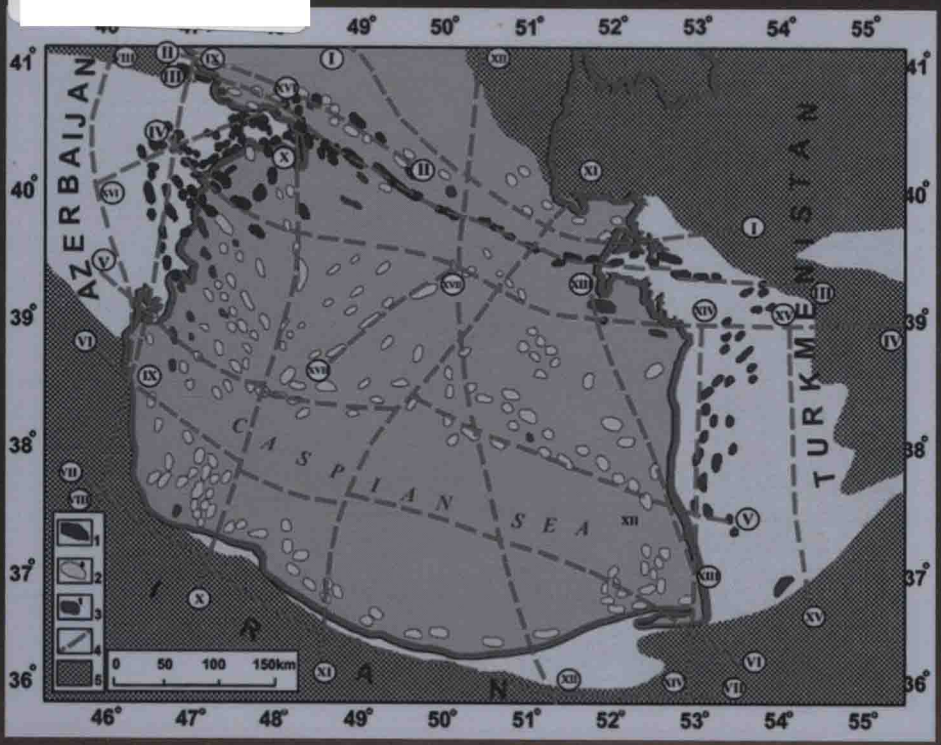
FLUID DYNAMICS OF OIL AND GAS RESERVOIRS



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Fluid Dynamics of Oil and Gas Reservoirs

DEDICATION

The book is dedicated to the memory of
Azerbaijan's national leader Heydar Alirza oglu Aliyev.

This volume is dedicated to the academician,
Professor George V. Chilingar, one of the foremost
experts in the field of petroleum geology in the world.

Fluid Dynamics in Petroliferous Areas of Mobile Belts

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Abstract

The book provides a first systemic synthesis in the geologic literature of all currently available data on hydrogeochemical, fluid-dynamic, geobaric and geo-temperature fields in the Alpine mobile belts[1]. Ground water chemical composition, its variations and distribution patterns in the natural reservoirs have been identified and analyzed. The nature and spatial occurrences of abnormally high formation pressure (AHFP) and abnormally high pore pressure (AHPP) in the subsurface of unbalanced folding in the mobile belts were studied. Their role in the formation of faults, regional and local structures, hydrocarbon migration and accumulation as well as the preservation and dissipation of hydrocarbon accumulations was identified.

The formation of geotemperature regimes and their association with oil and gas occurrences were reviewed. The role and significance of clay sequences' consolidation in forming the geo-fluid-dynamic regime of the lower structural stage was determined. The book includes a broad review of the role of hydro-geodynamic factors in the formation, distribution and forecast of oil and gas occurrences, of groundwater discharge (drainage) zone role in localizing hydrocarbon accumulations. A concept is developed of obligate functional association between large-scale hydrocarbon saturation of traps and spatially restricted overflowing-injection

[1] Here and thereafter, the authors understand "mobile belt" regions as Meso-Cenozoic depositional basins with typically geosynclinal vertical succession: basal conglomerates – carbonate massif – flysh – schliere (a clay series) – molasses sequence (alternation of clays and sands).

hydrogeological processes outside the framework of regional elision and artesian mechanisms. For all studied regions was for the first time developed and proposed a set of qualitative criteria and quantitative parameters of the commercial hydrocarbon productivity and the corresponding geologic models minimizing exploration risk factors and providing for the separate forecast of predominant oil or gas accumulation. The synthesis of the obtained information enabled the development of geo-fluid-dynamic models for all basins and of the conceptually new exploration strategy in these basins at minimized risk.

Introduction

The hydrocarbon (HC) generation, primary and secondary migration, formation and spatial distribution of the accumulations, the preservation and dissipation of oil and gas accumulations are realized within the "nature – natural fluids" system framework and are in essence derivatives of variscale multivector regional and local geo-fluid-dynamic processes.

