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. Akad. Nauk, 100,

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GEOCHEMISTRY

THERMODYNAMIC FACTORS RESPONSIBLE FOR SPATIAL SEPARATION OF PETROLEUM AND GAS DEPOSITS IN WESTERN SIBERIA[1]

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(Presented by Academician A.A. Trofimuk, February 3, 1971)

It has been known for some time that in the West Siberian petroliferous province the hydrocarbon deposits are zoned, petroleum occurring in some zones, and gas and condensate in others [3]. This zoning has been ascribed to segregation of hydrocarbons during their lateral migration in water-soluble form [illegible] to the nature of the primary organic matter [9, 12], and to the effect of various other factors, including composition and structure of the basement rocks [13].

Recently, Dobryanskiy [5, 6], and following them, some other foreign and Soviet investigators have demonstrated that the phases present in various hydrocarbon deposits are strongly influenced by thermodynamic conditions [2, 8-11, 14]. Some of these publications, notably [illegible], 11, 14] have also discussed the petroleum and gas deposits of Western Siberia from this point of view.

Because of the recent extensive exploration of the West Siberian province, including investigation of deeply buried Jurassic to Valanginian beds in its northern part, the discovery of geothermal anomalies, and accumulation of other new data, we can now examine this problem in greater detail.

Data on the thermodynamic conditions in more than 250 reservoirs are summarized in the diagram of Fig. 1, which shows an almost linear relation between the aggregation of the deposits and temperature and pressure. In most of the reservoirs the temperature ranges from 13 to 130°C, and the pressure from 65 to 240 atm. There is a definite division between predominantly gas and predominantly petroliferous deposits. The deposits exhibit conditions described by the lower half of the diagram, that is, temperatures from 13 to 70°C and pressures from 65 to 190 atm, while petroleum fields are described by the upper half of the diagram, that is the 50 to 130°C and 150 to 290 atm region.

There is, therefore, a definite differentiation of hydrocarbon deposits depending on thermodynamic conditions, but the boundary between the two regions is not sharp.

The diagram also describes a transitional zone in which both gas and petroleum fields, as well as petroleum deposits capped by gas (3 percent of all deposits in the zone) can be found. This zone with temperatures of 50 to 70°C and pressures of 155 to 190 atm. overlaps the upper part of the gas zone and the lower part of the petroleum zone.

The petroleum region shown on the diagram contains, besides the zone of coexistence of petroleum and gas deposits (just mentioned), two other subzones, namely a central subzone,

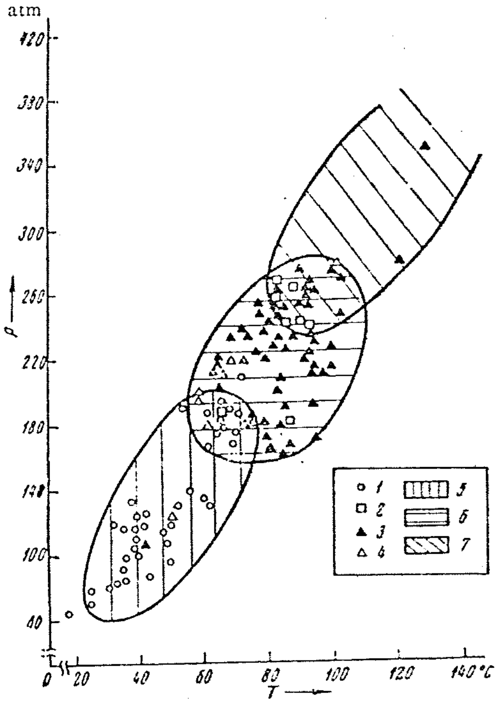

Fig. 1. Thermodynamic conditions in various petroliferous deposits. 1) - gas deposits, 2) - condensate deposits, 3) - petroleum deposits, 4) - petroleum deposits with gas caps, 5 - 7) - zones of predominance of gas (5), petroleum (6), and light petroleum and condensate (7) deposits.

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[1] Translated from: Termodinamicheskiye faktory differentsial nogo razmeshcheniya neftyanykh i gazovykh zalezhey Zapadnoy Sibiri. Doklady Akademii Nauk SSSR, 1972, Vol. 203, No. 2, pp. 453 - 455.

comprising oils with normal specific gravity, and an upper subzone of light oils and condensates. The central subzone exhibits temperatures of 55 and 100°C and pressures of 150 to 240 atm. The upper subzone (of light oils and condensates) exhibits temperatures of 80 to 130°C and pressures of 220 to 290 atm. It is transitional to the zone of condensate and gas fields, exhibiting still higher temperatures and pressures.

