Державна служба
геології та надр
України

ДКЗ

Івано-Франківський національний технічний університет нафти і газу
Інститут геологічних наук Національної академії наук України
Київський національний університет імені Тараса Шевченка
Львівський національний університет імені Івана Франка

2024

МАТЕРІАЛИ КОНФЕРЕНЦІЇ

IX міжнародна науково-практична конференція

НАДРОКОРИСТУВАННЯ В УКРАЇНІ. ПЕРСПЕКТИВИ ІНВЕСТУВАННЯ

7-11 жовтня 2024, м. Львів, Україна

IX international scientific-practical conference

SUBSOIL USE IN UKRAINE. PROSPECTS FOR INVESTMENT

7-11 october 2024, Lviv, Ukraine

UDK 556 (477)

CLASSIFICATION OF GEOTHERMAL RESOURCES BASED ON THE GEOTHERMAL PLAY TYPES AND ITS APPLICATION TO THE CONDITIONS OF UKRAINE

Liventseva H.[1], *Cand. Sci. (Geol.), Contract Researcher, hliventseva@geo3bcn.csic.es,*
Barylo A.[2], *Researcher, abarilo@ukr.net,*
1 – Geosciences Barcelona (GEO3BCN-CSIC) Institute, Barcelona, Spain, ,
2 – Geothermal Energy Department, Institute of Renewable Energy of the National Academy of Sciences of Ukraine

Outlines key features used in creating classifications of geothermal resources. One prominent example is the comprehensive multi-parameter classification developed by I. Moeck, which is based on the geothermal object's geological control and thermal regime. This classification categorizes geothermal formations into convective (CV) and conductive (CD) types based on heat transfer methods. This classification has been applied to Ukraine's primary geological structures, leading to territorial zoning according to the geothermal conditions.

Introduction

In recent years, Ukraine has done a lot to achieve the country's energy independence by attracting renewable energy sources, especially solar and wind, and to a lesser extent geothermal, to the economy's energy sector. The greatest development in geothermal energy was the use of low-potential energy sources with the help of heat pump technologies. Certain projects were also prepared for deep geothermal resources, which require more detailed and expensive pre-investment studies. The war made adjustments. Now we need not only modernization, but also restoration of the country's lost energy capacities. It is much easier to do this together with the international community, using progressive foreign experience and foreign investments, involving modern equipment and implementing the latest technologies.

The main problem of geothermal energy remains the weak preparedness of the resource base. Ukraine has a huge array of raw data, but this information is not systematized and not brought to a user-friendly form. Systematization of data should be carried out on the basis of classifications adapted to foreign analogues, standardization of terminology and definition of specialized concepts.

The purpose of the research: Based on the analysis of modern geothermal methodology, to determine the optimal classification of geothermal resources, which would take into account the geological, hydrogeological and geothermal conditions of the object. Using this classification, carry out preliminary zoning of the territory of Ukraine by assigning types (indexes) to the most promising geothermal regions of Ukraine**.**

1. Overview of geothermal classifications

Geothermal energy is at the interface of various fields of science, specifically geology, geophysics, hydrogeology, energy and economics. Specialists introduce their own concepts and definitions; develop classifications based on the characteristics of geothermal objects that are close to their specialty. This leads to the existence of numerous geothermal classifications [1-4]. Each classification enhances and refines the understanding of the research subject. But the primary requirements for developing classifications are, firstly, the utilization of common terminology that is clearly understood across various scientific disciplines, and, secondly, the standardization of features and characteristics to ensure comparability. Essentially, only comparable objects and properties should be distinguished and compared.

Famously, "Geothermal energy" – thermal energy contained within the Earth's subsoil [5]. "Geothermal sources" – solid, liquid and gaseous components of the Earth's subsoil that store geothermal energy [6].

The study of geothermal sources is carried out according to different directions or stages of research, each of which has separate tasks, terminology and classifications. Figure 1 shows the research directions of geothermal sources.

