GEOTHERMAL POTENTIAL OF SIBERIAN PLATFORMS

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ABSTRACT

Two huge platforms (the West-Siberian and Siberian) occupy the northern part of Asia. Geothermal information on the platforms is summarized as a set of maps of heat flow density and temperature contoured for the depths of 0.5, 1, 2, 3 and 5 km. It is shown that the young (Epi-Hercynian) West-Siberian Platform is characterized by generally higher temperature values at a given depth and the heat flow density that is twice that of the Siberian Platform. The temperature data have been used for estimating geothermal potential of the territory, the estimated total resources of geothermal energy in the platforms are amounting to 8.5 trillion tons of conventional fuel.

1. INTRODUCTION

Siberia occupies the northern part of Asia (Figure 1). The two huge platforms are the fundamental structures of the Earth's crust of Siberia. These are the young Epi-Hercynian West-Siberian Platform and older (Epi-Riphean) Siberian Platform.

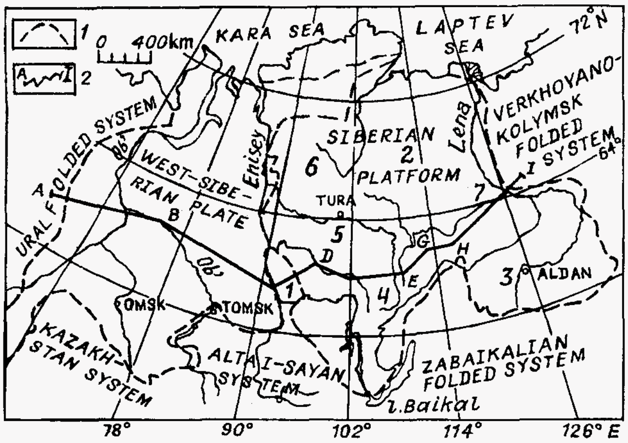

Fig.1. Review map of Siberia.
1 - boundaries of Siberian platforms; 2 - disposition of geothermal profile. Geological structures: Shields and Arch: I - Enisey Shield, 2 - Anabar Shield, 3 - Aldan Shield; 4 - Nepa-Botuoba Arch; Synclines: **5** - Kureyka, 6 - Tunguska, 7 - Vilyuy.

Within the limits of the Siberian Platfrom stabilization of continent crust was essentially completed in the early Proterozoic. The primary crust massifs which make up the crustal basement crop out at the Enisey (1), Anabar (2), Aldan (3) Shields. The rest of the Platform is covered by thick Paleozoic and Mesozoic sedimentary and volcanogenic rocks. The greatest thickness of the sedimentary cover (up to 10 km) occurs in the Kureyka (5), Tunguska (6) and Vilyuy (7) Synclines. The last tectonic activation of the region took place in Permo-Triassic when the large trap intrusion penetrated the sedimentary cover of the Platform. Another large unit in Siberia is the West-Siberian Platform (Plate). The crustal base of this young Platform consists of Riphean to Late Paleozoic continental blocks. The sedimentary cover is composed mainly of Mesozoic and Cenozoic terrigenous deposits; their thickness increases from 3-4 km in the central part of the platform to 9-10 km in the northern part. The formation of the Platform is thought to have been considerably influenced by Early Mesozoic rift folding and trap magmatism.

The widely developed permafrost zone produces a remarkable cooling effect on the geothermal field of the northern platform regions; its thickness ranges from 300-400 m in the northern part of the West-Siberian Plate to 1,000 m in the northeastern part of the Siberian Platform.

Geothermal investigations of the platforms under consideration began about 40 years ago. Thousands of boreholes have been drilled within the platform territory. Temperature and heat flow measurements have been obtained' in many boreholes, the maximum depth of the temperature measurements being **5** km with the average depth being 2 to 3 km.

Assessment of the geothermal potential of the Siberian platforms has been underway for a long time, becoming more specific as additional geothermal and hydrogeological information is obtained. The reports by Yu.D.Dyad'kin, E.I.Boguslavskiy, V.I.Kononov, A.A.Smyslov et al. presented in 1993 at an International Symposium in St.Petersburg (Problems...,1992), provide the most recent information.

