# Application of Advanced Seismic Methods from Exploration to Reservoir Engineering in the Petroleum Industry of Kazakhstan

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## ABSTRACT

This study examines the application of new seismic methods to improve the efficiency of geological exploration in Kazakhstan, from planning seismic exploration to interpreting the data obtained and preparing recommendations for further research. Taking into account the geological features of the regions of Kazakhstan and the urgent tasks of the extractive industry, advanced approaches such as high-density and wide azimuth seismic exploration, prestack depth migration (PSDM) and other methods for constructing seismic images in difficult geological conditions, geodynamic and geomechanical methods for optimizing exploration and operational work are proposed. The research is aimed at identifying the advantages of these methods in the conditions of complex tectonics and fault zones characteristic of Kazakhstan. It is expected that the introduction of new technologies will increase the accuracy of field exploration, improve production control and minimize environmental risks. This is especially important in the context of growing global demand for energy resources, as traditional energy sources are being depleted. The results obtained can be useful for the oil and gas and mining industries, as well as for public and private entities engaged in the search, exploration and production of hydrocarbon deposits.

## ACKNOWLEDGEMENTS

The author's experience and knowledge from working in geological and geophysical institutions in Kazakhstan from 1978 to 2024 served as the foundation for the thesis.

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**TABLE OF CONTENTS**

# LIST OF TABLES AND FIGURES

## List of tables



## List of figures

# 1. INTRODUCTION AND AIM OF STUDY

Seismic exploration using the reflected wave method (Reflection Seismology) is one of the most effective and widely used geophysical methods for studying the geological structure of the earth's interior, in particular, in the search and exploration of hydrocarbon deposits. The essence of the method is to generate artificial seismic waves and register their reflections from the boundaries of various rocks. Analyzing the data obtained, geophysicists receive information about the depth of these boundaries, their shape and properties of rocks.

In the initial stage, researchers successfully used Reflection Seismology to build geometric models of formation occurrence, enabling the identification of promising anticline-type structures.

Currently, in conditions of depletion of large easily accessible deposits, the focus has shifted to the creation of more detailed and accurate geological models capable of reflecting not only the geometry of deposits, but also their physical properties (porosity, permeability, saturation). This is necessary for the assessment of hydrocarbon resources and the development of optimal technologies for their extraction.

Tasks of modern seismic exploration:

- Building detailed geological models: Creating three-dimensional models that accurately reflect the geological structure of the studied area.
- Assessment of hydrocarbon resources: Determination of the volume of hydrocarbon reserves, taking into account their physical properties and the geometry of deposits.
- Field development design: Creation of field development plans that take into account the heterogeneity of the geological structure and properties of productive formations.

Problems and prospects:

- The complexity of data interpretation: The relationship between the characteristics of seismic waves and the physical properties of rocks is complex and ambiguous. Researchers use various geophysical and geological methods to establish it.
- Heterogeneity of geological environments: The high degree of heterogeneity in real geological environments complicates the interpretation of seismic data and the construction of accurate geological models. Improved accuracy: Modern technologies allow us to obtain more and more detailed and accurate seismic data. However, their effective interpretation requires powerful computing resources and specialized software.

Promising areas of development:

- 4D seismic survey: Allows you to track changes in the geological structure of the field during its development.
- Integration with other geophysical methods: Combining seismic data with data from other geophysical methods (electrical exploration, gravimetry, and magnetometry) allows you to get a more complete picture of the geological structure.
- Development of new methods of interpretation: Creation of new algorithms and methods of interpretation of seismic data, allowing determining the physical properties of rocks more accurately.

Conclusion:

Seismic exploration using the reflected wave method remains one of the key tools in the search and exploration of hydrocarbon deposits. Despite the successes achieved, geophysicists face new challenges related to the need to improve the accuracy and detail of geological models, as well as the development of new methods for interpreting seismic data. Solving these tasks will make it possible to develop hydrocarbon resources more efficiently.

## 1.1. BACKGROUND OF THE STUDY

The development of seismic methods in the oil and gas industry of Kazakhstan is closely related to the evolution of exploration and development of large deposits, as well as global trends in the introduction of advanced technologies.

The first stages of seismic exploration. In the middle of the XX century, within the framework of the state program for the exploration of natural resources, the first seismic surveys in Kazakhstan began. The main methods during this period included:

- 2D seismic survey, which provided basic information about the structure of sedimentary basins.
- Gravimetric and magnetic studies to search for large structural traps.

Key discoveries of those years include such fields as Uzen, Zhetybai and Kalamkas, the exploration of which formed the basis of the oil and gas sector in Western Kazakhstan.

The period after independence (1990s). After the collapse of the USSR, Kazakhstan faced the need to modernize the exploration industry. During this period:

- Kazakhstan has actively begun to attract international oil companies such as Chevron, Agip, and Shell, which have introduced advanced 3D seismic technologies.
- The introduction of field computer systems has made it possible to velocity up data processing and improve the quality of interpretation.

An example of the success of international cooperation was the large-scale seismic surveys in the Kazakh sector of the Caspian Sea in the amount of 27,000 km of marine 2D seismic exploration, the Tengiz field, where for the first time in Kazakhstan large-scale 3D seismic exploration was applied, providing accurate data for development.

2000s: transition to complex deposits and new methods. The early 2000s were marked by the development of complex and high-cost deposits, such as Kashagan on the shelf of the Caspian Sea. More advanced technologies were required for such deposits:

- Deep-sea seismic exploration and application of 4D seismic.
- Using software packages for reservoir modeling.

The key challenges during this period were the difficulties of working under high pressures and hydrogen sulfide formations. To enhance development, researchers introduced microseismic-based monitoring systems.

The last decade: digitalization and an integrated approach. Since the 2010s, there has been a trend towards digitalization of the industry in Kazakhstan. The use of artificial intelligence and machine learning has become an important element in the processing of big data. Also implemented were:

- Seismic sounding with multi-attribute analysis, enhancing the interpretation of complex structures.
- Hybrid methods (seismic + gravity exploration) to increase exploration accuracy in hard-to-reach areas.

An example of this approach was the integration of 4D seismic at the Karachaganak field, which made it possible to track the movement of gas and liquids in the reservoir.

Today, Kazakhstan continues to develop seismic technologies in cooperation with international partners and scientific centers. The emphasis is on:

Deep exploration of carbonate formations in the Caspian basin.

- Integration of remote monitoring and geophysical research data for more accurate field development.
- Smart monitoring systems that ensure sustainable inventory management and minimize environmental risks.

Conclusion. Thus, the evolution of the application of seismic methods in Kazakhstan reflects the global trends of the oil and gas industry.

## 1.2. STATEMENT OF THE PROBLEM

Over the past few decades, Kazakhstan has made significant progress in the field of geological exploration, having accumulated extensive experience in using modern seismic exploration methods in studying its sedimentary basins. The country has fifteen basins with a diverse geological structure and various oil and gas potential. This requires the use of high-tech approaches to study underground structures in detail and improve the accuracy of forecasting hydrocarbon deposits. The diverse geological conditions—ranging from platform areas with relatively simple structures to folded belts with complex tectonics—require the use of a broad spectrum of seismic methods and data processing technologies.

This study is an in-depth analysis and synthesis of the results of the application of advanced seismic exploration methods in Kazakhstan. It examines various aspects – from planning fieldwork to interpreting the data obtained and preparing recommendations for further research. The analysis covers both traditional methods, such as 2D seismic exploration, and modern high-resolution technologies, including 3D and 4D seismic exploration, as well as processing methods aimed at suppressing interference and improving image quality. In particular, researchers pay special attention to using technologies such as Pre Stack Depth Migration (PSDM), Full-Wave Inversion (FWI), and data processing with machine learning to automate and improve interpretation efficiency.

During the research, the author studied numerous scientific publications and reports on geological exploration conducted both in Kazakhstan and abroad. They paid special attention to analyzing cases of successful application of advanced technologies in similar geological conditions. This made it possible to develop effective strategies to improve the accuracy of forecasting hydrocarbon deposits.

The author's personal experience, including direct participation in the planning and conduct of 3D field seismic surveys, allows for a deep assessment of the effectiveness of various approaches. Specifically, the author contributed to the development of projects by determining the optimal survey parameters, considering the peculiarities of the geological structure. Additionally, the author planned data processing schedules, accounting for the specifics of the studied structures, such as the presence of salt domes, faults, and abrupt lithological changes. The author also participated in interpreting the obtained results and creating detailed geological models of subsurface structures. He worked directly with seismic data processing software such as Petrel, SeisSpace, and others, using various wave processing and migration algorithms. The author also participated in the preparation of reports presenting research results and developed recommendations for further geological and geophysical work, including proposals to optimize costs and improve research efficiency.

In addition, the study addresses issues of environmental safety during seismic exploration, as well as the analysis of the economic efficiency of various methods and technologies. In conclusion, the results of the study are summarized, the main conclusions are formulated and recommendations are given for the further development of seismic exploration in Kazakhstan, taking into account global trends in the development of exploration and the growing demand for hydrocarbon raw materials. Researchers are evaluating the prospects of applying new technologies, such as seismic exploration using unmanned aerial vehicles (UAVs) and artificial intelligence for automated data interpretation, and their potential impact on the efficiency and velocity of exploration in Kazakhstan. In general, the study demonstrates the significant potential of using modern seismic exploration methods to improve the efficiency of exploration in Kazakhstan and the successful development of its hydrocarbon resources.

The need to improve the efficiency of exploration significantly for hydrocarbons (HC) in Kazakhstan requires a rethink of existing approaches and the development of new seismic exploration techniques. The urgency of the task is due to the need to increase reserves both at new facilities and through additional exploration of fields already under development, where geological conditions suggest the presence of undetected potential. This is especially important in the context of depletion of traditional sources and growing global demand for energy resources.

The systematization of accumulated experience and knowledge in the field of seismic exploration is a priority task. This process involves analyzing data from past studies, identifying successful and unsuccessful strategies, and, most importantly, assessing the impact of various geological factors (tectonics, lithology, fluid saturation) on the quality of the seismic data obtained. Based on this analysis, researchers should develop new conceptual models that describe the geological structure of different regions in Kazakhstan, accounting for their specific characteristics. For instance, foothill zones, with their complex tectonic disturbances, require the use of specialized methods for processing and interpreting seismic data, such as pre-stack migration and full-wave inversion. In contrast, platform areas can focus on high-precision data recording and processing to identify subtle lithological changes that correlate with hydrocarbon deposits.

The development of new paradigms in seismic exploration involves the active introduction of advanced technologies. These include: multi-wave seismic exploration (broadband, full-azimuth), seismic exploration using various types of excitation sources (vibrators, explosive sources, pneumatic sources), new data processing methods (for example, deep learning, machine learning to automate interpretation), and integration of seismic data with data from other geophysical methods (gravimetry, magnetic exploration, electrical exploration) to obtain a more complete and reliable geological model.

Adapting existing methods and paradigms to the specific conditions of Kazakhstan is also an important task. This includes taking into account the features of the relief, climatic conditions, and the depth of the target horizons and the complexity of the geological structure. It is necessary to develop special methods for processing and interpreting seismic data to improve the accuracy and detail of studying the geological structure of exploration areas, taking into account the specifics of each region – from the West Siberian Plain to the Caspian shelf.

The creation of innovative approaches involves an interdisciplinary approach combining the efforts of geophysicists, geologists, oil and gas engineers and specialists in data processing and interpretation. The development of specialized software for automating data processing and interpretation, the creation of databases and information systems for storing and analyzing geological information will contribute to improving work efficiency and reducing costs. All this will make it possible to solve geological problems at a new methodological level and ensure an increase in hydrocarbon reserves in Kazakhstan.

## 1.3. RESEARCH OBJECTIVE/AIM

The purpose of this study is:

Application of advanced seismic methods from exploration to field development in the oil industry of Kazakhstan.

### 1.3.1. SPECIFIC OBJECTIVES

1. Analysis of the current state of application of seismic methods in Kazakhstan. An overview of the use of international and domestic technologies.
2. Study of the features of the geological structure of the Caspian basin and other regions. Identification of problems related to faults, salt domes and high reservoir pressures.
3. Comparing the effectiveness of traditional and advanced seismic methods: Conducting a comparative analysis of 2D and 3D exploration based on the accuracy of the results. Evaluation of the advantages of 4D seismic exploration for monitoring fluids in the reservoir.
4. Development of recommendations for optimizing exploration and development methods. Determining the conditions under which it is advisable to use seismic inversion. Development of a strategy for the integrated application of methods to reduce geological risks.
5. Study of examples of successful application of seismic methods in Kazakhstan. Case analysis using 3D and 4D technologies in the largest projects (Karachaganak and Tengiz). Assessment of the impact of the application of new methods on the productivity and sustainability of production.

These tasks cover key aspects of the application of advanced seismic methods, take into account the specifics of Kazakhstan's deposits and are aimed at improving the efficiency of exploration and development.

## 1.4. RESEARCH QUESTIONS

1. Introduction

The relevance of the topic for Kazakhstan (rich oil and gas and mineral resources). Overview of the role of seismic exploration in the oil and gas industry.

The purpose of the study and the tasks.

2. Overview of advanced seismic methods.

3D and 4D seismic exploration: advantages and applications at different stages of exploration and production. Seismic tomography for building detailed models. Seismic inversion: data transformation to evaluate the physical parameters of a rock. Reverse seismic migration (RTM): high-precision construction of deep models.

3. Stages of application of seismic methods

3.1. Exploration of deposits. Regional and detailed seismic survey. Identification of structural traps and reservoirs. Example: the use of 3D exploration in the Caspian basin.

3.2. Assessment and modeling of deposits. Creating static and dynamic models. The use of inversion methods to assess porosity and saturation.

3.3. Development and operation. 4D seismic for monitoring changes in the reservoir. Fluid movement control and determination of depletion zones.

4. The Kazakh context

Overview of deposits (Karachaganak, Tengiz, etc.). Technological level and existing projects using advanced methods. Examples of cooperation with international companies and the use of innovative technologies.

5. Conclusion

Conclusions on the role of best practices in improving the efficiency of exploration and development. Recommendations for the application of best practices in Kazakhstan.

## 1.5. SIGNIFICANCE OF THE STUDY

1. Optimization of exploration and development of deposits. Advanced seismic methods make it possible to determine the location and geometry of mineral deposits more accurately, which reduces the number of uncertainties and errors. This increases the efficiency of exploration and minimizes the risk of drilling "dry" wells.
2. Increasing the profitability of production. The use of 3D and 4D seismic exploration improves fluid motion control and optimizes field development. This helps to maximize the hydrocarbon recovery rate and reduce operating costs.
3. Maintaining Kazakhstan's leadership in the oil and gas market. Kazakhstan is one of the key players in the hydrocarbon market, and the introduction of advanced technologies strengthens its competitive position, attracting investments and supporting the stable development of the energy sector.
4. Saving time and resources during exploration. Advanced seismic methods allow you to obtain detailed data on the subsurface quickly, which reduces decision-making time and increases the efficiency of drilling planning.
5. Sustainable development and long-term planning. Monitoring reservoirs using 4D seismic helps to plan production in such a way as to maximize the use of reserves while maintaining productivity for the long term.

Thus, the study is important for improving the efficiency and sustainability of Kazakhstan's oil and gas industry, ensuring a balance between economic interests and environmental requirements.

## 1.6. SCOPE OF THE STUDY

For a comprehensive analysis of the application of advanced seismic methods in the oil industry of Kazakhstan, the study may cover the following key aspects:

1. Geographical coverage. The main oil and gas regions are Western Kazakhstan, including Atyrau, Mangystau and West Kazakhstan regions, Southern Kazakhstan, Kyzylorda region. Large deposits: Tengiz, Karachaganak, Urikhtau and Kumkol. These projects are the flagships of the oil and gas sector and show how new methods are being implemented in practice.
2. Technical coverage. 2D and 3D seismic exploration for exploration purposes. 4D seismic for mining monitoring and fluid motion modeling. Seismic sensing with high-resolution interpretation for accurate mapping of structures.
3. Integration with digital technologies. The use of machine learning and artificial intelligence (AI) for automatic interpretation of data. Implementation of cloud platforms and big data analysis systems for the management and exchange of seismic information.
4. Comparative analysis with international practices. Assessment of the compliance of Kazakhstan's approaches to advanced seismic methods with international standards and trends. Analysis of successful examples from other oil-producing regions (for example, the North Sea, the Persian Gulf) to adapt best practices.

Conclusions and recommendations. Assessment of the prospects for further implementation of advanced seismic technologies in Kazakhstan. Development of recommendations for improving infrastructure, training specialists and coordination with government agencies to increase production efficiency and minimize environmental risks.

This study covers all stages of the application of seismic methods — from prospecting and exploration to field development and production management. It also highlights the importance of technological, environmental and economic aspects for the sustainable development of Kazakhstan's oil and gas industry.

## 1.7. ORGANISATION OF THE STUDY

1. The purpose and objectives of the study

Objective: To study the effectiveness of new seismic methods for exploration and development in Kazakhstan.

Tasks. Analysis of existing seismic methods and their limitations. Adaptation and testing of new methods (for example, high-density and wide-azimuth seismic). Identification of the regions of Kazakhstan where the use of new methods is most effective. Assessment of the economic and environmental aspects of implementation.

2. The choice of seismic methods

Methods. 2D/3D seismic survey: To study the characteristics of reservoirs. The use of advanced algorithms for processing big data.

3. Research area and regional features

Regions: The Caspian region is promising for oil and gas exploration. South Turgay unconventional reservoirs.

Climatic and geological features: Accounting for conditions such as seasonal temperature fluctuations and complex geology.

4. Research methodology

1. Analysis of literature and data. Evaluation of current publications and reports on geophysical research in the region. Collection of historical data.

2. Field research. Application of new methods and comparison with traditional ones. Conducting experiments with different techniques (for example, vibration sources).

3. Data processing:

Using specialized software (for example, OpendTect or Petrel). Data modeling for forecasting geological structures.

# 2. LITERATURE REVIEW

## 2.1. GEODYNAMIC MODEL OF KAZAKHSTAN

Geodynamics of Kazakhstan is considered in the context of its complex evolution within the framework of plate tectonics. Kazakhstan is located in the central part of the Eurasian Plate, and its geological development is associated with major processes of convergence of lithospheric plates, collision of microcontinents and accretion of island arcs (Fig.2.1.1) [11].

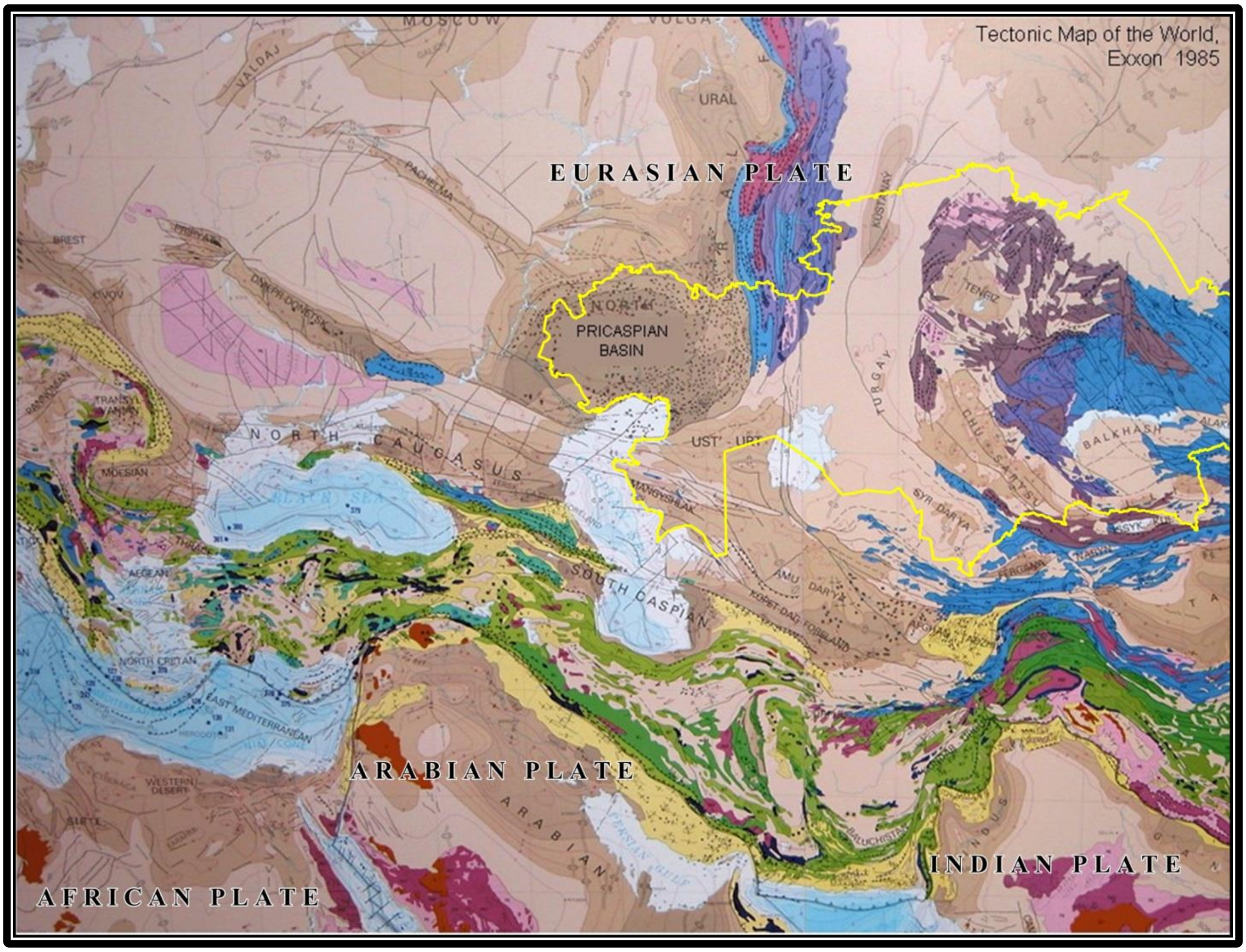



**Fig.2.1.1 Tectonic map**

The main stages of geodynamic evolution of Kazakhstan

1. Paleozoic: The formation of the Kazakh continent. In the Paleozoic, the region was a collection of microcontinents, terranes and island arcs. Their fusion occurred because of subduction of oceanic crust and accretion of terranes. The Ordovician and Devonian collision led to the formation of the Ural-Mongolian folded belt. The phase of major crustal stretching (intracontinental rifting) under the Caspian Basin began in the Late Precambrian and continued until the Early Paleozoic inclusive. Subsequently, it developed

as a spreading marine basin, possibly of a marginal type in relation to the Late Riphean-Vendian Paleoasiatic Ocean. The sinking of the basin continued throughout the Paleozoic era, only during the Permian phase there was a significant sinking of the central part of the basin, which caused rapid sedimentation of Kungur evaporites with a thickness of ± 8 km. Then this basin was isolated during a collision in the Late Paleozoic with the orogens – Uralic in the east and Scythian in the south, turned into an intracontinental depression with relict oceanic crust and a huge sedimentary complex of its filling.

Thus, the Hercynian orogeny (Late Paleozoic) completed the formation of the main structures of Kazakhstan. Hercynian processes formed granite batholiths and metamorphosed rocks.

2. Mesozoic: The destruction of mountain belts and the formation of sedimentary basins. During the Jurassic and Cretaceous periods, the processes of erosion and formation of large sedimentary basins (for example, the Turan Plate and the South Turgai basin) took place on the territory of Kazakhstan. These basins have become important sites of sedimentation and formation of hydrocarbon deposits.
3. Cenozoic: The collision of India and Eurasia and the activation of tectonic processes. The collision of the African-Arabian and Hindustan plates with the Eurasian plate in the Early Cenozoic influenced the formation of modern tectonic structures such as the Tien Shan and Zhetysu Alatau. In the central part of Kazakhstan, tectonic activity has decreased, but slow deformation of the Earth's crust continues due to compression and reactivation of faults. The Aral-Caspian depression became an important sedimentation area during this period.
4. Modern geodynamics: post-collision deformation and active faults. Currently, the main processes are compression and movement in the eastern part of Kazakhstan, especially in the Tien Shan and Alatau zones. These regions are characterized by seismic activity. Passive tectonics in the west (the Caspian lowland), where the processes are associated with the subsidence of the platform and the accumulation of precipitation. Horizontal movements of the Earth's crust within Central Kazakhstan associated with plate pressure on the periphery of Eurasia.

The main tectonic units of Kazakhstan

1. The Caspian Basin is a tectonic structure in the south-west of Kazakhstan and is part of the ancient East European Platform. It is a large sedimentary basin formed as a consequence of complex geological processes.

2. Part of the West Siberian plate in the north-west of Kazakhstan.
3. The Turan plate is a passive platform located in the west of Kazakhstan. It includes large sedimentary basins with oil and gas deposits.
4. The Kazakhstan folded region is the central part, dominated by ancient Hercynian structures.
5. Tien Shan is an active mountain belt in the south–east of Kazakhstan, formed as a result of Cenozoic compression.
6. Zhetysu Alatau and Altai are active orogenic zones characterized by deformation and seismicity.

Geodynamic model

Kazakhstan's geodynamics reflects the interaction between the Eurasian, African-Arabian, and Hindustani plates. The process began with accretion and subduction in the early stages, which formed ancient belts, followed by the collision and convergence of plates in later stages. In modern conditions, horizontal movements and fault reactivation occur. Thus, Kazakhstan is a unique region where ancient platform structures and active zones of modern tectonics combine.

## 2.2. SEDIMENTARY BASINS OF KAZAKHSTAN

There are 15 sedimentary basins in Kazakhstan, which were formed in different geological epochs and have significant reserves of oil, gas, coal and other minerals (Table 2.2.1). Of these, only six basins are basins with identified oil and gas potential: These are the Caspian, Ustyurt-Buzashinsky, Mangystau, Yuzhno-Turgay, Shu-Sarysuysky, Zaisan basins. Therefore, the search and exploration of promising sites, as well as new oil fields in promising intervals only in these basins can give maximum positive results of geological exploration [53].

**Table 2.2.1. Sedimentary basins of Kazakhstan**

| **№** | **Basin** | **№** | **Basin** |
|---|---|---|---|
| I | Pre-Caspian | IX | Teniz |
| II | Ustyurt-Bozachy | X | Chu-Sarysu |
| III | Mangystau | XI | Ili |
| IV | Aral | XII | Balkhash |
| V | Syrdarya | XIII | Alakol |
| VI | South-Turgay | XIV | Zaisan |
| VII | North-Turgay | XV | Pre-Irtysh |
| VIII | North Kazakhstan | | |

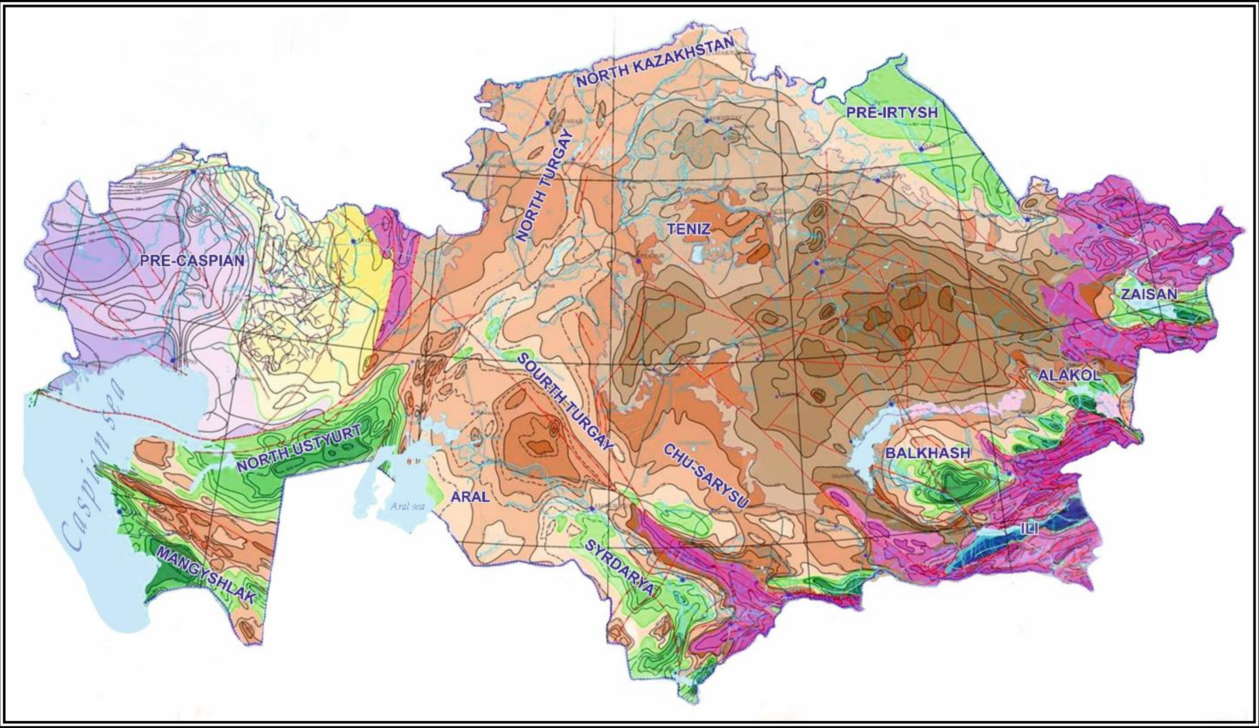



**Fig.2.2.1. Sedimentary basins of Kazakhstan**

180 fields have been discovered in the **Caspian basin**: 163 oil-bearing (90%), 17 gas and gas condensate (10%). Despite the fact that 76% of all deposits in the basin are associated with the above-salt part of the section, the subsalt deposits contain more than 90% of the explored reserves of the region. It is in the subsalt complex that unique deposits have been discovered (Kashagan, Tengiz, Karachaganak), most of the large (Zhanazhol, Korolevskoye, Kenkiyak, Alibekmola, Imashevskoye, Urikhtau) and medium-sized (Kozhasai, Akzhar East) deposits. Such a high concentration of hydrocarbon reserves in the subsalt section is largely due to the ancient laying of high-capacity traps in carbonate reservoirs, which preserved their reservoir properties better (than terrigenous ones) at great depths, and the presence of a regional tire folded by the powerful salt-bearing thickness of Kungur. The oil and gas potential is minimal in the fields of the western and northern zones, where only subsalt Middle Devonian-Lower Permian deposits are productive, at depths ranging from 1460 to 4800 meters. In contrast, the potential increases in the eastern and southern periphery of the basin, where both subsalt Upper Paleozoic deposits (depths of 3915-4418 meters) and suprasalt Upper Permian-Mesozoic strata (depths of 3000-3262 meters) are productive, particularly in the Astrakhan-Aktobe uplift system, which hosts dozens of deposits. Several small deposits (Beket, Chingiz, etc.) have been discovered in the central part of the basin,

where only above salt (Jurassic-Cretaceous) deposits are productive, however, the subsalt complex has been studied very poorly by drilling here.

In the **Ustyurt-Buzachinsky basin**, the main productive complexes are the Middle–Upper Jurassic, containing more than 50% of the initial potential resources, the Triassic accounts for 10%, the Lower Cretaceous -21%, and the Eocene - 8% [53]. About 90% of the explored hydrocarbon reserves are concentrated in the Buzachinsky arch area (area – 11 thousand $km^2$). The main deposits of the basin are located here – Kalamkas, Karazhanbas, Kalamkas Sea, Buzachi Severnoye. The stratigraphic range of productivity is maximal (Middle-Upper Jurassic, Lower Cretaceous). Small deposits in the Jurassic complex have been discovered within the boundaries of the Arystan-Yarkimbai stage and the Kyryn-Tokubai uplift zone (an area of 27 thousand $km^2$). Deposits have been found in Paleogene deposits at the Mynsualmas-Kumtyubinsk stage and in the Akkulkovsko-Bazoyskaya uplift zone. A total of 32 deposits have been identified in the basin (three of them – the Kalamkas Sea, Auezov, Khazar - in the Caspian Sea), of which 16 are oil and gas–oil, gas and gas condensate (concentrated in the northeastern regions of the basin). Most of the deposits in terms of initial reserves are medium and small (including marine Khazars and Auezov). The large deposits include Kalamkas, Karazhanbas, North Buzachi (all on the Buzachinsky vault), as well as the Kalamkas Sea (oil - more than 41 million tons, gas – more than 6 billion $m^3$), located in the Ukatna depression on the far dive of the Buzachinsky vault.

