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Ordovician intra-oceanic convergence in the Paleozoides of the Southern Urals

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The age of the volcanic complexes in the Southern Ural reflecting evolution of the intra-oceanic volcanic arc was estimated as the Ordovician by conodont biostratigraphy [2, 4, 5]. In the Sakmara and Sakmara-Voznesenka zones Ordovician volcanic rocks are represented by 3 types of assemblages, which compose nappes separated by serpentinite mélange. The depositional settings of these types were considered as (1) basin between passive continental margin and island arc; (2) intra-oceanic volcanic arc; (3) oceanic basin.

The first type, that is common in Sakmara zone and in the southern part of Sakmara-Voznesenka zone, is composed of arkoses (O_1t), siltstones, tuffites with basalt layers and sills (O_1a) and cherty tuffites (O_2l-O_3ash). Aphyric basalts of Kuragan Formation (O_1a) are referred to the tholeiitic series (AFM). The chondrite-normalized REE patterns are typical for N-MORB basalts. Primary mantle-normalized REE spider-diagrams show slight enrichment in Sr and other LILE and very slight depletion in Nb, Ta, Ti. We assume, that cherty tuffites were accumulated at the base of island arc.

The second type is also widely distributed in Sakmara zone and in the southern part of Sakmara-Voznesenka zone and represented by Guberlya and Baulus formations. In the northern part of the Sakmara-Voznesenka zone Guberlya Fm. occurs in small blocks within the serpentinite mélange of the Main Uralian Fault. Conodonts of the Guberlya Fm. are typical for the stratigraphic interval of *L. variabilis* to *P. anserinus* zones of the Lower Llanvirnian to Lower Caradocian. The Guberlya Fm. composed of picrites, aphyric and variolitic, basalts, high-Mg basaltic andesites, rhyolites, rhyolite tuffs and tuffites. Basalts belong to tholeiitic and calc-alkaline series. Two types of tholeites were recognized. The first type has low TiO_2 (0,87-1,56%), Al_2O_3(14,77-14-93%) and moderate percentage of alkalis (Na_2O+K_2O – 3,23-4,06%). The N-MORB-

normalized spider diagrams display slight enrichment of LILE (Rb, Ba, K, Sr) indicating MORB-type chemical affinity. The second type contains TiO_2 (1,63%-2,24%). The N-MORB-normalized spider diagrams show enrichment in LILE (Rb, Ba) and slight depletion in Ta and Nb. The obtained chemical data indicate OIB-type affinity. Calc-alkaline basalts vary in TiO_2 (0,87-2,2%), Al_2O_3 (14,43-14,92%), have high Na_2O+K_2O (3,39-5,6%). N-MORB-normalized spider-diagrams show enrichment in LILE (Rb, Ba, Sr) and depletion in Ta, Nb and Ti. The chemical data denote the IAB-type chemical affinity.

Conodonts of the Baulus Fm. are characteristic for the interval from $A.$ *tvaerensis* to $A.$ *ordovicicus* zones and are Caradocian – Ashgillian in age. The Baulus Fm. consist predominantly of basalts and basaltic andesites, dacites, rhyolites with minor amount of andesites, picrites and picritic basalts. The upper part of the sequence is represented by the volcanic massive sulphide (VMS) deposits (Yaman-Kasy, Blyava, Komsomol'skoe, Razumovskoe deposits). These ores contain vestimentiferan tubeworms, brachiopods and pelecypods of a wide age range. Thin layer of red cherts overlying the VMS deposits in the Blyava quarry yield the Caradoc–Ashgill conodont assemblage. It include *Dapsilodus mutatus* (Branson et Mehl), a transitional form of *Periodon* cf. *aculeatus* Hadding to $P.$ cf. *grandis* (Ethington), *Drepanodus robustus* Hadding, *Protopanderodus* cf. *liripipus* Kennedy, Barnes et Uyeno and *Panderodus* sp. Upward the section the beds of carbonaceous black shales occuring among the basalts of Blyava Fm. contain Llandoverian graptolites. At the Komsomolskoye deposit the cherts above VMS layer yield a similar conodont assemblage. Basaltoids are referred to the tholeiitic and calc-alkaline series. The chondrite-normalized REE diagrams consistently indicate an IAB nature. Spider diagrams show depletion in Ta, Nb, Ti, Sr and enrichment in LILE. We assume that Guberlya and Baulus formations reflect the evolution of the intra-oceanic volcanic arc (Guberlya arc).

The wide belt of the Ordovician Polyakovka Formation located in the northern part of the West Magnitogorsk zone. The cherty/basaltic complex (the third type of the rock assemblages) represents the upper part of the ophiolite association. The stratigraphic range, as estimated by conodonts, is middle Arenigian–Ashgillian [6]. Llanvirnian cherts contain redeposited Late Tremadocian *Loxodus bransoni.*

The Polyakovka formation includes low-Ti picrites, picritic basalts and basalts that are characterized by aphyric texture. Arenigian rocks have high TiO_2(2,2-4,2%) and can be refered to moderately alkaline trachybasalts. REE diagrams exhibit enrichment in LILE. These basalts are similar to rift olivinic basalts. Llanvirnian aphyric basalts have moderate TiO_2 (1,86-2,54%), low K_2O (0,26-1,47%) and high CaO (8,33-14,73%). REE trends are similar to tholeiitic with slight LREE-enrichment. The chemical data indicate N-MORB-type affinity. Llanvirnian chert/basalt sequence

associates with sheeted dyke complex. Fine-grained gabbroides of dykes have SiO_2 (41-46%), TiO_2 (0,95-1,21%), MgO (14,92-22,76%). On the N-MORB normalized diagrams they are enriched in Rb, Ba, La, Ce, Sr and Nd. REE patterns are consistent with tholeits with slight LREE depletion. Llandeilo-Ashgill volcanites are represented by basalts, basaltic tuffs with aphyritic and porphyritic textures. The chondrite-normalized REE diagrams show slight enrichment in LILE. These rocks display high K_2O (2,3%-3,5%) and TiO_2(1,9%-3,2%) and probably formed in within-plate oceanic environments.

The first type of the Ordovician rock assemblages is overlain by the Silurian Sakmara Fm. of black shales. The second and third types are covered by Llandoverian Dergaish (Blyava) Fm. of tholeiitic and calc-alkaline basalts, intercalated with black shales. Black shales of the Sakmara Fm. (U. Llandoverian-U. Silurian) overlap this section. In the Early Devonian (Emsian) island arc volcanism was displaced eastward (present-day coordinates) and the Magnitogorsk arc began its evolution.

Cessation of the Ordovician island arc volcanism and its displacement is connected with destruction of subduction slab and mantle diapir development. Mantle diapir made for H-T metamorphism. In the North Sakmara-Voznesenka zone metamorphism manifests in the garnet metagabbro with age 410 ± 5 – 414 ± 4 Ma [7]. In the Sakmara allochtone similar age – 415+8 Ma show the amphibolites in the foot nappe of the Khabarny ophiolite massive [1].

As evidenced by age and composition of the volcanic series of the Southern Urals the initial intra-oceanic convergence took place during the Ordovician after the opening of the Uralian Ocean.

This interpretation is in a good agreement with evolution of the Tagil arc of the Middle Urals Paleozoides. Age and composition of VMS-bearing complexes in the Tagil zone are similar to those in Baulus Fm. in the Sakmara zone. Evolution of the Guberlya island arc was terminated in Silurian time. During Early Devonian (Emsian) starts the evolution of the Magnitogorsk island arc that was collided in Late Devonian with the passive continental margin [3].

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