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Risk assessment of dangerous Aeolian processes within the Baikal rift zone

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Risk assessment of dangerous Aeolian processes within the Baikal rift zone

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Abstract. Among dangerous natural processes in the Baikal region we emphasize aeolian processes of high intensity which is due to dust storms caused by hurricane winds. The factors of the process development were studied, and special attention was paid to the wind regime and seismic activity, as well as to the catastrophic consequences and damage. We analyzed the number and duration of dust storms, calculated the deflation potential of the wind and the energy of the air flows. The morphology of aeolian relief forms, both deflationary and accumulative was studied. We forecasted sand dune drifts based on the analysis of the charted sand rose. Differences in structure, mechanism, and intensity of the processes are revealed depending on the hydroclimatic conditions during the monitoring period. In connection with global climate change, which is manifested in the Baikal region by an increase in the number of arid years of observations (35%), and the frequency of emergency situations associated with natural processes increases. It is necessary to continue the monitoring of aeolian processes in order to create long-term and short-term forecasts to avoid catastrophic consequences.

1. Introduction

The risk of natural emergencies in the Lake Baikal basin is caused by a complex of natural processes: geomorphological - landslides, debris, mudflows, water erosion, aeolian processes; atmospheric - dust storms and hurricanes; and hydrological – elevation of the water mirror, etc. Although aeolian processes are not among them, the scale and intensity of their manifestation demonstrate their high danger. Consequences of their activity, especially dust storms, can be significant and significantly disrupt the vital activities of the population, since the living conditions and production activities of people are deteriorated due to heavy air pollution.

Evaluation of the territories of Cisbaikalia at risk of emergencies of natural and man-made disasters was carried out by V.M. Plyusnin and I.N. Vladimirov [1]. The purpose of our research is territorial characteristics of the risk of dangerous aeolian processes during dust storms. A comprehensive analysis of natural and anthropogenic factors and the mechanism of deflation and dynamics had to be carried out for that purpose.

2. Models and Methods

The aeolian processes play an important role in relief formation of Cisbaikalia. The Baikal link is the northernmost in the Central Asian morphodynamic system of the aeolian cycle of matter. The study of the functioning of climatic and geomorphological systems at the regional level was carried out by stationary and route methods on the southwestern coast of Baikal since 2000. Long-term observations of the processes of exogenous relief formation allowed establishing regional patterns of geomorphological regimes, and seasonal rhythm and dynamics. The studies were carried out using

different field experiments, various methods and tools (benchmarks, dust collectors of various designs, etc.), analysis of cartographic material, aerial photographs and satellite images. For different regions of Cisbaikalia, certain processes with an inherent type of risk and distribution nature are characteristic.

3. Results and Discussion

The aeolian processes are most actively manifested in the steppe and forest-steppe landscapes of the Olkhon district, the western coast of Olkhon Island, and the mouth of the Goloustnaya river (Figure 1).