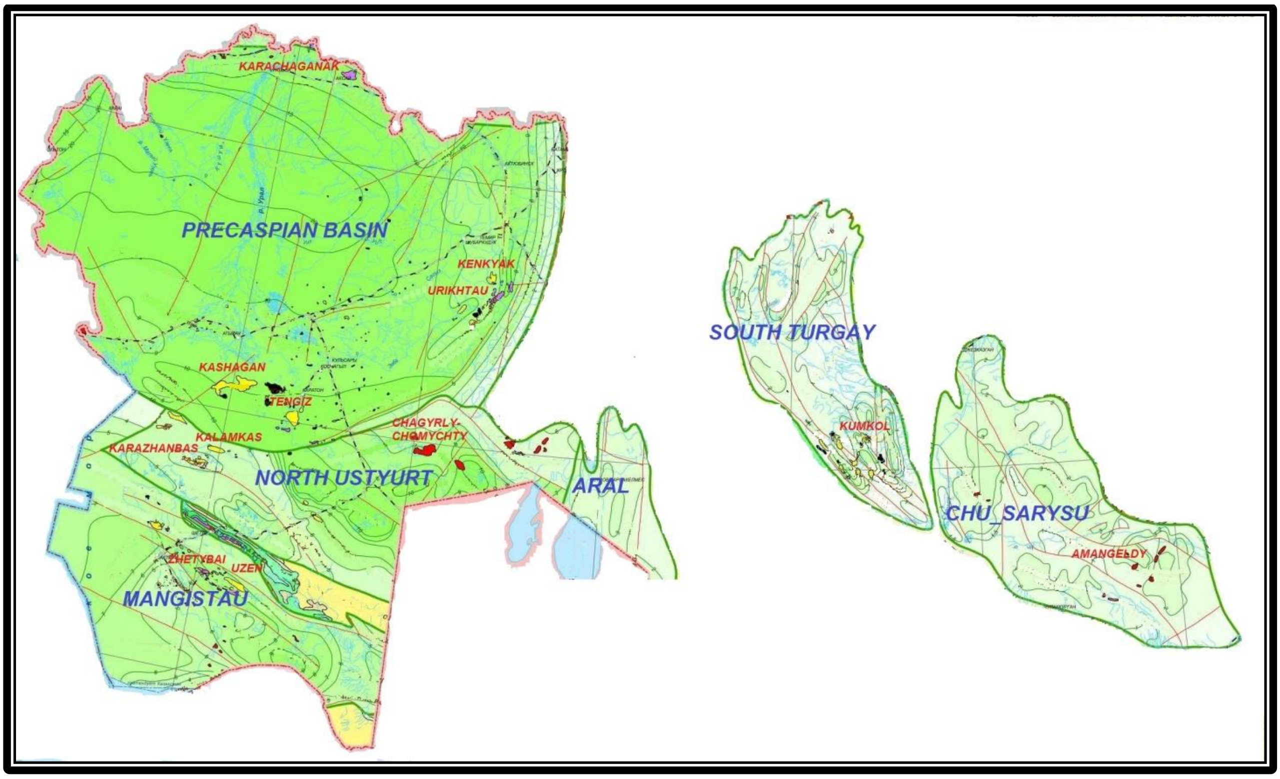



**Fig.2.2.2. The main deposits of Kazakhstan**

To date, 56 fields have been discovered in the **Mangystau basin**, of which 41 (74%) contain oil, and 15 (9%) are gas and gas condensate. The vast majority of deposits (65%) are concentrated at the Zhetybai-Uzen stage. The largest of them (Uzen and Zhetybai) are also located here. The area also features the maximum stratigraphic range of oil and gas content, including Paleozoic, Lower and Middle Triassic, all Jurassic periods, and in some cases, Lower and Upper Cretaceous deposits. In the northern region (Tyub-Karagansky Val), only Lower Cretaceous horizons are productive, while in the southern regions (Zhazgurlinsky trough, Aksu-Kenderlin stage), certain Jurassic and Lower Cretaceous horizons are productive. The Jurassic rock complex accounts for about 42% of the initial geological resources, while the Cretaceous rock complex accounts for approximately 30%. The initial proven reserves of the basin are about 730 million tons of oil and around 214 billion cubic meters of gas. Experts estimate the initial recoverable hydrocarbon resources of the entire basin at approximately 1.5 billion tons of conventional fuel.

To date, 23 deposits have been discovered in the **South Turgai** basin. The vast majority of them were located in the Aryskum trough and only two in the western part of the Mynbulak saddle. Most of the fields are oil, gas, and oil fields, and only four are gas and gas condensate fields. The productive horizons are sandstones of the Middle-Upper Jurassic and

Lower Cretaceous (Neocomian). With the exception of two, the deposits of the basin are small. Of these, the Konys (~10.6 million tons), Kyzylkiya North-Zapadnaya (~9.6 million tons) and Aryskum (~6.5 million tons) fields have the most significant initial oil reserves. tons of oil, ~6.7 billion m3 of gas). Large deposits are Kumkol and Akshabulak. The Akshabulak field (oil reserves – more than 42 million tons) is a multi-layered field, confined to a 3-domed brachianticline. Productive horizons are associated with deposits of the Upper Jurassic (three horizons) and Neocomian (one horizon). The depth of productive deposits is 1600-1915 m. The effective power ranges from 2.2 to 19.2 m, the porosity of the collectors is 11-20%, the permeability is 0.0028-0.03 $mm^2$. The prirazlomnaya anticline controls the Aryskum deposit, which contains two productive horizons in the Neocomian deposits, with depths ranging from 830 to 928 meters. The lower horizon of the Neocomian (horizon M-II) holds the field's main hydrocarbon reserves, where a gas deposit with an oil rim has been discovered. The reservoir consists of sandstones and siltstones with a porosity of 17.4% and a permeability of 0.054 $mm^2$. Oil field density ranges from 0.805-0.812 $g/cm^3$ to 0.820-0.854 $g/cm^3$. Sulfur content ranges from 0.11% to 0.52%, and paraffin content ranges from 8.15% to 36.0%. Methane content in the gas ranges from 37.5% to 93.9%. The initial proven reserves of the basin are 145.5 million tons of oil and 30 billion $m^3$ of gas.

11 gas fields in Paleozoic deposits have been discovered in the **Shu-Sarysui basin**, two of them are gas condensate. Gas inflows have been received in several areas (Kenderlyk, Tamgaltar, Terekhovskaya in the Kokpansor depression, Sayakpai, Kamgaly, Zhualy in the Muyunkum depression). Most of the identified deposits are concentrated in the Kokpansor and Muyunkum depressions. All fields are small (gas reserves do not exceed 3 billion $m^3$), only at the Amangeldy field gas reserves reach 26.8 billion $m^3$. Explored and estimated reserves of the basin amount to 41 billion $m^3$ of free gas and up to 1.7 million tons of condensate.

In recent years, explorers have drilled in the **Zaisan basin** at the Sarybulak, Karabulak, Mayskaya, and Topolevskaya structures. Positive results came from the Sarybulak structure. Of the seven wells drilled, four produced industrial gas inflows from Lower Paleogene deposits. Preliminary estimates show that industrial gas reserves in the Sarybulak structure amount to about 10 billion $m^3$. Exploration efforts are ongoing.

## 2.3. OVERVIEW OF THE GEODYNAMIC EVOLUTION OF KAZAKHSTAN ON THE EXAMPLE OF THE MANGYSTAU BASIN

### 2.3.1. Introduction

The geodynamic approach to the study of sedimentary basins on a regional and local scale over the past three decades has significantly changed the understanding of their structure, evolution and oil and gas content. The paleo geodynamic environment of sedimentation determines the material composition of rocks, the type, quantity and conditions of burial of organic matter. Subsequent geodynamic regimes affect the generation, migration, accumulation and preservation of oil and gas, the type of traps, the evolution of reservoir rocks and tires of natural reservoirs, which determines the geological resources of hydrocarbon raw materials [64].

According to the plitotectonic concept of the evolution of the lithosphere, in general, there are three types of plate movement: sliding with the formation of rifts, compression or displacement (diving) of one plate onto another and, finally, sliding or shifting of plates relative to each other. All movements of lithospheric plates occur on the surface of the asthenosphere under the influence of convective currents in the mantle. It is believed that the territory in question joined the East European Plate during the Late Paleozoic, Mesozoic and Cenozoic because of the subduction of the Tethys ocean floor under the adjacent Eurasian plate. The collision (collision of continents) in the Cenozoic of the African-Arabian and Hindustan plates with the Eurasian Plate, which at that time already united the East European-Turanian and Kazakh lithospheric plates, led to the closure of the Tethys Ocean and the emergence of the Alpine-Himalayan mountain belt.

According to Zholtaev G.J. [70] there were several rift zones in the Turanian Paleozoic lithospheric plate. The Bozashinsky arch and the South Embinsky uplift, which limit the territory under consideration in the north, are the result of inversion of the intracontinental rifts of the Bozashinsky and South Emba, respectively. The Mangystau-Tuarkyr inversion-rift zone, the origin of which is also due to the processes of intracontinental rifting, is separated from the North Ustyurt zone by a series of faults considered as a Mesothetis suture system, which separates the Late Paleozoic-Early Mesozoic compression and folding regions in the north from the stretching and rifting regions in the south. The zone is connected in the north, east and south by the Central Mangystau, Central Ustyurt and Karaaudan-Tuarkyr rift systems [64] (Fig.2.3.1).

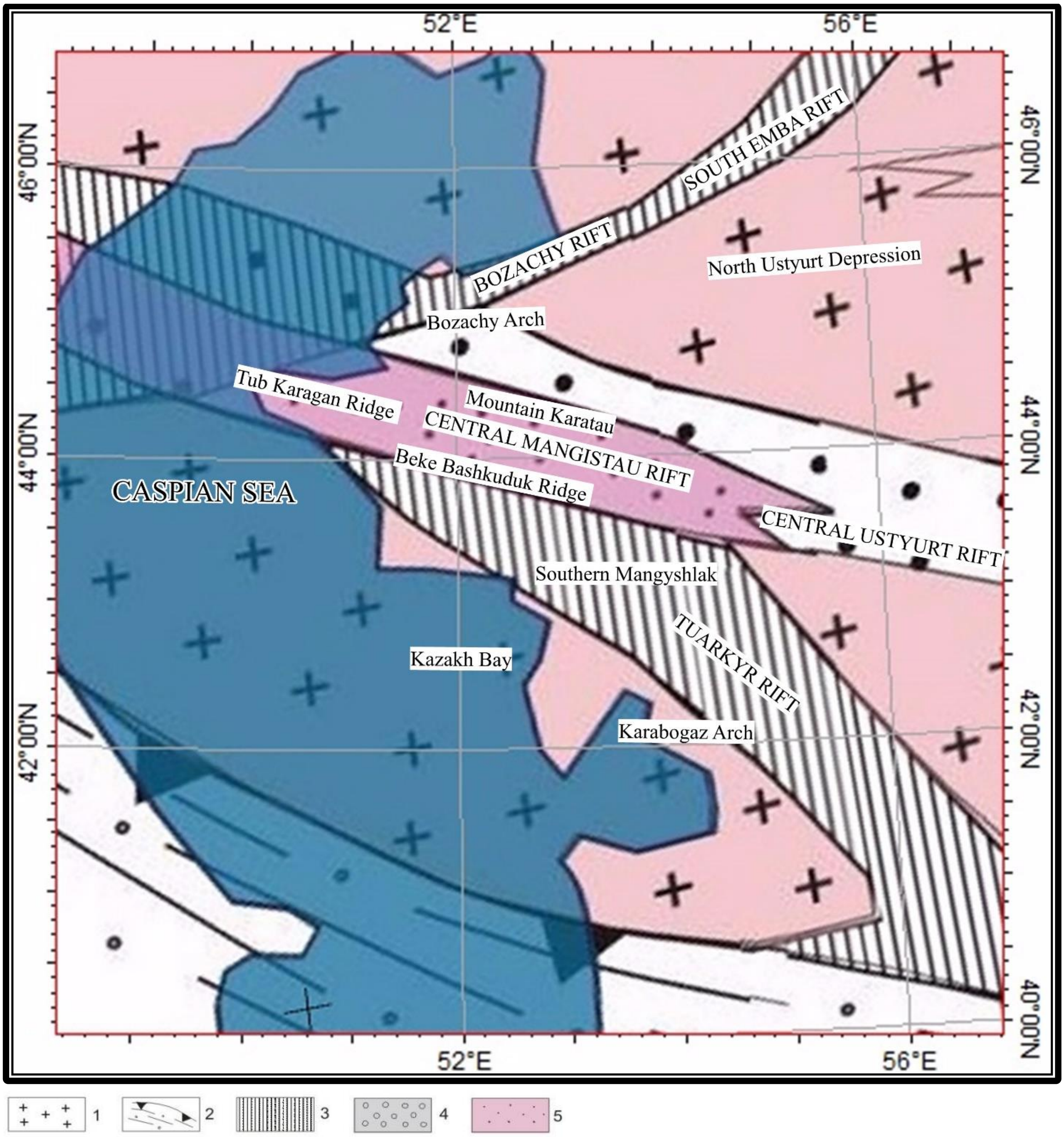



**Fig.2.3.1. Location of ancient massifs and linear dislocation zones (according to Zholtaev G.Zh., [69], 1992, with additions by Kalmagambetov J.K.)**

1-ancient massifs; 2-folded systems; I-Alpine and II-Ural-Tien Shan; Intracontinental rifts that have undergone inversion: 3-in the Early and Middle Paleozoic, 4 in the Carboniferous and 5 in the Permian

The **South Emba rift** system most likely originated in the Riphean-Vendian on the Early Precambrian (Archean-Early Proterozoic) basis. The ancient foundation is lowered here, apparently, to depths from 12-13 to 15-16 km. At the early, pre-Devonian phase of development, up to 1.5 -3.0 km of sediments could accumulate in the rifting zone. The main volume of sedimentary filling of the rift, represented by the Grauwak formation with a thickness of 7-10 km, was formed in the Devonian-Carboniferous period. In the Early Permian, a zone of inversion uplifts formed above the rift trough of the basement, expressed in the structure of Paleozoic complexes (the Yuzhno-Embenskaya or Zeltau zone). The intermittent development of these uplifts probably continued until the end of the Triassic, during which regional interruptions in precipitation accumulation repeatedly occurred in this zone [29].

The **Central Mangystau rift** was formed presumably in the Early-Middle Paleozoic, during which volcanogenic sedimentary rocks, limestones, and dolomites with a total thickness of up to 3-5 km, possibly more, accumulated here. After a short—term Late Paleozoic compression phase, in the Late Permian - Early Triassic, the riftogenic processes in this system resumed. The weak stretching was accompanied by minor manifestations of basalt volcanism and accumulation of a 1.5 — 2.5 km thick polyfacial flyschoid formation. At the boundary of the Triassic and Jurassic epochs, due to transverse compression (Early Cimmerian tectonic phase), inversion uplifts formed by folds formed in the thickness of their sedimentary filling occur in place of the rift throgs of this system. Intensive folding was accompanied by the formation of upwelling and upwelling dislocations. On the modern structural plan, its contours correspond to the Mangystau dislocation system of the north-northwest direction [Fig.2.3.2].

The **Central Ustyurt rift** was formed during two phases of stretching, the first phase corresponds to a strongly dislocated sequence of coarse-grained gravelites and quartz-siderite shales of Silurian age, and the second is the carbonate and terrigenous-carbonate strata of the Upper Devonian— carboniferous. The stretching stage is separated by a relatively short (Early Devonian) compression phase, which is associated with intense folding of the lower rift layer. The total thickness of the deposits corresponding to the main phases of stretching exceeds 2 — 2.5 km. In the early Permian, the development of the system as a complex of stretching structures culminates in the emergence of inversion mountains-anticlines. Subsequent sedimentation occurred here against the background of vertically differentiated movements of the rift base, which caused a change in the thickness of both Upper Paleozoic and Permian-Triassic strata in the range from 2 to 4 km and the formation of anticline-block structures in them.

The **Karaaudan-Tuarkyr rifts**, like the Central Ustyurt rift, originated in the Early Paleozoic on the continental crust. Devonian-Early Carboniferous deposits here are represented by intensively dislocated amphibolites, siliceous shales and quartzites, which are broken through by intrusions of gabbroids. These deposits are overlain by red—colored Permian and Triassic strata up to 4-5 km thick, consisting of conglomerates and gravelites with layers of tuffs and lavas. The latter, along with the increased thickness of sediments, indicates that the development of this system, as a stretching structure, continued until the end of the Triassic. At the beginning of the Jurassic, it dies off, and its deposits with erosion and angular disagreement are overlain by the terrigenous Middle Jurassic strata.

Rifting is the main factor in the formation of block structures of basement rocks and shear zones in them. The phases of completion (compression) of rifting created conditions for the opening of fault zones, and the subsequent regional activation of tectonic processes led to the appearance of multidirectional vertical movements in these fault zones and the use of these channels for the inflow of deep fluids and filling of anticline traps.

The influence of rifting on oil and gas formation and oil and gas accumulation has been repeatedly studied by many researchers using the example of industrial oil and gas rift basins in various regions of the world. Murzagaliev D.M. [38] associates the concentration of the Southern Mangystau oil and gas fields in the Zhetybai-Uzenskaya and Aksu-Kendyrli oil and gas accumulation zones with the conjugation of these zones of the Central Mangystau and Tuarkyr rifts. To this list, we can add the facts of the location of the deposits of the Bozashinsky group along the Bozashinsky rift, the connection of the deposits of the South Embinsky uplift and the Northern Ustyurt with the South Embinsky Rift, the proximity of the gas fields of Uzbekistan to the Central Ustyurt rift (Shakhpakhty, Dzhel, Zap. Barsakelmes, Akchalak, etc.).

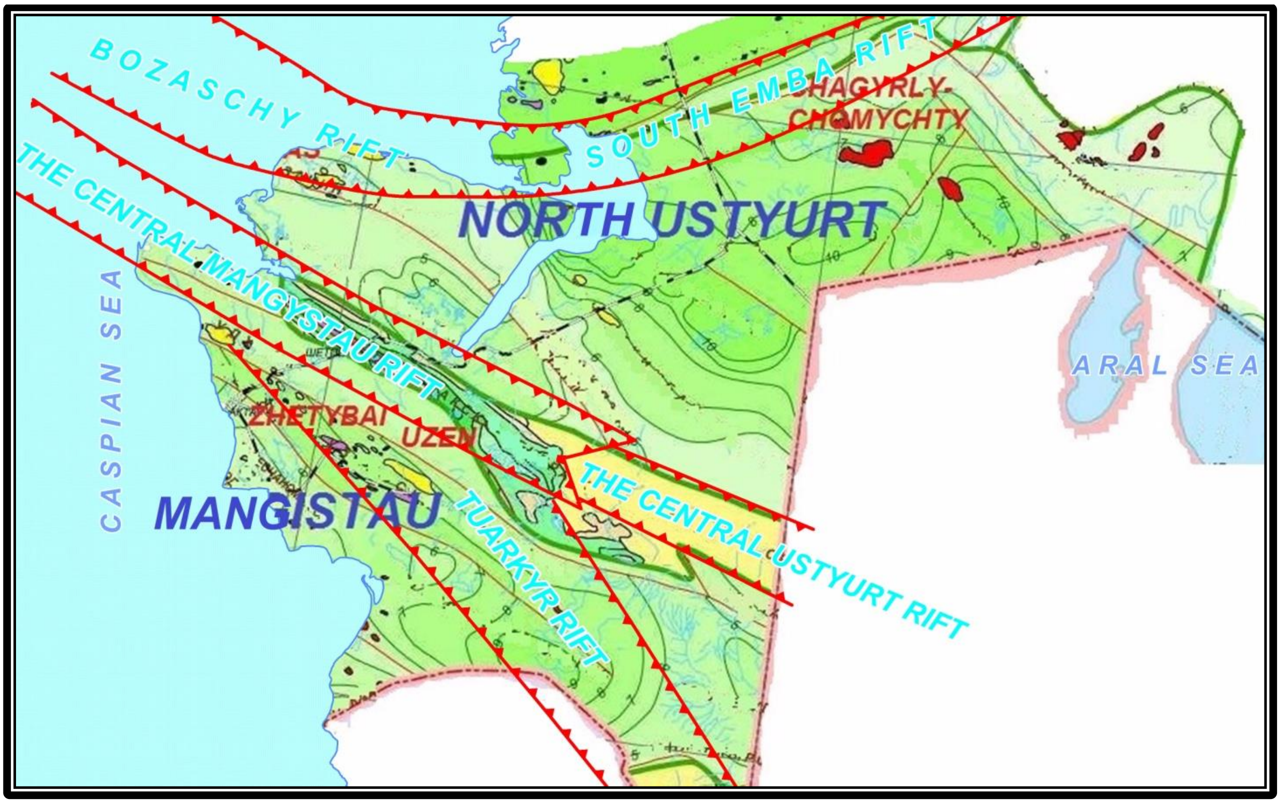



**Fig.2.3.2. The scheme of rifts on the tectonic map**

Thus, paleogeodynamic processes caused a change in sedimentation conditions in the area, paleogeographic and climatic conditions, paleogeomorphology of the Earth's interior and surface, geothermal and hydrogeological regimes. They provided high residual tectonic activity of rift zones, large capacities and areas of distribution of the above-rift plate complex, stable immersion during the Mesozoic and Cenozoic, a regime of increased heat flow, a favorable composition of sediments (reservoirs, tires) and the presence of local, not only anticlinal structures, as well as the inflow of deep fluids into them.

**2.3.2. Features of paleogeodynamics of Mangystau and characteristics of the section**

The Paleozoic and Upper Permian-Triassic deposits are the most exposed to paleogeodynamic processes within the Turan Plate, which, as a result of their intensive study by seismic exploration and deep drilling, have recently become a serious object of oil and gas exploration.  The most complete sections of these deposits have been studied in Southern Mangystau. The complexes in question are part of an intermediate structural floor, the upper boundary of which with a platform cover is usually drawn at the bottom of the Middle Jurassic age.

The complex Permian rifting of the Turanian plate is characterized by the syntectonic sedimentation of volcanoclastic rocks and multiple phases of inversion. It is believed that the Late Permian-Triassic opening was not the first structural reactivation of the Mangystau inversion-rift zone. The zone was most likely active throughout the Permian and earlier in the Carboniferous and Devonian. It is possible that older coal-bearing deposits of the Carboniferous period lie under the Permian sedimentation filling{ Table.2.3.1}.

**Table.2.3.1. Correspondence of the geodynamic evolution of the Mangystau crust to the Wilson cycle**

| Chronology | Appearance in Mangistau | Wilson cycle |
|---|---|---|
| Paleocene-Miocene | Right- and left-lateral strike-slip faults along the established structural trends of the NW-SE strike (~290º), associated with the indentation of the Indian and Arabian plates. | Post-collisional orogeny (deutero-orogeny). |
| Jurassic | NE-SW transpressional compression and inversion | Collisions |
| Triassic - Lower Jurassic | NW-SE compression with transpression, right-lateral strike-slip faults, NE-SW compression, and thrust faulting | Subduction with the formation of active margins of different types of plates |
| Upper Permian-Triassic | active rifting, development of half-grabens and grabens | seafloor spreading with the formation of mid-ocean ridges |
| Carboniferous-Devonian | early rifting, NW-SE extension | |
| Paleozoic | rift initiation stage | |
| Precambrian - Lower Paleozoic | pre-rift development, sub-meridional compression, crustal shortening and uplift | formation of an arch uplift preceding rifting |

At the end of the Permian and Triassic, sedimentation within the Mangystau basin was affected by the stretching regime associated with the worldwide disintegration of continents. Sedimentation of the Lower Triassic sediments (the Indian tier) occurred mainly under conditions of Late Permian-Triassic rifting. At this time, semi-grabens were formed here and filled with powerful Triassic sediments.  Triassic sediments inconsistently lie in places on intrusive and volcanic rocks, in places on quartzites and deformed red-colored rocks of the Upper Permian, while they are composed of two pronounced stratigraphic bundles of the Indo-Olenek and Anisian-Ladin ages. Both of these bundles consist of the following types of sediments: at the base of the facies from continental to coastal marine; in the middle of the limited marine facies, standing out over the surface of flooding; at the top of the continental and coastal marine facies. In the thickness of the Triassic, several inconsistencies are distinguished in accordance with stratigraphic and seismic data.

The Indian tier consists of terrigenous rocks from non-marine sediments to river sediments located along the edges of semi-grabens, and also from lacustrine layered clays deposited inside semi-grabens. Sediments from the Olenek to the Middle Triassic, accumulated during the subsidence of the rift, consist of limited-marine, coastal-marine and terrestrial carbonate and terrigenous rocks.

At the end of the Triassic, collisions of tectonic plates led to the inversion of semi-grabens and erosion of Triassic sediments. There is a major disagreement between the Triassic and the Jurassic. It looks as if the Rhet stage of the Triassic and the main part of the Lower Jurassic were missing.

Then the Middle Jurassic and Cretaceous deposits are deposited, covering the structurally complicated underlying layers with a "blanket". The Jurassic department as a whole consists of non-marine sediments, and mainly river sediments lie in the bottom of the Toar stage. According to the outcrops in the Karatau Mountains, it is clear that the Toar tier is separated from the Aalen one by a local angular disagreement. In the Aalenian and Bajocian times, river sediments dominate. The Bathian and possibly Late Bajocian rocks consist of transitional marine and open-sea siliceous terrigenous deposits. These deposits are often deltaic and riverine deposits. The Kellovian layer consists of transitional marine – open-sea siliceous terrigenous deposits, above which lies the interval of Oxford marine clay-carbonate deposits. The entire Upper Jurassic and part of the Calloway are a potential regional tire.

Widespread tectonic uplift and possible sea level drop at the Jurassic-Cretaceous boundary caused erosion and lack of sedimentation of Upper Jurassic and especially Lower Cretaceous deposits in Berrias-Valangin in some areas. The resumption of tectonic activity in the tertiary period led to the appearance of complex erosive sedimentary structures. Overlying the Jurassic-Cretaceous unconformity, the Berriasian, Valangin and Goteriv deposits consist of marine terrigenous and carbonate rocks, which are overlain by Barremian continental red-colored rocks. A large flooding surface stands out in the bottom of the Aptian tier. The Aptian strata have a large horizontal extent, which is typical for open-sea sediments, standing out more contrastingly in the wave pattern compared to the Middle Jurassic sediments, which were deposited in more limited marine conditions. Terrigenous sedimentation continues in the Aptian, Alba and up to the lower part of the Upper Cretaceous inclusive (Cenomanian), above the section the main part of the Upper Cretaceous deposits consists of carbonate rocks, ending at the top with layers of writing chalk, regionally widespread.

The most ancient Paleozoic rocks of the lower reaches of the intermediate structural floor were uncovered by wells within the northwestern slope of the Karabogaz arch at the structures of Yuzhny Alamuryn, Zhanaorpa, Tamdy and Bukbash, in the Peschanomyssk-Rakushechnaya uplift zone at the Oymasha deposit and in the Zhetybai-Uzen uplift and deflection zone at the Zhetybai deposit. They are represented by granitoids and sedimentary volcanic rocks, metamorphosed to varying degreesmost ancient Paleozoic rocks of the lower reaches of the intermediate structural floor were uncovered by wells within the northwestern slope of the Karabogaz arch at the structures of Yuzhny Alamuryn, Zhanaorpa, Tamdy and Bukbash, in the Peschanomyssk-Rakushechnaya uplift zone at the Oymasha deposit and in the Zhetybai-Uzent and deflection zone at the Zhetybai deposit. They are represented by granitoidsd sedimentary volcanic rocks, metamorphosed to varying degree platform cover.

In the Zhetybai-Uzen zone, the Zhetybai 25 well uncovered a thick layer of Paleozoic rocks (more than 700 m), which is divided into two intervals according to lithology. The lower range of 3950-4501 m is represented by weakly metamorphosed dense terrigenous rocks with a predominance of black mudstones in the section. The upper interval of 3720-3950 m is composed of less dense rocks with a predominance of coarse-grained material. At the same time, coarse-grained gray-colored siltstones and sandstones in the bottom of this interval gradually turn into mudstones in its upper part, which indicates a single cycle of sedimentation. The lower stratum is attributed to the Middle Paleozoic, the upper one to the Upper Paleozoic.

Granitoids and weakly metamorphosed black shales were discovered within the Peschanomyssky uplift at the Oymasha deposit. Black bituminous shales within the Oymashinsky uplift have undergone local metamorphism in contact with the granitoids that break through them and, as they move away from the uplift, they turn into black mudstones similar to the lower mudstone column opened in the Zhetybai 25 well. A thickness similar to the upper coarse-grained thickness from the Zhetybai well 25 was also uncovered in the Oymash well 20. Here slightly metamorphosed dark gray and greenish-gray sandstones, tuff sandstones, represent the rocks and siltstones with a pronounced shale structure and fractured.

Unlike sandstones and siltstones of the Triassic, the almost complete transformation of cement into sericite-chlorite-quartz aggregates with an admixture of albite, muscovite and biotite is characteristic of Paleozoic rocks.

Black shales and mudstones in the Paleozoic deposits of Southern Mangystau are enriched with humic organic matter and contain bitumen on the surface of cracks and strata. Above lies a layer of greenish-gray tuff sandstones, which are collectors in the Oymash well 20, where an oil inflow of 40 $m^3$/day was obtained from the interval of these rocks 3507-3526 m.

In the Oymasha well 12, an oil fountain of 350 $m^3$/day was obtained from the interval of 3720-3773 m, represented by the weathering crust of Paleozoic granite. The weathering processes are expressed by the existing structures of crushing and secondary mineralization, as a result of which quartz grains are preserved in weathered granites, and feldspar and other components are transformed into a clay mass of coalite composition.

In the areas of Shakhpakhty and Zhetybai, a thickness of dark gray, up to black, less often greenish mudstones, siltstones and sandstones, occasionally gravelites and limestones, as well as brown shales has been uncovered. This thickness differs from Mesozoic rocks by high apparent resistances. It is widely believed that dark-colored terrigenous rocks belong to a single lower-Middle carboniferous terrigenous complex [Fig.2.3.3.].

In sections of sq. 25 Zhetybayskaya, sq. 4 Yuzhno-Zhetybayskaya, square. 2 Shakhpakhty and Kossor under the pre-Jurassic red flowers, a thick layer of black clays with layers of multi-grained gray sandstone and siltstone has been uncovered. Characteristic inclusions of carbonaceous matter are found in clays. In terms of the area of the Mine, there is a noticeably increased content of carbonate material.

Deposits of the intermediate structural floor in the volume of the Upper Permian, Carboniferous and Devonian were discovered on the Buzachi peninsula. Carboniferous gray-colored deposits were uncovered in the G-7 square on the North Buzachinskaya square (2539-3500 m, face) and 1-N Northern Kalamkas (2520-4128 m, face). In sq. G-7, the rocks are poorly dislocated and are mainly represented by gray-colored mudstones and carbonates. In well 1-P, rocks are dislocated and divided into two formations: the lower one is mudstone with numerous dikes of andesite porphyrites, 1,150 m thick, and the upper one is of medium-Upper carboniferous age with a layered mixture of limestones and mudstones, about 450 m thick. It is estimated that a red-colored Upper Permian formation with a thickness of up to

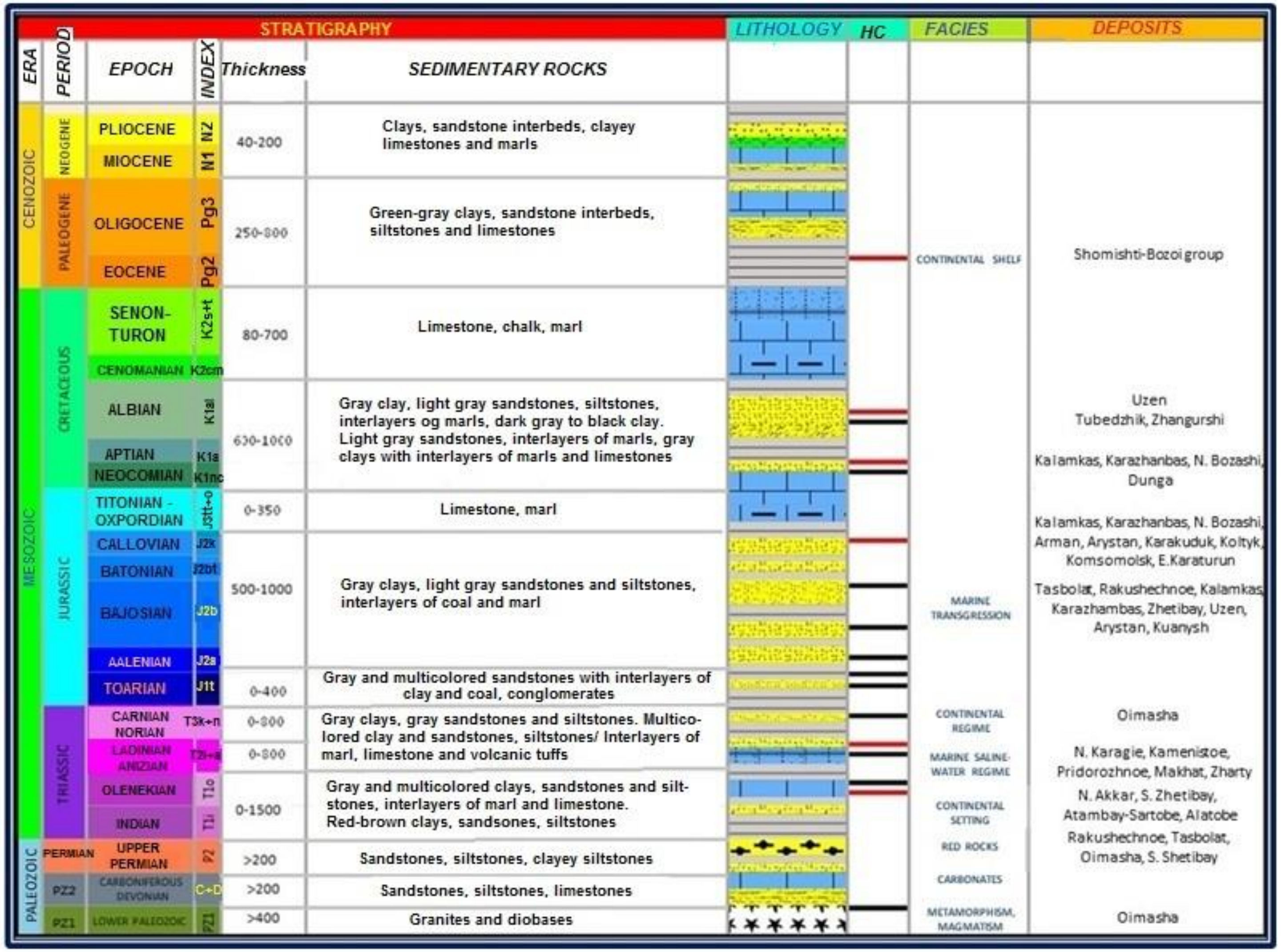



**Fig.2.3.3. Lithological and stratigraphic characteristics of the area**

900 m has been discovered on the Buzachi Peninsula, similar to the Chumishta formation found in the Chumishta and Ashtitaypak districts of Northern Ustyurt. Here the rocks are represented by red-brown mudstones; siltstones and sandstones, there are layers of anhydrites.

The oil and gas content of Paleozoic deposits has not yet been sufficiently studied, except for known cases of oil and gas content (Saura, Zhilanda, Oymash, etc.), in the future it is necessary to pay close attention to the prospects of Paleozoic deposits of the Sandy-Musk-Shell zone, the Kokumbai stage, the northern slope of the Karabogaz arch and in the Northern, Eastern and Southern Ustyurt zones bordering Uzbekistan.

Thus, the paleogeodynamics of the territory of Mangystau was distinguished by the manifestation of stress fields of different types and ages. In the process of geological development, some structural styles were superimposed on others, which is associated with the evolution of the stress-strain state of various blocks of the earth's crust. As a result, aggregates of different historical structural styles have been formed in long-term developing structures. These may include zones of deep faults, large rift structures, and vaults in areas of mantle diapirism. In their geological history, there was a multi-stage tectonic or tectonic-magmatic activation with a change in the types of stress and strain fields both in space and in time (for example, early paleoriferous and superimposed later thrust and shear zones).