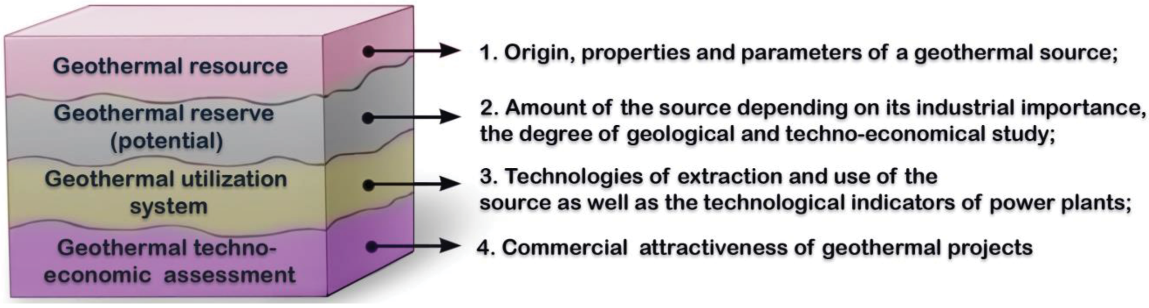
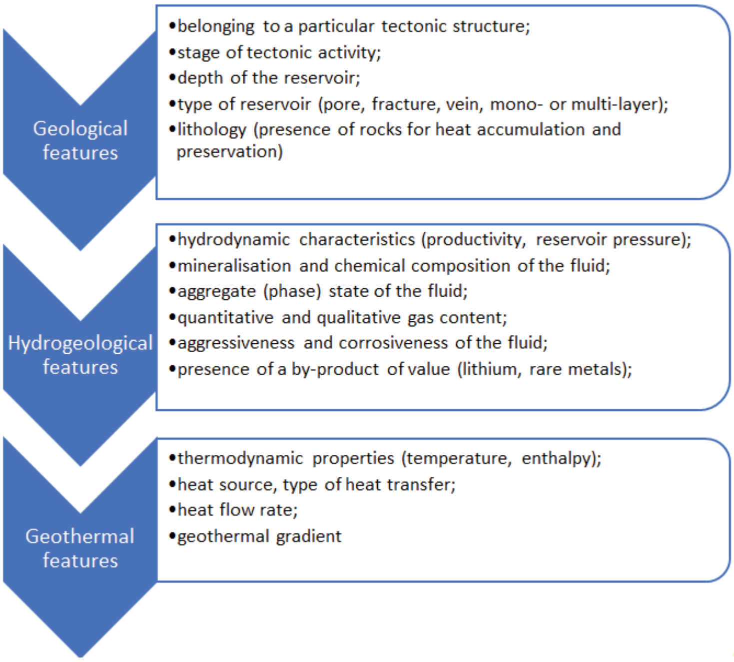


Figure 1. Research directions (stages) of geothermal sources



The features used to classify geothermal resources can be divided into three main groups (Fig. 2).

According to the authors, the most optimal implementation of the multi-parameter approach is the classification proposed by I. Moeck [3,4,7-9]. Moeck's classification is based on the «geothermal play», which serves as an indicator of geodynamic conditions and peculiarities in the geothermal structures. A geothermal play is a complex indicator determined by the geological development stage, geological processes within the structure, the type of heat transfer and the overall heat balance of the structure.

Figure 2. Classification features of geothermal resources [1-4]

The heat balance of a geological structure is typically formed by both convection and conduction, but the significance of each heat transfer method can vary greatly. Based on the priority of one of the heat transfer methods over another, Moeck's classification identifies the following types of geothermal resources, presented in Table 1.

Table 1

Classification of geothermal plays [2]

Type			Geological setting	Heat source	Dominant Heat Transport Mechanism
Convection Dominated	CV1 Magmatic	CV-1a Extrusive	Magmatic Arcs, Mid Oceanic Ridges, Hit Sports	Active Volcanism, Shallow Magma Chamber	Magmatic-hydrothermal Circulation
		CV-1b Intrusive	Magmatic Arcs, Mid Oceanic Ridges, Hit Sports	Active Volcanism, Shallow Magma Chamber	Magmatic-hydrothermal Circulation, Fault Controlled
	CV-2 Plutonic	CV-2a Recent or Active Volcanism	Convergent Margins with Recent Plutonic (< 3 Ma), Young Orogens, Post-orogenic Phase	Young Intrusion-Extension Felsic Pluton	Magmatic-hydrothermal Circulation, Fault Controlled
		CV-2b Inactive Volcanism	Convergent Margins with Recent Plutonic (< 3 Ma), Young	Young Intrusion-Extension Felsic	Hydrothermal Circulation, Fault Controlled

