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The role of the tectonic factor in the spatial distribution of suffosion depressions and the possibilities of fault zone reconstruction and their potential use for predicting deep-fluid migration pathways

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The spatial distribution of closed depressions (suffosion depressions) within the Dnipro–Donets Depression (DDD) in northeastern Ukraine was investigated. Approximately 400,000 depressions were identified over an area of about 126,000 km², and maps of their density were constructed. Significant spatial heterogeneity was established, with concentration maxima associated with fault zones and, in particular, with fault intersection nodes. The depressions are proposed as surface indicators of fractured and decompacted zones. The potential of this approach for predicting deep-fluid migration pathways is demonstrated. Using the Rechitsa Fault in the Pripyat Depression as an example, the spatial coincidence of local depression-density maxima with the locations of the four largest oil fields is considered. Remote mapping of depressions is proposed as a low-cost preliminary method for identifying potentially permeable zones for subsequent geophysical, gas-geochemical and drilling investigations.

Keywords: closed depressions, Dnipro–Donets Depression, faults, lineaments, permeability, degassing, hydrocarbons, oil fields, remote methods.

Роль тектонічного фактора у просторовому розподілі суфозійних западин та можливості реконструкції розломних зон і перспективи використання для прогнозування шляхів міграції глибинних флюїдів

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Досліджено просторовий розподіл замкнених депресій (западин) у межах Дніпровсько-Донецької западини (ДДЗ) на території північно-східної України. На площі близько 126 тис. км² дешифровано близько 400 тис. западин та побудовано карти їх щільності розподілу. Встановлено значну просторову неоднорідність розподілу, приуроченість максимумів концентрації до розломних зон і, особливо, до вузлів їх перетину. Запропоновано розглядати западини як поверхневі індикатори зон тріщинуватості та розущільнення. Показано перспективність використання цього підходу для прогнозування шляхів міграції глибинних флюїдів. На прикладі Річицького розлому в межах Прип'ятського прогину розглянуто просторовий збіг локальних максимумів щільності западин із положенням чотирьох найбільших нафтових родовищ. Запропоновано використовувати дистанційне картування западин як дешевий етап попереднього виділення потенційно проникних зон, перспективних для подальших геофізичних, газогеохімічних і бурових досліджень.

Ключові слова: суфозійні западини, Дніпровсько-Донецька западина, розломи, лінеаменти, проникність, дегазація, вуглеводні, родовища, дистанційні методи.

Introduction. Small closed, rounded depressions (suffosion depressions) are widespread within the Dnipro–Donets Depression (DDD), but their spatial distribution is highly heterogeneous. The aim of this study is to establish the role of the tectonic factor in the spatial structure of depression distribution and to assess the potential of their distribution for reconstructing fault zones and identifying areas of enhanced permeability of the geological environment.

Materials and methods. Spatial analysis was carried out for an area of approximately 126,000 km² within the northeastern part of the DDD. About 400,000 closed depressions were identified from satellite imagery in Google Maps. Geographic information processing and construction of density maps were used to analyze their spatial organization. The positions of depression fields and chains relative to known faults and lineament zones were analyzed separately.

Results. The density of depressions varies from their complete absence to 200–250 depressions per 1 km². The depressions form individual fields and linearly elongated clusters, which are often oriented along extensive lineament zones. Comparison of their distribution with known faults revealed that concentration maxima are associated with active fault zones, particularly with fault intersection nodes. For individual lineament zones, the depression density directly above the central part of a fault is, on average, 1.5–2 times higher than in the peripheral areas.

