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During the last 12 thousand years the Udokan volcanoes erupted alkaline basalts and trachites. The strike of the fissure magma channels changed from NW to NE during the Middle Holocene in the interval of 7.9-4.6 thousand years ago. The Udokan volcanic activity was controlled by the structures of the northeastern segment of the Baikal Rift and of the western segment of the Olekma-Stanovoi Orogenic Belt. It is suggested that the outbreak of the young volcanism was associated with an impulse of NW compression in the upper crust of the Olekma-Stanovoi Belt, and that the attenuation of the volcanic activity occurred as the compression relaxed and changed to a dominant NW crustal extension, the stress pattern typical of the Baikal Rift.

INTRODUCTION

Changes in the extensional stress orientations were established to have occurred during the Late Cenozoic in the continental rifts of East Africa, Eastern Europe, Eastern China, the western USA, and Southern Siberia [2], [12], [13], [20], [23], [27]. Stress patterns changed rapidly in the structures of the East African Rift System during the Quaternary [21], [22], [26], [28]. In Southern Siberia, extensional stress was reoriented from NE to NW in the Udokan lava field at the NE flank of the Baikal Rift system. This reorientation has been established for the first time by changes in the orientation of Late Cenozoic dikes, slickensided surfaces, and fissures in the Late Cenozoic volcanic rocks and topographically expressed faults [9], [10], [12]. This paper presents evidence of the stress pattern of the upper crust in the Quaternary volcanic zone of the Udokan Range and of its change in a very short period of time during the Middle Holocene.

Changes in crustal tectonic stress orientations are usually established by changes in the spatial geometry of fissure magma vents. Dikes, fissure volcanic edifices, and dike systems are usually oriented on central-type volcanoes in the directions of the maximal compressional stresses of the regional stress field [25].

The young volcanic edifices of the Udokan Range originated in an arc-shaped Quaternary volcanic zone 20 km long [5], [11]. Alkaline olivine basalt and hawaiite lavas flowed on both flanks of the zone. Under its central part and NE flank, basalt magma underwent differentiation, and benmoreites and trachites were erupted. The Early Pleistocene volcanic activities began with the successive flow of trachite, mugearite, and hawaiite lavas on the NE flank of the zone. The K-Ar dating [15] indicated that the valley benmoreite and trachite lava flows and one of the extrusive trachite lava domes, as high as 2067 m, had been produced during the Middle Pleistocene 0.48-0.38 million years ago. The young Late Pleistocene and Holocene volcanic structures, distributed in the central and NW parts of the volcanic zone were placed into the interval of 12 050 to 2100 years ago by the radiocarbon dating of wood fragments that had been buried during the eruptions [3], [18].

ORIENTATION OF MAGMA-CHANNELING VENTS

On the Early-Middle Pleistocene volcanoes of the Quaternary volcanic zone, most of the vents are buried under the lava flows and are poorly known thus far. On the Late Pleistocene-Holocene volcanoes, the vents are well delineated by the products of eruptions and are partially exposed by erosion. Their spatial positions suggest two episodes in the development of young volcanism: (1) an episode 12-7.9 thousand years B. P. with the NW orientation of the vents and (2) an episode 4.6-2.1 thousand years B. P. with the NE orientation of the vents (Fig.l).

The interval of 12-7.9 thousand years B. P. was marked by eruptions at the western flank and in the central part of the zone of Quaternary volcanism. Alkaline olivine basalt lavas flowed on the Khangura and Syni volcanoes, dated 8160+120 and 9240 + 120 years, and trachite lavas flowed on the Trakhitovyi (12 050+650 years) and Dolinnyi (7940 +110 years) volcanoes.

