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Geothermal conditions of Uzen' oil field

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Geothermal investigations of oil fields are a vital factor in understanding their geological structural characteristics and for determining the causes of anomalies in the chemistry of the waters, and of changes in the physicochemical properties of the oil. The role of geothermal investigations is increasing, particularly in connection with the development of large oil pools in which the formation pressure is to be artificially maintained by injecting surface waters. The cold water pumped into the oil beds markedly reduces the temperature in the zone of its injection and movement; under specific conditions, it may lead to segregation of paraffin crystals, which as a result of deposition in the pore channels, reduce the permeability of the rocks, the well yield, and the coefficient of oil output of the beds. Injection of cold water may have a particularly deleterious effect on the exploitation of oil horizons containing high-paraffinic oil and composed of beds with different permeabilities, leading to different rates of flow of water through them. Research connected with the development of large oil fields must therefore primarily envisage study of the natural initial geothermal background, with which all subsequent changes may be compared.

This paper gives the results of geothermal investigations of the large Uzen' oil field on the Mangyshlak peninsula. The oil pools in this field are located fairly near the surface, have a high-paraffinic character and bed temperatures very close to the crystallization point of paraffin under bed conditions. In this respect the Uzen' field is unique.

To monitor the change in the thermal field of the pools during exploitation, the VNIIneft' Institute in 1969 began a program of detailed geothermal investigations. The first stage of this work led to the establishment of the natural thermal field unaffected by exploitation.

The Uzen' field is located in a large brachyanticline, elongated in a sublatitudinal direction and complicated by a number of domes and disjunctive dislocations. The fold is asymmetric: the dip on the north slope is 3-4°, on the south slope 6-8°; amplitude reaches 330 m. The fold is located in the eastern sector of the Zhetybay-Uzen' tectonic deep, included, together with the more southernly Segendyk and Zhazgurla depressions, in the South Mangyshlak trough system.

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Within this system of troughs boreholes have revealed sedimentary formations (from Quaternary to Triassic, inclusive) with an overall thickness of 4500 m. The cross section consists largely of arenaceous-argillaceous rocks. In the core of the Karatau meganticline, located north of the Zhetybay-Uzen' deep, all the deposits of the sedimentary mantle outcrop. Middle Jurassic deposits are exposed in the dome of the Beke-Bashkuduk arch.

The area in which the field is located has a rather complex relief. The center is a plateau with absolute heights in the range 200-240 m. The closed Uzen' basin is located in the western sector (absolute heights 100-30 m), and the shallower Tungrakshin basin (minimal absolute height 132 m) in the eastern sector. Both basins have steep, precipitous sides.

The principal oil reserves are associated with Upper-Middle Jurassic rocks; the overall thickness of the productive part of the cross section exceeds 800 m. Small gas pools occur in Cretaceous horizons in the dome of the structure.

Six principal producing horizons, namely the XIII-XVIII (numbered downward) horizons, have been distinguished in this field; their depth ranges from 1050 to 1500 m. The pools are domal and their size decreases downward. Small gas caps are found in the domes of the structures in all the horizons except the XV and XVIII. The producing horizons are separated from one another by clay partings, 1-20 m thick (usually 6-10 m). The reservoirs, represented by argillaceous sandstones and siltstones, exhibit high facies variability. Up to 13 producing beds and partings are distinguished in each horizon.

The Uzen' oils contain up to 26% paraffin, the saturation temperature of the oils by paraffin being the same or much the same as the bed temperature. At 30°C on the surface, degassed Uzen' oil loses its fluidity and is converted to a viscous-plastic mass.

A change in the physicochemical properties of the oils is observed in the pools. In the zone of water-oil contacts, and in the sectors correlated with established or postulated disjunctive dislocations, the viscosity of the oil increases (from 3.6 to 11 centipoise in the beds) and the content of asphalt-resinous components also increases, with a simultaneous decrease in the gas saturation of the oils.