The diagram does not show which of the two factors, temperature or pressure, is the controlling one, for both are functions of depth. According to Kontorovich et al.[9], in the 1500 to 3000 m depth range, pressure has no noticeable effect on metamorphism of organic matter, so the principal factor must be temperature. Nalivkin, Yevseyev et al. [14] are even more definite on this point. Using the data of Landes, A.I. Bogomolov, and K.I. Panina, they state that temperature is the factor controlling not only the kind and quantity of petroleum hydrocarbons being formed but also controls their later transformations during subsidence of the reservoirs.

The data on the Salymol petroleum field are important in connection with this problem. Here petroleum reservoirs with anomalously high pressure occur in intensively fractured bituminous argillites of the Bazhenovo suite (bed Yu_0). The productive zone is best developed on the Salyma area, where gushers (wells Nos. 12, 18, 24, 27P) discharge 150 to 800 m^3 of oil/day. The reservoir pressures range from 421 to 426 atm, and the temperatures from 128 to 132°C. On the diagram this deposit is represented by a highly anomalous point with pressures 150 to 180 atm higher than normal. However, the petroleum from this field is normal, with specific gravity of 0.825 g/cm^3, tar and asphaltene content of 2.5 percent, 3.9 percent paraffins, and 0.24 percent sulfur. This petroleum has undergone little transformation during subsidence of the reservoir.

The relatively insignificant effect of pressure on petroleum alteration at depth is also indicated by the data of Anikiyev [1], who shows that petroleum fields exist in eastern Ciscaucasus and Western Pakistan at bed pressures of 450 to 500 atm., at 570 atm in northern Iran, and as much as 888 atm in Louisiana. Since the petroleum in these fields exists at the relatively low depths of 1600 to 1900 m, we can assume that temperatures are relatively low, the result being a relatively low degree of catagenesis.

The predominant effect of temperature on transformation of petroleum in reservoirs is proved by the presence in the southeastern part of the West Siberian plate of a group of condensate fields in Jurassic beds (group Yu) of the Pudino dome and Sredne-Vasyuganskiy swell. These large upwarps lie in a zone of a weak positive temperature anomaly (geothermal gradient of 4.0 to 4.5°C per 100 m, bed temperatures of 100 to 110°C), and the condensate deposits must have formed from petroleum by heat-assisted catalysis, as has been suggested by several investigators. The presence of oil fringes in many of these gas reservoirs (Luginetskoye, Myl'dzhinskoye, Verkhne-Salatskoye, etc.) confirms this view.

However, the decrease of reservoir pressure is among the most important factors in formation of gas deposits and gas caps. Conversely, increase of pressure may cause solution of gas in petroleum or in water and thus change the aggregation of matter in the deposit. But increase of pressure has practically no effect on petroleum deposits.

One more conclusion follows from examination of Fig. 1. According to new data, the temperature in the lower zones of the sedimentary mantle in the northern part of the West Siberian plate, at depths of 6 to 7 km, should not exceed 110 to 130°C, because the geothermal gradient in this region (according to the few available measurements) ranges from 2.0 to 2.5°C per 100 m, i.e., it is 1.5 to 2 times lower than in the central and southern parts of the plate. Such temperatures are found in many deposits of normal petroleum, and on the diagram they would be found in the region of petroleum deposits. For this reason, we consider as somewhat premature the conclusion of Nalivkin and his colleagues [14] that the Jurassic strata of the northern part of Western Siberia should contain mainly gas deposits, fewer condensate deposits, and still fewer light petroleum fields.

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REFERENCES

1. Anikiyev, K.A. Tr. Vsesoyuzn. neft. n.-i. geol.-razv. inst., No. 233, 1964.
2. Buyalov, N.I. and E.V. Zakharov. Neftegaz. geol. i geofiz., No. 11, 1970.
3. Gurari, F.G., V.P. Kazarinov et al. Geologiya i neftegazonosnost' Zapadno-Sibirskoy nizmennosti - novoy neftyanoy bazy SSSR (Geology and Petroleum and Gas Reserves of the West Siberian Plain, The New Petroliferous Province of the USSR). Novosibirsk, 1963.
4. Gurari, F.G. Tr. Sib. n.-i. inst. geol., geofiz. i min. syr'ya, No. 47, 1966.
5. Dobryanskiy, A.F. Geokhimiya nefti (Geochemistry of Petroleum). Moscow-Leningrad, 1948.
6. Dobryanskiy, A.F. Khimiya nefti (Chemistry of Petroleum). Leningrad, 1961.
7. Yerofeyev, V.F. Sov. geol., No. 11, 1970.
8. Kortsenshteyn, V.N. Tez. k simpoziumu: Gidrogeologicheskiye kriterii otsenki perspektiv neftegazonosnosti Russkoy platformy (Abstracts for Symposium: Hydrogeologic Criteria for Evaluating Petroleum and Gas Reserves on the Russian Platform), Minsk, 1969.
9. Kontorovich, A.E., N.
Nefteproizvodyashchiy
iya obrazovaniya nefti
otlozheniyakh Zapadno
mennosti (Petroliferou
ditions of Formation o
Mesozoic Deposits of
Plain). Moscow, 1967
10. Landes, K.K. Bull. A
Geologists, 51, 6, 196

