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# EARTH SCIENCES

## MONITORING OF SEISMIC GEODYNAMICS OF THE EARTH'S CRUST ON THE TERRITORY OF ARMENIA

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### Abstract

According to the studies of a number of authors, the confinement of earthquake epicenters to zones of active deep faults has been established in Armenia. But, not all faults are characterized by the same seismicity. The most seismically active are the general Caucasian faults and two northeast-trending faults: Akhuryan and Ararat-Sevan. According to seismo-statistical data, Pambak-Sevan, Pambak-Sevan-Syunik, Garni, Akhuryan are especially highly active. There is a differentiation of faults in terms of seismic activity along their strike. In the event of earthquakes of medium and large strength, it is necessary to consider active blocks and fault nodes. Seismically active fault nodes are Spitak and Sevan. To determine the activation of seismicity in the study area, based on the catalogs of earthquakes for (2011-2022) and the general seismic regime, a map of background seismicity was constructed. The hydrogeodynamic effects that preceded the geodynamic processes of the earth's crust in the central region were revealed, according to changes in the dynamics of the groundwater level and the chemical composition of mineral waters.

**Keywords:** monitoring, seismic, fault dynamics, hydrogeodynamics, hydrogeochemistry, earthquake.

### Introduction

Over the past ten years (2011-2022), a large number of seismic events have been registered in the region of central Armenia. A map of the seismicity of the territory of Armenia for the indicated years has been compiled. The increased activity of the geodynamic processes of the earth's crust in the studied central region of Armenia confirms the seismic activity of the region in recent years. The purpose of this study is to confirm the activation of the geodynamics of Central Armenia according to seismic geodynamics, based on the data of the study of the movement of the earth's crust and establishing a connection between variations in the stress-strain state of the earth's crust and the kinematics of deep faults. The stress-strain state of the earth's crust in the central region is calculated based on the data of water level variations in hydrogeodynamic boreholes and anomalous changes in the chemical composition of mineral waters. The stress-strain state of the earth's crust in central Armenia contributed to the formation of a compression structure along the middle segment of the Garni fault and along the Ararat-Sevan fault. The resulting stress field is characterized by numerical values of deformations ( $E=10^{-6}$ ,  $10^{-7}$ ) on the fault zones of the listed deep faults. Based on anomalous changes in the composition and level of groundwater, hydrogeochemical and hydrogeodynamic effects that precede tectonic movements of the earth's crust were revealed. The gas composition is the first to react to the stressed state of rocks: carbon dioxide ( $CO_2$ ), the second is the macrocomponent composition of mineral waters. The epicenters of the occurred earthquakes are mainly confined to the zones of deep faults: Garni, Ararat-Sevan and partly along the Yerevan deep faults. Based on the research results, the dependence of earthquake epicenters on the longitude and latitude of coordinates is shown. From the dependence obtained, it follows that

the earth's crust of central Armenia is subject to deformation processes (compression) both in the meridional and latitudinal directions. To determine the maximum depth of the distribution of the hypocenters of the earthquake sources, a graph of the dependence of occurred earthquakes on depth was drawn up. The predominant depth of the distribution of the hypocenters of the occurred earthquakes reflects the extent of the deformation processes of the earth's crust along the vertical. As a result, it can be noted that the strengthening of the geodynamic processes of the earth's crust in central Armenia is a manifestation of the activation of the Garni and Ararat-Sevan deep faults.

### Materials and Methods

The studies of the activation of geodynamic processes of the Earth's crust of central Armenia were carried out according to the seismic regime, changes in the dynamics of groundwater in hydrogeodynamic boreholes, and variations in the chemical composition of mineral waters. The seismically active region of Armenia is characterized by complex tectonics with multiple deep faults of the pan-Caucasian and anti-Caucasian lineaments. Tectonics of the research area includes seismotectonic megablocks of Yerevan and Gegam-Vedi. The intensive development of the tectonic movements of the Gegam-Vedi megablock were accompanied by subhorizontal tectonic movements directed to the SW. Currently, the movement of the Yerevan megablock is developing towards the SW-SE direction. All these movements are accompanied by the development of centers of numerous relatively weak earthquakes on the front-facing SW and SE parts of the formations of the folded and covered complexes. At the same time, the faults of the folded complex are transformed into structures of the first-order, and the structural plan for the development of modern tectonic movements are outlined by the locations of epicenters of relatively

strong earthquakes at the intersection knots of transverse (NE)–longitudinal (NW), i.e., fundamental-crustal faults [9]. The Yerevan seismotectonic knot under consideration is distinguished by the development of a regional NE-SW prostration of the fault along the river. Khndzorut - v. Chambarak - v. Shorzha- Lake Sevan - v. Yeranos - Geghama Highlands between the rivers Jrvezh - Azat, further moving to the East, according to the earthquakes that occurred on October 23, 2011, follows the line of Aigezard - Mount Ararat - the city of Van. At the same time, according to geophysical data, the Ararat-Sevan fault is distinguished here [6]. The regional fault is distinguished by geological interpretation of aerial and space photographs [10], a set of geophysical data, and field studies. Yerevan seismotectonic knot is mainly the result of tectonic movements of the fault-interfault zone. Moreover, the mentioned movements were accompanied by multistep left-shifts of blocks both inside the Azat fault zone and in the contact aureole of parts of the Gegham-Vedi megablock and are the consequences of the subhorizontal displacement of the Gegham-Vedi megablock in the SW direction approximately within 28-36 km. As a result, Garni seismically active fault was identified in this place [11]. Moreover, the mentioned movements were accompanied by multistep left-shifts of blocks both inside the Azat fault zone and in the contact aureole parts of the Gegham-Vedi megablock and are the consequences of the subhorizontal movement of the Gegham-Vedi megablock in the SW direction approximately within 28-36 km. As a result, the Garni seismically active fault was identified in this place [12]. At present, the mentioned relatively active tectonic movements have largely been stabilized. Accordingly, the movement of the near-fault parts of the Yerevan megablock continues relatively weaker and more interestingly and is accompanied by Yerevan fault and formations of the folded complex. This is confirmed by the development of modern, as on the example of 2006-2007, earthquake epicenters, relatively weak and medium, slightly stronger than the earthquake in the frontal SW and SE parts of the Yerevan megablock. The earthquake centers of relatively weak earthquakes are developed on the right bank of the Araks River [7]. Thus, with the help of paleotec-

tonic analysis, it is possible to identify seismically active and passive tectonic blocks and faults, as borehole as to determine the nature and direction of modern tectonic movements.

As the seismicity distribution on the map shows, earthquake epicenters are not located on faults, but it is possible to identify segments of regional faults, to which areas of seismicity concentration (seismogenerating zones) gravitate. Active and passive fault segments (as regards the presence of modern movements) are determined based on the data of GPS velocities:  $2.7 \pm 0.9 \text{ mm/g}$  in Metsamor,  $1.7 \pm 1 \text{ mm/g}$  in Yerevan and  $2.0 \pm 0.9 \text{ mm/g}$  in Sevan tectonic blocks.

#### Seismicity analysis

It is typical for the seismicity of central Armenia that the vast majority of earthquake sources have a depth of 10-15 km, the stress field is sharply inhomogeneous. Earthquake epicenters are stretched out along regional deep faults and boundaries of tectonic faults. The territory of central Armenia includes the following sources of seismic events: Yerevan, Dvin, Ararat, Parakar and Garni earthquakes [3]. The earthquakes belong to the types of neotectonic movements and their development zones correspond to areas of high velocity gradients of the modern (Neogene-Anthropogenic) vertical tectonic movements. In the study area the seismogenic knot Ararat is distinguished as the area of the intersection of the Ararat zone of deep faults with Ararat-Sevan. Ararat strong earthquakes dating back to 739 and 1840 ( $M=6.7$ ) are also confined to the knot zone of earthquakes, which includes Garni earthquake (1679,  $M=7.0$ ), the epicenter of this event was located in the area of the Garni village. The process of seismic activity of the earth's crust manifests itself in the form of discrete events - earthquakes.

The catalog of earthquakes in central Armenia includes about 150 events. The depths of the earthquakes that occurred are in the range between  $2.0 \div 16 \text{ km}$ . In the work, a sample of earthquakes with  $K \geq 8.5$  for 2011-2022 was done as borehole as a diagram of the distribution of seismicity in central Armenia was developed (Fig. 1). The spatial distribution of earthquakes with  $K = 7 \div 8$  compose the background seismicity of the study area (Fig. 2)

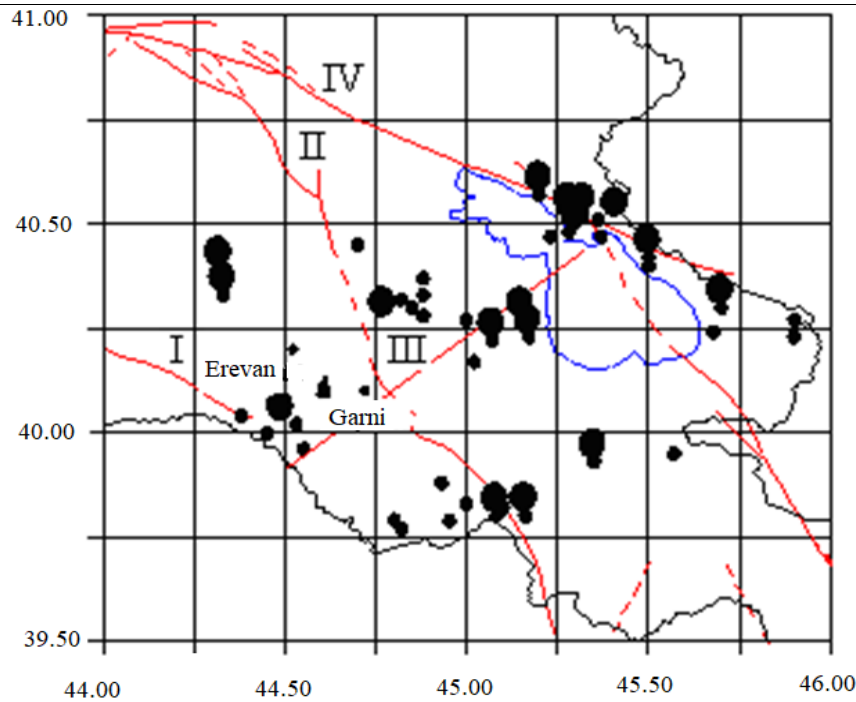


Fig.1. Scheme of location of earthquake epicenters in central Armenia

● -  $M > 2,5$  -  $10 \leq K \leq 8,5$ ; ● -  $M > 4$  -  $K \geq 12$ ;

--- - deep faults: I-Yerevan fault, II- Garni fault, III- Ararat Sevan fault, IV- Pambak Sevan

The diagram indicates the confinement of strong earthquakes to deep faults: in the west to the Yerevan fault, in the east to the Pambak-Sevan fault, and in the center to the Garni fault. The map of the seismic background of the region (Fig. 2) reflects an increased background of seismicity, which, possibly, contributes to the activation of the dynamic processes of the Earth's

crust in the central part of the region and the development of movements along the Bazum-Sevan, Garni and Ararat-Sevan deep faults.

The map of the seismic background reflects the density of earthquake epicenters inside and at the borders of tectonic blocks: Metsamor, Yerevan, Aparan-Sevan and Sevan research areas, as borehole as at the fault zones of Yerevan, Ararat-Sevan, Garni and Pambak-Sevan deep faults.

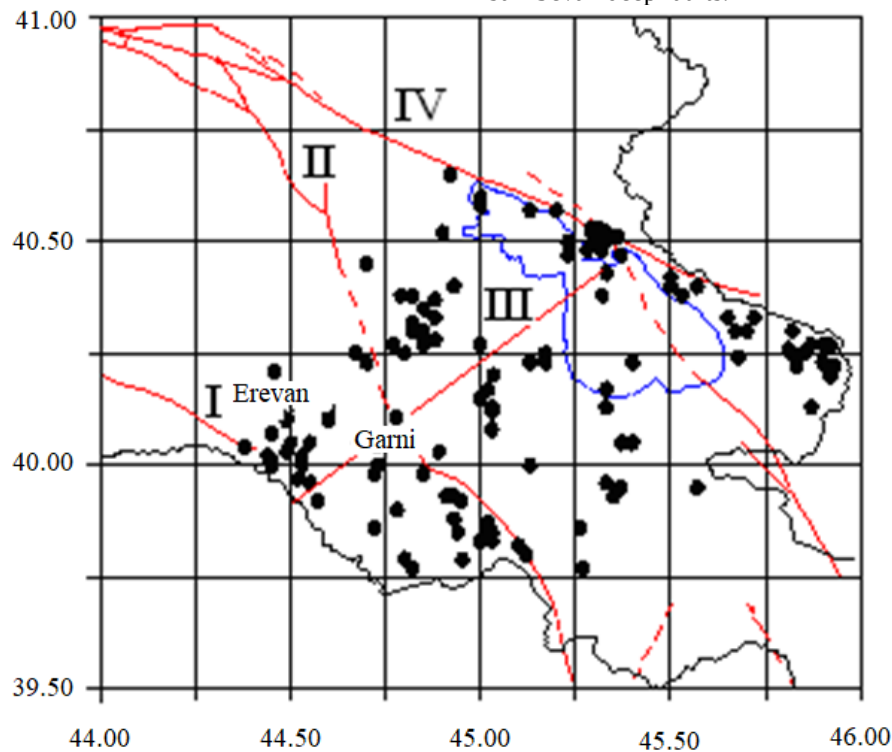


Fig.2. The map of seismic background of Central Armenia for 2011÷2022. ● -  $9 \leq K \leq 8$ .

A graph of earthquake recurrence based on the Gutenberg-Richter law [15] in the integral form  $Lg N = a + bM$  has been developed (Fig. 3).

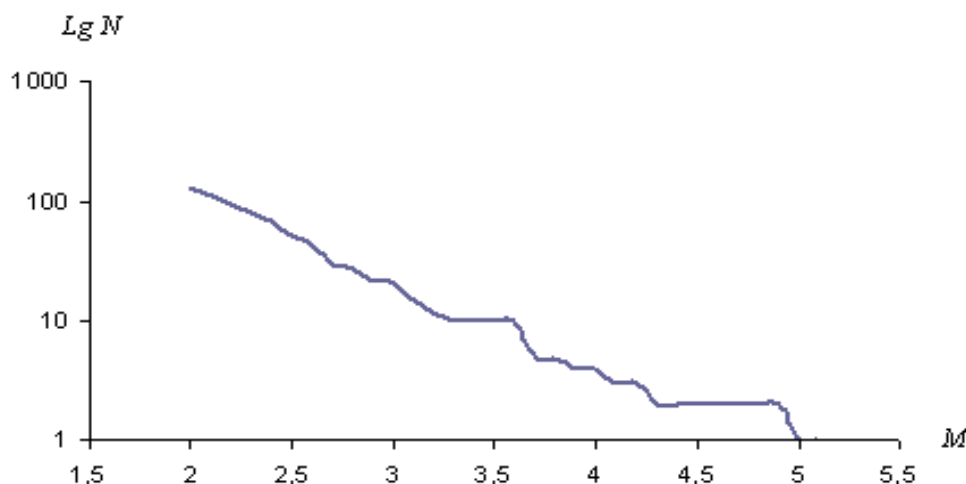


Fig. 3. Recurrence schedule for earthquakes that occurred in 2011-2022.  $N$  - number of earthquakes,  $N = 51$ ,  $M$  - magnitude of earthquakes,  $M = 1.5 - 5.5$ .

The main parameters of the seismic regime are determined:  $a=3.5$  - seismic activity and  $b=0.7$  - graph inclination. The value of parameter  $b$  is overestimated in relation to the average value  $b=0.5$ . on the territory of Armenia. Figure 3 shows that the rectilinear section of the graph is typical only for the interval of magnitudes  $2.0 < M < 3.0$ . The  $M > 3.0$  graph indicates the recurrence of stronger earthquakes. The reason for the nonlinearity of the recurrence graph in the layered-block structure of the Earth's crust [14] is that large sources of big earthquakes do not fit in the same layer as small ones, but have deeper horizons.

The paper studies a graph of the dependence of earthquake epicenters on the longitude and latitude of

coordinates (Fig. 4). As a result, it was revealed that the earthquakes that occurred in central Armenia in 2018 have a near-meridional direction (compression), earthquakes for 2019 have a latitudinal direction (compression). Epicenters of earthquakes that occurred in 2021 on the eastern coast of Lake Sevan, also have a meridional direction (compression). From which it follows that in central Armenia the Earth's crust is subject to deformation processes (compression) both in the meridional and latitudinal directions, and on the eastern coast of Lake Sevan in the latitudinal direction (compression).

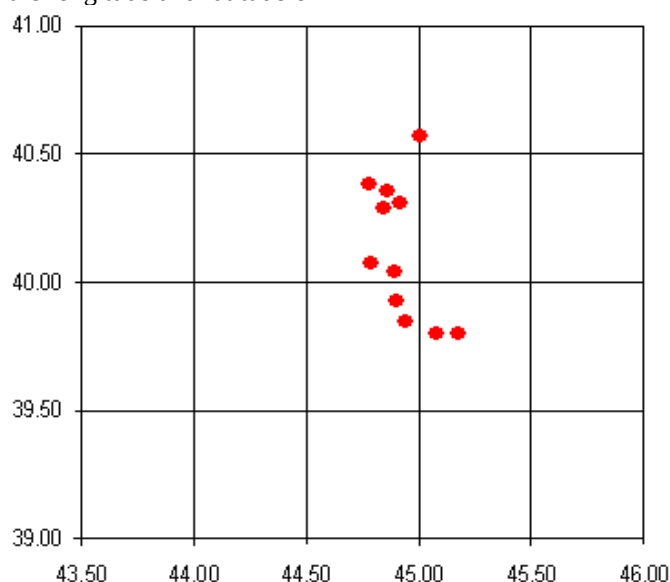


Fig. 4. Graph of dependency from the longitude and latitude of the epicenters of earthquakes in central Armenia  
● - earthquake epicenters

**3.1 Hydrogeodynamic and hydrogeochemical data.** At present, great importance is given to the dynamics and geochemistry of groundwater and their role

in the development of geotectonic processes. According to the method of hydrogeodynamic (HGD) precursors developed at the Institute of Physics of the Earth [4], we have been conducting research on the territory

of Armenia since 1989. There are long time series on the water level of the observational network of hydrogeodynamic boreholes and the chemical composition of the waters of mineral springs in the central region of

Armenia. In this area NN 2,3,8,18,27 hydrogeodynamic boreholes and I, II, III, IV mineral springs are located (Fig. 5).

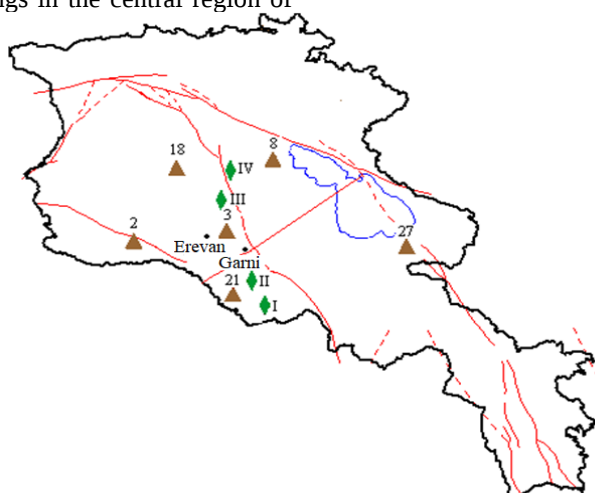


Fig.5. Map of the territory of Armenia with hydrogeodynamic and hydrogeochemical observation points in the central part. ♦ I- Surenavan, II- Vedi, III-Arzni, IV-Bjni- Mineral sources, ▲ (2,3,8,18,21,27) – hydrogeodynamic boreholes, --- - deep faults.

The method for highlighting hydrogeodynamic effects from the data of hydrogeodynamic boreholes includes statistical processing methods and data interpretation. Periodic variations in the level of groundwater have been identified, which can be associated with the influence of tide-forming forces. Low-amplitude periodic groundwater variations are identified, caused by sawtooth variations, which are associated with a slow rise in the water level and its sharp decline and indicate the presence of weak deformations.

A characteristic feature of sawtooth variations is that they occur against the background of a trend of rising or falling water levels in a borehole, which can be used as an indicator for determining the activity of tectonic blocks [8]. Further, we consider the results received on changes in water levels in hydrogeodynamic boreholes located in various tectonic blocks of central Armenia (Fig.5) in order to identify active blocks, in comparison with the seismic regime of the region for 2011÷2022.

Observation borehole No. 2 is located in the northern part of the Metsamor tectonic block, limited from the north by the Yerevan deep fault. Metsamor block GPS data is  $2.7 \pm 0.9$  mm/yr. The water level in the borehole has a weak seasonal value, the average statistical level is 16.2m. The amplitude of level fluctuations is 2-3 cm. The upward trend has been observed in the water level of borehole No. 2 since 2006. Hydrogeodynamic effects are observed before earthquakes with  $M \geq 4$ , the duration of the effect is 1.0÷1.5 months, the effect is stepped. From 2011 to 2013, an increase in the water level in the then a decrease in the water level of the borehole was registered. The water level in the borehole has been rising from 2017 to 2021.

