and erosion. Thus, the time lag between crystallization of zircon grains in the near-surface intrusion and their burial in sediments of the proximal basin is a few million years (Brandon and Vance, 1992; Shapiro *et al.*, 2001).

Fission-track age of zircons from sandstones of the South Anyui suture zone. Sandstones were sampled from the distal flysch sequence in the upper course of the Uyamkanda River (samples 9947 and 9947/1) and the proximal flysch sequence with members of coarse-grained polymictic sandstones (Sample 9986) in the lower course of the Uyamkanda River (Fig. 2). Zircon grains were extracted from sandstones in the Laboratory of Accessory Minerals, Institute of the Lithosphere of Marginal Seas. The zircon age was determined in the Fission-Track Dating Laboratory of the Union College (Schenectady, New York, United States) using the external detector method (Wagner and Van den Haute, 1992). The zircon grains were pressed into FEP TeflonMT plates (2×2 cm^2). Two plates were prepared for each sample. The plates were successively polished on the abrasive disc using diamond pastes (9 and 1 μm) and Al_2O_3 paste (0.3 μm). The NaOH–KOH mixture was used for the chemical etching of plates at 228°C during 10 h (first plate) and 15 h (second plate). After etching, the plates were covered by the detector (mica with a low uranium content) and irradiated in the thermal neutron flux with a density of about 2×10^{15} neutron/cm^2 (Oregon University Nuclear Reactor) simultaneously with the Fish Canyon Tuff (FCT), Buluk Tuff (BL), and uranium-doped glass (CN-5) standards (Hurford, 1998). An Olympus BX60 microscope with automated system and digital table was used for track calculation (dry method, maximal magnification 1600). The factor S (Hurford, 1998) based on 10 age standards (6 FCT samples and 4 BL samples) was 316.22 ± 9.57.

In total, from 38 to 50 zircon grains were dated for every sample (Table 2). The Zetaage 4.7 program developed by M.T. Brandon (Yale University, United States) was used for the calculation of ages of separate zircon grains. The fission-track grain-age samples show a wide range (Fig. 7), indicating the presence of several different-age zircon populations. We used the BinomFit 1.8 program proposed by M.T. Brandon (Yale University, United States) and algorithm from (Galbraith, 1988) for the decomposition of different-age populations. The Zetaage 4.7 and BinomFit 1.8 programs are available at http:\\love.geology.yale.edu/~brandon.

Two different-age zircon populations are present in sandstones (Table 2, Figs. 7a–7c), suggesting that the zircons were not subjected to secondary heating and their age remained unreset after the burial in sediments. However, researchers have reported examples of the presence of several zircon populations within a single sample (Hasebe *et al.*, 1993; Garver and Bartholomew, 2001). Some of them experienced secondary heating (i.e., their age is reset), whereas the age of other populations corresponds to their cooling time in the provenance. This is usually typical of prolonged residence of the rock at temperatures close to that of the zircon track system closure, and the zircons therein have different properties and degrees of tracks heating. Zircon properties, which affect the track heating, are poorly studied so far (Rahn *et al.*, 2002). Researchers have primarily focused attention on the disturbance of zircon grain structure by α-decay tracks, anomalous U content, U/Th ratio, and other parameters. Garver and Bartholomew (2001) showed that the secondary heating of tracks at lower temperatures (about 200°C) occurs in U-rich zircon grains with a structure highly disturbed by α-decay tracks. In the grain age–U content plot, overheated grains form a separate cluster that disturbs the typical linear dependence of normally heated samples (Garver and Bartholomew, 2001). We compiled similar plots for dated samples from the South Anyui suture zone (Figs. 8a–8c). They do not reveal distinct separate clusters and significant deviations from the linear dependence. Thus, we can assume with confidence that the zircon age in samples from the South Anyui zone remains unreset and corresponds to the cooling time in provenance. The age of host rocks is always younger relative to that of rock clasts. Hence, the age of young zircon populations (155.4 ± 9.0, 149.6 ± 10.2, and 131.7 ± 7.5 Ma for samples 9947, 9947/1, and 9986, respectively) determines lower age limits for the host sediment accumulation. If the sedimentation was synchronous with volcanic eruptions in the immediate vicinity, the age of the young zircon population should be close to that of terrigenous sequences.