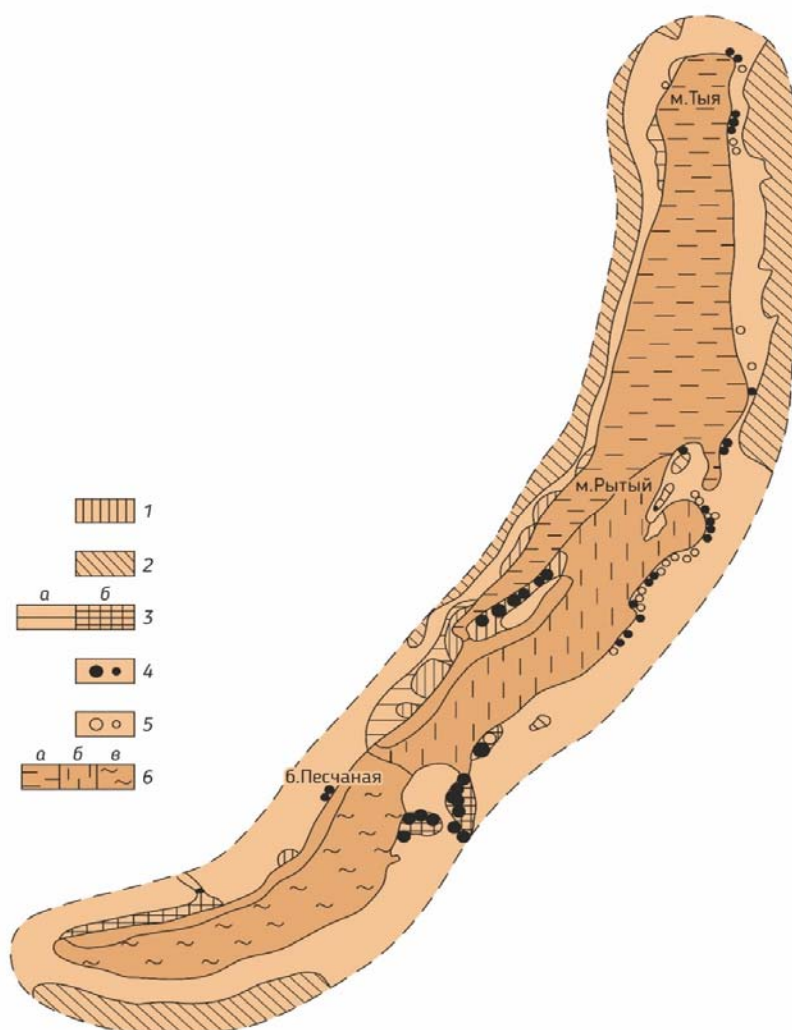


Figure 1. Aolian processes in the Lake Baikal basin.

Deflation (areal): 1. most intense (steppes); 2. intense (golets); 3. weak (mountain forest belt with sparse forests and anthropogenic disturbances).

Accumulative aeolian forms (sand dunes): 4. with active deflation of sandy material; 5. potential; 6. areas of accumulation of aeolian material at the bottom of Baikal [2] with an average speed ($\mu\text{m}/\text{year}$): a) 1.5; b) 1.8; c) 10.6.

The distribution and intensity of aeolian processes depends on two leading factors - wind regime and earth's surface without or with a reduced vegetation cover. The Baikal basin is characterized by

a complex system of winds. Here, longitudinal, transverse, mountain-valley and breeze winds are observed. They are associated with global and local circulation of air masses. So, the main longitudinal winds are the 'Verkhovik' (upper) wind (north and north-east) and 'Kultuk' which blows from the southern point of Baikal towards the north. The strongest transverse winds, short-term in duration, are the northern and northwestern ones (the local name 'Gornaya' (mountainous)), formed due to the breakthrough of cold air masses through the narrow valleys of the Primorskii Range. 'Gornaya' is characterized by exceptional gustiness, it always blows across the lake and in comparison with other Baikal winds has the greatest duration, namely from August to December. The wind reaches its particularly high force (40 m/s) in the valley of the Sarma river (the local name of the wind 'Sarma') and in the valley of the Goloustnaya river (local 'Kharahaikha' or 'Tarkhaikha'). These winds are called often "Baikal'skaya bora". According to T. T. Taisayev, because of the very same desiccating mountain wind - the Sarma - those dry stony steppes appeared with hollow-ridge relief, with basins of blowing, with sulphate lakes along the western coast of Baikal. [3].

All catastrophes on Lake Baikal took place in the winds of the northwestern quarter. From October 14 to 15, 1901, near the Cape Kobylia Golova, due to the strong wind of 'Sarma', a shipwreck occurred on Lake Baikal, 176 people from the ship "Potapov" have sunk. [4]. By the same occasion the death of the research ship "Shokal'skii" should be attributed which occurred on the morning of August 2, 1983 near the cape Krasnyi Yar, one kilometer from the coast in front of numerous eyewitnesses. Against the background of a strong 'Gornaya' wind on the water with the simultaneous action of other longitudinal winds, and an extremely rarely observed tornado, the vessel had been turned over. For some time it kept afloat upward with a keel, making circular movements until it sank. The wind speed at the same time reached 40 m/s [5]. In the valley of the Bugul'deika river the northwestern mountain wind of destructive force is retained up to 4 days. The wind carried dust and small pebbles and knocked people down. During the period when the 'Bugul'deika' blows, the cattle are not driven out to pastures. 'Shelonnik' blows from the east to the northwest coast; 'Barguzin' crosses the lake basin from the northeast to southwest, from the Barguzinskii bay to the Olkhon Island. Within the basin, wind speeds are higher in the Middle and Southern Baikal, which is associated with the predominance of cyclone and rear invasions in the southern and middle parts of the lake and with a greater degree of orographic protection of the northern part of the basin. During a year in the Baikal region the number of storm days reaches 65-73 and in the area of the Goloustnaya delta it averages 52 days.