Borehole: No. 3 was drilled in the Yerevan tectonic block and is located near the NE-SE fault, which runs diagonally along the marked tectonic block, with the SW - Yerevan deep fault. The data of the Yerevan tectonic block according to GPS measurements in the

block is  $1.7 \pm 1$  mm/yr. Weak seasonal value. The amplitude of water level variations is 0.92m. It is characterized by low-amplitude variations in the water level in the borehole. A sharp increase in the amplitudes of water level variations was recorded from 2011 to 2015. Then, an abrupt change in the water level in the borehole is observed. Until 2021 a slow decrease then a slow increase was recorded in the water level in the borehole.

Borehole No. 18 is located in the SW of the Aparan-Ankavan block. The borehole is characterized by a multistage and continuously rising groundwater level. From 1990 till mid 1994, within the Aparan-Hankavan tectonic block, a continuous increase in stress was observed, associated with the movements of this block, mainly in the northeast direction. From 1999 till 2008 the water level in borehole No. 18 slowly increased. Starting from 2009 until 2018 the water level in the borehole almost remained unchanged, then a dramatic rise in the water level by 126 cm started and since 2021 there is a trend of water level increase. The level of this borehole is characterized by the presence of tidal variations, which is an indicator of the response of the borehole-formation system to a change in volumetric deformation.

Borehole No. 21 is located on the SE of the Yerevan tectonic block. Since 2008 there has been an increase in the water level in the borehole, which continued until 2015. Sawtooth changes amidst the rising of the water levels were observed in the borehole between 2011-2015, which is a reflection of the geodynamic processes (compression) occurring in the upper layers of the Earth's crust of the Yerevan tectonic block. During the next two years, a decrease in the level was observed, followed by an increase in the water level until 2021. Hydrogeodynamic effects according to the variations of the water level of boreholes No. 21 before earthquakes with  $M \geq 2.5$ , the duration of the effect is

1.0÷1.5 months, the form of effects in most cases is stepwise.

Hydrogeodynamic borehole No. 27 was drilled in the SE of Sevan tectonic block. The change in the water level in the borehole is characterized by a weak seasonal variation of the groundwater level. According to the GPS data the Sevan block is  $-1.2 \pm 0.9$  mm/yr. Since 1994, according to the variations of the water level of borehole No. 27, a three-stage continuous increase has been observed, which probably indicates the tectonic activity of the Sevan block. Periodic variations in the water level of borehole No. 27 for 2011÷2015 have

been identified, which can be associated with the impact of tide-forming forces. Since 2019 there is an increase in the water level in the borehole.

When compared with the seismic regime of the region (for 2011÷2022) the data on the water level in hydrogeodynamic boreholes, according to the method for identifying hydrogeodynamic effects [4], hydrogeochemical effects were revealed that preceded the geodynamic processes of the Earth's crust.

Hydrogeodynamic effects of earthquakes according to the changes in water levels in observation boreholes.

| dd.mm.yy.    | Earthquake parameters |           |     |    | Hydrogeodynamic effects |          |                         |
|--------------|-----------------------|-----------|-----|----|-------------------------|----------|-------------------------|
|              | $\varphi$             | $\lambda$ | M   | D* | $\bar{K}^*$             | $\delta$ | A*                      |
| Borehole №3  |                       |           |     |    |                         |          |                         |
| 28.03.2012   | 40,05                 | 44,55     | 2,7 | 19 | 8,21                    | 0.02     | $A = \bar{K} + 3\delta$ |
| 27.09.2012   | 40,12                 | 45,03     | 2,4 | 45 | 8,28                    | 0.03     | $A = \bar{K} + 4\delta$ |
| Borehole №18 |                       |           |     |    |                         |          |                         |
| 10.02.2012   | 40,68                 | 44,35     | 2,9 | 20 | 25,19                   | 0.02     | $A = \bar{K} + 3\delta$ |
| Borehole №21 |                       |           |     |    |                         |          |                         |
| 05.01.2012   | 39,95                 | 44,42     | 2,3 | 20 | 23,68                   | 0.01     | $A = \bar{K} + 3\delta$ |
| 01.05.2012   | 40,00                 | 44,53     | 2   | 10 | 23,96                   | 0.01     | $A = \bar{K} + 4\delta$ |
| Borehole №27 |                       |           |     |    |                         |          |                         |
| 29.01.2012   | 40,33                 | 45,65     | 2,4 | 20 | 22,91                   | 0.04     | $A = \bar{K} + 3\delta$ |
| 28.09.2012   | 40,38                 | 45,53     | 2,3 | 25 | 21,93                   | 0.16     | $A = \bar{K} + 2\delta$ |
| 05.02.2021   | 40,51                 | 45,41     | 5,1 | 43 | 23,88                   | 0.02     | $A = \bar{K} + 2\delta$ |

D\*-epicentral distance,  $\bar{K}^*$  - background value, A\*-value of hydrogeodynamic effect, M- magnitude,  $\delta$  - dispersion

Thus, the geodynamics of the mentioned tectonic blocks limited by deep faults are described: Yerevan, Ararat-Sevan faults, the Garni deep transverse fault intersects the Yerevan tectonic block. The strengthening of the activity of the geodynamic processes of the earth's crust under study in the central region of Armenia confirms the seismic activity of the region in recent years, the spatial distribution of earthquake epicenters in the middle and on the borders of tectonic blocks, near-fracture zones of deep faults. The strengthening of the activity of the geodynamic processes of the earth's crust under study in the central region of Armenia confirms the seismic activity of the region in recent years, the spatial distribution of earthquake epicenters in the middle and on the borders of tectonic blocks, near-fracture zones of deep faults. Near meridional direction of the epicenters of the earthquakes, indicating the presence of deformation processes (compression), in the studied part of the region

The nature of changes in the level of water in hydrogeodynamic boreholes: raising and lowering, against the background of the trend, water levels in hydrogeodynamic boreholes, the presence of periodic sawtooth variations of the water level. Hydrogeodynamic and hydrogeochemical effects (tab. 1, 2) have been revealed preceding the earthquakes that occurred in the region. All of the above-mentioned reflects the increased activity of the Yerevan tectonic block and the concentration of stress along the Ararat-Sevan and Garni deep faults.

**3.2 Hydrogeochemical data.** The task of hydrogeochemical monitoring is to identify hydrogeochemical effects, generally in the changes of the macrocomponent and gas composition of water accompanying geodynamic movements of the Earth's crust. The monitoring network includes observations of hydrogeochemistry of mineral water sources. Surenavan (I), Vedi (II), Arzni (III), Bzhni (IV) (fig. 5). The quantitative composition of total mineralization and carbon dioxide dissolved in water mineral sources for the period of observation is presented on Fig. 6. Methodology for identifying hydrogeodynamic effects includes statistical methods of data processing and interpretation. The observations on mineral water sources. NN I, II started in 2006, and NN III, IV started in 2008. Hydrogeochemical anomalies have been revealed, mainly in changes in the macrocomponent and gas composition of water, preceding and accompanying geodynamic movements of the Earth's crust of central Armenia. Anomalies of the gas and macrocomponent composition of groundwater are a reflection of the stressed state of formations. Concentration changes under the influence of tectonic activity occur in a certain sequence. Gas composition is the first to react to the stressed state of formations: carbon dioxide (CO<sub>2</sub>), the second macrocomponent composition. In the current research, the obtained results of the geochemical composition of mineral waters for the last years are presented, comparing them with the seismicity of the region.

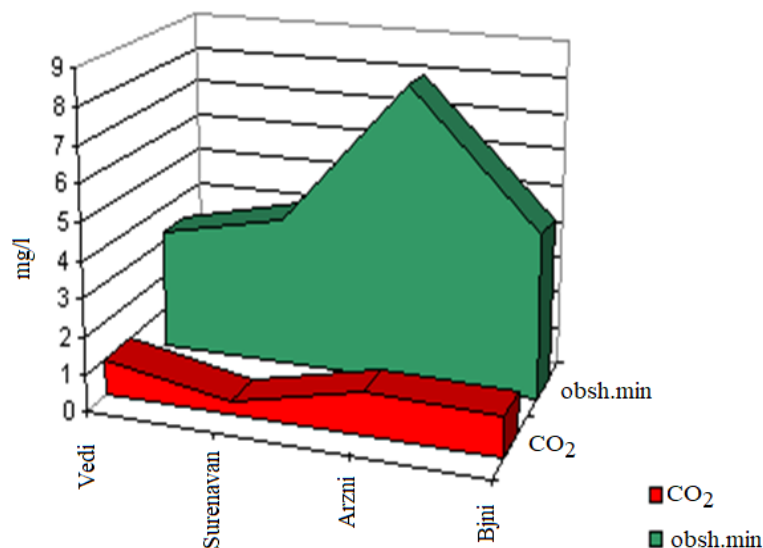


Fig.6.

Diagram of the content of total mineralization and dissolved in water mineral sources of carbon dioxide ( $\text{CO}_2$ ).

In the statistical processing of the data of geochemical time series, the method based on the estimation of variability of dispersion in time intervals was used. The considered forecasting method is based on statistical evaluation of the variability of carbon dioxide dispersion in adjacent time intervals. At the same time, the average value of the dispersion as borehole as the speed of its changes is used. The processing of time series of the change of concentration of carbon dioxide has been carried out based on the water of hydrogeochemical observation stations: NN II, IV. The average value of carbon dioxide content in water is 1161mg/l and 1957mg/l. The graph of variations of the time series

of carbon dioxide gas, according to the laboratory analysis of water samples of mineral springs and variations of the  $\text{CO}_2$  dispersion value was developed (Fig. 7). The obtained image reflects the periods of increase and correspondingly decrease of the dispersion values. The obtained results were compared with seismic events that took place at different distances from the observation point. Before seismic events, there is an increase in the dispersion value at the beginning, and then its decrease. Most often, seismic events correspond to minimal dispersion values, which can be taken as a prognostic sign [2].

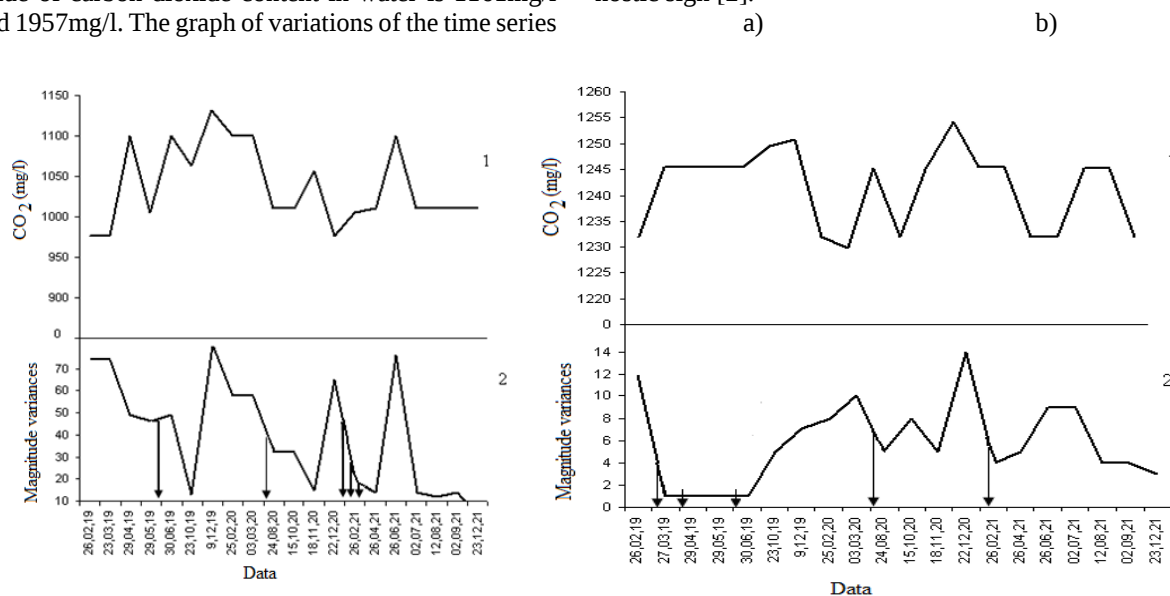


Fig. 7a,b. Graph of variation of  $\text{CO}_2$  concentration and its dispersion in the waters of mineral springs of Vedi (a) and Bjnim (b). 1-actual data, 2- dispersion. Arrows indicate earthquakes

According to the changes in the value of the total mineralization of the water of the Arzni mineral spring, there has been an increase in recent years, which indicates the deformation processes in the areas where the mineral waters are released due to the geodynamic processes of the Earth's crust. It is possible to assume that

the water-bearing rocks of the Arzni deposit are undergoing deformation-compression, which suggests the activation of tectonic movements of the Yerevan-Ordubad block, where the Arzni and Bjni mineral water deposits are located.

As a result of comparing the seismic regime of the region (for 2011÷2022) with the parameters of the chemical composition of mineral waters, hydrogeochemical effects preceding the geodynamic processes

of the earth's crust, in particular earthquakes, were received[2] (Table 2).

Hydrogeochemical effects according to the parameters of the chemical composition of mineral waters preceding earthquakes.

Table 2

| dd.mm.yy.  | Earthquake parameters |       |     |    | Hydrogeochemical effects |    |          |      |    |           |          |    |            |      |    |            |  |  |
|------------|-----------------------|-------|-----|----|--------------------------|----|----------|------|----|-----------|----------|----|------------|------|----|------------|--|--|
|            | φ                     | λ     | M   | D* | Mg                       |    |          | Cl   |    |           | obsh.min |    |            | HCO3 |    |            |  |  |
|            |                       |       |     |    | K̄*                      | δ* | A*       | K̄*  | δ* | A*        | K̄*      | δ* | A*         | K̄*  | δ* | A*         |  |  |
| Arzni      |                       |       |     |    |                          |    |          |      |    |           |          |    |            |      |    |            |  |  |
| 14.10.2011 | 40,3                  | 44,66 | 3,6 | 9  | 218                      | 2  | A=K̄+8 δ | 2503 | 8  | A=K̄+13 δ | 8371     | 11 | A=K̄+18 δ  |      |    |            |  |  |
| 13.02.2021 | 40,02                 | 44,49 | 4,9 | 38 |                          |    |          |      |    |           |          |    |            | 2055 | 6  | A=K̄+13 δ  |  |  |
| Bjni       |                       |       |     |    |                          |    |          |      |    |           |          |    |            |      |    |            |  |  |
| 14.10.2011 | 40,3                  | 44,66 | 3,6 | 29 | 73                       | 4  | A=K̄+2 δ | 427  | 11 | A=K̄+5 δ  | 4388     | 9  | A=K̄+4,5 δ |      |    |            |  |  |
| 06.06.2018 | 40,92                 | 44,28 | 3,1 | 40 |                          |    |          |      |    |           | 4614     | 32 | A=K̄+6 δ   | 2266 | 10 | A=K̄+3 δ   |  |  |
| Vedi       |                       |       |     |    |                          |    |          |      |    |           |          |    |            |      |    |            |  |  |
| 13.02.2021 | 40,02                 | 44,49 | 4,9 | 28 | 111                      | 9  | A=K̄+3 δ | 136  | 6  | A=K̄+3 δ  |          |    |            | 2002 | 7  | A=K̄+2,5 δ |  |  |
| Surenavan  |                       |       |     |    |                          |    |          |      |    |           |          |    |            |      |    |            |  |  |
| 13.02.2021 | 40,02                 | 44,49 | 4,9 | 39 |                          |    |          |      |    |           | 4051     | 28 | A=K̄+5 δ   |      |    |            |  |  |

background value, A\*-value of hydrogeodynamic effect,  $\bar{K}^*$  - b

Thus, changes in the gas and chemical macro component composition of mineral waters of central Armenia are an indicator of the stressed-deformed state of the Earth's crust in the region. The map of the stress-strain state of the Earth's crust in central Armenia was built based on the numerical values of calculated deformation values, located around each observation point of hydrogeodynamics and hydrogeochemistry, as a result of the earthquakes that occurred in recent years with M>3. Based on the obtained values of calculated deformations, maps of isolines of equal deformation

values were developed with the use of weight coefficients [8]. According to the map (fig. 8), in the central part of the region of Armenia, a compression structure is formed. The structure of the compression is most intense along the middle segment of the Garni fault and almost along the entire Ararat-Sevan fault. The resulting stress field is characterized by high values of deformations ( $E=10^{-6}$ ,  $10^{-7}$ ), which took place on the near-fault zones of the Garni and Ararat-Sevan faults, as a result of the earthquakes.

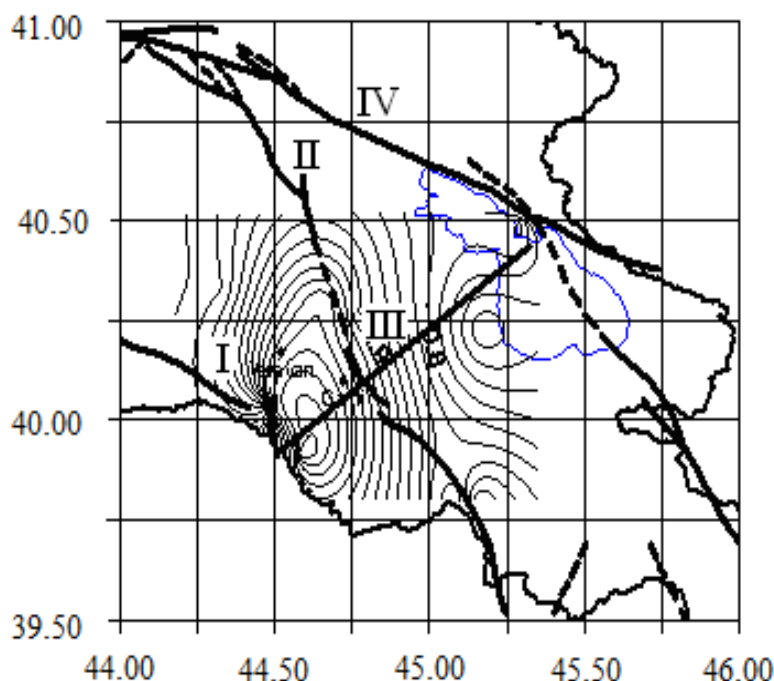


Fig.8. Map of stress strain state of Earth's crust of Central Armenia.-isolines of deformations, --- - deep faults: I-Yerevan fault, II- Garni fault, III- Ararat-Sevan fault, IV- Pambak-Sevan.

#### 4 Discussions

Processing and interpretation of hydrogeodynamic and geochemical data of groundwater in the region makes it possible to increase the reliability of assessing the stress-strain state of the earth's crust over time in the territory of Central Armenia [2].

Using the results of hydrogeodynamics and geochemistry of water and seismic regime in combination is important when analyzing data from monitoring the seismic geodynamics of the territory of Armenia [ 10].

#### 5 Conclusions

Paleotectonic analysis of the studied material according to a number of authors helps to identify seismically active and passive tectonic blocks and faults, as borehole as determine the nature and direction of modern tectonic movements.

The compiled seismicity map of Central Armenia indicates and confirms that strong earthquakes are confined to deep faults.

The seismic background of the study area is overestimated, which may contribute to the activation of geodynamic processes of the earth's crust in the central part of the region.

Hydrogeodynamic and hydrogeochemical precursor effects preceding the earthquakes that occurred during the research period were identified.

An assessment of the stress-strain state of the earth's crust in the territory of central Armenia is given, as a result of the interpretation of the data obtained on the water level of hydrogeodynamic boreholes, the geochemistry of mineral waters and the seismic regime.

It was also revealed that the change in tidal deformations can be taken as a prognostic sign. Slow drops (rises) in the level of groundwater in the form of a trend reflect long-term changes in the stress-strain state of the environment.

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# ECONOMIC SCIENCES

## GENGHIS KHAN'S ECONOMIC POLICY AND ITS CHARACTERISTICS

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### Abstract

The establishment of the Mongol Empire, which spanned Eurasia, was initiated by Genghis Khan and have been successfully expanded by his successor, Ögedei Khan, and their descendants for a few hundred years. The success of this empire has been undoubtedly attributed to its military might and organization. However, in this paper, we discuss the economic policies of Genghis Khan and Ögedei Khan that potentiated the Mongol Empire's military power and helped establish a vast empire where fair trade, communication, and exchange were possible throughout Eurasia. We believe that these policies enabled the Mongol Empire's economy to be what we would call a globalized economy today.

**Keywords:** Economic policy, Mongol Empire, Genghis Khan, Ögedei Khan, trade policy, economic infrastructure, tax system.

