Hybrid expert systems at forecasting problem solution
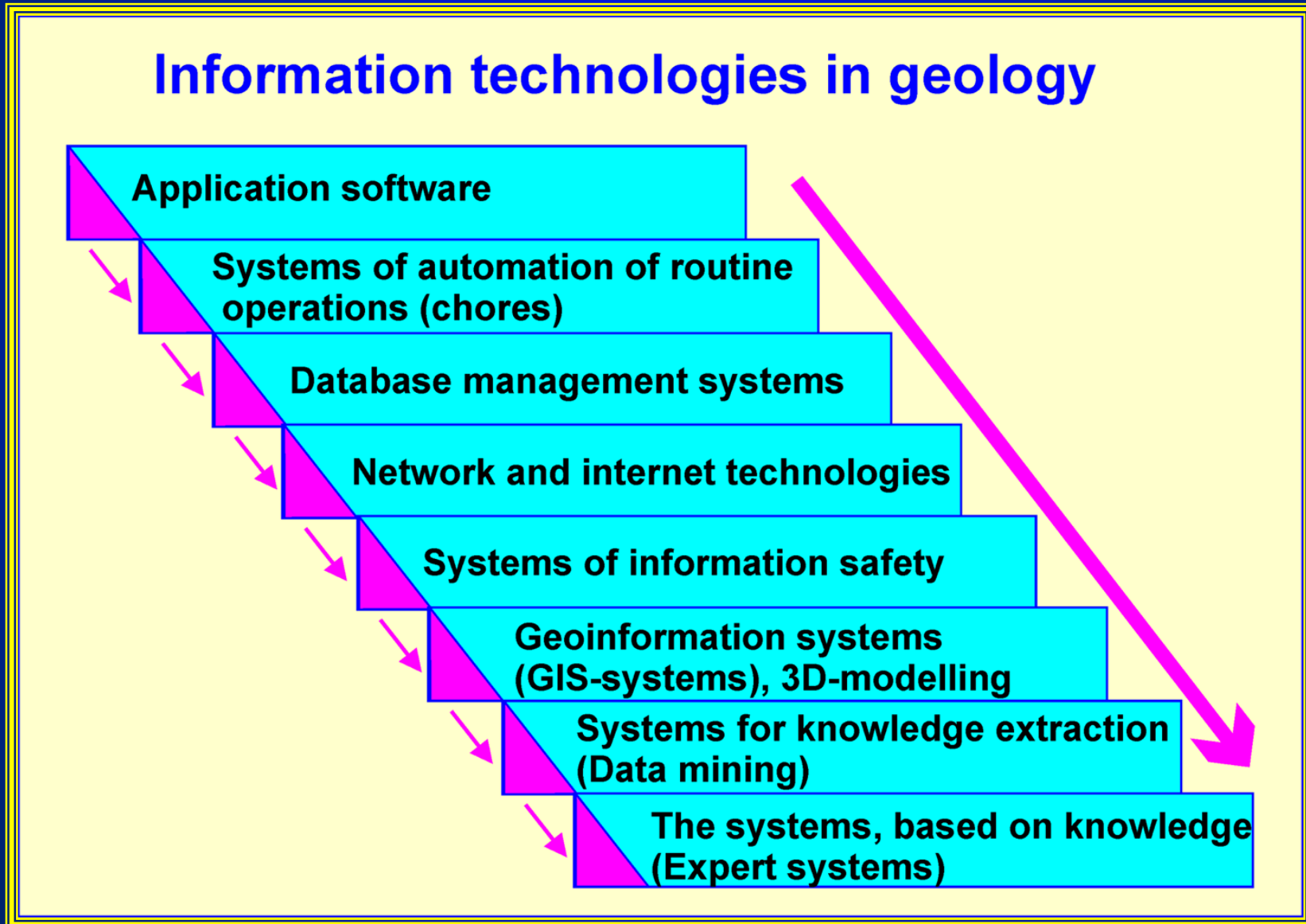
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The modern stages of development of information technologies in geology

# Expert systems for decision of forecasting problems

1. **PROSPECTOR** - for estimation of prospects of the search for various types of minerals [Duda et al., 1979];
2. **DRILLING ADVISOR** - at borehole drilling for geological prospecting [Hollander, Iwasaki, 1983].
3. **GENESIS** - for automation of technology of construction and use of prospecting-search complexes [Bugaets et al., 1986; Vostroknutov, 1999, 2006];
4. **SERGE** - for classification of geochemical anomalies by searches of firm minerals [Bonnefoy et al., 1989];
5. **GEO** - for the regional forecasting of lead-zinc deposits of Bulgaria [Gitis et al., 1989];
6. **OLOVO** - for an estimation of tin deposits [Rodionov,Cyrkin, 1995];
7. Expert system for statistical forecasting of average and large deposits [Zhao et al., 1996].
8. Forecasting block of system **GIS-INTEGRO** [Cheremisina, Finkelshtein, 1999];
9. Expert system for an estimation of scales tungstic ore deposit [Mitrofanov et al., 2009].

Systems, based on knowledge (Expert systems)

The system, based on knowledge - artificial intelligence system, is one, in which subject knowledge is presented in an explicit form and separated from other knowledge of system.

The geological information accumulated now is used nonrationally. In overwhelming size it is intended for expert informing and only insignificant part of it is used for the purpose of receiving for forecasting and controlling solutions.

