BASIN MODELING - AN EFFECTIVE TOOL OF SYNERGY IN GEOSCIENCES[1]

HAVZA MODELLEMESİ - YERBİLİMLERİNDE SİNERJİ İÇİN ETKİLİ BİR YAKLAŞIM

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ABSTRACT: In many disciplines of geosciences and particularly in petroleum geology a study can hardly be conducted without the involvement of a great number of subdisciplines. Therefore, organization of integrated multidisciplinary teams becomes more and more important. Hereby, a synergy effect is also expected. However, the use of the synergistic team approach can be problematic as demonstrated by the varying success of several companies. Oil and gas accumulations are formed as the result of many processes during basin evolution and hereby a great number of parameters are acting as the controlling parameter. Therefore, a successful exploration can't be performed without a full consideration of the close inter-relationships between all of these parameters and processes. Basin modeling, which is based on the numerical simulation of the respective processes in a deterministic manner enables a full integration of the processes and parameters. Consequently, one needs a team of experts in different fields of geosciences in order to conduct a basin modeling study. Therefore, basin modeling offers a possibility for synergy in geosciences. In this paper, the close similarity between the inter-relational structures of a synergistic team approach and formation of oil and gas accumulations is demonstrated. Furthermore, basin modeling is briefly presented and it is shown how it can help to ensure synergy in geoscientific studies.

Key Words: Synergy, basin modeling, petroleum exploration

ÖZ: Yer Bilimlerinin birçok disiplininde ve özellikle petrol jeolojisindeki bir çalışmayı çok sayıdaki alt disiplinden yardım almaksızın başarmak olanaklı değildir. Bu nedenle çok disiplinli entegre takımların oluşturulması giderek önem kazanmaktadır. Bu bağlamda sinerjinin de sağlanması arzu edilmekte ve beklenmektedir. Ancak, sinerjinin sağlanacağı bir takım çalışmasını gerçekleştirme, uygulamaların gösterdiği gibi kolay olmamaktadır. Petrol ve gaz sahaları havza gelişimi sırasında meydana gelen birçok sürecin sonucunda oluşmaktadır. Bu esnada çok sayıda parametre de belirleyici bir rol oynamaktadır. Bu nedenle, tüm bu süreç ve parametreler ile bunların arasındaki ilişkilerin gözetilmediği arama çalışmalarının başarı şansı bulunmamaktadır. İlgili süreçlerin deterministik anlamda matematiksel simülasyonuna dayanan havza modellemesi tam bir entegrasyon sağlamaktadır. Bir havza modellemesi çalışması için yer bilimlerinin farklı dallarında uzmanlaşmış bir takıma gereksinim bulunmaktadır. Bu nedenle, havza modellemesi arzu edilen sinerjinin sağlanması için de bir olanak sunmaktadır. Bu makalede sinerjetik bir takımın fonksiyonel yapısı ile hidrokarbon sahalarının oluşumu arasındaki benzerlik sergilenmiştir. Ayrıca, havza modellemesi yöntemi kısaca tanıtılmış ve bunun yer bilimleri çalışmalarında arzu edilen sinerjinin sağlanmasına nasıl yardımcı olabileceği gösterilmiştir.

Anahtar Kelimeler: Sinerji, Havza Modellemesi, Petrol Aramacılığı

INTRODUCTION

Geosciences have been undergoing a drastic change during the last few decades. This change can be described in general as "from a more descriptive towards a more quantitative natural science" (Welte, 1989). This is caused on the one hand by the great technological improvements in measuring devices and analytical procedures and on the other hand by incredible developments in computer sciences. Hence nowadays geoscientists are able to use data collected from molecular (nanometer) to continental (thousands of kilometers) scale to solve one single geoscientific problem. Additionally, all these data can be processed and managed very effectively with the help of computers and simulation of

[1] Presented at the 6th Latin American Congress on Organic Geochemistry, October 18-21, 1998, Margarita Island-Venezuela.

very complex processes can be performed within few minutes; which was not possible two decades ago. As a consequence, conducting a modern geoscientific study requires involvement of a great number of subdisciplines several of which have to act together. Hereby, a synergy effect is actually unavoidable.

