Predictive Models for Roadheaders’ Cutting Performance in Coal Measure Rocks

*A. Ebrahimabadi1, K. Goshtasbi2, K. Shahriar3, M. Cheraghi Seifabad4

1Department of Mining, Faculty of Engineering, Islamic Azad University, Qaemshahr Branch, Qaemshahr, Iran
2Department of Mining, Faculty of Engineering, Tarbiat Modares University, Tehran, Iran
3Department of Mining, Metallurgical and Petroleum Engineering, Amirkabir University of Technology, Tehran, Iran
4Department of Mining, Isfahan University of Technology, Isfahan, Iran, 84156-83/11

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ABSTRACT

Roadheaders offer a unique capability and flexibility for the excavation of soft to medium strength rock formations, hence; are extensively used in underground mining and tunneling operations. A critical issue in successful roadheader application is the ability to evaluate and predict the machine performance. The main objective of this research study is to investigate the cutting performance of roadheaders in coal measure rocks by paying special attention to the influence of discontinuity orientation (alpha angle) and the specific energy. With this respect, a database was established from detailed field data including the measured instantaneous cutting rates (ICR) and geomechanical parameters of the coal measure rocks for each cutting condition in the tunnels. The database was then analyzed by utilizing the statistical method in order to yield new predictive models. The influence of alpha angle (the angle between tunnel axis and the planes of weakness) on roadheader performance was investigated and the correlation between them was found to be good ($R^2=0.96$). The analysis of the specific energy also showed that there is a relatively good relation ($R^2=0.91$) between this parameter and ICR. Finally, the new predictive models for ICR (with respect to alpha angle and specific energy) showed to have highly correlated relationships within the limits of measured values and hence may successfully be used to evaluate the performance of medium-duty roadheaders in coal measure rocks.

Keywords: Performance prediction, Roadheader, Alpha angle, Specific energy, Coal measure rocks
INTRODUCTION

The more widespread use of mechanical excavators, such as roadheaders, continuous miners, impact hammers and tunnel boring machines is a trend set by increasing pressure on the mining and civil construction industries to move away from the conventional drill and blast methods to increase productivity, decrease production costs, improve competitiveness and safety, and reduced number of personnel. Roadheaders are a unique class of mechanical excavation machines used in the mining industry particularly in coal mining and industrial minerals. Roadheaders are very versatile excavation machines favored in mining operation due to a high degree of mobility, flexible cutting profile (i.e., horseshoe), selective mining, providing immediate access to the face and the capability to cut medium strengths rocks with compressive strength of up to about 100 MPa (Copur et al, 1998).

Performance prediction is an important issue for successful roadheader application and generally deals with machine selection, production rate and bit consumption. Performance prediction encompasses the assessment of instantaneous cutting rate (ICR), bit consumption rates and machine utilization for different geological units. The instantaneous cutting rate is the production rate during cutting time (tons or m³ /cutting hour). Bit or pick consumption rate refers to the number of picks changed per unit volume or weight of rock excavated (picks / m³ or m³ / pick). Machine utilization is the percentage of time used for excavation during the project. The roadheader production rate and pick consumption are controlled by several parameters including (Rostami et al, 1994):

- Rock parameters, such as rock compressive and tensile strength, etc.
- Ground conditions, such as degree of jointing (RQD), joint conditions, ground water, etc.
- Machine specification, including machine weight, cutter head power, sumping, arcing, lifting, and lowering forces, cutter head type (axial or transverse), bit type, size, number and allocation of bits on the cutter head, the capacity of back up system, and other characteristics.
- Operational parameters, such as shape, size, and length of opening, inclination, quality of labor, etc.

A combination of these parameters determines the production rate of a given machine in a certain ground condition.

The paper, first gives a brief background of roadheader performance prediction models and then information about a database from the detailed field data including machine performance and geotechnical parameters in entries from the Tabas Coal Mine project (the largest and fully mechanized coal mine in Iran). Thereafter, the paper highlights some of the previous attempts made to construct models to predict the roadheaders performance in Tabas coal mine. Using the data, subsequently, a set of performance prediction equations are developed.