Within the suture zone between the Eurasian and Turanian plates, a sharp uplift of the foundation occurs, followed by a gentle fall in the south direction under the Buzachin uplift, reaching a depth of 8-9 km in the area of the North Mangystau deformation zone. Outside of the main Paleozoic and Mesozoic submerged basins, grabens and linear depressions, the depth of the foundation of the Turanian plate generally varies within 3.5-6.0 km.

The regional Mangystau-Tuarkyr inversion-tectonic zone divides the plate into two different parts. The Middle Paleozoic and Middle Devonian strata are in contact with the southern and northern tectonic fringes. The Mangystau-Tuarkyr rifting and inversion zone has an average width of 60 km (in the current state of deformation), a maximum width of 120 km in the southeast of the Karatau Mountains and decreases to 25 km in Turkmenistan. The roof of the Upper Carboniferous lies at a depth of more than 10 km in some parts of the North Mangystau graben with overlying Permian deposits of molasses with a thickness of 6-8 km with a predominance of clastic rocks. The remaining deep depressions within the Turan Plate include the Northern and Central Ustyurt and Barsakelmes in the Aral Sea.

The area has experienced strong rifting associated with regional stretching and syntectonic filling with a thickness of 7-10 km in the zones of deep expansion. The direction of movement along this boundary during the Late Devonian and Triassic was right-hand, although there are signs of left-hand movement at the local level. In the Middle and Late Triassic, there was a sharp inversion and denudation along the stretch zone. Pronounced regional angular disagreement at the boundary of the Late Triassic and Early Jurassic indicates the processes of uplift, erosion and removal of large volumes of filling (in places up to 7-10 km) Permian grabens, which lasted until the Middle Jurassic.

In the south, the region consists of a pile of structural blocks from large to small sizes, microplates, narrow plates and clastic formations, often separated by wedge-shaped melange, which explains the work of local right- and left-sided thrust tectonics, reactivation and inversion of existing structural trends and faults associated with the indentation of the above-mentioned southern continents in Paleocene and Miocene time.

### 2.3.3. Modern geodynamics of the region

One of the main methods of studying modern geodynamics is the use of aerospace information data. Thus, in the book [20] V.P. Gavrilov showed that the closest connection between oil and gas accumulations is noted with regional faults of continuous development, which are established by all methods of geophysics, are often confirmed by drilling and find their expression in the morphology of the relief, i.e. with the category of faults that are most clearly distinguished on satellite images. Also, a geological analysis of the network of lineaments based on deciphered satellite images of Southern Mangystau and Buzachi peninsula allowed us to establish their dynamic development and revealed the following patterns:

– the lineaments of the Mangystau (west-northwestern) strike control folding, local uplifts are associated with them, compression occurred along them, which significantly negatively affected the porosity of rocks;
– the north-northeast strike lineaments are characterized by the presence of fracture zones formed under stretching conditions. Chains of mud volcanoes are connected with them.

Since it is the newest structural elements that are best expressed in satellite images, they are an important source of information about modern tectonic processes. Morphological diagnostics of active structures, clarification of their spatial relationships and the degree of activity at different depths are aimed at improving the structural and kinematic model of the modern lithosphere, a model without which it is impossible to decipher the tectonics of the geological past. Trans-regional lineaments are highlighted and mapped on small-scale satellite images, which stimulated the development of ideas about the nature of extended and deep linear zones of long-term activity in the localization and formation of deposits.

Direct methods of remote search for oil and gas deposits have also developed by registering geothermal, geochemical and other landscape indicators caused by them.

Various signs of local impacts of geodynamic processes, manifested in the form of anomalous geological objects, which are recorded by field geophysical methods - seismic, electrical, gravity and magnetic exploration, surface geochemical studies, thermal surveys are becoming relevant today when creating geological models at any stage of the life of the deposit [6].

The territory of the Mangystau and Buzachi peninsulas, as well as the adjacent areas of Northern Ustyurt, is covered by high-precision aeromagnetic survey at a scale of 1: 50,000 [42]. The analysis of high-precision aeromagnetic survey materials significantly complements the understanding of the modern geodynamics of the region (Fig.2.3.4).

The data show a multi-level arrangement of structural trends in the region. In general, the predominance of the west-northwestern (290-300°) and north-northeastern (20-40°) stretches is characteristic, however, the pattern of the fault network within the Precambrian and Paleozoic parts of the platform is markedly different: the first is characterized by sub-latitude (270-280°) and north-northeast (20-30°) fault orientations, while for Mangystau, which is also more fragmented, the west-northwest (290-310°) and north-northeast (20-40°) stretches are predominant. The faults of the northwestern orientation coincide with the extension of the main structural zones of the Mangystau foundation, were formed during the completion of the Hercynian stage of development (interlaced faults) and by their nature are compression structures.

Kinematically, the faults of the northeastern strike are left-sided shifts or upslope shifts. The largest of them, as noted above, is the fault zone extending from Cape Rakushechny to the northeast. Along it, the foundation structures are shifted laterally by a distance of 35 km (see Fig. 2.3.1). Left-hand movements and the occurrence of local anomalies with an S - shaped long axis are confirmed. This shift can be confidently traced only within the limits of


**Fig. 2.3.4. Fault map of the west of the Turan plate based on high-precision aeromagnetic survey materials [Popkov et al., [42], 1985, with additions by Kalmagambetov Zh.K.]**

a - the largest faults are the boundaries of foundation blocks of different ages; b - faults are the boundaries of structural and formation zones in the foundation body; c other faults; d - axes of local maxima; d - axes of local minima of the field; e — faults according to seismic data along the horizon of the Middle Triassic V22 roses - fault strike diagrams: I - for the entire study area, P — Precambrian part of the platform, W — Epipaleozoic

Mangystau: In the northeast, it runs into the Kyryn-Tokubai fault. By its nature, this shear zone resembles transformative disturbances.

The strike of 20-40° in combination with the prevailing direction of 290-300 ° forms an almost orthogonal fault system penetrating into the Northern Buzachi, Northern-Central-Southern Mangystau and adjacent territories of the Turan and Scythian plates to the south and west.

The neotectonic stresses of Mangystau were also studied by the structural-geomorphological (SG) method of reconstruction of shear tectonic stresses of platforms at Gubkin Russian State University of Oil and Gas (NRU), [46]. The method is based on the analysis of feathering fractures in the zone of dynamic influence of shear type faults. The mutual orientations of the feathering fractures in the shear zone and their orientation with respect to the main fault were generalized in [24] (Fig. 2.3.5). If the orientation of small rectilinear relief elements — megatracks isolated near the lineament, both among themselves and in relation to the fault corresponds to one of the orientations of the feathering breaks in the shear zone in Fig.2.3.5, then it is assumed that the lineament and megatracks are tectonic in nature and are caused by shear displacement along the fault.

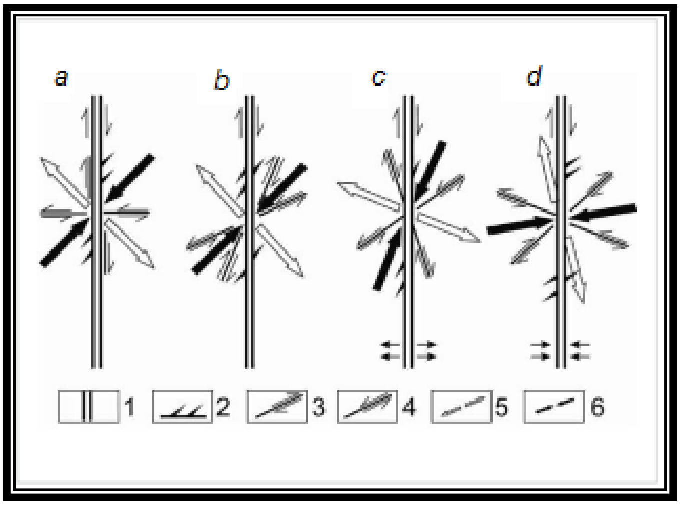



**Fig. 2.3.5. Paragenesis of feathering cracks in the shear zone [Gzovsky, [7], 1975] or "Gzovsky pallet".**

Variants of the stress state at cleavage angles close to 45° (a), 45° (b), conditions of additional stretching (c) and compression (d) are shown in the lower part of the faults with arrows normal to the fault plane.

1 — fracture; 2 — separation crack; 3, 4 — chips with right (3) and left (4) shear kinematics; 5, 6 — orientation of the axes of tension (5) and

The use of the SG method makes it possible to determine the orientation of the compression and stretching axes in the horizontal plane, the direction of shear movement along the fault (right-left shift) and to assess the geodynamic situation of the formation of a fault in the sedimentary cover - additional compression or stretching (Fig. 2.3.5, c and d).

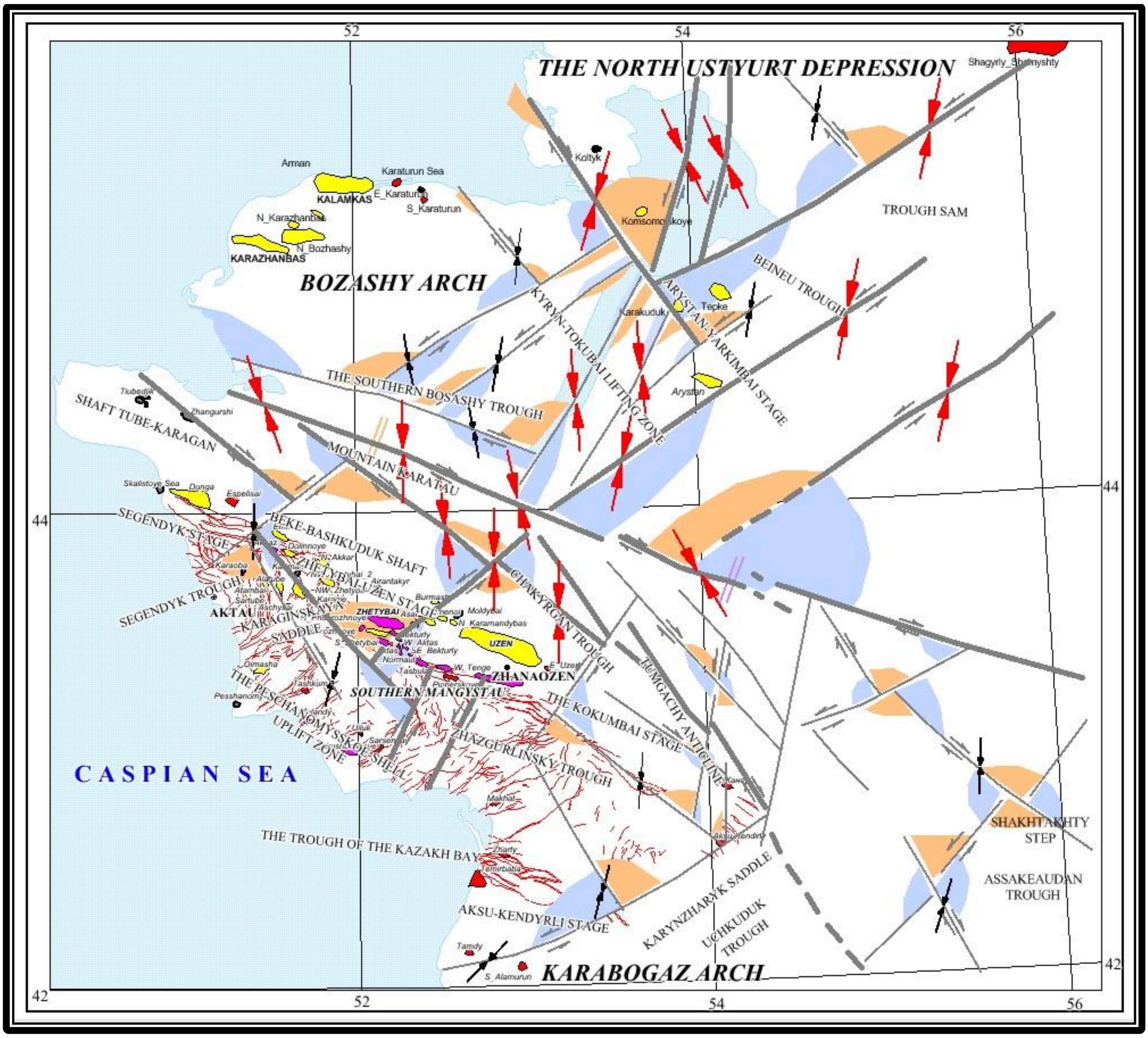



**Fig. 2.3.6 — Diagram of the latest geodynamics of the west of the Turan plate (Sim L.A. et al., [46], 2019)** 1-4 - faults deciphered from satellite imagery and topography: 1st-I, 2nd- II ranks, 3rd - assumed I-th and 4th - II-th grades; 5-6 - orientations of the compression axes in the horizontal plane: 5 - I-th and 6 - II-th ranks; 7-8 - shifts: 7 — confident, 8 — assumed; 9-10 - geodynamic conditions: 9 - compression, 10 - stretching; 11-12 -local conditions in sectors: 11- compression, 12 – stretching

In oil and gas-bearing areas in horizons where the role of a fractured reservoir is decisive (deep-lying horizons, unconventional reservoirs, foundation weathering crusts), compression and stretching sectors that form at the intersection of multidirectional shifts play an important role. At the intersection of diagonal shifts, the sectors of local stretching are opened to the west and east, and the sectors of local compression are opened to the north and south. In Fig. 2.3.6, these sectors are shown in the corresponding color: blue – stretching sectors, red — compression sectors. In the territory of Mangystau, in connection with the development of the main traditional deposits, prospects are opening up for the identification of hydrocarbon deposits in the deep-lying horizons of the foundation and its weathering crusts that do not have high porosity values, which is becoming a very urgent task. The role of the presence of cracks, and even more so, the degree of their disclosure increases dramatically. Under equal geological conditions, a geodynamic environment is created in the stretching sectors that is more favorable for permeability, providing increased hydrocarbon production rates.

Since the actual material for this method is data from the decryption of relief elements, the age of the restored SG by the stress state method is taken as the latest and modern.

The use of the SG method on the territory of the Mangystau peninsula is justified by the above data of V.I. Popkov and co-authors on the role of shifts in the tectonics of the region and their activity at the latest and modern stages of tectonic development [32].

Studies have shown that the deformation of the study area occurs in a shear stress field with a meridional orientation of the compression axis and a latitudinal orientation of the stretching axis. This orientation of the axes of the main normal stresses is due to the development of the Alpine structures of the Caucasus and the Kopet Dagh.

The selected stretching sectors, other things being equal, provide increased permeability of rocks due to the stretching environment, so they can be informative.

#### 2.3.4. The imaging of geodynamics on seismic data

The wave pattern of the Southern Mangystau section clearly outlines the structure of the Triassic complex with distinct seismic horizons in the section, traced from the Zhetybai-Uzen stage in the north to the Peschanomyssk-Rakushechny arch and the Aksu-Kendyrlin stage in the south.  This is:

V1 – top of the Triassic complex;

V2 –top of the Middle Triassic;

V21 – top of the Middle Triassic limestone;

V22 – bottom of the Middle Triassic carbonates;

V3 – top of the Lower Triassic;

VI – Permian top?

The upper part of the Triassic section, apparently the Upper Triassic and the upper part of the Middle Triassic sediments, is composed of clay "transparent" complexes and is considered as a single regional cover separating the Triassic and Jurassic oil complexes in most of Southern Mangystau.

On the maps shown in the previous section, all the highlighted faults of the Triassic section are marked in red. The analysis shows that the faults are grouped in two directions. The dominant fault strike is the NWZ-SE, which is formed under the influence of compression along the sub meridional direction in the Late Triassic. The fault system is clearly right-stepped, and lower-order syntectonic structures are associated primarily with regional stretching. The second subordinate extension of the SVV-SWZ faults. The angle between two conjugate fault systems (contractible dihedral angle) averages 95°. There appears to be a clear right-step shear system in which faults develop in the sub latitudinal direction. The right-hand shear zones have lower-order faults in their composition, which indicate the presence of many deformations caused by regional stretching. These data confirm the existence of an active pair of regional right-sided shifts that operated in the region at the end of the Triassic. These circumstances show that the extensions during the evolution of the area were determined not only by Permian rifting in the region, but also with stretching and/or spreading basins along the right-sided shear faults. The abundance of shifts apparently occurred at the end of the Permian – early Triassic, before the closure of the Paleo Thetis Ocean.

The figures below show the fault system of the area of the northwestern part of the Zhetybai-Uzen stage, which were described by the author in [29]. The northernmost fault in the Triassic is an upsurge of the NWZ-SE with a mixer inclined to the north, a hanging wing in the south, breaks through almost the entire Permo-Triassic section, the discharge amplitude is up to 1200 m, has the largest length in the area. To the south, there is also a series of sub-vertical faults of different lengths, which dissect only the Middle Triassic section [Fig.2.3.7].

Even further south, there are groups of discharge shifts, which apparently make up dynamos with interconnected characteristics, which have a north-westerly and north-easterly direction, respectively. Right-sided horizontal shear faults are developed in the NW direction, and left-sided faults in the SW direction. In accordance with the direction of movement of these two groups of relief shifts, it can be established that the direction of the main stress - from the north-northeast to the south-southwest direction, coincides with the direction of the regional compression stress [Fig.2.3.8].

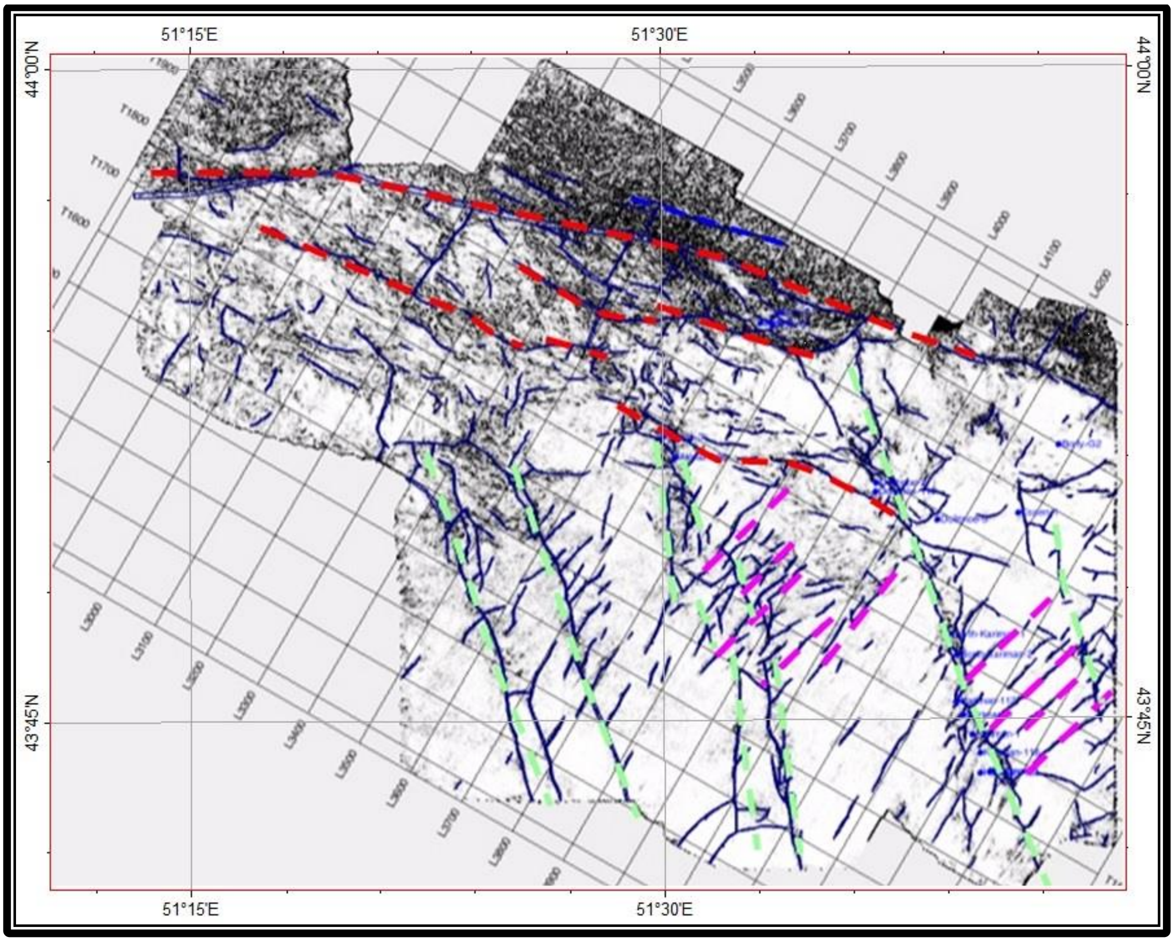



**Fig.2.3.7. Fault system of the NW part of the Zhetybai-Uzen stage (Kalmagambetov Zh.K., [29], 2019)**

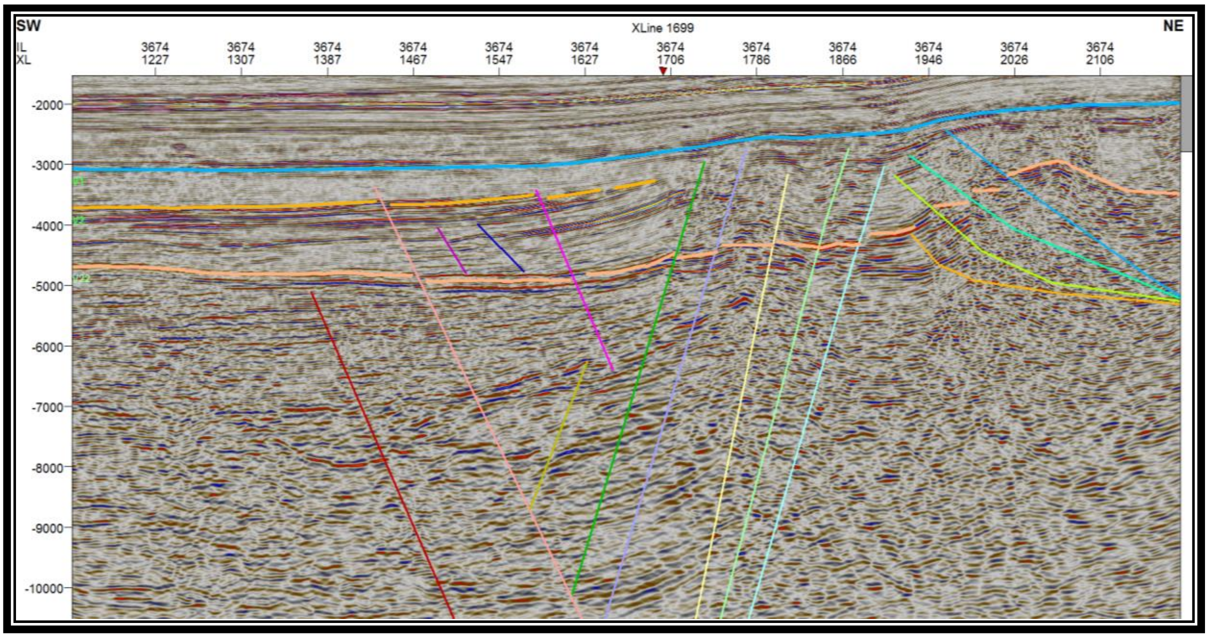



**Fig.2.3.8. Reverse, normal and strike-slip faults on the meridional seismic section (Kalmagambetov Zh.K., [29], 2019)**

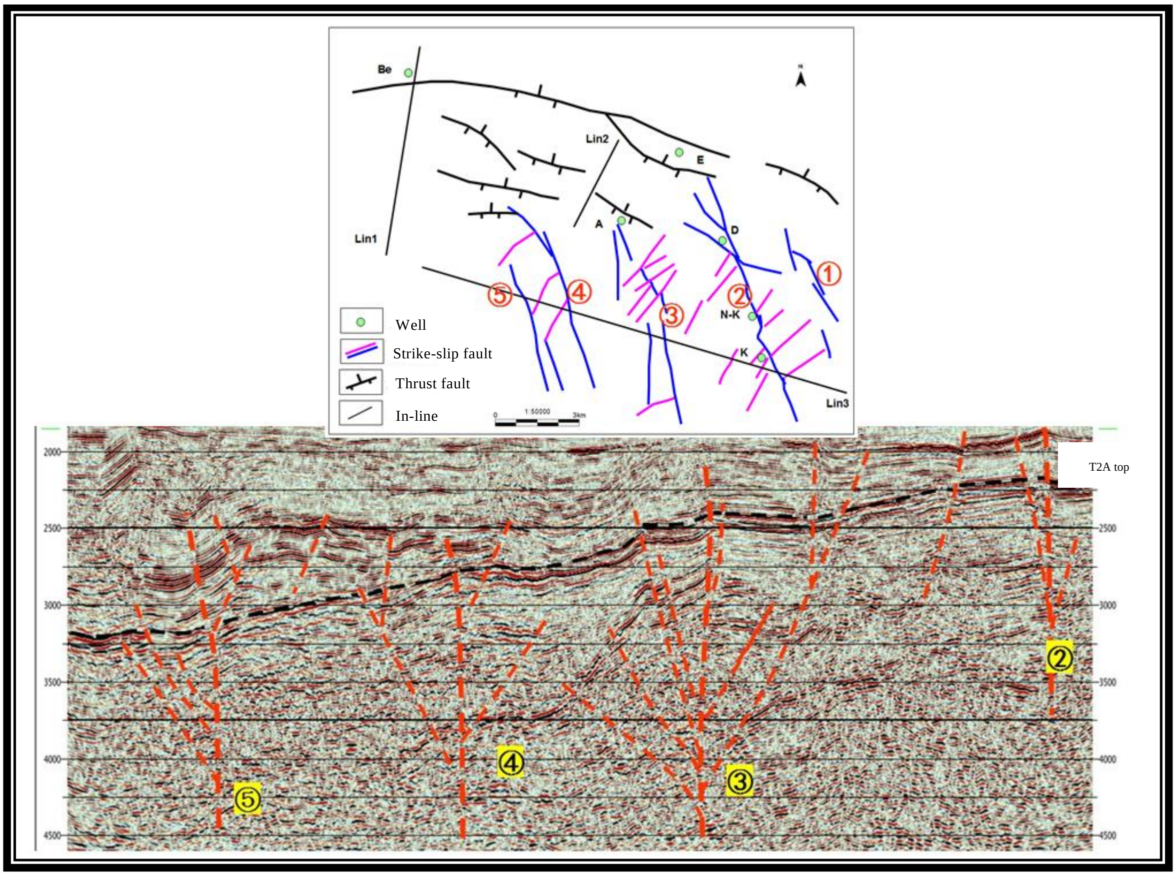



**Fig.2.3.9. Strike-slip faults in the seismic section in the N-E direction (Kalmagambetov Zh.K., [29], 2019)**

Thus, under the influence of regional compression in the direction of the CER-South, upsurges are formed in the sub latitudinal direction, and under the influence of tangential compression, fault zones of horizontal shear of the CER direction are formed [Fig.2.3.9].

### 2.3.5. Direct signs of modern geodynamics

By studying the modern geodynamics of oil and gas accumulation zones in different tectonic settings, general patterns of their localization have been established. It is shown that hydrocarbon accumulations are controlled by systems of deep faults rooted in the mantle and characterized by modern tectonic activity, which manifests itself in modern movements of the Earth's surface and time variability of geophysical fields [7]. The results of a comprehensive geological, geophysical, fluid dynamic and geochemical study of oil and gas accumulation zones indicate that the formation of deposits continues at the present stage. It is associated with the foci of discharge of deep fluid systems in the most permeable areas of fault zones.

According to M.V. Bagdasarova [6], geodynamic and fluidodynamic parameters of oil and gas accumulation zones obtained at special geodynamic polygons are the first methodological developments that make it possible to understand the connection of modern deep processes with the formation of fluidogenic minerals, including oil and gas, and geodynamic criteria can be the basis for new direct methods of their search.

In the works of Sokolov B.A., Starostin V.I. [47, 50], a unified fluid dynamic concept of the formation of mineral deposits, both metallic and hydrocarbon, is proposed. In the upper part of the Earth's crust, fluid dynamic systems are realized in the form of two groups of regional geological structures: ore-magmatic (volcanogenic ore) centers and sedimentary oil and gas ore basins [36].

The manifestation of internal geodynamic activity is closely related to the sedimentation processes of sedimentary strata formation, the distribution of sandy-clay material in them, and the post-sedimentation processes of local geotectonics and fluid dynamics up to the present time. According to N.P. Zapivalov, "almost all accumulations of oil and gas in the lithosphere are confined to foci of fracturing, to systems of disturbances and discontinuous dislocations, as well as to various gradient zones" [68]. Therefore, the study of foci and zones of active geodynamics and fluid migration provides valuable information about the nature of the hydrocarbon reservoir as a whole. Oil and gas content is spatially related to the regions of regional fluid migration from the depths along the zones of sub vertical fracturing [68].

Considering these local foci as traces of the manifestation of internal geodynamic activity, regardless of their name (dynamically stressed zones, sub vertical destruction zones, etc.), it is possible and necessary to identify obvious relationships between the manifestation of dynamic activity of the Earth (both on a global, regional and local scale) and sedimentation processes of sedimentary strata formation, the distribution of sandy-clay material in them with appropriate filtration and capacitance properties, post-sedimentation processes of local geotectonic up to the present time. In the concept of degassing of the Earth, which has been actively gaining the ranks of its supporters in recent years, such zones and areas of rock destruction are the main gas and fluid-conducting channels [68].

The most degraded rock zones are the most "attractive" for the trajectories of geodynamic energy and fluid flows. These same zones are clearly manifested in all geophysical and geochemical fields, forming mineral deposits of almost all types. Due to the migration of mobile components through permeable zones, such objects of manifestation of modern geodynamics, often called disjunctive tectonic structures, manifest themselves not only in geophysical, but also in geochemical fields, which creates the basis for sorting out promising areas identified by structural geophysical methods.

The predominant spatial shape of the sub vertical destruction zones has the form of narrow tubes with blurred lateral boundaries, which was established using observations using high-resolution 3D seismic methods.

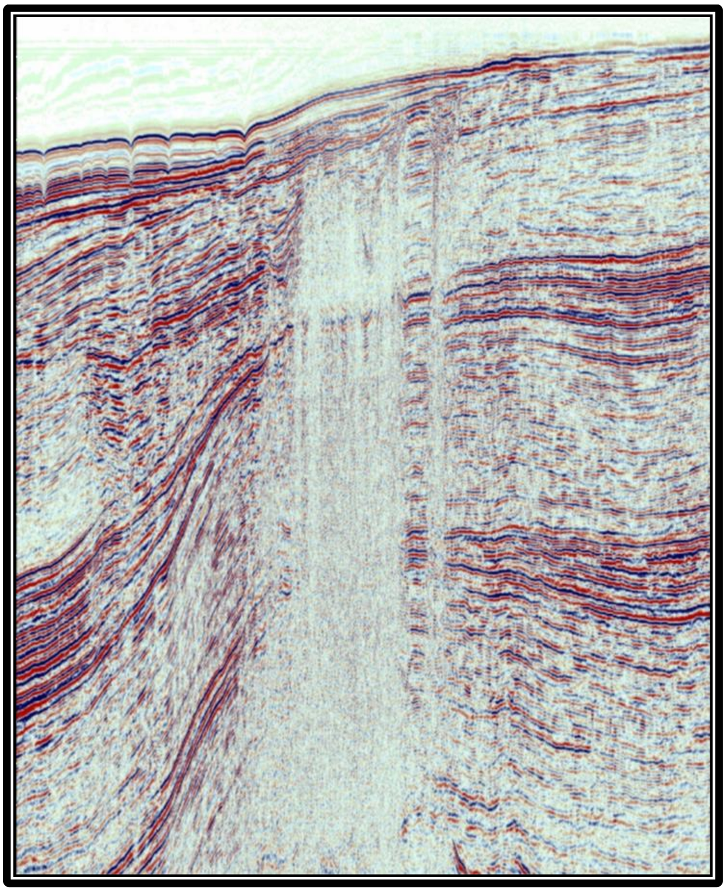


**Fig.2.3.10. "Gas Chimneys" in the Caspian Sea**

Even in areas remote from active seismotectonic zones and faults, separate destruction zones and entire systems of FDD with variable concentrations penetrating from the basement part of the geological section upwards into the Mesozoic-Cenozoic sedimentary complex are clearly recorded.

The direction of research on fluid dynamics aspects of oil and gas content is also widely represented in foreign scientific literature [4, 25]. The so–called "gas pipes" (Gas Chimney) and "VAMP structures" (Velocity & Amplitude structure) and others are considered as signs indicating the presence of vertical migration of hydrocarbons and criteria for searching for deposits [4, 25] (Fig. 2.3.10).

The analysis of seismic profiles for the identification of faults in the sedimentary column was carried out visually, using the Kingdom and Petrel software complexes, which provide great visualization capabilities, additional processing methods before and after summation. They allow you to get rid of obvious "noises", emphasize the inconsistencies of individual parts of the section and highlight the largest of them. In all cases, the main signs for distinguishing a discontinuous structure were localized displacements of a similar set of reflecting horizons (bundles) or zones of acoustic "chaos" (Fig. 2.3.10). The reasons for the appearance of such disintegration sites may be the presence of a fracture zone in the sediments or the existence of a gas-saturated migration channel, which in turn, as a rule, are confined to specific fault structures. For each of the violations, the fall directions relative to the profile strike, the angle of incidence and the width of the zone were recorded (the last two parameters, if possible). In addition, the diagram of the research site indicated the location of the rupture outlet to the bottom surface or the projection of the end of the dislocation hidden in the sediment column onto it.

### 2.3.6. Conclusions

The geodynamic approach to the search for hydrocarbon deposits lies in the fact that in the future, it is proposed to search for new promising objects not only by the shape of the supposed traps, as it always has been, but by the entire content of the deep seismic section, where signs of paleo- and modern geodynamic signs of the discharge zone of deep fluid systems, along which deposits of various types are formed kind of. The main search feature in this case should be the foundation faults, their modern tectonic activity and fluid conductivity, which can be reflected in the seismogeological section.