Synergy is defined as "the cooperative action of discrete agencies so that the total effect is greater than the sum of the effects taken independently". Several companies with varying success have tried the synergistic team approach during the last two decades. As demonstrated by a real experiment the critical aspect by organizing integrated multidisciplinary synergistic teams is the internal functionality of the team, e.g., how team members function among themselves (Sneider, 1986). Hereby, an unbureaucratic, very flat, project oriented organization scheme is the key factor, which enables a direct communication of team members almost without any managemental hierarchy (Figure 1).

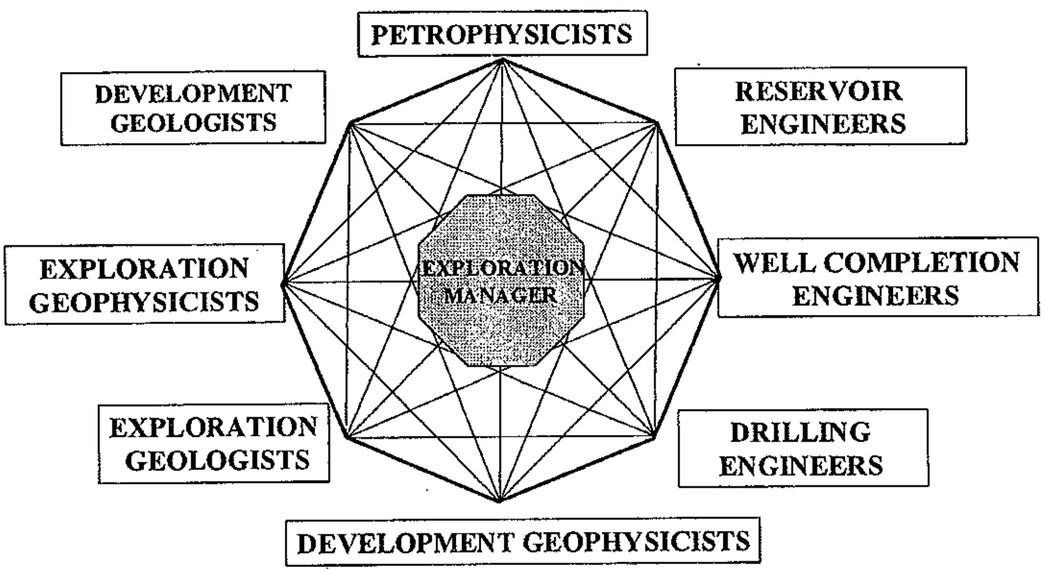

Figure 1. Synergistic organization of a petroleum exploration company (modified from Sneider, 1986).
Şekil 1. Bir petrol arama şirketinin sinerjetik organizasyon şeması (Sneider, 1986'dan değiştirilerek).

We believe, that almost all aspects in geosciences and particularly in petroleum exploration have an inter-relational structure similar to the synergistic team approach. The aim of this paper is to demonstrate this close similarity and to show how basin modeling can help to ensure the required synergy in petroleum exploration and also in other geoscientific studies.

SYNERGISTIC NATURE OF PETROLEUM SYSTEMS AND EXPLORATION

A successful petroleum exploration strategy can only be defined if elements and processes of the respective petroleum system are fully understood. Determination of the elements such as source, carrier and reservoir rocks, traps and seals and definition of the processes such as generation, migration and accumulation of hydrocarbons necessitates the utilization of several geoscientific disciplines ranging from field geology to molecular organic geochemistry. In Figure 2 some of the geodisciplines required for the respective investigations of the elements and processes of a petroleum system are shown. Searching of hydrocarbon generation in source rocks necessitates knowledge, which can be gained in addition to the basic geodisciplines such as stratigraphy, paleontology, etc., mainly from geothermics, sedimentology, organic geochemistry and petrophysics The investigation of hydrocarbon accumulation, which is controlled by the appropriate configuration of reservoir and seal rocks to form a trap requires the involment of even more geodisciplines including structural geology, exploration geophysics, reservoir geology and geophysics (Figure 2). Consequently, if a petroleum system in a certain area has to be studied, one has to use almost all the major disciplines of geosciences. Even investigation of only one aspect such as generation of oil and/or gas in a given source rock requires a multidisciplinary approach. Hereby, the temperature is the only governing factor (Tissot and Welte, 1984). Therefore, the temperature history of a source rock, which is controlled by the thermal history of the respective sedimentary basin (Yalçın and Welte, 1988; Yalçın et. al., 1997) has to be determined.