		Orogens, Post-orogenic Phase	Pluton, Heat Producing Element in Rock	
	CV-3 Extensional Domain	Metamorphic Core Complexes, Back-Arc Extension, Pull-apart Basins, Intracontinental Rifts	Thinned Crust-Elevated Heatflow, Recent Extensional Domains	Fault Controlled, Hydrothermal Circulation
Conduction Dominated	CD-1 Intracratonic Basin	Intracratonic/Rift Basins, Passive Margin Basins	Lithospheric Thinning and Subsidence	Litho/Biofacies Controlled
	CD-2 Orogenic Belts	Foreland Basins within Fold-and-Thrust Belts	Crustal loading and Subsidence Adjacent to Thickened Crust	Fault/Fractured Controlled, Litho/Biofacies Controlled
	CD-3 Crystalline Rock Basement	Intrusion in Flat Terrain	Heat Producing Element in Rock, Hot Intrusive Rock	Hot Dry Rock, Fault/Fractured Controlled

2. Zoning of the territory of Ukraine based on the geothermal plays

The zoning is based on the geological and structural principle, using first-order geological structures as the territorial units. The authors have identified five of the most promising structures in Ukraine, characterized by favorable geothermal conditions and hydrogeological properties suitable for the formation of geothermal deposits.

The types of the most important geological structures in Ukraine were determined according to their geothermal conditions. Key factors considered include location within the tectonic plate system, stage of tectogenesis, structural and geological features, lithology, hydrogeological and geothermal conditions, predominant type of heat transfer, heat balance, heat source, magmatic and volcanic processes, and the influence of salt tectonics.

The results of determining the types of geothermal plays for the main structures of Ukraine are shown in Table 2.

3. Features of Ukrainian geothermal play types

Table 2

Characteristics of the main structures of Ukraine according to the classification of geothermal conditions (plays)

Name of the structure (abbreviation)	Index	Type of heat transfer	a. Geodynamic setting; b. Geological control; c. Depth of the foundation;	a. Heat source; b. Conditions of storage and consumption of heat	Tempera-ture, ºC at depth, [10]			Heat flux, mW/m^2	Hydrogeological conditions	Presence of hydrocarbon deposits; Degree of production, %. [11]	Estimation of available resources, toe/m^2 [10]
					3 km	5 km	10 km				
1	2	3	4	5	6			7	8	9	10
Transcarpathian Depression (TD)	CD-2	Conductive	a. Orogenic basin-type internal trough overlain by a young late alpine structure; b. Tectonic faults, effusive and intrusive volcanism, folding, lithological control; c. 0.5-5 km	a. High heat flow due to thinning; Upward convection of heat by fluids along faults; b. Sedimentary cover contains thick clayey rock layers that contribute to heat retention; Salt diapirs - heat transfer channels	100-200	160-265	300-500	77-133	Artesian basin; Aquifers are unconfined in extent and isolated; Water enrichment is usually low; The general feeding area is the CSF, Upward filtration of fluids along faults	Oil deposits are known in small fields; Gas deposits are confined to brachyanticlines and are difficult to extract	2,44; Partially used in balneology and recreation