RECONSTRUCTION OF SEDIMENTATION SETTINGS IN THE SOUTH ANYUI BASIN DURING THE LATE JURASSIC–EARLY CRETACEOUS

Figure 5 demonstrates several schematic Upper Jurassic–Lower Cretaceous successions. Only sections VIII and IX are autochthonous, i.e., close to the initial position. Despite the probable tectonic northward displacement, sections I and II belong to the Alazeaya–Oloi belt. Sections III–VII are tectonically displaced and are allochthonous in the South Anyui suture zone and Anyui–Chukotka belt (Sokolov *et al.*, 2001). Unfortunately, the displacement amplitude of every tectonic thrust is unknown. We cannot also definitely determine the deposition site of sediments of the Upper Jurassic–Lower Cretaceous complex (Alazeaya–Oloi belt or South Anyui paleobasin). The root zone of nappes composed of rocks of sections III–VII is overlain by structures of the Alazeya–Oloi belt. Therefore, when reconstructing sedimentation settings for the Late Jurassic–Early Cretaceous period, we could take into consideration only indirect indications of initial lateral zonality in the South Anyui paleobasin. We assumed that the Late Jurassic–initial Early Cretaceous interval corresponded to the development of convergence zone along the southern (in modern coordinates) boundary of the paleobasin (Parfenov, 1984; Sokolov *et al.*, 2001).

Table 2. Fission-track age of detrital zircons from sandstones of the South Anyui suture zone

Sample no.	Lithology	Nt	Age of zircon populations, Ma	
			P1	P2
9986	Proximal turbidites	50	131.1 ± 7.5 88.5%	344.5 ± 70.3 11.5%
9947	Distal turbidites	47	155.4 ± 9.0 94.4%	354.2 ± 90.3 5.6%
9947/1	The same	38	149.6 ± 10.2 79.5%	293.8 ± 59.9 20.5%

Note: (Nt) Number of dated grains; (P1, P2) zircon populations calculated using the BinomFit 1.8 program (Brandon, 1992, 1996). The accuracy of age determinations is ±1σ (%). Abundance of grains from a particular generation relative to the total number of dated grains.

Second half of the Late Jurassic. In the Oxfordian–Tithonian, the passive margin of the Chukotka–Arctic Alaska bordered the South Anyui basin in the north. Marine sedimentation in the basin mainly occurred in grabens (Fig. 9a).

The oceanic crust formation in the South Anyui basin terminated in the Callovian– Oxfordian (Sokolov *et al.*, 2001). The basin intensely accumulated terrigenous material that was probably transported from both the Chukotka–Arctic Alaska microcontinent and Eurasia. The pyroclastic material was delivered from the island arc in the Alazeya–Oloi zone (Fig. 9a). The paleoaccretionary prism in the frontal part of the zone could produce olistostrome horizons. It is not inconceivable that some Upper Jurassic marine volcanic rocks (pillow-lavas with volcanomictic flysch) formed in the back-arc basin of the Alazeya–Oloi island arc. In the modern structure, similar sequences of the older (?) age are only registered in the western part of the Alazeya–Oloi belt (Parfenov, 1984; Oksman, 1998). The tuffaceous–terrigenous flysch (samples 9947 and 9947/1) was probably accumulated in the fore-arc basin of the