The eroding ability of wind is determined by the action of wind loads on the soil surface. The energy of the air flow acting on the underlying surface during the deflation-dangerous period (April, May, and June) was calculated. At the same time, the wind speed was taken into account according to the gradations from critical for zonal soil to the maximum possible; as well as the duration of wind in each gradation of speed. The destructive energy of the flow E_p corresponds to the energy difference at a given speed V_i within a certain range and critical speed V_{cr} . The mathematical relationship for calculating the flow energy was proposed by A.N. Sazhin (1995) and has the form:

$$E_p = 0.625 (V_i^3 - V_{cr}^3) t,$$

where t is the flux exposure time [6]. The critical wind speed for chernozems and chestnut powdery-carbonate gravelly soils of the steppe landscapes of the mouth areas of the Goloustnaya, Bugul'deika and Sarma is 10 m/s. Wind energy reaches its highest value in the spring in the Sarma region (Table 1).

Table 1. Airflow energy (J/m²) during the period of dust storms

Weather station	Average data		
	April	May	June
Bolshoe Goloustnoe	141 10 ⁶	29 10 ⁶	22 10 ⁶
Sarma	214 10 ⁶	172 10 ⁶	29 10 ⁶
Khuzhir	896 10 ⁶	226 10 ⁶	22 10 ⁶

In addition, the deflationary wind potential or wind loads (r_j) were calculated using the equation

$$r_j = 0.01 V_i^3 f_i,$$

where V is the average wind speed in velocity group I, f is the duration expressed as a percentage of the total observation period in the j direction and speed group i . Wind loads for each month were represented as the sum of the corresponding values for each direction (eight points). The annual deflationary potential was summed up by months. It varies in Cisbaikalia from 60-100 and more (Table 2). For example, wind loads on the western coast of Lake Baikal have changed in recent years as 74 (Khuzhir), 117 (Bol. Goloustnoe), 84 (Sarma) in 2016, and 82, 91, 93, respectively in 2017. The high deflationary wind potential indicates active relief-forming wind activity. In the annual load mode, there are three seasonal peaks: winter (December-January), spring (April, May) and early autumn (September).

It is in April-June when dust storms are formed, this period is the most deflation- dangerous (Table 3). The strongest and most erosion-dangerous short-term northern winds in terms of duration are the northern and northwestern ones. During the monitoring period, the deflation potential of the northwestern winds reached 10–14. Weak wind loads are typical for the late winter period (February-March), summer period, especially July and for October. In July and August, eastern winds dominate with weak eroding ability (r) from 0.01–0.02 to 1–2. During this period, local Baikal anticyclones are formed over Lake Baikal.

Table 2. Climatic characteristics that determine the development of aeolian processes in Cisbaikalia during the monitoring period of 2000-2017

Climatic Conditions (Moisture)	Precipitation, mm	Mean Annual Precipitation, mm	Mean Annual Wind Speed, m/s	V_{\max} m/s	Climate Coefficient of Erosion (C)	Amount of Dust Storms (N)	Wind deflation potential (r_j)
Bolshoe Goloustnoe							
Humid	more than 300	324	4.0	25	7	0	91
subhumid	250-300	274	3.6	27	10	3	82
dry	less than 200	193	3.9	27	13	4	109
Sarma							
humid	more than 250	268	2.9	31	3	0	93
subhumid	150-200	198	2.8	34	7	0	105
dry	less than 150	133	3.1	29	9	1	117
Khuzhir							
humid	more than 250	279	3.5	27	9	3	79
subhumid	150-200	188	3.5	29	13	4	58
dry	less than 150	110	3.4	25	24	6	85

Table 3. Average monthly deflation potential of wind in the deflation-dangerous period of the year