Precarpathian Depression (PD)	CD-2	Conductive	a. Basin-type orogenic foothill trough, young Late Alpine (Early Neogene) structure; b. Large tectonic faults, thrusts (inner zone of the trough is pushed over the outer zone), dumps; Folding, lithological control; c. 1.5-4.5 km	a. High enough heat flow due to the proximity to the Carpathian orogen; b. A thick sedimentary cover consisting mainly of clayey rocks with sporadic isolated aquifers within it; Strong overthrust creates favorable conditions for heat preservation	65-120	110-170	150-300	32-80	Artesian basin; Aquifers are unconfined in extent and isolated; Water enrichment is usually low; General feeding area - EEP; Local upward filtration of fluids along faults	Gas fields are concentrated in the outer part and oil fields in the inner part; gas fields; about 90	2,34
Dnipro-Donets Depression (DDD)	CD-1	Conductive	a. Intracratonic rift, closed by an intra-platform aulacogen, with a thick thickness of Mesozoic-Cenozoic sediments b. Fault-block tectonics, halokinesis, folding, lithological control; c. 0.5- 22.5 km	a. Medium heat flow, but very significant depths of permeable layers. Conduction dominates; convection dominates in the marginal deep faults of the structure. b. Salt diapirism (heat transfer channels and flows between aquifers)	60-100	90-130	150-250	31-66	Large artesian basin; System of powerful, long-striated aquifers and complexes, System of regional waterways; High water enrichment; General feeding area - EEP	DDD is the main oil and gas producing region of Ukraine average -56%	2,18
Donets Fold Structure (DFS)	CD-1	Conductive	a. Devonian aulacogen, laid down on a pre-Baikal base and deformed in the Late Hercynian; b. Deep faults, disjunctions, flexures, large folds complicated by a series of smaller folds, lithological control; c. 7-22 km	a. Thick sedimentary cover. The maximum heat fluxes are confined to the zones located in the sedimentary strata above the faults in the basement; b. High thermal conductivity of salt diapirs causes local positive thermal anomalies in roof rocks	70-140	110-220	200-400	27-133	Hydrogeological massif of formation-fracture and fracture-vein waters and numerous artesian mulches; Unconformity of aquifers in area and in section; Water enrichment is very diverse, sometimes very high; General feeding area - marginal parts of the structure; flows along faults	Coalbed methane	2,22
Black Sea Depression (BSD)	CD-2	Conductive	a. Subduction zone, Mesozoic-Cenozoic epicontinental basin, superimposed by young Cretaceous structure; b. Deep faults, dips, faults of different amplitudes, lengths and ages, structural protrusions, depressions and localized uplifts; c. 0-5 km	a. In the northern part, medium heat flux due to significant subsidence of the crust due to loading with erosion products; in the southern part, high heat flux associated with subduction; b. Thick sedimentary cover with natural heat loss from more heated layers to less heated ones	70-140	110-220	200-400	38-92	Artesian basin; Unstable distribution of water-bearing and water-resistant sediments; Isolated aquifers; Usually high-water enrichment; General feeding area - the southern part of the EEP and the Crimean Mountain range	A major oil and gas region in the world	2,25; Partially used in balneology and recreation

4. Discussion and conclusions

Based on these conditions, the authors have identified the following subtypes of conductive geothermal plays for Ukraine, which are listed in Table 3. and Figure 3.

Table 3

Subtypes of conductive plays heaters for Ukrainian conditions

Structure	Type		Geodynamic environment Heat source	Conditions of heat storage and transportation
Dnipro-Donets Depression (DDD)	CD-1a	Aulacogen	Stretching and thinning of the Earth's crust, the rise of the asthenosphere, ancient magmatism; a thick sedimentary cover	Large depth of aquifers; Lithologic - facies control; Fault control Salt diapirs - heat transfer channels
Donets Fold Belt (DFB)	CD-1b	Folded structure based on a rift	Thinning of the Earth's crust due to stretching, ancient magmatism; Convergent folding;	Lithologic and facies control; Exposure of ancient rocks to the surface due to folds
Transcarpathian Inner Depression (TD)	CD-2a	Orogenic belt Neogene magmatism	Thinning of the earth's crust; Raising of the asthenosphere; Recent volcanism, magmatism; Active faults;	The sedimentary cover contains thick layers of clayey rocks that contribute to heat retention; Salt diapirs are heat transfer channels; Fault control

Precarpathian Marginal Depression (PD)	CD-2b	Orogenic belt Without magmatism, thrust	Thickening of the Earth's crust due to the advancement of the CFS and sedimentation; Active faults	The sedimentary cover contains thick layers of clayey rocks that contribute to heat retention; Thrust

Thus, on the scale of first-order structures, heat transfer by conduction dominates the heat balance of large geological formations.