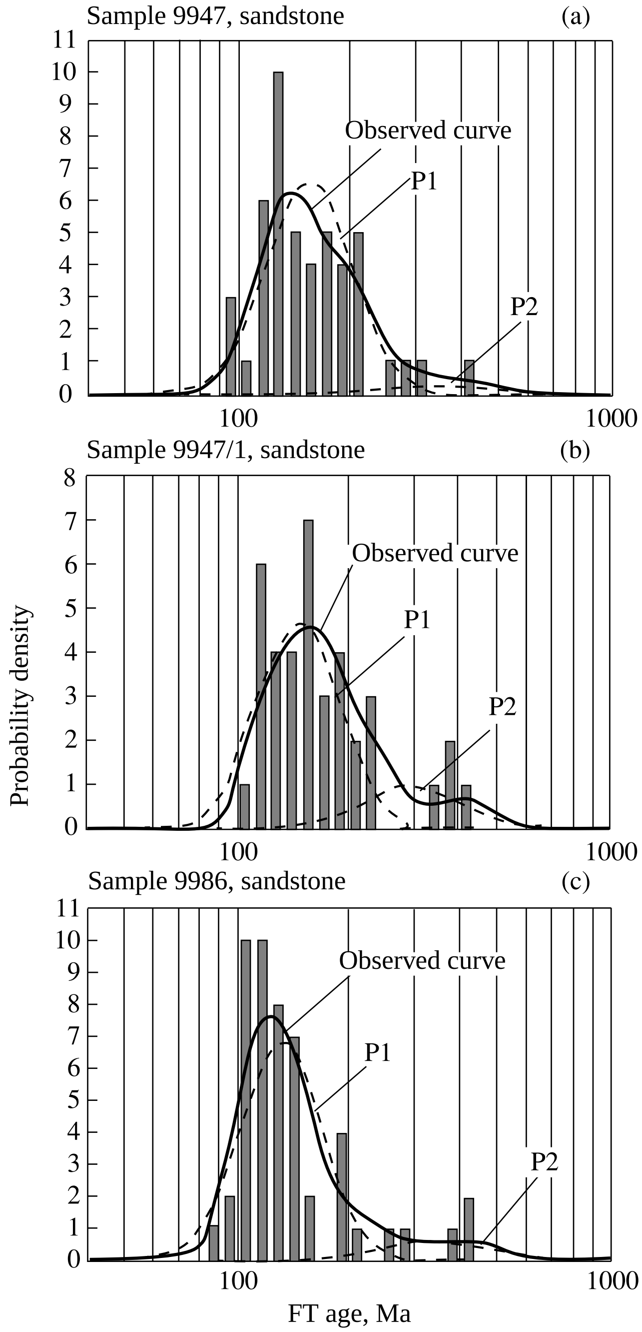


Fig. 7. Distribution plots of fission-track ages of zircon grains from samples (a) 9947, (b) 9947/1, and (c) 9986. (P1, P2) peaks of populations 1 and 2 (Table 2) discriminated using the BinomFit 1.8 program (Brandon, 1996). The time scale is logarithmic.