The fact that Genghis Khan was a brilliant economic policymaker is confirmed by the assessment by various researchers and "Washington Post" has named him "Man of the Millennium" in the 1990s. According to Washington Post, "Genghis Khan and his successors created a vast free trade zone covering Europe and Asia, strengthening the ties between Western and Eastern civilizations. It can be said that this was the General Agreement on Tariffs and Trade (GATT) system of the Middle Ages. They were the first to create a communication network connecting the world 700 years before the creation of the Internet."<sup>1,2</sup>

The question of what exactly the economic policy of Genghis Khan, man of the second millennium, was aimed at and by what mechanisms it was implemented, rightly attracts the attention of today's scholars. Genghis Khan's economic policy and the mechanisms by which it was implemented are recorded to some extent in historical sources such as "Mongolian Secret History", "Sudriin Chuulgan (Jāmi' al-Tawārīkh)", "Mongol National Encyclopedia", "Zasakh Bilig", and "Ikh Zazag Khuuli (The Yassa)". According to these sources, in addition to implementing specific economic and business measures, Genghis Khan implemented his economic policy using taxes, customs, and rewards. The main goal of his economic policy was to eliminate any pretexts that threatened the independence and sovereignty of Mongolia, strengthen its independence in all respects, and to revive the state's economy in a short time, and to reliably ensure the economic independence and freedom of his nation.<sup>3,4</sup>

In order to ensure the economic independence of the Great Mongolian Empire, he took specific measures to structurally reform the economy, such as developing

animal husbandry, regulating land relations, protecting the environment, regulating internal and external trade, economic infrastructure, state finance and the tax system, and widely use knowledge, talent, and technical and technological advances in economic activities.<sup>5</sup> Thus, when implementing decisive measures to develop the economy, first of all, nomadic animal husbandry was brought under the jurisdiction of the mingghan (a social-military unit of 1000 households) and the number of livestock was intensively increased.<sup>6</sup> The traditional Mongolian system of nomadic, agricultural, and military systems was changed and organized into a compact urban system. During the reign of Genghis Khan and his successors, livestock was kept under state protection and control, and was counted and accounted for annually.<sup>7</sup>

Within the framework of his policy on the development of livestock, he prioritized a fiscally frugal approach. Firstly, he promoted the economical use of livestock for food and economic purposes and encouraged the preservation and processing of livestock without loss. Secondly, he established proper rules for hunting various types of animals, determining under what conditions and when hunts are allowed.<sup>8</sup>

It is noted in the "Mongolian Secret History" that the Great Khan paid great attention to caring for his livestock, and this can be seen as an expression of his policy on agriculture. In 1206, when the Great Mongol Empire was established and Emperor Genghis Khan took over the reign, a new era began in which land relations were made a key component of state policy. In addition issues surrounding national independence, social and economic development, people's livelihood, customs, and environmental protection were legally guaranteed in a complex system.

<sup>1</sup> Joel Achenbach. "The era of his ways; In which we choose the most important man of the last thousand years", Washington Post, December 30, 1995.

<sup>2</sup> M. Hoang "Genghis Khan - An Emperor of All Men". New York, 2000.

<sup>3</sup> Ishjamt I. "Compilation of Mongol Historical Writings", Ulaanbaatar, 1998.

<sup>4</sup> Nyamosor N. "Mongol Economy and Society in the 13th Century: Execution of Great Yasa Law", Ulaanbaatar, 1999.

<sup>5</sup> Dorj Tudev, "The charm of leadership of Genghis Khan", pp 169, Ulaanbaatar, 2016.

<sup>6</sup> B.Y. Vladimirtsov "Chingiz Khan; The Social system of the Mongols: Mongolian Nomadic Feudalism", Moscow, 1934.

<sup>7</sup> Bayanjargal Ch. "Economic Policy and Legacy of Genghis Khan", Ulaanbaatar, 2004.

<sup>8</sup> Jack Weatherford, "Genghis Khan and the Making of the Modern World", pp 84, Crown and Three Rivers Press, 2004.

At that time, the owner of the entire land was the ruler of the state, Genghis Khan. For other purposes, land was only lent for usage. At that time, land was divided the following 3 types;

1. The State Land. Land which is under the complete control of the Khan or the land belonging to the mingghan

2. The Protected Land. This was the land granted by Genghis Khan to the Golden family (Genghis Khan's direct relatives) for generations to own, and was called "inj".

3. The Gift Land. This was land that was awarded as a reward to nobles, military commanders, and others who had served the emperor (the state and the people) and had rendered meritorious service, and was called "tushee". Not only the lands protected by Genghis Khan, but also the lands under the authority of the Golden family, the Tumen (a social-military unit of 10000 households), and the Mingghan commanders were not their own property, but were deemed their possessions.<sup>9</sup>

Genghis Khan paid special attention to trading with neighboring countries, and as a result foreign merchants came to Mongolia freely. For example, the "Mongolian Secret History" records that "Genghis Khan met a merchant named Hasan of Sartuul at Lake Balzhun, who was buying ten thousand sabres from Alahushdigithur of Ongud and sabres and squirrels from the people living on the Ergune River."<sup>10</sup> It is also recorded that Genghis Khan sent multiple envoys to Khorezm with a proposal to trade, but the envoys were repeatedly massacred, causing him to declare war with the country, which he won and occupied Khorezm. Thus, with the establishment of an empire spanning Asia and Europe, a global free trade zone was established. By paying close attention to the importance of international trade relations in the development of the national economy, and by actively developing it and taking practical steps, Genghis Khan can be considered to have laid the foundation for the current economic globalization of mankind.<sup>11</sup>

Among the five major Mongolian livestock, horses were of particular importance. This is because horses were not only ordinary livestock, but also were military defense and had strategic importance. In volume I of his work "Khalkh Towchoon", the famous Mongolian historian Gongor. D argues that the Ministry of Horse Breeding used to carefully count the state's horse herd every year and report to the Khan of how it grew or perished, and that no one except the Khan was allowed known the exact number of horses in the herds.<sup>12</sup>

Crafting also played a significant role in the Mongol economy. Since ancient times, every Mongolian had a tradition of making various weapons and ornaments from wood, clay, bone, leather, bronze, iron, gold, silver, and stone.<sup>13</sup>

When leading the state of the Great Mongol Empire, Emperor Genghis Khan used to reward those who had worked hard and devotedly, to stimulate their enthusiasm, activity, and interest. Genghis Khan, after seeing the results of people's work, generously rewarded those who had achieved success with high positions and valuables, regardless of their social status, whenever possible. The rewards were both material and emotional.<sup>14</sup>

In continuation of his father's policy, Ögedei Khan, while expanding Genghis Khan's political reforms, paid great attention to the issue of economic management. There is reason to believe that the success of Ögedei Khan's economic policy was associated with some of the specific advantages of his policies. During Ögedei Khan's reign, handicrafts and manufacturing were greatly encouraged. In addition to manufacturing military products such as weapons, armors, curved swords and bows suitable for slashing and shooting from horseback, great attention was paid to establishing and operating industries for the household needs of herders, such as ger carts and simple carts that could be pulled by three, four, or more oxen. There is evidence that there was a smelting furnace (factory) in the city of Kharkhorum.<sup>15</sup> Ögedei Khan established many handicraft factories in Mongolia and employed about 200 thousand domestic and foreign craftsmen and builders for crafting.<sup>16</sup>

Ögedei Khan's customs and tribute policy had a significant impact on the development of the country's economy. In 1229, he issued a law on the unified state tribute to be collected into the Khan's treasury, and established the amount and procedure for the tribute to be collected from livestock and agriculture.<sup>17</sup> In addition, he inspected and weighed the land of foreigners who settled in Mongolia and imposed taxes. In 1233, an amendment was made to the state tax law, and a tax was levied on horses, cattle, and sheep for every 100 heads. Taxes on traders were also tightened. In 1230, the Salt Tax Law, in 1234 the Trade Customs Law, and in 1236 the Millenary Law (10.149) were issued, and customs duties were collected in accordance with world standards, taking into account the income of foreign and domestic merchants.<sup>18</sup>

An orphan support fund was established, and measures were taken to provide scholarships to the families of heroes who had died in the war, and to reduce and exempt the lower classes from taxes. In 1236, Ögedei Khan issued a decree that issued paper money, which was the first in the world. The Ministry of Internal Affairs was established in 1231 and headed by Yulai Chu Cai, the Khan's son-in-law. Yulai Chu Cai also initiated the separation of military and civil administration in the same year. This meant that the military governors and millenary governors were only responsible for military affairs, and the collection of tribute and other land affairs were handled by specially appointed officials. This was the

<sup>9</sup> History of Mongol State. Vol. 5. pp 143, Ulaanbaatar, 2003.

<sup>10</sup> The Secret History of the Mongols, Ulaanbaatar, 1990.

<sup>11</sup> Adam Hart-Davis, "History: The Definitive Visual Guide: from the Dawn of Civilization to the Present Day", London, 2007

<sup>12</sup> Gongor D. "Chronicle of the Khalkha Mongols. Vol. I", Ulaanbaatar, 1978.

<sup>13</sup> Amar A. "A Concise History of Mongolia", Ulaanbaatar, 1989.

<sup>14</sup> Natsagdorj Sh. "Chronicles of Genghis Khan", Ulaanbaatar, 1991.

<sup>15</sup> Ishtseren. L, Sasada. T, et. al., "Some results of the chronological study of ancient iron ore smelting furnaces", *Ancient studies; Studies on Nomadic Cultures*, Ulaanbaatar, 2024

<sup>16</sup> John Larner, "Marco Polo and the Discovery of the World", *Yale University Press*, 1999.

<sup>17</sup> History of Mongol State. Vol. 5., Ulaanbaatar, 2003.

<sup>18</sup> Unen Setsen "Studies on the Secret History of the Mongols", *Indiana University Press*, 1965.

beginning of a completely new relationship of management, separating military and civil affairs.

During the reign of Ögedei Khan, a unified monetary and financial policy was implemented throughout the Empire. A census was taken in 1233-1236. Tax and credit policies were reformed. Merchants were banned from lending money at excessively high interest rates. Ögedei Khan enriched the political and state reforms of Genghis Khan with economic reforms and business reforms. It is said that the great task of dismounting from concurring and governing the great empire built by Genghis Khan on horseback began precisely with Ögedei Khan.<sup>19,20</sup>

Let us consider the purpose of the mechanisms noted in historical sources, regarding the specific economic measures, as well as the mechanisms of customs, taxes, and incentives that were used as incentives for the implementation of economic policies. Regarding taxes and customs, Genghis Khan established and implemented the norms of taxes and tributes to form the treasury of the Great Mongol Empire. The amount of official taxes varied in the regions of the Great Mongol Empire, and in general, once a year, if one head of livestock out of a hundred was less than one hundred, the official tribute was exempted, 1 tar was taxed on each hectare of grain from the peasants, and any other goods could be taxed, and the rich were obliged to pay 7-10 dinars in taxes per year.<sup>21</sup> It is noted in historical records as follows, "The king, who has inherited the wealth from his great father should not burden the citizens, and should only be given a sheep from his country for soup every year. Only one sheep out of a hundred should be slaughtered, and spare some for the poor. Wonder how drink would be taken if all was taken from the citizens every time his brothers and sisters, and the great benefactors gather? He should be given a mare from each myanggan, and permanent milkers should be employed for milking, and herdsmen for herding those mares, and they should be exchanged regularly, and some should be employed for herding the foals."<sup>22</sup>

The government of the Great Mongol Empire exempted the elderly and the disabled from taxes, and provided tax relief under certain conditions. Intellectual workers, monks, and religious figures were exempted from paying taxes within the scope of the Great Mongol Empire, and other citizens were obliged to pay customs duties. In the classical formulation of economic theory, serfs paid both product and labor for their taxes. However, the form of monetary taxes was almost nonexistent at that time.

An official called "darguchi"<sup>23</sup> was appointed and employed, who was responsible for conducting a census of the country's population, determining and collecting the appropriate taxes from them, and transporting them to the capital of the empire. Darguchi were special administrative representatives or deputy governors appointed by the Great Khan in the conquered territories and were the tax collectors. Initially, Darguchi were associated with military affairs, but later they became

exclusively civil servants. During the empire, the Darguchi system spread rapidly throughout the conquered countries of Asia and Europe. An example from historical reports about darguchi system is as follows, "Genghis Khan has issued a decree that "A darguchi was appointed in all settlements. Father and son named Yalav and Mashud Khurumi from the Sartuul clan, came from the Urungechi settlement and discussed the customs of their settlements with Genghis Khan, and they were told about the taxes and customs. Mashud Khurumi was appointed the chief for the settlements of Bukhara, Semisgei, Urungechi, Odan, Kisgar, Uriyan, Gusen, and Daril, while Yalav, the father, was appointed to the Khitan Enund settlement. Since they knew of the customs and traditions of settlements among the Sartan people, they were appointed to govern over the Khyatan citizens and serve as their leaders". Thus, an independent special organization with tax collectors called "Darguchi" worked throughout the empire and established tax and tribute standards, which on the one hand formed the state budget, and on the other hand, implemented flexible tax policies such as discounts and exemptions, which varied depending on the living standards of the people.

As Genghis Khan deeply felt that the independence of Mongolia would ultimately be secured by the growth of its economic power, he consistently pursued his economic policy and skillfully implemented economic levers and mechanisms, thereby developing and strengthening the economic base of all Mongolia, uniting many countries and states and established a unified Great Mongol Empire.

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<sup>19</sup> Natsagdorj Sh. Duke Toh and his Disciples. - Ulaanbaatar, 1968.

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<sup>21</sup> Boldbaatar. J, Baasanjav. Z, "History of the World", pp 149, Ulaanbaatar, 2002.

<sup>22</sup> Dalai Ch. "Compilation of Some Chronicles of the Mongol's History", Ulaanbaatar, 1995.

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**ANALYSIS OF MECHANISMS FOR STATE REGULATION OF INNOVATIVE DEVELOPMENT  
AND DIRECTIONS FOR THEIR OPTIMIZATION****Laibing Xu,**ORCID: <https://orcid.org/0009-0005-4114-1541>**Hairu Yu***National Technical University of Ukraine "Igor Sikorsky Kyiv Polytechnic Institute"*

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DOI: [10.5281/zenodo.17170460](https://doi.org/10.5281/zenodo.17170460)**Abstract**

This paper examines the mechanisms of state regulation in promoting innovation and development, highlighting key regulatory tools, policy frameworks, and economic incentives. We use empirical data from multiple countries to evaluate the effectiveness of these mechanisms and propose optimization strategies. Drawing on Schumpeterian and endogenous growth theories, this study emphasizes the importance of technological progress and knowledge spillovers in economic development. The role of the state is analysed in the context of market failures, the availability of public goods, and institutional economics. In addition, we focus on case studies from China and Ukraine to illustrate the practical application of these mechanisms and provide a comparative analysis of their regulatory approaches. The results of the study provide insights for improving policy efficiency and ensuring sustainable innovation growth.

**Keywords:** National Regulation, Innovation Policy, Economic Development, Optimization, and Empirical Analysis.

Innovation and development are important drivers of economic growth, technological progress and improving national competitiveness. Economic growth is a tool to measure the development and progress of a country, and technological innovation is one of the factors influencing economic growth, which contributes to the development and modernization of production methods. Therefore, technological innovation is a major driver of economic growth and human progress. Spending on innovation, R&D, and investment in innovation supports competition and progress. As a result, sustainable economic growth has been achieved. This ensures the conservation of resources for future generations and economic and social growth [1]. Effective national regulation plays a key role in shaping innovation ecosystems by providing financial incentives, legal frameworks, and institutional support. This paper explores various regulatory mechanisms and evaluates their effectiveness using empirical data. Innovative concepts that have traditionally been limited to technological advancements have transcended their traditional boundaries. The mechanism for the state to regulate and develop innovation now covers a wider range of aspects, integrating economic, social and policy dimensions. We suggest that "innovation cooperation" is a better framework than "technology transfer" to advance international efforts at technology for sustainable development. Such a framework allows for a broader and more holistic perspective on technology-related cooperation between countries. It also stresses the need for equitable partnerships, rather than donor-recipient relationships, and the need to develop local innovation capacities to more effectively mobilize technology to help developing countries achieve sustainable development [2]. In this context, the role of national governments goes beyond mere regulation and extends to being active promoters and catalysts of innovation.

Innovation remains a key driver of economic growth, requiring the creation of novel and enhanced products and services that trigger an increase in eco-

nomic activity. For an invention or service to be considered an innovation, it must contribute significantly to the national economy by contributing to the optimal use of resources and the creation of a competitive advantage.

The concept of innovation dates to the beginning of human existence and has played a key role in improving labor productivity and the global economy. Nevertheless, modern innovation systems are distinguished by their unparalleled speed of implementation of new ideas.

The development of world civilization shows that the phenomenon of "innovation" is considered a paradigm for national development. Thus, the innovative development of the national economy usually refers to the process of social production, the key feature of which is the use of accumulated knowledge and its transformation into innovation. Only after that can innovation become the basis for the growth of the national economy and be appropriately adapted to dynamically changing conditions. This process is initiated in the context of the economic growth strategy and involves the renewal of the engineering and technological base of production, which is related to the reduction of energy and resource intensity, the reduction of environmental burdens, the increase of labor productivity, the comprehensive development of individual capacities, the increase of motivation to carry out creative (including scientific) activities, the process of democratization of society, etc. Innovative ideas for the development of the national economy can be implemented through a well-developed system of relations and institutions that create the necessary conditions for the implementation of scientific and technological progress within the framework of a well-defined national development strategy [3].

**Government Policy & Innovation**

Direct investment in R&D can be achieved through an effective way for governments to regulate innovation development mechanisms: governments

fund basic and applied research through grants, subsidies, and public research institutions. Tax incentives and fiscal support: R&D tax credits, venture capital support, and low-interest loans encourage private sector innovation. Strengthen IP protection: A strong patent system incentivizes innovation by ensuring a return on investment. Promoting innovation clusters and industrial policies: The government promotes the development of regional innovation hubs and strategic industries. At the same time, government efficiency has a positive impact on innovation output, which promotes innovation output by improving government efficiency [4].

We can also further analyze from the direction of the guiding mechanism, from the direction of the market-oriented mechanism, rationally use market incentives to protect the property rights of scientific and technological innovation, and incentives for the transformation of achievements to mobilize the enthusiasm of enterprises and scientific research institutions, and use investment and financing means to guide the flow of capital to high-risk and high-return innovative enterprises, such as venture capital, government guidance funds, etc., to maintain the social competition mechanism through the market fair competition mechanism to eliminate backward production capacity and stimulate the innovation vitality of enterprises.

From the perspective of policy-oriented mechanism, the use of financial support, industrial policy, science and technology policy and other measures to play the role of government policy at the macro level, through financial allocation, subsidies, national procurement, tax exemption and other ways to guide the

flow of resources to key innovation areas, and formulate priority development of industrial directions (such as new energy, high-end manufacturing, digital economy, artificial intelligence, etc.). We will set up major national science and technology projects to promote basic research and original innovation, further release the advantages of scientific and technological production capacity and create an ecological chain of new enterprises empowered by science and technology.

In terms of the guidance mechanism of laws and regulations, we will improve the system of scientific and technological patent protection and trade secret protection, formulate relevant international protection laws on scientific and technological intellectual property rights, and protect the rights and interests of the achievements brought about by scientific and technological innovation. Formulate scientific and reasonable standards and rules for innovation evaluation, avoid the failure to implement scientific and technological achievements, lack of scientific and technological practicability, and establish review and social ethics norms in the development of new technologies (such as bioengineering, AI, and new energy).

Based on having effective ways and guidance mechanisms, we should strengthen innovation-oriented performance evaluation, establish a multi-evaluation system that includes social, environmental and ethical dimensions, promote "shifting from input-oriented to output-oriented", pay attention to innovation results and value realization, carry out systematic coordinated development, and "correct the direction" of guidance failure or side effects in a timely manner.

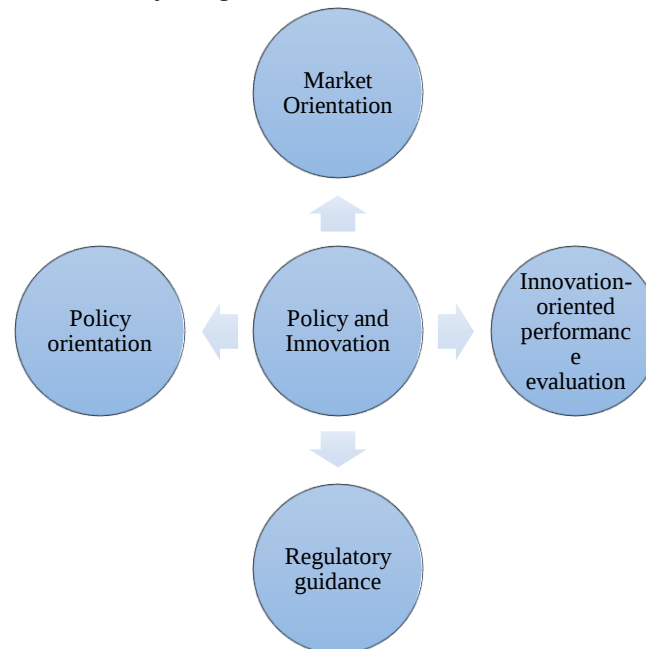


Figure 1: Government Policies and Innovation-Oriented Mechanisms

#### Analysis of regulatory mechanisms

Implement the basic functions of the regulatory mechanism and supervise in accordance with laws and regulations: ensure that innovative behaviors comply with laws and regulations and national strategic directions. Formulate risk prevention and control mechanisms: especially in the fields of financial technology

and biomedicine, to prevent systemic and ethical risks. Dynamic supervision mechanism: In view of the rapid evolution of technology, flexible mechanisms such as "sandbox supervision" and "inclusiveness and prudence" are implemented. Inclusive Prudential regulation aims to pursue a dynamic balance between efficiency and safety, and it requires the government to

give the necessary time and room for trial and error in the development of new business forms, and to intervene in a timely and appropriate manner according to the size of public risks, which is a new regulatory model that is conducive to solving the traditional regulatory dilemma [5].