In the early 1990's, a large group of Russian investigators reviewed and systematized the temperature and heat flow data for the Siberian platforms. Heat flow and temperatures were contoured for the depths of 0.5, I, 2, **3** and **5** km and published (Duchkov et al., 1994). These data were then used to obtain a more reliable estimate of geothermal potential of the upper sedimentary sequence in the study area. The present paper brief discusses the results of these investigations.

2. METHODS OF MEASUREMENT AND EVALUATION OF GEOTHERMAL PARAMETERS AND GEOTHERMAL POWER POTENTIAL

The methods used for the measurement of subsurface temperature and rocks conductivities have been discussed in detail by A. Duchkov (1991), R. Dorofeeva et al.(1994), A. Duchkov and L.Sokolova (1994). Briefly, however, most of the temperature data were obtained by exploratory organizations using different electrical thermometers during the drilling and testing of exploration wells. The measured temperature values were corrected as needed for the cooling effect of permafrost, for example in shallow wells. Where several temperatures at a given depth were available from different holes in a region, they were averaged. The geothermal gradient and the heat flow density (HFD) for the section were determined from the average values. In some cases, it was necessary to extrapolate the data to depths which were greater than the deepest bottom hole temperature.

The thermal conductivity of core samples obtained from boreholes was determined in the laboratory by different devices but mainly by a thermal comparator (Duchkov, 1991). The main advantages of the instrument are its relatively high speed of measurement and the ability to make measurements of specimens of arbitrary size and shape provided a smooth surface **less** than *3* cm in diameter can be prepared. The accuracy of the HFD value obtained depends on the accuracy of the unperturbed geothermal gradient and the thermal conductivity values used; we estimate that the combined error amounts 10 to 15% of the final value, i.e. about *5* to 7 mW m $^{-2}$.

The geothermal potential of the Siberian platforms was estimated for a layer with a lower depths of *5* to 6 km and the upper one determined by a user (Dyad'kin et al.,1991). The assessments were performed for two likely scenarios: 70/20°C for a hot water supply and 90/40°C for a heating regime where the numerator is the mean temperature of the source fluid and the denominator is the mean temperature of the waste fluid. These values are typical for the area which contains petrogeothermal and hydrogeothermal resources. In making the assessment we have assumed the use of current technology used elsewhere in recovering hydrothermal resources, that is, using either the traditional flow and pump technology or the newer 2-stage circulation technology (Shpak,1980; Shpak et al., 1992).

3. RESULTS AND DISCUSSION

3.1. Heat Flow Density.

The most up to data distributions of HFD and temperature values have been contoured for 0.5, 1, 2, *3* and *5* km depths; Figure 2 shows the distribution of HFD while Figs. *3* and **4** show the distributions of temperature for the 2 and *5* km depths. For depths to *3* km only measured values were used; for th pth range *3* to *5* km some extrapolated values were used

The mean values of temperatures and HFD are shown in Table which also gives the number of reliable values used in determining the mean and mean square deviation of these values. Figure *5* is a section showing the temperatures at various depths up to *5* km together with a profile of the surface HFD; superimposed on the section is the generalized geological structure.

Over the whole of the region, it can be seen from Figs. 2 and 5 and Table 1 that the heat flow varies from 20 to 90 mW m^{-2} with the mean value for the West-Siberian Plate being 53±15 and the Siberian Platform being 38±13 mW m^{-2}. While the low

Table 1. Mean values of geothermic parameters

Parameters	West-Siberian Plate			Siberian Platform		
	n	*m*	*MSD*	*n*	*m*	*MSL*
Heat Flow Density, (mW m^{-2})	660	53	15	220	38	13
Temperature, (^{0}C) at depth of						
0.5 km	415	12	8	200	8	6
1 km	400	29	10	110	15	8
2 km	342	60	11	105	30	10
3 km	191	92	16	80	47	14
5 km	139	141	30	60	82	20

n - number of values used to obtain the mean value m and the mean squared deviation *MSD.*

HFD value is typical of the Siberian Platform and West-Siberian Plate margins, even lower values (20 mW m^{-2} on average) are found for the oldest parts of the Siberian Platform (the Shield areas and the Nepa-Botuoba Arch). In the Kureyka, Tunguska, and Vilyuy synclines part of the Platform the HFD ranges from 40 to 50 mW m^{-2}; over most of the West-Siberian

