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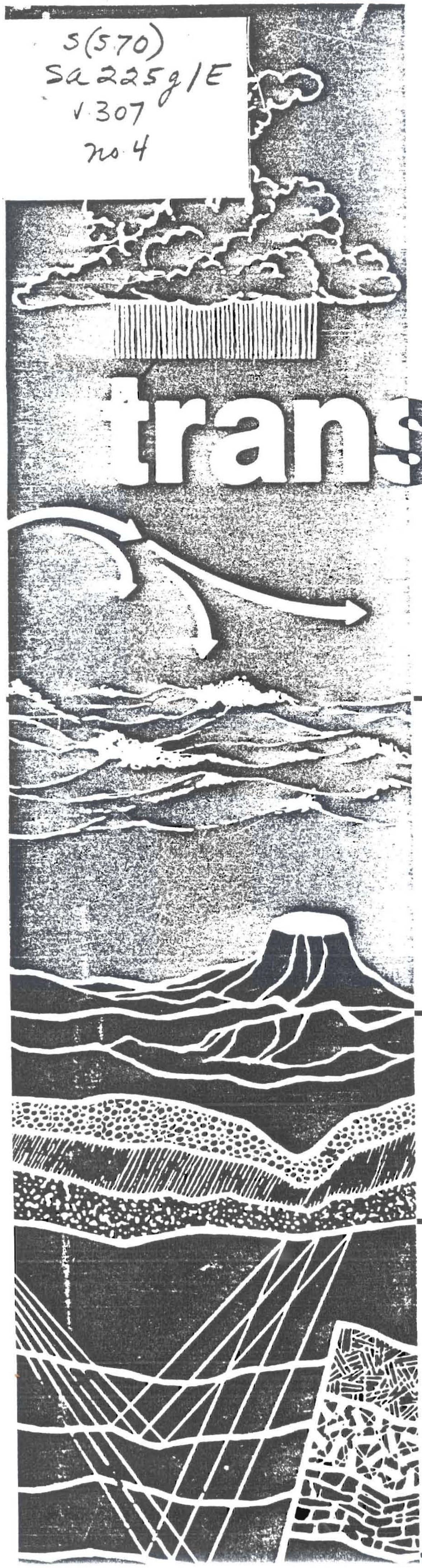

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ASSOCIATION OF ENDOGENOUS MINERALIZATION WITH EARTHQUAKE-PRONE INTERSECTIONS OF LINEAMENTS[1]

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(Presented by Academician M.A. Sadovskiy, January 27, 1988)

We shall investigate the lateral correlation between earthquake-prone sites and endogeneous metal deposits in three zones of the Alpine Belt: the Greater Caucasus, the Western Alps, and the Pyrenees.

The input data used to evaluate this correlation consisted of identifications of sites where earthquakes of magnitude $M > 5.0$ are possible. This identification was based on morphostructure zoning charts, as well as charts of geological, geomorphological and geophysical properties [1-3], and maps of mineral occurrences [4-6]. The morphostructure zoning procedure used to predict earthquake sites in seismically active mountain chains [7, 8] identifies several categories of morphostructures with different degrees of tectonic activity, namely areal morphostructures (mountain chains, megablocks and blocks), as well as the linear zones of tectonic deformation that separate them (i.e., lineaments), and points of intersection of the lineaments (nodes). Each morphostructrual category is described by a set of indicators [7, 8]. It has been shown [2, 3, 9, 10] that the epicenters of strong earthquakes tend to be located at nodes. This conclusion has been confirmed by microstructural zoning in the Greater Caucasus, the Western Alps and the Pyrenees, where all earthquake epicenters with $M > 5.0$ prove to be located at the intersections of lineaments.

The problem of identifying earthquake-prone sites in these regions consisted of partitioning the overall set of nodes into high-seismicity (H) and low-seismicity (L) nodes, in which earthquakes with $M > 5.0$ were respectively likely and unlikely to occur.

The partitioning of the nodes in terms of their geological and geophysical properties was accomplished with the help of the Kora-3 classification algorithm [2, 3, 9] (in the case of the Western Alps and the Pyrenees, the nodes were circles with radii of 25 km centered at the points of intersection of the axes of lineaments).