Since the operations in the Uzen' field

include cross-sectional intervals up to 120-140 m thick, the thermal field of each of these must be investigated both along the strike and through the thickness. Investigations of the initial temperature distribution over the cross section of productive rocks can therefore be performed only in wells which have been idle for a considerable time; these include: a) observation and piezometric wells; b) producing wells which have not been operated for some time; c) wells waiting to be brought into operation after drilling. Temperature measurements were performed at 5-10 m intervals in the producing horizons in wells of these types.

For this purpose we used mainly VNII liquid-piston-type thermographs with local temperature recording. The thermographs were calibrated in a piezometric well, in which preliminary repeated temperature measurements were performed by maximal thermometers, calibrated in the laboratory.

To monitor the operation of the thermograph, a maximal thermometer was simultaneously lowered into the wells; this enabled us to check the functioning of the thermograph from readings at the end point of the measurements. This procedure ensured a measurement accuracy of ± 2°C. More than 100 wells were investigated and temperature measurements were made at 3500 points.

Figure 1 shows the geothermal cross section of the central sector of the field. From the boundaries of the neutral layer, located at a depth of 40-45 m, the bed temperature increases from 18 to 92° at a depth of 2020 m. The nonuniformity of the temperature increase with depth is reflected fairly clearly by the change in the geothermal steps in the individual intervals of the cross section. The abrupt geothermal steps usually occur at the boundaries of the stratigraphic or lithological complexes.

The mean magnitude of a geothermal step is 26.2 m/°C. High steps (40 m/°C) correspond to Eocene and Upper Cretaceous calcareous marls. In the Cenomanian and Upper Albian arenaceous-argillaceous rocks, it decreases to 33 m/°C. Higher up in the cross section, as far as the bottom of the Hauterivian stage, the geothermal step shows little change (from 23 to 25 m/°C), but increases to 40 m/°C in the Valanginian sandstones. The Oxfordian-Callovian clay marls have the lowest step (20 m/°C). The step then increases with depth: to 23 m/°C at the boundary of the Callovian and Bathonian stages, to 27 m/°C at the boundary between the XVII and XVIII horizons, and to 40 m/°C in the lower sector of the XXIV horizon.

The basic features of the isothermal surfaces reflect the depth structure of the fold, as may be readily seen in the geological-geothermal cross section (fig. 2).

Principal attention was devoted to an investigation of the geothermal conditions in the productive oil horizons. In the range of the XIII-XVIII horizons the temperature varies from 53.5° to 72°C; the Uzen' field was therefore classed as a region with elevated abyssal temperatures.

The geothermograms of all the wells are basically similar. The change in the rate of temperature increase is very small, as may be seen from the mean values of the geothermal step (see table).

The mean value of the geothermal gradient for all the horizons is 4.25° per 100 m, the mean geothermal step is 23.5 m/°C. However, a detailed analysis showed that from several features (general appearance, slopes, distinctive changes in the geothermal parameters from one seam to another, etc.), the geothermograms of the wells may be placed in four groups, characteristic of specific zones of the field (fig. 3).

Wells located in the Central dome are included in the first group. The geothermograms recorded in these wells exhibit a virtually linear increase in temperature with depth. The deviation of the temperature for the individual partings from the mean straight line does not exceed (±) 0.1-0.2° and is due to the difference in the thermal conductivities of the rocks (sandstones and clays) composing the cross section. Lesser slopes are displayed by the sector correlated with horizon XIII and the upper part of horizon XIV, i.e., with rocks of the Callovian stage. At a distance of 15-20 m from the top of horizon XIV, the slope of the geothermograms begins to increase gradually with depth. This change is accompanied by a change in the value of the geothermal step: minimal values (21.4 m/°C) are observed for horizon XIII, and maximal values (24.4 m/°C) for horizon XVII.

The second group includes wells located west of the Central dome, up to the boundaries of the Uzen' basin. The geothermograms of these wells exhibit an abrupt change in temperature in the upper sector of horizon XV. The sharpest change (up to 1°) is observed in the axis of the fold. Toward the boundaries of the zone, the amplitude of the fold decreases to 0.5° or less. The geothermal step is minimal (15 m/°C in the range of horizon XV). The sectors of the temperature distribution curve above and below horizon XV are usually nearly linear and have virtually equal geothermal steps (22.6-23.4 m/°C).