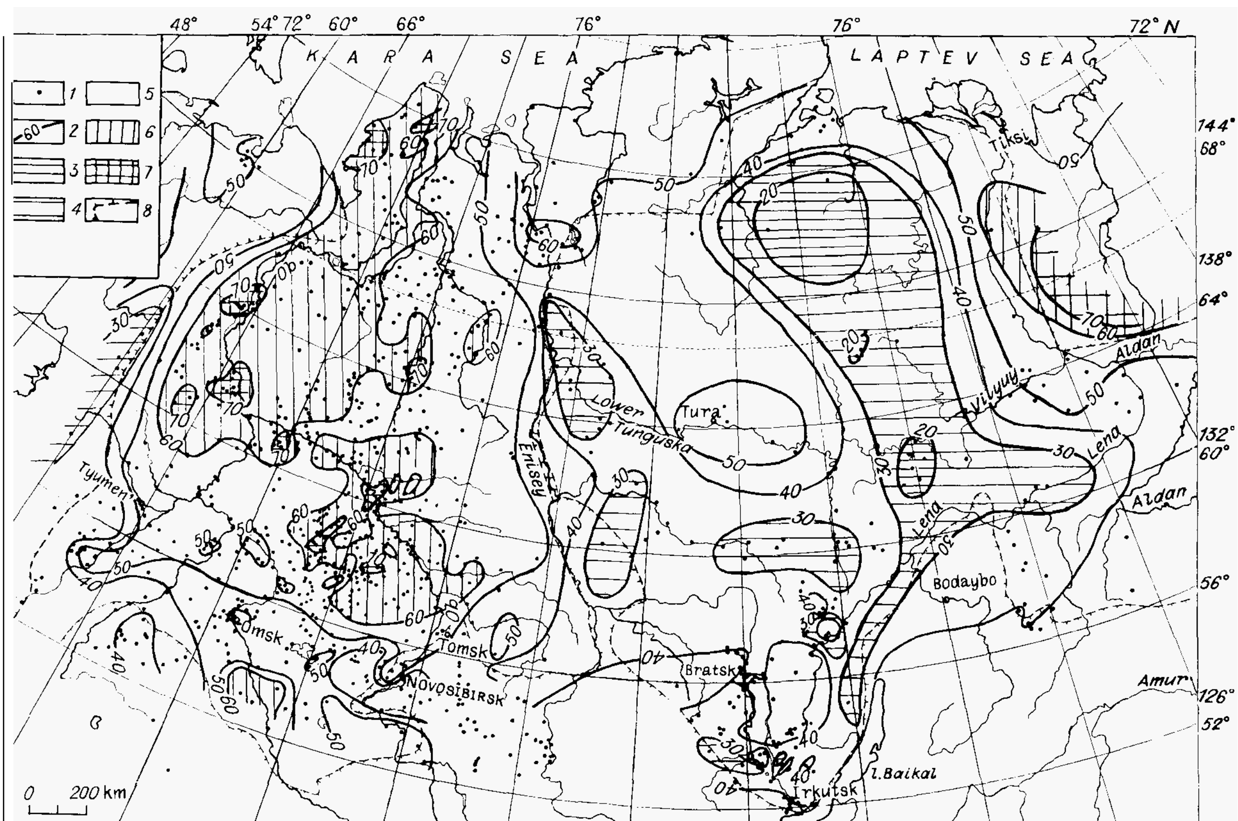

Fig.2. Heat flow map of Siberian platforms (after Duchkov,1991; Dorofeeva et al.,1994 with additions).
1 - sites of the geothermal measurements and estimations; 2 - HFD isolines, in mW m^{-2}; *3* to 7 - regions of the HFD variation ranging: below 20, 20-30, 30-60, 60-70 and over 70 mW m^{-2}, respectively; 8 - boundary of platforms.