BACKGROUND ON PERFORMANCE PREDICTION MODELS FOR ROADHEADERS

Sandbak (1985) and Douglas (1985) used a rock classification system to explain changes in roadheader’s advance rates at San Manuel Copper Mine in an inclined drift at an 11% grade (Bilgin et al., 2004). Gehring (1989) studied the relationship between ICR and rock uniaxial compressive strength (UCS) for a milling type roadheader with 230kW cutter head power and an Alpine Miner AM 100 ripping type roadheader with 250kW cutter head power. He developed following equations without giving correlation coefficients:

\[ \text{ICR} = \frac{719}{\text{UCS}^{0.78}} \]  

(1)

for ripping type roadheaders, and

\[ \text{ICR} = \frac{1739}{\text{UCS}^{1.13}} \]  

(2)

for milling type roadheaders.
Where \( ICR \) denotes as cutting performance \((\text{m}^3/\text{hr})\), and \( UCS \) as the uniaxial compressive strength \((\text{MPa})\). Based on rock compressive strength and rock quality designation, Bilgin et al. (1988, 1990, 1996, 1997, 2004) had also developed a performance (ICR) equation as:

\[
ICR = 0.28 \cdot P \cdot (0.974)^{\text{RMCI}}
\]

\( \text{RMCI} = \frac{UCS \times (RQD/100)^{2/3}} \)

where \( P \) is the power of cutting head (hp), \( \text{RMCI} \) is the rock mass cuttability index and \( \text{RQD} \) is the rock quality designation (%). Copur et al. (1997, 1998) studied the variation of cutting rate with \( \text{UCS} \) based on available field performance data for different types of roadheaders at different geological conditions. They stated that if power and weight of roadheaders were considered together, in addition to rock compressive strength, the cutting rate predictions would be more realistic. The predictive equations for transverse (ripping type) roadheaders are as follows:

\[
ICR = 27.511e^{0.0023(RPI)}
\]

\[
\text{RPI} = \frac{P \times W}{\text{UCS}}
\]

Here, \( \text{RPI}, \text{UCS}, W, P \) and \( e \) denote roadheader penetration index, uniaxial compressive strength \((\text{MPa})\), roadheader weight \((\text{t})\), power of cutting head \((\text{kW})\), and base of natural logarithm, respectively. Thuro and Plinninger (1999) determined the relationship between the cutting rate and the uniaxial compressive strength for 132kW roadheader. They found that the correlation between \( \text{UCS} \) and cutting performance is not sufficient in predicting the cutting rate. They obtained higher correlation by putting the cutting performance against specific destruction work \((\text{kJ}/\text{m}^3)\). Specific destruction work \((W_z)\) is defined as the measurement for the quantity of energy required for destruction of a rock sample or – in other words – the work, necessary to built new surfaces (or cracks) in rock. They presented the following predictive equation:

\[
ICR = 107.6 - 19.5 \ln(W_z)
\]

where \( W_z \) is the cutting performance \((\text{m}^3/\text{hr})\) and the specific destruction work \((\text{kJ}/\text{m}^3)\).

Another way of predicting the machine instantaneous cutting rate is to use specific energy described as the energy spent to excavate a unit volume of rock material. Widely accepted rock classifications and assessments for the performance estimation of roadheaders are based on the specific energy found from core cutting tests. Detailed laboratory and in situ investigations by McFeat-Smith and Fowell (1977, 1979) showed that there was a close relationship between specific energy values obtained separately from both core cutting tests and cutting rates for medium and heavy weight roadheaders.

One of the most accepted methods to predict the cutting rate of any excavating machine is to use, cutting power, specific energy obtained from full scale cutting tests and energy transfer ratio from the cutting head to the rock formation as indicated in the following equation (Rostami et al, 1994):

\[
ICR = k \frac{P}{SE_{opt}}
\]

where \( P \) is the cutting power of the mechanical miner \((\text{kW})\), \( SE_{opt} \) is the optimum specific energy \((\text{kWh}/\text{m}^3)\), and \( k \) is the energy transfer coefficient depending on the mechanical miner utilized. Rostami et al. (1994) strongly emphasized that the predicted value of the cutting rate was more realistic if the specific energy value in the equation was obtained from the full-scale linear cutting tests in optimum conditions using real life cutters. Rostami et al. (1994) pointed out that \( k \) changed between 0.45 and 0.55 for roadheaders and from 0.85 to 0.90 for TBM.