In order to detect horizontal inhomogeneities reflecting vertical faults of the sedimentary cover and foundation, which may be the most permeable systems in the geological section, the practice of regional geological exploration of the subsurface should be revived, now by deep seismic exploration at the modern software and technical level.

Regional geological and geophysical studies have always been and remain a powerful tool for understanding the basic laws of the geological structure of poorly studied regions and lithological and stratigraphic complexes, assessing the prospects for oil and gas potential of large territories and determining priority areas and areas for oil and gas exploration.

The ultra-deep seismic survey conducted in Russia since 1993 in Tatarstan and adjacent territories, as well as in other oil and gas regions of the country, provides new information about the structure of large tectonic elements. This contributes to solving fundamental problems of oil and gas geology, and also allows solving applied problems. New data on the structure of the Earth's crust were obtained using deep seismic exploration of the Earth's surface, conducted according to regional profiles in a number of oil regions, which made it possible to substantiate new approaches to solving the task. Thus, on the Tatseys geotraverse, which crossed almost the entire Volga-Ural province, the connection of the deep structure of the Earth's crust with the structure and oil content of the sedimentary cover was convincingly shown (Trofimov, 2006). Inclined reflectors were observed under large oil accumulations, reflecting fault zones that dissect the entire Earth's crust and, in some cases, penetrate into the upper mantle. In the upper part of the foundation and in the sedimentary cover, the steepness of these faults increased, they became sub vertical and stood out in seismic time sections according to traditional signs. Along such faults (or parts of them), called by researchers oil channels (Trofimov, Korchagin, 2002), deep hydrocarbon fluids enter traps" [58].

The parameters of the observing systems of ultra-deep seismic exploration are similar to those used in regional prospecting seismic exploration, with the exception of increased distances from the source to the receiver (up to 10-24 km). The pitch of the shot points (SP) is 100-200 m (grouping of 4-5 sources), the pitch of the reception points (RP) is 50 m (grouping of seismic receivers), and the overlap multiplicity is up to 90-100. Such a dense network of observations provides an abundance of solutions to regional and global problems at a high quality level. In addition, a dense network and an average frequency reception range allow the use of primary materials for both ultra-deep Earth surveys on reference profiles and for solving exploration tasks in the upper part of the Earth's crust.

Tables 2.3.1 and 2.3.2 below provide the actual parameters of the methodology of the conducted field work in Russia for reference when setting the parameters of ultra-deep seismic exploration in Kazakhstan.

**Table.2.3.2. Parameters of the UD – CMP 1-EV profile development on the Eastern European platform**

| №п/п | ACQUISITION PARAMETRES | VALUES |
|---|---|---|
| 1. | Receiver Interval, m | 50 |
| 2. | Shot Interval, m | 100 |
| 3. | Number of Channels | 200 |
| 4. | Full Fold | 90 |
| 5. | Maximum shot-receiver Offset, Xmax, m | 9025 |
| 6. | Minimum Offset, Xmin, m | 25 |
| 7. | Type of recording spread (inline) | Symmetric split-spread |
| 8. | Channels | 1-180 - ПВ - 181-360 |
| 9. | Offsets | 9025-25- ПВ - 25-9025 |
| 10. | Record Length, s | 25 |
| 11. | Acquisition sample rate, s | 0.004 |
| 12. | Type of receivers | GS-20DX |
| 13. | Number of receivers in group | 12 |
| 14. | Base of group, m | 50 |
| 15. | Source Type | Vibroseis |
| 16. | Mark of vibrator | SB-14-150 MTK |
| 17. | Number of vibrators in group | 4 |
| 18. | Base of group, m | 50 |
| 19. | Peak ground force, t/s | 50 |
| 20. | Sweep | linear |
| 21. | Number of Sweeps/VP | 6 |
| 22. | Sweep Length, s | 20 |
| 23. | Sweep Frequency (Hz) | 12-60 |
| 24. | Recording System | Input/Output-II |

**Table.2.3.3. Parameters of the SG-OGT – 2-DV profile development in Eastern Siberia**

| №п/п | ACQUISITION PARAMETRES | VALUES |
|---|---|---|
| 1. | Receiver Interval, m | 50 |
| 2. | Shot Interval, m | 100 |
| 3. | Number of Channels | 312 |
| 4. | Full Fold | 78 |
| 5. | Maximum shot-receiver Offset, Xmax, m | 8950 |
| 6. | Minimum Offset, Xmin, m | 25 |
| 7. | Type of recording spread (inline) | Asymmetric split-spread |
| 8. | Channels | 1-180 - ПВ - 181-312 |
| 9. | Offsets | 8975-25- ПВ - 25-6575 |
| 10. | Record Length, s | 25 |
| 11. | Acquisition sample rate, s | 0.004 |
| 12. | Type of receivers | GS-20DX |
| 13. | Number of receivers in group | 12 |

| | | |
|---|---|---|
| 14. | Base of group, m | 44 |
| 15. | Source Type | Vibroseis |
| 16. | Mark of vibrator | SB-20-150 MTK |
| 17. | Number of vibrators in group | 4 |
| 18. | Base of group, m | 50 |
| 19. | Peak ground force, t/s | 60 |
| 20. | Sweep | linear |
| 21. | Number of Sweeps/VP | 6 |
| 22. | Sweep Length, s | 20 |
| 23. | Sweep Frequency (Hz) | 12-48 |
| 24. | Recording System | Input/Output-II |

For the regional study of great depths, as a starting project, it is proposed to work out three 2D profiles of ultra-deep seismic exploration in Mangystau with a total length of 275+187+370 = 832 km. At a step of 100 m, this is 8320 SP. According to them, promising areas with fluid dynamic characteristics will be determined.

Profile 1 (275 km) has an azimuth of 40° SW and runs from the Rakushechny uplift through the Zhetybai-Uzen stage, Beke-Bashkuduksky shaft, Shakyrgan trough, the southern slope of the Mountain Karatau, Yuzhno-Bozashinsky trough, Kyryn-Tokubai uplift zone, Arystan-Yarkimbai stage, intersecting their prostration, to the Beineu trough. Profile 2 (187 km) also with an azimuth of SV 40° intersecting the extension of the Aksu structures-the Kendyrli stage, the Tuarkyr fault, the Karaaudan shaft, the Zhazgurlinsky depression, the Kokumbai stage, the Tumgachinsky anticline to the Central Ustyurt. Profile 3 (370 km) with an azimuth of 310° NW along the stretch from the Tyub-Karagansky shaft to the Ushkuduk trough in the south [Fig.2.3.11].

And also, to study large depths over large areas, it is proposed to introduce a 3D technique with a sparse network, in this case, a system is proposed where the step of the SL is 1200 m, the step of the SP is 100 m, i.e. 1,000,000 / (1200*100) =8.3 SP per 1 sq.km of area [Table.2.3.4]. That is, the number of SP 8 times less than with standard prospecting seismic exploration 1,000,000/ (300*50) = 66.67 SP.

The starting area of sparse 3D shooting is 1000 square.km is set in the area of the Karaaudan shaft and the Tuarkyr fault to determine promising gas traps [Fig.2.3.11].

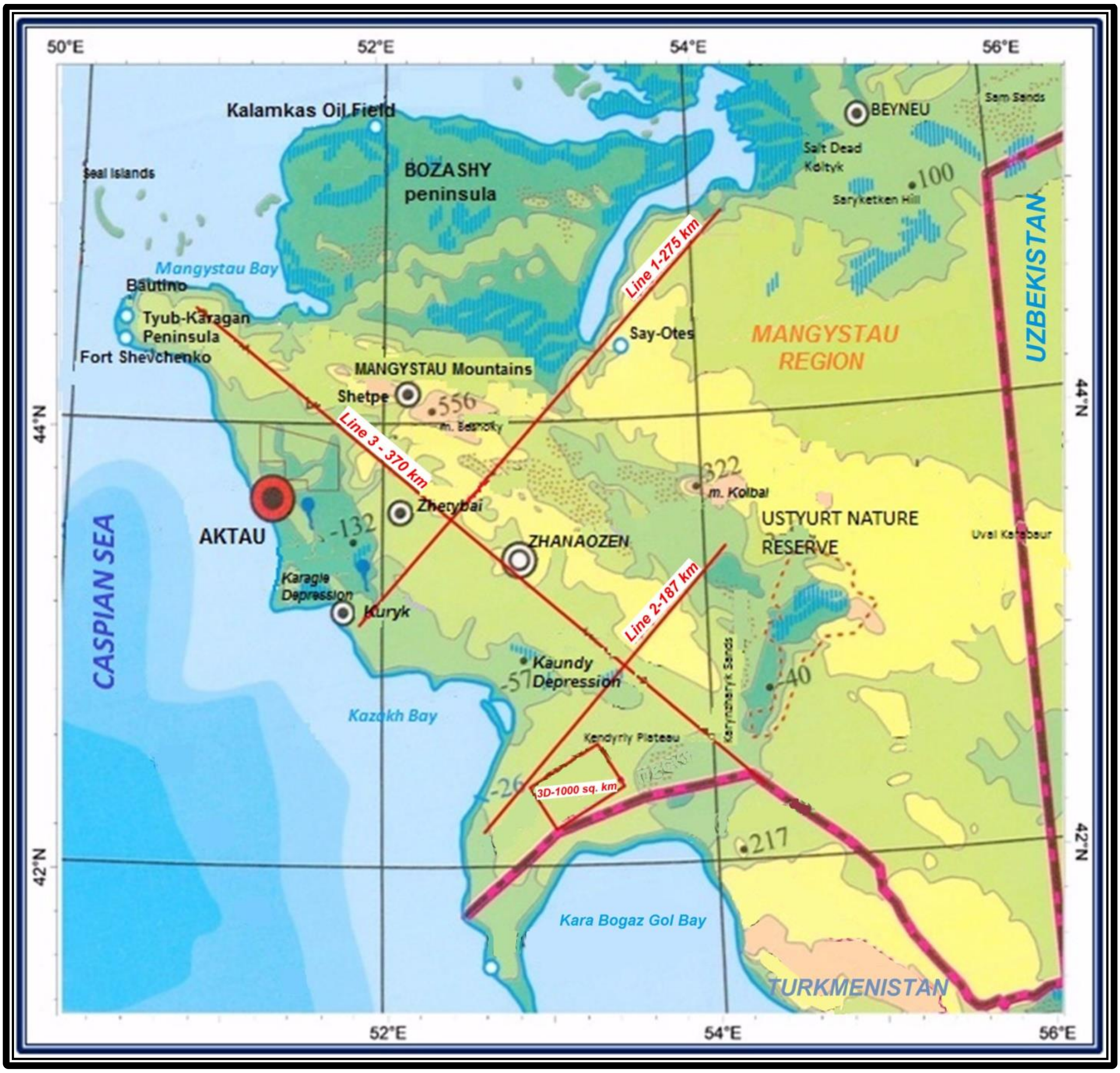



**Fig.2.3.11. The initial project of ultra-deep seismic exploration and sparse 3D surveying in Mangystau**

**Table.2.3.4. Parameters of the sparse 3D shooting technique**

| SURVEY PARAMETERS | DESIGN |
|---|---|
| Inline bin size | 25 |
| Crossline bin size | 50 |
| Receiver Interval | 50 |
| Shot Interval | 100 |
| Shot Line Interval | 1200 |
| Receiver Line Interval | 400 |
| Number of Channels | 120 |
| Number of Receiver Lines | 24 |
| Number of Receivers per Line | 240 |
| Total Number of Channels | 5760 |
| Number of moving RLI | 12 |
| Salvo | 5 |
| The base of Salvo | 400 |
| Number of Shot Lines in Patch | 1 |
| Number of moving SLI | 1 |
| Crossline Fold | 12 |
| Inline Fold | 5 |
| Full Fold | 60 |
| Inline Size of Patch | 5975 |
| Crossline Size of Patch | 4800 |
| Aspect Ratio | 0,80 |
| Max of Min Offsets | 1226,02 |
| Xмах | 7664,24 |
| Inline length of the full fold | 40,00 |
| Crossline length of the full fold | 25,00 |
| Total area of the Full Fold | 1000 |
| Inline size of the area to achieve full Fold | 46,0 |
| Crossline size of the area to achieve full Fold | 25,4 |
| The total area of the survey | 1167,8 |
| Number of SP per 1 sq.km: | 8,3 |
| Total number of SP: | 9732 |
| Number of RP per 1 sq.km: | 50,0 |
| Total number of RP: | 58389 |

# 3. DATA AND METHODOLOGY

## 3.1. RESERVOIR SEISMIC AND DIRECTIONS OF ITS PROGRESS IN KAZAKHSTAN

### 3.1.1. Introduction

3D seismic exploration is currently the main tool for mapping oil and gas facilities not only at the exploration stage, but also at the production stage of an oil and gas field. If earlier seismic exploration was used only to delineate an oil and gas deposit, today the situation has changed, and in most cases seismic information becomes a valuable data source at the stage of describing the properties of the formation. Seismic data is transformed into a constantly operating and updated field management tool, both when calculating and recalculating the balance reserves of the field, and when planning production throughout the life cycle of the field. Such seismic exploration is called oil field seismic.

Although it was previously recognized that changes in lithological and petrophysical properties and the nature of reservoir saturation affect the recorded signal, the resolution of these data and their processing capabilities were insufficient for a detailed description of the reservoir characteristics.

The resolution of seismic exploration is higher when the velocity is low and the frequency is high. Therefore, shallow layers, which are usually characterized by a lower wave velocity and a higher frequency composition, are displayed with a higher resolution than deep-lying layers (Table 3.1.1). At the same time, high frequencies cannot penetrate to great depths, since the Earth acts as a natural filter that removes higher frequency components (absorption effect). This means that the deeper our target reflecting horizons are the lower the frequencies and therefore the resolution [3] (Fig. 3.1.1).

**Table 3.1.1. Seismic resolution ranges by depth and age of rocks**

| **Age of the Rocks** | **Very young** | **Young** | **Middle-aged** | **Old** | **Very old** |
|---|---|---|---|---|---|
| Depth, m | Very shallow | Shallow | Average depth | Deep | Very deep |
| Velocity (m/s) | 1600 | 2000 | 3500 | 5000 | 6000 |
| Dominant frequency, Hz | 70 | 50 | 35 | 25 | 20 |
| Wavelength, m | 23 | 40 | 100 | 200 | 300 |
| Resolution, m | 6 | 10 | 25 | 50 | 75 |

A typical vibration source can generate signals with a dynamic range of approximately 8-105 Hz. Extending the bandwidth of the original seismic signal by adding low and high frequencies uniquely improves the resolution of seismic recordings. It has been experimentally proven that increasing the amount of low-frequency energy emitted by the source improves the ability to characterize the properties of rocks through seismic inversion. Thus, increasing the dynamic range of seismic signals has been and remains the main task in planning and conducting seismic surveys of an oil field. The solution to this problem is achieved by using modern advanced seismic equipment, improving the design methodology, conducting 3D seismic surveys, and improving the software for processing seismic data. One of the ways to increase the resolution of seismic recording may be the use of new vibrators such as DX-80 (WesternGeco) weighing about 36 tons, which allows you to create swipe signals in the frequency range 3-150 Hz [17].

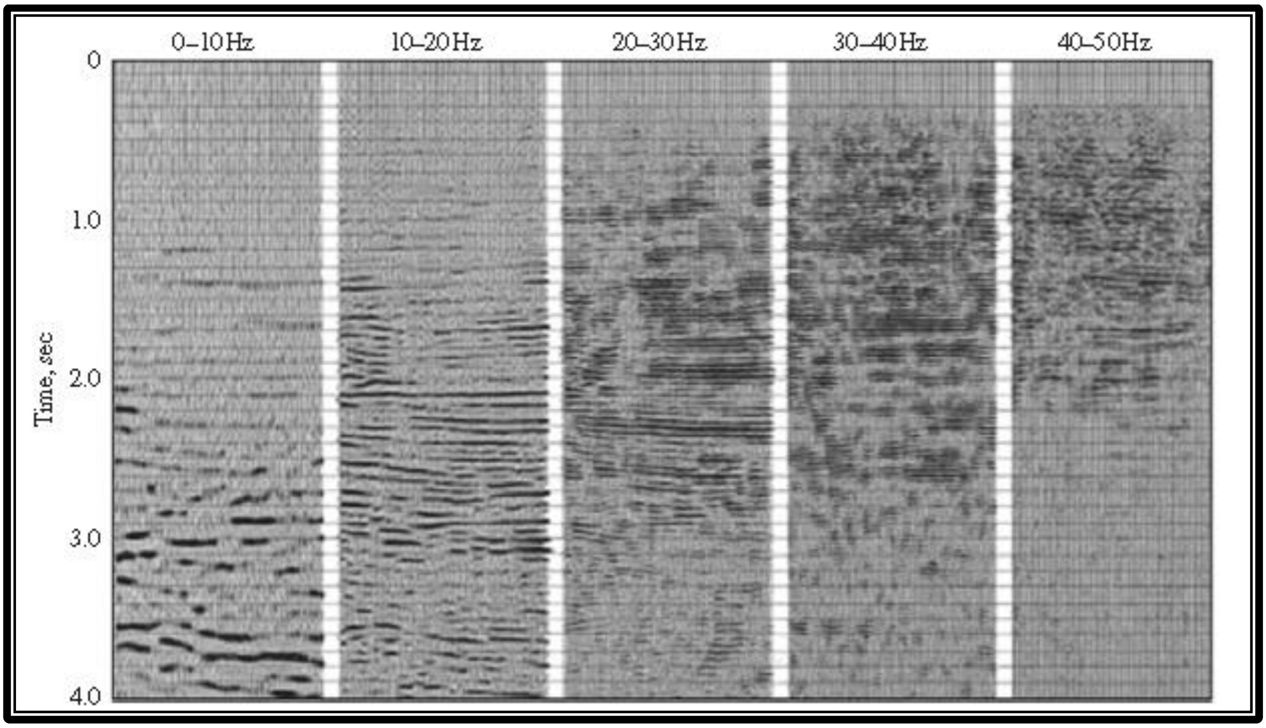



**Fig.3.1.1. Frequency distribution of the seismic signal by time section [5]**

### 3.1.2. Transition to high-density seismic

To date, medium-frequency 3D seismic prospecting has prevailed in Kazakhstan and such 3D survey parameters (a cross-type system) have been practically standard: The step of the receiving line (RLS) is 300 m., the step of the excitation line (SLS) is 300 m., the step of the reception points RP) is 50 m., the step of the shot points (SP) is 50 m., the bin dimensions are 25x25 m. The shooting density is 66.7 physical observations per 1 sq. km. If a seismic contractor has 6000-8000 channels with such parameters, sufficiently flexible wide-azimuthal observation systems are designed to successfully solve the tasks of searching for oil and gas facilities in the sedimentary basins of Kazakhstan.

But such systems are no longer optimal for studying shallow, low-power and small-sized objects in the fields under development, as well as for solving problems of forecasting their filtration and capacitance properties.

Due to the discovery of mostly all large and easily detectable deposits, oil and gas companies are increasingly paying attention to small-sized and complexly constructed hydrocarbon traps and unconventional reservoirs. And accordingly, they pose increasingly difficult tasks to seismic exploration, which must not only provide accurate structural constructions, but also determine the types of reservoirs, and map their fracturing and oil and gas saturation. 3D seismic exploration of a new technological level can be used to solve such complex tasks (15). "This is both high-resolution, high-density, and broadly azimuthal (full-azimuthal) seismic exploration at the same time" [15].

Recently, high-density seismic technologies have been rapidly developed abroad, which have obvious advantages for improving the quality of seismic data. The most important advantage of these technologies is the high spatial sampling frequency of the observed wave field and more accurate quantization of surface waves for their subsequent better subtraction during processing, minimal group intervals and generally single sources and successors create an unambiguous signal spectrum in the frequency-wavenumber (f-k) region. The high spatial quantization frequency also creates optimal conditions for correcting the static corrections of each source and receiver individually, and prevents non-synchronous overlap of amplitudes due to non-identical surface conditions in the group. Due to the better preservation of the high-frequency components of the signal, the resolution and accuracy of the seismic image are much improved. As a result of improving the spatial sampling rate, traces of the influence of field alignment on the data are also minimized.

The accuracy of time migration before summation is greatly influenced by the density of seismic image traces per square kilometer (formula proposed by Norman Cooper, [40]):

$Td=10^6 Nfold/Bsize$,

Where Td is the density of image traces per unit area, traces/ km2; Nfold is the multiplicity of coverage; Bsize is the area of the bin, $m^2$. As is known, migration helps to increase the horizontal resolution of seismic images by correctly positioning reflected waves in their correct position and reducing the diameter of the Fresnel zone.

In the West, leading geophysical companies have developed three advanced technologies in recent years: HD3D (Petroleum Geo-Services), Eye-D (CGG), and Q-land (WesternGeco)

(Table 3.1.2). All these technologies were aimed at improving the quality of seismic data by increasing the density of their spatial sampling at sea after data collection and after, they were adapted for ground-based seismic exploration [33].

**Table 3.1.2. Advanced high-density seismic technologies**

| Technology type | Service company | Representative technology | Application range | Main parameters |
|---|---|---|---|---|
| Small group interval and high imaging trace density | PGS | HD3D | Land, sea | Bin size: offshore 3.125 m × 6.250 m; onshore 12.5 m × 12.5 m<br>Imaging trace density: above 40 × $10^4$ trace/$km^2$<br>Processing: wide azimuth, anisotropy; interpretation:<br>prestack elastic inversion |
| | CGG | Eye-D | Land, sea | |
| Single-point receiving, indoor digital grouping, and high density | WEI | Q-land | Land, sea | Bin size: onshore 5 m × 5 m; digital single point, 3 × $10^4$<br>trace instrument; processing: DGF, wide azimuth,<br>anisotropy; interpretation: prestack elastic inversion |

Application examples show that high-density seismic exploration is an effective technology for improving signal-to-noise ratio, vertical and horizontal resolution. In addition to improving the density of spatial sampling, in these technologies it is possible to increase the aspect ratio of the active arrangement, realize a full (wide) azimuth, which as a result provides great opportunities for studying the anisotropy and fracturing of reservoirs based on elastic inversion according to migration data before summation.

In Kazakhstan, the first high-density 3D seismic survey was performed in 2009 by Azimut Energy Services (AES, Integra) in the conditions of the complex infrastructure of the Karashaganak oil field [51]. In this survey, with the deployment of up to 18,000 channels in real time and 5 vibrators, record field performance was achieved - up to 2,800 physical observations per day, 1 petabyte of more than 800 square kilometers of 330-fold data on the SP-RP grid of 20x20 m with a Xmax of more than 9,000 m was obtained within 6 months.

The project used small bases of source groups – 2 vibrators based on 13 m. and reception - a circular group of 12 seismic receivers with a diameter of 17.5 m.

With a sweep signal length of 14 seconds and a listening time (recording length) of 6 seconds, one accumulation was worked out in an average of 20 seconds. This was facilitated by the use of the flip-flop shooting technique in combination with the slip-swipe technology. The subsequent swipe signal of the 2nd vibrator group began while listening to the previous one. Thus, when using 4 groups of vibrators, which were moved in advance to the points of the following physical observations, an average productivity of 1,700 SP/day was achieved.

To work with a large number of channels, the 428 central electronics system was specially modified, and new communication equipment was purchased that allows the central electronics to "control" vibrators and distribute channels in a large active arrangement.

The results of the new 3D survey showed a dramatic improvement in the quality of seismic data at the field and contributed to clarifying the assessment of hydrocarbon reserves and the points of laying new wells [54].

With the arrival of the international Chinese company BGP on the market of Kazakhstan, separate examples of the application of relatively high-density seismic technologies have appeared in other fields of Kazakhstan [Table 3.1.3]. Conditionally high density in Chinese technologies is achieved by reducing the distances between SL and RL to 100-200 m and the bin size to 10 m, using linear or circular groups of receivers on a small base, sources in the amount of 1 or 2 vibrators per observation and only 1 accumulation (sweep). To reduce the traces of the receiving line, the smallest salvo of SP (3-5) is used in the center of the placement and one movement of the receiving lines after shooting the strip. To obtain a wide azimuth, the number of receiving lines is increased to obtain an almost square arrangement. Depending on the depth of the target horizons, the Hmm is selected, the value of which determines the required number of channels of active placement. In the systems designed in Kazakhstan, the number of active channels is in the range of 5,000 – 10,000, and to ensure the smooth operation of the seismic batch, BGP can currently supply up to 20,000 channels at the same time. Productive work is ensured by the use of the "flip-flop" shooting technique, in some cases "slip-swipe" and the presence of 4-5 sets of fleets of 2 vibrators that can work simultaneously.

**Table 3.1.3. Relatively high-density seismic technologies used in Kazakhstan**

| SURVEY | KARASHAGANAK | TENGIZ | UZEN | TAISOYGAN | AKSAI |
|---|---|---|---|---|---|
| 3D spread | 15RL * 1SP * 660RP | 28 RL x 6 SP x 204RP | 44 RL x 4SP x 336RP | 30 RL x 3SP x 180RP | 44 RL x 5SP x 232RP |
| Bin size | 10 m x 10 m | 25 m x 25 m | 15 m x 15 m | 25 m x 25 m | 10 m x 10 m |
| Full Fold | 330 | 238 | 924 | 450 | 638 |
| Inline Spread | 6590-10-20-10-6590 | 5075-25-50-25-5075 | 5025-15-30-15-5025 | 4475-12.5-25-12.5-4475 | 2310-10-20-20-2310 |
| Receiver Line Spacing | 300 m | 300 m | 120 m | 150 m | 100m |
| Group Interval | 20 m | 50 m | 30 m | 50 m | 20 m |
| Shot Line Spacing | 300 m | 300 m | 120 m | 150 m | 80 m |
| SP spacing | 20 m | 50 m | 30 m | 50 m | 20 m |
| Number of active channels | 9 900 | 5712 | 14 784 | 5 400 | 10 208 |
| X мах | 9327 m | 6415 m | 5669.33 m | 4997.6 m | 3183.11 m |
| Aspect Ratio | 1 | 0.82 | 0.52 | 0.5 | 0.95 |
| Density of seismic traces per sq. km | 3 300 000 | 380 800 | 4 105 000 | 720 000 | 6 380 000 |

New methods of increasing the productivity of vibrator operations have become cost-effective due to the presence of permanent recording systems with a very large number of channels and the ability of new source control systems to manage a large number of vibrator fleets. Vibrators can be deployed both individually and as part of a group, working simultaneously at the same source location [17]. After completing the set number of accumulations (sweeps), the base plates are lifted and the vibrators "move forward" to the next position, usually at a distance of 25-50 m. At this time, the reflected signals continue to be recorded in the recording system for 4-6 seconds, called the "listening time" (recording length). If, say, the length of the swipe is 8 seconds and the moving time is up to 8 seconds, at least 16 seconds of time will be required before the start of production of the next swipe (Fig.3.1.2).


**Fig.3.1.2. Traditional shooting**

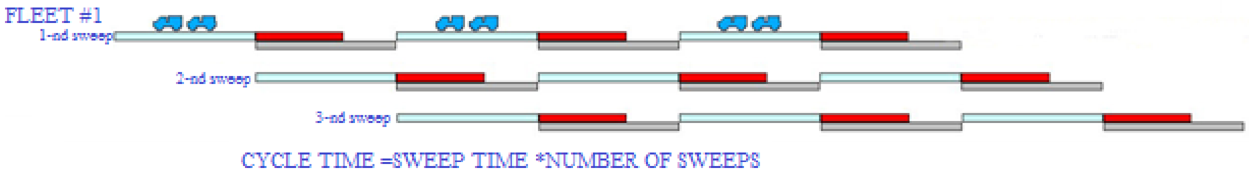



**Fig.3.1.3. Cascade shooting**

With cascade shooting, the next accumulation starts immediately after the completion of the production of the previous sweep, thereby eliminating listening time (Fig.3.1.3). Cycle time, or the interval between two consecutive production sweeps, is a major deterrent to improving the performance of vibrator operations. Productivity can be increased by using more than one set of vibrators: the second set starts sweep sweep immediately after listening to the signals of the first set. This method, called flip-flop acquisition, is currently a widespread method (Fig.3.1.4).

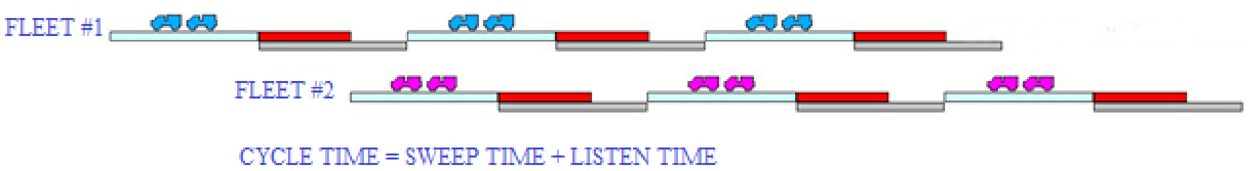



**Fig.3.1.4 Shooting using the "flip-flop" technique**

In single-park and flip-flop operations, the cycle time depends on the length of the swipe. Subsequently, the "slip-swipe" technique was developed, in which the next swipe starts to run before the end of production of the previous swipe. In the "slip-swipe" technique, the minimum allowable interval between two consecutive excitation times is called a slip (slip). The cycle time is therefore only equal to the sliding time and does not directly depend on the length of the sweep. However, acquisition with long swaps usually requires long slip times to avoid strong signal interference by the harmonics of subsequent swaps(Fig.3.1.5).

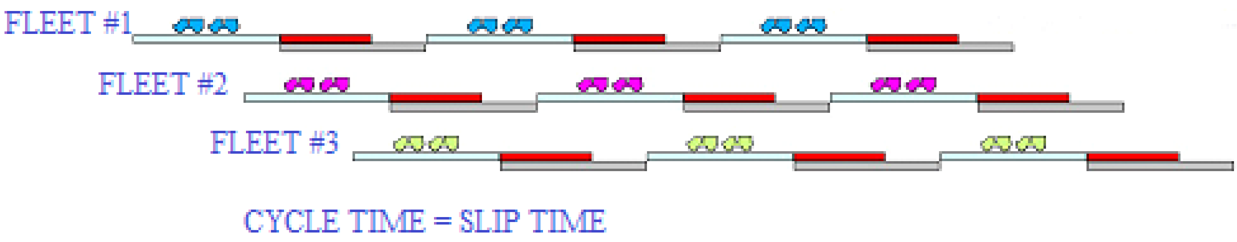



**Fig.3.1.5 Shooting using the "slip-sweep" technique**

Further improvement of vibratory operations is associated with the development of various simultaneous shooting techniques – independent simultaneous shooting (ISS, Independent Simultaneous Shooting) and controlled simultaneous sources (MSS, Managed Simultaneous Sources). In controlled shooting methods, vibrators are controlled by modern vibrator electronics systems such as VE464 of the Sercel428XL recording system, which are able to follow prescribed rules. One of the latest developments is the technique of "distance-separated dithered slip sweep" - DSSS (distance-separated dithered slip sweep) (Fig.3.1.6).

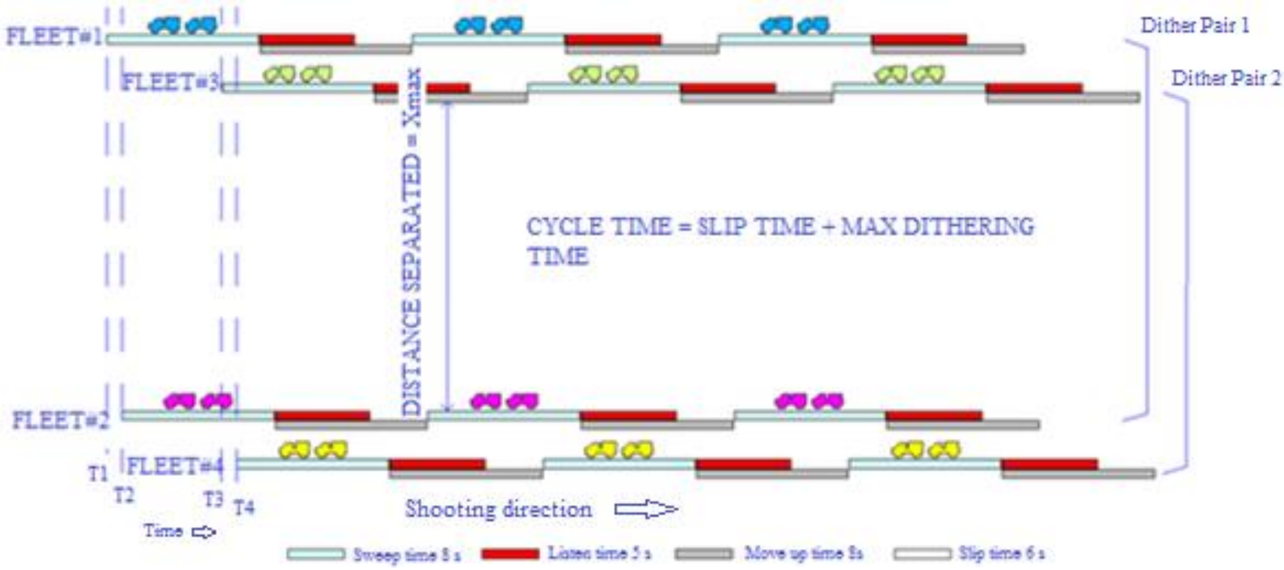



**Fig.3.1.6 Shooting using the "DSSS" method**

In the "slip-swipe" technique, as well as in all simultaneous shooting techniques, the received recordings must be subjected to subsequent special processing aimed at clearing them from the interference of harmonics of simultaneously received signals from other sweeps.

### 3.1.3. **Issues of processing high-density wide-azimuth data**

Processing of high-density data is itself complicated due to the large volumes of primary seismic survey data. As can be seen from the table 3.1.3 the density of trails in individual surveys is more than 6 million trails per 1 sq.km. Thus, the 2009 3D survey at the Karashaganak field has the following data volume:

Survey area ~ 900 sq.km.