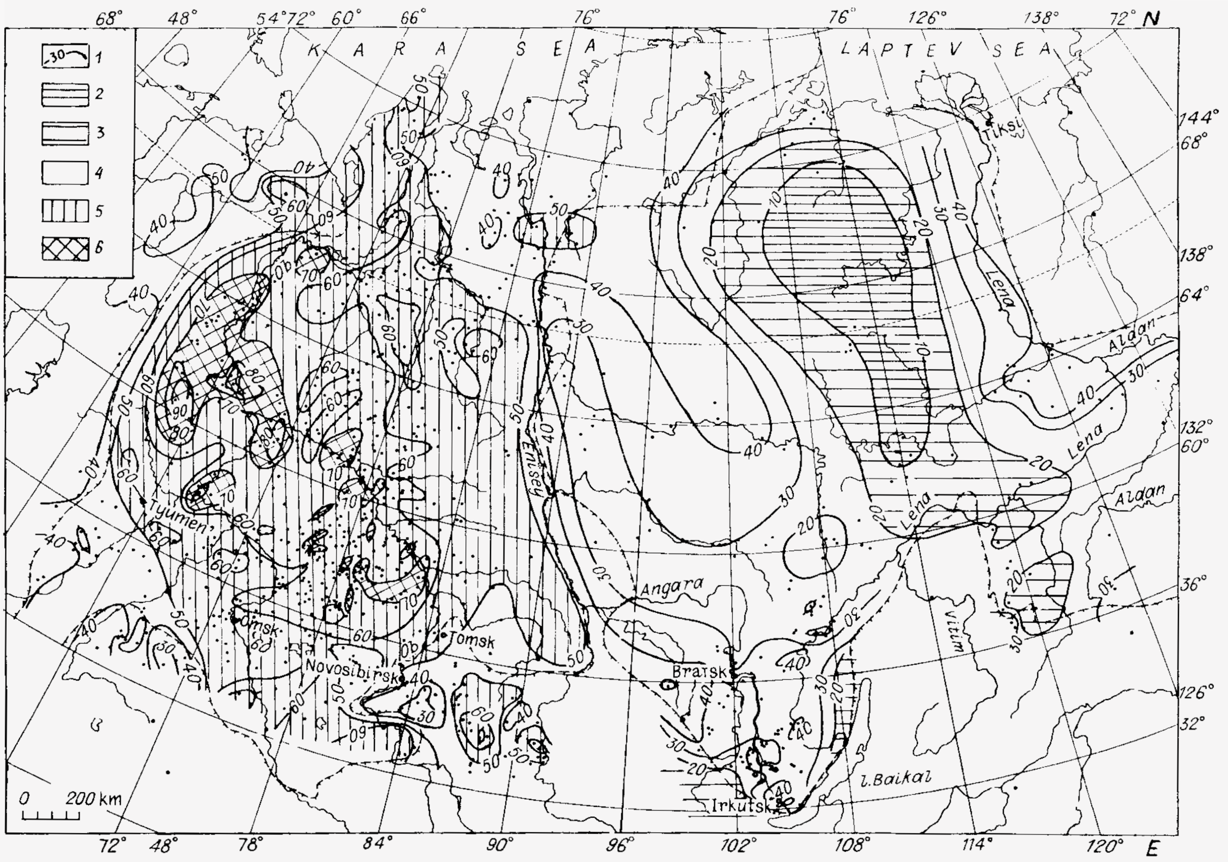

Fig.3. Temperature distribution in Siberian platforms at the depth of 2 km.
1 - temperature isolines, in "C; 2 to 6 - regions of temperature variations ranging: below 10, 10-20, 20-50, 50-70 and over 70°C, respectively.

Plate the HFD ranges from 50 to 60 $mW\ m^{-2}$, but regions with even higher HFD values of 80 to 90 $mW\ m^{-2}$ have becn recognized in the nothwestern and central parts of the plate. HFD variations within the Siberian platforms are determined mainly by the time since stabilization of the crust in the regions (Duchkov,1991; Dorofceva et al.,1994). Local anomalies may be caused by variations in the radiogenic heat production, permafrost effects, particularly in shallow wells (Duchkov et al.,1994), and fluid convection in the sedimentary cover.

3.2. Temperature

It is clear from Table 1 and Figs. 3 to 5 that the temperature gradients, and therefore the rate at which temperature increases with depth, vary considerably across the region. Since the details can be seen form the figures we discuss only briefly the behaviour in various depth ranges.