Figures 1-3 are morphostructure zoning maps showing the resulting partitioning of nodes into classes H and L in the Greater Caucasus, the Western Alps and the Pyrenees. The classification was based on the geological, geophysical and morphostructural properties of the nodes. The properties that proved to carry the most information in all three regions were: (1) the minimum elevation in a node (H_{min}); (2) the range ΔH of height variation in a node; (3) the combination of relief types; (4) the percentage of the total area occupied by "unconsolidated" (Quaternary) deposits (Q); (5) the number (NL) of lineaments intersecting in a given node; (6) the number NLI of lineaments passing through the area of the node; (7) the number NF of faults in the node area; (8) the distance R-I from the center of the node to the nearest first-rank lineament; (9) the distance R-II to the nearest second-rank lineament; (10) the distance R_{int} from a given intersection to the nearest intersection of lineaments; (11) the Bouguer anomaly gradient (BAG); (12) the difference ΔBA between the smallest and largest values of the Bouguer anomaly.

Table 1 shows the characteristic indicators of high-seismicity nodes as identified by the above classification process and used to produce the partitioning shown in Figs. 1 to 3. An indicator is a combination of the values of several properties shown in a row of the table. As Table 1 indicates, the high-seismicity nodes in all three regions exhibit a high degree of tectonic fragmentation and high contrast of vertical movements. The high-seismicity nodes in the Western Alps and Pyrenees also contain strong nonuniformities at depth.

The results of morphostructural zoning and partitioning of the nodes into classes H and L were compared with the locations of the largest endogenous ore deposits in each region. In the Western Alps and Pyrenees we considered deposits that are currently being worked and with yields or reserves of: more than 10^4 tons in the case of lead-zinc and silver ores; more than 100 tons in that of uranium ores; more than 500 tons in the case of tungsten-molybdenum ores; more than $5 \cdot 10^5$ tons in that of

[1] Translated from: O svyazi endogennogo orudeneniya s rezul'tatami raspoznavaniya seysmoopasnykh peresecheniy lineamentov. Doklady Akademii Nauk SSSR, 1989, Vol. 307, No. 2, pp. 328-332.

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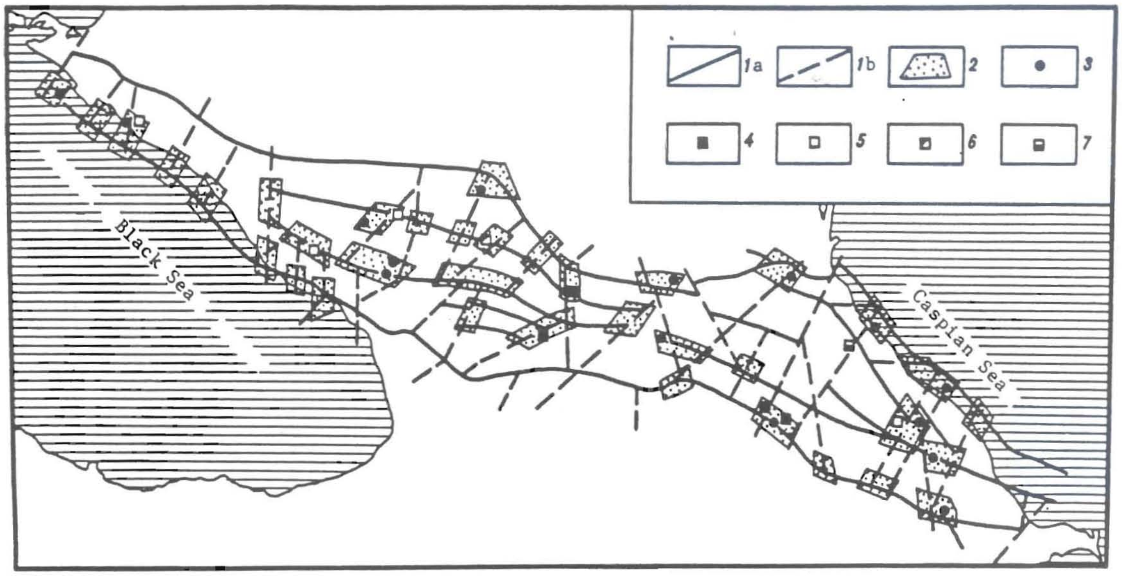

Fig. 1. Simplified morphostructural zoning chart showing identified nodes and metal deposits of Greater Caucasus: *1*) Axes of morphostructural lineaments (a, longitudinal, b, transverse lineaments); *2*) High-seismicity nodes; *3*) Epicenters of post-1900 earthquakes with $M > 5.5$; Endogenous are deposits; *4*) lead-zinc and silver ores; *5*) mercury ores; *6*) tungsten and molybdenum ores; *7*) strontium ores.