**DESCRIPTION OF TABAS COAL MINE PROJECT**

Tabas coal mine, the largest and unique fully mechanized coal mine in Iran, located in central part of Iran near the city of Tabas in Yazd province and situated 75 km far from southern Tabas. The mine area is a part of Tabas-Kerman
coal field. The coal field is divided into 3 parts in which Parvadeh region with the extent of 1200 Km² and 1.1 billion tones of estimated coal reserve is the biggest and main part to continue excavation and fulfillment for future years.

The Coal seam has eastern-western expansion with reducing trend in thickness toward east. Its thickness ranges from 0.5 to 2.2 m but in the majority of conditions it has a consistent 1.8 m thickness. Room and pillar and long wall mining methods are considered as the main excavation methods in the mine. The use of roadheaders in Tabas coal mine project was a consequence of mechanisation of the work. Coal mining by the long-wall method with powered roof supports requires rapid advance of the access roads. On the other hand, the two alternatives for mining very thick coal seams, i.e. room-and-pillar and long wall in flat seams, also requires the use of roadheader driving galleries in the coal seams. Four DOSCO MD 1100 roadheaders of 34 t in weight, with a 82-kW axial cutting head mainly used in driving galleries with coal measure rocks (coal, siltstone and mudstone) in the Tabas coal mine. Figs.1 and 2 show DOSCO MD 1100 roadheader and typical view of rock formations encountered in the tunnels’ route. Table 1 indicates the basic specifications of these roadheaders (Dosco Ltd, 2008).

![Figure 1. DOSCO MD1100 roadheader fitted with axial boom used in Tabas Coal Mine project (Dosco Ltd, 2008).](image1)

![Figure 2. Typical view of rock formations encountered in the tunnels route. (All dimensions are in meter).](image2)

As seen in Table 2, a comprehensive database of field performance from Tabas Coal Mine was established by using the detailed data including machine performance and geomechanical parameters for 62 cutting cases in tunnels and entries of the proposed project (Ebrahimabadi, 2010).

**PREVIOUS PREDICTIVE MODELS IN TABAS COAL MINE**

Studies regarding the performance prediction of roadheaders in the Tabas coal mine project were done from a detailed field data including...
Table 1. Typical specifications of DOSCO MD 1100 roadheaders (Dosco Ltd, 2008)

<table>
<thead>
<tr>
<th>Specification</th>
<th>Value</th>
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<tbody>
<tr>
<td>Machine weight (Base machine)</td>
<td>34 tons</td>
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<tr>
<td>Total power (Standard machine)</td>
<td>From 157 kW</td>
</tr>
<tr>
<td>Power on cutting boom (Standard machine)</td>
<td>82 kW axial, 112 kW transverse</td>
</tr>
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<td>Hydraulic system working pressure</td>
<td>140 bar</td>
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<td>Tracking speeds – Sumping/Flitting</td>
<td>0.038/0.12 m/sec</td>
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<td>Ground pressure</td>
<td>1.4 kg/cm²</td>
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<td>Machine length</td>
<td>8060 mm</td>
</tr>
<tr>
<td>Machine width</td>
<td>3000 mm</td>
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<tr>
<td>Machine height</td>
<td>1700 mm</td>
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</table>

machine performance and geomechanical parameters in tunnels and entries of the project. Consequently, a comprehensive field performance database was established (Ebrahimabadi, 2010; Ebrahimabadi et al., 2011). As a result, models to predict the performance of roadheaders based on brittleness index were developed. Rock mass brittleness index (RMBI) is defined in order to investigate the influence of intact and rock mass characteristics on roadheaders performance. Results demonstrated that RMBI is highly correlated to instantaneous cutting rate (ICR) ($R^2=0.98$). Moreover, through the further analysis and normalization, pick consumption index (PCI) was introduced as a parameter having a good relation with pick or bit consumption rates (PCR) ($R^2=0.94$). The predictive equations were as follows (Ebrahimabadi, 2010; Ebrahimabadi et al., 2011):

$$RMBI = e^{\left(\frac{UCS}{BTS}\right)} \times \left(\frac{RQD}{100}\right)^3$$  \hspace{1cm} (9)