The Syni and Khangura volcanoes are characterized by the interbedding of pyroclastic deposits and basalt lavas. The NW-striking fissure of the Syni volcano dissected two adjacent glacier cirques. The fissure is 1200 m long. The lava flowed from the cirques to the valley of the Syni River and flooded it. On the Trakhitovyi volcano, eruptions occurred in a glacier cirque located 300 m above the floor of the Syni valley. The slope of the valley was first covered by a layer of cherry-red trachite ignimbrite, 1.5-2 m thick. The next layer with a thickness of 10-12 m consists of red uniform cinder. Thereafter, plagioclase trachite lava flowed. A crater 150 m across was produced in the glacier cirque during the closing phase of the explosive activity. The NW strike of the trachite channeling vent is accentuated by the distribution of the lateral eruptions on the slope of the valley NW and NE of the crater. Two explosion craters were formed along the NW-striking trachite channeling fissure.

During the interval of 4.6-2.1 thousand years B. P. volcanic activity was concentrated in the central part of the volcanic zone, where eruptions occurred on the Aku volcano 94620+100 years) and on the Chepe volcano (2230+50 to 2100±80 years).

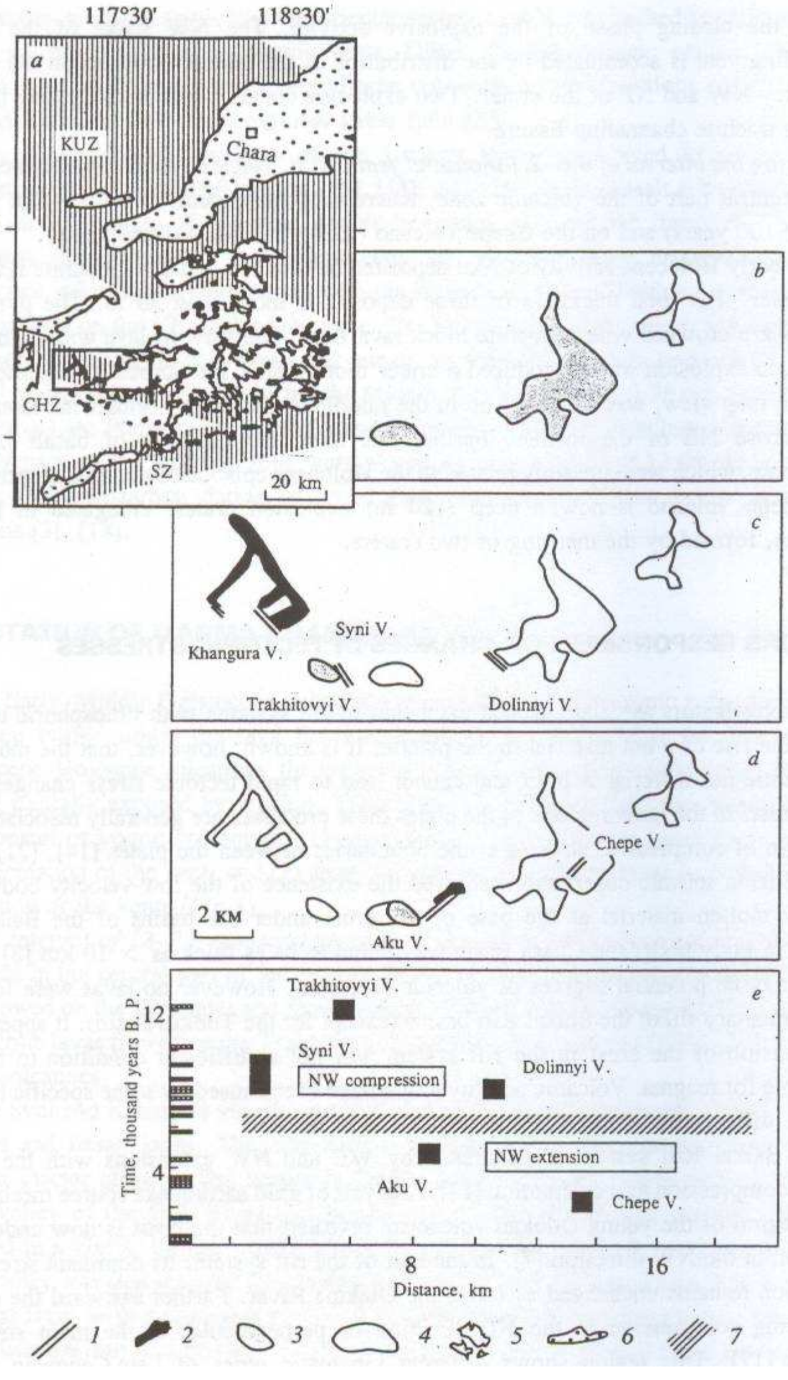
The early Holocene activity of Aku deposited beds of red and black trachite ignimbrite and cinder. The total thickness of these deposits is more than 30 m. The pyroclastic deposits are crowned with a trachite block lava flow. The flow of lava was followed by a volcanic explosion which produced a crater more than 1 km across. A trachite dome, round in map view, was squeezed up in the middle of the crater. Somewhat later a new crater arose NE of the former. Farther NE there are outcrops of basalt lava and agglutinate, which were possibly related to the Holocene episode of the Aku eruptions **[5].** The Chepe volcano is now a deep (120 m) explosion crater, elongated in the NE direction, formed by the merging of two craters.