For depths between 0.5 and 1 km, the background gradient is perturbed by the cooling effect of permafrost, especially in the north. In the north and northeast of the platforms, temperature at 0.5 km depth is less than 0°C. At 1 km depth temperatures are as low as 0°C within the Anabar Shield where the permafrost is also the thickest. In the southern WestSiberian Plate where there is no permafrost, the temperatures at 0.5 krn and 1 km depth average 18 and 34°C respectively. As may be expected, the number of temperature measurements in a given depth range decreases with increasing depth. However, as can be seen from Table 1, at all depths the number of values for the WestSiberian Plate is more than twice as many as those for the Siberian Platform.

The influence of permafrost is negligible below 1.5km and the variation of temperature at 2 km depth is determined mainly by the HFD at depth. Higher temperatures at 2 km depth are a characteristic of the West-Siberian Plate, reaching 80 to 90°C in places whereas in the Siberian Platform it does not reach over *50°C.* In the large platform blocks such as the Anabar Shield and the Nepa-Botuoba Arch, the temperature ranges between only 10 to 20 °C. Similar differences occur at the *3* km depth and 5 km depth (see Figs. **4** and 5)

***3.3.* Geothermal Potential**

The total amount of energy which might be extracted from a formation is the sum of that available from the rock matrix (the petrogeothermal component) and from its contained fluids (the hydrogeothermal component). Using this concept and the geothermal data presented above, Dyad'kin et al. (1991) have divided the territory into three regions of differing potential. Unfavourable - the central and northern Siberian Platform; Favourable - synclines on the Siberian Platform and the southern and central West-Siberian Plate; Very Favourable - the central and northern regions of the WestSiberian Plate with estimated resources equivalent to $11/7x10^{12}$ t of conventional fuel for 90°C and 70°C fluid temperatures respectively, where 1 tonne of conventional fuel is taken to be 29.3 GJ. In more practical terms, two major productive water bearing complexes have been identified in the West-Siberian Plate in the terrigenous Cretaceous, the first in the depth range 1.2 to 1.5 km and the second at a depth of over 2 km (Kulikov and Mavritskiy, 1983). Using traditional pumping technology the energy resource is estimated to be equivalent to $27x10^{6}$ t of conventional fuel per year; if recirculation technology can be used the estimate increases to $9x10^{9}$ t of conventional fuel per year.

4. CONCLUSIONS

This paper is the first to present a summary of thermal data and geothermal potential to a depth of 5 km obtained from a vast territory of north Asia including the West-Siberian Plate and the Siberian Platform. Temperature conditions in the interior of the platforms differ sharply. On average th near