$$ICR = 30.74RMBI^{0.23}$$  \hspace{1cm} (10)

$$PCI = e^{RMBI} \times \left(\frac{UCS}{P}\right)$$  \hspace{1cm} (11)

$$PCR = 45.10PCI^{-0.15}$$  \hspace{1cm} (12)

where RMBI is the rock mass brittleness index, $UCS$ is the uniaxial compressive strength of rock (MPa), $BTS$ is the Brazilian tensile strength of rock (MPa), RQD is the rock quality designation of the rock mass (%), PCI is the pick consumption index, PCR is the pick consumption rate (m$^3$/pick), and P is the cutter head power (kW). In the Equation 11, P is considered to be 82 kW (the cutter head power of the DOSCO MD 1100 roadheader).

It should be noted that the Equations 9-12 were achieved from the analysis of 42 cutting cases. After gathering additional data from other cutting cases and subsequently establishing a database with 62 cutting cases, Equation 10 has been modified to the following equation:

$$ICR = 9.07 \ln(RMBI) + 29.93$$  \hspace{1cm} (13)

It must be stated that in the above predictive equations don’t include the influence of discontinuities orientation and the specific energy. Therefore, in this research study new models are developed in order to involve these factors.

**DATABASE ESTABLISHMENT**

The type and density of discontinuities have a crucial importance on both the behavior of a rock mass and machine advancement. In order
Table 2. Summary of rock properties, roadheaders performance, rock mass brittleness index, alpha angle and the specific energy for all cutting cases (Ebrahimabadi, 2010)

<table>
<thead>
<tr>
<th>Case No.</th>
<th>Representative uniaxial compressive strength (MPa)</th>
<th>Representative Brazilian tensile strength (MPa)</th>
<th>RQD (%)</th>
<th>Measured instantaneous cutting rate (m³/hr)</th>
<th>Calculated rock mass brittleness index (RMBI)</th>
<th>Calculated alpha angle (Deg.)</th>
<th>Calculated specific energy (MJ/m³)</th>
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to be able to quantify the influence of discontinuity orientation on roadheader performance, the alpha angle that is the angle between the tunnel axis and the planes of weakness are used. In order to calculate the alpha angle, the orientation of the discontinuities and the driven direction of the roadheaders were measured in the field. The alpha $\alpha$ in degrees can be calculated using the following equation (Yagiz, 2008):

$$\alpha = \arcsin\left(\sin \alpha_f \cdot \sin(\alpha_t - \alpha_s)\right)$$

(14)

where $\alpha_f$ and $\alpha_s$ are the dip and strike of the encountered planes of weakness in the rock mass, respectively. $\alpha_t$ is direction of the tunnel axis. Moreover, specific energy is one of the most important factors in determining the efficiency of cutting systems. Widely accepted rock classification and assessment for the performance estimation of roadheaders was based on the specific energy found from core cutting tests. The test involved instrumented cutting tests on 76mm diameter cores at a depth of cut of 5mm, cutting speed of 150 mm/s with a chisel-shaped tungsten carbide tool having 10% cobalt by weight, 3.5-μM nominal grain size, rake angle of (-5°), back clearance angle of 5° and tool width of 12.7 mm (Fowell and McFeat-Smith, 1979). Detailed laboratory and in situ investigations carried out by Fowell and McFeat-Smith (1979) showed that there was a close relationship between specific energy values obtained from core cutting tests and cutting rates of medium and heavy-weight roadheaders. They formulated core cutting specific energy as in Equation 15 (Hartman, 1992):

$$SE = -4.38 + 0.14 (0.037UCS + 0.254)$$

(15)

$$+ 3.30(UCS^{rac{1}{2}} + 0.000018(0.441UCS - 8.37) + 0.0057CC)$$

Where SE is the specific energy (MJ/m³), UCS is the rock uniaxial compressive strength (MPa) and CC is the cementation coefficient. The cementation coefficient is based on petrographic descriptions of the rock. In order to quantify the degree and type of cementation, McFeat-Smith (1977) carried out a study on thin sections and photomicrographs of broken surfaces of a range of sedimentary rock types. The following conclusions were reached:

1. The type of cementation should be assessed according to the hardness of the cementing material.
2. The grain size of quartz cements, i.e., sand, silt, and clay influence the strength of the bond and should be represented in that order.