Problems in the regulatory mechanism, the lag of institutional iteration: the development of emerging technologies is faster than the adjustment of regulatory mechanisms (such as AI, blockchain, etc.), it is recommended to improve the level of regulatory technology and introduce regulatory technology: the use of big data, artificial intelligence and other means to improve the accuracy and real-time nature of supervision. Construction of digital monitoring platform: Build a national database of innovative behaviors to achieve dynamic data analysis and risk early warning.

Multi-departmental supervision, poor coordination: inter-departmental functions are crossed, data is not shared, reducing regulatory efficiency, it is recommended to build a coordinated and efficient supervision system to establish a cross-departmental linkage mechanism: such as the "ministry + local" joint supervision team to achieve information sharing and rapid response. Promote "inclusive and prudent" regulation: Implement regulatory sandboxes in emerging areas that allow for controlled trial and error.

It is recommended to optimize and improve the legal and regulatory system and revise relevant laws and regulations in a timely manner: in view of the rapid changes in emerging industries, establish a rapid legislative response mechanism. Strengthen the protection mechanism of intellectual property rights: optimize the patent examination procedure and increase the punishment for infringement.

Uneven local regulatory capacity: unbalanced regional development, resulting in significant differences in policy implementation effects Strengthen local governments' innovative regulatory capabilities Classified and hierarchical supervision: Formulate regulatory standards and implementation strategies according to local conditions. Local pilots drive national promotion: accumulate experience through regional pilot reforms, and then replicate and promote them nationwide.

As an institutional guarantee for the government to regulate and control innovation and development, the regulatory mechanism plays an irreplaceable role in guiding technology for good, avoiding systemic risks, and creating a fair innovation environment. The complexity of the modern innovation ecosystem requires the regulatory mechanism to shift from "static compliance" to "dynamic collaboration", from "command-based management" to "flexible and inclusive", and from "domestic control" to "global collaboration". Only by building a systematic, intelligent and ethically com-

patible regulatory system can we truly achieve a balance between innovation and development and social responsibility.

### **Empirical research and comparative analysis**

Take, for example, the innovative cooperation between Chinese and Ukrainian enterprises.

#### **Case 1: "Madasich" acquisition case**

Madasich is a world-influential aircraft engine manufacturing enterprise in Ukraine [6]. In 2017, China Tianjiao Airlines signed an acquisition agreement with a Ukrainian company with the intention of introducing key aviation power technologies. However, the National Security Service of Ukraine blocked the transaction on national security grounds and froze the trading assets under pressure from the United States, and ultimately failed to complete the transaction. The Chinese company then initiated international arbitration.

The case reflects the opaque regulation of the Ukrainian state in terms of strategic technology exports and its vulnerability to external political interference. At the same time, it also shows that Chinese enterprises face technology transfer barriers and institutional uncertainty in overseas acquisitions. The absence or imbalance of the national regulatory mechanism directly restricts the smooth progress of innovation cooperation. From Schumpeter's point of view, the instability of the institutional environment inhibits the release of entrepreneurship and the continuous advancement of innovation.

#### **Case 2: Sino-Ukrainian agricultural technical cooperation project**

In the context of the Belt and Road Initiative, some Chinese agricultural technology companies have invested in the development of agricultural technologies in Ukraine, including intelligent irrigation systems, seed improvement, and the introduction of agricultural machinery and equipment [7]. Under the policy promotion, the local government of Ukraine provides land resources and tax incentives, and Chinese enterprises bring technology and management experience. This cooperation has significantly improved local agricultural productivity in a short period of time and has formed a good demonstration effect.

However, in the process of implementation, some enterprises are facing investment uncertainty due to problems such as unclear property rights and weak contract enforcement in the Ukrainian land system. This shows that although good macroeconomic policies can promote the initiation of cooperation, a sound legal system and regulatory mechanism are the foundation for ensuring the stability of cooperation. From the perspective of endogenous growth theory, the project is conducive to knowledge diffusion and human capital improvement, but institutional deficiencies limit its continuous spillover effect.

Table 1

## Comparison of typical cases of innovation cooperation between Chinese and Ukrainian enterprises

| The name of the project            | Content of cooperation                            | Support Mechanism                      | issue                                                                                                                                         |
|------------------------------------|---------------------------------------------------|----------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------|
| Acquisition of Madasic             | Introduction of aero engine technology            | Bilateral agreements of intent         | The Ukrainian government blocks, political interference, and the supervision of national technology export needs to be transparent            |
| Agricultural technical cooperation | Seed breeding, irrigation, agricultural machinery | Policy encouragement and local support | The property rights of the land are unclear, the contract execution is poor, and the rule of law guarantees the implementation of cooperation |

Comparative analysis of the regulation and supervision mechanisms of China and Ukraine. A comparison of the mechanisms between the two countries shows the following significant differences:

**Policy formulation mode:** China is characterized by government-led policies, relying on national planning and top-level design, and has strong policy stability; However, Ukraine's policies change frequently, and there are problems such as insufficient implementation and great influence of political fluctuations.

**Technology transfer supervision:** China has a clear approval mechanism for technology import and export, and it is supervised by classification and level. Ukraine,

on the other hand, lacks a systematic export control system and often intervenes ad hoc administration, causing uncertainty in cooperation.

**Legal and intellectual property protection:** China has established a relatively complete intellectual property protection mechanism and has set up special courts to handle technology disputes. Although Ukraine has relevant legislation, the level of law enforcement and judicial guarantees is low.

**Market participation mechanism:** Chinese enterprises have strong innovation vitality and experience in government funding, market demand and international cooperation. Ukrainian enterprises rely on national research institutes and lack market-driven and technology transfer platforms.

Table 2

## Comparison of key elements of the national regulatory mechanism of China and Ukraine

| Key elements                            | Situation in China                                                                               | Situation in Ukraine                                                        |
|-----------------------------------------|--------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------|
| Policy stability                        | High (Five-Year Plan, Long-term Strategy)                                                        | Low (frequent party turnover)                                               |
| Technology export/introduction control  | Clarify the classification and approval system                                                   | Lack of systematic criteria, ad hoc interventions                           |
| Intellectual property protection system | Perfect, with specialized courts                                                                 | Regulations exist, but enforcement is poor                                  |
| Enterprise innovation driven            | The market is active and the combination of government, industry, academia and research is close | Rely on scientific research institutions, and lack of marketization         |
| Transparency of cooperation             | Higher                                                                                           | There is a lot of political interference, and the information is not public |

**Policy implications and optimization suggestions**

As far as China is concerned, it should continue to strengthen the compliance review mechanism for foreign technical cooperation, establish a platform for tracking and evaluation of Belt and Road investment projects and digital supervision and strengthen the whole-process supervision and risk early warning of overseas cooperation projects.

For Ukraine, it is necessary to promote the construction of the legal system in the field of technology, clarify the list of national strategic technologies, optimize the foreign investment management system, and

introduce China's successful experience in the construction of science and technology parks and the mechanism for the transformation of achievements.

At the bilateral level, it is proposed to establish a "China-Ukraine Coordination Committee for Scientific and Technological Cooperation", establish a joint review mechanism and a security framework for technology transfer, and enhance the transparency and trust of cooperation on the basis of respecting national interests.

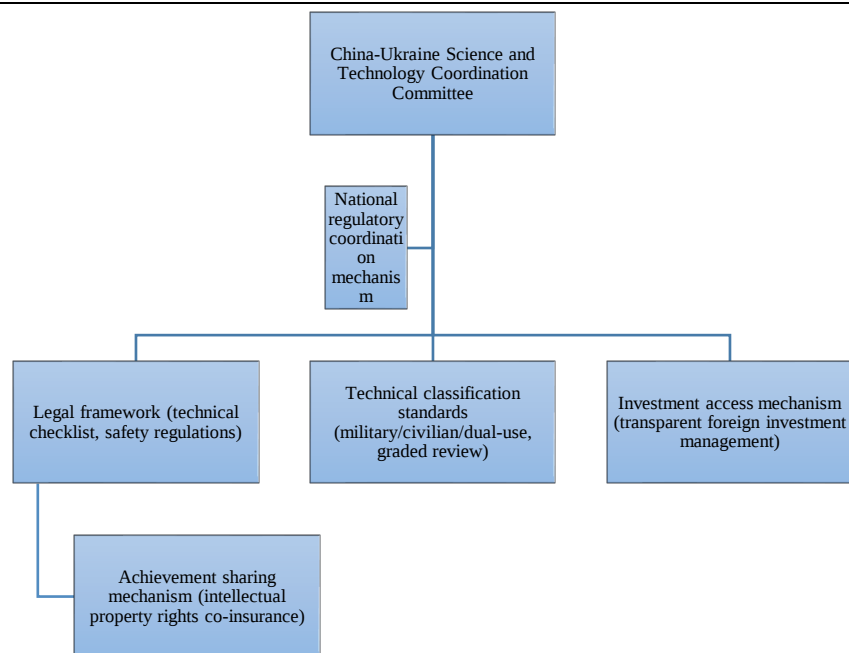


Figure 2: Roadmap for the optimization of the regulatory mechanism for China-Ukraine innovation cooperation

### Conclusion

The innovation cooperation between Chinese and Ukrainian enterprises has great potential in terms of technological complementarity and market mutual benefit, but the degree of matching between the state regulation and regulatory mechanisms determines whether the cooperation can be promoted steadily. Through the empirical evidence and institutional comparison, it can be seen that relying solely on market promotion is far from enough to ensure the long-term benefits of cooperation, and it is necessary to establish a coordinated, efficient and law-based cooperation mechanism at the national level.

In the future, on the basis of jointly improving the regulatory system and cooperation platform, China and Ukraine are expected to achieve high-quality innovation and win-win results. Guided by Schumpeter's innovation theory and endogenous growth model, China-Ukraine cooperation can form a virtuous circle in terms of institutional incentives, knowledge dissemination and technology accumulation, encourage non-governmental cultural innovation exchanges, support industry-university-research cooperation between universities of the two countries, and inject endogenous impetus into the sustainable development of the bilateral economy.

When using the established rules and mechanisms to deal with specific matters, the two sides need to avoid being bound by the rules, and need to follow the development of the times to timely regulate, innovate, and optimize the development mechanism to form a virtuous circle.

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## IMPORTANT FACTORS AFFECTING THE DEVELOPMENT OF ORGANIZATIONS IN SUBSOIL INDUSTRY

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### Abstract

The essence of the economic system of subsoil use is examined, including its content, elements, and features in a mixed economy. Particular emphasis is placed on the evolution of economic theory and the role of the state as the primary regulator of economic entities operating in the mineral resource complex and its infrastructure. The text illustrates the role of modern economic theory as a science in developing and justifying the principles of the territorial-economic system of subsoil use, both theoretically and practically.

**Keywords:** subsurface use sector, subsurface use management, subsurface use management mechanisms, organizational and economic mechanisms, small and medium-sized subsurface use organizations.

The economic system of subsoil use is a historically established and enshrined in law, operating in the subsoil use sector as a set of principles, rules, and norms that determine the form and content of the main economic relations between entities arising in the process of production, distribution, exchange, and consumption of economic products obtained from the subsoil. In practical terms, it represents a specially organized system of relations between economic entities that directly or indirectly ensure the production, distribution, exchange, and consumption of resources naturally found in the earth's subsoil.

The functioning of the economic system of subsoil use should be aimed at fulfilling the most important socio-economic tasks of society:

- ensuring the economic growth of all entities involved in subsoil use;
- coordinating all types of economic activity in the field of subsoil use;
- creating favorable socio-economic conditions that contribute to improving the quality of life in the country and region; complying not only with the country's industrial policy, but also creating favorable conditions for the implementation of the social goals of the entire national economy [1].

An important characteristic of the economic system of the subsoil use sector is that it covers the entire set of economic relations arising in the process of human interaction with the earth's resources in order to transform them into elements of life. That is why the functioning of the subsoil use sector is linked to the emergence of many social problems in society, and not only of an economic nature.

It is well known that the subsoil use sector generates the most significant portion of funds at the national level. However, this raises a legitimate question: how effectively and fairly are these funds being used?

The state protects its rights as the owner and creates conditions and prerequisites to ensure that the processes of development and use of non-renewable mineral resources are in the public interest. The current situation in the field of subsoil use in Kazakhstan, on the contrary, illustrates what can happen when the system of basic and complementary institutions that determine the norms, rules, and procedures for involving subsoil resources in economic circulation is incomplete. As a

result, the interests of the controlling shareholders of subsoil user companies have been taken into account in the process of developing and using mineral resources, rather than the interests of society.

On the other hand, social factors play a very important role in the dynamics of innovative development in the field of subsoil use. Without changing the essential nature of the economic system of subsoil use, its content is transformed in the process of its development. Both the quantitative and qualitative characteristics of economic entities elements of the system and the content and forms of interaction between them change.

The economic system of subsoil use involves not only economic processes based on the property relations that have developed in the relevant subsoil use sectors. This system also involves organizational and management processes based on the diversity and development of various organizational and legal forms of economic activity of entities in the subsoil use sector, as well as direct production processes that ensure the extraction, enrichment, transportation, etc. of land resources. Therefore, from our point of view, the economic system of the subsoil use sector is only a component (albeit a very important one) of the complex economic system of the subsoil use sector. The results of research conducted over the past two decades confirm the fact that in practice there are no purely economic (and even less so financial) mechanisms for subsoil use: there are organizational and economic, organizational and managerial, economic and managerial mechanisms, etc [2].

The economic system of subsoil use is an eco-socio-economic system. Its economic goals cannot and should not be achieved without addressing environmental and social issues. However, these tasks are often associated with the implementation of certain types of non-economic efficiency, which in some cases contradict traditional, generally accepted criteria of economic efficiency. At the same time, the current activities of a particular economic entity or its project management are, by their nature, unprofitable or even loss-making. Therefore, in our opinion, assessing the efficiency of the economic system of the subsoil use sector solely from the perspective of profitability and return on investment criteria does not take into account the usefulness of many types of infrastructure activities that create the necessary conditions for its normal functioning

[3]. In turn, a reliable system for supporting core activities is necessary for the effective operation of the main production units of subsoil use companies and their economic efficiency as a necessary condition for economic growth not only at the micro level, but also for improving the quality of life in the relevant region and the country as a whole, at all levels of economic management.

The functioning of the economic system of the subsoil use sector is a set of interactions between its elements - economic entities linked by certain relationships, among which financial and legal relationships occupy a central place. At the same time, the forms of ownership of the interacting economic entities may vary. Their coexistence is the basis for the development of various organizational and economic forms of public-private partnership [4].

Under the general laws of globalization and integration of the world economy, the laws governing the functioning of the economic system of subsoil use extend beyond its internal environment and beyond the system itself. From this perspective, issues related to the functioning of the internal market of the territorial-economic system of subsoil use take a back seat. Small and medium-sized businesses in the subsoil use sector occupy a modest position for objective reasons, while the activities of transnational corporations cannot be confined to the rigid boundaries of the relevant territory. Therefore, subsoil use is characterized to a greater extent by inter-country and inter-regional interactions based mainly on commodity-money relations. The internal market within the territorial-economic system of subsoil use, as a closed system, has minimal capacity in reality and in some cases practically does not exist [5].

On the other hand, there are many regions in the national economy with a pronounced raw materials specialization, including single-industry towns and urban-type settlements, whose infrastructure directly depends on the nature of the work of one or two city-forming enterprises. However, even in this case, the financial support of the municipal and social infrastructure of the relevant territory is mainly provided on the basis of inter-country and inter-regional interactions, which can be both inter-sectoral and intra-sectoral in nature.

Modern economic theory reserves for itself the development and justification of the principles of functioning of the territorial-economic system of subsoil use. The practical significance of this work lies, first, in assessing the place of the market in this system alongside existing areas of weakened and completely absent markets in order to identify the forms and scope of economic laws; secondly, in assessing the place and role of

the state in this system at all levels of government; thirdly, in assessing the effectiveness of the functioning of subsoil use enterprises in terms of their impact on the development of the territory and the country as a whole [6].

The results of economic research show that the growth of export prices for mineral resources, on the one hand, creates favorable conditions for the growth of both its revenues and those of the regions and the country as a whole. On the other hand, it "washes out" resources from the territorial-economic system of subsoil use as a closed system and thus reduces the business activity of many domestic enterprises. However, this is not always the case. According to the results of even more global studies, it should be noted that internal and external interactions can behave in three ways: dominate each other, compete with each other, or support each other. All these interactions are usually of a flow nature. Therefore, in some cases, we may be talking not about individual interactions, but about flows of interactions.

Based on an analysis of the key determinants of the modern development of economic systems and the economic system of subsoil use, in particular, it can be concluded that research into the economic system of subsoil use should be based on the integration of closely interrelated political-economic and institutional approaches.

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# HISTORICAL SCIENCES

## НАУЧНЫЕ ОТКРЫТИЯ НА ВОСТОКЕ И ЗАПАДЕ (СРАВНИТЕЛЬНЫЙ ПОДХОД НА ОСНОВЕ ИСТОРИЧЕСКИХ МАТЕРИАЛОВ)

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## SCIENTIFIC DISCOVERIES IN THE EAST AND WEST (COMPARATIVE APPROACH BASED ON HISTORICAL MATERIALS)

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### Аннотация

В статье рассматривается Средневековый период (VII-XV вв), как в странах Востока, так и Запада, где наблюдались значительные научные и технологические достижения. С незапамятных времен люди наследовали свои знания от предыдущих поколений, совершенствовались на их основе, адаптируя эти знания к своим нуждам, передавали их будущим поколениям. Знания собирались с помощью упорных наблюдений, по мере накопления опыта, а также благодаря интуитивной прозорливости. Несмотря на географическую удаленность и культурные различия, в развитии науки и технологий этих регионов прослеживаются параллели и взаимовлияния. Будущее Человеческой цивилизации прямо связано с нашей способностью учиться на основе исторического опыта как Восточной, так и Западной цивилизаций. Поджог знаменитой библиотеки в Александрии в 390г. христианскими фундаменталистами привел к потере большого количества книг из классического наследия Человечества. Основная часть работ греческих и ряда римских ученых оставалась неисследованной на протяжении длительного периода истории. Мусульманские ученые не только возродили это наследие, но дополнили его своими собственными наблюдениями и исследованиями в области философии, астрономии, истории, математики, химии и медицины. Вклад мусульманских ученых в науку свидетельствует о большом прогрессе научного развития в мире. До Ренессанса Запада произошёл Ренессанс Востока. С XVI века шло развитие науки на Западе. Умалчивались многие труды, открытия, изобретения мудрецов средневекового Востока. С XIX века велись исследования трудов ученых Средневекового Востока. Сегодня имеется много идей, открытий, относящихся ученым раннего периода, которые именуются учеными более позднего времени. Исследуя труды ученых Средневекового Востока и Запада, мы видим сходства идей, открытий и изобретений. Проблема актуальная.

### Abstract

The article examines the Medieval period, covering the (VII-XV th) centuries, both in the East and West, where significant scientific and technological achievements were observed. Since time immemorial, people have inherited their knowledge from previous generations, improved on it, adapted this knowledge to their needs, and passed it on to future generations. Knowledge was collected through persistent observation, as experience accumulated, and also thanks to intuitive insight. Despite the geographical distance and cultural differences, parallels and mutual influences can be traced in the development of science and technology in these regions. The future of Human civilization is directly linked to our ability to learn from the historical experience of both Eastern and Western civilizations. The burning of the famous library in Alexandria in 390 by Christian fundamentalists resulted in the loss of a large number of books from the classical heritage of Mankind. The bulk of the works of Greek and some Roman scholars remained unexplored for a long period of history. Muslim scholars not only revived this legacy, but supplemented it with their own observations and research in the fields of philosophy, astronomy, history, mathematics, chemistry, and medicine. Muslim scholars to science is evidence of the great progress of scientific development in the world. Before the Renaissance of the West, there was the Renaissance of the East, which we are only now beginning to talk about out loud. Since the XVI th century, science has been developing in the West. Many works, discoveries, and inventions of the sages of the medieval East were hushed up. Since the XIX th century, studies have been conducted on the works of scientists of the Medieval East. Almost all the works, discoveries, and inventions of the sages of the medieval East were hushed up. Exploring the works of scholars of the Medieval East and West, we see similarities in ideas, discoveries and inventions. There were no references

from Western scholars, the information was hushed up. Recently, the scientific world has been talking out loud about the works of Eastern scientists. The problem is relevant.

**Ключевые слова:** Восток, Запад, наука, изобретения, идеи, сходства, параллели.

**Keywords:** East, West, science, inventions, ideas, similarities, parallels.

При исследовании истории науки часто встречаются параллели (повторы) открытий и изобретений, выполненных учеными Востока и Запада в разное время. Появляется ряд вопросов, самый ответственный из которых: "Знали ли они о том, что это было до них?" Сегодня имеется много идей, открытий, относящихся ученым раннего периода, которые именуются учеными более позднего времени.

В период Средневековья, охватывающий VII-XV века, как в странах Востока, так и Запада наблюдались значительные научные и технологические достижения. Несмотря на географическую удаленность и культурные различия, в развитии науки и технологий этих регионов прослеживаются параллели и взаимовлияния.