Station	Wind deflationary potential Months of the year		
	April	May	June
Bolshoe Goloustnoe	6.4	9.2	4.2
Sarma	8.7	9.6	2.1
Khuzhir	5.7	6.2	3.0

The occurrence of dust storms is associated with strong winds. Annually 1 to 4 dust storms are recorded near Bolshoe Goloustnoe and Khuzhir in spring and summer. Dust storms can last from several minutes to several hours, but sometimes, e.g., in Khuzhir in 2015, a dust storm lasted 2 days and 4 hours. In some years, if the snow cover is thin and there are some foci of deflation, dust storms and dust drifts are observed even in winter (in November and December). In Sarma, although the energy of the air flow is high for the study area, dust storms are rarely observed, which is explained by the presence of debris pavement on the soil surface, which prevents it from deflation. Thus, in the study area, strong winds blow associated with global transport and local circulation for about a third of the year.

The number of dust storms correlates with climatic indicators. The climate index is the most important indicator for determining the potential danger of aeolian processes. When calculating it, the average annual wind speed V , annual precipitation H , average annual air temperature, associated with

$$C = 10^2 V^3 / (H/T + 10)^2 [7],$$

were taken into account. In the western Cisbaikalia, in humid years deflation is relatively moderate (C less than 10), in semi-humid and semiarid - strong (C 10-15), in arid ones - very strong (C more than 15).

The active influence of wind flows on the geosystems of the Baikal coast cause the formation of aeolian facies, both deflationary and accumulative [8]. The west coast of the lake is characterized by the dominance of deflation processes. Wind denudation has here an areal character. When a loose cover is disturbed, the fine earth is quickly swept away by wind and re-deposits on the surface of the coastal plain. The deflation of sandy strata and the formation of moving aeolian forms are characteristic of the western coast of Olkhon and the eastern coast of Baikal, where blowing basins, deflation residues, dunes and sandy covers occur (Figure 2), as exemplified by Peschanoye Stow, located 20 km north of Khuzhir and known for its sand dunes, hills and ridges, which occupy an area of about 3 km².

These are the largest sand deposits in area, not only on Olkhon Island, but also on the whole western coast of Baikal. Sand drift is directed to the southwest or southeast, as evidenced by the annual sand roses, dominated by the winds of the north quadrant bearing from the northeast or northwest. The sand roses were charted according to the method developed by S. G. Fryberger [9, 10]. On the edge of the forest, where the sand breaks, you can find stilted trees that rose 30-40 cm above the sand on their roots.

When wind blows from the lake to the land, loose material moves onto the slopes of the Primorskii Range. In the converse case, the smallest particles are carried away and deposited on the water surface. An experiment conducted near the Akademicheskii Range showed that the suspended substances in snow of the aeolian winter transport have 45% particles from the rocks of the western coast. Wind drift into the lake is 3.6 microns/year. Aeolian flow consists of dust and sand. Pelite and silt particles dominate. Larger sand particles move by saltation with the surface stream. During wind transport, material is sorted by size, shape, and specific gravity of particles. Large and heavy particles remain on the surface of deflated sediment, covering the surface and protecting it from further dispersal. The mineral composition of the suspension is dominated by an aluminosilicate substance containing the main rock-forming elements. The dust storm material is enriched with phosphorus, nickel, cobalt, etc. During an aeolian event (a dust storm), the wind flow behaves selectively: deflation dominates in some areas, and accumulation dominates in others. As a result, there is a change in the microrelief of the earth's surface. The aeolian accumulation on the experimental sites in humid years was less than 50 g/m², in moderately wet 50-100 g/m² and in arid 100-500 g/m².

Conjugated analysis of the climatic features of the southwestern Cisbaikalia and exomorphogenesis showed that exogenous relief-forming processes are closely associated with processes similar in dynamism in the air and water systems. Natural processes on the mountain slopes are closely associated with the lake basin. It is the conjugate development of natural processes that determine their dynamics and features of development. In addition, natural processes occur under tectonic instability. Cisbaikalia is a significant part of the Baikal rift zone, which belongs to the most earthquake-prone regions of Russia. About 9 thousand earthquakes per year are recorded here, the possible maximum intensity of