3. The degree of cementation is significant in extreme cases, and major variations in the porosity of a rock provide a suitable measure of this.

The quantification of a Cementation Coefficient (CC) which has been constructed according to these observations is as follows:

CC=1 for non-cemented rocks or those having greater than 20% voids, CC=2 for Ferruginous cement, CC=3 for Ferruginous and Clay cement, CC=4 for Clay cement, CC=5 for Clay and Calcite cement, CC=6 for Calcite or Halite cement, CC=7 for Silt, Clay or Calcite with Quartz overgrowths, CC=8 for Silt with Quartz overgrowths, CC=9 for Quartz cement, Quartz mosaic cement and CC=10 for Quartz cement with less than 2% voids. According to this quantification and based on field observations, CC=5 is considered for the coal measure rocks in the Tabas coal mine.

Detailed field investigations were carried out where the machine performance and the geomechanical properties of the coal measure rocks encountered in the Tabas coal mine project were collected. With this regard, the values of instantaneous cutting rate were measured in the field and the values of rock mass brittleness index, alpha angle, and the specific energy were calculated using Equations 9, 14 and 15, respectively for each cutting case, as listed in Table 2.

**NEW PREDICTIVE MODELS BASED ON ALPHA ANGLE AND SPECIFIC ENERGY**

After the establishment of the database, statistical analysis was used to investigate the relation between the parameters. Subsequently, the relation between ICR, RMBI and \( \alpha \) angle was investigated and the correlation between them was found to be good (\( R^2 = 0.96 \)). Consequently, the following predictive equation for calculating the ICR with respect to \( \alpha \) was obtained:

\[
ICR = 5.56RMBI + 0.60\alpha - 8.17 \tag{16}
\]

Where RMBI is the rock mass brittleness index, and \( \alpha \) is the angle between tunnel axis and the planes of weakness in degrees. Summary of statistical model is given in Table 3.

Comparison between the measured and the predicted ICR is given in Figure 3 for each cutting case. Using Equation 16 for prediction of ICR with respect to \( \alpha \), a reliable relationship between the predicted and the measured ICR was obtained with \( R^2 = 0.96 \). Table 4 shows the values of measured and predicted ICR with percentage of relative errors between them.

In this study, the specific energy was calculated for each cutting case and its relation with the instantaneous cutting rate was then investigated. Consequently, the relation between them was found to be relatively good (\( R^2 = 0.91 \)), as demonstrated in Figure 4. Summary of statistical model is given in Table 5. The predictive equation is as follows:

\[
ICR = -0.18SE^3 + 28.57SE - 92.82 \tag{17}
\]

where SE is specific energy (MJ/m³). Using Equation 17 for the prediction of ICR with respect to the specific energy, another relationship between the predicted and the measured ICR was obtained with \( R^2 = 0.91 \) (Figure 5). Table 4 shows the values of measured and predicted ICR with percentage of relative errors between them.

<table>
<thead>
<tr>
<th>Model Type</th>
<th>( \alpha )</th>
<th>( R^2 )</th>
<th>Adjusted ( R^2 )</th>
<th>Std. error of the estimation</th>
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Dependent variable: Measured ICR (m³/hr)

a. Predictors: (Constant), RMBI, \( \alpha \)
Figure 3. Linear regression between measured ICR and predicted ICR (with respect to alpha angle) ($R^2=0.96$).

Figure 4. Relation between measured ICR and specific energy ($R^2=0.91$).