В формировании Цивилизации наука Человечества прошла ряд сложных этапов: Месопотамия, Древний Китай, Индия, Египет; античный период – Древняя Греция и Рим; Средневековый Восток; Ренессанс Запада и современная наука. О ранних Цивилизациях мы мало знаем. Процесс развития шел в своеобразной форме волны (Восток-Запад-Восток-Запад и т.д.). Поочередно этап передавался с Востока на Запад, который выполнив свою функцию "высокая культура и наука" постепенно передавал это на Восток и т.д. Ясно, что научные знания, информация вливались из одного периода в другой. Получая эти информации, ученые пользовались ими не только в форме материала, которые исследовались, возобновлялись, также, появлялись новые идеи, открытия и так шло развитие.

С незапамятных времен люди наследовали свои знания от предыдущих поколений, совершенствовались на их основе, адаптируя эти знания к своим нуждам, передавали их будущим поколениям. Знания собирались с помощью упорных наблюдений, по мере накопления опыта, а также благодаря интуитивной прозорливости. До греко-римской цивилизации ученые Халдеи, Вавилона, Финикии, Египта, Индии и Китая внесли огромный вклад в сферу понимания человеком устройства Вселенной и это продолжалось вплоть до VII в. до н.э.. Вклад греков продолжался до II в. до н.э., после чего они погибли, оказавшись в железных тисках Рима. Последний не смог продолжить политику созидания, инновации и научных исследований. В течение этого периода вклад греков оказался в забвении до тех пор, пока не был вновь обнаружен и усовершенствован для дальнейшего прогресса благодаря мусульманам.

Будущее Человеческой цивилизации прямо связано с нашей способностью учиться на основе исторического опыта как Восточной, так и Западной цивилизаций. До Ренессанса Запада произошел Ренессанс Востока. Умалчивались многие труды, открытия, изобретения мудрецов средневекового Востока. Проблема актуальная. Исследования по этому вопросу велись и ведутся сегодня.

Как было выше отмечено, Европа после античного времени находилась в тяжелом положении, ибо научные, медицинские, академические, исследовательские работы были остановлены на протяжении 1000 лет. Поджог знаменитой библиотеки в Александрии в 390г. христианскими фундаменталистами привел к потере большого количества книг из классического наследия Человечества. Основная часть работ греческих и ряда римских ученых оставалась неисследованной на протяжении этого длительного периода истории. Мусульманские ученые не только возродили это наследие, но дополнили его своими собственными наблюдениями и исследованиями в области философии, астрономии, истории, математики, химии и медицины. Вклад мусульманских ученых в науку свидетельствует о большом прогрессе научного развития в мире. Исламская цивилизация характеризовалась высокоинтеллектуальным развитием общества, где знания и просвещение приобрели значимую сущность и функцию. Каждый регион состязался в высоком профессиональном и прогрессивном развитии медресе-университетов, где преподавали видные ученые-энциклопедисты. И это было важным фактором образовательной системы. Важную роль играла ниспосланная священная книга «Коран», в которой были даны не только правила жизни социума и личности, но и векторы развития всех наук, которые могли дать комплексный ответ на многие вопросы изучения самой Вселенной и освоения тайн планеты Земля, и ее предназначения Человечеству. Именно такое многогранное и всеохватывающее освоение наук дали такие невероятно прогрессивные результаты и открытия, опередившие свою эпоху, давшие толчок последующим открытиям до сегодняшнего дня. Восточные, мусульманские ученые того периода достигли наивысшего уровня в научном развитии. Находясь в авангарде этих знаний, они тем самым оказали большое влияние на историю Человечества. В своей работе ученые применяли такие научные категории, как эксперимент, наблюдения, рационализм, объективность и профессионализм. Их труды великолепно продемонстрировали отсутствие конфликта между верой и наукой. Научное наследие мусульман заложило основы прогресса науки и технологии в Европе во II тыс. Европа того времени находилась в состоянии, которое называется "темным веком", и несколько не будет преувеличением сказать, что именно знакомство европейцев с мусульманами и Восточной цивилизацией послужило началом Европейского Ренессанса. Работы мусульманских ученых широко использовались в качестве учебных пособий во многих европейских университетах вплоть до XVII века. Арабские тексты переводились на европейские языки. В средневековый период Университеты Ирака, Сирии, Египта, Испании, Кордовы, Каира и т.д. стали крупными мировыми учебными центрами, куда студенты стекались со всей Европы для

получения образования. Энциклопедические работы по медицине известных медиков, таких как ал-Рази и Ибн Сина, изучались в европейских университетах до XVIII в. Историк Бриффорт писал: "то, что мы называем наукой возникло в результате новых методов экспериментирования, наблюдения и измерения, которые были введены в Европу мусульманами. Современная наука базируется на традициях исламской цивилизации"[10,с.50]. Необходимо отметить, что 90% мусульманской научной литературы сегодня хранится в европейских рукописных фондах и библиотеках.

Элементы точных наук появились в странах шумеро-вавилонской и египетской культуры, зачатки физических, астрономических, математических учений в странах Юго-Восточной Азии, появление и развитие этих учений в античных Греции и Риме, зарождение новых учений точных наук в эпоху Средневековья на Востоке и их развитие в эпоху Возрождения на Западе – это путь развития точных наук. Это общее достояние Человечества. Преемственные связи между Древним Востоком и Древней Грецией, Древней Грецией и Средневековым Востоком, Средневековым Востоком и Ренессансом Запада сильны.

В исламском мире Средневековья наблюдался значительный прогресс в математике, физике, астрономии и медицине. В X веке на арабский язык была переведена "Великая математическая система астрономии" Птолемея, известная как "Альмагест". Также были переведены труды Евклида, Аристотеля и Архимеда, что способствовало развитию точных наук. Арабские ученые активно занимались практическими задачами и экспериментами, что отличало их подход от античных традиций.

Уровень медицины и больниц в мусульманском мире на несколько столетий опережал европейские аналоги. Что касается учебных методов, то они оказали большое влияние на европейскую науку. Арабская практика обхода студентами больничных палат, практикуемая при медицинских школах, неоднократно встречалась в медицинских школах в Салерно. Арабские методы обучения остались частью стандартной системы медицинских занятий в западных медицинских школах.

В медицине Ибн ал-Нафис ал-Карши (1210 – 1288гг) из Дамаска составил схему и объяснил циркуляцию крови за три века до Вильяма Гарвея (1578 – 1657гг). В Испании ал-Захрави в Хв. изобрел хирургические инструменты, удалил катаракту и усовершенствовал многие хирургические процедуры. При хирургических операциях он накладывал швы нитями, полученными из кишечника животных, чем пользуются и в современное время. Ибн Зухр (1094 – 1162гг) ввел метод наложения швов на рану с помощью шелковой нити. Большой вклад внесли мусульманские врачи в области фармакологии. В XVII в. в Англии огромная работа по систематизации лекарственных препаратов была проделана в Фармакопии Лондонского Колледжа Докторов (1618г.). При этом были использованы труды нескольких крупных ученых, таких как Гипократ (460 до н.э. – 370 до н.э.), Гален, (129 – 216гг) Авиценна (Ибн Сина) (ум.1037г.) и Ибн Закария Рази (865 –

925гг). Мусульманские врачи предприняли серьезные шаги и выполнили монументальную задачу по созданию первых классических медицинских учебников в том формате, который используется среди студентов медицинских учреждений даже сегодня. Эти учебники были основаны как на оригинальных греческих работах, так и на новых научных данных, собранных мусульманскими медиками. Самыми известными учеными, которые внесли вклад в создание таких трудов были ал-Рази (Резес, 932 г.), ал-Захрави (1013 г.) и Ибн Сина(1037 г.). [14,с.139.]

На Востоке поняли значение числа ноль, которое было известно в Индии, и передали его для остального мира; Леонардо да Винчи (1452 – 1519гг) изучил арабскую систему исчисления и ввел ее в Европе; алгоритм был изобретен ал-Харазми в IX в., а Абу аль-Вафа Бузджани (940 – 998гг.) разработал тригонометрию. Ибн ал-Хайсам (965 – 1040гг) изобрел оптику, доказав, что лучи отражаются от предметов и попадают в глаза, а также дал сведения об оптическом обмане, бинокулярном зрении, миражах, радуге и сияниях. В трудах Насиреддина Туси (1201 – 1274гг) имеются исследования по оптике. Но позже эту тему затронул Исаак Ньютон (1643 – 1727), которого называют основателем оптики. Джабир ибн Хайян (721 – 815гг) приготовил серную кислоту и классифицировал химические вещества в VIII в. Мусульманскому ученому Ибн Халдуну (1332 – 1406гг) принадлежит заслуга в основании дисциплины о социологии. Ал-Идриси (1100 – 1165гг.), который жил в Сицилии, составил книгу по ближневосточной истории и географии Европы, изобразив 70 карт различных частей мира. Ал-Бируни (973 – 1048гг.) и Ибн Баттута (1304 – 1377) были известными путешественниками и историками, чьи научные работы до сегодняшнего дня считаются большим вкладом в историю и географию.

Произведение "Зидж Эльхани" ("Таблицы Эльхан") является астрономическим каталогом, который был составлен в результате упорного труда под руководством Насиреддина Туси (1201 – 1274) коллектива Марагинской обсерватории на протяжении целых 12-ти лет. Это был единственный астрономический каталог, которым пользовались в течение 200 лет до постройки Улугбекской обсерватории. Благодаря произведению "Шакл-уль-гита" ("Произведение о полном четырехстороннике") плоская и сферическая тригонометрия стали независимыми математическими предметами. В этом произведении Н.Туси впервые дает понятие о сферическом полярном треугольнике, а также приводит доказательство многих теорем, принадлежащих Бируни. Именно в этом своем произведении он указывает на написание со стороны Абуль Вафа Бузджани (949 – 998) теоремы тангенсов и формул подсчета синуса единичного угла. Во время исследований западные востоковеды выяснили, что тригонометрические открытия Насиреддина Туси, а также полученные им формулы в области тригонометрии, точь в точь были "повторены" спустя 200 лет немецким астрономом и математиком Региомontanом (XVв.). В результате притяжения Луны,

Солнца и других планет (в то время в геоцентрической системе Луна и Солнце считались планетами), точное значение прецессии Земли, суточное внешнее скольжение Солнца, таблица солнечных и лунных затмений, определение точных географических координат 256 населенных пунктов, ценная научная информация о наличии новых земель – все это было достижением Н.Туси и руководимого им коллектива Марагинской обсерватории. Н.Туси вычислил положение точки весеннего равноденствия в течении ста лет и угол скольжения основных точек небесной сферы -  $1^{\circ}23'4''$ , а также изучил и исследовал структуру календаря [16, с.9]. Интересно, что именно произведения “Шархи-тагвим” и “Ихтияр-и-Сейрул Гамар”, которые являются чрезвычайно важными в области астрономии, были великолепно написаны Насирэددином Туси в форме стихов. Среди произведений Туси особое внимание привлекает также известная всем книга под названием “Джавахирнамэ” или “Ташаввугнамэ”. Эта книга состоит из 26-ти глав, в которых повествуется о драгоценных камнях, некоторых других камнях, ароматических органических соединениях и даже о важных лекарственных растениях. Здесь также кратко говорится о местах нахождения драгоценных камней, методах их обработки, недостатках и правилах хранения. Следует отметить, что, создавая свою гелиоцентрическую теорию, Н.Коперник в большинстве своем использовал теорему окружностей, доказанную Насирэددином Туси [16, с.10]. Научную “Марагинскую революцию” в астрономии, выполненную учеными Туси, Урди и Шатыр в XIII в, назвали “революцией Коперника”(XVIв). Предполагалось, что Коперник, используя доступную математику, был в состоянии создать новую планетарную систему. Считали, что “революция Коперника” зависела от творческой способности нового применения классических греческих произведений (Евклида, Птолемея). Это предположение к концу 50-х годов XX в. стало разрушаться. Такие ученые – историки науки, как Отто Нейгебауэр, Эдвард Кеннеди, Джордж Салиба начали пересматривать математику Кеплера. Они обнаружили, что революцию в астрономии Кеплера сделали две необходимые теоремы, не разработанные древними греками. Сама схема Птолемея физически невозможна. Проблема – недостаток Экванта [17, с.55].

У Нейгебауэра возник вопрос: построил эти две теоремы Коперник сам или заимствовал из какого-то греческого труда? Между тем, Кеннеди, работая в Бейруте, обнаружил астрономические статьи, написанные на арабском языке, датированные 1350 г. Эти документы содержали незнакомую геометрию. Во время посещения США он показал их Нейгебауэру. Эти работы были интересны последнему. Они содержали геометрию, идентичную модели Коперника о движении Луны. Текст был написан астрономом Ибн аль-Шатыр (ум.1375). В его работе кроме всего прочего, была и «теорема Коперника», которую разработал 300 лет до Коперника известный астроном Насир ад-Дин ат-Туси.

“Пара Туси”, как называется эта теорема, решает многовековую проблему, от которой страдали

Птолемей и многие другие древнегреческие ученые – астрономы. Эта теорема о том, как круговое движение может генерировать линейное движение. Здесь рассматривается движение двух шаров. В два раза меньший шар помещен в большой. Они оба в движении, но в противоположном направлении. Малый шар вращается внутри большого. “Пара Туси” диктует, что исходная точка касания этих шаров будет колебаться назад и вперед вдоль диаметра большой сферы. Установив небесные сферы должным образом, эта теорема объясняет, как эпицикл мог двигаться равномерно вокруг экванта дифферента, и до сих пор колеблется назад и вперед по направлению к точке дифферента. Вторая теорема, найденная в системе Коперника, эта Лемма Урди, выдвинутая в 1250 г сотрудником Марагинской обсерватории Муаййад ад-Дин ад- Урди.

Стало известно, что путешественник Х.Колумб, отправляясь в свои путешествия с целью открытия новых населенных территорий, в своем дневнике с большим мастерством и умением использовал таблицу из географических координат для 256 населенных пунктов, составленную гениальным ученым Насирэددином Туси. Причем эта таблица была очень популярна в Европе еще за 200 лет до самого Х.Колумба. Было доказано также, что находящиеся в обсерватории датчанина Тихо Браге несколько приборов являются точной копией тех, которыми пользовались в Марагинской обсерватории. Вплоть до сегодняшних дней в Дрезденской галерее хранится звездный глобус, являющийся прибором из Марагинской обсерватории, и следует серьезно исследовать то, что каким путем этот прибор был вывезен на Запад. К сожалению, многое использованное учеными Средневекового не отмечается, делается без ссылок. В трудах ученых средневекового Востока, мусульман, использованная литература, материал или идея ясно отмечается, чья она и откуда [18, с.57].

Книги великого ученого Насирэددина Туси по математике, в особенности “Тахрир Эглидис”, длительное время являлись лекционными книгами известных ученых Западной Европы, в том числе учителя И.Ньютона - Джона Валлиса из Оксфордского университета. Очень интересно, что в первой редакции книги “Тахрир Эглидис” Н.Туси представил доказательство теоремы Пифагора в 36-ти вариантах.

Г.Дж.Мамедбейли указывал, что в 1891-ом году в Стамбуле был найден один древний экземпляр произведения Туси “Шаклуль-Гита” и его текст отпечатан типографским способом на французском и арабском языках. Проходит совсем немного времени, как среди историков математики Западной Европы разгораются сильные споры и Генрих Зутер, потративший много сил на изучение истории астрономии и математики на Востоке, доходит до той степени, что начинает вообще отрицать роль Региомонтана в развитии этих наук. К тому же положительное влияние этой работы состояло еще и в том, что у Браун Нюхля среди произведений, посвященных истории тригонометрии, появился новый научный труд – “Nassir Eddin Tusi

and Regiomontan”, являющийся в ряду подобных произведений монументальным.

В отличие от западной традиции, с точки зрения мусульманских ученых, между религией и наукой не существовало конфликта. Элви и Дуглас определили пять основных причин, способствующих продуктивному развитию исламской науки: чрезвычайно большое уважение, которое Ислам оказывает занятию наукой; общая поддержка со стороны правителей и других влиятельных людей; готовность мусульман обмениваться идеями с представителями других культур; арабский язык, который вскоре станет средством обмена идеями во всем мусульманском мире, и требование соблюдения аккуратности и точности в исполнении исламских обязанностей.

Мусульманские ученые того периода достигли наивысшего уровня в научном развитии. Находясь в авангарде этих знаний, они тем самым оказали большое влияние на историю Человечества. Работы мусульманских ученых широко использовались в качестве учебных пособий во многих европейских университетах вплоть до 1600 г. Арабские тексты переводились на латинский и другие европейские языки. Энциклопедические работы по медицине известных медиков, таких как ал-Рази и Ибн Сина, изучались в европейских университетах до XVI в. Как было отмечено выше, мусульманские ученые дали научные знания Европе, когда она переживала период "темного века". Джордж Сартон, изучавший вопрос о мусульманских ученых, писал, что в течение периода 750-1150 гг. вклад мусульманских ученых в науку был несравним в своем великолепии и включал достижения таких титанов, как ал-Рази, ал-Фараби, Ибн ал-Хайсам, ал-Хаваризми, Ибн Сины, ал-Байруни и Ибн Халдун. Р.С.Бриффольт пишет: "То, что мы называем наукой появилось в результате новых экспериментальных методов, методов наблюдения и измерения, которые были привнесены в Европу арабами. Современная наука является самым весомым вкладом исламской цивилизации, который стал доступен всем независимо от рода, расы, касты, вероубеждения или национального происхождения. Сохранение цивилизации нуждается в лучшем понимании, совместном использовании и признании нашего общего наследия"[13, с.139].

В Западной Европе научное развитие в Средние века тесно связано с религиозными учреждениями, особенно монастырями, где сохранялись и переписывались античные тексты. Однако в этот период также возникали новые идеи и методы, такие как схоластика, стремившаяся объединить веру и разум. В позднее Средневековье, особенно в эпоху Возрождения, происходило возрождение интереса к античным знаниям и развитие новых научных подходов.

Исаак Ньютон в XVII веке обнаружил, что белый свет состоит из лучей разного цвета, но подобное открытие было сделано аль-Хайтамом (ал-Хасан) в XI веке и Насиредином Туси XII веке (трактат "О радуге"), Камаль ад-Дином в XIV веке. Азербайджанский ученый, ученик Ибн Сины, Бахманйар ал-Азербайджани (XI) в труде "ат-Тасил"

излагает световые явления и природу солнечных лучей. Труд ал-Хасана об оптике был на уровне трудов И.Ньютона. Аль-Хайтама считают отцом оптики.

Считается, что концепция ограниченности природы материи была впервые введена Антуаном Лавуазье в XVIII веке. Он обнаружил, что при изменении состояния или формы материи, ее масса не меняется. Например, если воду превратить в пар, или соль растворить в воде, то общая масса останется неизменной. Принципы этого открытия были разработаны мусульманским ученым из Узбекистана аль-Бируни (973-1048). Лавуазье пользовался трудами мусульманских ученых средневековья.

Считается, что концепция отрицательных чисел стала известна только в 1545 году благодаря Джеронимо Кардано. Однако, отрицательные числа были изобретены индийским математиком и астрономом Брахмагуптой (598-665 гг). Его основная работа "Брахма-спхута-сиддханта" впоследствии была переведена на арабский язык "Синд Хиндом". Мусульманские математики использовали отрицательные числа в различных арифметических функциях, по крайней мере, 400 лет до европейских ученых [3, с 6].

В 1614 году Джон Непер изобрел логарифмы и логарифмические таблицы. Однако мусульманские математики изобрели логарифмы и логарифмические таблицы на несколько веков раньше, в XIII веке. Такие ученые как Аль-Хорезми (ок.780 – ок.850), занимались алгеброй и таблицами чисел. Их работа с прогрессиями, особенно геометрическими, закладывала основы для понимания логарифмических отношений. Аль-Хорезми – один из основоположников алгебры, математик, астроном, географ. Астрономы использовали таблицы синусов и тангенсов, что требовало сложных вычислений. Это в дальнейшем подтолкнуло к созданию логарифмов как способа упростить такие расчеты. В Европе таблицы тригонометрических значений использовались в XV-XVI вв [1, с.27]

В XVII веке Рене Декарт обнаружил, что алгебра может быть использована для решения геометрических задач. Однако математики Халифата сделали это еще в начале IX века. Сабит бин Курра был первым, кто сделал это, и его последователь Абу-л-Вафа, чья книга X века использовала алгебру для развития геометрии.

Считается, что Исаак Ньютон, в XVII веке, работал биномом, который является ключевым компонентом в алгебре. Однако мусульманские математики начали использовать бином для решения алгебраических задач еще в X веке [4, с.206].

Ибн Фирнас из исламской Испании изобрели очки в IX веке, они изготавливались и продавались по всей Испании на протяжении более двух веков. Но считается, что английский учёный Роджер Бэкон (ум. 1292) первым изобрел стеклянные линзы для улучшения зрения. Исследования в области оптики и изобретение очков Роджера Бэкона всего лишь повторение работ аль-Хайтама (ум. 1039), на которые Бэкон часто ссылается.

На Западе порох был разработан Роджером Бэконом в 1242 году. Роджер Бэкон узнал о формуле пороха из латинского перевода арабской книги. Создателями формулы пороха являются китайцы. Китайские изобретатели создали порох и использовали его состав, очистив с помощью калиевой селитры, и начали применять в военных целях, изобретая ракеты и торпеды. Они использовали порох в военных целях, включая гранаты, осколочные бомбы, ракеты и даже раннюю форму ружья/пушки еще в XII веке (династия Сун). Через арабов огнестрельное оружие попало в Европу. Первые изображения пушек в Европе датируются 1326 годом, и к XV веку европейцы разработали более совершенные модели, такие как аркебузы и бомбарды.