Wells of the Uzen' basin come within the third group. In this part of the field, the cross section of horizons XIII and XIV exhibits thick sandstone bands, usually possessing higher thermal conductivities than clays. Furthermore, the hydrogeological factor apparently has an effect on the temperature conditions of this sector.

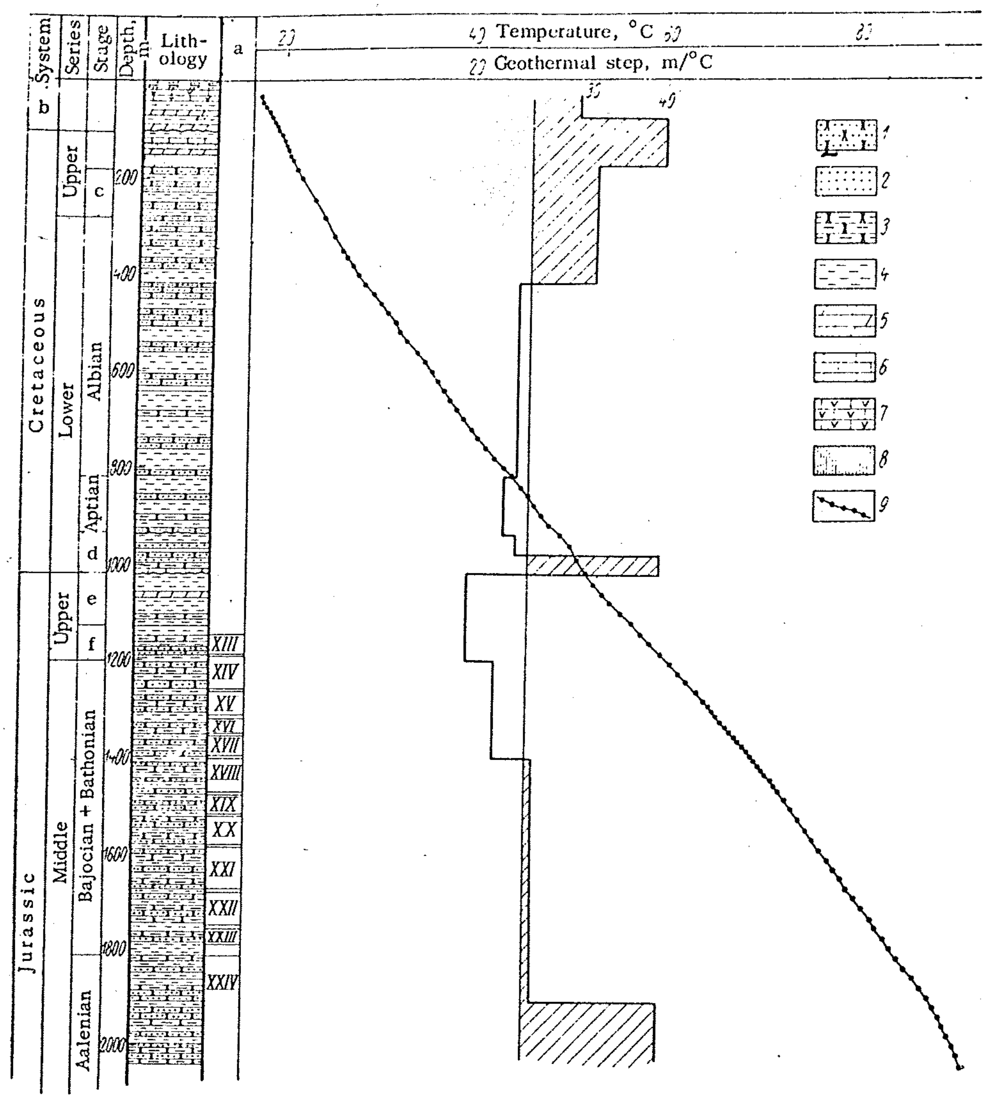

FIGURE 1. Geothermal cross section of central sector of the Uzen' field.