Table 4. Measured and predicted ICR with percentage of relative errors between them for all cutting cases (Continued)

<table>
<thead>
<tr>
<th>Case No.</th>
<th>Measured instantaneous cutting rate (m³/hr)</th>
<th>Predicted instantaneous cutting rate (with respect to alpha angle) (m³/hr)</th>
<th>Relative error between measured and predicted instantaneous cutting rate (with respect to alpha angle) (%)</th>
<th>Predicted instantaneous cutting rate (with respect to specific energy) (m³/hr)</th>
<th>Relative error between measured and predicted instantaneous cutting rate (with respect to specific energy) (%)</th>
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Table 5. Typical specifications of DOSCO MD 1100 roadheaders (Dosco Ltd, 2008)

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<th>R²</th>
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<th>Std. error of the estimation</th>
</tr>
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<td>0.91</td>
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</tbody>
</table>

Dependent variable: Measured ICR (m³/hr)

a. Predictors: (Constant), SE (MJ/m³)
The second model (Equation 17) has been developed only based on SE. It is due to investigate the relation between ICR and SE to gain in which ICR value, the specific energy represents the minimum value. Having this ICR and its corresponding RMBI, the $\alpha$ angle can be calculated using Equation 16. As a consequence, the excavation routes should be designed on the basis of this value to yield maximum cutting performance (minimum specific energy). It should be noticed that the optimum SE can be best measured by utilizing linear cutting machine but because of lack of the equipment, specific energy determined using Equation 15. Moreover, it should be kept in mind that findings with the alpha angle that is investigated for axial (milling) type head as in this work may not be fully considered for transverse type roadheaders, due to the fact that the cutting position of each cutting head is orientated differently with respect to the tunnel axis.

Utmost care should be paid when considering cutting head power of roadheaders for performance predictions, as roadheaders with different cutting head type are also seen to perform differently. Machines with transverse (ripping) type cutting heads generally have higher motor power and lower weight, while the opposite is true for those of axial type. An ICR value obtained with a transverse machine, may also be achieved by a similar size milling (axial) type machine, all operating in similar conditions, i.e. machines are likely to perform the same duty despite having different cutting head motor power. It is, therefore, important to mention that the findings in this work are suitable to predict the performance of medium-duty roadheaders fitted with axial cutting head. In performance prediction, many authors discard the cutting head design. Previous works (Hekimoglu and Fowell, 1990; Hekimoglu, 1995; Hekimoglu et al., 2003; Hekimoglu and Ozdemir, 2004) clearly showed that under the identical conditions, the cutting performance of mechanical excavators such as roadheaders and coal shearsers dramatically increased with a modification in their cutting head/drum design.

CONCLUSIONS

Primarily, field investigations were conducted in order to determine the geomechanical properties and machine performance in the Tabas coal mine project. Special attentions were made on determining the influence of discontinuity orientation and specific energy of the coal measure rocks on the performance of roadheaders. With this respect, the alpha angle (the angle between the tunnel axis and the planes of weakness) and the specific energy (the work to excavate a unit volume of rock) were determined for each cutting case. The instantaneous cutting rates (the machine performance) were also measured for each cutting case. Subsequently, a database regarding the required parameters was established. The statistical analysis was then utilized to establish relations between the ICR and various parameters of the database. With this respect, two new performance predictive models (with respect to alpha angle and the specific energy) were developed. The comparison between the measured and the predicted ICR using the two developed models show to have a good correlations. However, it is observed that the correlation for the model utilizing the alpha parameter is higher ($R^2=0.96$) than the model using the specific energy ($R^2=0.91$). Within the measured variables and available conditions, the predictive models established in this work for ICR may successfully be used for performance prediction of medium-
duty roadheaders of axial (milling) type operating in coal measure rocks.

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REFERENCES


Dosco Overseas Engineering Ltd., 2008. WWW. dosco.co.uk


Hekimoglu, O.Z., and Fowell, R.J., 1990. From research into practice In-situ studies for design of boom tunnelling machine cutting heads. 31st U.S. Rock Mechanics Symposium, Colorado School of Mines, USA.


McFeat-Smith, I., 1977. Rock property testing for the assessment of tunneling
machine performance. Tunnels and Tunneling, 29-33.