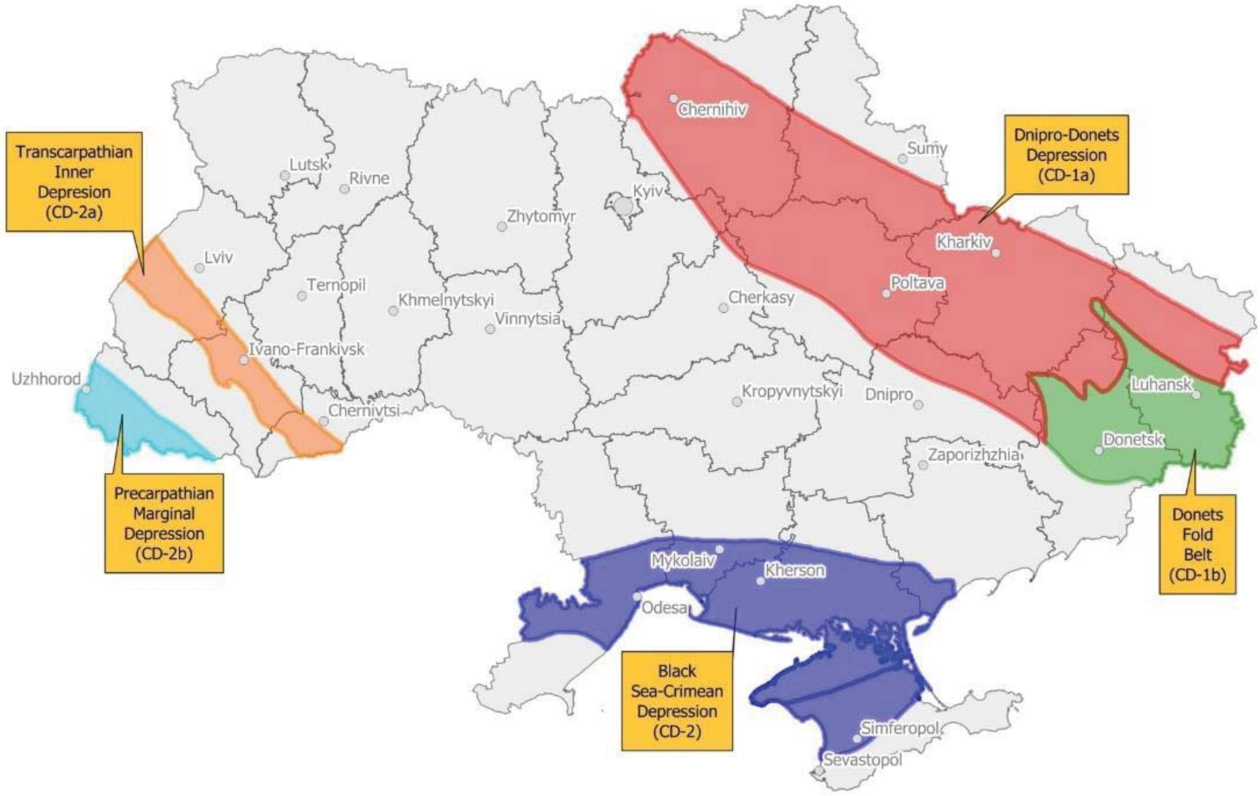


Figure 3. Zoning of the territory of Ukraine based on the geothermal play types

However, the convective component plays a significant role in shaping the thermal regime of individual structures. Almost all structures possess active deep faults through which hot fluids are filtered ascend. Therefore, the convective component becomes increasingly important for smaller structures and individual geothermal fields, potentially becoming the decisive factor. Additionally, exploitation productive horizons lead to decrease in reservoir pressure, thereby enhancing the inflow of deep hot fluids.

The classification of geothermal plays is continually evolving as new subtypes are identified. The next stage in developing the geothermal energy resource base involves creating geothermal catalogs and maps based on the Moeck classification, similar to those developed in Mexico and Spain. For example, the Institute of Cartography and Geology of Catalonia (ICGC) has produced a universal map of Geothermal Resources of Deep Origin in Catalonia (RGOPCat), synthesizing potential and relevant information on geothermal resources in Catalonia.