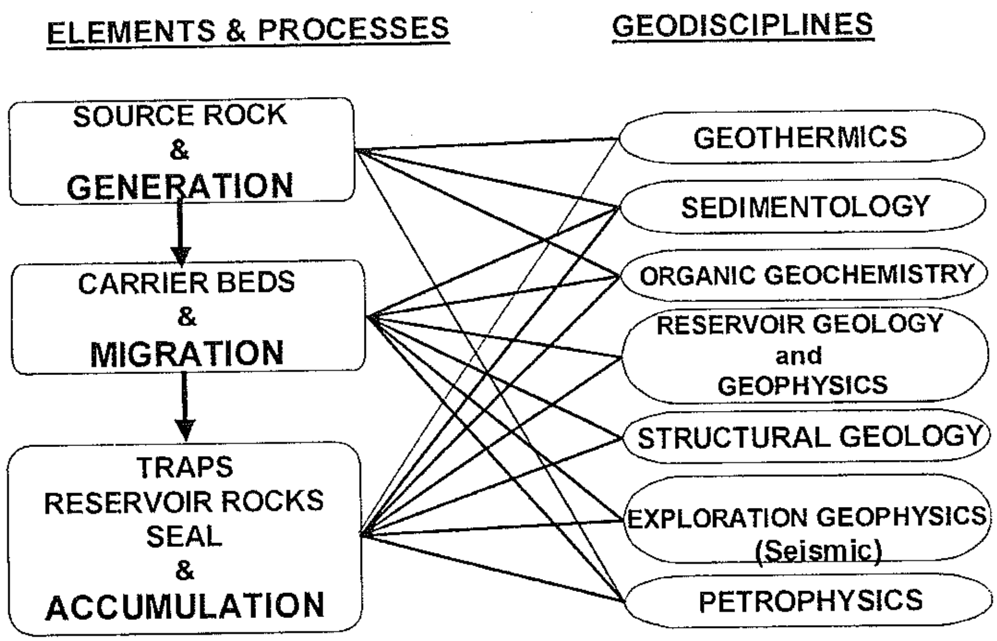

Figure 2. Elements and processes of a petroleum system and geodisciplines which are required to study them.
Şekil 2. Bir petrol sistemindeki unsur ve süreçler ile bunların incelenmesinde yararlanılan yer bilimleri dalları.

Main controls of the temperature history of a source rock are burial history, heat flow density and surface temperatures and their temporal changes during the basin evolution. Heat flow density and surface temperatures define the lower and upper boundary condition for the heat transfer, respectively. Lithologic properties of the basin fill and the water flow are responsible for the conductive and convective transfer of heat, respectively. Burial history of a source rock can only be determined if related data on the basin subsidence, on the stratigraphy of the sedimentary sequence and on the ages of sedimentary, erosional and non-depositional events are available. Tectonics, stratigraphy and paleontology are the respective geodisciplines, which are necessary to obtain the required data (Figure 3). The heat flow density and its temporal distribution can be determined and estimated if related information can be obtained from geothermics and plate tectonics. Similarly, for the surface temperatures one needs studies in the fields of paleo-geography, paleo-climatology and isotope geochemistry. Petrophysics and sedimentary petrography are the respective geodisciplines for an accurate determination of the lithology and sedimentology, hydrogeology and geomorphology for the determination of the hydrologic conditions during basin evolution (Figure 3). Moreover, each of the above-mentioned parameters is interrelated, interdependent and thus they affect each other as demonstrated in Figure 4 for lithology. How sediments consolidate (compact) is a function of the effective stress, the difference between the overburden and pore pressure (Smith, 1971). Hereby, lithology also plays an important role, since different lithologies have different compressibility values, which results in different rates of fluid flow. Fluid flow defines the pressure build-up in pores and the pore pressure controls not only the further compaction but also the heat transfer trough the respective sediments, since the water content has a major effect on the thermal conductivity of the sediments (Yalçın, 1991; Poelchau et. al., 1997). Consequently, lithology also influences the thermal history and generation of hydrocarbons. Processes related to the movement of generated hydrocarbons in a petroleum system are also controlled by the lithology of the respective units, so that expulsion, migration and diffusion of oil and gas cannot be evaluated without considering the lithology (Figure 4). On the other hand processes mentioned in Figure 4 are also linked with each other very closely, so that any of them has to be considered when a complete system evaluation is targeted.