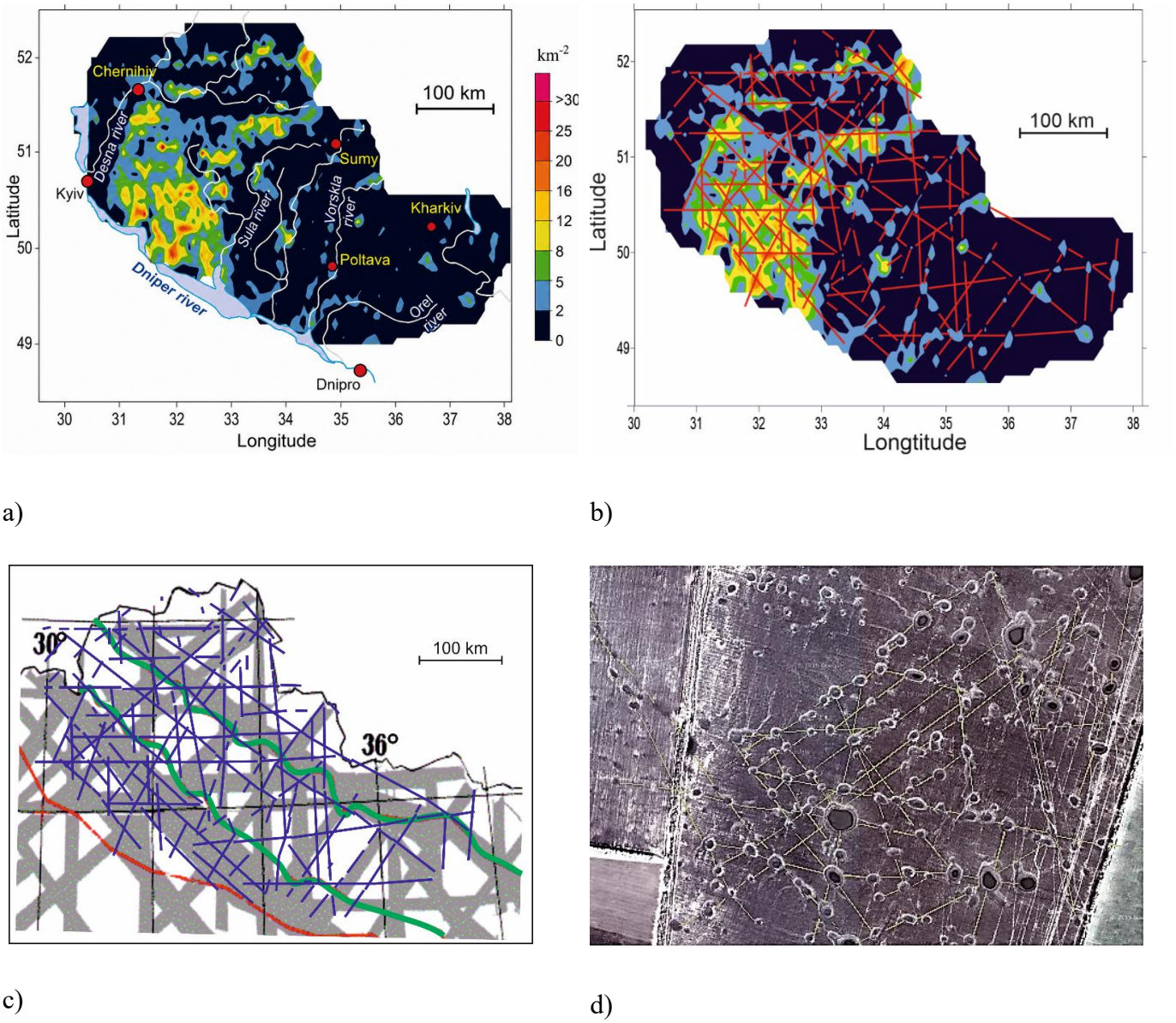

Fig. 1. Spatial distribution of depressions (a), reconstruction of fault zones from the structure of depression fields (b), comparison with independent [1] data (c), and linear organization of depressions (d).

The reconstruction of hypothetical lineaments based on depression-concentration maxima shows good agreement with known reactivated faults identified by conventional geological and geophysical methods [1]. The similarity in the orientations of depression fields, their chains, and faults indicates structural control over their formation. The results make it possible to consider the depressions not merely as individual landforms, but as a set of surface manifestations of zones of enhanced fracturing and decompaction.