Now there is the time of transition from the systems operating with data for the purpose of knowledge acquisition, to the systems, which use knowledge for solution of geological problems .
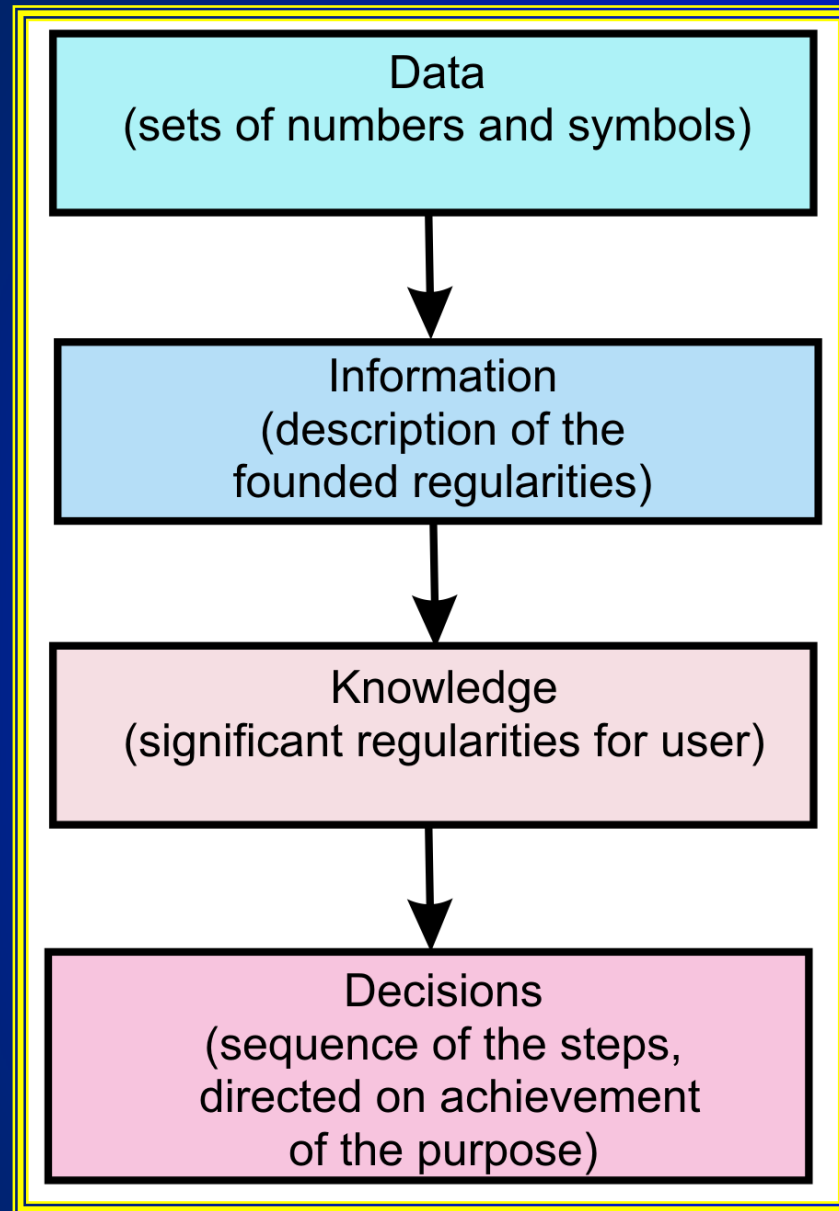
Transformation diagram "data – information – knowledge - decision"

(on [Popov etc., 1996], with additions)

The most effective systems, based on knowledge, are the *hybrid expert systems*, for which the knowledge base includes not only knowledge of experts, but also the regularities received as a result of the analysis of available databases.

The knowledge base is understood as the organized set of knowledge submitted in the form which supposes their automated use in expert system.

Data
(sets of numbers and symbols)

↓

Information
(description of the founded regularities)

↓

Knowledge
(significant regularities for user)

↓

Decisions
(sequence of the steps, directed on achievement of the purpose)

Units of system of decision-making:
objects of research, purpose, decision-making rules