Consequently, a play concept in hydrocarbon exploration can only be evaluated if all these close interrelationships between parameters and processes are fully considered. Here is the analogy with a successful multidisciplinary team is obvious. This leads us again to the concept of multidisciplinary teams where a synergistic effect would help to increase the success ratio in petroleum exploration. At this particular point, basin modeling offers a unique possibility where experts of different subdisciplines in the project team can act in a synergistic manner.

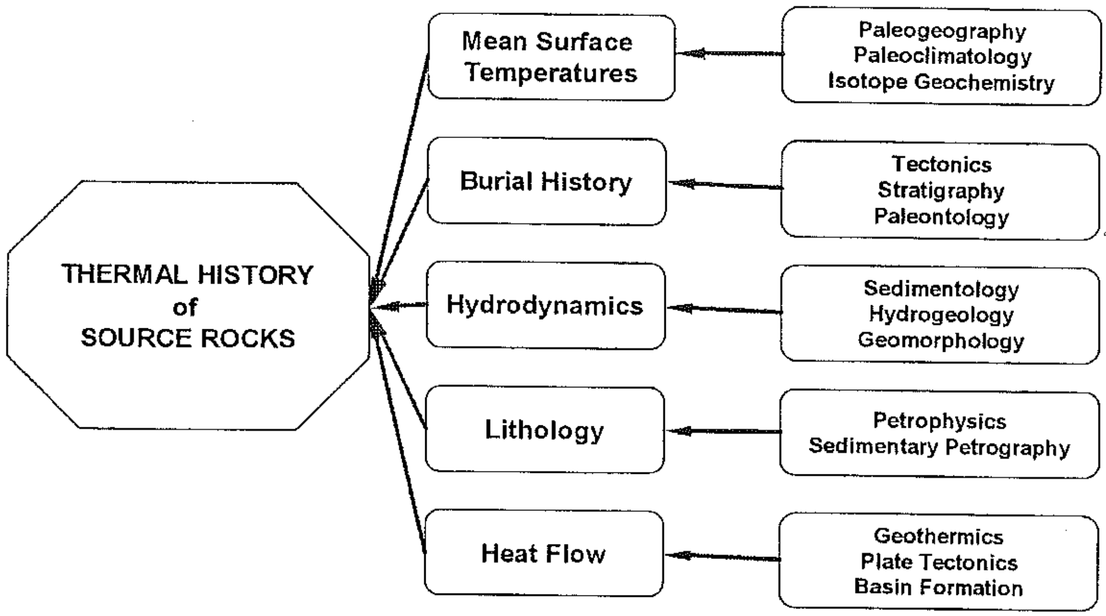

Figure 3. Factors affecting the thermal history of a source rock and related geodisciplines required to study them.
Şekil 3. Ana kayaların termal evrimini etkileyen faktörler ile bunların araştırılmasında yararlanılan yer bilimleri dalları.