Potential use for hydrocarbon exploration. Of particular interest is the possibility of using the spatial distribution of depressions to preliminarily identify zones of enhanced permeability in the geological environment and to predict hydrocarbon migration pathways. The Rechitsa Fault area within the Pripyat Depression provides an illustrative example (Fig. 2). Pronounced heterogeneity of depression density is observed along the fault, with local maxima confined to individual segments of the fault zone. The locations of the four largest oil fields in the area spatially correspond to such local maxima.

The observed spatial correspondence may have a common structural-hydrogeological explanation. Tectonic movements along the fault created conditions for the formation of structural hydrocarbon traps, while fault-related zones of fracturing and decompaction may have provided favorable pathways for their vertical migration. Individual fault segments and nodes where differently oriented faults intersect are potentially the most permeable. Under modern conditions, the same zones of enhanced permeability may facilitate meteoric-water infiltration, concentration of subsurface flow,

and the development of suffosion processes manifested by the formation of groups and chains of depressions.

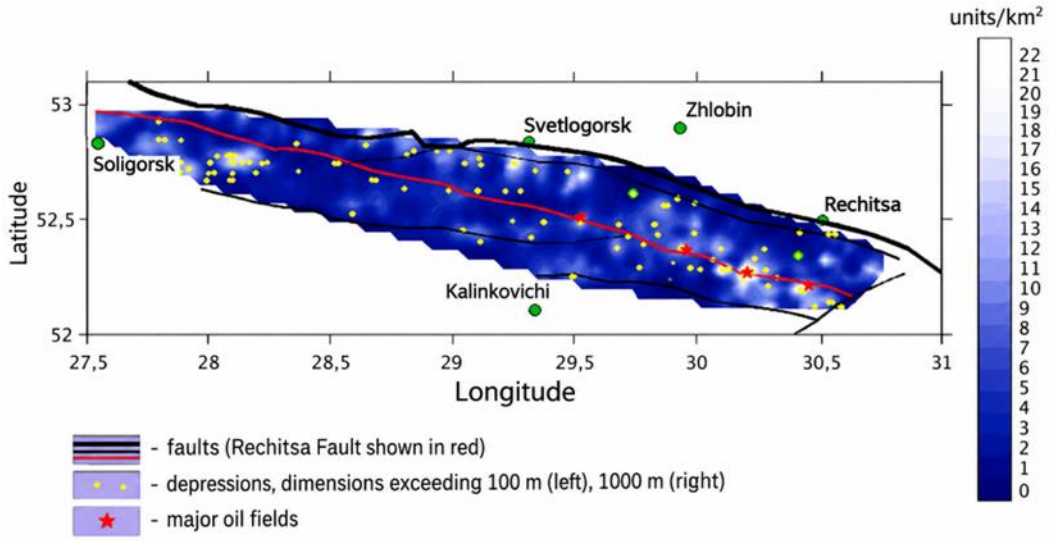

Fig. 2. Distribution of depression density along the Rechitsa Fault and locations of the four largest oil fields.

Thus, spatial mapping and quantitative analysis of depression density may be regarded as a low-cost remote method for the preliminary identification of zones of enhanced permeability that are promising for further geophysical, gas-geochemical and drilling investigations. In hydrocarbon-bearing basins, such zones may be useful for predicting possible hydrocarbon migration pathways and identifying prospective exploration areas. At the same time, depressions should not be directly equated with hydrocarbon accumulations: the working hypothesis is that they may share a common relationship with zones of enhanced fracturing and permeability.

Conclusions. The tectonic factor is one of the key controls on the spatial organization of depressions in the DDD. Their fields and chains may reflect fault and fractured zones, including those that are weakly expressed by conventional geological and geophysical methods. The spatial coincidence of local depression-density maxima with the four largest oil fields in the Rechitsa Fault area indicates the potential value of further testing this relationship. The next step should be a statistical assessment of the spatial correspondence between oil fields and depression-density maxima and comparison with a random distribution.

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