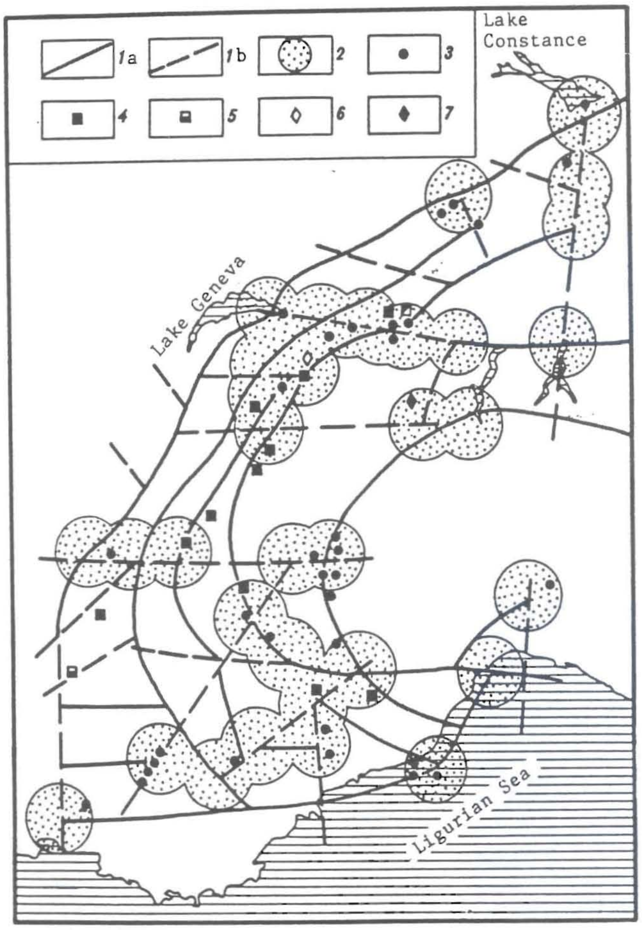

Fig. 2. Simplified morphostructural zoning chart showing nodes and metal deposits of Western Alps: *1*, *2*) as in Fig. 1; *3*) Epicenters of earthquakes with $M > 5.0$. Endogenous deposits: *4*) lead-zinc and silver ores; *5*) strontium ores; *6*) uranium ores; *7*) gold.

Table 1

Characteristic indicators of high-seismicity nodes

Area	H_{min}, m	ΔH, m	Combination of relief types				Q, %	NL	NLI	NF	R-I	R-II	P_{int}	BAG km/10 mgal	ΔBA, mgal
			S/P	S/PU	rs	PU/P					km				
Greater							> 5						< 27		
Caucasus	< 600	> 2100		-											
($M \geq 5.5$)		> 2100					> 20								
				-			> 5			> 5					
	< 600					-				> 5					
			-				> 20								
					-		> 20								
Pyrenees		> 1400	+												
($M \geq 5.0$)		> 2400		-									< 27		> 47
Western											≤ 32			≤ 2	≤ 65
Alps											> 0			≤ 2	≤ 65
($M \geq 5.0$)											≤ 32	0			≤ 65
									> 3			0			≤ 65
									> 4					≤ 3	> 45
												0, ≤ 40			> 45
								2			> 32				> 45
								2			> 32			≤ 3	
								> 2	≤ 3					≤ 2	
							> 10		> 3			≤ 40			
							> 10	> 2			< 32				

Notes. S, mountain slope; P, piedmont plain; PU, piedmont upland; CS, continental slopes.

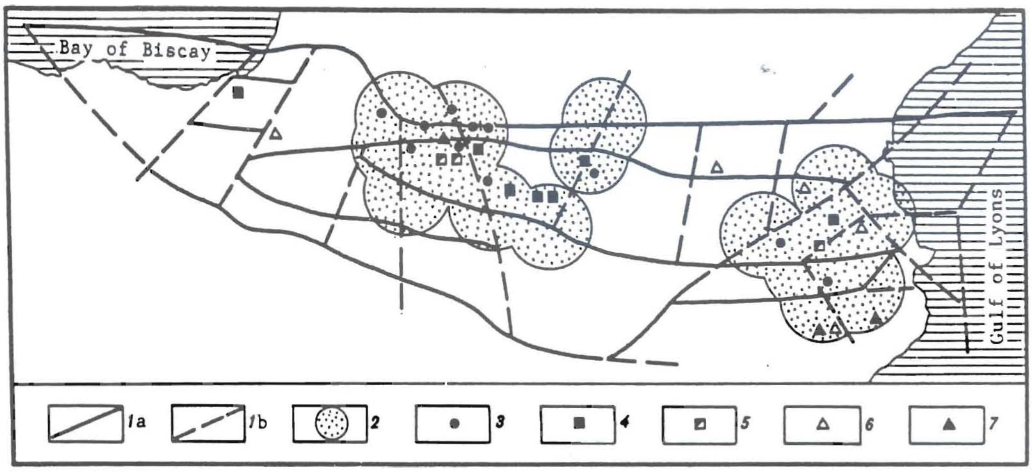

Fig. 3. Simplified morphostructural zoning chart showing nodes and ore deposits of Pyrenees: *1-4*) as in Fig. 2. Endogenous deposits; *5*) tungsten-molybdenum ores; *6*) magnesium ores; *7*) barium ores.