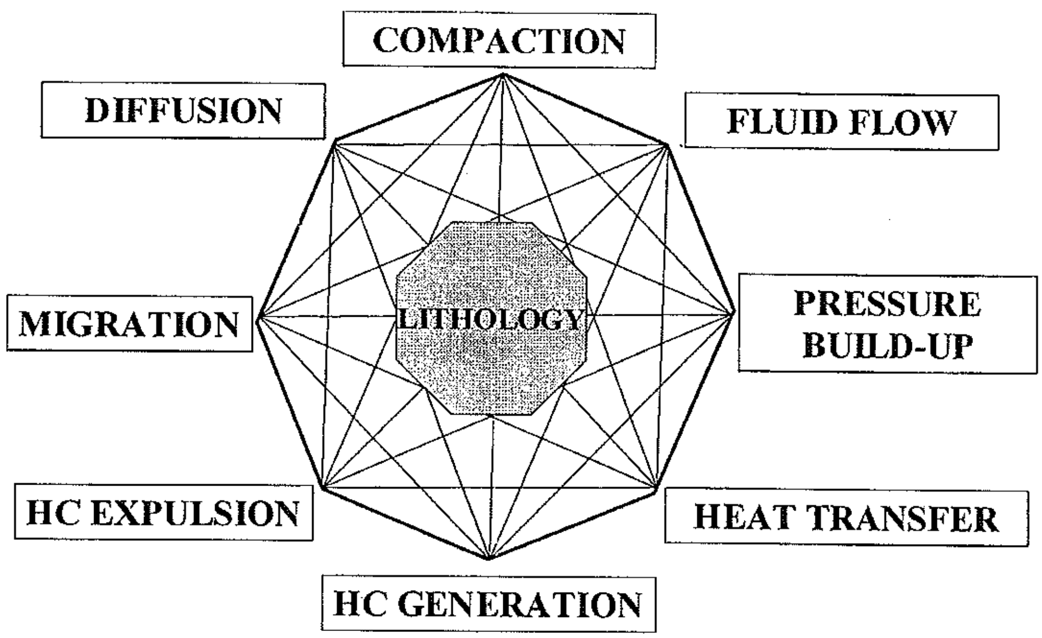

Figure 4. Processes which are closely linked with each other and affected by lithology.
Şekil 4. Birbirleriyle doğrudan bağlantılı ve litolojinin etkilediği süreçler.

BASIN MODELING

Basin modeling, which has been widely accepted as an exploration method is the general term for the numerical simulation of physical and chemical processes such as compaction of sediments, fluid flow and pressure build-up, transfer of heat and generation, expulsion and migration of hydrocarbons in a sedimentary basin (Welte and Yalçın, 1988; Yalçın, 1991). The first applications of basin modeling in petroleum exploration were in early eighties (Welte and Yükler, 1981) although the basic principles were established much earlier. Darcy's concept of fluid flow thorough porous media (Darcy, 1856), Terzaghi's approach of consolidation of sediments by effective stress (Terzaghi, 1925), transfer of heat by conduction (Carslaw and Jaeger 1959), the kinetic approach of hydrocarbon generation (Tissot, 1969) are still in use almost in all the basin modeling programs (Hermanrud, 1993).

Basin modeling generally uses a deterministic forward modeling approach, which is consisted of the following steps (Figure-5):

d) Simulation of the respective processes or system evolution until present and obtaining results.

e) Comparison of modeling results with the real system with the help of measured values and if necessary modification of the conceptual model for a new simulation.

f) Analysis of the result after a reasonable match between computed values and measured values have been obtained.

Further details of basin modeling are given by Hermanrud (1993), by Welte et al. (1997) and by Düp-