Компас был изобретен китайцами, которые, возможно, были первыми, кто использовал его для навигационных целей между 1000 и 1100 годами. Наиболее ранние ссылки на использование компаса в навигации на Западе были сделаны англичанином Александром Неккамом (1157-1217). Однако мусульманские географы и мореплаватели, возможно узнав о магнитной стрелке из Китая, раньше использовали магнитные иглы в навигации. Они изобрели компас и передали знания о его использовании в навигации на Запад. Европейские мореплаватели полагались на мусульманских лоцманов и их инструменты при изучении неизвестных территорий. До компасов с древних времен для определения местоположения на Востоке и территории Азербайджана использовали астробии.

Греческий философ и математик **Фалес Милетский** более 25 веков назад наблюдал странное явление: янтарь (по-гречески “электрон”), натертый шерстью, притягивает легкие предметы. Чем был вызван интерес Фалеса? Может быть, люди древности нашли способ получать и использовать электричество? Это предположение может оказаться правдой. В 1936 году археологи нашли древний глиняный горшок с железным прутом и медной пластиной. Конструкция очень похожа на прибор, который изобрел в 1800 году итальянский ученый **А. Вольта**. “**Вольтов столб**” состоял из чередующихся дисков цинка и меди, разделенных картонными прокладками, смоченными соленой водой. При контакте этих металлов возникала химическая реакция, которая создавала постоянный ток. Это был первый в мире источник непрерывного электрического тока. Изобретение произвело сенсацию в научном мире и открыло новую эру в развитии электротехники. **Вольтов столб** стал прародителем современных аккумуляторов и батареек.

Архимед (287-212 гг. до н.э.) предполагал, что планеты вращаются вокруг Солнца. Это было сказано позже Коперником (1473-1543).

Рукописи средневековых авторов, написанные на арабском и фарсидском языках, сегодня хранятся в известных рукописных фондах, фундаментальных библиотеках и университетах мира (Дрезден, Лейпциг, Лондон, Берлин и т.д.). Многие из этих рукописей были несколько раз переписаны, переведены на европейские языки, изданы и пере-

изданы. Это говорит о том, что на Западе были знакомы с произведениями, трудами ученых Востока [12, с.7]. По словам замечательного английского востоковеда У.М. Уотта – “Наука, созданная народами мусульманского Востока, оставалась на высоком уровне по крайней мере до XVII в.” [15, с.178]. Научное наследие Средневекового Востока заложило основы для прогресса науки и технологии в Европе. Член-корр. АН СССР Е.Э.Бертельс писал: “Если вспомнить, что в истории европейской культуры период IX-XIII вв. представляет собой время глубочайшего упадка, то нельзя не прийти к выводу, что именно труды восточных философов вывели европейские народы из тупика и указали им путь дальнейшего развития” [14, с.97].

Проблема движения планет, занимавшая умы древних греков, астрологов Халдея и Вавилонян, создателя геоцентрической системы Коперника и, наконец, Великого Галилея, превратилась во время Ньютона в прикладную научную задачу. Она стала идеальной областью для применения законов Ньютона, и, можно сказать, что решение проблемы движения планет с помощью теории Ньютона было высшим достижением наук XVII века и “Естественное и вечное” по Аристотелю, движение планет оказалось требующим некоторой силы [8; 9]. Логически чувствуя эту научную закономерность, еще в XI веке Бахманйар ал-Азербайджани (993-1066) в книге “Ат-Тахсил” писал: “Круговое движение может существовать лишь потому, что есть какая – то причина У небесного кругового движения есть начало, отрешенное от материи, телесная сила, представляющая себе частные предметы, сила, связанная с желанием и движущая сила” [4, с. 87].

В результате своих исследований Бахманйар приходит к заключению, что во Вселенной единственным движением является вращательное и тем самым делает новое предположение о свойствах пространства и времени. Бахманйар пишет: “... движения прямолинейного и уходящего в бесконечность, не бывает” [6, с.107; 5; 7; 2]. Из этого заключения становится так же зримым искривление пространства. Эта характеристика пространства была выявлена А.Эйнштейном в XX в.

Считается, что печатный станок был разработан в 1454 году Иоганном Гутенбергом. Однако, 100 лет раньше в исламской Испании использовались сборные латунные формы. Если посмотреть в более ранний период, то оказывается, сборные формы для печати впервые были изобретены в Китае. В 1041 году китаец Пи-Шенг создал шрифты из обожженной глины. В 1200 году в Корее были созданы шрифты, отлитые из бронзы.

Технология по производству бумаги была заимствована мусульманами у китайцев, затем распространена на Ближнем Востоке и в Европе, что привело к росту книгоиздания. Первая фабрика по производству бумаги была построена в Багдаде в 794 году, затем в Египте в 800 году и Андалусии в 950 году. Это способствовало распространению знаний и развитию науки в исламском мире. В Европе производство бумаги началось позже: в Византии около 1100 года, в Германии в 1228 году, в

Англии в 1309 году. Это также способствовало развитию образования и науки в Европе.

Аль-Джазари в 1206 году описал около 50 механизмов, включая часы, кодовые замки и автоматические устройства, что свидетельствует о высоком уровне инженерной мысли на Востоке. В Европе схожие механизмы начали появляться позже, во время Ренессанса, когда идеи автоматизации и сложных механизмов стали более распространены.

Мусульманские ученые, такие как Аль-Хорезми, внесли вклад в развитие алгебры и тригонометрии. Их труды были переведены на латинский язык и оказали влияние на европейскую науку. Европейские ученые, используя переведенные арабские тексты, продолжили развитие математики и астрономии, что привело к научной революции в последующие века [11; 12; 14].

Подобных выше изложенным сходствам и параллелям в мире очень много. Можно сделать вывод, что некоторые из них выполнены при неизвестности ранних работ. В данном случае к идее или открытию приводит состояние науки в тот момент. Но есть случаи, когда автор идеи или открытия знаком с раньше выполненными работами и не признает повтором свою работу. Часто мир признает последние открытия.

Сходства между Восточной и Западной наукой Средневековья проявлялись в стремлении к систематизации знаний и поиске рациональных объяснений природных явлений. Переводы арабских научных трудов на латынь в XII-XIII веках способствовали передаче знаний с Востока на Запад, что оказало значительное влияние на европейскую науку. В Средние века между Востоком и Западом существовали значительные параллели в научных открытиях и изобретениях, часто обусловленные обменом знаниями и технологиями. Таким образом, несмотря на различия в культурных и религиозных контекстах, между Востоком и Западом существовал обмен знаниями, способствовавший общему прогрессу науки и технологий.

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## TECHNICAL SCIENCES

### ЧИСЕЛЬНЕ МОДЕЛЮВАННЯ ПИЛОВОГО ЗАБРУДНЕННЯ ПОВІТРЯ НА ПРОМИСЛОВИХ МАЙДАНЧИКАХ: ЕКСПРЕС МОДЕЛЮВАННЯ

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### NUMERICAL MODELING OF DUST AIR POLLUTION AT INDUSTRIAL SITES: EXPRESS MODELING

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### Анотація

Боротьба з пилом є важливим напрямом в галузі охорони праці та екологічної безпеки. Для оцінювання ефективності використання того або іншого засобу боротьби з пиловим забрудненням повітря потрібно мати спеціальні методи розрахунку. В роботі розглянуто побудову чисельних моделей аеродинаміки та масопереносу, що дають можливість методом обчислювального експерименту визначати ефективність використання захисних екранів для зниження пилового забруднення повітря на промислових майданчиках. Побудова чисельних моделей базується на інтегруванні фундаментальних рівнянь механіки суцільного середовища за допомогою кінцево-різницевої схем. Наведено результати обчислювального експерименту.

### Abstract

Dust control is an important area of occupational health and safety. To evaluate the effectiveness of using a particular means of protecting against dust air pollution, it is necessary to have special calculation methods. This paper considers the construction of numerical models of aerodynamics and mass transfer, which make it possible to determine the effectiveness of using protective screens to reduce dust air pollution at industrial sites by computational experiment. The construction of numerical models is based on the integration of the fundamental equations of continuum mechanics using finite-difference schemes. The results of a computational experiment are presented.

**Ключові слова:** промисловий майданчик, пилове забруднення повітря, масоперенос, чисельне моделювання.

**Keywords:** industrial site, dust air pollution, mass transfer, numerical modeling.

### Вступ

Боротьба з пиловим забрудненням повітря на промислових майданчиках відноситься до особливо важливих задач в галузі охорони праці та екологічної безпеки [1, 4, 10]. На практиці використовують різні засоби боротьби з пилоутворенням та зменшенням інтенсивності та розмірів пилового забруднення в повітрі. Кожен засіб має свої переваги та недоліки. Але на практиці, при розробці стратегії боротьби з пилом, потрібно мати методи розрахунку ефективності використання того або іншого засобу. В першу чергу, це відноситься до теоретичних методів визначення ефективності засобів боротьби з пилом, оскільки проведення фізичних експериментів в даній області потребує значного часу та досить великих коштів. Тому, зокрема в роботі проєктних організацій, значна увага приділяється використанню математичних моделей. До таких моделей висувається ряд вимог, а саме, швидкість розрахунку та врахування найбільш важливих фізичних факторів, що впливають на формування концентраційних полів. Аналіз літературних джерел [1-3, 5-8] показав, що розвиток таких теоретичних методів дослідження залишається важливою задачею.

### Мета

Побудова чисельних моделей аеродинаміки та масопереносу для оцінювання концентраційних полів пилу на промислових майданчиках при використанні захисних екранів.

### Методика

Для прогнозування пилового забруднення на промисловому майданчику, де є області пилоутворення, потрібно вирішити дві задачі:

1) задача аеродинаміки – визначення поля швидкості повітряного потоку на промисловому майданчику за наявності перешкод;

2) задача масопереносу – розрахувати концентраційне поле пилу на промисловому майданчику.

**Модель аеродинаміки.** Так як розглядається задача по визначенню ефективності захисного ек-

рану для зменшення пилоутворення на промисловому майданчику, то потрібно визначити деформацію поля швидкості повітряного потоку під впливом екрану. Наявність захисного екрану на промисловому майданчику призводить до зменшення пилоутворення шляхом зміни аеродинаміки потоків на майданчику. Але для практики важливо мати швидкорозрахункові методи визначення концентраційних полів пилу при різних метеоумовах, параметрів екрану тощо. Далі розглядається побудова таких моделей.

Для розрахунку поля швидкості на промисловому майданчику використовується модель потенціального руху. В цьому випадку, використовується наступне рівняння:

$$\frac{\partial^2 P}{\partial x^2} + \frac{\partial^2 P}{\partial y^2} = 0, \quad (1)$$

де  $P$  – потенціал швидкості.

Компоненти вектора швидкості вітру визначаються так:

$$u = \frac{\partial P}{\partial x}, v = \frac{\partial P}{\partial y}. \quad (2)$$

Якщо розглядається тривимірна задача аеродинаміки, то моделююче рівняння аеродинаміки має вигляд:

$$\frac{\partial^2 P}{\partial x^2} + \frac{\partial^2 P}{\partial y^2} + \frac{\partial^2 P}{\partial z^2} = 0. \quad (3)$$

Компоненти вектора швидкості вітру для тривимірного процесу руху визначаються так:

$$u = \frac{\partial P}{\partial x}; v = \frac{\partial P}{\partial y}; w = \frac{\partial P}{\partial z}. \quad (4)$$

Граничні умови для рівняння Лапласа розглянуто в [7].

Для розв'язання рівняння (1) використовується явна різницева схема:

$$P_{ij}^{n+1} = P_{ij}^n + \Delta t \frac{P_{i+1,j}^n - 2P_{ij}^n + P_{i-1,j}^n}{\Delta x^2} + \Delta t \frac{P_{i,j+1}^n - 2P_{ij}^n + P_{i,j-1}^n}{\Delta y^2}.$$

Розрахунок закінчується коли виконується умова:

$$|P_{i,j}^{n+1} - P_{i,j}^n| \leq \varepsilon, \quad (5)$$

де  $P_{i,j}^{n+1}$  – значення потенціалу швидкості на новій ітерації;  $P_{i,j}^n$  – значення потенціалу швидкості на попередній ітерації;  $\varepsilon$  – мале число.

Значення компонент швидкості розраховується на сторонах комірок так:

$$v_{ij} = \frac{P_{i,j} - P_{i,j-1}}{\Delta y}.$$

Для чисельного інтегрування рівняння (3) використовується метод умовної апроксимації. Для цього рівняння (3) приводиться до «нестационарного» вигляду:

$$\frac{\partial P}{\partial t} = \frac{\partial^2 P}{\partial x^2} + \frac{\partial^2 P}{\partial y^2} + \frac{\partial^2 P}{\partial z^2}, \quad (6)$$

де  $t$  – фіктивний час.

Далі записується двокрокова схема розщеплення:

$$\begin{aligned} \frac{P_{i,j,k}^{n+\frac{1}{2}} - P_{i,j,k}^n}{\Delta t} &= \left[ \frac{-P_{i,j,k}^{n+\frac{1}{2}} + P_{i-1,j,k}^{n+\frac{1}{2}}}{\Delta x^2} \right] + \left[ \frac{-P_{i,j,k}^{n+\frac{1}{2}} + P_{i,j-1,k}^{n+\frac{1}{2}}}{\Delta y^2} \right] + \left[ \frac{-P_{i,j,k}^{n+\frac{1}{2}} + P_{i,j,k-1}^{n+\frac{1}{2}}}{\Delta z^2} \right], \\ \frac{P_{i,j,k}^{n+1} - P_{i,j,k}^{n+\frac{1}{2}}}{\Delta t} &= \left[ \frac{P_{i+1,j,k}^{n+1} - P_{i,j,k}^{n+1}}{\Delta x^2} \right] + \left[ \frac{P_{i,j,k+1}^{n+1} - P_{i,j,k}^{n+1}}{\Delta y^2} \right] + \left[ \frac{P_{i,j,k+1}^{n+1} - P_{i,j,k}^{n+1}}{\Delta z^2} \right]. \end{aligned} \quad (7)$$

На кожному кроці розщеплення системи (7) невідоме значення потенціалу швидкості визначається за явною схемою.

Розрахунок закінчується, коли виконується умова, що аналогічна (5).

Значення компонент швидкості розраховується на бічних сторонах контрольного об'єму наступним чином:

$$u_{ijk} = \frac{P_{i,j,k} - P_{i-1,j,k}}{\Delta x}, v_{ijk} = \frac{P_{i,j,k} - P_{i,j-1,k}}{\Delta y}, w_{ijk} = \frac{P_{i,j,k} - P_{i,j,k-1}}{\Delta y}.$$

Здійснено програмну реалізацію побудованих чисельних моделей аеродинаміки.

**Математична модель масопереносу.** Для опису концентраційних полів на промисловому майданчику використовується наступне моделююче рівняння:

$$\begin{aligned} \frac{\partial C}{\partial t} + \frac{\partial uC}{\partial x} + \frac{\partial (v-w)C}{\partial y} &= \text{div}(\mu \cdot \text{grad}C) + \\ &+ \sum_{i=1}^N Q_i(t) \delta(x - x_i) \delta(y - y_i). \end{aligned} \quad (8)$$

де  $C$  – значення концентрації пилу на промисловому майданчику;  $u, v$  – компоненти вектору швидкості повітряного потоку в проекції на осі координат  $x, y$ , відповідно;  $x_i, y_i$  – декартові координати  $i$ -ого точкового джерела емісії пилу;  $t$  – час;  $\mu_x, \mu_y$  – коефіцієнти турбулентної дифузії;  $\delta(x-x_i)\delta(y-y_i)$  – дельта-функція Дірака, за допомогою якої в моделі задається місце емісії пилу. Інтенсивність емісії пилу дорівнює  $Q$ . Даний параметр визначається на базі існуючих емпіричних моделей або відомих експериментальних даних.

Аналогічне рівняння використовується для розрахунку тривимірних концентраційних полів пилу на промисловому майданчику.

Для побудови чисельної моделі пилового забруднення повітря на промисловому майданчику здійснюється таке розщеплення моделюючого рівняння:

$$\frac{\partial C}{\partial t} + \frac{\partial uC}{\partial x} + \frac{\partial vC}{\partial y} = 0, \quad (9)$$

$$\frac{\partial C}{\partial t} = \frac{\partial}{\partial x} \left( \mu_x \frac{\partial C}{\partial x} \right) + \frac{\partial}{\partial y} \left( \mu_y \frac{\partial C}{\partial y} \right), \quad (10)$$

$$\frac{\partial C}{\partial t} = Q_i \delta(x - x_i) \delta(y - y_i), \quad (11)$$

де прийнято  $v=v-w$ .

Для чисельного інтегрування рівняння (9) використовується змінно- трикутна різницева схема [2], для чисельного інтегрування рівняння (10) ви-

користується метод умовної апроксимації. Чисельне інтегрування рівняння (11) здійснюється за допомогою метода Ейлера.

Розробка кодів на базі побудованих чисельних моделей здійснена на мові FORTRAN.

Далі на рисунках наведено результати чисельного моделювання концентраційних полів пилу на промисловому майданчику. Розрахункова схема показана на рис. 1. Розглядаються два сценарії: наявність вертикальних екранів (рис. 1, а) та наявність «Т»-подібних екранів (тобто екранів складної форми, рис. 1, б).

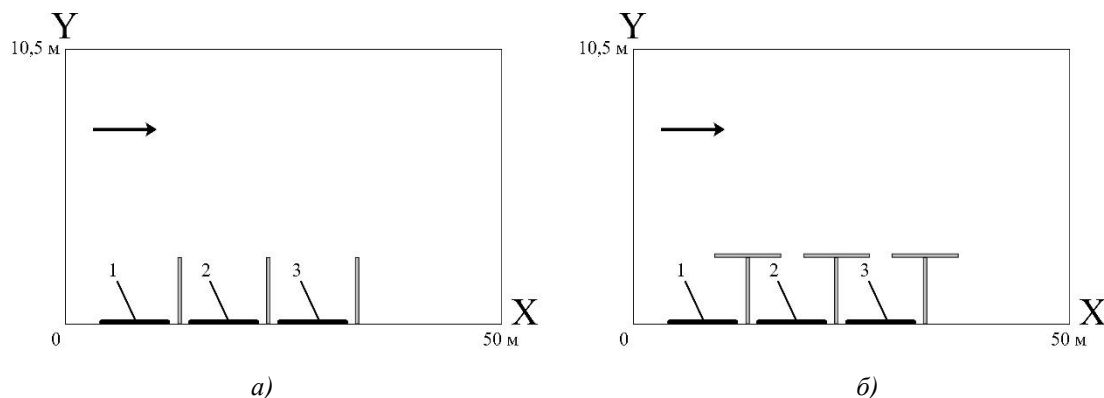


Рис. 1. Розрахункова схема: 1, 2, 3 – область пилоутворення

Далі на рисунках показана концентрація пилу ( $\text{мг/м}^3$ ) на промисловому майданчику для кожного сценарію задачі.

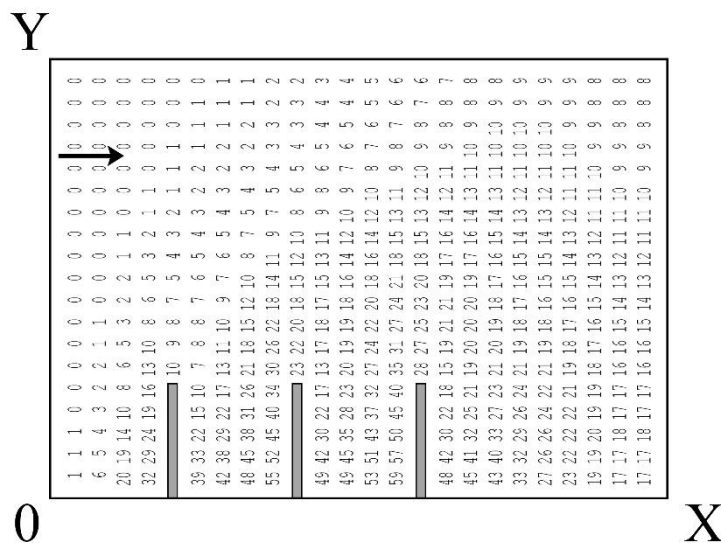


Рис. 2. Концентраційне поле пилу на промисловому майданчику, сценарій № 1

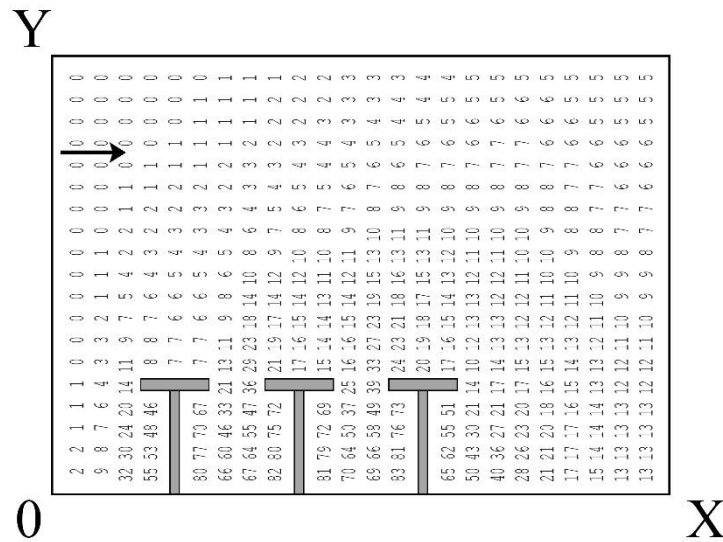


Рис. 3. Концентраційне поле пилу на промисловому майданчику, сценарій № 2.