a - Productive horizon
b - Tertiary and Quaternary
c - Cenomanian
d - Barremian Hauterivian Valanginian
e - Oxfordian
f - Callovian

1 - sandstone
2 - sand
3 - siltstone
4 - clay
5 - marl
6 - limestone
7 - shell-limestone
8 - chalk
9 - geothermogram

For these reasons the corresponding geothermograms have a complex configuration. The mean value of the geothermal steps for this group increases with depth from 22.6 to 25.4 m/°C.

The fourth group includes wells located along disjunctive dislocations in the northwest sector of the Central dome, and certain wells in the region of the Khumurun dome. The change in temperature with depth in these sectors is virtually linear, but the geothermal steps reach 31 m/°C. From the temperature curves recorded in neighboring wells, the geothermograms in the fourth group of wells deviate toward lower temperatures as one goes down the cross section.

The temperature of the top of horizon XIII (fig. 4), for which we have most data, varies from 53.3°C in the center of the Uzen' basin to 68°C in the south flank of the structure.

Broadly speaking, the strike of the isotherms

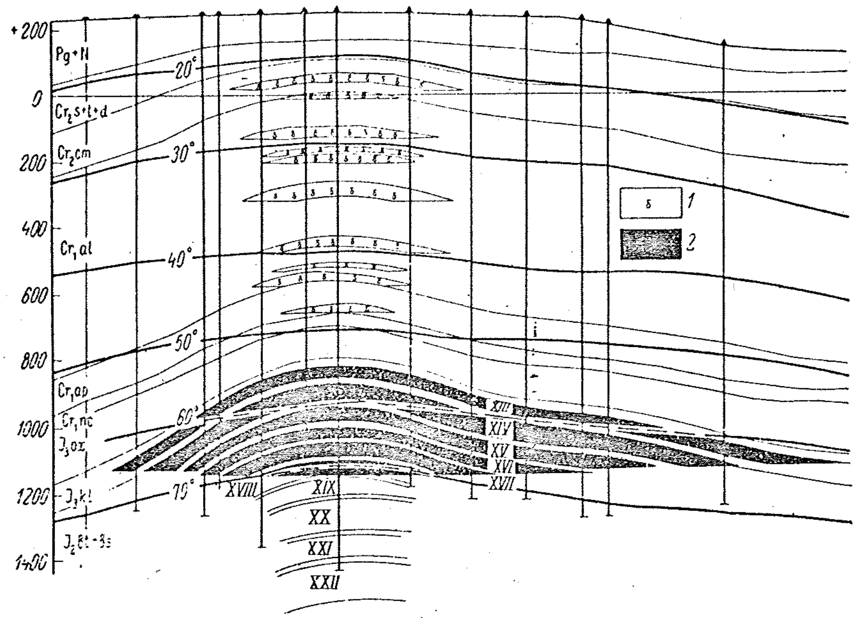

FIGURE 2. Geological-geothermal cross section I-I of the Uzen' field (see fig. 4).

Pools: 1 - gas 2 - oil

Horizon	Geothermal gradient, °C/100 m	Geothermal step, m/°C
XIII	4.52	22.1
XIV	4.22	23.7
XV	4.33	23.1
XVI	4.13	24.2
XVII	4.08	24.5

coincides with that of the contour lines of the top of the horizon. This pattern is traced most clearly in the Central dome. The crown of the dome has a temperature of about 55°. The temperature increases with the depth of the beds, the increase being particularly rapid in the southeast of the structure. To the north and west of the Central dome, as one approaches the Uzen' basin, the temperature increase is somewhat slower; here the isotherms are less distinct than the structure contours. As a consequence the temperature difference between the pool outline and the dome of the structure is 10-13° in the southeast, and 5° in the remainder of the field. The marked change in the topography at the boundary of the plateau and the basin greatly suppresses the effect of the structural factor on the thermal field of this oil field. For this reason the isotherms do not completely reflect the west pericline of the Khumurun dome, located in the flank of the Uzen' basin, whereas the east pericline, located in the plateau, is defined fairly clearly by the curvature of the isotherms.