FACTORS RESPONSIBLE FOR CHANGES IN TECTONIC STRESSES

Many investigators associate crustal extension in rift systems with lithospheric thinning during the rise of a hot material in the mantle. It is known, however, that the movement of a mantle hot material is inert and cannot lead to rapid tectonic stress changes in the upper crust. In the inner regions of the plates these processes are generally associated with the origin of compressive stresses at the boundaries between the plates [14], [21], [23].

Explosion seismic observations showed the existence of the low-velocity bodies of a partially molten material at the base of the crust under the basins of the Baikal Rift system. A body under the Chara Basin was found to be as thick as > 10 km [8]. These bodies may be potential sources of volcanic eruptions. However no lavas were found in the sedimentary fill of the Baikal Rift basins (except for the Tunkin Basin). It appears that the extension of the crust in the rift system was not a sufficient condition to make it permeable for magma. Volcanic activity might have been caused by some specific tectonic stresses, different from the regional stress field of the rift.

The Baikal Rift system is dominated by WE and NW extensions with the nearly vertical compression axis orientation [17]. Analysis of mild earthquake source mechanisms in the region of the young Udokan volcanism revealed that the crust is now undergoing extension in the NW direction [7]. In the east of the rift system, its dominant stress axes orientation remains unchanged as far as the Olekma River. Farther eastward the crust is undergoing compression in the NE direction or perpendicular to the main structural elements [17]. This region shows different kinematic types of Late Cenozoic faults, including thrusts and strike-slip faults that


117°30'
118°30'
a
KUZ
Chara
56°40'
CHZ
56°00'
SZ
20 km
b
c
Syni V.
Khangura V.
Trakhitovyi V.
Dolinnyi V.
d
Chepe V.
2 км
Aku V.
e
Trakhitovyi V.
12
Syni V.
NW compression
Dolinnyi V.
NW extension
4
Aku V.
Chepe V.
Time, thousand years B. P.
8
16
Distance, km
1
2
3
4
5
6
7

arose as a result of the NW compression of the crust [6]. This region is situated within the Olekma-Stanovoi orogenic system which originated as a result of a collision between the Izu-Bonin arc and the Honshu arc [14].