Як можна бачити з рис. 2 та рис. 3, найбільш інтенсивне пилове забруднення має місце на ділянках, що розташовані між захисними екранами. Також можна побачити, що концентрація пилу над «Т»-подібним захисним екраном менше ніж над вертикальним екраном.

Слід відзначити, що час розрахунку кожного сценарію був 3 с. Таким чином, за допомогою побудованих чисельних моделей можна виконати серію прогнозних розрахунків протягом робочого дня з метою визначення місця раціонального розташування екранів та їх розмірів.

#### Висновки

1. Побудовано 2D та 3D чисельні моделі для рішення задачі аеродинаміки – визначення поля швидкості повітряного потоку на промисловому майданчику за наявності перешкод (захисні екрани).
2. Побудовано 2D та 3D чисельні моделі для рішення задачі масопереносу – визначення концентраційних полів пилу на промисловому майданчику.
3. Розроблені чисельні враховують найбільш важливі фізичні фактори, що впливають на формування концентраційних полів пилу в повітрі.
4. Моделі можуть бути реалізовані на комп'ютерах малої та середньої потужності.
5. Подальший розвиток даного напрямку буде присвячений дослідженню закономірностей пилоутворення від джерел на різних об'єктах гірничої промисловості.

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## APPLICATION OF DISTANCE MEASUREMENT METHODS FOR MINE DETECTION

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DOI: [10.5281/zenodo.17170491](https://doi.org/10.5281/zenodo.17170491)**Abstract**

Distance-based methodologies for mine detection leverage various principles of distance measurement to enhance the efficiency and accuracy of identifying landmines in both military and humanitarian operations. These approaches employ physical sensors—such as radar, magnetic, acoustic, and optical systems—to measure the distance between the sensor and potential targets, thereby enabling the detection and localization of mines. Technologies like ground-penetrating radar (GPR) and electromagnetic induction (EMI) have demonstrated effectiveness in identifying mines at different depths. Furthermore, recent advancements in machine learning and artificial intelligence have significantly improved the interpretation of sensor data, facilitating mine detection in complex and cluttered environments. This methodology presents a promising solution for increasing safety, reducing manual labor, and accelerating the clearance process. In this study, global practices in explosive detection were analyzed, key indicators for mine detection were identified, and the potential application of innovative technologies in this field was evaluated. Emphasis was placed on methods based on dielectric conductivity, as well as radio and thermal radiation, due to their effectiveness in remote mine detection. Landmine contamination continues to pose a severe challenge to national security, humanitarian safety, and post-conflict reconstruction efforts.

**Keywords:** Mine detection; Distance-based methodologies; Ground-penetrating radar (GPR); Electromagnetic induction (EMI); Sensor technology.

**Introduction**

The ability to detect mines from a safe distance using advanced sensor-based technologies offers a transformative solution to both military and civilian mine action programs. This paper examines the strategic application of distance-based detection methods—including ground-penetrating radar (GPR), electromagnetic induction (EMI), and thermal imaging in the context of post-conflict security operations. It explores how integrating these technologies with unmanned aerial vehicles (UAVs) can enhance operational effectiveness, reduce human casualties, and accelerate clearance timelines. The study highlights the importance of technological integration into defense policies, military doctrines, and international demining standards, contributing to the broader discourse on security innovation and risk reduction in mine-affected regions (Valters 2014).

Landmines influence the development of vegetation due to the emission of explosive vapors, which alter the chemical and physical properties of the surrounding soil. In 1996, the United Nations initiated the formulation of the *International Standards for Mine Clearance Operations* for humanitarian purposes. According to these standards, existing technical means for mine detection and neutralization do not ensure a sufficiently high level of clearance. As a result, more than

80% of cleared areas are still manually demined with human involvement [1] which significantly compromises the safety of mine clearance personnel. The detection and neutralization of mines and explosives remains a critical issue for the Republic of Azerbaijan. In line with Presidential Decree No. 854 dated July 18, 1998, titled *On the Restoration and Reconstruction of Territories*, the National Agency for Mine Action (ANAMA) was established to coordinate mine clearance efforts in the liberated territories. The use of unmanned aerial vehicles (UAVs) in mine detection presents promising opportunities. For instance, drones equipped with metal detectors can fly close to the ground surface to identify buried mines. Once a mine is detected, the UAV can mark its location on a digital map, signal it physically on the terrain, or even deploy a detonator for remote neutralization. Plastic mines, which differ thermally from the surrounding soil, can be identified through thermal contrast observable at sunrise and sunset. Infrared cameras and UAVs equipped with specialized software are employed for this purpose. Conventional mine detection methods under the soil surface rely on detecting disturbances in static properties—such as magnetic, electrostatic, thermal, and olfactory anomalies—caused by the presence of foreign objects. However, these methods often require large, complex equipment and do not guarantee

100% detection accuracy [2-3] Landmines represent a continuing threat to security, not only as remnants of past conflicts but as persistent tactical hazards in current and future hybrid warfare environments. Their indiscriminate nature affects civilians, impedes reconstruction, and challenges stabilization efforts. International norms, such as the Ottawa Treaty, seek to limit landmine deployment, but millions remain active in former war zones. For Azerbaijan and other post-conflict states, comprehensive mine clearance is essential to restoring territorial integrity and enabling displaced population return. Despite technological advances, mine clearance still relies heavily on manual labor. This exposes demining personnel to considerable risk, undermines operational efficiency, and slows recovery. The integration of distance-based technologies—particularly those deployed via unmanned systems—offers strategic benefits for state actors seeking to enhance defense readiness, border security, and post-conflict resilience. The strategic dimension of mine action has garnered increasing attention across security, defense, and policy research. NATO's Standardization Agreement (STANAG) 2910 outlines procedures for military mine clearance but acknowledges limitations in conventional manual detection. Similarly, the United Nations Mine Action Service (UNMAS) identifies the adoption of advanced technologies as a priority for both military and humanitarian missions. Recent scholarly work [3,10] emphasizes the growing role of sensor-based mine detection in improving situational awareness and reducing operational risk. These technologies also align with doctrines of Intelligence, Surveillance, and Reconnaissance (ISR), offering value not just in mine detection but in terrain mapping, logistics planning, and hybrid threat environments.

Furthermore, the deployment of unmanned systems for mine detection parallels broader trends in asymmetric warfare and remote engagement, allowing state actors to exert control in denied areas without risking personnel. The integration of these tools into strategic security frameworks remains an evolving but urgent imperative. Distance-based mine detection encompasses a range of techniques using electromagnetic, thermal, and acoustic principles to locate subsurface explosive threats. The technologies fall under two main categories:

**Active methods:** Emitting signals (e.g., radio, UHF) and analyzing reflections (e.g., GPR, EMI)

**Passive methods:** Measuring environmental anomalies (e.g., thermal radiation, dielectric permittivity)

UAV integration enhances these methods, enabling real-time imaging and wide-area coverage—essential for mine detection in inaccessible or hazardous zones. This not only improves tactical ISR capabilities but also aligns with modern battlefield doctrines emphasizing mobility, automation, and precision. GPR transmits high-frequency radio waves into the ground and measures reflections to detect buried objects. Its effectiveness varies based on frequency: higher frequencies (200 kHz) offer greater resolution but shallower

depth; lower frequencies (50 kHz) penetrate deeper but reduce accuracy. This method identifies conductive objects by detecting disturbances in electromagnetic fields. EMI systems are efficient in detecting metal-cased mines and can be mounted on drones for large-scale scanning. Exploiting differences in thermal inertia, thermal cameras detect anomalies in surface temperature caused by buried mines—particularly effective during diurnal cycles (sunrise/sunset). This passive method is promising for detecting plastic mines often missed by metal-based systems. The adoption of distance-based mine detection methods holds significant strategic value:

**Force Protection:** Reduces risk to personnel during clearance operations, especially in unstable regions.

**Operational Mobility:** Enhances rapid area denial or clearance for advancing military units.

**Post-Conflict Stabilization:** Accelerates the restoration of infrastructure and resettlement.

**ISR Enhancement:** Adds intelligence-gathering value beyond mine detection (e.g., terrain mapping).

**Civil-Military Integration:** Strengthens dual-use capabilities applicable to border security, counterterrorism, and disaster response.

For Azerbaijan, the integration of these technologies into national demining and defense operations directly supports its strategic goals in reclaimed territories. At the international level, such technologies contribute to cooperative security initiatives and peace-keeping doctrines. While the Ottawa Convention focuses on banning the use of anti-personnel mines, it lacks enforcement mechanisms for clearance speed and innovation. Countries like Azerbaijan—dealing with legacy minefields—require not only compliance but active support for high-tech solutions. International partnerships, including NATO's Science for Peace and Security Programme and EU CBRN Centres of Excellence, can play pivotal roles in transferring, funding, and scaling mine detection technologies. Embedding these tools in international policy frameworks is crucial for long-term impact.

#### Material and method

Recent research highlights two promising applications of ultra-high-frequency (UHF) technologies for subsurface object detection:

**Radio Location Method:** This approach involves the directional emission of UHF signals onto the soil surface and the registration of signals reflected by buried objects. Its development is challenged by the high absorption capacity of the soil, which reduces the signal-to-noise ratio. Nevertheless, it is useful for detecting metallic objects and mines containing metal components. The PRS-7 is a handheld mine detection system engineered to locate both metallic and minimum-metal (non-metallic) mines using advanced ground-penetrating radar (GPR) and electromagnetic induction technology. Designed for rapid deployment in combat and humanitarian demining scenarios, the PRS-7 offers reliable detection even in mineralized or cluttered soil conditions. [2]



Figure 1. - PRS-7 Portable Mine Detecting Set: Designed for detecting both metallic and non-metallic mines (Daniels, D. J., 2004)

**1. Thermal Irradiation Method:** This technique involves irradiating the soil with UHF energy and accurately measuring changes in surface temperature. Detection is based on the disruption of the heat flow caused by objects whose thermal properties differ from those of the surrounding soil. Unmanned aerial vehicles

(UAVs) outfitted with thermal imaging systems are capable of surveying expansive terrain to identify potential landmine locations. By detecting subtle variations in thermal signatures on the surface, these drones enhance the efficiency and safety of demining operations, especially in inaccessible or high-risk zones.



Figure 2. – Drone with Thermal Camera: Drones equipped with thermal cameras can survey large areas to detect landmines based on thermal signatures. (Rzayeva 2025)

The image shows a high-resolution quadcopter drone equipped with a forward-facing thermal imaging camera. The drone is in mid-air, hovering low above a grassy terrain. Its thermal camera lens emits a distinct reddish hue, indicating active infrared sensing. The rotors are in motion, and the background reveals a mixed patch of dry and green grass—suggestive of a real-world outdoor environment such as a former conflict zone or a mine-contaminated field.

Technical capabilities of such a drone system:

**Payload:** Thermal infrared (IR) sensor, typically operating in the 8–14  $\mu\text{m}$  range for landmine detection.

**Imaging Technology:** Radiometric thermal imaging capable of detecting minute heat variations caused by subsurface anomalies (e.g., landmines absorbing solar heat differently).

**Flight Capabilities:** Autonomous or remote-piloted, with GPS navigation, waypoint mapping, and real-time data transmission.

**Use Case:** Humanitarian demining, battlefield surveillance, search and rescue, and environmental monitoring.

**Strategic Application:**

**Mine Action Operations:** Identifying thermal differentials where landmines disturb the soil or vegetation heat profile.

**Risk Reduction:** Minimizes human exposure by enabling aerial inspection prior to manual demining.

**Cost-Efficiency:** Offers scalable, repeatable, and safer alternatives to traditional ground-based detection.

Thermal performance can be affected by weather, soil composition, and vegetation.

Best results during early morning or late afternoon when temperature contrasts are more pronounced.

Great — here’s a **comprehensive technical and schematic overview** of drones equipped with thermal cameras for landmine detection, structured for academic or strategic research use:

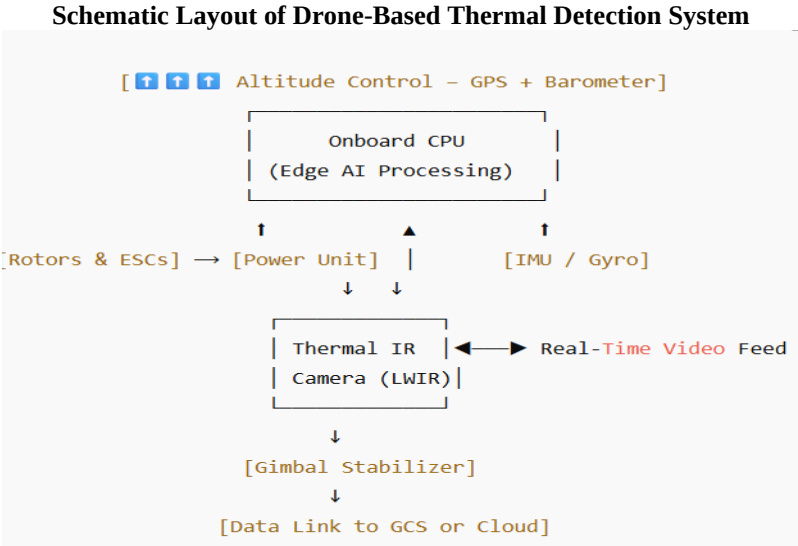


Table 1.

| A comprehensive technical and schematic overview |                                                                                             |
|--------------------------------------------------|---------------------------------------------------------------------------------------------|
| Component                                        | Description                                                                                 |
| Drone Platform                                   | Multirotor (e.g., DJI Matrice, Parrot Anafi USA), suitable for low-altitude, stable flight. |
| Thermal Camera                                   | Long-Wave Infrared (LWIR), e.g., FLIR Tau 2, DJI Zenmuse XT2                                |
| Resolution                                       | 640×512 pixels (typical for radiometric thermal imaging)                                    |
| Spectral Band                                    | 8–14 μm (sensitive to heat signatures)                                                      |
| Gimbal System                                    | 3-axis stabilization for precise imaging                                                    |
| Processing Unit                                  | Onboard CPU or edge AI (e.g., NVIDIA Jetson) for image preprocessing                        |
| Connectivity                                     | Encrypted RF link or 4G/5G with real-time transmission to ground station                    |

Operational Workflow

- Mission Planning:** UAV flight paths defined over suspected minefields.
- Thermal Data Capture:** Conducted during optimal time (dawn or dusk).
- Image Analysis:** Thermal anomalies flagged using edge-AI or later processed via ML models.
- Ground Verification:** Heat anomaly maps guide human deminers or ground robots.

Table 2.

| Strategic Advantages  |                                                                                          |
|-----------------------|------------------------------------------------------------------------------------------|
| Benefit               | Implication for Military / Humanitarian Ops                                              |
|                       | Reduces personnel exposure in high-risk zones                                            |
| Rapid Deployment      | Suitable for post-conflict zones and border regions                                      |
| Thermal Signature Use | Detects buried mines based on disturbed soil heat exchange                               |
| Interoperable         | Can be integrated into broader ISR (Intelligence, Surveillance, Reconnaissance) networks |

Experts suggest that the second method—thermal (infrared) radiation detection—is more promising for mine identification. When exposed to sunlight, the soil above a mine heats differently than the surrounding soil. In infrared imagery, this creates a visible thermal contrast: during the day, the mine area appears brighter,

while at night it cools faster and appears darker (Fig. 3) [4-6]

$$T_t \neq T_t$$

(1)

Here, T<sub>t</sub> – soil temperature, M<sub>t</sub> – temperature of underground object (mine). If the condition expressed

in Equation (1) holds true, it indicates a potential presence of a mine within the surveyed area.

Accordingly, the model representing the probability of mine presence in the area can be formulated as follows:

$$\begin{cases} T_i = M_i \text{ there are no mines in the area,} \\ T_i \neq M_i \text{ there are mines in the area.} \end{cases}$$

### Results and discussion

Dielectrics are materials that do not conduct electric current. They exist in gaseous, liquid, and solid states and are composed of electrically neutral atoms and molecules. Dielectrics can be classified into two categories based on molecular structure: polar and non-polar. When subjected to an electric field, the charges bound within the dielectric material shift in opposite directions, causing the dielectric to become polarized. This induced polarization generates its own electric field, which counteracts and thereby reduces the external electric field within the dielectric. Dielectric permeability (also referred to as relative permittivity) is a dimensionless physical quantity characterizing a dielectric medium. It indicates the extent to which the force of interaction between two electric charges in the medium is reduced compared to the force in a vacuum. The

value of dielectric permeability varies depending on the material type and is influenced by parameters such as frequency, temperature, and pressure of the applied electric field.

$$\varepsilon = \frac{F_o}{F} \quad (2)$$

Here,  $\varepsilon$  is the dielectric permittivity of the medium, a single nameless physical quantity that shows how many times the Coulomb force decreases when passing from vacuum to a homogeneous dielectric, while the distance between the charges remains constant [8-11]

The dielectric permittivity of the medium is also a quantity that shows how many times smaller the electric charge is inside a homogeneous dielectric and the intensity it creates at a given point.

$$\varepsilon = \frac{E_o}{E} \quad (3)$$

The dielectric constant of different substances can differ significantly. For example, in vacuum  $\varepsilon=1$ , in distilled water  $\varepsilon=81$ . The following table shows the dielectric constant of substances at a temperature of 20° C.

Table 3.

Dielectric permittivity of various substances [2].

| Materials | Dielectric strength | Materials     | Dielectric strength |
|-----------|---------------------|---------------|---------------------|
| paper     | 3-7                 | paraffin      | 2,1-2,2             |
| vacuum    | 1                   | plastic       | 2,8-4,5             |
| water     | 80-81               | mica          | 6-7                 |
| air       | 1                   | glass         | 4-7                 |
| quartz    | 4,3                 | porcelain     | 6-8                 |
| kerosene  | 2,1                 | ebonite       | 2,8                 |
| oil       | 2,5                 | ethyl alcohol | 24                  |

Let us assume that the dielectric permittivity of the soil is  $\varepsilon_t$ , and the dielectric permittivity of the mine or  $\forall$  object under the ground is  $\varepsilon_m$ . Then, the model of the presence of a mine in the area will be as follows:

$$\begin{cases} \varepsilon_t = \varepsilon_m \text{ there are no mines in the area,} \\ \varepsilon_t \neq \varepsilon_m \text{ there are mines in the area} \end{cases}$$

To enhance the contrast between the dielectric permittivity of subsurface objects and that of the surrounding soil, it is essential to increase the soil moisture content. Typically, water is sprayed onto the area being surveyed for mines using specialized technical equipment.

As a result, the dielectric permittivity of the moistened soil differs significantly from that of the mines, enabling effective mine detection through microwave-based methods.

The underlying physical principle of this detection process is as follows: an electrical impulse is converted into radio waves by a transducer and directed towards the suspected mined area. When these waves encounter a mine, they are reflected back and captured by the transmitting device. The reflected signal is then processed, and the image of the detected "object" is displayed on a computer monitor for further analysis.

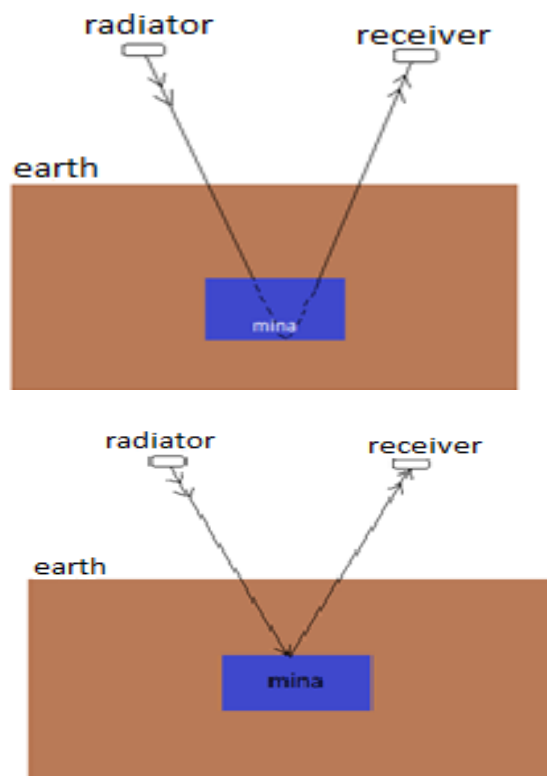


Figure 3. – Transmission and reception of signals from a ground penetrating radar [3].

Waves are transmitted at 2.45 and 5.8 QHs.

The quality of the results depends on:

- The power of the transmitter ( $1\text{ mW} < W < \dots$ );
- The efficiency of the converter;
- The sensitivity of the receiver;
- The high resolution and contrast of the display.

The system must be designed so that it can be used in any weather conditions, even at extreme temperatures [19]. The stronger the signal transmitter, the greater the probability of detecting an object

$$\lim_{W \rightarrow W_{\max}} P_{\text{obyekt}} = 1.$$

$$W \rightarrow W_{\max}$$

Here,  $W$  and  $W_{\max}$  are the power of the transmitted signals, and  $P_{\text{obyekt}}$  is the probability of detecting an object (mine).