If one excludes the effect of relief by introducing corresponding temperature corrections for the difference in the altitudes of the wells on the plateau and in the basin, the entire Khumurun dome is clearly outlined by the isotherms.

In the center of the basin, where the relief is less complex, the structural factor is again clearly manifested. Here the isotherms mainly reiterate the outlines of the structure contours, and the Parsamurun dome is reflected by the temperature minimum.

The thermal field in the north flank of the structure has the most complex structure. Here several positive and negative anomalous sectors are distinguished against a background of an increase in temperature with the depth of the top of the horizon.

All the principal features observed for horizon XIII are retained in the underlying rocks.

Elucidation of the causes of formation of the thermal anomalies of the north flank revealed that they coincide with the hydrochemical anomalies.

In both the Jurassic and Cretaceous

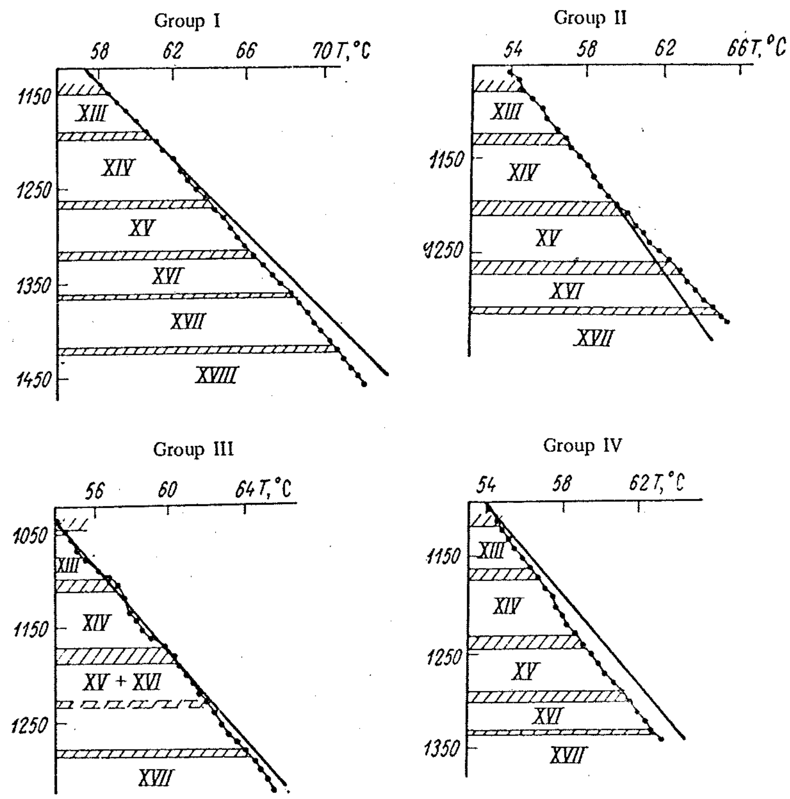

FIGURE 3. Types of thermograms for the Uzen' field (Roman numerals denote productive horizons).