In the region of the Udokan Range the structures of the northeastern Baikal and western Olekma-Stanovoi mobile systems spatially overlap one another. The K-Ar dating of rocks from the Udokan lava field [15] showed that this volcanic activity had been controlled not only by the structures of the northeastern flank of the Baikal system, but also by those from the western flank of the Olekma-Stanovoi system. The first eruptions of ultrabasic alkaline lavas occurred in the north of the field ~ 14 million years ago simultaneously with beginning of the extension and subsidence of the Chara Basin in association with the reactivation of the Kodar-Udokan structurally weak zone of the Aldan Shield. The Chara Basin and several small basins, located in this zone, belong to the Baikal Rift system. The subsequent eruptions of trachites and alkaline basalts shifted southward and occurred during three reactivation episodes of the Chukchuda and Stanovoi weak zones: 9.6-7.4, 4.0-2.6, and 1.8-0.002 million years ago. The reactivation of the latter two weak zones reflected pulsatory compression in the Olekma-Stanovoi system. The extension impulse at the northeastern flank of the Baikal system, which was accompanied by volcanism, was repeated 3.2-2.4 million years ago.

Proceeding from the general spatial-temporal distributions of eruptions in the Udokan volcanic field, the volcanism of the last 12 thousand years must have been controlled in a large measure by the tectonic activity of the Olekma-Stanovoi system. One can see in Fig. 1 that its NW compression was the dominant stress in the zone of young volcanism 12-7.9 thousand years ago. A change in the stress pattern of the volcanic zone in the later half of the Holocene to a rift pattern points to the attenuation of the NW compression in the Olekma-Stanovoi system.

The young volcanic cones of the Udokan Range are arranged along the same Quaternary arcuate volcanic zone, comparable in its size and the duration of lava eruptions with the long-lived volcanic centers of Kamchatka and other regions of recent volcanism [1]. The Early Pleistocene young "valley" lava flows on the NE flank of the volcanic zone are partially buried under

Figure 1 Model for the evolution of Quaternary volcanism on the Udokan Range: *1* - spatial orientation of fissure magma vents, 2 - alkaline basalt lava, 5 - benmoreite and trachite lavas, *4* - lava outliers of previous eruptions, *a* - boxed area is location of Quaternary eruptions; 5 -outliers of the Udokan lava field; 6 - rift basins; 7 - structurally weak crustal zone; KUZ -Kodar-Udokan zone; SZ - Stanovoi zone; CHZ - Chukchuda zone [15]. *b, c, d*- 480-380,12-7.9, and 4.6-2.1 thousand years ago, respectively, *e* - age variations of young volcanoes along the W-E trending zone of Quaternary volcanism, *8* - Middle Holocene variations of magma vent orientations in association with a change from the NW compression of the upper crust to its NW extension. Plotted on the time scale are dates of paleoseismic dislocations in the central part of the Baikal Rift system after [4], [19], and [24].

Quaternary alluvium. It appears that after the attenuation of volcanic activity from the end of the Early Pleistocene to the Holocene this part of the territory was subsiding, the magnitude of subsidence being a few tens of meters. The later eruptions in the central and NW segments of the volcanic zone were accompanied by the uplift of the territory. As a result of these movements the recent river valleys grew 2-4 and more meters deeper relative to the base of the Middle Pleistocene and Late Pleistocene-Holocene lava flows [11]. It appears that the spatial-temporal stress variations in the upper crust under the flanks of the long-lived Quaternary arcuate volcanic zone were not only controlled by regional stress variations but also reflected to a certain extent the subsidences and uplifts of the crustal material above deep-seated magma reservoirs.

CONCLUSION

All of the dated paleoseismic movements of the Baikal Rift system occurred during the last 12 thousand years (Fig. 1) [4], [19], 24]. The same time interval was marked by volcanic activity not only on its NE flank (Udokan Range) but also on its SW flank (Eastern Sayan Range) [16]. It appears that the intensification of tectonic activity at the end of the Pleistocene and in the Holocene served as a trigger for volcanic eruptions.

The Udokan lava field is situated in the region of the spatial superposition of the strain field of the northeastern Baikal Rift system and that of the western Olekma-Stanovoi orogenic system. The established Middle Holocene change in the trends of the fissure magma vents proves that the new outbreak of volcanic activity was caused by one of the compression impulses in the upper crust below the Olekma-Stanovoi system. Volcanism attenuated as compression was relieved and replaced by NW extension characteristic of the Baikal system.

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