According to the principle of consecutive detailing there are selected as the cores space forecasting-metallogenic taxsons: *metallogenic zone, ore region, ore knot, ore field and deposit*.
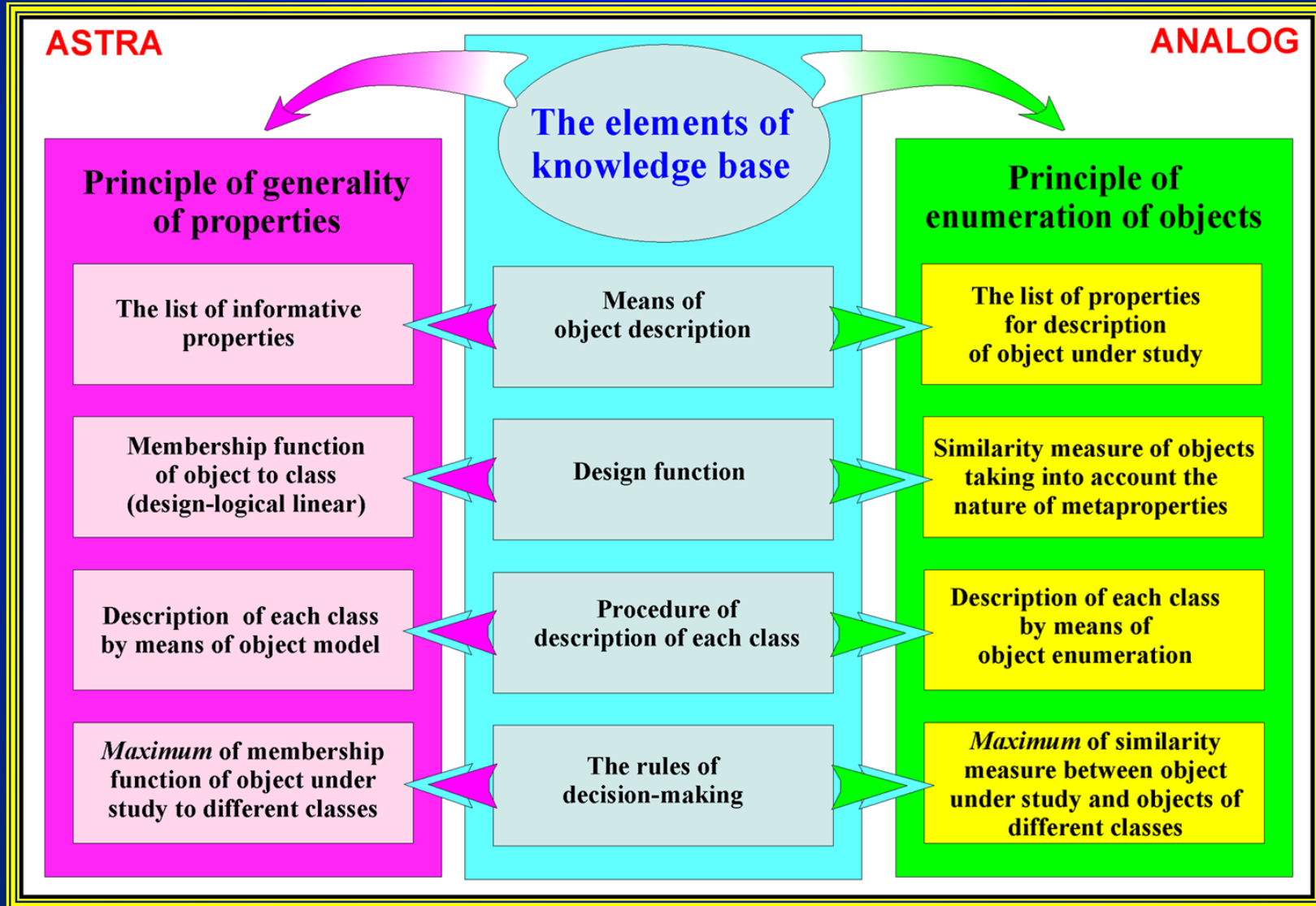
Purpose:
- Definition of ore-formation type of deposits;
- Estimation of their scale.