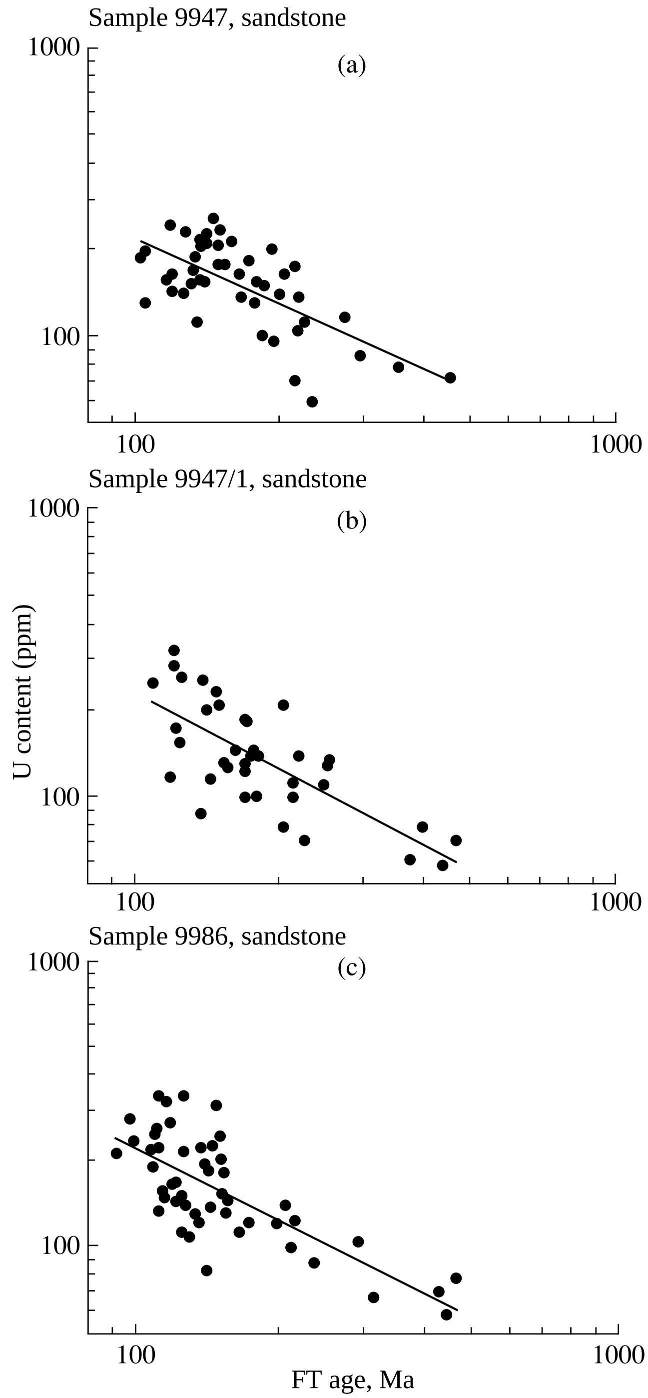


Fig. 8. Dependence of fission-track ages of zircon grains on the U content plotted for samples (a) 9947, (b) 9947/1, and (c) 9986. The scale is logarithmic.

Alazeya–Oloi island arc (Fig. 9a).

First half of the Early Cretaceous. In the Berriasian–Hauterivian, the lateral succession of structures was complicated by active folding (Parfenov, 1984; Natal'in, 1984; Bogdanov and Til'man, 1992; Sokolov *et al.*, 2001). This explains regressive patterns of Upper Jurassic–Lower Cretaceous sections (Radzivill and Palymskii, 1972; Paraketsov and Paraketsova, 1989). Simultaneously, the watershed area between the Angarka and Uyamkanda rivers accumulated turbidites in the Early Cretaceous (Fig. 5, III). This indicates the existence of a substantially spacious and deep basin north (in modern coordinates) of the folding and thrusting zone (Fig. 9b). The basin accumulated sample 9986