earthquakes is 9-10 points, the acceleration of the ground oscillations is 400-900 cm/cm², the ground oscillation velocity is 55-180 cm/s, the amplitude of the soil oscillations is 20-80 cm and the area of simultaneous tremors is from 0.1 to 8–20 km² [10]. One of the largest recent earthquakes was Kultukskoe (M 6.2) on the Southern Baikal on August 27, 2008. It is considered a clear manifestation of the contemporary activity of the Baikal rift. It happened on the Southern Baikal, it was connected to the southeast end of the Main Sayan Fault. Tangible tremors spread over a vast area. The most affected settlements were Kultuk, Utulik, and Slyudyanka. Numerous debris, landslides and rockfalls are noted in the mountains and on steep slopes. Eyewitnesses, who were in the nearby woodlands, felt strong shaking of the soil, accompanied by the swaying of trees and the swing of high grass. High seismicity affects the intensity of exogenous processes of relief formation, which locally and briefly can have a catastrophic manifestation [11]. The nature of the impact of earthquakes on the earth's surface can be pinpoint, linear and areal. In the latter case, the seismic event is usually accompanied by large-scale gravitational effects causing massive movements of disintegrated rock material across the earth's surface, which have a damaging effect on it, its elements, including structures and human beings, even if the earthquake epicenter is located remotely.

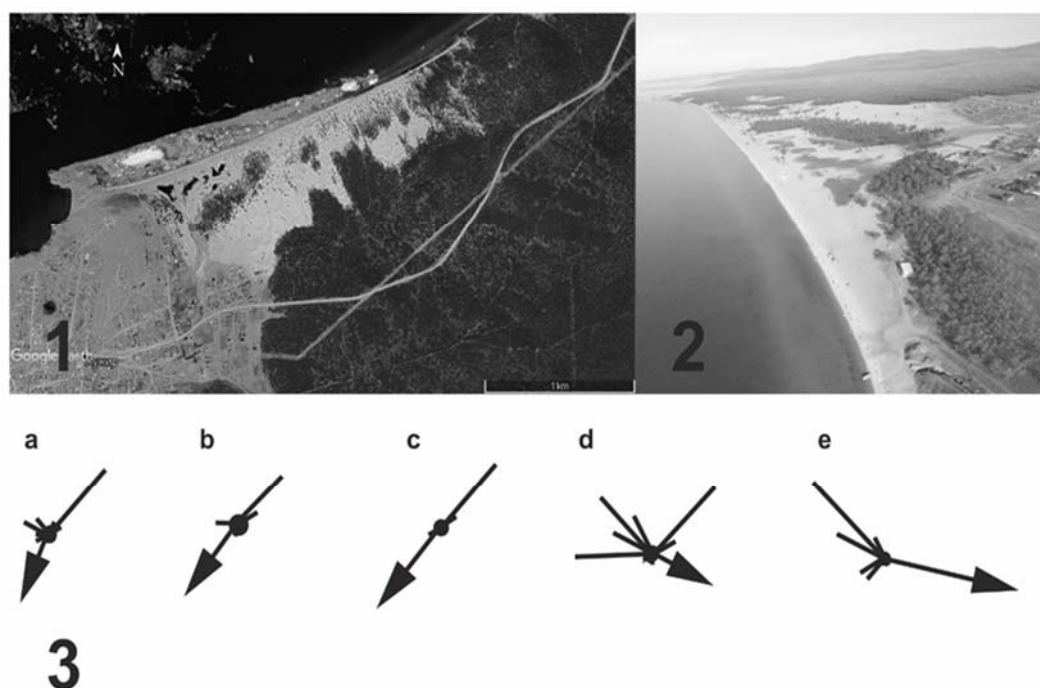


Figure 2. Dunes along the coast of the Sarayskii Bay

1. Satellite image (Google Earth, 2019);
2. Picture (photo credit by S. Makarov, 2018);
3. Sand roses of the monitoring territory during the deflation threatening period in 2013:
 - a – April: $DP = 74$, $RDP = 23$, $DP/RDP = 0.3$;
 - b – May: $DP = 39$, $RDP = 22$, $DP/RDP = 0.6$;
 - c – June $DP = 47$, $RDP = 34$, $DP/RDP = 0.7$;
 - d – September $DP = 142$, $RDP = 23$, $DP/RDP = 0.2$;
 - e – December $DP = 176$, $RDP = 80$, $DP/RDP = 0.5$, where DP – drift potential, RDP – the resultant drift potential, DP/RDP – index of the directional variability of the wind (Fryberger, 1979).