Number of shot points (SP) ~ 300,000

Number of receiver points (RP) ~ 100,000

Number of midpoints (CMP) ~ 9,000,000

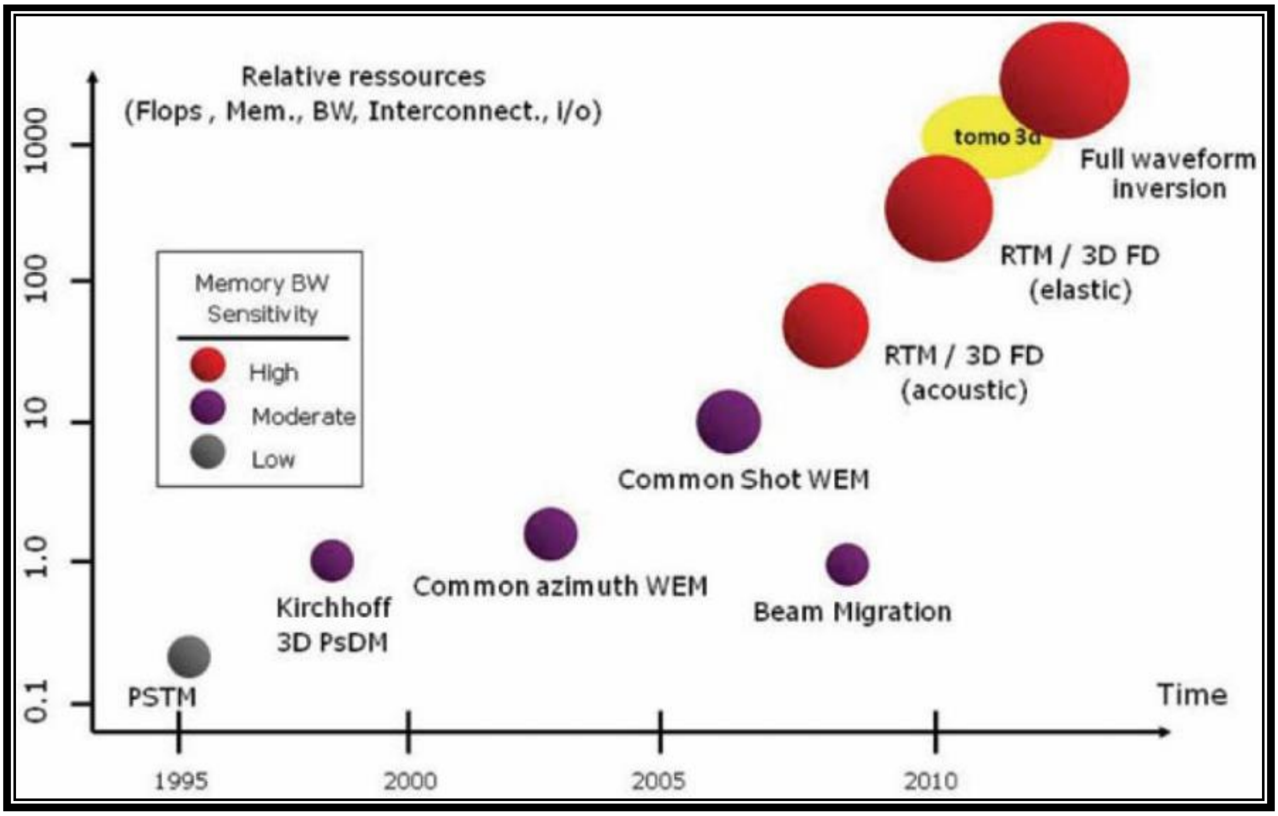
The Fold of the CMP 330

Number of tracks (records) ~ 3 billion

Recording length 20 seconds, 10000 sample, 4 bytes/sample

Thus, the volume of only the initial data of the project reaches 1 petabyte of computer information. In recent years, the main volumes of high-performance computing at data centers in oil and gas seismic exploration have been implemented on powerful clusters consisting of hundreds and thousands of computing nodes (nodes) with single- or multi-core central processing units (CPUs). Modern clusters mainly cope with the standard processing of huge amounts of 3D marine and terrestrial seismic data, however, they require significant capital investments and complex cooling systems, consume tens and hundreds of kilowatts of electricity, and require qualified technical and system maintenance.

At the same time, detailed data processing using "heavy" migration algorithms before summing, say, reverse time (RTM) requires prohibitively high computational costs (weeks and months), which forces processing centers to continue increasing the number of nodes in the cluster.




William Camp and Philippe Thierry, The Leading Edge, January 2010

**Fig. 3.1.7. Resource intensity of modern seismic processing**

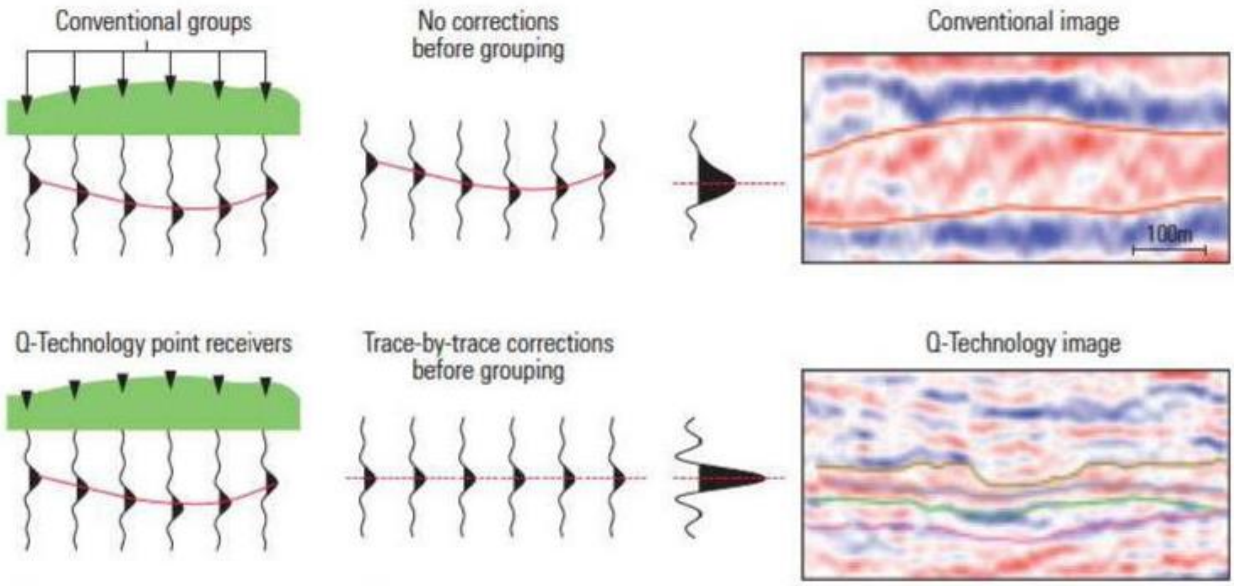



**Fig. 3.1.8. Calculation and correction of static corrections in the case of point receivers**

In the case of point receivers and bin sources, the survey results are very small, and the volume of field information increases more than 2-3 times than with standard surveys [17]. Therefore, for example, the developers of Q-land technology have developed a special method for forming a digital array (DAF), which, after preprocessing the observed wave field, allows you to switch to a larger survey bin size. At the preprocessing stage, all the advantages of point data collection are used to the maximum

- f-k suppression of surface and other interference is carried out;
- individual calculation and surface-coordinated corrections of static corrections of point sources and receivers are performed (Fig. 8);
- Surface-matched amplitude compensation is performed;
- 3D regularization and signal processing with anti-aliasing filters are carried out.

Only after using all the advantages of point data collection, the density of sources and receivers is reduced to an acceptable size for subsequent processing.

The data collected by the "slip-swipe" and simultaneous shooting techniques require processing aimed at separating the SP recordings from the superimposed noises of other shootings. Methods of passive and active separation are distinguished here. Passive separation implies the simple application of a standard processing graph, which is applied to ordinary data; all the effects of interfering vibrations are mainly suppressed as a result of summation and migration. With active separation, special methods are used to suppress the effects of superimposed SP, mainly f-x deconvolution in domains other than the excitation domain, where superimposed signals manifest as random noise, and a specially developed sparse inversion method.

Widely azimuthal data (WAZ) requires special processing for azimuths and deletions. This is where the concept of obtaining cubes of common deletion vectors (COV, Common Offset-Vector) comes to the rescue, similar to obtaining time sections of common offsets (CO) when processing 2D data. An ordinary orthogonal 3D survey can be considered as a set of single surveys, each of which is obtained by a separate "cross arrangement" (a pair of SP and RP lines) (Fig.3.1.9a). The common midpoints (CMP) of the correct cross alignment forms a grid of single CMP (Fig.3.1.9b), where the offsets of the SP-RP gradually increase from the center of the "cross alignment" to the edges (Fig.3.1.10c), and the azimuths change uniformly from 0° to 360° (Fig.3.1.10d). Such CMP grids have the same deletions and azimuths for any "cross arrangements". If we take the "cells", the size of which is the INLINE step of the RL, and the CROSSLINE step of the SL from each "cross arrangement", and place them side by side, then they will make a correct mosaic without a gap and overlap in both directions (Fig.9e and f). This mosaic forms a cube of a single overlap of the entire survey

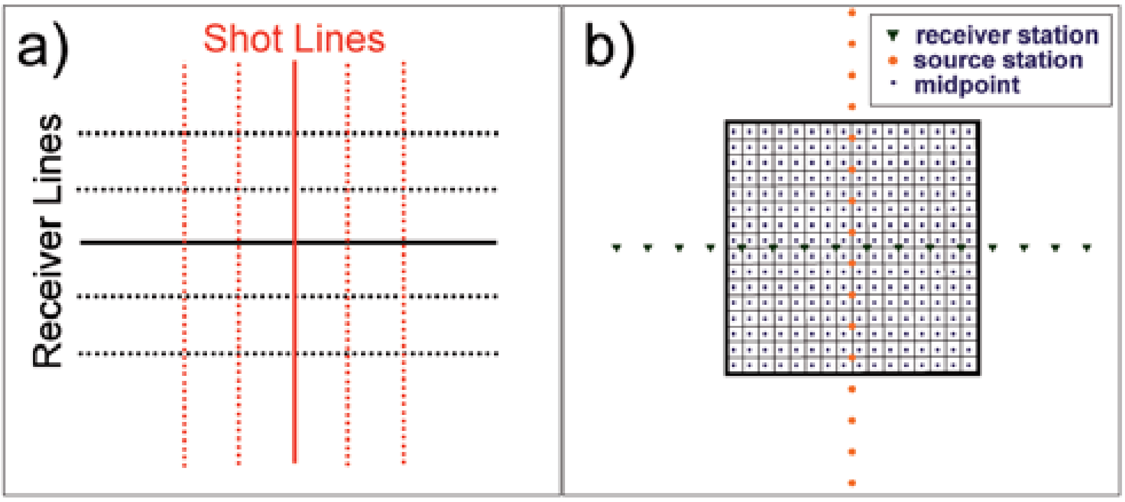



Fig. 3.1.9. "Cross spreads" and a grid of single points of one "cross spread"

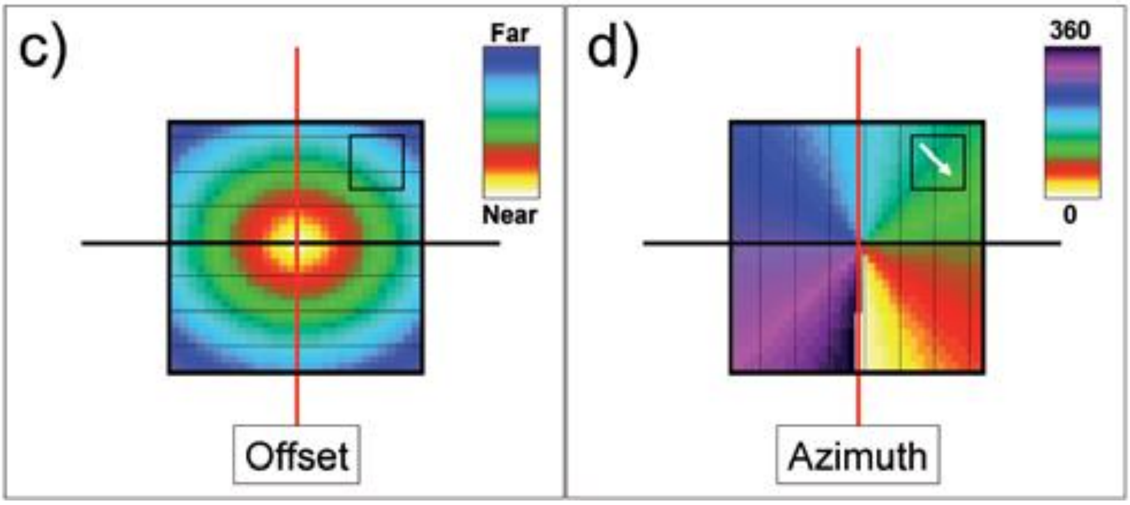



Fig. 3.1.10. Distribution of offsets and azimuths of one "cross spread"

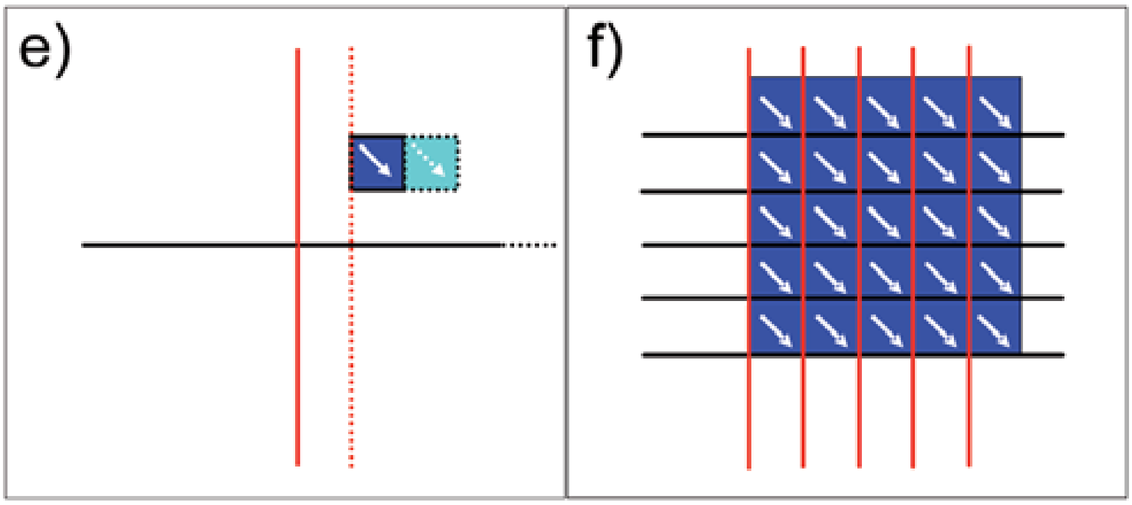



Fig. 3.1.11. Formation of a single cube COV

area with the same distances and azimuths, or a single cube of common vector offsets (Common Offset-Vector, COV).

An orthogonal land survey may be viewed as the sum of sub surveys acquired by each 'cross-spread' (a source-receiver line pair) (a). CMPs from a well behaved cross-spread fall on a single fold grid (b). Offsets increase progressively from the source-receiver line intersection. A rectangular 'tile' of CMPs have similar offsets (c) and azimuths (d). If the tile size is chosen to match the source and receiver line spacing, the same tile from the cross-spread associated with the adjacent shot line (dotted and cyan) will lie adjacent to the first tile (e). Collecting all the tiles from all the cross-spreads results in coverage of the full survey area with single fold data that has similar offsets and azimuths (f)

Such a COV cube has a minimum dispersion of azimuths and deletions, is single, and can be migrated independently, and there is no need to split by azimuth. When migrating individual COV cubes offline, information about both deletion and azimuth is automatically saved. After migration, the COV cubes are re-sorted back into the OST seismograms for subsequent summation and processing. Thus, the integrity of the wide-azimuth signal (WAZ) is maintained to ensure the expected image quality improvement from wide-azimuth and ultra-dense data acquisition.

COV cubes are also useful in studying attributes that differ at different azimuths, such as amplitude variation with distance and azimuth (AVAZ), azimuth velocity variation, etc.

The results of processing broadband and wide-azimuth data in recent years have been extensively demonstrated by Western geophysical companies using various examples. Seismic data with a bandwidth of over six octaves, including low frequencies starting from 1.5 Hz, raises the seismic of an oil field to a new level of possibilities for studying the geological structure of oil fields.

### 3.1.4. Advantages of interpreting high-density data

Higher resolution, 3D cubes with dense sampling provide an excellent opportunity to study the internal structure of the formation using modern three-dimensional visualization programs [Fig. 3.1.12].


**Fig. 3.1.12. Common interpretation and modeling systems**

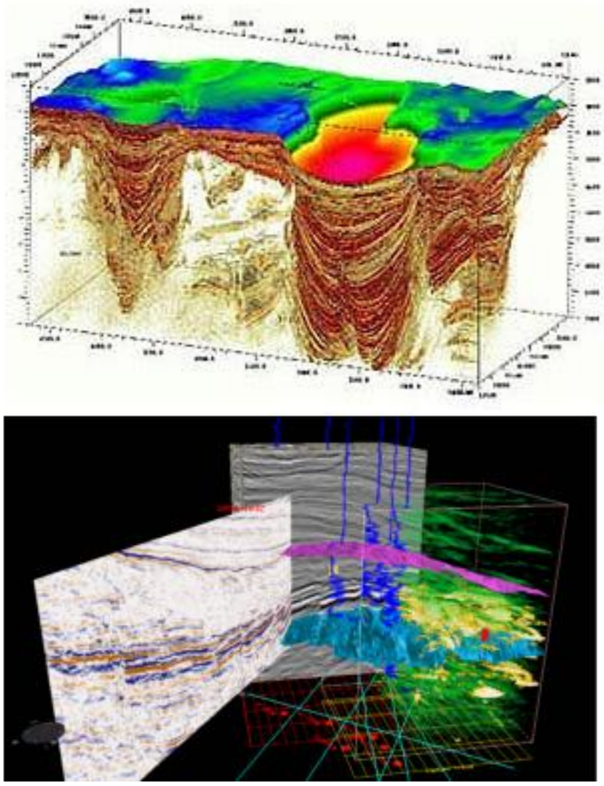


**Fig. 3.1.13. Volumetric visualization and modeling**

Spatial interpretation is very convenient, and allows for a better understanding of the stratigraphic and structural features that could lead to internal heterogeneity of the formation than on vertical sections, which require interpretation from profile to profile. The interpretation of 3D data leads to an excellent definition of the geometry of the formation and the quantitative determination of the rock parameters necessary for the development of the deposit. However, this requires unambiguous correlations of seismic and productive horizons, which must begin with careful calibration of existing wells, followed by structural constructions and assessment of rock properties. Today, 3D interactive interpretation is performed quickly and accurately using powerful and sophisticated software [Fig. 3.1.13].

The internal structure of the formation can be determined using traditional temporal interpretation (temporary sections and sections, arbitrary and composite sections in any direction [Fig. 3.1.14] through wells), as well as analysis of seismic attributes such as slope, azimuth, curvature, coherence, etc.

Reconstructed and arbitrary seismic lines connecting wells are simple, but extremely useful in analyzing seismic responses with respect to known reservoir properties at wells. Correlation profiles through wells help calibrate seismic data and establish control markers to predict the filtration properties of horizons in the inter-well space and beyond.

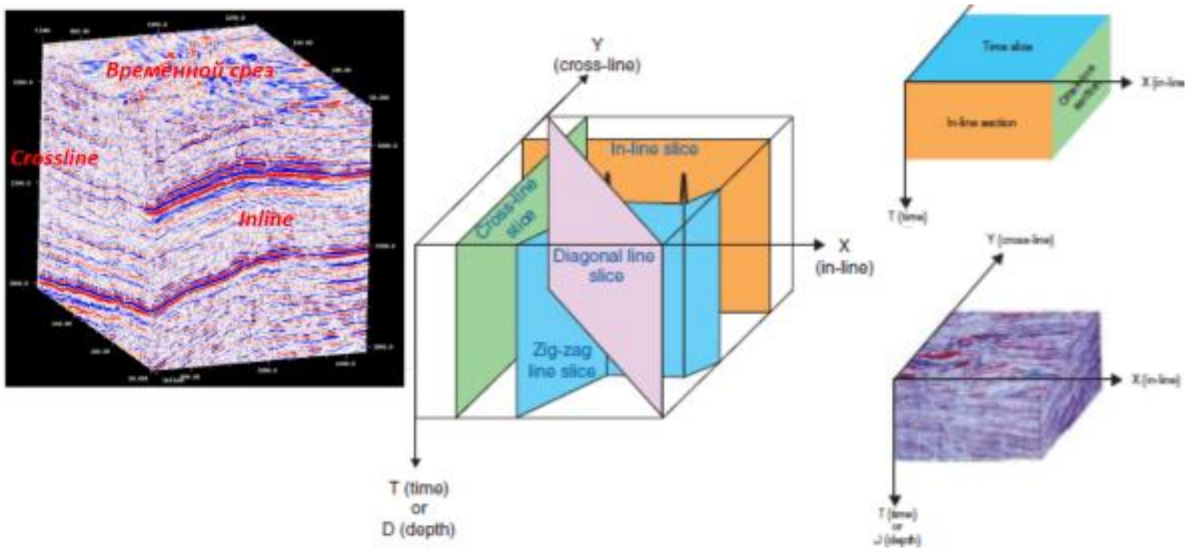



**Fig. 3.1.14. Obtaining various sections from a 3D cube**

The technique of horizontal slicing (temporary or deep sections, sections along correlated horizons) allows you to identify subtle deep features of sedimentation, such as channels, deltas, sand bars, cones of outflows, etc., in the plan. Such sections turn out to be very similar to satellite images, where the geomorphological features of the Earth's surface are clearly visible and trends in the stretching of structural traps, "salt domes", tectonic disturbances, features associated with seismic amplitudes that cannot be determined when interpreting only vertical time sections are clearly indicated.

Another commonly used method is to display amplitude values in a specific cube window. For example, the calculation of rms amplitudes in a time window along the interpreted horizon is used as an easy and fast way to determine possible distribution zones of light hydrocarbons.

## 3.2. SEISMIC IMAGING IN SALT TECTONICS (ON THE KARACHAGANAK FIELD EXAMPLE)

### 3.2.1. Introduction

The giant oil and gas fields of Tengiz, Karachaganak and Kashagan are located in the carbonate complexes of the Caspian sedimentary basin, which is located under a thick layer of saline sediments (Fig.3.2.1).

These deposits accumulated here during the geological history of the basin, starting from the Lower Permian, and developed in subsequent epochs until the beginning of the Jurassic period, creating the so-called "salt tectonics", and forming various types of salt structures in the section.


**Fig.3.2.1. Map of deposits of the Precaspian basin [15]**

In the wave picture, salt bodies are characterized by a transparent seismic record, against which bundles of dynamically strongly pronounced multiphase reflections from anhydrite formations are often distinguished. Areas of salt with inclusions of rocks of other lithology are usually called "dirty salt". These inclusions can vary in size from several meters to tens of meters. Figure 3.1.2 shows a characteristic time section of the Caspian basin. As can be seen from the figure, salt tectonics forms in the section an alternation of sections with large (salt body) and small (enclosing rocks) elastic wave propagation velocities.

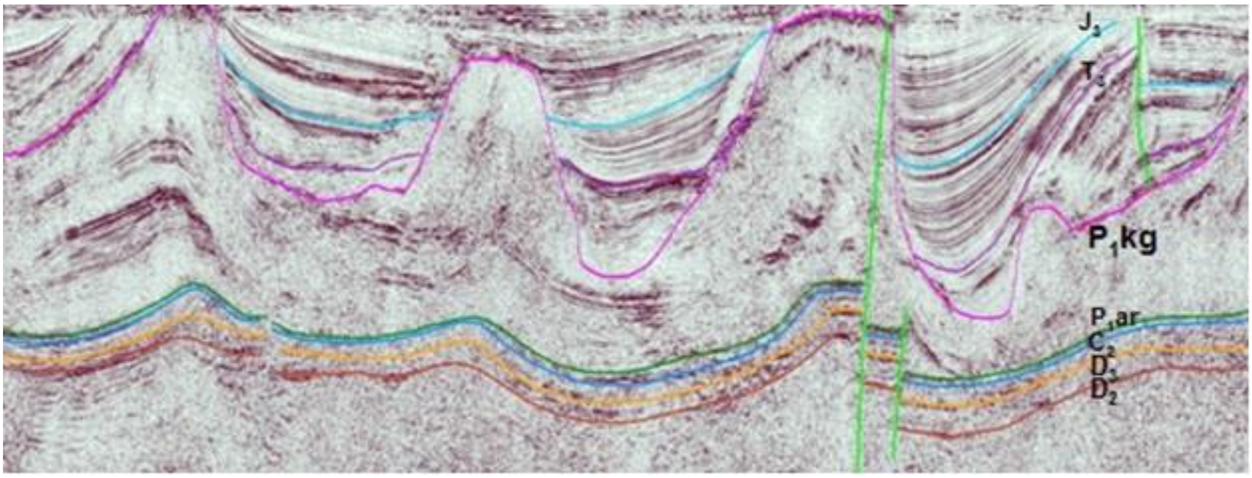



**Fig.3.2.2. A characteristic time section of the Caspian basin illustrating various types of salt structures**

Figure 3.1.3 below shows a model of the lithological and stratigraphic section, the northern side of the Caspian Basin, where the large Karachaganak oil and gas condensate field is located, confined to the carbonate reef structures of the Famensk-Carboniferous and Early Permian ages. In the Upper Permian-Triassic period, various types of mobilized salt bodies, cornices (allochthonous structures) were formed here, connected with the help of feeding lines with basal salt (autochthonous), or generally disconnected from it.

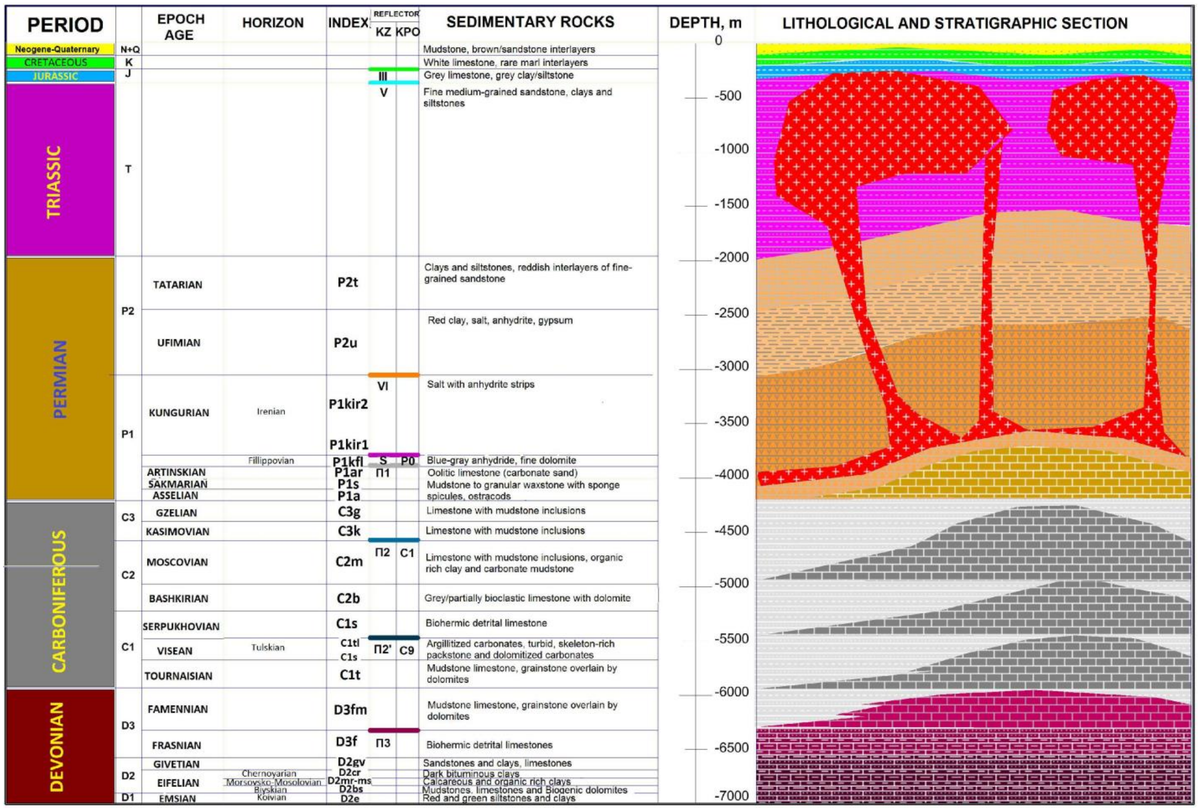



**Fig. 3.2.3. Lithological and stratigraphic section of the northern side of the Caspian basin according to [12] with additions by Kalmagambetov J.K.**

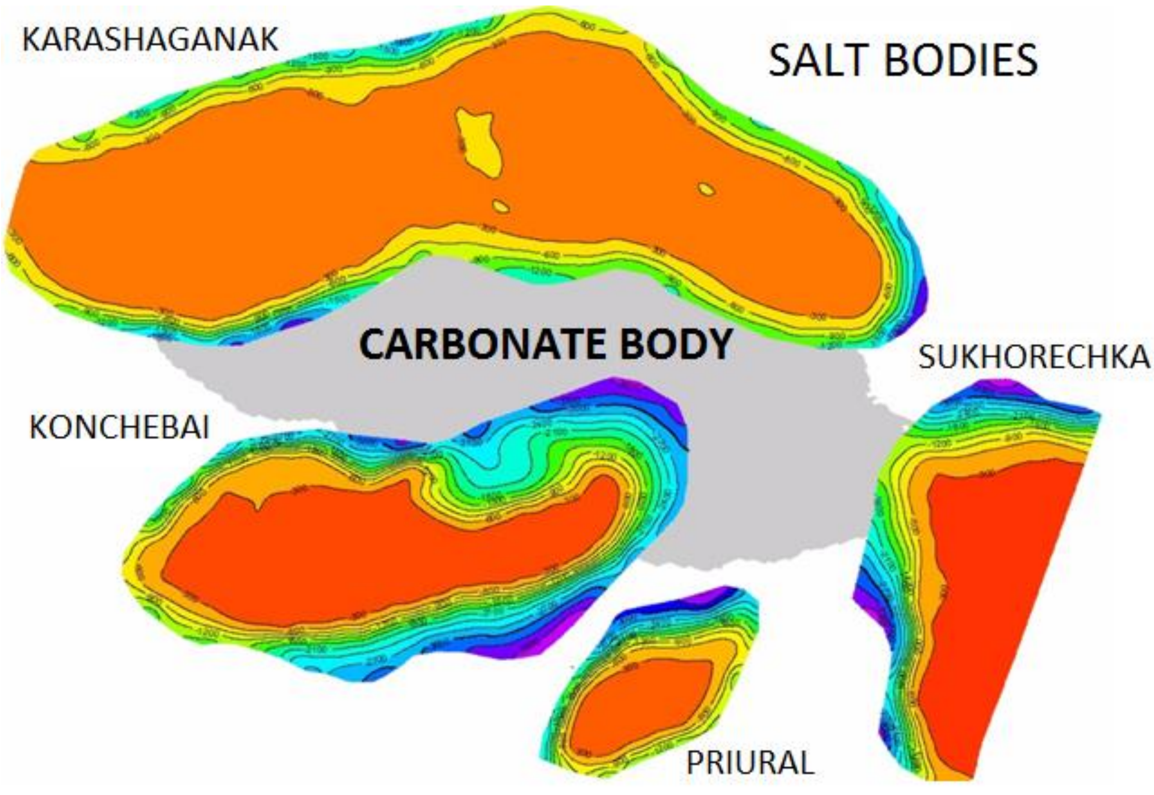



**Fig.3.2.4. The relationship of salt and carbonate bodies of the Karachaganak deposit**

The relationship between large subsalt uplifts and salt domes develops in different ways (Fig.3.2.4). The Karachaganak deposit covers the area of the inter-dome trough, to the periphery of which the domes of Karachaganak, Konchebai, Sukhorechka, and Priuralny gravitate. On the vault of Tengiz and the edge of the vault there are domes Beles, Beles South, Beles South-West, Karasor, Karasor East, etc., forming ridges of north-western and north-eastern directions, reflecting low-amplitude disturbances in the body of the carbonate massif. The domes of the Desert, Tazhigali, and Karaton roughly follow the contour of the Primorsky subsalt uplift.

The depth of the roof of the salt column at the Karachaganak deposit varies from 100-200 m on domes to 4000-4500 m in the central part of the Karachaganak mulda. Their thickness naturally increases from several tens of meters in the vault of the deposit to 3000-4000 m or more on the Karachaganak and Konchebai domes. The salt tectonics manifested in the Upper Permian and Triassic completely modified the structural plans of both the suprasalt and subsalt complex of sediments. In the average structural and lithological complex of the salt-bearing strata of Kungur, sharply disharmonious structures were formed both in relation to the underlying and overlapping floors. At the same time, the development of salt dome structures was largely predetermined by the structural features of the foundation elements, since salt domes and shafts mostly repeat the orientation of the side salt ledge. The Karachaganak salt dome complicates the northern wing of the structure, Konchebai — the southern one, to the east of which the Sukhorechensk dome was formed [30].

The complexity of the structural characteristics of the salt column, the inhomogeneous velocity field of elastic waves propagation in it requires careful preparation of a 3D seismic exploration project to study the subsalt deposit (Fig.3.2.5), starting

- with the design of the survey,
- quality control during data collection,
- preprocessing stages,
- thorough testing of parameters,
- building a velocity model and
- ending with the final migration.

For accurate visualization of subsalt structure in the subsurface, one can rely only on careful application of 3D deep migration prior to summation. This sequence of work was followed during the last 3D at the Karachaganak field, processing and interpretation of its data.