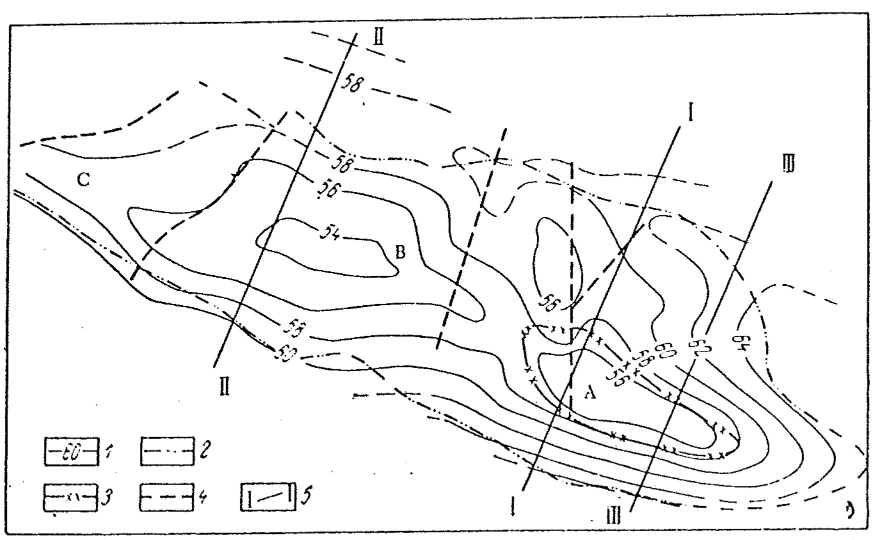

FIGURE 4. Map of isotherms at top of horizon XIII (Uzen' field).

1 - isotherms, °C
2 - outer oil pool outline of horizon XIII
3 - inner oil pool outline of horizon XVII
4 - lines of established and postulated disjunctive dislocations
5 - profile lines

Domes: A - Central B - Khumurun C - Parsamurun

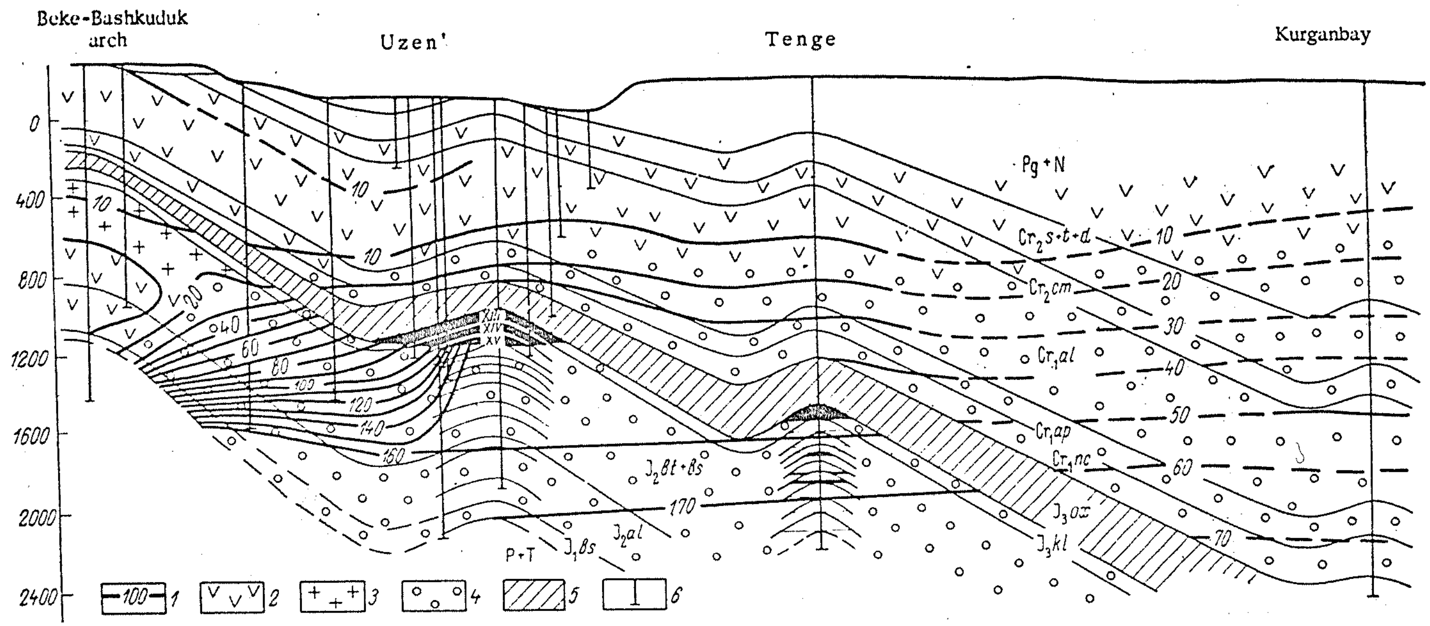

FIGURE 5. Hydrogeological cross section II-II of the South Mangyshlak artesian basin (see fig. 4).