The spectrum of exogenous relief processes in Cisbaikalia is determined by the climatic conditions of observation years. According to climatic features, the monitoring years were classified in Table 2. In

the last 20 years, lukewarm subhumid (37%) and dry years varying in the heat degree (29%) are most often repeated. Cold very dry years were observed once in the last 20 years. Thus, in the Cisbaikalia within one denudation cycle for the last 20 years, semi-humid states predominate. This phase is characterized by the development of water erosion and aeolian processes of moderate intensity. When the humidification decreases (climatic coefficient of erosion less than 10), semi-arid states manifest themselves. In these years, the probability of anomalous and extreme manifestations of aeolian processes is very high. Deflation is observed on emergent landforms (brows and turfed surfaces of convex slopes, vertex areas, non-deserted dunes in the coastal zone, etc.). Blowing of sand is from a few millimeters to 1-10 cm and more.

Humid states occur in 1% of cases, they form in extremely wet years, when the fluvial processes are dramatically activated. Thus, when on August 10-11, 2016 heavy rain brought in Cisbaikalia 60 to 110 mm precipitation with a maximum intensity over the interval of 0.48-0.65 mm/min, and this fact led to the formation of temporary streams and even mudflows. In Cisbaikalia a trend of modern climate warming has been reflected in accordance with the global temperature growth, and an increase in the mean annual temperature at a rate of 0.45°C over 10 years has been observed. This trend is insignificant (1.2%/10 years) with a contribution to the dispersion of 2%.

To determine the activity of modern exogenous relief-forming processes, we conducted an experiment. Debris material was annually removed from the key sites on a slope. According to the newly emerged rotted rocks and rubble, we can judge the intensity of matter movement. Thus, in 2008 (the maximum manifestation of tectonic activity during the observation period) the number of debris appeared was maximum (1670), whereas in relatively tectonically calm conditions it was 500–1000 (Table 4). Migration of matter within the plain contributes to the reduction of bond strength between particles of loose material as a result of seismic activity. Surface deposits with a thickness of 1–5 cm are characterized by maximum dynamism. Removal of fine earth by deflation and erosion leads to sandy soil and covering with rubble.

Table 4. The size and amount of detrital material collected from the key site on the slope of the Podkamennaya mountain near the settlement of Bolshoe Goloustnoe

Fraction size, mm	Years												
	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
1–5	150		167	125	132	145	117	366	524	815	902	120	127
	1		0	0	7	8	6					8	3
6–10	667	432	312	300	181	406	151	147	140	288	144	676	272
11–20	246	123	51	154	73	94	60	102	66	61	55	197	186
21–50	10	19	23	51	22	10	16	27	17	12	18	13	30
51–100		1		3								1	

Along the aeolian processes, the appearance of detrital material on the key sites is facilitated by water erosion. Over the summer, about five cases of erosion hazardous showers with precipitation of 10 mm each and an intensity of more than 0.1 mm/min are observed in the study area. Usually, once a summer, there is a shower with a sum of precipitation exceeding 20 mm and an average intensity of 0.1-0.5 mm/min. The most erosion threatening are heavy rainfalls with a sum of precipitation of more than 30 mm and an intensity of more than 1 mm/min, but they are rare.

4. Conclusions

Thus, the fine earth is removed by water and wind, and the surface of the slopes is “armored” with debris. The seismic environment and anthropogenic pressure (overgrazing and high recreational load) contributes to the intensification of the matter movement within the plain.

As can be seen from the above, the analysis of natural factors, the number of dust storms, the climatic deflation index, the deflationary potential of the wind, and its energy allowed to establish their chorological and temporal dynamics of processes, relationship between natural phenomena and processes, and hence to predict their geomorphological danger. The active development of modern relief-forming processes contributes to an increase in the matter migration to Lake Baikal and, to a certain extent, to the aggravation of the ecological situation. Besides, the physical characteristics of aeolian deposits, topographical, climatic and environmental conditions enhance sand dune drift in various places of the study area, which requires special attention and control.

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