Decision-making rules for estimation of perspective area:
 are formulated by the expert-geologist or settled up on standard database objects that raises objectivity of result.
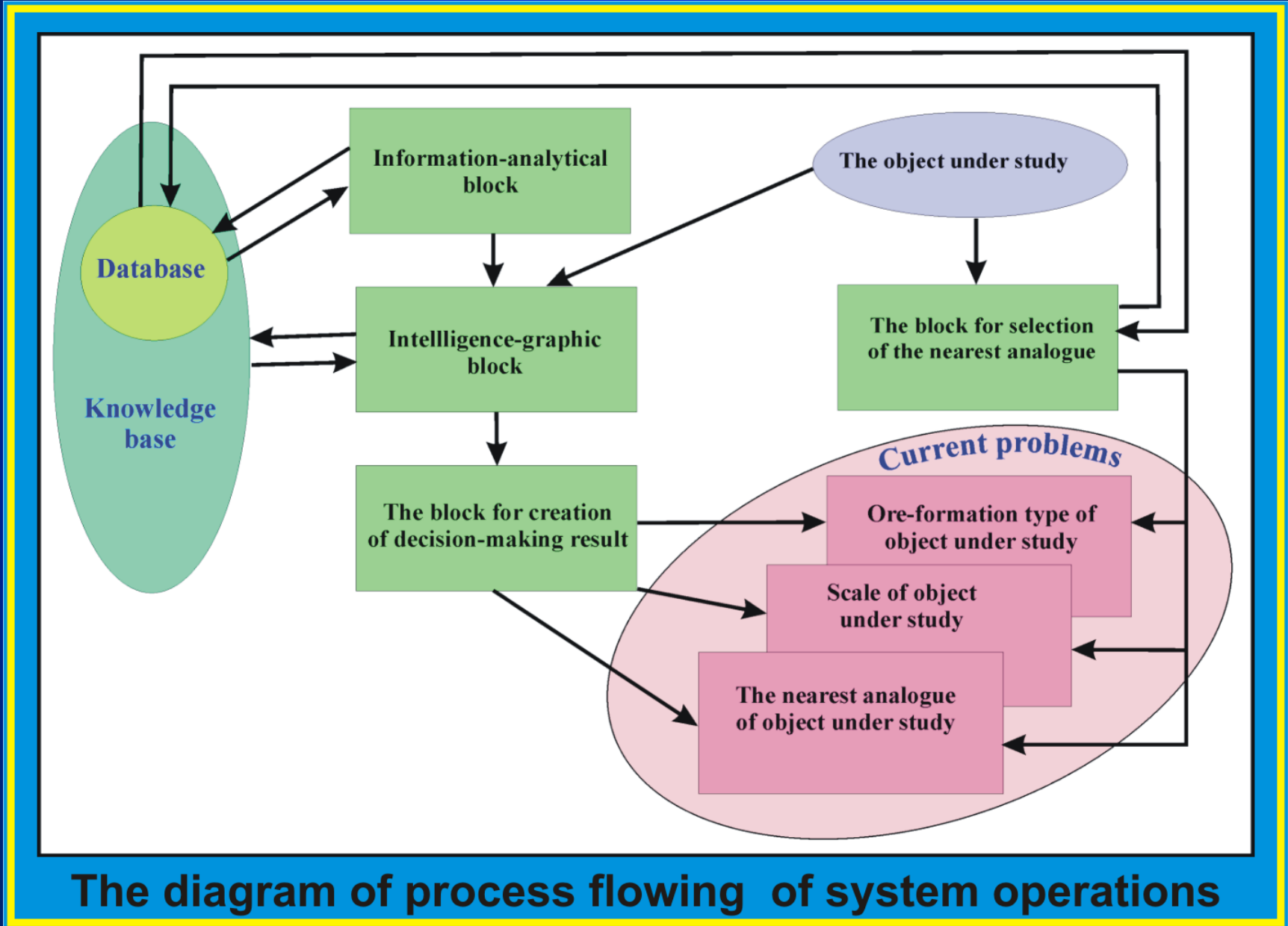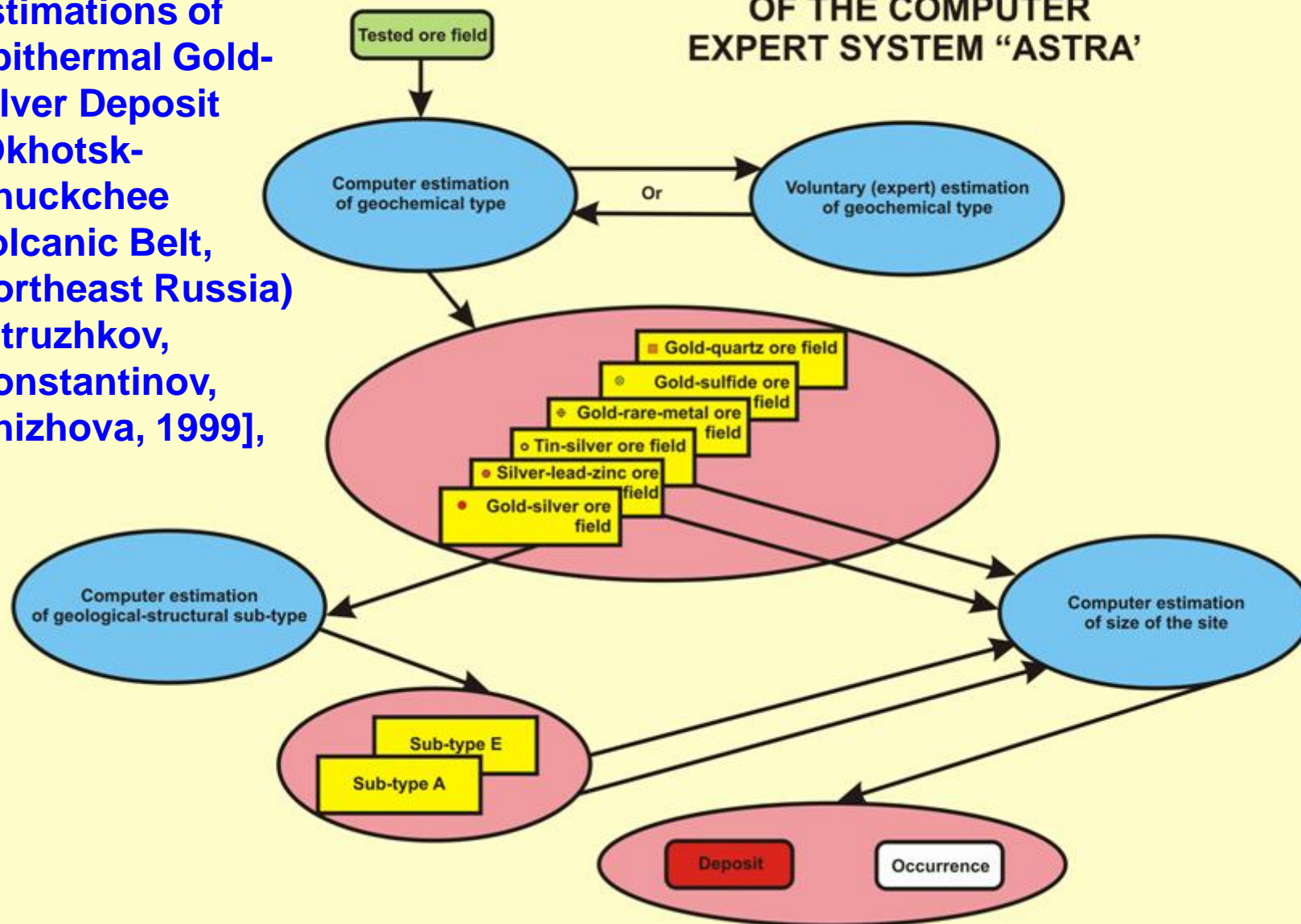
The diagram of process flowing of system operations

The features of construction of knowledge base at the using of different approaches for its designing