With this method, it is possible to detect not only mines, but even small details under the ground. Similarly, the receiver must work with minimal losses. In other words, it must “hear” the sound of mines hidden in the ground well (Fig. 4).

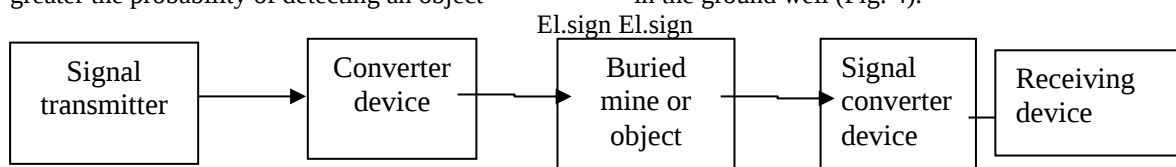


Figure 4. – System operating principle

The system can be briefly outlined as follows. It consists of four main components:

- Transmitter,
- Converter,
- Receiver,
- Monitor (screen).

Electrical signals generated by the transmitter are converted into radio waves by the converter and directed towards the Earth's surface [12-13]. When these waves encounter any subsurface object, including a mine, they are reflected back. The reflected waves are converted once again into electrical signals by the converter, amplified by the receiver, and then transmitted to the monitor for visualization.

Knowing the propagation speed of radio waves in soil or rock, the distance to the detected object can be

calculated by measuring the time interval between signal transmission and reception. This process is repeated multiple times per second to generate continuous data. [14] Although the system is primarily designed to operate at a frequency of 200 kHz, variants functioning at 50 kHz can also be developed. It is important to note that the monitor may also display signals reflected from various other subsurface objects encountered along the wave's path between the surface and the mine [15]. Signal filtering and purification is a complex topic and thus is beyond the scope of this discussion; however, it suffices to mention that signals from other underground objects, aside from mines, can also be captured and interpreted.

Regarding operational frequencies:

At **200 kHz**:

The detection depth decreases,

The radiation angle narrows,  
Target detection accuracy and resolution improve,  
Sensitivity to noise decreases.

#### At 50 kHz:

The detection depth increases,  
The radiation angle widens,  
Target resolution and detection accuracy deteriorate,

Sensitivity to noise increases.

#### Conclusion

The system's performance is inherently dependent on the chosen operating frequency, as it influences both the electromagnetic wave's penetration depth and spatial resolution. Higher frequencies (e.g., 200 kHz) offer improved resolution due to shorter wavelengths, enabling better discrimination between closely spaced sub-surface objects. However, increased soil attenuation at these frequencies limits effective detection depth. Lower frequencies (e.g., 50 kHz) facilitate deeper penetration owing to reduced attenuation but compromise spatial resolution, making precise object identification more challenging. Consequently, a balance must be struck between detection depth and resolution, considering specific operational requirements and soil characteristics.

Environmental factors such as soil heterogeneity and moisture content also significantly affect wave propagation velocity and attenuation, introducing potential signal distortions. These variations necessitate the use of advanced signal processing algorithms to accurately interpret received signals.

Signal-to-noise ratio (SNR) plays a crucial role in detection efficacy. While the system incorporates amplification and filtering techniques to improve SNR, external electromagnetic interference and reflections from non-mine objects present ongoing challenges. To address these issues, modern mine detection systems increasingly integrate machine learning and adaptive filtering techniques to differentiate mines from clutter and false positives effectively. [16-17]

Moreover, real-time imaging capability allows operators to monitor detected objects dynamically, facilitating immediate decision-making during clearance operations. Integration with GPS and digital mapping software further enhances the precision of mine localization and documentation, improving overall operational safety and efficiency. The fusion of advanced sensor technologies with unmanned aerial platforms offers a paradigm shift in mine detection strategy. These systems address both operational and humanitarian objectives-enhancing safety, precision, and speed. However, their strategic value lies in integration: into doctrine, policy, and partnerships. As warfare evolves, so too must demining-shifting from manual risk to technological advantage. The findings indicate that the proposed methods allow for the identification of mines from a safe distance, thereby enhancing the safety of demining personnel.

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# VETERINARY SCIENCES

## ПОЛИМЕРАЗНЫЙ КОМПЛЕКС ВИРУСА БОЛЕЗНИ НЬЮКАСЛА: МОЛЕКУЛЯРНАЯ ОРГАНИЗАЦИЯ, ДИАГНОСТИЧЕСКИЕ МИШЕНИ И СТРАТЕГИИ КОНТРОЛЯ

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## NEWCASTLE DISEASE VIRUS POLYMERASE COMPLEX: MOLECULAR ORGANIZATION, DIAGNOSTIC TARGETS, AND CONTROL STRATEGIES

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### Аннотация

Вирус болезни Ньюкасла (ВБН), относящийся к авипарамиксовирусам, продолжает представлять серьёзную угрозу для мировой птицеводческой отрасли. Способность вируса реплицироваться и вызывать заболевание напрямую зависит от работы его полимеразного комплекса, включающего нуклеопротеин (NP), фосфопротеин (P) и крупный полимеразный белок L. Настоящий обзор обобщает данные современной литературы (2015–2024 гг.) с учётом фундаментальных исследований, предоставляя механистическую характеристику этих трёх белков. Особое внимание уделено их молекулярной структуре, функциям в репликации и патогенезе вируса, а также их роли как мишеней для диагностики и мер контроля, с акцентом на вирулентные генотипы VII и XIII, доминирующие в современных вспышках у кур и другой домашней птицы. Рассмотрены молекулярные методы диагностики, включая ОТ-ПЦР и секвенирование, а также комплексная стратегия контроля, охватывающая вакцины нового поколения, противовирусные препараты, генетическую устойчивость и меры биобезопасности.

### Abstract

Newcastle Disease Virus (NDV), an avian paramyxovirus, remains a significant threat to the global poultry industry. The virus's ability to replicate and cause disease is fundamentally dependent on its polymerase complex, comprising the nucleoprotein (NP), phosphoprotein (P), and the large polymerase (L) protein. This review synthesizes recent literature (2015–2024), supplemented by foundational research, to provide a mechanistic overview of these three proteins. We focus on their molecular structures, functions in viral replication and pathogenesis, and their roles as targets for diagnostics and control, with an emphasis on virulent genotypes like VII and XIII that dominate current outbreaks in chickens and other domestic poultry. The review covers molecular diagnostic methods, including RT-PCR and sequencing, and discusses a multi-pronged control strategy encompassing next-generation vaccines, antiviral agents, genetic resistance, and biosecurity.

**Ключевые слова:** вирус болезни Ньюкасла, полимеразный комплекс, нуклеопротеин (NP), фосфопротеин (P), крупная полимераз (L), меры контроля.

**Keywords:** Newcastle Disease Virus, polymerase complex, nucleoprotein (NP), phosphoprotein (P), large polymerase (L), control measures.

### 1. Структура и функции полимеразного комплекса ВБН

Ядром репликации и транскрипции ВБН является рибонуклеопротеидный (RNP) комплекс. Он

состоит из одноцепочечной РНК отрицательной полярности, инкапсидированной NP, формирующего спиральную структуру. Этот NP-РНК шаблон служит субстратом для РНК-зависимой РНК-полиме-

разы (RdRp) белка L, который рекрутируется в комплекс при участии кофактора белка Р. Гены вируса расположены последовательно вдоль генома (3'-NP-P-M-F-HN-L-5'), что обуславливает градиент

экспрессии белков, критически важный для жизненного цикла вируса [4].

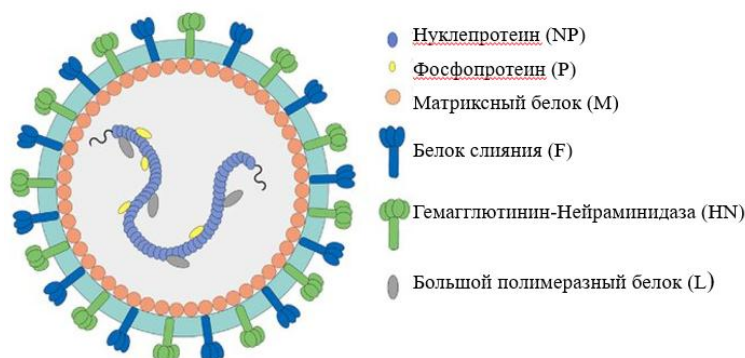


Рисунок 1 – Структура вируса болезни Ньюкасла

### 1.1 Нуклеопротеин (NP)

NP — многофункциональный структурный белок, необходимый для формирования RNP-комплекса и взаимодействия с клеточными факторами хозяина (рисунок 1).

**Молекулярные особенности:** NP состоит из ядра, фланкированного гибким N-концевым доменом (N-arm) и C-концевым хвостом (C-tail). Эти внутрисобственно-дисорганизованные области играют ключевую роль в высших функциях белка. N-arm совместно с белком Р индуцирует жидкостно-жидкостную фазовую сепарацию (LLPS), что приводит к формированию вирусных включённых тел (IB) в цитоплазме. Делеция N-arm полностью устраняет образование IB и синтез вирусной РНК [1]. C-tail участвует в связывании геномной РНК и рекрутировании L; предполагается, что его фосфорилирование регулирует переключение между репликацией и транскрипцией [1].

**Роль в патогенезе и уклонении от иммунного ответа:** Вирулентные генотипы развили сложные механизмы подавления иммунных ответов с участием NP. NP генотипов VII и XIII индуцирует лизосомальную деградацию клеточного адаптерного белка 14-3-3ε, что подавляет MAVS-зависимую сигнализацию и снижает активацию RIG-I/MDA5-опосредованного интерферонового ответа [3]. Полиморфизм L450F в NP генотипа VII ослабляет взаимодействие с eIF4A1, уменьшая загрузку вирусных мРНК на рибосомы, что изменяет стратегию репликации. У большинства изолятов XIII генотипа сохраняется остаток L450[2].

### 1.2 Фосфопротеин (P)

P — некаталитический, но ключевой компонент полимеразного комплекса, выполняющий функции молекулярного шапса и шаперона.

**Молекулярные особенности:** P — высокофосфорилированный олигомерный белок (обычно тетрамер) с N-концевым доменом, связывающим мономерный NP<sup>o</sup> и предотвращающим его агрегацию. C-концевой домен P закрепляет L на NP-РНК-шаблоне и участвует в LLPS. C-концевая α-спираль P служит «затравкой» для LLPS; её удаление блокирует образование IB и синтез РНК. В генотипе

XIII зафиксированы замены Ala→Thr, которые могут изменять фазовую сепарацию [1].

**Роль в патогенезе:** Ген Р кодирует также аксесорные белки V и W через РНК-редактирование. Белок V участвует в иммунном уклонении и регуляции активности полимеразы. Мутация W195R в V ослабляет взаимодействие с NP, вызывая увеличение размеров IB и ускорение репликации in vitro, но снижение вирулентности in vivo [7].

### 1.3 Крупный полимеразный белок (L)

L — каталитическое ядро вируса, обеспечивающее репликацию генома и транскрипцию.

**Молекулярные особенности:** L (~250 кДа) содержит RdRp-домен (мотивы A–E), домены эпироирования мРНК и метилирования. L транскрибирует гены последовательно с 3'-конца, формируя градиент экспрессии: NP>P>M>F>HN>L [4].

**Роль в патогенезе:** у высокопатогенных штаммов VII.1.1 градиент экспрессии «пологий» (NP:P:M: F:HN: L ≈ 1:0,73:0,64:0,60:0,56:0,53) [5], что обеспечивает баланс ранних и поздних белков. L взаимодействует с шапероном HSP90β; ингибирование HSP90β дестабилизирует L и прекращает синтез РНК [6].

### 2. Роль полимеразного комплекса в патогенезе и вирулентности

Скоординированное действие белков NP, P и L лежит в основе патогенеза ВБН, особенно тяжёлого течения болезни, вызываемого вирулентными генотипами у птицы.

Эффективная репликация и уклонение от иммунного ответа: Формирование IB посредством LLPS, индуцируемого NP и P, создаёт защищённые микросреды для синтеза вирусной РНК, экранируя вирусные компоненты от сенсоров врождённого иммунитета, таких как RIG-I [1]. Одновременно NP опосредует деградацию адаптерного белка 14-3-3ε, что дополнительно подавляет MAVS-зависимую сигнализацию и способствует быстрому росту вируса [3]. Это ведёт к стремительному размножению вируса в лимфоидной и нервной ткани, вызывая лимфоидную депрессию и энцефалит, характерные для инфекции вирулентными штаммами [8].

Тонкая настройка вирулентности: Вирулентность определяется не только скоростью репликации, но и балансом. Пологий транскрипционный градиент генотипа VII обеспечивает пропорциональный синтез всех вирусных белков, что поддерживает быструю системную диссеминацию [5]. Регуляторные механизмы, такие как взаимодействие V-NP, демонстрируют, что оптимальная, а не максимальная активность полимеразы обеспечивает наибольшую приспособленность вируса в хозяине [7].

Зоонозный аспект: Основными хозяевами ВБН являются птицы, однако вирус способен вызывать лёгкий конъюнктивит и гриппоподобные симптомы у людей, преимущественно у работников птицеводческих хозяйств или лабораторий. Полимеразный комплекс необходим для ограниченной репликации в клетках человека, но видовые барьеры препятствуют развитию системного заболевания.

### 3. Диагностические приложения

Гены, кодирующие компоненты полимеразного комплекса и другие структурные белки, являются основными мишенями для молекулярной диагностики, необходимой для эпиднадзора, патотипирования и управления вспышками.

Молекулярное выявление и патотипирование:

Реал-тайм ОТ-ПЦР (rRT-PCR): Тесты, нацеленные на консервативные участки генов NP и M, широко применяются для быстрого и чувствительного выявления вируса класса II в клинических и экологических пробах [9].

Анализ сайта расщепления: Вирулентность определяется аминокислотной последовательностью в сайте расщепления белка слияния (F). ОТ-ПЦР с последующим секвенированием (Sanger или NGS) позволяет выявить полибазический мотив (например, <sup>112</sup>RRQKR[F<sup>117</sup>]), характерный для велогенных штаммов [10].

Генотипирование и филогенетический анализ:

Для отслеживания эволюции ВБН используется полное секвенирование гена F или всего генома. Филогенетические методы (IQ-TREE, BEAST) позволяют классифицировать изоляты по генотипам и субгенотипам (VII.1.1, VII.2, XIII.1) [11]. Молекулярная эпидемиология необходима для оценки эффективности вакцин, так как вспышки штаммов с вакцинным несовпадением распространены. Установлено доминирование генотипа VII в Африке и Азии, и рост распространённости генотипа XIII в Южной Азии [10,11]

Перспективные и экспресс-методы диагностики:

Мультиплексные иммуноанализы: Платформы типа Luminex позволяют одновременно определять антитела к NP ВБН и другим возбудителям (например, вирусу гриппа птиц), что ускоряет серомониторинг и оценку охвата вакцинацией [12].

Изотермическая амплификация и CRISPR: Полевые методы, такие как RT-LAMP и RPA, в сочетании с системами Cas12a, обеспечивают чувствительность, сопоставимую с rRT-PCR, но в формате,

пригодном для применения в хозяйствах с ограниченными ресурсами [13].

### 4. Стратегии контроля

Эффективный контроль ВБН требует комплексного подхода, включающего вакцинацию, разработку противовирусных средств, генетический отбор и строгую биобезопасность.

Вакцинация:

Живые аттенуированные вакцины (LAV): Классические штаммы (LaSota, B1) до сих пор применяются, но ведутся работы над термостабильными вариантами (Mukteswar, V4) для условий с ограниченным «холодным» снабжением [14,15].

Инактивированные вакцины: Масляные эмульсионные вакцины обеспечивают длительный иммунитет и безопасны для несушек и племенной птицы. Использование генотип-специфичных штаммов (например, VII.2 из Бангладеш) повышает эффективность [16].

Рекомбинантные векторные вакцины: Технология обратной генетики позволяет использовать ВБН в качестве вектора для экспрессии антигенов других патогенов (IBDV, ILT), что даёт бивалентную защиту [18,19,20].

ДНК-вакцины: Плазмидные конструкции, экспрессирующие F и HN генотипа VII, показали защитную эффективность и обладают стабильностью при хранении без холодовой цепи [22].

Противовирусные и хост-направленные подходы:

РНК-интерференция: shRNA, нацеленные на консервативные участки NP, демонстрируют широкий спектр ингибирующей активности *in vitro* [25].

Малые молекулы и природные соединения: Идентифицированы клеточные факторы (RABGAP1L, TARBP), необходимые для репликации ВБН и являющиеся потенциальными мишенями для препаратов [24]; репозиционированные препараты (эметин) и природные вещества (флавоноиды) также обладают активностью [26,27].

Модуляция иммунитета хозяина: Усиление врождённого иммунитета, например, через экспрессию TRIM32 или применение галектина-1B, может ограничить репликацию вируса [28,29].

Генетическая устойчивость:

Некоторые породы кур демонстрируют природную устойчивость к ВБН. Африканские местные куры имеют полиморфизмы, связанные с низкой смертностью, а порода Фаюми быстрее активирует врождённый иммунный ответ<sup>3031</sup>. Картирование QTL и выявление дифференциально экспрессируемых генов может способствовать селекции устойчивых линий [32].

Биобезопасность:

Независимо от прогресса в вакцинации, основой профилактики остаётся биобезопасность. Строгая гигиена, система «all-in/all-out», разделение стад и контроль живых птичьих рынков доказали свою эффективность [33,34]. Комплексные программы, сочетающие вакцинацию, обучение фермеров и меры биобезопасности, наилучшим образом снижают частоту вспышек [15,35,36].

Таблица 1

| Основные характеристики, диагностика и цели контроля полимеразного комплекса вируса NDV |                                                                                                                                                                                                                                                                               |                                                                                                                                                                                                                                                                         |                                                                                                                                                                                                                                                                    |
|-----------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Белок                                                                                   | Ключевые молекулярные характеристики и функции                                                                                                                                                                                                                                | Применение диагностических мишеней                                                                                                                                                                                                                                      | Методы контроля и мишени                                                                                                                                                                                                                                           |
| NP (нуклеопротеин)                                                                      | Инкапсидирует геномную РНК вируса.<br>N-участок инициирует LLPS с Р-белком для образования включений [1].<br>Разрушает 14-3-3ε хозяина, подавляя врождённый иммунитет.<br>Аминокислота 450 (L/F) регулирует трансляцию вирусной мРНК [2].                                     | <b>Ген:</b> используется в пан-класс II rRT-PCR для широкой детекции [9].<br><b>Антиген:</b> в мультиплексных сероанализах (Luminex) для мониторинга вакцин. [12].                                                                                                      | <b>RNAi:</b> консервативный ген — мишень для шРНК-антивирусов.<br>Вакцинный антиген: в цельновирионных и субъединичных вакцинах.<br><b>Лекарственная мишень:</b> интерфейс NP–P (LLPS) для малых ингибиторов.                                                      |
| P (фосфопротеин)                                                                        | Шаперон NP, связывает NP–РНК с L-белком.<br>С-концевой домен необходим для LLPS и образования включений [1].<br><b>Кодирует белки V/W</b> (РНК-редактирование);<br>V-белок регулирует активность полимеразы и вирулентность.<br>Шаперон NP и связывает NP-РНК с белком L [7]. | <b>Ген-мишень:</b> используется в RT-qPCR для оценки градиента транскрипции в исследованиях патогенеза [5].<br><b>Филогенетика:</b> последовательности гена P применяются для изучения эволюции вируса.                                                                 | <b>Мишень аттенуации:</b> мутации в Р- или V-белке (например, W195R), снижающие вирулентность и применяемые при разработке вакцин [5].<br><b>Лекарственная мишень:</b> интерфейсы P–NP и P–L перспективны для противовирусных препаратов.                          |
| L (большая полимераз)                                                                   | РНК-зависимая РНК-полимераза (RdRp) с функциями экзирования и метилирования.<br>Обеспечивает последовательную транскрипцию с характерным градиентом.<br>Зависит от шаперона хозяина HSP90β для стабильности и функции [6].                                                    | <b>Ген-мишень:</b> секвенирование L-гена используется в глубоком филогенетическом анализе для уточнения эволюционных связей.<br><b>Транскрипционный профиль:</b> измерение уровня мРНК L-гена позволяет определить градиент транскрипции и потенциальную вирулентность. | <b>Лекарственная мишень:</b> активный центр RdRp — классическая точка воздействия; взаимодействие L–HSP90β — подтверждённая мишень, направленная на фактор хозяина.<br>Мишень аттенуации: мутации в L-белке применяются для создания живых аттенуированных вакцин. |

**5. Заключение**

Полимеразный комплекс ВБН — это высокоорганизованная молекулярная система, играющая ключевую роль в репликации вируса, иммунном уклонении и патогенезе. Современные исследования показали, что координация функций NP, P и L — включая LLPS-опосредованное формирование IB, деградацию клеточных белков и тонко настроенные транскрипционные градиенты — обеспечивает высокую вирулентность генотипов VII и XIII. Эти знания уже используются для совершенствования диагностики и мер контроля. Перспективы борьбы с ВБН лежат в интегрированном подходе, включающем генотип-специфичные рекомбинантные вакцины, хост-направленные противовирусные средства, селекцию устойчивых пород птицы и, прежде всего, неукоснительное соблюдение биобезопасности.

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