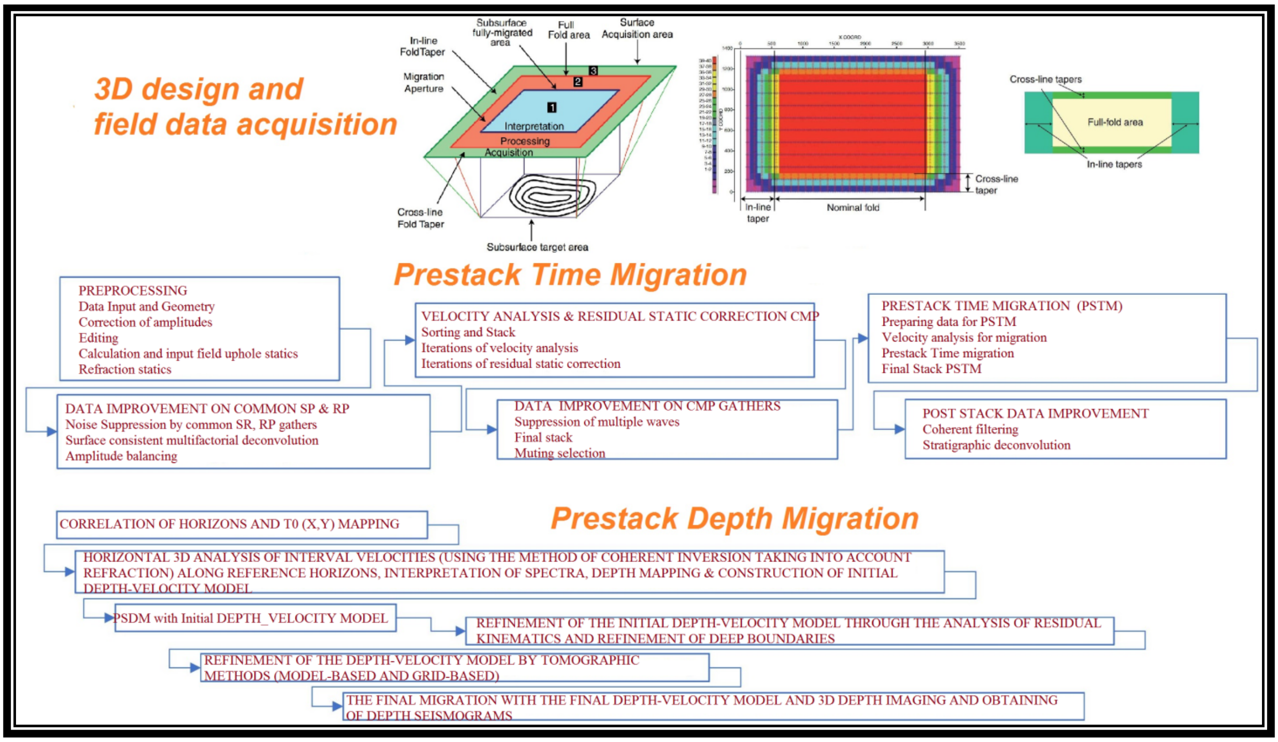



**Fig.3.2.5. Strategy for the preparation of a 3D seismic exploration project for the study of subsalt carbonate complexes**

### 3.2.2. **Field data acquisition**

Currently, various new technologies for data collection, processing and interpretation have been developed to overcome the difficulties of obtaining images in the subsalt section. Recent advances in data collection technology - obtaining data over a wide azimuth and with large distances, high-density seismic observations have opened up great opportunities to improve the quality of seismic images - the bandwidth and spatial resolution of seismic data have been increased, multiple noise reduction has been achieved, excellent conditions for high-precision high-velocity analysis and migration of seismic data have been created [44].

In addition, improvements in computer equipment currently make it possible to use hundreds and thousands of processor cores for computing and storing large amounts of data, which allows using new approaches to constructing seismic images of subsalt structures.

Thus, the new 3D seismic surveys of 2009 at the Karachaganak field (Fig.3.2.6 - 3.2.7) were carried out at the modern level:

- high-density and wide-azimuthal,
- the bin size is 10*10 m versus 25*25 m before,
- Xmax 9327 m vs. 5873 m,

– Survey Fold is 330 vs 40,

– the density of observations is 3300000/64000 = 51 times higher than in 1999,

this contributed to an abrupt improvement in the quality of seismic data at the field [28].

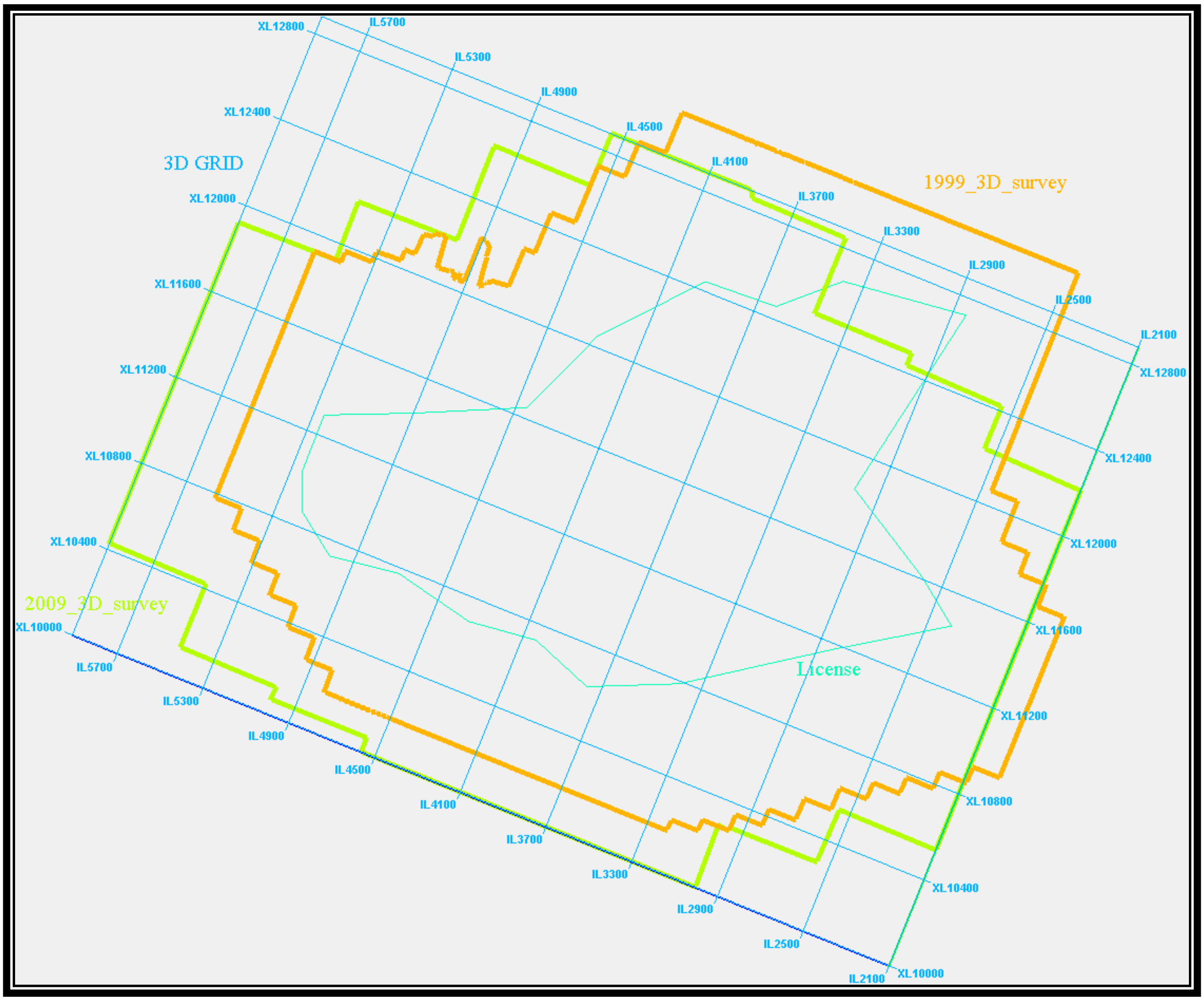



**Fig.3.2.6 Survey contours of 1999 and 2009**

**Table 3.2.1. Comparison of the parameters of 3D data collection in 1999 and 2009 at the Karachaganak field**

| PARAMETERS | 3D SEISMIC SURVEY 1999 | 3D SEISMIC SURVEY 2009 |
|---|---|---|
| 3D Spread | 10 RL * 4SP * 160 RP | 15 RL * 1SP * 660 RP |
| Bin Size | 25 m *25 m | 10 m *10 m |
| Full Fold | 40 | 330 |
| Inline Spread Configuration | 3985-35-70-35-3985 | 6590-10-20-10-6590 |
| RL Spacing | 500 m | 300 m |
| RP Spacing | 50 m | 20 m |
| SL Spacing | 500 m | 300 m |
| SP Spacing | 50 m | 50 m |

| | | |
|---|---|---|
| Total No of channels | 1600 | 9900 |
| Xmax | 5873 m | 9327 m |
| Aspect Ratio | 1.19 | 1 |
| No traces / sq.km | 64000 | 3300000 |

### 3.2.3. Processing strategy

Seismic data processing is also changing synchronously with changes in seismic data collection technology. Modern software for seismic data processing contains almost all time and depth migration algorithms before summation, tools for modeling and design of field seismic data collection systems, including the latest full-azimuth surveys [10].

The parent companies of the international consortium - operator of the field – Chevron and Eni, as well as Shell, which have extensive experience and advanced technologies for studying subsalt structures in the conditions of the salt basins of the Gulf of Mexico, actively participated in the processing of the new seismic survey of 2009 at the Karachaganak field. As a result, a processing strategy was developed, which was implemented in the following stages (Fig.3.2.7):

1. Fast track processing in the time domain with advanced interpretation of the results. The goals are to control the quality of the data obtained, and prepare the initial data for testing various technologies for building a depth-velocity model and algorithms for deep migration before summation, available from parent companies. This processing was performed at the Almaty Processing Center of Petroleum Geo-Services (PGS) Kazakhstan LLP during 2010. Fast Track time processing was a standard processing in the time domain, including:

– assigning the geometry of observations to data, and binning;
– signal processing, including amplitude adjustment and bandpass filtering, aimed at suppressing various interference (in particular, intense surface waves);
– deconvolution aimed at optimal compression of seismic signals and compensation of differences in their shape due to the distorting effect of sharply inhomogeneous surface conditions of excitation-reception of seismic waves;
– calculation and correction of static corrections compensating for the influence of the sharply inhomogeneous upper part of the section in terms of velocity and bringing the data to a single horizontal level of reduction;
– selection and input into seismograms of external muting, cutting off the intense waves of the first intakes.

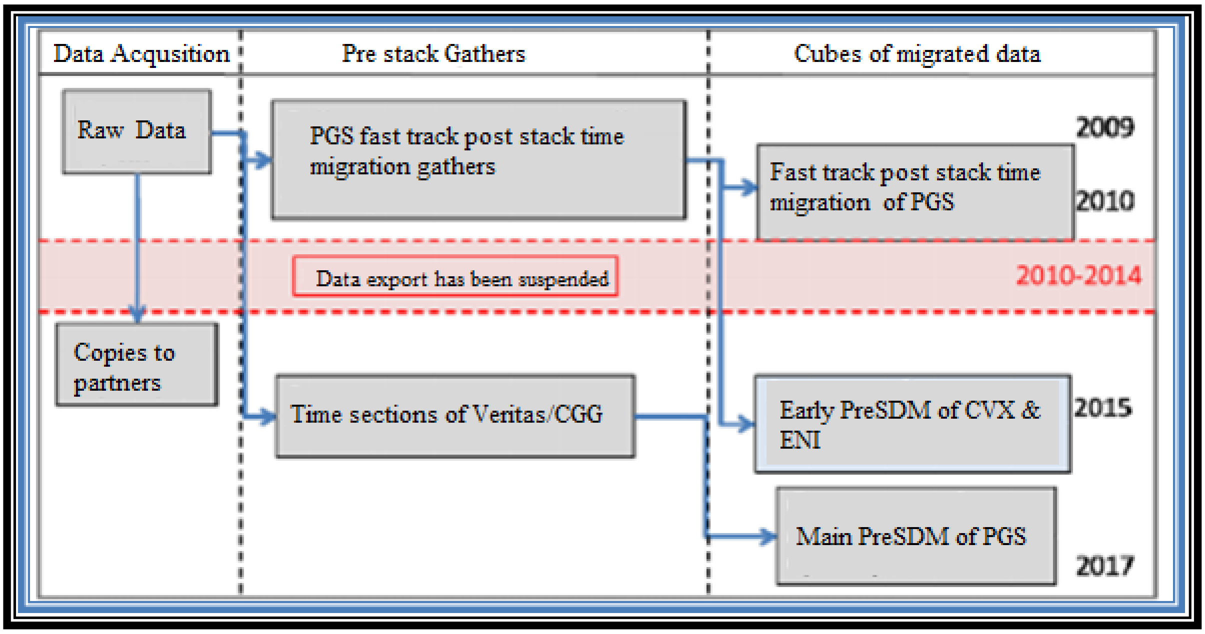



**Fig.3.2.7. Implemented processing strategy at the Karachaganak field**

2. Complete temporary processing of data using the method of temporary migration before summation. The main objectives are the suppression of basic noise, calculation and correction of static corrections. This processing was performed in 2014 by Veritas Caspian LLP in Almaty using advanced CGG software. The results of the pre-summation time processing (pre-summation seismograms and statics) were transmitted as source data for the basic pre-summation deep migration (PSDM) performed in 2016-2017.
3. Early deep migration before summation (Early PSDM) according to accelerated processing data in parent companies. The purpose of these studies was to build an optimal depth-velocity model through early deep migration. The parent companies were already familiar with the data and specific problems of processing seismic data from the Karachaganak field, as they were re-processing the data from the 1999 3D survey. As a result of velocity modeling, new VSP data and acoustic logging data obtained since 2004 were introduced into the previously used model. As a result of successive deep migrations before summation, the first two seismic data cubes were created for use in well design, reservoir mapping, and as input data for reserves recalculation. A new depth-velocity model and various migration algorithms were tested (Fig.3.2.8).

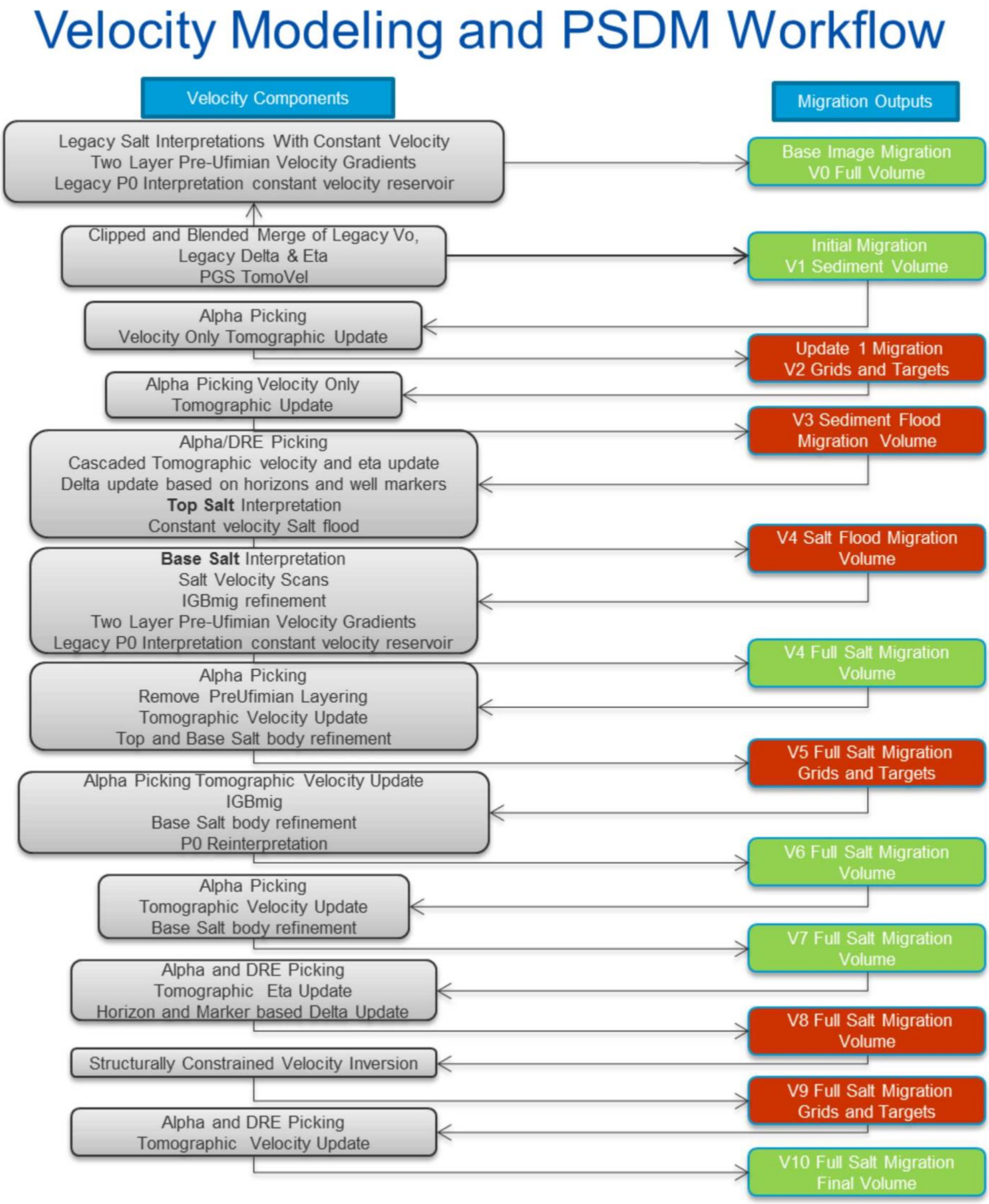



**Fig.3.2.8. Velocity modeling and PSDM processing graph of Chevron**

4. The main deep migration before summation (Final PSDM) was performed at PGS Kazakhstan LLP in Almaty. This project was carried out from December 2015 to June 2017. The use of an alternative deep migration algorithm and an optimized velocity model resulted in a third deep data cube, which is used in combination with two early data cubes.

The main goal of the project was to obtain a detailed structural and stratigraphic image of Paleozoic reservoirs. The main focus of the research was aimed at studying the target depths from 3,500 to 7,500 meters. Very bright velocity contrasts between salt and other evaporites and with the host medium, from moderate to very high values, served as a source of errors in determining depths in previous studies. In this regard, the construction of a correct seismic image of the Karachaganak field was a very responsible and difficult task of these exploration works.

The following scope of work has been completed:

- data import and construction of an initial velocity model – loading of seismic, Uphole/VSP, AK for 300 wells, reference horizons, stratigraphic chops, merging of velocity models - temporary processing and early deep migrations before summation;
- inclined transversal isotropy (TTI), construction of a velocity model of the upper part of the section up to the Irenian horizon. Calibration of the roof of the Tatar horizon and the marking horizons of the Mesozoic strata by wells showed that the seismic data are shallow and the use of negative anisotropy is required. Thus, it was decided to remove the tomostatic model (180m from the relief), and the delta was reduced from 1% to 0.1%. Several repetitions of tomography refinement were performed, as well as complex tomography refinement to improve the velocity model and anisotropy, which also helped to obtain flatter seismograms and a better image.
- building a velocity model of salt deposits, salt bodies were subjected to pouring at a constant velocity of 4575 m/s in order to form an image of the sole of the salt.
- From the proposed two interpretations of the soles of the salt (Chevron and Eni), the interpretation of the Eni company was chosen. The horizontal variability of salt diapirs was taken into account by calculating the average velocities based on acoustic logging, then their interpolation and smoothing in the x, y directions were performed.
- construction of a velocity model of subsalt deposits (pre-Ufa horizon up to P0); analysis of horizon residuals P0 showed that the seismic horizon P0 was located higher than the depth of the marking horizon along the well, which was adjusted by calibration using a constant scalar value calculated from the roof of the Tatar horizon and the roof of salt deposits up to P0. An increase in the velocity in the subsalt deposits made it possible to reduce the discrepancy from -133 m to 0 m. Next, scalar values corresponding to each well are calculated, interpolated over the entire area and applied to the velocity model in

order to increase the number of wells falling within the acceptable range of discrepancies of +/- 50 m.

- construction of a velocity reservoir model (up to horizon C9 and below). A constant velocity of 5800 m/s was taken as a starting point. The refinement of the tomography helped smooth out the seismograms and improve the image quality. The velocity model below the roof of the Zhivet horizon +150 m was flooded at a constant velocity of 4,500 m/s. Smoothing and clipping were used for the final velocity setting.
- the final prestack depth migration (Kirchhoff algorithm); The final velocity model (M18.3) was used to calculate Kirchhoff migration. Additional model improvements were made to improve the image in the reservoir, below the Karachaganak salt body and the slopes of the salt dome, and, consequently, additional adjustment of the velocity model was performed. As a result, the additional Kirchhoff migration is calculated on the new high-velocity model M21 (Fig.9).
- data processing after migration. During this stage, measures were developed to mitigate seismic interference and increase the signal-to-noise ratio by effectively equalizing reflections. The following methods were applied: structural matched filtering, linear interference suppression, Radon conversion, residual kinematic correction and trim statics correction.
- Post stack data processing was mainly used to attenuate residual noise and compensate for amplitude instability. Applied procedures: time-variable filter, Q-compensation (amplitude only) below the P0 horizon according to seismic data after summation and amplitude compensation.

The final result of the PreSDM showed an improvement in the flatness of the seismograms and the image quality of the summarized sections.

The velocity model of the upper part of the section, which should be combined with the velocity model of the early PreSDM, was removed from the initial construction of the model, since the analysis of the residuals of clastic deposits showed that low velocities in the shallow part significantly affect the tuning of seismic data on reference horizons, and this velocity model did not correspond to the logging data.

When constructing the high-velocity model, the radial migration of Gaussian beams was mainly used, since it works much faster than the Kirchhoff migration. A comparison of the results of radiation migration and Kirchhoff migration shows better image quality, a more logical sequence of geological events and smaller artifacts during Kirchhoff migration (Fig.3.2.10), which allow for a more reliable interpretation of the data.

The interpretation of the salt roof was carried out on the basis of the provided early interpretation of the PreSDM. The interpretation of the salt sole of the Eni company was chosen for the work, which was more consistent from a geological point of view. The salt bodies were flooded with velocities calculated using borehole data.

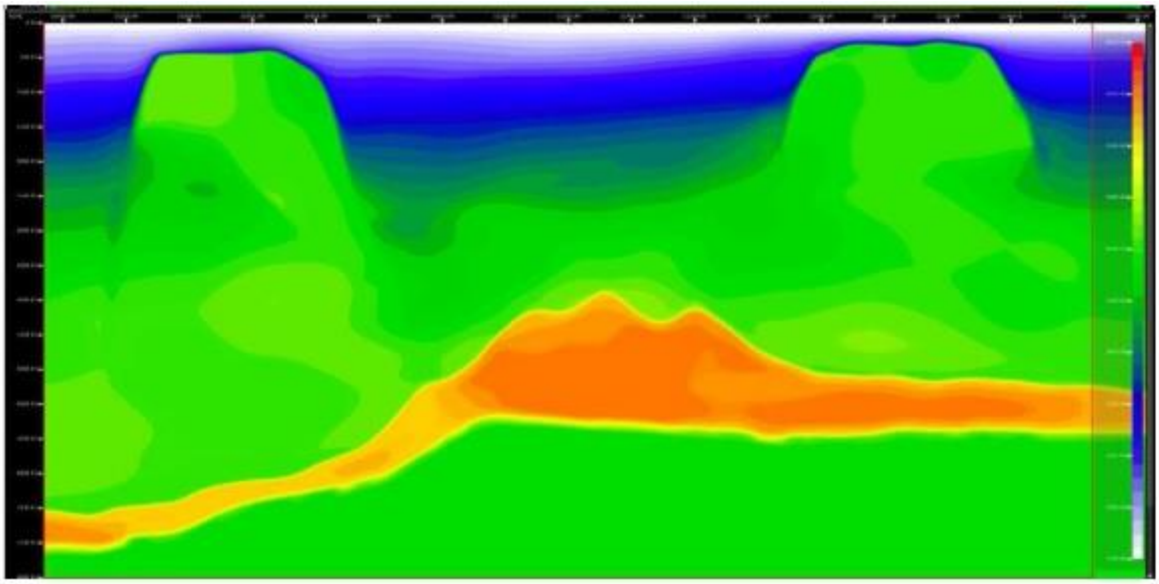


**Fig.3.2.9. Depth-velocity model M21 (velocity range 1700- 6000 m/s)**

The number of wells falling within the range of +/- 50 m in the final velocity model M21 was 46% and 35% for horizons P0 and C9, respectively. The M22 model has reduced the discrepancies between seismic and borehole data to 89% and 80%. However, the M21 model was retained as the final model, since scaling on the M22 model had a negative impact on the data. Post-processing was mainly aimed at improving image quality by increasing the consistency of the horizons data. This was achieved using the procedures of "residual kinematics" and "trim-statics". The amplitudes below the salt bodies degraded after migration, which was balanced using Q compensation and other amplitude compensation tools.

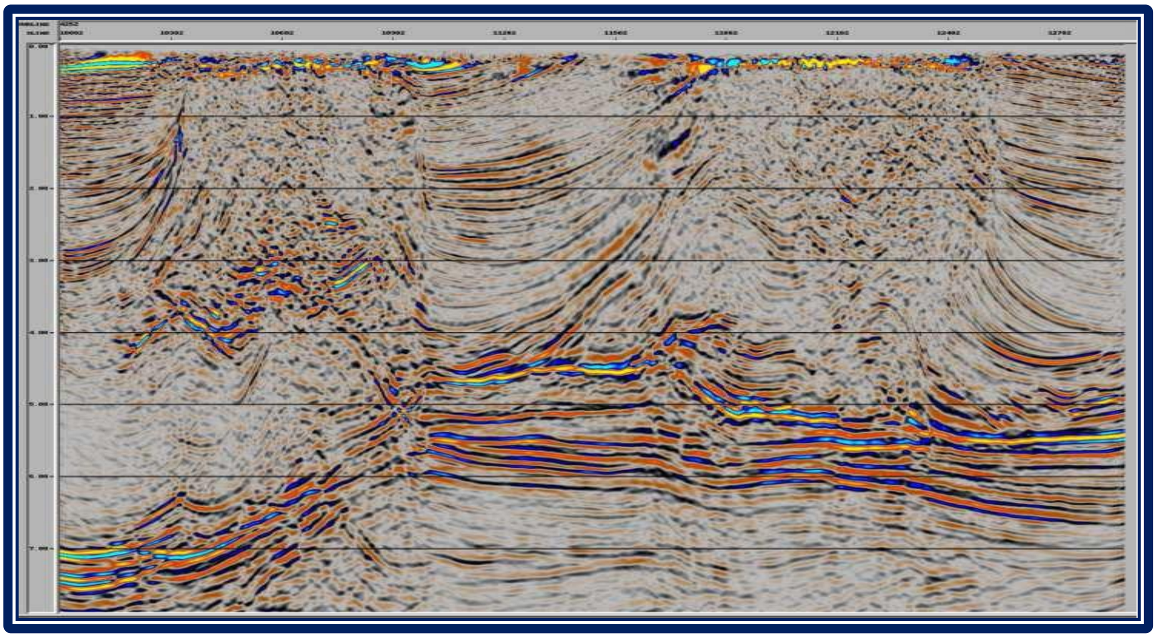


**Fig.3.2.10. The result of the Kirchhoff migration**

### 3.2.4. Construction of a depth-velocity model of the field

Constructing an optimal depth-velocity model of the deposit to perform deep migration before summation in conditions of complex salt tectonics of the deposit is a difficult and responsible task of interpretative processing. As is known, under these conditions, the target horizons are carbonate complexes located at a depth of about 5 km; they are overlain by powerful salt bodies of complex shape, between which sandy-clay sediments (mulda) are located. Schematically, the construction of a model in such conditions can be divided into 3 stages:

1. Determination of velocities in a sandy-clay stratum
2. Determination of the geometry of the salt body
3. Determination of the geometry and velocities of subsalt deposits

It is worth noting that the first two points are critically important for the best focusing of subsalt reflections.

The traditional way is to use the approach described above based on horizon-by-horizon analysis, building an initial model, deep migration and subsequent iterations of tomography and migration. This approach often requires both significant computational costs and the constant participation of a geophysicist in the process of performing all stages of work.

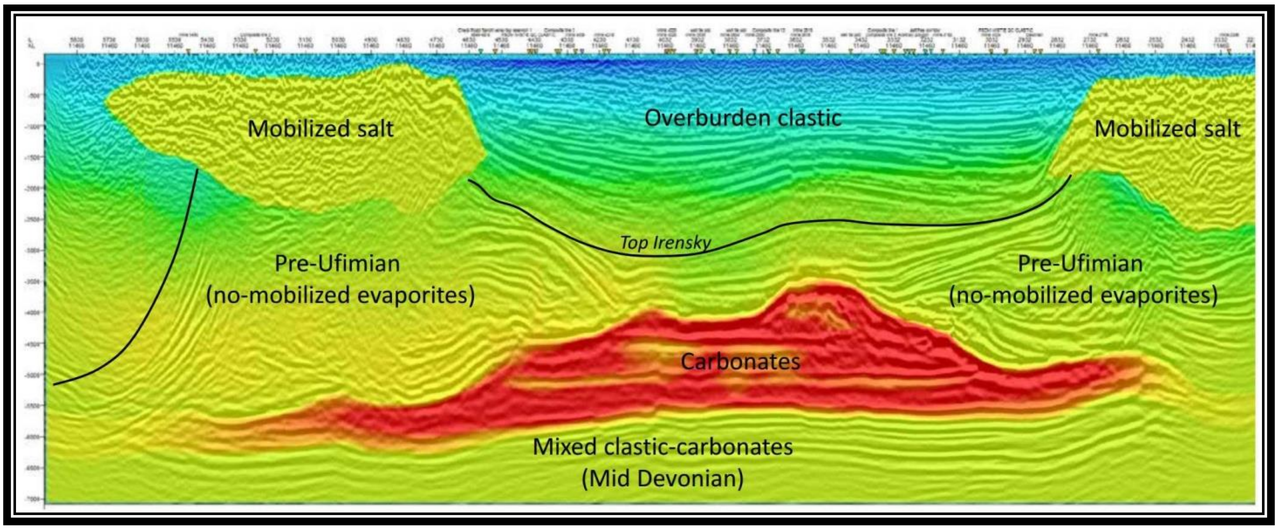



**Fig. 3.2.11. Conceptual model of the deposit**

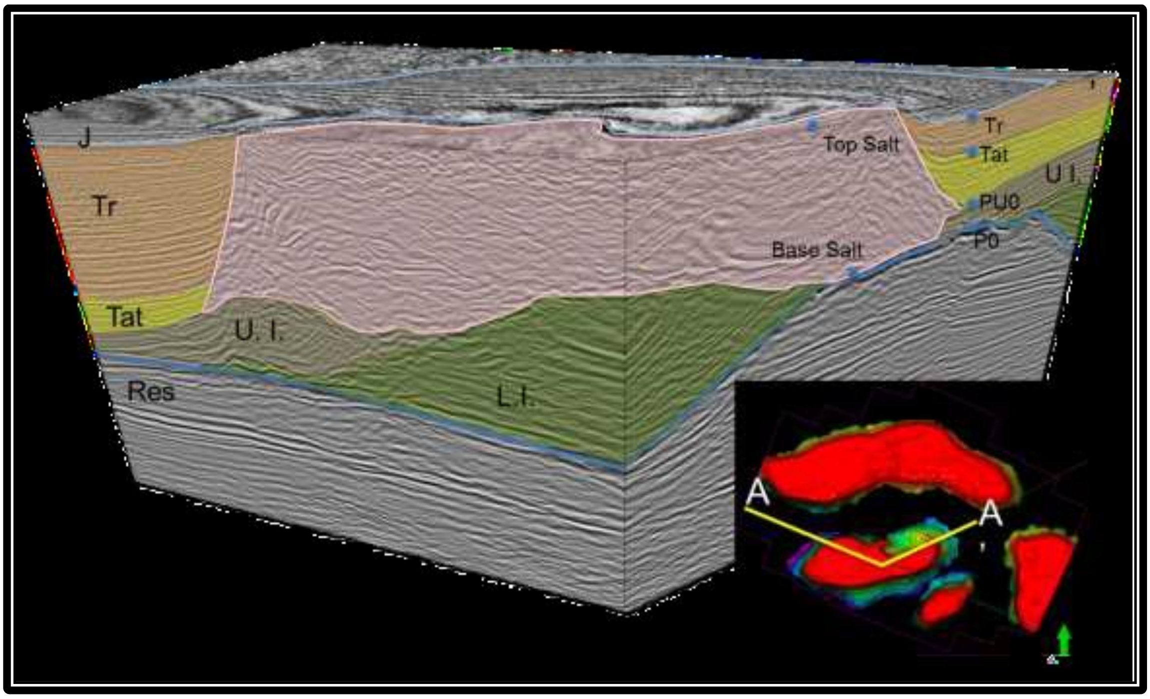



**Fig.3.2.12. The block diagram along the A-A' line through the Konchebai salt body shows the salt body (pink) and the ratio of deposits covering the reservoir,**

Res – the body of the deposit, below the horizon P0 (roof of the Filippov deposits), L.I., U.I. – Irena mixed deposits, Tat – Tatar, Tr – Triassic, J – Jurassic deposits

Various approaches and processing graphs were used to build a velocity model depending on the geological structure of the strata: a conceptual model of the deposit was adopted, which is shown below in Fig.3.2.11 – mobilized or allochthonous salt of the Lower Permian age in the form of salt bodies and diapirs, forms four domes on the territory of the deposit – Karachaganak – the largest northern salt body, Konchebai - the second largest body, immediately south of Karachaganak, is Konchebai Vostochny - a small body adjacent to Konchebai in the southeast and Sukharechka – the eastern body, the gaps between the domes and the arches of the domes are covered with a sandy-clay stratum of the Upper Permian (starting from the Tatar age) - Cenozoic age, allochthonous salt is supported from below by a thickness of unmobilized autochthonous evaporites, which, when constructing the model, were divided into two parts – Upper Yen and Lower Yen mixed strata of anhydrites, salt and sandy-clay rocks. Immediately above the main carbonate reservoir of the Permian-carbon age, a continuous layer of Permian Phillip anhydrites with a thickness of 10 to 300 meters or more lies everywhere, which is considered the main covering of the deposit, the roof of these deposits is designated in this work as the P0 horizon (Fig.3.2.12).