ASTRA

ANALOG

The elements of knowledge base

Principle of generality of properties

Principle of enumeration of objects

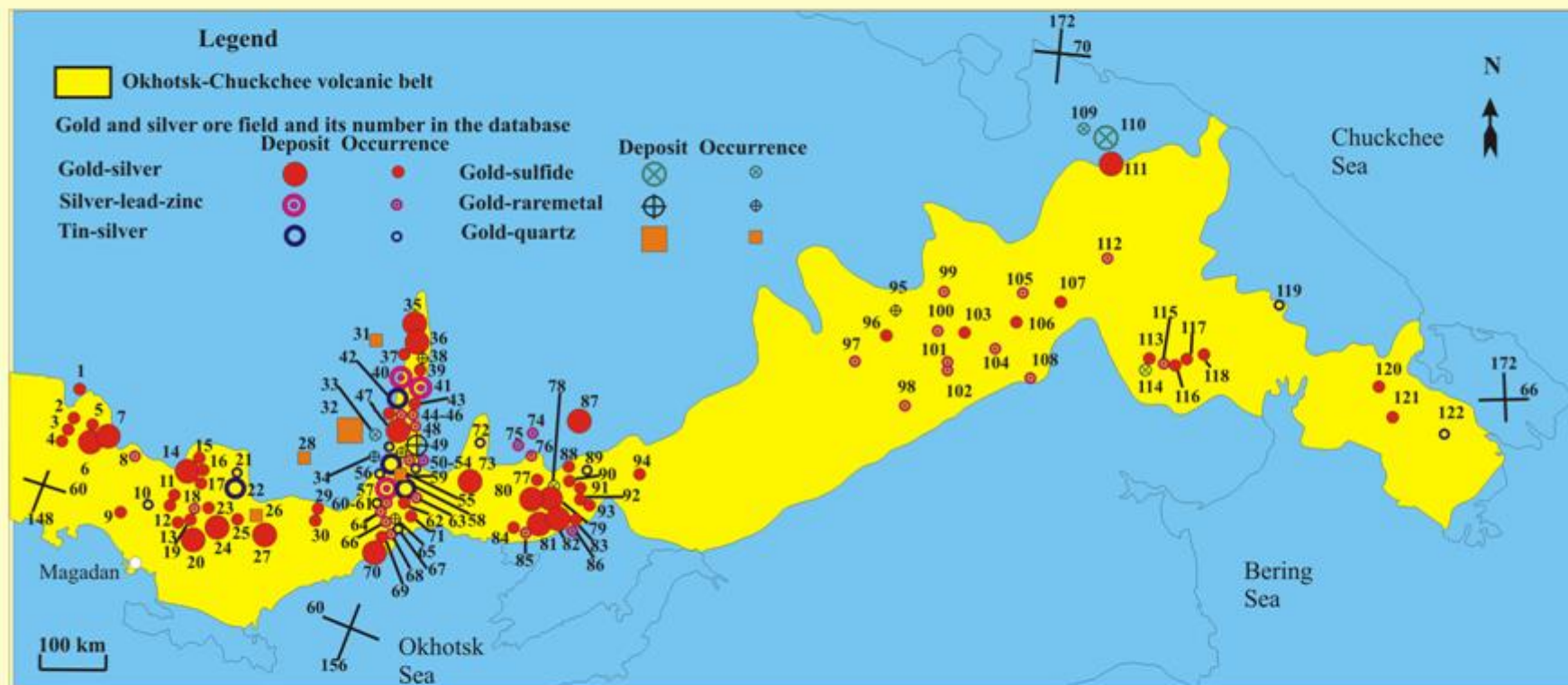|		
The list of informative properties	Means of object description	The list of properties for description of object under study
Membership function of object to class (design-logical linear)	Design function	Similarity measure of objects taking into account the nature of metaproperties
Description of each class by means of object model	Procedure of description of each class	Description of each class by means of object enumeration
Maximum of membership function of object under study to different classes	The rules of decision-making	*Maximum* of similarity measure between object under study and objects of different classes

Expert system for estimations of Epithermal Gold-Silver Deposit (Okhotsk-Chuckchee Volcanic Belt, Northeast Russia) [Struzhkov, Konstantinov, Chizhova, 1999],

GENERALIZED SCHEME
OF THE COMPUTER
EXPERT SYSTEM "ASTRA'

Tested ore field

Computer estimation
of geochemical type

Or

Voluntary (expert) estimation
of geochemical type

- Gold-quartz ore field
- Gold-sulfide ore field
- Gold-rare-metal ore field
- Tin-silver ore field
- Silver-lead-zinc ore field
- Gold-silver ore field