The stated paradigm assumes a probability of obligate objective existence of quantitative interrelations between various parameters of the HC host geologic media (traps, reservoirs) and natural fluids. This circumstance is the subject of our study. It determines a possibility of identification and, in this case, acceptability of the utilization of quantitative interrelations and associations between oil and gas occurrences and the parameters of the natural reservoirs, and the general geo-fluid-dynamic field of the regions (hydrogeochemistry, ground water dynamics, thermobaric conditions in the traps, etc.). These form new rather reliable qualitative exploration criteria and quantitative parameters of the hydrocarbon saturation, thereby improving exploration efficiency and decreasing exploration risks.

History of natural hydrocarbons in the Earth's crust, from their generation to the destruction of their accumulations, at each stage occurred within the pore-fractured rock space. This void space is saturated in situ by syngenetic sedimentogenic ground water. Thus, hydrocarbons begin their path in variously dynamical hydrogeological medium. That is why all aspects of petroleum geology should be treated as private derivatives of global hydrogeological processes of various sequence and intensity.

The proposed new geo-fluid-dynamic concept provides the following advantages:

- It enables sufficiently reliable identification of the environments where the migration was absent or substantially restricted; the identification of optimum conditions for the

formation and preservation of phase-variant accumulations and for the HC destruction.
- It also enables a reliable differentiation at the early exploration stages of the entire prospect inventory into productive (oil- and gas-saturated) and "dry" traps and, therefore, the conduct of high-efficiency, directed exploration.

The methodology is based on the occurrence (established for all basins in the mobile belts) of essential spatial association of the oil and gas accumulation zones and individual productive structures exclusively with the discharge (drainage) areas and locations of sub-regional fluid-dynamic systems connected with large lineaments.

The identification, evaluation and practical application of the aforementioned quantitative interrelations are particularly important for the active neotectonic (dynamically "excited", "unbalanced") geologically complex basins of the Alpine mobile belts. There, the implementation of the standard exploration strategy and techniques rooted in the half-century-old exploration empirics within relatively simple, tectonically "quiescent" platform regions with the dominating old foursome of "source rocks/traps/reservoir rocks/seals" turns out to be costly and often unsuccessful.

A most telling example is the South-Caspian Basin (SCB). There, the largest western transnational companies and consortia, working under the PSA arrangements from 1995 through 2008, drilled 28 exploratory wells, up to 7,301 m deep (almost 24,000 feet). The wells were spudded on the structures deemed highly potential and preliminarily subjected to high-resolution 3D seismic surveys. The effort cost about $1 billion and did not result in a single commercial discovery (Rachinsky, 2008).

The geologically complex oil and gas basins within the Alpine mobile belts in most cases have an exceedingly great number of distinctive features. They include:

- divergent tectonic structures of the heterochronous structure-formational stages; in geologic time, directionally and sign-wise variable regional tectonic motions; mosaic step-block structure.
- stratigraphic complexes, intervals and lithofacies of isolated tectonic blocks separated by the extended high-amplitude regional faults.
- ample depositional lacunas; drastic lithofacies and reservoir property variability in the sections (mostly Cenozoic) formed under the environment of the unbalanced avalanche deposition.

- rhythmicity of the section expressed in the periodic replacement, in the vertical direction, of clay varieties with the sand ones.
- sequential regional pinch-outs of individual intervals both up- and down-dip of the general folding.
- active manifestation of paleo- and neotectonic stress mechanisms.
- widespread fault, diapir, fracture and nappe overthrust tectonics with common mélange-like "twisted" lamination of the crushed clays, carinate and "overturned" folded forms.
  - in some regions, density inversion of the depositional section with thick unconsolidated (sometimes even quasi-liquefied) high-porosity water-saturated plastic (mostly montmorillonite) clays with AHPP (sometimes up to the geostatic level).
  - in some regions, seismic velocity inversions with chaotic seismic events on the cross-sections accompanied by negative gravity, electric and magnetic anomalies.
  - common zones of tectonic fracturing; sometimes intense mud volcanism; high micro- and macro-seismicity with common earthquakes.
  - peculiar, often "inverted" hydro-geochemical profile. AHFP in the reservoirs; and large-scale subvertical interformational and inter-reservoir fluid-mass transfer.

All of these features obviously require the application in the planning and conduct of exploratory operations of conceptually new techniques taking into account the manifold complexity of the structure and fluid dynamics.