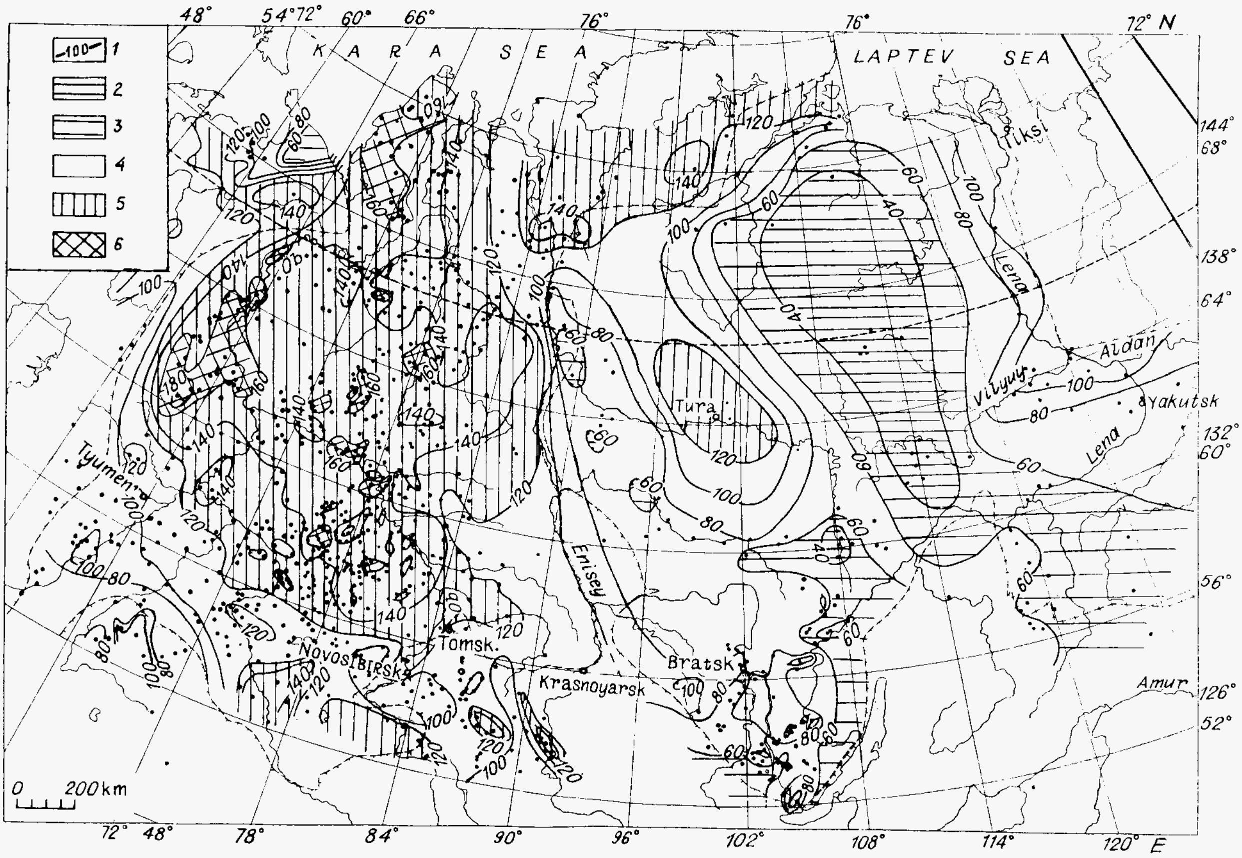

Fig.4. Temperature distribution in Siberian platforms at the depth of 5 km.
1 - temperature isolines, in °C; 2 to 6 - regions of temperature variations ranging: below 40, 40-60, 60-120, 120-160 and over 160°C, respectively.

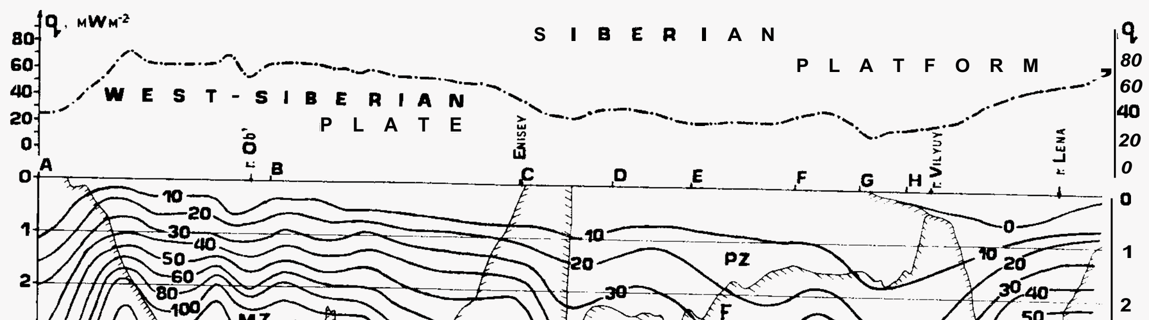

Fig.5. Geothermal section across the Siberian platforms.
1 - HFD profile, 2 - temperature isolines, in °C; 3 - heterogeneous basement (F)of Siberian platforms (over-platform deposits: **MZ** - deposits of Mesozoic age, PZ - deposits of Paleozoic age).

surface HFD and the temperatures at depths to 5 km within the young West-Siberian Plate are 1.5 to 2 times those of the older eastern portion. The analysis indicates that the regional HFD variations correlate with the time since stabilization of the crust and are related to the variations of mantle heat flow density. Temperature distribution at all depths is determined mainly the HFD but modified by such local variables as structure, radiogenic heat production, fluid flow and permafrost, although the effects of the latter become significant below 1.7 km.

With the new data we have been able to re-estimate the geothermal potential of the region under two assumptions - that of direct pumping and that of using recirculation technology. For the West-Siberian Plate the total geothermal potential is 11 and 7 trillion tonnes respectively; if the unpromising Siberian Platform region is included the potential increases to 15.5 and 8.5 trillion tonnes respectively, If we confine the estimates to the most practical water bearing complexes of the West-Siberian Plate the estimate is reduced to the equivalent of tens of millions of tonnes of conventional fuel per year.

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