1 - isolines of equal mineralization, g/lit

Types of water:
2 - sodium sulfate
3 - sodium hydrocarbonate
4 - calcium chloride
5 - principal confining bed
6 - wells

hydrogeological stages, investigations have established the existence of recent infiltration conditions, the water flowing away from the intake area of Gornyy Mangyshlak and the Beke-Bashkuduk arch toward the south-southeast.[1] Within the limits of Gornyy Mangyshlak and the Beke-Bashkuduk arch, which frame the South Mangyshlak basin on the north, one finds fresh or slightly salty waters of the sodium hydrocarbonate type (V. A. Sulin).

Southeast of the infiltration regions, mineralization and metamorphism of the stratal waters increase and the water is now of the magnesium chloride or calcium chloride type; the oxidizing conditions are replaced by reducing conditions, the gas saturation of the waters increases and their heads decrease (fig. 5).

Toward the south-southeast, against the background of increasing mineralization of the stratal waters and their increasing gas saturation, the Jurassic and Cretaceous rocks exhibit narrow zones of southward penetration of waters with reduced mineralization and gas saturation. Several of these anomalous zones have been revealed in the Uzen' field.

The localization characteristics of the anomalous zones and the marked extension of the latter toward the south are attributable to the greater permeability (fracturing) of the rocks in certain sectors of South Mangyshlak. These sectors apparently appeared during formation of uplifts, particularly before the Tortonian period, when intense movements of the basement led to the formation of practically the present-day structural plan of the region within which the Uzen' field is located.[2] The great amplitude of the movements in a relatively small area (the distance between the center of the Uzen' uplift and Karamandybas is not more than 20-25 km, and between Uzen' and Zhetybay not more than 50-60 km) led to the appearance of tensile forces throughout the Mesozoic sedimentary strata and

[1] Gattenberger, Yu.P., V.A. Lutkov, and V.V. Yagodin, HYDROGEOLOGY OF THE UZEN' FIELD. Geologiya Nefti i Gaza, no. 3, 1967.

[2] Chakabayev, S.Ye. et al., Geologiya i neftegazonosnost' Yuzhnogo Mangyshlaka (GEOLOGY AND OIL-AND-GAS BEARING CHARACTERISTICS OF SOUTH MANGYSHLAK): Izd-vo Nauka, Alma-Ata, 1967.