Therefore, the understanding must become imperative of the fact that the main criteria in the exploration process are not the qualitative geologic indices: source rocks, traps, reservoirs and seals, which describe not only the **hypothetical probability** of the presence of commercial hydrocarbons, but the rigid regionally-specific quantitative interrelations of structural, thermobaric, lithofacies, reservoir property, hydrodynamic and hydrogeochemical parameters of the natural reservoirs, which determine the **actual probability** of their fill-up with oil and/or gas. The regional oil-gas-saturation of some formations and horizons, the availability of high- and fair-quality reservoirs, contrasting structural traps and thick clay seals is a combination of the **necessary** but not at all the **sufficient** factors of the commercial oil and gas occurrences.

The ***purpose*** of this study is the development of fluid-dynamical fundamentals of the oil and gas accumulation process, of the optimum forecasting strategy and techniques, planning of the exploration for commercial oil and gas occurrences in the Alpine mobile belt basins.

The ensuing ***tasks*** included:

- analysis of the genesis, structure and parameters of the geo-fluid-dynamical fields (hydro-geochemical, hydro-geodynamical, geobaric, geotemperature, etc.).
- the establishment of actual interrelations between the infiltration, elision and overflowing-injection components in the water-exchange within deep horizons.
- the identification of the role of geo-fluid-dynamical factors and mechanisms in the formation of folds and fault dislocations, diapirism, mud volcanism, nappe-overthrust tectonics, structural plans and their relationship between various stratigraphic intervals and structural-formation stages.
- the development of a theoretical oil and gas accumulation model based on the objective inclusion of the dominating geo-fluid-dynamical factors' role in the formation and distribution of the commercial oil and gas occurrences.
- the development of optimized methodologies and techniques for separate forecast and directed exploration of phase-variant accumulations and fields as well as of the complex of qualitative criteria and quantitative parameters of the commercial oil and gas accumulation in natural reservoirs within the Alpine mobile belt basins.

The implementation of the purpose and the solution of the ensuing tasks required the anticipatory detailed review and conceptual interpretation of the specifics of the corresponding geologic domains. It was accomplished based on a systemic analysis of the identified geo-fluid-dynamic correlations performed utilizing the integrated quantitative consideration of the regional and local structural and tectonic specifics, spatial distribution of lithofacies in the section, placement of the natural hydrocarbon accumulations and the localization of their commercial reserves.

Probabilistic statistical processing of the experimental and mathematical modeling results identified spatial patterns in the variability of 33 geo-fluid-dynamical and petroleum geologic parameters. The approximation of binate and multiple correlations between the tectono-structural, hydro-geochemical, hydro-geodynamic, baric, geotemperature, lithological and

reservoir parameters versus the hydrocarbon saturation parameters of local structures (proved hydrocarbon reserves density in million tons of oil equivalent per square kilometer) was conducted. This processing modeled the conditions and environments at different formation stages of the commercial oil and gas occurrences and the absence (incomplete formation and destruction) of the hydrocarbon saturation. It provided for a reliable geologic interpolation into the studied areas and extrapolation into the adjacent territories subject to the exploration and initial appraisal.

The synthesis of all obtained information enabled the development of geo-fluid-dynamic models of the regions listed below and the determination of the oil and gas windows and the limits in the geologic section of the commercial oil and gas occurrences for individual regions and tectonic zones as well as the substantiation of their specific hydrocarbon potential. These, in turn, enabled the mapping of individual structures most prospective for the conduct of exploration and of low-potential areas and contract blocks placed beyond the extrapolated zero productivity line.

This book is a first attempt of the interpretation based on the geo-fluid-dynamic concept, of making strategic decisions and of the practical application in the exploration of the quantitative correlation between the actual natural reservoir parameters and the extent of their hydrocarbon saturation. The information base of this study is the data on 364 best studied oil and gas fields and prospects in 10 basins within the Alpine mobile belts. They include intermontane depressions: the South Caspian (120), the Padan (18), the Viennese (30), the Irrawaddy-Andaman (14), the Los-Angeles (28) and the Maracaibo (26) and foredeep basins: the Carpathian (28), the Indolo-Kuban (49), the Terek-Caspian (30) and the Zagros (21). The basin set is geographically representative. The number of the covered fields and prospects forms a broad database and provides for the variety of specific geologic environments and the representativity of the database.

The study is based on the openly published and confidential field information collected by the authors, on over 70,000 formation water chemical analyses, 10,000 formation temperature measurements in wells with stabilized thermal regime, 3,500 initial formation pressure measurements and on the interpretation of a massive production and petrophysical data.

The authors believe that the study results may benefit planning and conducting exploratory operations in the other basins of mobile belts similar to the studied ones in their tectonotype, composition of the lithological formations, geologic history, etc. The large amount of the included field information used in the study makes the book a valuable reference volume.

In the chapters and sections dealing with the South Caspian Basin, the authors chose to preserve in most cases the pre-1991 names of the local structures as the bulk of many decades of the geologic publications is based on these toponymics. The subsequent total change in the field and prospect names devalues the previous data and deprives the younger generation of geologists of the full-fledged utilization of this treasure.

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