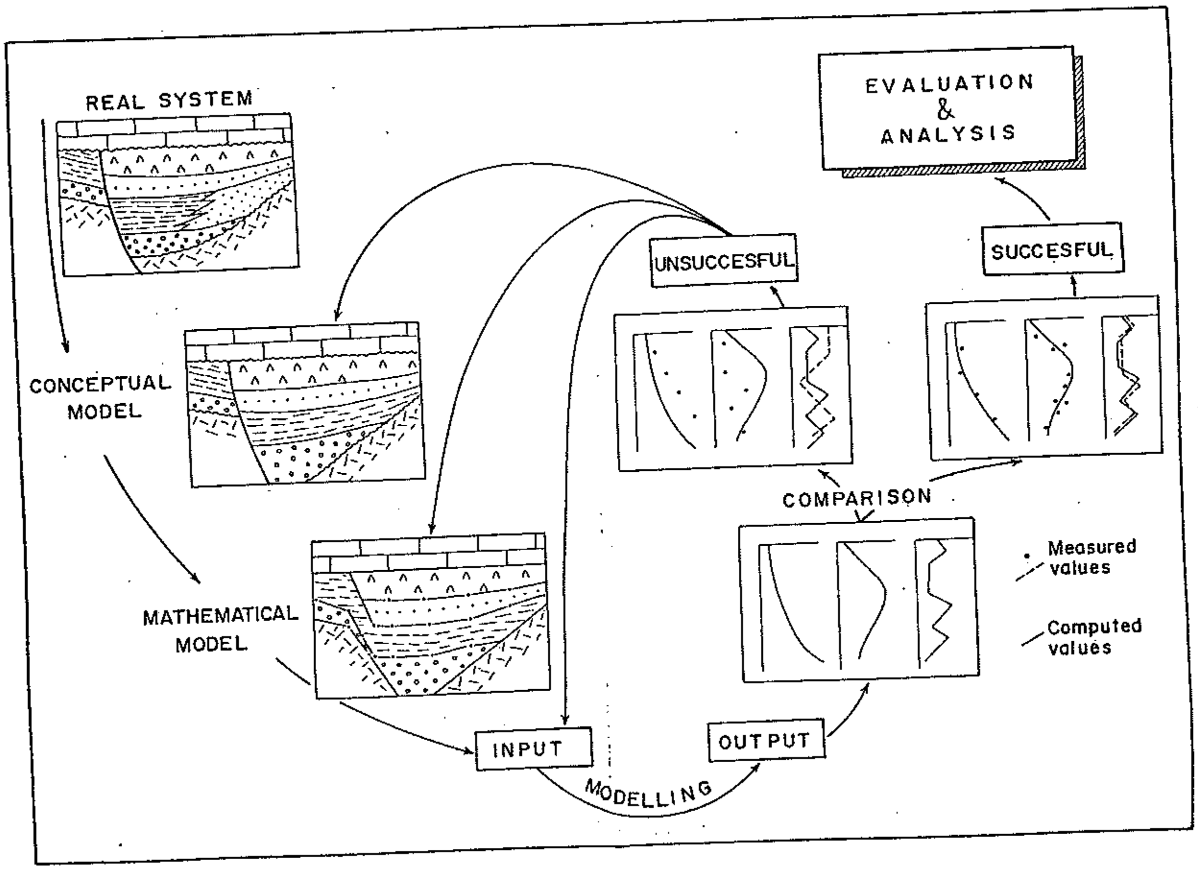

Figure 5. Steps of a basin modeling study (from Yalçın, 1997).
Şekil 5. Bir havza modellemesi çalışmasındaki evreler (Yalçın, 1997'den).

a) Definition of the processes and/or system to be modeled including definition of the system parameters, determination of system boundaries in time and space, assessment of relationships between parameters and processes.

b) Construction of a mathematical model including definition of initial and boundary conditions, derivation of the mathematical equations, finding of suitable algorithms and testing of the stability of mathematical solutions.

c) Construction of conceptual model from the system and preparation of the input data.

penbecker et al. (1998). From the geoscientific point of view, construction of the conceptual model with the respective input and their modification are the most critical and also most didactic steps in basin modeling (Welte and Yalçın, 1985, Yalçın, 1991 and Poelchau et al., 1997).

The conceptual model has to be constructed in uninterrupted temporal sequential order using geochronologic entities called "events". Each event represents a given time span during which a process with a certain uniqueness takes place. The input data for each event consist of age, duration, and thickness (deposited or eroded), petrophysical parameters (porosity, density, permeability, compressibility, thermal conductivity, heat capacity), bathymetry, surface or sea-floor temperatures, heat flow, type and amount of organic matter (if source rocks are deposited) and kinetic parameters of oil and gas generation. It is obvious that one really needs a team of geoscientific experts in order to conduct a basin modeling study, where the team members have to work together since both construction and modification of the conceptual model requires an interactive working procedure. That the team members has to attack the problem in an uninterrupted sequential order is a new way of thinking leading to critical questions which otherwise are never asked. Therefore, both steps help in arriving to a much better understanding of basin evolution even before any simulation result is available. Hereby, some of the very valuable information is gained simply by the created synergy.

CONCLUSIONS

Basin modeling as a geoscientific method enables not only synergy, but it also contributes to a better understanding of complex geological systems. With this powerful tool, geoscientists are well equipped and able to analyze effects of diverse parameters on various processes, to test possible geological evolution scenarios and to make experiments in real time. After a successful basin modeling study, geoscientists are able to define the temporal evolution of each process from the beginning until present, quantitatively. So, questions like when in a source rock oil and gas generation started, when expulsion took place and whether a certain trap was available during migration of hydrocarbons, can be answered precisely, enhancing the success ratio in petroleum exploration.