Computer estimation
of geological-structural sub-type

Computer estimation
of size of the site

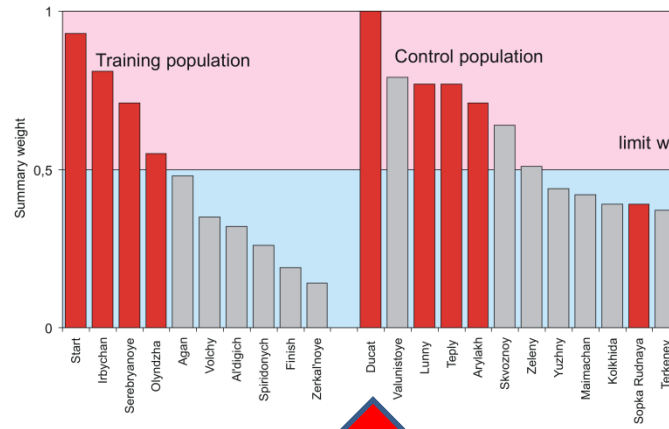Sub-type E

Sub-type A

Deposit

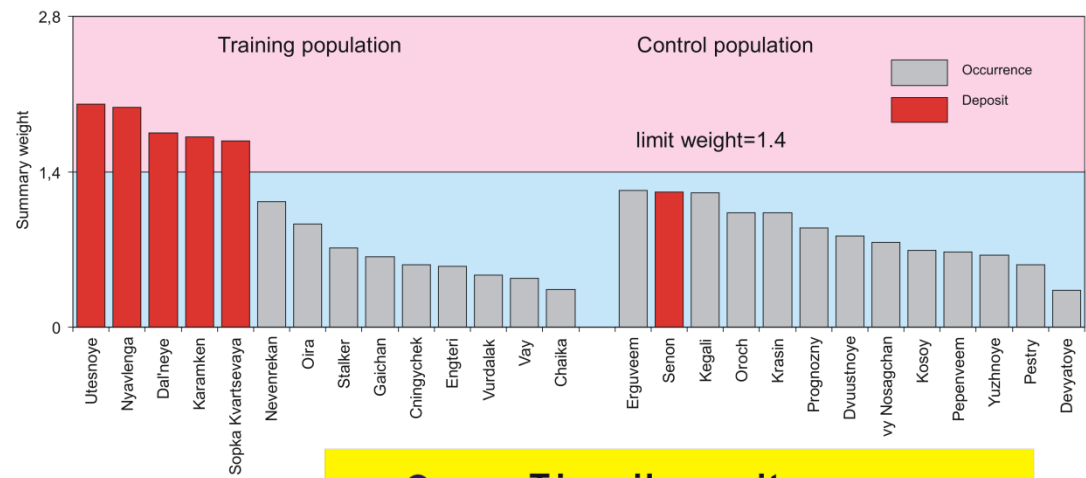Occurrence

Locations of the tested ore fields

List of gold and silver ore fields: 1-Khuren, 2-Burdalok, 3-Sukhoye, 4-Chaika, 5-Utro, 6-Serebryanoye, 7-Senon, 8-Tsentralnoye, 9-Oira, 10-Kandychan, 11-Agan, 12-Ushelnoye, 13-Gaichan, 14-Agatovskoye, 15-Zerkal'noye, 16-Pravy Nosagchan, 17-Chingychek, 18-Ugryumy, 19-Finish, 20-Karamken, 21-Iregandzha, 22-Kheta, 23-Kolkhida, 24-Utesnoye, 25-Devyatoye, 26-Tengkeli-Gluharinoye, 27-Nyavlenga, 28-Govorlivoye, 29-Yuzhnoye, 30-Engteri, 31-Gromadinskoye, 32-Amandyrkhanskoye, 33-Kupolok, 34-Tainik, 35-Arylakh, 36-Lunny, 37-Zeleny, 38-Shumok, 39-Askold, 40-Mechta, 41-Tydid, 42-Maly Ken, 43-Krasin, 44-Nachal'noye-I, 45-Nachalnoye-II, 46-Irguchan, 47-Ducat, 48-Neag, 49-Podgornoye, 50-Kontaktovoye, 51-Porozhistoye, 52-Volnistoye, 53-Naletnoye, 54-Malyutka, 55-Naporistoye, 56-Karasayskoye, 57-Goltsovoye, 58-Trud, 59-Ozernoye, 60-Verkhne-Tapskoye, 61-Porfirovoye, 62-Maimachan, 63-Kengrendya, 64-Dzhet, 65-Khalali, 66-Rogovushka, 67-Khakanzya, 68-Dyuken, 69-Spiridonych, 70-Teply, 71-Ulikskoye, 72-Khakyrchan, 73-Olyndzha, 74-Zapadny, 75-Koargychan, 76-Khivach, 77-Prognozny, 78-Sumnoy, 79-Irbychan, 80-Sopka Kvartsevaya, 81-Start, 82-Dal'neye, 83-Era, 84-Nevenrekan, 85-Khoichan, 86-Al'digich, 87-Kubaka, 88-Stalker, 89-Shirokaya, 90-Oroch, 91-Volchy, 92-Dvuustnoye, 93-Vay, 94-Kegali, 95-Malo-Peledonskoye, 96-Pestry, 97-Gangut, 98-Serovskoye, 99-Oranzhevoye, 100-Gornostayevoye, 101-Kosoy, 102-Verkhne-Anadyrskoye, 103-Khayalgyveem, 104-Chineyveem, 105-Bely Kamen, 106-Yuzhny, 107-Skvoznoy, 108-Pravy Irvyveem, 109-Sredne-Ichuveemskoye, 110-Mayskoye, 111-Sopka Rudnaya, 112-Krasnye Gory, 113-Osenneye, 114-Nygchekvaam, 115-Zhilnoye, 116-Shakh, 117-Valunistoye, 118-Terkeney, 119-Levo-Alabashlynskoye, 120-Erguveem, 121-Pepenveem, 122-Dioritovoye

Knowledge base

Database

Method of multivariate classification → Object classes

Logical-informative analysis → The list of informative properties

The rules of decision-making

Diagram for creation of knowledge base using mathematical methods

Informative weights for definition of expected formation (mineral) type and the scale of mineralization

Identification

Identification of geological-structural sub-type

	Host rocks	A	A	A	E	E	E	E
109	Interlayered sandstone, siltstone, and shale		1					
110	Argillite		1					
112	Hornfel			1				
121	Flows of felsic volcanics and their tuff	1			1	0	1	0
122	Flows of felsic and intermediate volcanics and their tuff	0			1	1	1	1
123	Intermediate and mafic subvolcanic bodies	0			1	1	1	1
124	Felsic subvolcanic body	1	1		1	0	0	1
125	Granitoide intrusive			1				
		AND	AND	AND	AND	AND	AND	AND

Gold-silver sites (sub-type A)

Gold-silver sites (sub-type E)

Tin-silver sites

Screen window for data entry

ANALOG
The System for the Selection of Analogues

Udereyskoe
? expected formation type of mineralization
? the scale of ore mineralization