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Vol. 203, No. 3, pp. 685 -

Kontorovich, A.E., N.M. Babina et al. Nefteproizvodyashchiye tolshchi i usloviya obrazovaniya nefti v mezozoyskikh otlozheniyakh Zapadno-Sibirskoy nozmennosti (Petroliferous Strata and Conditions of Formation of Petroleum in the Mesozoic Deposits of the West Siberian Plain). Moscow, 1967.

Landes, K.K. Bull. Am. Assoc. Petrol. Geologists, 51, 6, 1967.

11. Lindtrop, N.T. N.-i. Vsesoyuzn. inst. ekon. min. syr'ya, otd. nauchnotekhnich. inform., ser. geol., No. 3, 1969.
12. Nesterov, I.I. Tr. Zap.-Sib. n.-i. geol.-razv. neft. inst., No. 15, 1969.
13. Nikonov, V.F. In: Genezis nefti i gaza (Genesis of Petroleum and Gas), Moscow, 1967.
14. Nalivkin, V.D., T.P. Yevseyev et al. Geol. nefti i gaza, No. 6, 1969.

TEMPERATURE OF FORMATION OF ZINNWALDITE-AMAZONITE-ALBITE APOGRANITE[1]

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(Presented by Academician V.S. Sobolev, February 22, 1971)

There are two hypotheses on the origin of amazonite granite: 1) amazonite granite crystallizes from molten magma rich in volatiles and rare alkalies [1, 2]; 2) it is formed in the postmagmatic amazonitization stage by metasomatic alteration of previously crystallized granite [3, 4] to lithionite-amazonite-albite apogranite [3]. Supporters of the first hypothesis believe that a granite melt relatively rich in lithium and fluorine can persist to 550°, with lepidolite, albite, amazonite and topaz remaining stable because of the wider range of crystallization of quartz. Those workers who support the second hypothesis assume that granite is amazonitized in the late alkaline stage of the postmagmatic process, at temperatures of 250° to 200° [4].

We studied inclusions in quartz from different zones of zinnwaldite-amazonite-albite apogranite. The rocks studied are confined to zones of extensive jointing near the apex of a granite pluton. Geologic, petrographic, mineralogic and geochemical investigations showed that this apogranite had been formed from biotite granite of the first phase, from leucocratic granite of the second and the third phases and, in part, from the surrounding schist. Our study of inclusions of molten material in quartz from biotite granite has already enabled us to estimate the crystallization temperature of the granite [6]. Allowing for our new additional data, the range of homogenization temperatures of these inclusions can now be estimated at 800° to 1020°.

In terms of mineral parageneses and position in the metasomatic column, the following vertical and horizontal zones can be identified in the studied apogranite: 1) unaltered granite of the first and second phases; 2) microclinized, muscovitized and slightly albitized granite of the first and the second phases; 3) protolithionite-microcline-albite apogranite; 4) zinnwaldite-amazonite-albite apogranite; 5) zinnwaldite-albite-amazonite apogranite; 6) banded zinnwaldite (cryophyllite)-amazonite-albite apogranite; 7) zinnwaldite (albite)-topaz-quartz greisen of the outer contact; 8) quartz-amazonite veins in granite, apogranite and schist. Our mineralogic and petrographic study of the main rock-forming minerals of apogranite revealed several generations of minerals (as many as four) within each of the zones studied. In this connection we should note that the composition of albite changes up the section from No. 12 in the third and the fourth zones to No. 0 to 2 in the sixth and the eighth.

In quartz from all the zones studied we detected gas-fluid inclusions with a varying gas to fluid ratio (10 : 90 to 90 : 10). These inclusions consist of two phases: gas and fluid (salt solution). The inclusions in quartz from quartz-amazonite veins of the eighth zone also contain fluid CO_2, which accounts for as much as 8 percent of them by volume. Primary inclusions occur sporadically, in groups of two or three; they generally have a more or less isometric shape and are not associated with healed cracks. Secondary inclusions are numerous; they occur within healed cracks and differ in their phase ratios. High-temperature inclusions homogenize into fluid and gas phases, but low-temperature varieties homogenize only into the fluid phase. The total number of inclusions studied exceeds 5000, although reliable data were obtained for a much smaller number (Table 1).

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[1] Translated from: Temperaturnyye usloviya formirovaniya tsinnval'dit-amazonit-albitovykh apogranitov. Doklady Akademii Nauk SSSR, 1972, Vol. 203, No. 3, pp. 685 - 688.