ACKNOWLEDGEMENT

This study was partly supported by the Research Fund of the Istanbul University (Project Number B-40/180998). This contribution is gratefully acknowledged.

ÖZET

Yer Bilimleri son birkaç on yıl içinde önemli değişimlere uğramakta ve giderek kantitatif bir bilim dalı haline gelmektedir. Bunda bir yanda ölçme ve analiz tekniklerindeki teknolojik gelişmeler, diğer yanda ise bilgisayarların sağladığı olanaklar etkili olmaktadır. Modern bir yer bilimi çalışması, farklı dallardaki birçok uzmanın birlikte çalıştığı takımlarca yapılmaktadır. Takım çalışmasının bir sinerji etkisi yaratması da söz konusudur. Sinerjetik bir takımın en belirgin özelliği, takımı oluşturan fertler arasındaki ilişkilerin şeklidir. Bunun olabildiğince bürokrasiden uzak, yatay ve problem çözmeye yönelik bir organizasyon şemasına oturtulması en kritik unsurdur. Böyle bir takım ile bir çok jeolojik süreç arasında belirgin yapısal benzerlikler bulunmaktadır. Bu makalede işleyişteki bu benzerliklere yer verilecek ve havza modellemesi yönteminin sinerji yaratmadaki katkısı gösterilmeye çalışılacaktır.

Bir yöredeki petrol sisteminin unsur ve süreçleri ile bunlar arasındaki ilişkilerin tümüyle açıklanamadığı arama çalışmalarının başarı şansı bulunmamaktadır. Bu hususların saptanması ise ancak tüm yer bilimleri dallarındaki uzmanlıklardan yararlanılmasıyla mümkündür. Örneğin petrol ve doğal gazın oluşumunda etkili olan ana kayanın sıcaklık tarihçesinin ortaya konabilmesi için levha tektoniğinden izotop jeokimyasına kadar uzanan konulardaki uzmanlıklara gereksinim bulunmaktadır. Bunun yanısıra litoloji gibi bir tek özellik konsolidasyondan difüzyona kadar bir dizi süreci birden kontrol edebilmektedir. Bu anlamda havzalardaki jeolojik süreçlerin doğası ile farklı dallardaki uzmanların entegre olarak çalıştığı takımlar arasında benzerlikler bulunmaktadır. Arzu edilen sonuçlara uyumlu ve entegre işleyişler sonucunda ulaşılmaktadır. Uyumlu entegrasyon sinerjiyi de beraberinde getirmektedir.

Uyumlu takımların oluşturulmasında karşılaşılan zorlukların aşılmasında havza modellemesi yöntemi bazı olanaklar sunmaktadır. Çok farklı jeolojik süreçlerin numerik simülasyonuna dayanan yöntemin uygulanması için havza ve jeolojik evrimi hakkında tüm bilinenlerden yararlanılarak bir kavramsal evrim modeli ortaya konmakta ve buna dayanılarak girdi (input) hazırlanmaktadır. Modelin kalibrasyonu için de modelleme sonucu elde edilen bulgular ile mevcut ölçüm sonuçları karşılaştırılmakta ve gerektiğinde kavramsal modelde değişikliklere gidilmektedir. Tüm bu aşamalar için bir dizi uzmanın birlikte ve uyumlu bir takım halinde çalışması gerekmektedir. Bu da arzu edilen sinerjiyi beraberinde getirmektedir.

Havza modellemesi sinerjinin yanısıra yer bilimlerinde uzun bir zamandır eksikliği duyulan sayısal yaklaşımı ve karmaşık jeolojik olayların kavramsal bir bütünlük içinde ele alınmasını da sağlamaktadır. Bunun da ötesinde jeolojideki zaman boyutunun olanaksız kıldığı "deneysel jeoloji" sanal ortamda da olsa mümkün olmaktadır. Bunun sonucunda değişik evrim senaryolarının test edilmesi, duyarlık analizlerinin yapılması ve zamana bağlı değişimlerin ortaya konması, bir başka deyişle jeolojik geçmişe bir pencerenin açılması, başarılabilmektedir.

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Makalenin geliş tarihi : 24.01.2001
Makalenin yayına kabul tarihi : 16.04.2001
Received : January 24, 2001
Accepted : April 16, 2001