For the terrigenous covering layer of sediments, the approach was based on mesh tomography. The initial model (V0) was built based on the velocities obtained in 2006 (during deep migration before summing up the data of the early 3D survey, previously performed by Eni in Milan) without taking into account salt and carbonates. The possibility of using a model of the upper part of the section, built with accelerated PGS processing, was tested, but it was immediately rejected, due to the fact that the velocitys of the VMS in it turned out to be overestimated.

The initial model was gradually updated, first according to the isotropic approach, the short-range routes were straightened, and then according to the anisotropic approach, in order to straighten the long-range routes and ensure compliance with the marks of the reservoir roof in the well.

After completion of this stage, the following main conclusions were made:

- an increase in velocity with depth due to compaction, with a change in the gradient on the roof of the Tatar deposits,
- the presence of anisotropy within the Tatar deposits.

The second key stage in the construction of the model was the contouring of the roof of the salt body. For the medium in the space between the casting level and the roof of the salt body, the velocities in the mold were used; the velocity in the salt body was chosen constant and equal to 4575 m/s. The main difficulty at this stage is the correlation of the salt roof. The source for the initial correlation of the salt roof was a seismic cube after temporary migration after summation. The construction of the salt thickness model was carried out according to the concepts of salt tectonics. The velocity was set at the same value of 4575 m/s, which is typical for the average composition of the salt lithology. For the purpose of constructing a high-velocity model, the actual complexity of the geological structure of the salt was simplified (numerous salt eaves, feeding lines and disconnected remnants of basal salt). The interpretation of the salt roof was performed on the basis of Kirchhoff migration by filling the thickness to the salt with the velocities of the overlying sediments, while the salt sole was interpreted on the basis of reverse migration in the time domain (RTM) by pouring salt below the roof with salt velocities. The interpretation of the salt sole was controlled by the marks of the salt sole in the wells, determined on the basis of acoustic velocity logging diagrams. Gravimetric modeling was carried out at the Western Konchebai site, where the interpretation of the "Eni" and "Chevron" soles of the salt were very different (up to 1-2 km). By taking the density values for salt 2-2.1 g/cubic cm (which are the reference values used by Eni in the Caspian basin), a proper correspondence between the values of the measured and modeled gravity values was achieved, confirming the interpreted salt reliefs. In the end, they agreed to use the Eni and Chevron models for the final deep migration before summing up the PGS.

The third stage is the correlation of subsalt carbonate complexes. The velocity in them was chosen to be equal to 5800 m/s. The model of the subsalt layer included the pre-Ufa non-mobilized salt below the roof of the Irenian horizon, Paleozoic carbonate rocks and terrigenous carbonate deposits of the Middle Devonian. For this part of the model, the processing graph was designed to maximize the traceability of horizons P0 (approximately the roof of the collector), C1 and C9 (roofs of the main horizons of the collector) in terms of focus and depth accuracy. This particular graph was developed to address the issues highlighted during deep migration in 2006, where the slopes of the carbonate deposit were usually depicted at least 300-400 meters deeper than the marks of the reservoir roof in the well. The main task in this case was to, taking into account the values of 270 chops for horizon P0 and 159 chops for horizon C9, introduce them into the process of building a high-velocity model, thereby eliminating image stretching after migration. For the Daufim horizon, the goal was to achieve an accurate depth and image of the horizon P0. The velocity of carbonates was calculated by interpolating data from 168 acoustic velocity logging diagrams scaled to the seismic frequency range, guided by obtaining a seismic image of the C9 horizon linked to their roof marks along the wells. The resulting model (Fig.3.2.10) provides a satisfactory straightening of the common reflection points (OGT) with excellent alignment of the formation roof marks in wells within the tolerance range of +/-50 meters, for 97% of wells.

Finally, a reverse migration was performed in the time domain at a frequency of 40 Hz, and the data was transferred to perform the final migration. The processing graph after summation was directed to improve the stratigraphic details of the reservoir. Compared to the PDM of 2006, the latest RTM demonstrates an improvement in the image of the reservoir structure, in particular on the northern and southern wings of the main field and on the western reef structure. The occurrence of seismic stratigraphic details (clinoforms) between P0 and C1, and C1 and C9 is confirmed, and in some cases even with better images. Slope clinoforms are also evident in carbonates below C9, although they have not been particularly focused on.

### 3.2.5. Migration algorithms

The reason for the wide range of migration algorithms and their implementations is that none of them fully meets such important criteria as maintaining all slopes of reflecting boundaries, complex velocity changes, adaptation to any observation systems, reduced noise levels, while remaining cost-effective. Any migration method should include extrapolation capable of accounting for strong horizontal velocity variations and large slopes. The most commonly used migration methods include these essential elements.

Modern approaches to the construction of deep images are based on a reasonable combination of steady-state Kirchhoff migration with migration based on wave field extrapolation (Fig.3.2.13). With the increasing availability of larger and faster computers, methods other than Kirchhoff can be more widely used for migration; however, Kirchhoff migration is likely to remain relevant due to low resource intensity to evaluate the initial depth-velocity model, anticipating any other deep migration based on the wave equation.

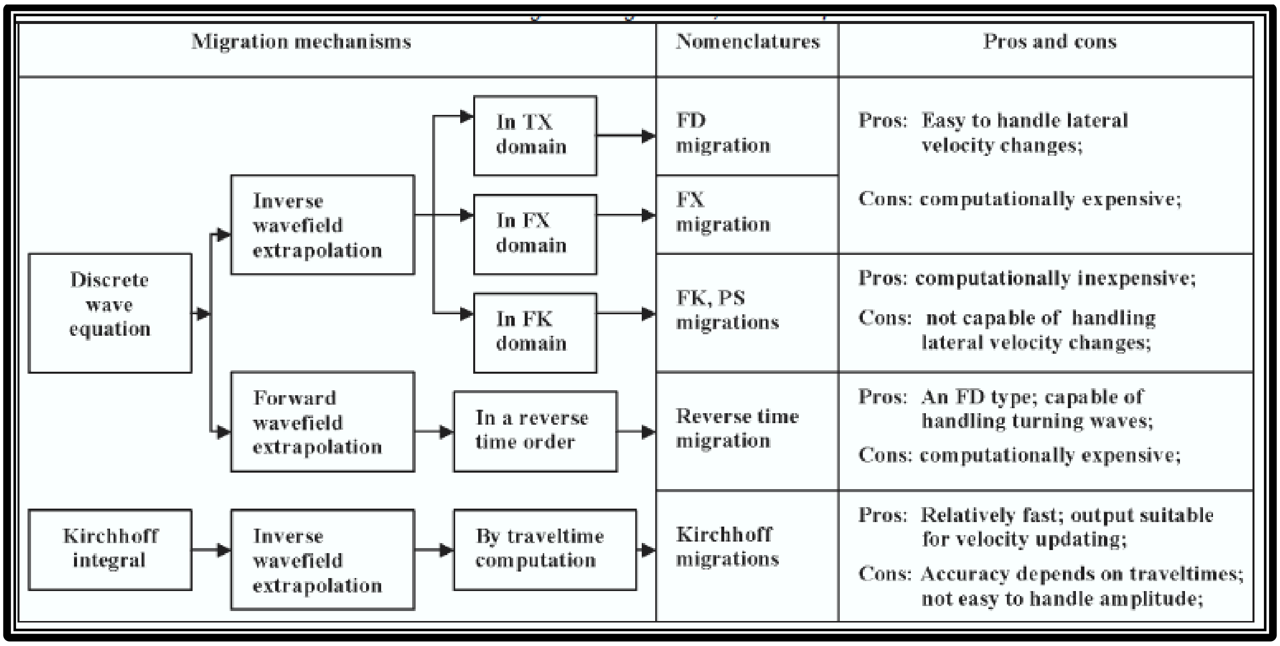



**Fig. 3.2.13. Migration methods**

There are four main categories of such methods: Kirchhoff deep migration (KMIG), one-way wave field extrapolation migration (WEM), RTM, and beam migration (BMIG). In the beginning, KMIG was the only widely available tool, although single implementations of the other three methods were used in limited numbers. Then WEM became commercially available, and in the first half of the 2000s it was recognized as the leading technology for obtaining subsalt images. The rapid adoption of the WEB in the industry was reflected in its equally rapid addition of RTM, starting around 2005. Meanwhile, BMIG was being developed in different directions of performance or accuracy (Hill 1990, Sherwood 2008), gradually becoming the preferred tool in situations where computing velocity is of paramount importance or when its nonlinear side effect reducing noise is desirable (Fig.3.2.14).

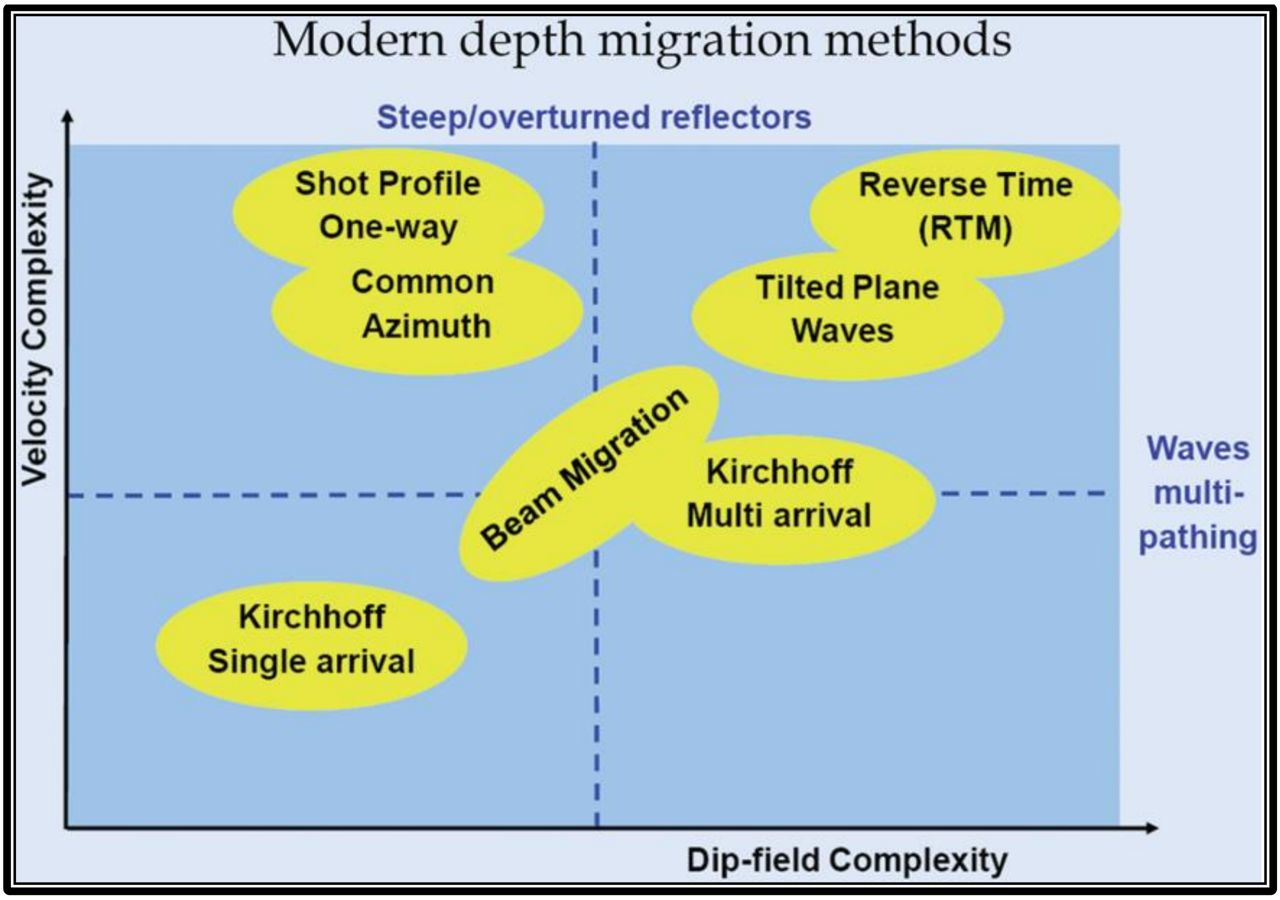



**Fig. 3.2.14. Migration algorithms**

Although these four methods seem to be very different in their functions, they are all based on the principle of visualization, which states that reflective boundaries exist at points in the medium where the entry of the descending wave coincides in time with the ascending wave. Therefore, deep migration before summation is a two-step process. First, the wave field from sources (according to CRP seismograms) and from receivers (according to CSP seismograms) continues down to all deep levels in the medium. At the same time, the expressions of one-sided wave equations for extrapolation differ in sign for the wave fields of the source and receiver. Then, at each depth, the fields descending from the source and receiver combine to create an image, in accordance with the principle noted above. The differences between these four methods are due to the different ways in which they reconstruct two wave fields in the subsurface from recorded data.

With a small additional loss of accuracy, we can make assumptions about 1) an acoustic medium and 2) a smoothly varying density (actually constant in most applications). These assumptions lead to a simplified wave equation, which is a common starting point for all four migration methods. Each approach then proceeds to apply different approximations to this wave equation to develop its own separate algorithm. Then you can add anisotropy and absorption to the image without any significant changes in the structure or characteristics of the algorithm.

### 3.2.6. Other methods of seismic imaging

Deep migration to summation and full waveform inversion technology, although they are the main directions followed by the industry, are not the only visualization methods offered by suppliers.

There are alternative approaches to visualization, which are known as "velocity-independent visualization", because they do not require the construction of an explicit velocity model, but try to directly estimate the running time of operators.

According to the standard of the CMP method, one CMP gather is stacked to obtain one time section trace, and the curvature at the point does not need to be taken into account. But if we begin to combine seismograms of neighboring points of the CMP, then we need to take into account the curvilinearity of the reflecting horizon or site. The essence of the methods of constructing seismic images before migration is to take into account the curvilinearity of reflectors when focusing (summing) reflected waves. For this, unlike the CMP method, long observation intervals (several CMP samples) are used, on which two parameters of the curved reflecting boundary are determined - slope and curvature. In addition, as in the CMP method, a constant average velocity is determined over the focusing interval. Unlike the CMP method, where one-dimensional velocity enumeration (velocity analysis) is used to construct time sections, these new methods perform a three-dimensional enumeration of the slope, curvature of the reflector and velocity (or parameters related to these characteristics of reflectors) (Fig.3.2.15). In the methods of Common Reflection Surface – CRS (Jäger, Mann, Hocht, Hubral, 2001) and Multifocusing – MF (Gelchinsky, Berkovitch, Keydar, 1999). Stronger interference suppression is carried out by focusing on large apertures, taking into account the curvature of the reflecting surfaces.

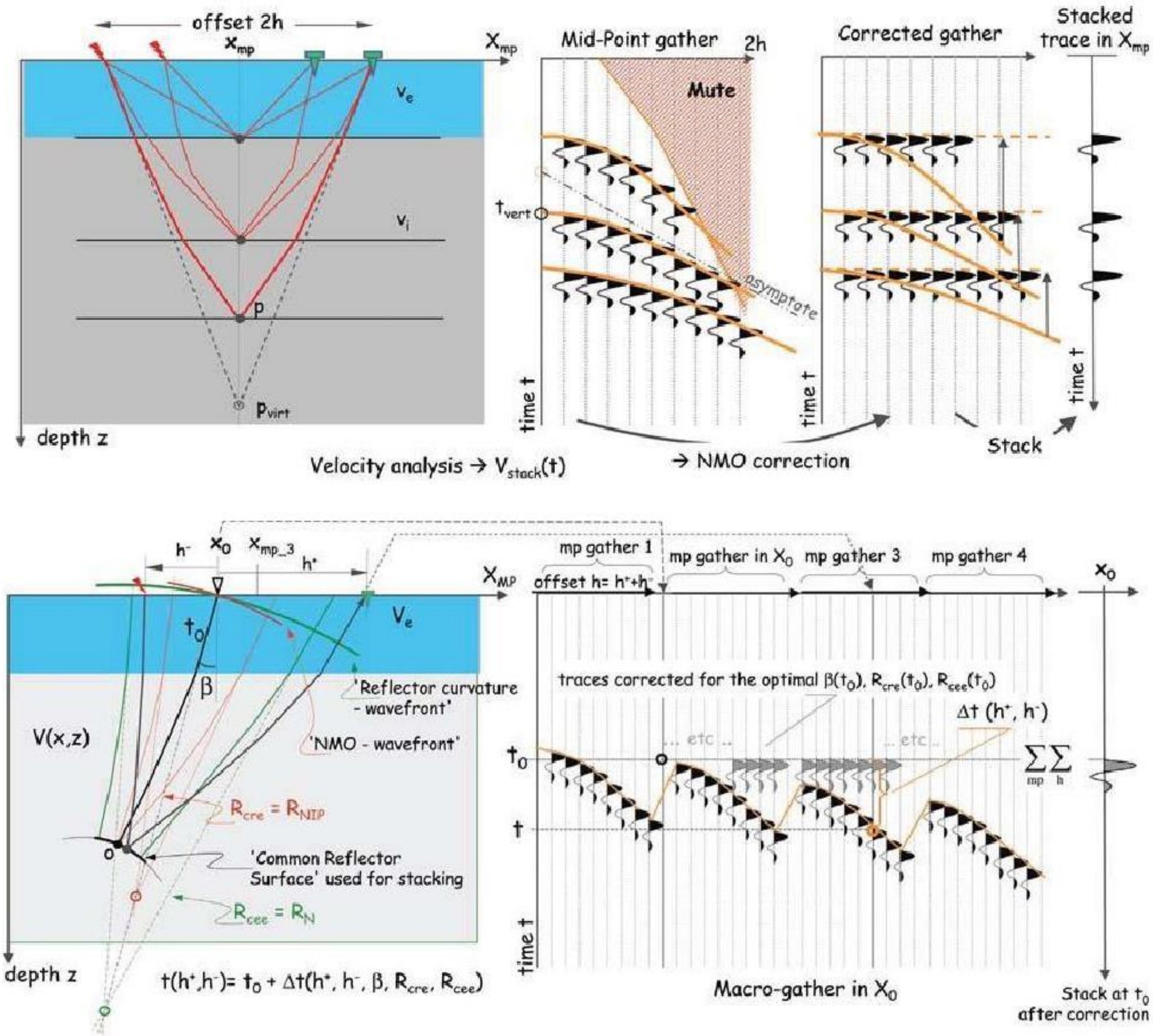



**Fig.3.2.15. Comparison of the OGT method (a) and focusing on several OGTS (b) according to [14]**

In 2D seismic exploration, three parameters are used in summation methods and the multifocusing method (flat MF) and the common reflecting area method (CRS): the radii of curvature of the normal to the reflection point, the radius of curvature of the reflector itself and the angle of approach of the wave, which is also the angle of inclination of the reflector. In 3D (spherical MF), another parameter is added – the slope of the plane containing the source, receiver and reflection point. But the formulas for expressing the kinematic correction in MF and CRS are different – the CRS formula is based on the Taylor decomposition, and in MF the time field decomposition is used, where two complex square roots are calculated.

It is noted that the planar and spherical MF is better suited for modeling the kinematic correction of diffracted waves.

The improvement in the signal-to-noise ratio resulting from this optimal coherence improvement consistent with the reflector defines these methods for applications in hard-to-reach areas where the signal is weak or data collection is sparse, for example, for outdated data or data obtained in conditions of inaccessibility.

CRS and MF create non-migrated images of zero-deletion data. Then they need to migrate. Migration after summation, whether in time or depth, may be sufficient if the image has already been optimized (Fig.3.2.16). Throughout the section of the migrated MF cube, there is a significant improvement in the quality of tracing the supporting and auxiliary reflecting horizons and a more contrasting selection of tectonic disturbances. Reflections appeared in the area of the salt dome, which are a continuation of the horizons from the mulda zone, which indicate a more complex shape of the salt dome and the presence of salt cornices. The tracing and resolution of the recording of subsalt horizons have significantly improved, including reflections characterizing the internal geological structure of the productive interval of carbonate deposits [8].

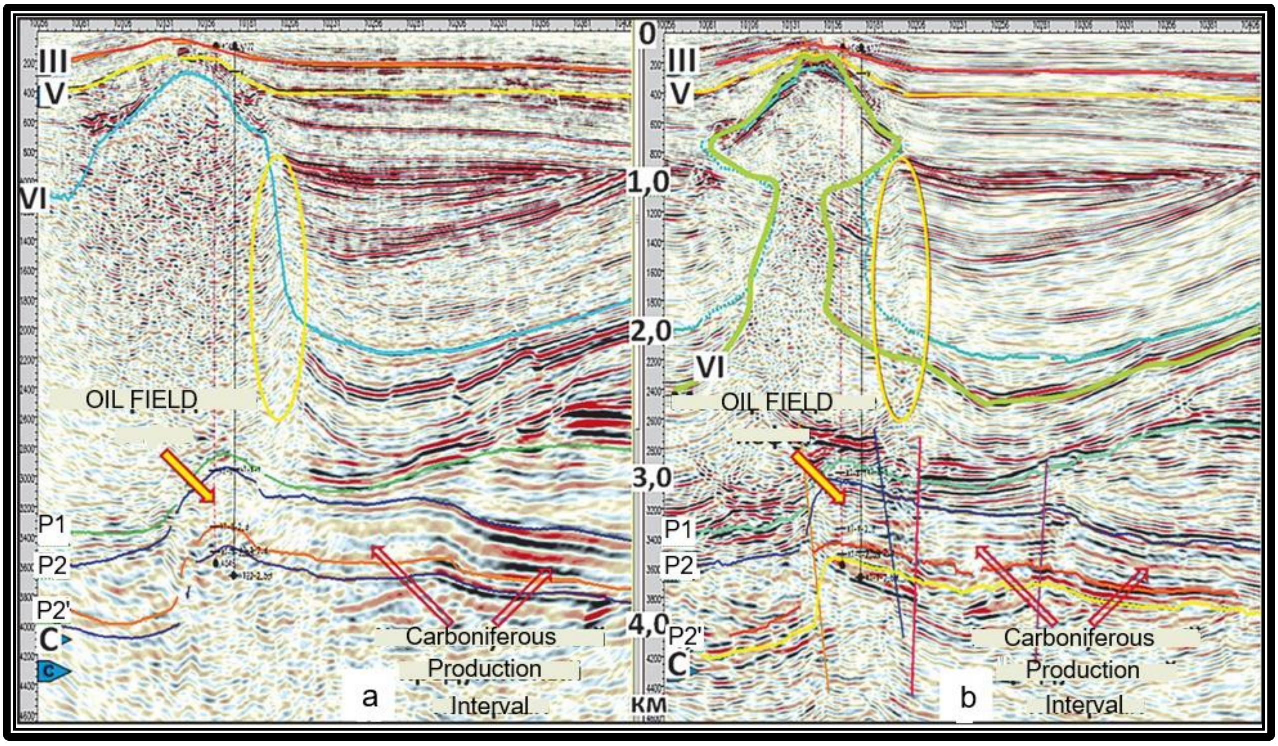



**Fig.3.2.16. Sections from cubes of migrated seismic cubes**

obtained using the standard method (a) - temporary migration before summation (PreSTM) and using multifocusing technology (b) - temporary migration after summation (PostSTM) (with the kind permission of S.M. Isenov)

In addition to CRS and MF, there are other methods of multifocusing seismic data – these are:

– double focus and common focus point (CFP, Berkhout, 1997), this method is not commercially implemented as a service,
– diffraction imaging, this method is also implemented by Geomage, the author of MF, as a diffraction multifocusing (DMF) technology, and along with MF, it is provided to subsurface users as processing services to highlight diffraction objects associated with tectonic disturbances and fracture zones. There are numerous positive examples of the application of MF and DMF technologies in Kazakhstan, carried out by Geomage KZ [26, 27],
– seismostratigraphic summation [22], (SSS, Gritsenko S.A., 2021), a relatively new method using summation bases of any length, whereas the MF method uses summation bases not exceeding a third of the Fresnel zone, and gives coherence of output data much higher than in the MF and CRS methods.

### 3.2.7. Resume

Due to the fact that complex subsalt and intrasalt objects are increasingly becoming objects of interest in exploration and production, it becomes important to ensure close integration of processing and structural interpretation in order to provide an iterative approach to salt interpretation. For the success of seismic projects in the conditions of salt tectonics, it is necessary to strive for the full integration of technologies for interpretation and construction of depth-velocity models with advanced algorithms for obtaining deep images. This leads to a more accurate interpretation, faster iterations of the tomographic inversion and thus to greater confidence in the construction of the image of subsalt objects.

Deep Migration before Summation (PreSDM) is the most accurate seismic solution for visualizing subsurface structures due to its ability to focus and position reflections in the context of strong lateral velocity fluctuations. The accuracy of the velocity model is the key to successful visualization using modern methods of constructing an interval velocity model (IVMB), since only an accurate velocity model can allow migration algorithms to properly take into account the propagation of seismic waves and the bending of the beam trajectory in the depth region. This means that the accuracy of the velocity model, in turn, is confirmed by the image quality.

Today, with the rapid development of computing power, PreSDM with IVMB are common seismic data processing procedures. In practice, these tasks are usually performed by two types of analysts: interpreters diving into the world of processing, and handlers diving into the world of interpretation.

Two migration implementation schemes are usually used. The first one considers the migration problem from a kinematic point of view, which means that ray theory is used in migration. The recorded amplitudes can be moved to their reflection points by distributing them in semicircles that represent the location of possible reflection points, or by summing them along hyperbolas whose vertices are at reflection points.

The second migration implementation scheme considers the migration problem from a dynamic point of view, which means that migration uses wave theory. The dynamic migration procedure transforms seismic data from a record on the earth's surface into data that mimics records on a number of lower source data. Each starting point is separated by a constant depth step dz (depth display) or time step dt (time display). This procedure is called reverse wave field extrapolation. For each starting point, we apply the visualization principle, according to which the smallest part (the first step) of the non-migrated dataset is actually in the correct position and does not need to be migrated. As the data is converted to consistently lower data values, the topmost part of each result is saved and combined with the others to form a migrated section.

Of the two schemes, the kinematic one is more intuitive, because using the concept of the trajectory of the beam and the wavefront; you can mentally predict the result of migration. In fact, this is the basis of the earliest migration implementations, such as Kirchhoff summation. The dynamic approach based on the wave equation is less intuitive. It consists of two stages: extrapolation of the wave field and visualization.

The terms "direct modeling" and "inversion" are familiar to geophysicists. A direct task is a task in which the model of the earth is known and data is requested. Alternatively, the inverse problem is a problem in which the data is known and a model of the earth is searched for. Seismic collection is similar to the forward task, but the seismic imaging task is actually the reverse task. We have the data, and we want to know the model of the earth, in particular the structure of the subsurface. The means of converting direct modeling are ray tracing and the wave equation. The means of inversion transformation are reverse ray tracing and migration.

# 4. CONTENTS AND RESULTS

## 4.1. THE MAIN OIL AND GAS BASINS OF KAZAKHSTAN

Sedimentary basins are actively studied using seismic exploration and drilling methods, which makes it possible to refine the geological structure and identify promising areas for hydrocarbon exploration.

### 4.1.1. The Caspian Basin

4.1.1.1. Stratigraphy

The stratigraphic section of the Caspian Basin is one of the most interesting geological structures in Eurasia. The depression is located in the southern part of the East European Platform and has a powerful sedimentary cover that reaches 15-25 km. The section is characterized by sediments of different ages and genesis — from the Precambrian to the Quaternary period.

The main stratigraphic complexes:

1. Precambrian:

Crystalline basement rocks consisting of granites, gneisses and metamorphic complexes lie at the base of the section. Riphean deposits (sandstones, shales) are found in a number of sites. These rocks practically do not participate in the oil and gas potential of the region.

2. Paleozoic (Cambrian – Permian):

Paleozoic deposits form a significant part of the section and are associated with the main oil and gas complexes:

Cambrian and Ordovician: thin- layered carbonate rocks and clay deposits.

Silurian and Devonian: represented by terrigenous and carbonate rocks, including reef complexes, which serve as good reservoirs for oil and gas.

Carboniferous period: coal-bearing and carbonate deposits are widely developed. Many oil and gas deposits have been identified within their limits.

Perm: marine carbonates, gypsum and salts, which create reliable tires for hydrocarbon deposits.

3. Mesozoic (Triassic – Cretaceous):

Terrigenous rocks (sandstones, siltstones) are found in the Triassic and Jurassic layers. It is in these deposits that productive horizons such as the Jurassic gas and gas condensate fields are located. Cretaceous deposits are mainly represented by marine sediments (clays and marls).

4. Cenozoic (Paleogene – Quaternary period):

The sediments of the Paleogene and Neogene are mainly represented by clay sediments. Quaternary sediments are formed under the influence of river and lake processes, as well as Aeolian sediments. Oil and gas content is insignificant in these horizons, but they play an important role in hydrogeology.

#### 4.1.1.2. Tectonics

The Caspian Basin is a unique geological structure in the south of Eastern Europe and the western part of Kazakhstan. It is notable for its vast depth and complex tectonic history, which plays a key role in the oil and gas geology of the region. The depression is located within the Caspian region, covering the south-west of Kazakhstan and partly Russia. Its sedimentary cover reaches a thickness of up to 25 km, which makes it one of the deepest continental-type depressions in the world.

Large tectonic units surround the depression: The Eastern European Platform in the north and west, the Mangystau massif in the east, the Caucasian and Turkmen-Elat folded zones in the south. The formation of the depression is associated with a combination of tectonic processes: sedimentary accumulation, sinking of the lithosphere and interaction with active folded zones in the south.

The depression was formed as a result of prolonged subsidence from the Paleozoic era. It is believed that the main stage of its development occurred in the Late Paleozoic — Mesozoic.

The southern and eastern parts of the region were influenced by the collision and convergence of the Eurasian and Arabian plates. This caused additional faults and uplifts, especially in the areas of contact with the Caucasus and Kopetdag.

The main faults are oriented mainly in the sub meridional and sub latitudinal directions, dividing the depression into blocks. The region has active and seismically active zones associated with plate movement and local faults, especially in the southern part, near the Caucasus.

#### 4.1.1.3. Oil and gas potential

The depression is one of the largest oil and gas basins in the world (the Caspian oil and gas basin). The deposits of the Permian, Triassic and Jurassic periods contain large reserves of oil and gas. Geological faults and folds play a key role in the formation of hydrocarbon traps.

Thus, the Caspian Basin is a complex and multicomponent tectonic region characterized by the interaction of platform and orogenic structures, which had a significant impact on the formation of its unique geological and oil and gas characteristics.

### 4.1.2. Mangystau and Ustyurt

4.1.2.1. Stratigraphy

The stratigraphic section of Mangystau and Ustyurt covers a wide time scale, including from Paleozoic to Cenozoic deposits. These regions are important from a geological point of view, as they contain oil and gas bearing structures and are the object of geological exploration.

The main features of the stratigraphy of the regions.

1. Paleozoic

The Mangystau section is mainly represented by terrigenous rocks: sandstones, siltstones, clay shales. Oil and gas horizons are found in the deposits of Devonian and Carboniferous. The Ustyurt is dominated mainly by carbonate rocks (limestones, dolomites) with terrigenous layers.

2. Mesozoic

The Mangystau Triassic is mainly represented by continental and marine sandy-clay deposits. In the Jurassic, rocks alternate with marine facies (sandstones, clays, limestones). The presence of carbonaceous layers is noted. This is a key horizon for the search for hydrocarbons. In the Cretaceous, the main sediments are represented by limestones, marls and clays, which play an important role in the formation of structural traps. Productive horizons with gas meet here.

3. Cenozoic

It includes Neogene and Quaternary sediments, dominated by continental sediments: sands, clays and pebbles formed in an arid climate. The role of Cenozoic rocks in oil and gas content is secondary.

4.1.2.2. Tectonics

The tectonics of Mangystau and Ustyurt reflect the complex history of geological processes within the western part of Kazakhstan. These territories are located at the junction of different tectonic structures, and their formation is associated with multiple stages of deformation, including Alpine and Hercynian tectonic processes.

Mangystau is a peninsula on the eastern coast of the Caspian Sea. The foundation of the region is based on platform rocks of the Hercynian fold (Paleozoic) overlain by younger sedimentary complexes. Tectonic structures are formed by a series of anticlines and synclines associated with compression and fractures. Significant tectonic movements and volcanic activity occurred in the Triassic and Jurassic, which led to the formation of bends and uplifts. Modern deformations are expressed in the form of rises and falls, which is associated with general movements in the Caspian basin region. Faults and folds indicate continued contractions against the background of Kopetdag and Karakum activity.

Ustyurt is a plateau located between the Caspian and Aral Seas. The plateau lies on a Paleozoic foundation covered with a thick layer of Mesozoic and Cenozoic sedimentary rocks. Large paleodepressions (for example, the Bozachinsky arch) have been developed in the Ustyurt region, in which sedimentary deposits have accumulated. There are large uplift and deflection zones on the plateau. Faults most often have a sub latitudinal or meridional direction. In the Cenozoic, there were changes in the level of sedimentation due to fluctuations in the level of the Aral and Caspian seas. Lifting and lowering are also controlled by movements at the borders with other platforms.

Mangystau and Ustyurt are separated by a number of fault zones, but have a common tectonic history associated with Hercynian and Mesozoic processes. Currently, they are important geological objects being investigated for the search for hydrocarbons and the study of tectonic processes that took place at the junction of the Eurasian Plate and the Turan platform.

4.1.2.3. Oil and gas potential

These regions are also of great interest to Kazakhstan's oil and gas industry. In both regions, Mesozoic deposits (especially Jurassic and Cretaceous) are the main objects for the search for hydrocarbons.

In Mangystau, oil deposits are often associated with anticline structures and tectonic disturbances.

In Ustyurt, productive horizons are also associated with traps in carbonate and terrigenous deposits.

### 4.1.3. South Turgai basin

4.1.3.1. Stratigraphy

The South Turgai basin is located in the south of Kazakhstan and is an important oil and gas province. The stratigraphic section of the basin covers from Paleozoic to Cenozoic deposits. The main structural elements include the alternation of sedimentary rocks of different ages and lithology, which creates good conditions for the formation of hydrocarbon deposits.

1. The Paleozoic (Devonian — Carboniferous) is represented by continental and marine deposits of terrigenous and carbonate rocks. The base contains metamorphic and granitoid basement rocks. There are signs of oil and gas saturation in Devonian and carbonate rocks.