Analogues

Vasilkovskoe
Vorontsovskoe
Tokur

By analogy

Udereyskoe
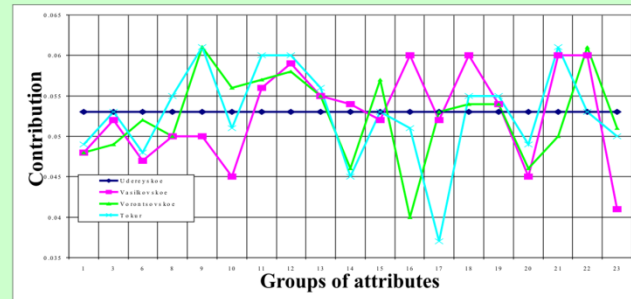expected formation type of mineralization
the scale of ore mineralization;
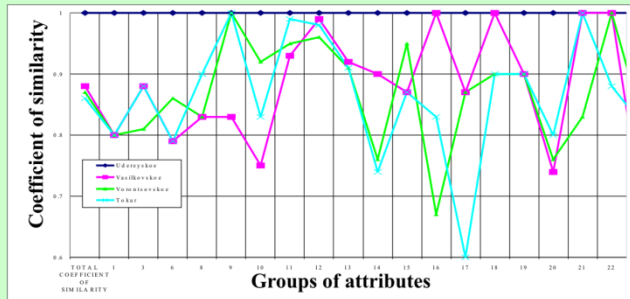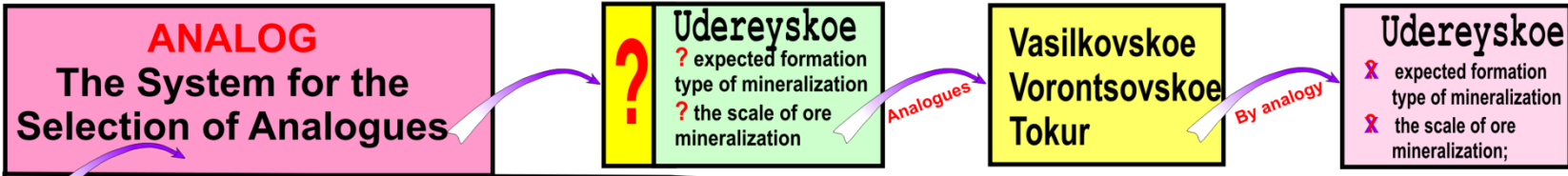
Estimation of similarity between estimated and reference deposits

Database of the standart objects

247 Gold Ore Deposits over the World

Estimated contributions of the groups of the attributes to the total coefficient of similarity

No of the group of the attributes in database	Groups of the attributes for estimation of similarity	Estimated deposit Udereyskoe	Reference deposits Vasilkovskoe	Vorontsovskoe	Tokur
	TOTAL COEFFICIENT OF SIMILARITY	1.00	0.88	0.87	0.86
1	Regional geological structures guiding the spatial distribution of auriferous provinces	1.00	0.80	0.80	0.80
3	Geological formations that compose the ore field	1.00	0.88	0.81	0.88
6	Elements of structures that control the location of the largest orebodies and pipes	1.00	0.79	0.86	0.79
8	Host rocks	1.00	0.83	0.83	0.90
9	Host rock metamorphic facies	1.00	0.83	1.00	1.00
10	Formations and facies of metasomatites in aureole	1.00	0.75	0.92	0.83
11	Minerals of the hydrothermally altered rocks	1.00	0.93	0.95	0.99
12	Ore minerals	1.00	0.99	0.96	0.98
13	Gold paragenetic associations in ores	1.00	0.92	0.92	0.91
14	Gold geochemical associations	1.00	0.90	0.76	0.74
15	Ore textures	1.00	0.87	0.95	0.87
16	Gold grade	1.00	1.00	0.67	0.83
17	Gold particle size	1.00	0.87	0.87	0.60
18	Host rock age	1.00	1.00	0.90	0.90
19	Mineralization age	1.00	0.90	0.90	0.90
20	Typical elements of primary and secondary halos	1.00	0.74	0.76	0.80
21	Geophysical anomalies (position in gravity field)	1.00	1.00	0.83	1.00
22	Geophysical anomalies (position in magnetic field)	1.00	1.00	1.00	0.88
23	Geologic parameters of commercial significance	1.00	0.69	0.83	0.82

No of the group of the attributes in database	Groups of the attributes for estimation of similarity	Estimated deposit Udereyskoe	Reference deposits Vasilkovskoe	Vorontsovskoe	Tokur
	TOTAL COEFFICIENT OF SIMILARITY	1.00	0.88	0.87	0.86
1	Regional geological structures guiding the spatial distribution of auriferous provinces	0.053	0.048	0.048	0.049
3	Geological formations that compose the ore field	0.053	0.052	0.049	0.053
6	Elements of structures that control the location of the largest orebodies and pipes	0.053	0.047	0.052	0.048
8	Host rocks	0.053	0.050	0.050	0.055
9	Host rock metamorphic facies	0.053	0.050	0.061	0.061
10	Formations and facies of metasomatites in aureole	0.053	0.045	0.056	0.051
11	Minerals of the hydrothermally altered rocks	0.053	0.056	0.057	0.060
12	Ore minerals	0.053	0.059	0.058	0.060
13	Gold paragenetic associations in ores	0.053	0.055	0.055	0.056
14	Gold geochemical associations	0.053	0.054	0.046	0.045
15	Ore textures	0.053	0.052	0.057	0.053
16	Gold grade	0.053	0.060	0.040	0.051
17	Gold particle size	0.053	0.052	0.053	0.037
18	Host rock age	0.053	0.060	0.054	0.055
19	Mineralization age	0.053	0.054	0.054	0.055
20	Typical elements of primary and secondary halos	0.053	0.045	0.046	0.049
21	Geophysical anomalies (position in gravity field)	0.053	0.060	0.050	0.061
22	Geophysical anomalies (position in magnetic field)	0.053	0.060	0.061	0.053
23	Geologic parameters of commercial significance	0.053	0.041	0.051	0.050