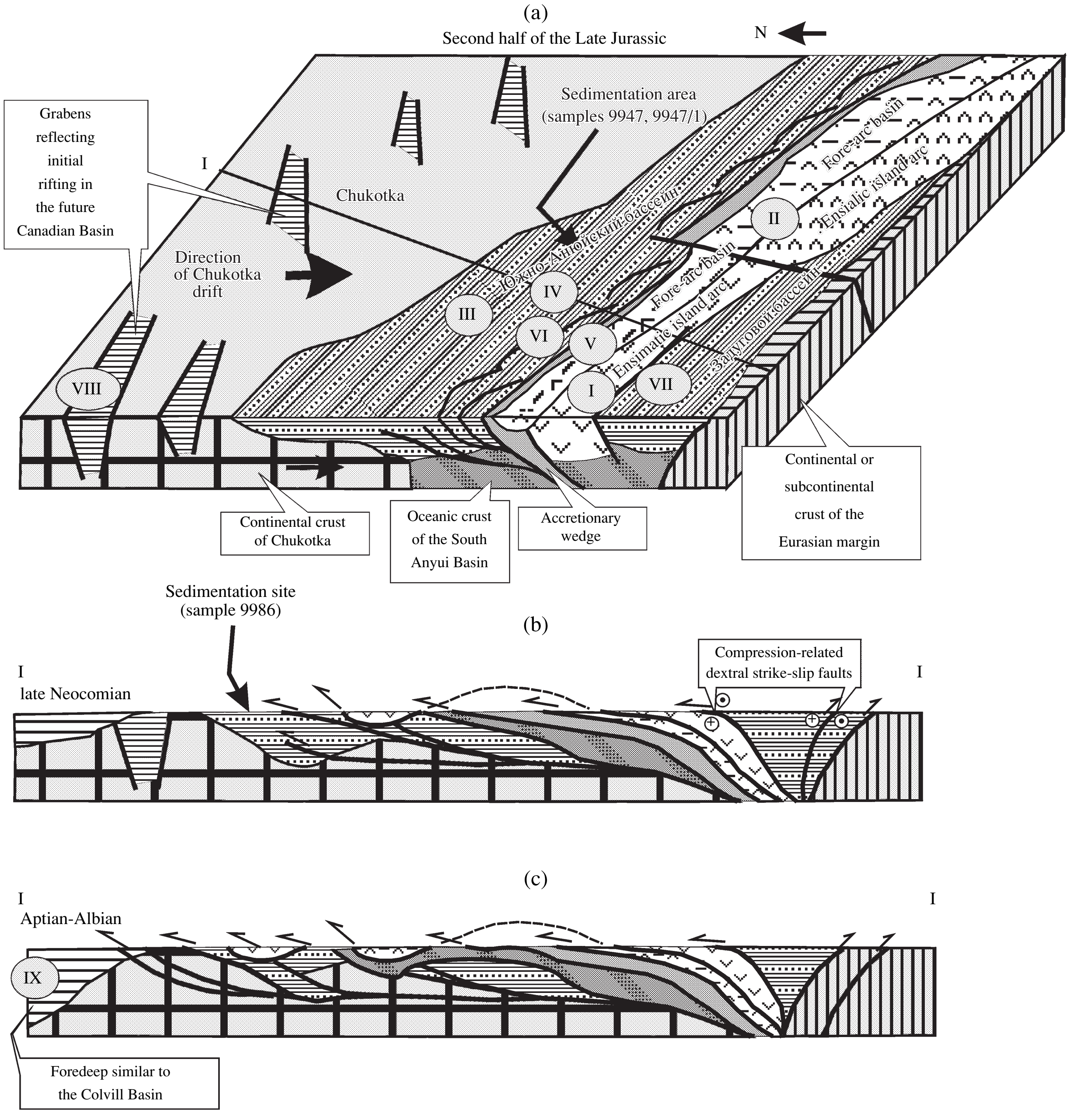
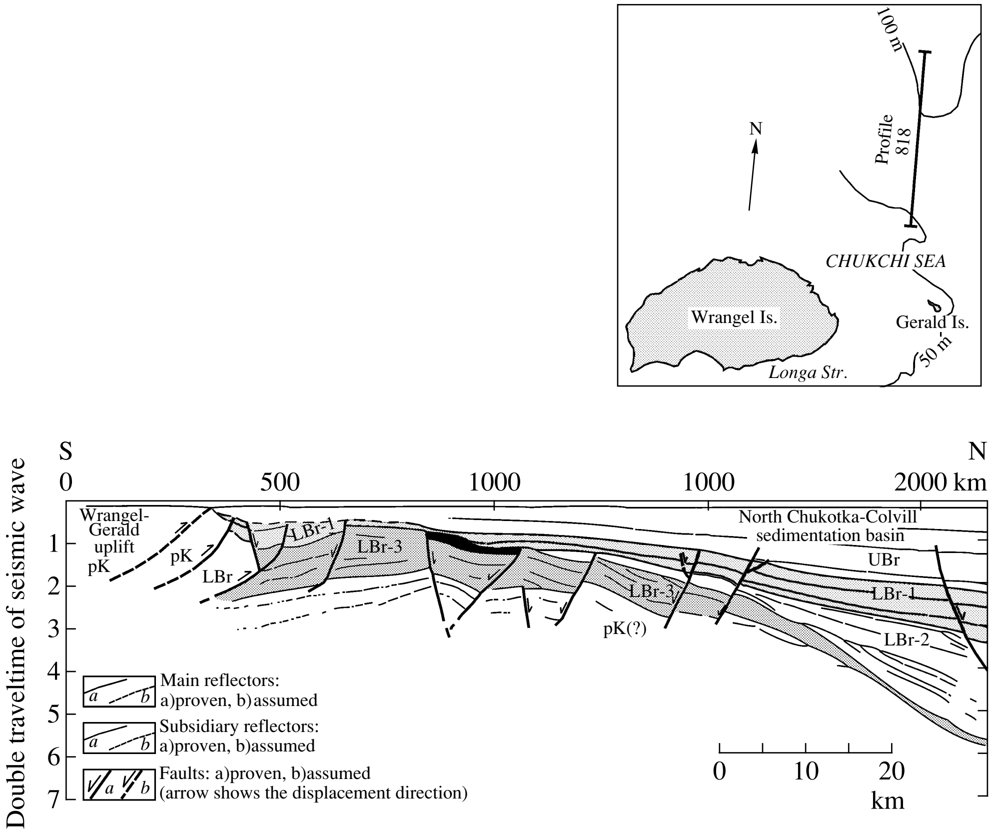