2. The Triassic Jurassic is represented by continental deposits: siltstones, sandstones and clays. The Jurassic sediments contain coal-bearing horizons and promising oil deposits. The Jurassic complex also contains important oil reservoirs in the sandstones.

3. The chalk (lower and upper) is represented by sedimentary rocks of marine and continental origin: sandstones, clays and limestones. Upper Cretaceous deposits often act as tires for oil and gas deposits.

4. Paleogene — Neogene have marine and lagoon sedimentation conditions and is represented by clays, marls, less often sandstones and conglomerates. They serve as regional tires for more ancient hydrocarbon deposits.

5. Quaternary sediments are alluvial and Aeolian sands, loess, important for hydrogeological research, but do not contain hydrocarbon resources.

Oil and gas horizons

The main productive strata are Jurassic and Cretaceous deposits. The sandstones of these horizons often form porous reservoirs with good reservoir properties. The upper complexes (Cretaceous and Paleogene) act as tires, preventing the migration of hydrocarbons.

4.1.3.2. Tectonics

The South Turgai basin is of interest to geologists and geophysicists due to its complex tectonic history. These structures were formed as a result of multiple stages of deformation associated with various geodynamic processes, such as plate collisions and stretching.

The South Turgai basin is located in the southern part of Kazakhstan and was formed mainly in the Mesozoic and Cenozoic. In the Triassic and Jurassic, the basin is laid down as a depression structure in the stretching mode. At this time, precipitation of continental and shallow-water marine origin was accumulating. In the Cretaceous, the continuation of stretching leads to further lowering of the basin and the accumulation of a powerful thickness of sedimentary rocks. In the Late Cenozoic, partial uplift and erosion occurred as a result of Alpine tectonics. The formation of large faults and folds is also associated with compression at this time.

Tectonic features: Sub-latitude faults and uplifts prevail. In places, relics of rift structures are observed. Precipitation has a significant capacity (up to several thousand meters), which makes the basin promising for hydrocarbon potential.

### 4.1.4. Shu-Sarysui basin

4.1.4.1. Stratigraphy

The Shu-Sarysui basin is one of the large sedimentary basins rich in minerals such as oil and gas. The stratigraphy of this basin has a complex structure and includes sedimentary rocks of various geological periods, from the Paleozoic to the Quaternary period.

1. Paleozoic: Includes layers from Ordovician to Permian deposits. At this stage, the basin was actively developing; sedimentary rocks of marine and continental origin were formed, including limestones, dolomites and clay shales. Carbonate rocks of Paleozoic age are often the main reservoirs of hydrocarbons.

2. Mesozoic: The Mesozoic era accounts for the formation of continental-type precipitation, which is associated with the gradual uplift of the land. In the Lower and Upper Triassic, as well as in the Jurassic and Cretaceous sediments, sandstones, mudstones and coal-bearing deposits were formed. Cretaceous deposits play an important role in the oil and gas potential of the region, being both reservoirs and tires.

3. Cenozoic: Includes Paleogene and Neogene deposits. Coarse-grained sandstones and conglomerates appear in Neogene sediments, which is associated with the continental sedimentation regime. In the Quaternary period, the basin was finally formed in its modern form, with the appearance of modern alluvial and deluvial deposits.

4.1.4.2. Tectonics

The Shu-Sarysui basin is located to the south and is characterized by a more complex tectonic history. It represents a depression that has also been subjected to multiphase deformations.

The main stages of formation:

1. Paleozoic:

The basin is based on Paleozoic platform rocks, which indicates the ancient foundation of the structure.

2. Mesozoic — Cenozoic:

During this period, the pool was actively developing as a depression. The accumulation of powerful sedimentary strata occurred under conditions of both continental and shallow sedimentation.

3. Alpine orogeny (Late Cenozoic):

Deformations caused by compression lead to the formation of folds, uplifts and activation of faults. Partial tectonic uplifts also occur during this period.

Tectonic features: Characterized by alternating depressions and uplifts separated by large faults. Anticlines and synclines that are promising for oil and gas exploration are distinguished in the basin structure. The region is under the influence of Alpine folding, which led to the activation of tectonic processes in the later stages.

Both basins have significant hydrocarbon resources and are of interest for seismic and geological exploration. Their tectonic development is associated with the complex interaction of riftogenic and orogenic processes, as well as with the movements of the Eurasian and Indo-Australian plates.

### 4.1.5. Zaisan basin

4.1.5.1. Stratigraphy

The Zaisan depression, located in the eastern part of Kazakhstan, is also of interest to geologists and oil and gas explorers. The stratigraphic structure of this depression and the assessment of oil and gas potential are associated with its complex tectonic evolution and sedimentary filling.

The stratigraphic section includes sedimentary and volcanogenic rocks of various geological periods:

1. Paleozoic. At the base of the section there are sediments of Devonian and carboniferous, represented by terrigenous and carbonate rocks, as well as volcanites. At the end of the Paleozoic, the territory underwent active tectonic deformation, which led to the formation of folded structures and discharges.
2. The Mesozoic. The activation of continental sedimentation processes occurred in the Triassic and Jurassic. Continental sandstones, siltstones and clay deposits were formed, which are important as possible reservoirs. Coal-bearing strata are also present in the Jurassic, indicating favorable conditions for the accumulation of organic matter.
3. Cenozoic. In the Paleogene and Neogene, there were processes of accumulation of powerful molasses, as well as continental lake and river deposits. These rocks can also serve as reservoirs, but generally have less significant prospects compared to Mesozoic strata.

4.1.5.2. Tectonics

The Zaisan Depression is a large intermountain depression in Eastern Kazakhstan, located between Altai in the north and Tarbagatai in the south. It has a complex tectonic history, including both stretching and compression processes. The formation of the depression is associated with Paleozoic, Mesozoic and Cenozoic geodynamic events, which makes it an important object for studying structural geology and mineral prospecting.

Geological structure and tectonic evolution

1. Paleozoic (Riphean — Paleozoic)

The Zaisan depression is laid on the foundations of Paleozoic orogenic structures associated with the formation of the Kazakhstan and Altai folded belts.

In the Paleozoic, intense collision processes occurred during the accretion of microplates, which created folded structures and a system of large faults.

2. Mesozoic (Triassic — Cretaceous period)

Rifting begins in the Triassic, which led to the formation of depression zones and the laying of a sedimentary basin.

During the Mesozoic, under the conditions of the continental regime, there was an accumulation of powerful strata of terrigenous and lacustrine sediments. These sediments indicate stable sedimentation and gradual sinking of the territory.

Volcanic rocks of the Jurassic period are recorded in places, indicating episodes of crustal stretching.

3. Cenozoic (Paleogene — Quaternary period)

At a late stage (Cenozoic), the depression was influenced by Alpine tectonics associated with increased compression as a result of the collision of the Indian and Eurasian plates.

During this period, the surrounding mountain systems (Altai and Tarbagatai) were uplifted, which was accompanied by the development of faults and folded structures inside the depression. Active compression led to the formation of uplifts, anticline structures and faults within the basin.

Thus, the Zaisan depression is an intermountain depression with elements of riftogenic and orogenic processes. The depression is divided by large faults into separate blocks. Faults formed in different tectonic epochs control both sedimentation and deformation processes. Anticlinal and synclinal folds formed in the Cenozoic against the background of regional compression, some of which are promising for hydrocarbon deposits. The sedimentary rocks of the depression include terrigenous and lacustrine deposits up to 3-5 km thick, which indicates its long history of sinking and filling.

Geodynamic significance and minerals. The Zaisan depression is of interest from the point of view of oil and gas geology, since its sedimentary complexes and anticlinal structures may contain hydrocarbon traps. The depression is also promising for the extraction of coal and ore minerals. The geodynamic evolution of the region is related to the global processes of collision and stretching that occurred in Central Asia during the Paleozoic, Mesozoic and Cenozoic.

## 4.2. ASSESSMENT OF THE OIL AND GAS POTENTIAL OF THE TRIASSIC AND PALEOZOIC DEPOSITS OF KAZAKHSTAN

### 4.2.1. Triassic

Triassic deposits in Kazakhstan have a certain oil and gas potential, especially in the western and central parts of the country. These deposits were formed under difficult tectonic conditions, which created favorable conditions for the accumulation, migration and conservation of hydrocarbons. The Triassic period in Kazakhstan was characterized by a change in marine and continental sedimentation conditions. At that time, shallow marine basins and lagoons were developing, as well as lake and river sediments accumulated in coastal and marine areas. Depression zones and grabens were formed against the background of post-Paleozoic tectonic activity. The most interesting are Western Kazakhstan (the Caspian Basin) and the Southern Turgai trough. Terrigenous rocks (sandstones, siltstones, clays) prevail, which can act as collectors and tires.

- Caspian Basin: Triassic deposits are found in this basin, which may contain gas and oil deposits in traps formed by structural and lithological factors.
- The Southern Turgai trough: The region is promising for the presence of gas in Triassic sandstones, where fluidores are represented by clay layers.
- Mugojars and Tien Shan: Triassic deposits are found here in fragments, but may be of interest in a detailed study.

#### 4.2.1.1. Types of promising traps and collectors

- Structural traps: Anticlinal uplifts associated with late tectonic movements.
- Lithological traps: The transition of sandstones into clays, creating shielding conditions for fluids.
- Stratigraphic traps: Abrupt changes in the composition of rocks within the Triassic section can be favorable for the accumulation of hydrocarbons.

#### 4.2.1.2. Geophysical and geochemical data

- 2D and 3D seismic exploration: Used to identify structural traps and determine the thickness of Triassic layers.
- Gravimetry and magnetometry: Useful for mapping major depressions and areas of possible precipitation accumulation.

- Geochemical analysis: Triassic sediments may contain organic matter, but mostly of medium maturity, which is more predisposing to gas formation.

##### 4.2.1.3. Successful examples

Although most of the production in Kazakhstan is concentrated in Paleozoic sediments, some gas manifestations have been recorded in the Triassic sandstones of the Caspian Basin. These results confirm the prospects for a more detailed study of the Triassic horizons, especially at great depths.

##### 4.2.1.4. Challenges and limitations

Deep occurrence: Triassic deposits are often found at significant depths (more than 3-5 km), which increases the cost of drilling and exploration.

Tire tightness: Confirmation is needed that clay horizons can effectively retain hydrocarbons.

Average maturity of organic matter: In some areas, Triassic deposits may be less favorable for oil accumulation and more suitable for gas.

##### 4.2.1.5. Conclusions and recommendations

The Triassic deposits of Kazakhstan have moderate oil and gas potential, especially in the structural and lithological traps of the Caspian Basin and the Southern Turgai trough. The most promising areas are:

- Deep drilling in areas with structural uplifts.
- Comprehensive use of geophysical methods to clarify the nature of traps.
- Geochemical analysis to assess the maturity of organic matter and the type of possible hydrocarbons.

Continued research in Triassic sediments may open up additional reserves of gas and, to a lesser extent, oil, which will be an important contribution to the energy sector of Kazakhstan.

### 4.2.2. Paleozoic

The Paleozoic deposits of Kazakhstan are of significant interest for geological exploration and oil and gas research, due to the complex geological history of the region and the diverse types of sedimentary basins. The assessment of the prospects of these deposits includes an analysis of structural features, lithological and facies composition, tectonic evolution and the results of previous drilling operations.

Kazakhstan in the Paleozoic was at the junction of several tectonic plates, which led to the formation of a number of folded zones and platform areas. Tectonic processes contributed to the formation of various sedimentary basins in which carbonate and terrigenous deposits with potential for oil and gas accumulation accumulated.

4.2.2.1. Types of prospective deposits

Cambrian–Devonian: During this period, shelf and lagoon basins developed, where carbonate facies (limestones, dolomites) predominate, potentially being a reservoir for oil and gas.

Carbon: Coal-bearing basins developed (for example, in the Karaganda basin), as well as carbonate platforms with good reservoir properties.

Perm: More continental conditions were formed, which led to the accumulation of terrigenous rocks (sandstones and siltstones), which can act as both reservoirs and tires.

4.2.2.2. Oil and gas potential

The most promising sites in Paleozoic deposits include:

– Devonian and carboniferous carbonate reservoirs. They often have fractures that increase their capacity and permeability.
– Reef structures. Oil deposits can be found in reef development zones (especially in carboniferous).
– The sandstones of Perm. In later layers, gas accumulations occur, especially at depths where terrigenous rocks serve as a reservoir.

4.2.2.3. Examples of successful deposits

Some deposits in Western Kazakhstan, such as Tengiz and Karachaganak, contain deposits associated with Paleozoic carbonate deposits. This confirms that Paleozoic formations can be large reservoirs of hydrocarbons.

4.2.2.4. Geophysical surveys

To search for promising areas in the Paleozoic, the following are used:

– 3D seismic exploration, which allows detailed study of structural traps and facies zones;
– Gravimetry and magnetometry, useful for determining large tectonic structures;
– Geochemical analysis of core and fluids to determine the maturity level of organic matter.

4.2.2.5. Conclusions and recommendations

The Paleozoic deposits of Kazakhstan have a high potential for oil and gas exploration and development, especially in carbonate platforms and reef zones. Promising areas for further research are:

  – Development of deep horizons (deeper than 5-6 km), where there may be deposits that have not yet been explored.
  – Comprehensive geophysical studies to clarify the structure of traps and reservoir properties.

- The use of hydraulic fracturing (FRACKING) technologies to increase the productivity of fractured carbonate reservoirs.

Thus, a competent combination of exploration methods and a modern approach to development will increase the efficiency of resource development in the Paleozoic basins of Kazakhstan.

# 5. DISCUSSION

## 5.1. APPLICATION OF HIGH-DENSITY WIDE-AZIMUTH SEISMIC EXPLORATION FOR THE STUDY OF OIL AND GAS RESERVOIRS IN KAZAKHSTAN

Kazakhstan has significant oil and gas reserves concentrated in the complex geological structures of the Caspian Basin, Tengiz field, Karachaganak and Kashagan fields. Due to the high structural complexity and heterogeneity of reservoirs, the use of modern technologies, such as high-density wide-Azimuth seismic exploration (WAZ, Wide-Azimuth Seismic), is required to study them more accurately and improve production efficiency.

Advantages of high-density wide-azimuth seismic exploration

1. Increased resolution: Collecting data in many directions and azimuths allows you to get a more detailed image of the collectors.
2. Detection of rock anisotropy: Wide-azimuth seismic survey helps to identify changes in the physical properties of the rock in different directions, which may be associated with fracturing or stresses.
3. Combating multiple waves and interference: Increasing the density of sources and receivers improves the suppression of multiple waves and improves image quality.
4. Fluid saturation prediction: The use of multicomponent WAZ data makes it possible to more accurately interpret the types of fluids in the reservoir.

Application in Kazakhstan

- In Kazakhstan, the use of high-density WAZ seismic exploration is especially relevant due to: Deep and complex geological structures (for example, carbonate reefs in Tengiz and Kashagan).
- The presence of fractured collectors, which makes it difficult to use traditional 3D surveys.
- High salt content and salt domes, which create strong interference in seismic data.

Examples of successful application

1. Tengiz field: The use of WAZ made it possible to more accurately determine the boundaries of reef structures and predict fracturing.

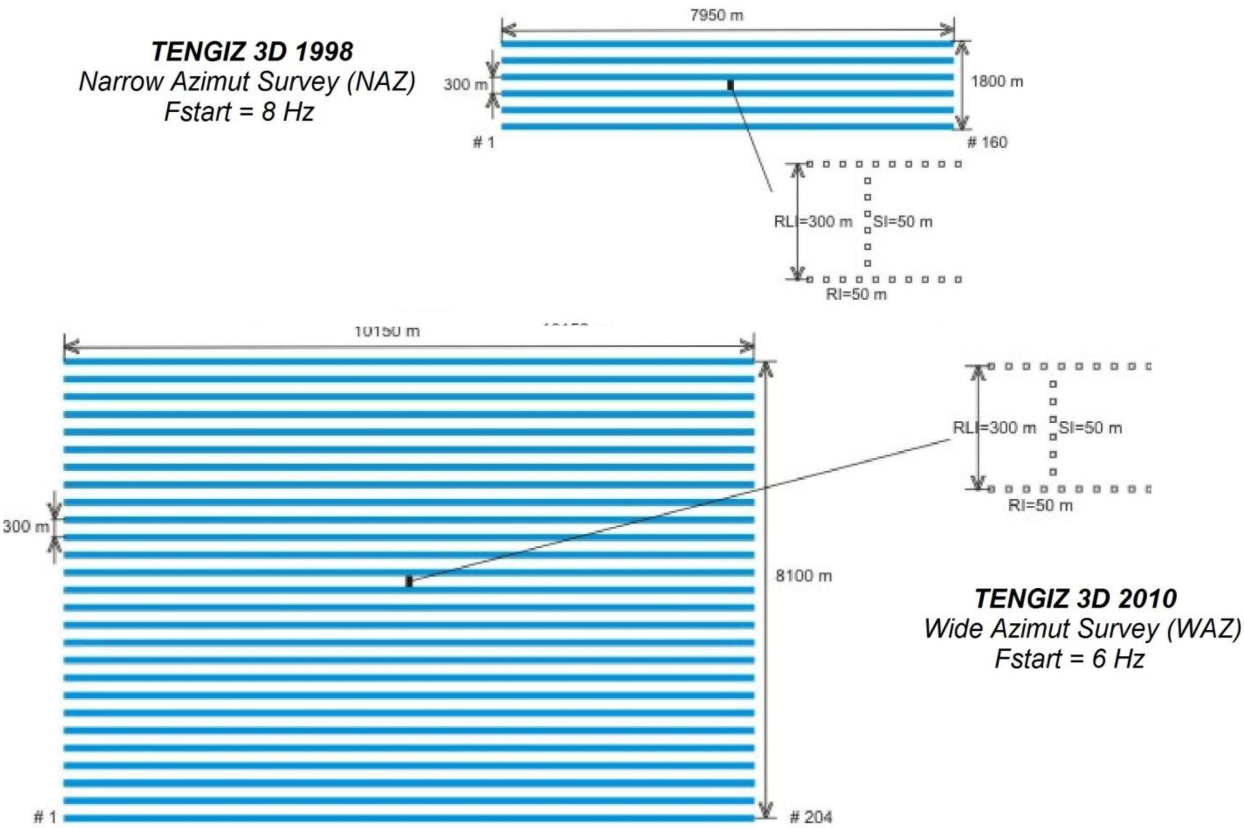



**Fig.5.1.1. Comparison of NAZ and WAZ techniques**

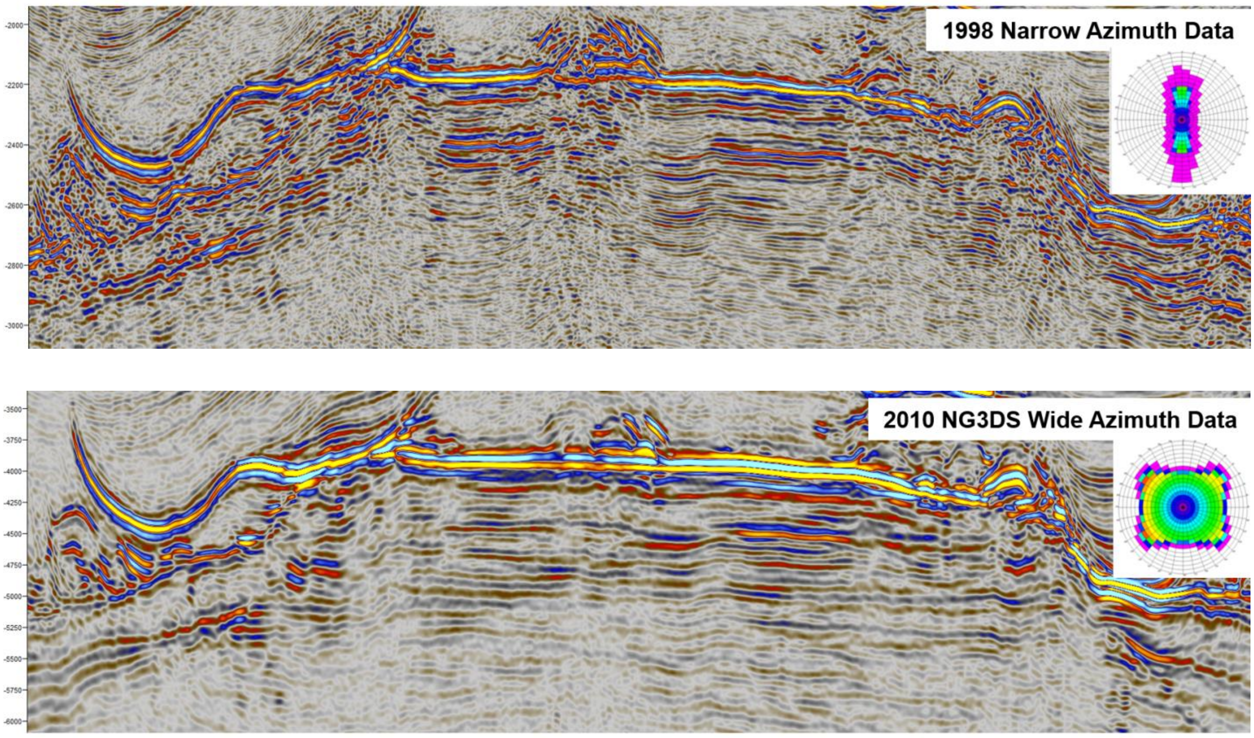



**Fig. 5.1.2. Comparison of 1998 and 2010 data**

2. Karachaganak field: High-density imaging has improved the seismic image and provided a better understanding of the anisotropy of the formation.
3. Kashagan field: The use of wide-azimuth survey contributed to the optimization of drilling and the development of a fluid saturation model.

Challenges and solutions

1. High cost: WAZ shooting requires a large amount of equipment and sources, which increases costs. Solution: Using local contractors and optimizing field work.
2. Processing large amounts of data: Huge amounts of information are generated that require complex processing. Solution: Implementation of high-performance computing systems and machine learning algorithms.
3. Environmental and logistical constraints: Conducting surveys in remote areas and protective zones. Solution: Development of safe routes and minimization of environmental impact.

Conclusion

High-density wide-azimuth seismic exploration is a promising technology for studying Kazakhstan's oil and gas reservoirs. It allows increasing the accuracy of interpretation of geological structures, optimizing production and minimizing geological risks. The introduction of this technology contributes to the effective development of complex deposits and an increase in hydrocarbon production in the region.

## 5.2. SEISMIC IMAGING IN SALT DOME TECTONICS ON THE EXAMPLE OF THE TENGIZ AND KARACHAGANAK DEPOSITS

Introduction

The Tengiz and Karachaganak deposits in Kazakhstan are characterized by complex geological conditions associated with salt dome tectonics. Salt domes and coverings distort the propagation of seismic waves, creating serious problems in constructing accurate seismic images. Modern methods of processing and interpreting seismic data make it possible to reduce the influence of these factors and improve understanding of the deep structure of reservoirs.

Geological features

1. Tengiz field:

A giant oil field in a carbonate reef with extensive salt cover.

Salt dome structures contribute to the deformation of rocks and cause severe anomalies in seismic data.

Reef carbonate platforms have fracturing and heterogeneous porosity.

2. Karachaganak field:

A gas condensate field with a deep-lying salt body.

Complex tectonics with salt leads to distortion of reflections from productive horizons and makes it difficult to build reliable seismic images.

Problems of seismic survey in conditions of salt tectonics

1. Change in wave propagation velocities: Salt has a high velocity (about 4500-5500 m/s), which leads to curvature of wave fronts and distortion of seismic data.

2. Multiple waves: Reflexes from the boundaries of salt bodies create multiple waves that degrade the image quality.

3. Shadows under salt domes: Due to the significant velocity difference, zones are formed that are poorly illuminated by seismic waves.

4. Anisotropy of the medium: The presence of cracks and inhomogeneities in carbonate formations complicates the interpretation of the data.

Methods of constructing seismic images

1. Application of wide-azimuth seismic survey (WAZ):

Collecting data on multiple azimuths allows you to compensate for distortions from domes and improves the image of subsalt structures.

The use of a wide azimuth provides a better understanding of anisotropy and the identification of fractured zones.

2. Depth migration taking into account velocities (RTM, Reverse Time Migration):

It makes it possible to build an accurate image in conditions of complex tectonics.

RTM corrects wave trajectories taking into account the complex velocity distribution and provides high image quality under salt bodies.

3. Tomographic modeling:

The velocity models obtained by tomography help to refine the velocity distribution and correct errors in the image.

Tomography also allows you to identify areas of low and high velocity under the domes.

4. Multi-wave seismic (PS-conversion):

The use of seismic waves of different types (P- and S-waves) to increase the information content of the data.

S-waves are less affected by fluids and provide additional information about the rock structure.

Examples and results

1. Tengiz:

The use of RTM and WAZ made it possible to increase the image resolution and accurately determine the fracturing of reef structures.

Subsalt traps were identified, which expanded the development potential.

2. Karachaganak:

The use of a tomographic approach and depth migration has improved the accuracy of determining gas condensate deposits.

Optimization of velocity models has reduced drilling risks.

Challenges and solutions

1. High computational costs: RTM and tomography require significant data processing resources.

Solution: Implementation of high-performance computing systems and cluster solutions.

2. Lack of velocity data: The lack of information about velocities at great depths makes it difficult to build models.

Solution: Application of calibration data from deep wells and joint inversion.

3. Effective control of multiple waves: Complex multiple reflections can mask important signals.

Solution: Using adaptive algorithms for suppressing multiple waves.

Conclusion

The construction of seismic images in the conditions of salt dome tectonics, as in the Tengiz and Karachaganak fields, requires the use of high-precision methods such as WAZ photography and deep migration. The use of advanced technologies and modeling makes it possible to overcome geological difficulties and reduce risks during drilling and development. These approaches provide a more complete understanding of the structure of subsalt reservoirs and contribute to efficient hydrocarbon production.

## 5.3. GEODYNAMIC APPROACH TO THE SEARCH FOR HYDROCARBON DEPOSITS BY SEISMIC EXPLORATION USING THE EXAMPLE OF THE MANGISTAU BASIN

Introduction

The Mangistau basin, located in the west of Kazakhstan, is one of the promising regions for hydrocarbon production. Its geological structure was formed as a result of complex geodynamic processes, including plate collision, faulting and inversion movements. In this regard, traditional seismic exploration methods are complemented by a geodynamic approach that takes into account the evolution of the basin and structure-forming processes, which increases the efficiency of searching for oil and gas deposits.

Geological and geodynamic features of the Mangistau basin

1. Tectonic evolution:

The basin was formed as a result of the interaction of the Eurasian and Turanian plates.

Stretching and formation of grabens occurred in the Mesozoic, and inversion (uplift of structures) was observed in the Late Cenozoic.

2. Complex faulting:

There are numerous deep faults dividing the basin into blocks and affecting the migration and accumulation of hydrocarbons.

Tectonic discharges and uplifts create traps of structural and stratigraphic types.

3. Reservoirs and fluid saturation:

Hydrocarbon deposits are associated with carbonate and terrigenous deposits.

Jurassic and Triassic age formations play a key role as productive horizons.

Principles of the geodynamic approach in seismic exploration

The geodynamic approach implies taking into account the dynamic evolution of the basin and the processes governing the formation of traps. This requires the use of a complex of seismic methods and modeling.

1. Integrated use of seismic data:

2D and 3D seismic surveys make it possible to identify both structural and stratigraphic traps.

The results of the interpretation of faults and tectonic disturbances associated with fluid migration are taken into account.

2. Geodynamic modeling:

Reconstruction of tectonic evolution helps to determine the periods of stretching and compression that affect the formation of traps.

Fluid migration modeling, taking into account faults and tectonic movements, helps to search for zones with a high probability of saturation with hydrocarbons.

3. Integration of geological and seismic data:

Data on the lithological composition and physical properties of rocks (for example, the velocity of P- and S-waves) allow you to create more accurate models of deposits.

The interpretation of anisotropy and fracturing helps to predict areas of increased porosity.

Application of the geodynamic approach in the Mangistau basin

1. Identification of inversion structures:

The use of deep migration (RTM) and tomographic modeling made it possible to identify inversion uplifts that play the role of anticline traps.

2. Identification of active faults and migration routes:

Seismic fault mapping helped to identify areas where fluid migration from the underlying horizons was active, which increases the likelihood of finding deposits.

3. Identification of zones of increased porosity and fracturing:

Anisotropy analysis based on WAZ survey data made it possible to predict zones of increased permeability that can serve as reservoirs for hydrocarbons.

Challenges and solutions

1. Data distortion due to complex tectonics:

Tectonic faults and uneven sedimentation make it difficult to build accurate images.

Solution: Application of multicomponent seismic and migration with a full wave field (FWI) for model correction.

2. Incomplete data on deep structures:

Deep horizons are poorly illuminated by traditional methods.

Solution: Using deep drilling and gravimetric exploration data to complement seismic models.

3. High data processing and interpretation costs:

Processing large amounts of data requires significant computing resources.

Solution: The introduction of cloud technologies and machine learning to accelerate interpretation.

Conclusion

The geodynamic approach to the search for hydrocarbons in the Mangistau basin makes it possible to increase the accuracy of the forecast of deposits, taking into account the evolution of the basin and migration processes. The combination of seismic methods, geodynamic modeling and interpretation of fault tectonics data makes it possible to detect complex traps and optimize field development.

## 5.4. USING THE EXPERIENCE OF USING DEEP SEISMIC EXPLORATION FOR STUDYING THE DEEP STRUCTURE OF THE EARTH'S CRUST IN RUSSIA

Introduction

Seismic exploration by the method of common mid points (CMP) is actively used in Russia to study the structure and properties of the Earth's crust. The CMP method, also known as CDP (Common Depth Point), allows you to obtain detailed images of deep structures of the Earth's crust and mantle at great depths. It is used not only for the search for hydrocarbons, but also for fundamental studies of tectonic processes and the structure of the earth's crust. In Russia, the CMP method has been successfully applied in various geological regions — from sedimentary basins to tectonic areas with a crystalline foundation.

The main features of the CMP method

1. Principle of operation: The method is based on multiple registration of reflected waves from the same depth point when changing the position of sources and receivers.

This increases the signal-to-noise ratio and allows you to get high-quality images at great depths.

2. Advantages of the method: The possibility of constructing detailed seismic sections of the Earth's crust. It is effective in studying complex geological objects such as folded zones and deep faults.

3. Depth coverage: The CMP method allows you to explore the Earth's crust at depths of up to 10-15 km or more. In combination with deep migration, the data can be used to map the mantle and tectonic boundaries.

Examples of the application of the CMP method in Russia

1. Barents-Kara region:

The CMP method was used to study the tectonic structure of the northern shelves. Deep faults and boundaries between the sedimentary cover and the crystalline basement were discovered. This made it possible to optimize the exploration of hydrocarbons.

2. The Ural-Mongoloid Belt and the Siberian platform:

In the Urals, the seismic survey of the CMP revealed deep tectonic faults and subduction zones of ancient plates. In the area of the Siberian Platform, the method made it possible to study fault systems and the internal structure of the lithosphere, which increased understanding of the processes of continental rifting.

3. The Caucasus and the Kola Peninsula:

In the Caucasus, CMP was used to study deep tectonics and the mutual interaction of plates under conditions of active compression. Contacts between Archean and Proterozoic crustal blocks have been identified on the Kola Peninsula, which is important for geological cartography.

Contribution to fundamental research and practical significance

1. Study of the structure of the Earth's crust and mantle: The CMP data make it possible to identify horizontal and inclined boundaries in the Earth's crust, fault zones and magmatic bodies. Information about wave velocities in the mantle and crust is used to understand geodynamic processes such as rifting and subduction.

2. Prospecting and exploration of minerals: The method is actively used in the oil and gas provinces of Russia, such as the West Siberian and Timan-Pechora basins. CMP is also used for exploration of solid minerals, including metals and minerals, on the Kola Peninsula and in Eastern Siberia.

3. Seismotectonic research and seismic safety: CMP helps to identify active faults and potentially dangerous zones, which is important for assessing seismic hazards and designing engineering structures.

Technological challenges and solutions

1. Processing large amounts of data: Seismic exploration by the CMP method requires complex data processing and interpretation.

Solution: Using cluster computing and parallel processing algorithms to velocity up work.

2. Anisotropy and heterogeneity of the environment: In areas with anisotropy and complex structures (for example, folded zones), data distortion occurs.

Solution: Using deep migration and multicomponent data to adjust the results.

3. High costs of filming and interpretation: CMP requires high costs for field work and subsequent data processing.

Solution: The use of combined methods (for example, CMP and gravimetry) to reduce costs and improve accuracy.

Conclusion

The use of the CMP method in Russia has made it possible to significantly expand knowledge about the deep structure of the Earth's crust and increase the efficiency of prospecting for hydrocarbons and solid minerals. The use of this method in combination with new data processing technologies and geodynamic models contributes to both fundamental research of tectonic processes and applied exploration tasks.

The application of advanced seismic methods in Kazakhstan is causing discussions covering both technical aspects and economic and environmental issues.

Thus, the successful application of advanced seismic methods in Kazakhstan requires an integrated approach — from choosing optimal technologies to ensuring sustainable development of the region. It is important to combine innovation, competent project management and compliance with environmental standards to achieve long-term goals in the country's oil and gas industry.

## 6. CONCLUSIONS

Conclusions

The application of advanced seismic methods at all stages — from exploration to development of oil and gas fields — in Kazakhstan demonstrates significant results and prospects:

1. Increasing the efficiency and accuracy of exploration: The introduction of 3D and 4D seismic allows you to create more detailed geological models and track changes in deposits over time, which is critically important for mature and hard-to-recover reserves.

2. Reducing risks and costs: The use of modern data processing methods and interpretation algorithms can reduce exploration errors, reduce the number of failed wells and increase the profitability of projects. This is especially true in conditions of unstable oil prices.

3. Exploration of complex geological objects: Advanced seismic methods make it possible to study deposits in complex regions more precisely, such as the Paleozoic basement, which has traditionally been difficult to mine.

4. Environmental challenges and social responsibility: Along with technological advances, it is important to take into account the impact on the environment and the need to interact with local communities. Seismic surveys must comply with international environmental standards in order to minimize their impact.

In conclusion, success in using advanced seismic techniques in Kazakhstan depends on an integrated approach that includes innovation, risk management and compliance with sustainable practices. These technologies help the country to effectively develop the oil and gas industry and adapt to the changing conditions of the global energy market.

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