Charts (Coefficient of similarity vs Groups of attributes; Contribution vs Groups of attributes) legend: Udereyskoe, Vasilkovskoe, Vorontsovskoe, Tokur

Reference deposits	Similarity coef.	Latitude	Longitude	
Udereyskoye	1	N58°46'	E94°36'	🔴
Vasilkovskoye	0.878	N58°28'	E69°22'	🔴
Vorontsovskoye	0.868	N59°39'	E60°15'	🔴
Tokur	0.863	N53°08'	E139°05'	⚪
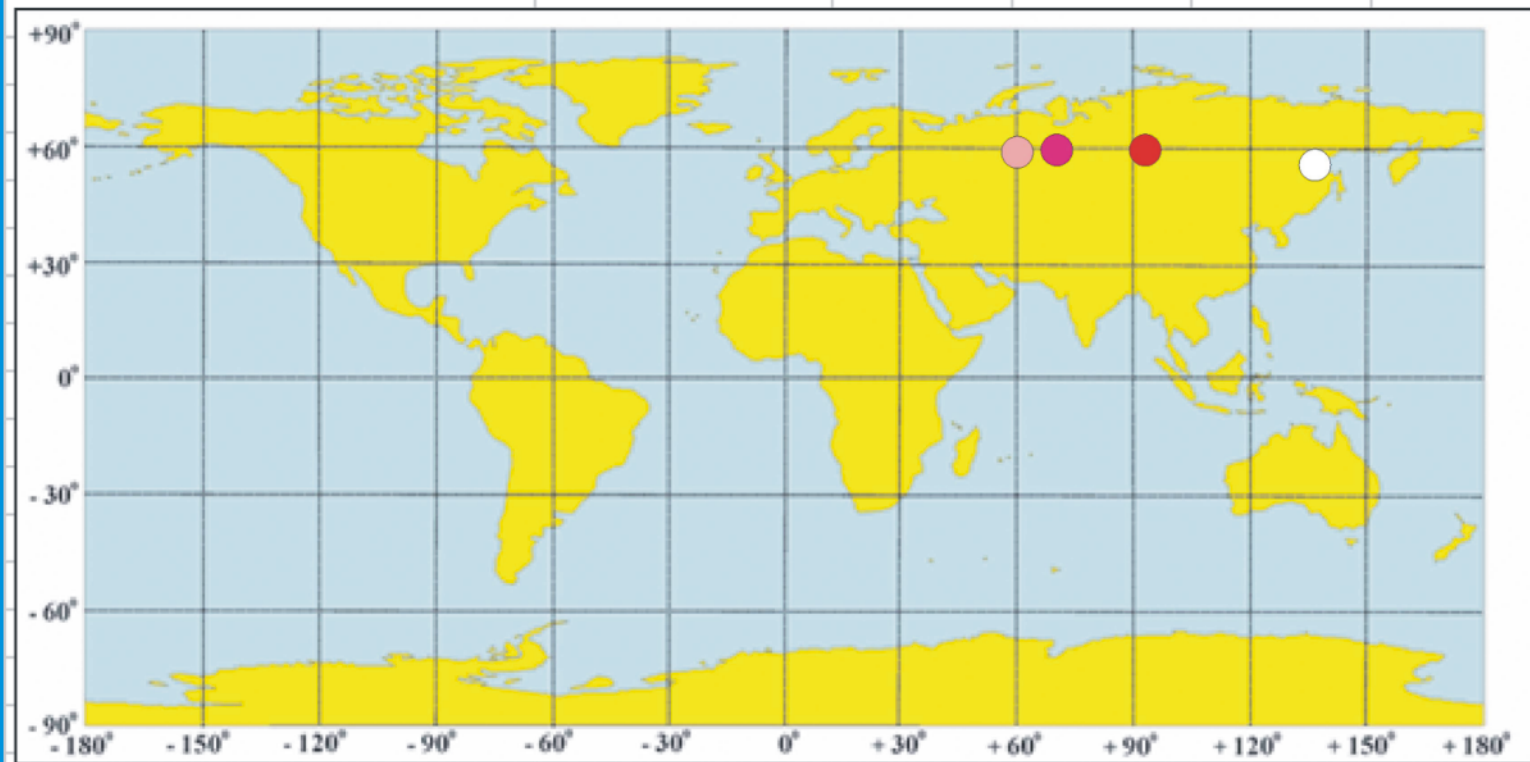
The representation of result in map form

Conclusion

The complexity of the solving problem (forecasting and estimation of ore deposits) makes necessary to use the expert systems of hybrid type, in which the combination of various ways of representation of scientific knowledge may be applied (expert's knowledge; the regularities, received as the result of the processing of available database).

It will demand complication of used mathematical methods, for maintenance of fast receiving of reliable results.
Technologies ASTRA and ANALOG can be used for development of expert systems for estimation of diversified metallic mineral deposits.

In each case, the specificity will consist in the creation of a knowledge base for specific metal with specific information indicators designed for the solution of forecasting problems.

Thank you for attention!