Drawing from Icelandic and international geothermal expertise, the National Energy Regulatory Agency of Iceland (Orkustofnun) has collaborated with the Institute of Renewable Energy of the National Academy of Sciences to develop proposals for advancing geothermal energy in Ukraine [12].

Cataloging of geothermal provinces allows for systematic and user-friendly organization of information, serving as a tool for strategic planning in geological and geothermal exploration and evaluation of promising geothermal fields.

Future steps in studying Ukraine's geothermal energy sources include detailed zoning of smaller structures, quantifying their geothermal reserves, and selecting promising sites to develop specific commercial proposals for the creation of geothermal energy systems.

References:

1. Dickson M.H., UNESCO, eds., Geothermal energy: utilization and technology, UNESCO, Paris, 2003. https://unesdoc.unesco.org/ark:/48223/pf0000133254.
2. Nador A., Part II – Introduction to deep geothermal energy: play types, potential estimation methods, geothermal modelling, classification of resources/reserves. Basic concepts of deep geothermal energy., (2017). https://www.interreg-danube.eu/uploads/media/approved_project_output/0001/09/1f53379454bd1499fbb2907ac041878adbefadd5.pdf.
3. Breede K., Dzebisashvili K., Falcone G., Overcoming challenges in the classification of deep geothermal potential, Geoth. Energ. Sci. 3 (2015) 19–39. https://doi.org/10.5194/gtes-3-19-2015.
4. Moeck I.S., A new 'geothermal play type' catalog: Streamlining exploration decision making, in: Proceedings, Thirty-Ninth Workshop on Geothermal Reservoir Engineering, Stanford University, Stanford, California, 2014. https://pangea.stanford.edu/ERE/pdf/IGAstandard/SGW/2014/Moeck.pdf.
5. U.S. Energy Information Administration (EIA), Geothermal explained, U.S. Energy Information Administration (EIA) (2022). https://www.eia.gov/energyexplained/geothermal/ (accessed February 24, 2024).
6. National standard of Ukraine. Geothermal energetics. Terms and definitions. ДСТУ 7498:2014: Геотермальна енергетика. Терміни та визначення понять. – Чинний від 2014-10-01, (2014). https://online.budstandart.com/ua/catalog/doc-page.html?id_doc=84604.
7. Moeck I.S., Catalog of geothermal play types based on geologic controls, Renewable and Sustainable Energy Reviews 37 (2014) 867–882. https://doi.org/10.1016/j.rser.2014.05.032.
8. Moeck I., Bendall B., Minnig C., Manzella A., Yasukawa K., Geothermal Play Typing – Current Development and Future Trends of a Modern Concept for Geothermal Resources Assessment, in: Proceedings World Geothermal Congress 2020, Reykjavik, Iceland, 2020. https://www.lovegeothermal.org/wp-content/uploads/16074.pdf.
9. Moeck I., Beardsmore G., Harvey C., Cataloging Worldwide Developed Geothermal Systems by Geothermal Play Type, in: World Geothermal Congress 2015, Melbourne, Australia, 2015.
10. Gordienko V.V., Gordienko I.V., Zavgorodnyaya O.V., Logvinov I.M., Tarasov V.N., Usenko O.V., Geothermal atlas of Ukraine, Kyiv, Ukraine, 2004.
11. KUSHNIR S., KOST' M., DUDOK I., PANKIV R., Baroosmotic analysis of hydrogeological conditions at Khidnovychy gas field (Ukrainian Precarpathia), Геологія і Геохімія Горючих Копалин (158-159) (2012) 68–81. http://dspace.nbuv.gov.ua/handle/123456789/60467.
12. Pétursson B., Ketilsson J., eds., Geothermal Policy Options and Instruments for Ukraine. Based on Icelandic and International Geothermal Experience Report Prepared for the Ministry for Foreign Affairs in Iceland., Orkustofnun, National Energy Authority, Iceland, 2016. https://gogn.orkustofnun.is/Skyrslur/OS-2016/OS-2016-01.pdf.