barite ores; and 1 to 10 tons in that of gold [5, 6]. In the case of the Greater Caucasus we considered the deposits shown on the standard metallogenic map [4].

We found that 93 percent of the deposits in the three regions were located within the morphostructural nodes (see Figs. 1 to 3); 80 percent of the deposits were associated with nodes that had been classified as exhibiting high seismicity. Thus, we have clear evidence of a correlation between zones in which earthquakes with $M > 5.0$ are likely to occur and the sites of endogenous mineral deposits in the Western Alps, the Pyrenees and the Greater Caucasus.

The correlation of mineral deposits with fault nodes has long been known [1]; the new aspect of the present treatment is the fact that most of the deposits considered are associated with potential high-seismicity nodes and that many of them are the sites of the strongest earthquakes recorded in the above regions. This indicates that metallogeny and earthquake generation are likely to have common tectonic causes. Let us attempt to identify a mechanism that could cause earthquakes and endogenous metal deposits to be associated with the same nodes.

We found that the high-seismicity nodes had a high degree of tectonic fragmentation and contrast of vertical movements, indicating low strength of the crust in these regions. By virtue of this fact, high-seismicity nodes are zones of preferential percolation of liquids and gases from the mantle and the activation of hydrothermal and other processes that give rise to many types of ore deposits. The high permeability of the crust in the node areas also tends to lead to differences in the degree of deformation and in the very nature of tectonic stresses in the lineaments whose intersections constitute the nodes. Longitudinal lineaments are generally deep faults that were emplaced in the geosynclinal stage and were retained (or were rejuvenated) during the orogenic period when they were subjected to compression with a shear component. Transverse lineaments are most common in orogenies of the Recent stage and are mainly under extensional or shear stresses. Thus, during orogenic periods, a complex geodynamic situation arises at the sites of intersection of lineaments (i.e., nodes), promoting increased migration of fluids, which in turn makes possible more vigorous endogenous mineralization than in the other segments of the lineaments. Furthermore, it is also reported [12] that migration of fluids plays an important role in earthquake generation.

Thus, our results indicate that the most favorable conditions for both processes occur in nodes assigned to the high-seismicity group.

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A THREE-DIMENSIONAL MODEL OF THE ATMOSPHERE AND THE OCEAN IN A TYPHOON ZONE[1]

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The interaction between ocean and atmosphere is the most pronounced in powerful tropical cyclones (TC). There, the energy fluxes from the ocean, mainly in the form of latent heat, are as high as 1 to 2 kJ/m² [1, 2]. Much of the moisture thereby evaporated from the ocean condenses in the clouds, but about 5 percent of the liberated energy is converted to kinetic energy of the cyclone. During the hurricane season, about 20 percent of the Northern Hemisphere's atmospheric kinetic energy is generated in TC zones [3].

The sea surface temperature (SST), which largely governs the rates of surface evaporation, as well as the convective stability of the atmosphere, directly affects the intensity of the cyclonic circulation, especially during the early period of its development. On the other hand the friction of hurricane-strength winds against the ocean surface induces a significant rearrangement of the thermodynamic structure of its upper layer, so its surface temperature decreases. Tropical cyclones leave behind them a zone of vortex and wave disturbance with a width of as much as a few hundred kilometers (TC wake), in which the SST variations are of the order of several degrees. If a tropical cyclone remains stationary (or moves very slowly) for 1 to 2 days, then find (from observations [4, 5] and numerical calculations [6]) that a cyclonic circulation of synoptic scale is generated in the underlying ocean. This synoptic circulation, as well as the cyclone wake, persist for several weeks after the storm has passed.

The decrease in the surface temperature of the sea under the cyclone may weaken the latter. The effect of this feedback was estimated in [7]. But the model of the ocean-atmosphere interaction described in [7] was of a limited potential because

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[1]Translated from: Trekhmernaya model' atmosfery i okeana v zone tayfuna. Doklady Akademii Nauk SSSR, 1989, Vol. 307, No. 2, pp. 333-337.

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