Fig. 9. Paleoreconstruction of the South Anyui basin and South Anyui suture zone for the Late Jurassic–Early Cretaceous. (a) Block-diagram demonstrating tectonic situation in the Yarakvaam segment of the South Anyui basin during the second half of the Late Jurassic; hypothetical profile I–I demonstrating tectonic situation in the (b) Neocomian and (c) Aptian–Albian. Roman numbers in circles correspond to those designating Upper Jurassic–Lower Cretaceous stratigraphic sections in Fig. 5.

sediments. A weak subaerial island-arc volcanism continued in the Alazeya–Oloi zone (Til'man, 1973; Parfenov, 1984; Bogdanov and Til'man, 1992). The Anyui–Chukotka foldbelt shows the presence of Berriasian–Valanginian autochthonous arkosic flysch complexes probably accumulated during regression of the opening Canadian basin (Grantz *et al.*, 1988, 1998; Embry, 1998).

Hauterivian-Barremian time. The peak of nappe formation was followed by the accumulation of coarse-grained sediments of the neoautochthon (Fig. 5, IV) that was also subsequently involved into the thrust structure. The front of tectonic thrusts probably reached the southern shelf of the Canadian basin (in modern coordinates) by the end of the Neocomian. Figure 9b



pK–Undivided pre-Cretaceous sequence
LBr–Undivided Cretaceous sequence
LBr-1–LBr-3–main seismostratigraphic units in the Aptian-Albian-Upper Cretaceous sequence
UBr–Undivided Paleogene sequence

Fig. 10. Geological–geophysical time section along seismic profile 818 in the western Chukchi Sea northeast of Wrangel Island (Grantz *et al.*, 1990). Inset shows location of the profile.

clearly shows deformations of Aptian–Albian sedimentary sequences in the Colvill basin of northwestern Alaska (Grantz *et al.*, 1988, 1994). As is seen in the central part of profile (Fig. 10), seismocomplex LBr, whose base corresponds to the Aptian, is underlain (without signs of unconformity) by a more ancient stratified seismocomplex of probably Early Cretaceous or Late Jurassic–Early Cretaceous age.

Terminal Early Cretaceous. According to (Grantz *et al.*, 1988), the Aptian-Albian interval was marked by an intense terrigenous sedimentation occurred in the Colvill and North Chukotka basins along the southern periphery of the Canadian basin (Fig. 9c). The fold–thrust structure of the South Anyui suture zone was almost completed by that time, and only low-amplitude reverse thrust and strike-slip displacements disturbed the normal attitude of Cretaceous and Paleogene strata. The southern part of the seismic profile in Fig. 10 shows that reverse thrust deformations of northern vergence disturb the attitude of Paleogene strata in the North Chukotka trough northeast of Wrangel Island (Grantz *et al.*, 1990).

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