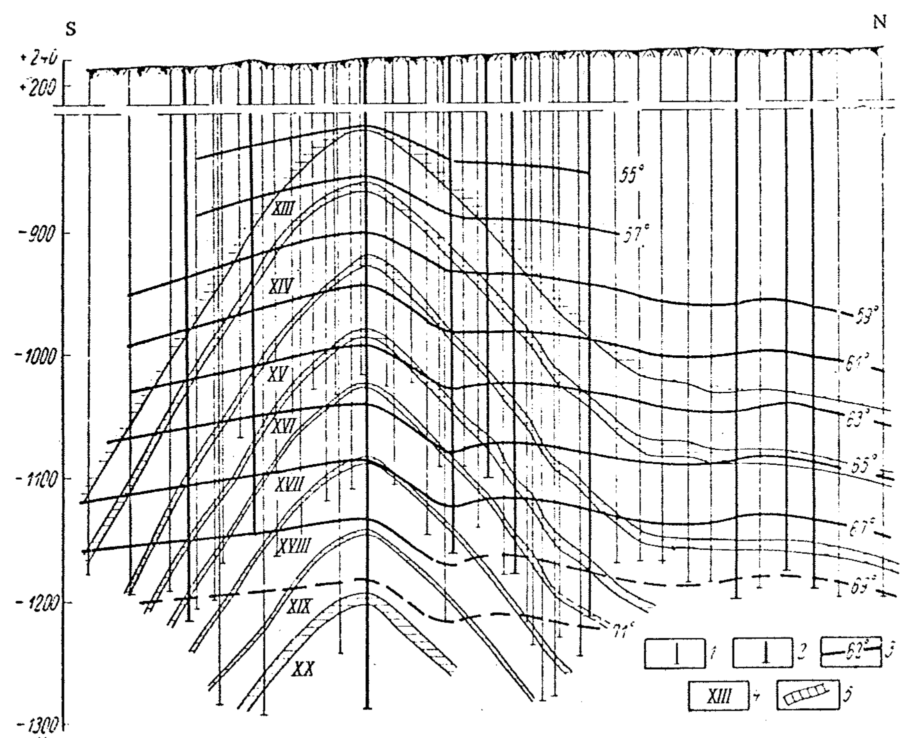

FIGURE 6. Geological-geothermal cross section III-III of the Uzen' oil field (see fig. 4).

Wells:
1 - drilled
2 - investigated drilled wells
3 - geotherms, °C
4 - productive horizons
5 - clay partings between productive horizons

therefore to the formation of fissured zones, and perhaps faults, across the strike of the structures.

The appearance of fissure systems created favorable conditions for the movement of water from the infiltration areas into the heart of the basin.

It is characteristic that above the anomalous zones, closed basins of the Uzen' and Karagiye type are usually located on the surface. This coincidence is evidently not mere chance: the basins were formed under the effect of erosion processes at the sites of appearance of "weakened" zones.

According to L. N. Yefremova, cores with signs of landslides were obtained when wells were sunk through Jurassic rocks in the center of the Uzen' basin. A number of the rock specimens exhibit stratification at an angle of 45-85° and signs of leaching. Similar rocks were also found in wells between the Khumurun and Central domes.

The "weakened" fissured sectors were the principal paths of preferential movement of the less mineralized waters from the north to the dome of the fold, where the oil pools are located. These waters oxidized the oils near the fissured zones; this is indicated in particular by the results of investigations of certain wells where influxes of water with a high content of a black bituminous deposit and an odor of hydrogen sulfide were recorded.

The rather immobile oxidized oil blocked the pore channels, thus cutting the path by which the oil flowed from the periclinal sectors of the structure to its arch. This prevented "straightening" of the oil pools and formation of a single water-oil contact, so that the water-oil contact now occupies a stagewise position over the cross section.

The formation mechanism of the thermal anomalies is apparently as follows. As the stratal waters pass through the trough separating the Uzen' structure from the Beke-Bashkuduk arch, they are heated to a temperature somewhat greater than in the dome of the Uzen' uplift (the difference between the height marks in the dome of the uplift and the axis of the trough is 200-250 m). Within the Uzen' structure the hot stratal waters give up their heat to the surrounding rocks, maximal heat transfer occurring in the zone of fissured rocks. The appearance of zones with a negative thermal anomaly is due to the fact that in the case in question the waters are introduced into areas where the bed temperatures are higher than in the axis of the trough, with the result that the rocks are cooled.

The presence of a cooled zone in this oil field is readily seen from the geological-geothermal cross section (fig. 6), constructed from injection wells of series II. In the northern part of the profile the isotherms are almost parallel to the boundaries of the horizons. As the isotherms approach the axis of the fold they bend, but rise sharply only much farther south than the structural bend of the strata.

Thus our investigations have made it possible to establish for the first time in the operation of large fields with an extensive oil-bearing level the initial natural geothermal background of the oil pools correlated with the Uzen' uplift and to reveal the complex pattern of change of the thermal field with the structural factor of the topography and hydrogeological conditions. The correlation of the geothermal anomalies with tectonically weakened sectors may be used as a characteristic feature for tracing zones of intenser fracturing, disjunctive dislocations, and other complications, a knowledge of which will help to reveal the formation conditions of oil pools and to operate the latter efficiently.

IGR/cm