Palynological Analysis of Neogene Mammal Sites of Turkey – Vegetational and Climatic Implications

Türkiye’de Neojen Memeli Bulgu Yerlerinden Palinolojik Analizler – Vejetasyonel ve İklimsel Çıkarımlar

*Nurdan YAVUZ IŞIK*, Gerçek SARAÇ, Engin ÜNAY, Hans de BRUIJN

1Ondokuz Mayıs University, Civil Engineering Department, 55139 Kurupelit-Samsun, Turkey
2Mineral Research and Exploration Institute, Ankara, Turkey
3Cumhuriyet University, Sivas, Turkey
4Institute of Earth Sciences, University of Utrecht, the Netherlands

ABSTRACT

Pollen assemblages from lacustrine sediments that have known positions relative to mammal faunas in central and western Turkey are analysed. The stratigraphical order of the pollen samples is based on the stage of evolution of the associated mammal remains. The early Early Miocene pollen spectra indicate a flora dominated by mega-mesothermic elements such as Engelhardia and this flora reflects a subtropical climate. The decrease of mega-mesothermic elements during late Early Miocene suggests a slight decrease in temperature. During Middle Miocene a rich mixed forest flora including Quercus, Engelhardia, Zelkova, Parrotia persica, Alnus, Cedrus and Pinus indicative of a warm temperate climate are identified. The loss and decrease in abundance of several mesothermic elements indicates a possible climatic deterioration in Late Miocene. The Late Miocene flora reflects wide open areas with dominant Asteraceae. The Pliocene and Pleistocene palynofloras are similarly rich in herbs such as Asteraceae, Amaranthaceae/Chenopodiaceae and coniferous trees (Pinus, Tsuga, Cedrus, Abies) developed in a humid-temperate climatic condition. These palaeoclimatological interpretations are basically supported by the mammal faunas collected from the same localities.

Key Words: MN zones, Neogene, pollen, Turkey, vegetation, climate.

ÖZ


N.Y.Işık
E-mail: nurdany@omu.edu.tr
INTRODUCTION

Continental fossil floras (represented by pollen, leaves, fruits) often lack reliable age determinations (Kovar-Eder et al. 1996). Such floras should wherever possible be dated by independent techniques (radiometry, magnetostratigraphy, mammalian biochronology). If a floral locality is found in association with small mammals the relative age control is good, but due to the different preservation potential of animals and plants, it is not easy to integrate floral and faunal data (but see Yavuz-Işık 2008). The often poor age control of fossil floras makes temporal comparisons difficult. Plants tend to be preserved under anaerobic, non-alkaline, low-energy conditions, whereas mammal remains are often found in alkaline, well-oxidized, high-energy deposits (Strömberg et al. 2007). As a result, palynomorph floras commonly reflect different depositional environments than do vertebrate fossils. Despite this, fossil pollen and vertebrates sometimes occur in the same deposit, or even in the same layer (Brugal et al. 1990).

The aim of this study is to reconstruct palaeovegetation from the palynology of sediments associated with vertebrate assemblages of known ages in central and western Turkey. This is based on an already published pollen analysis of Keseköy samples (Yavuz-Işık 2008) and new data on surface samples from various localities using botanical taxonomy and a quantitative approach of the pollen data. It is the first paleobotanical study in this region based on samples that have known positions relative to mammal faunas. This approach allows the stratigraphical correlation of different vegetation types.

In Turkey there are some palynological studies, to identify climatic conditions and vegetation during Neogene, in which studied samples were dated by radiometric data (Yavuz-Işık, 2008; Yavuz-Işık and Toprak 2010), marine fossils (Sancay et al., 2006) pollen and spores (Akgün and Akyol 1999; Karayiğit et al., 1999; Kayseri and Akgün, 2008) and also mammals (Akgün et al., 2000; Yavuz-Işık, 2007; Kayseri ve Akgün, 2010). In the last couple of years palynological data have been analyzing by climatic programmes to get quantitative climate data. Akgün et al., (2007) was the first to produce quantitative climatic data by applying the Coexistence Approach method of Mosbrugger and Utescher (1997) in Turkey. The authors reported that during Chattian and Aquitanian warm subtropical (mean annual temperature between 16.5-21.3 °C), during early-late Serrevalian subtropical (mean annual temperature between 17.2-20.8 °C) and during the Late Miocene warm temperate climatic conditions were present in Western and Central Anatolia. By using the same method Kayseri and Akgün (2008, 2010) also produce quantitave climatic data based on pollen assemblages. Recently, Akkiraz et al. (2010) shown temporal palaeo-precipitation values in Western and Central Anatolia during the Miocene via same method. The climatic results of these studies, wherever possible, are compared with the results of the current study.

MATERIALS AND METHODS

Sample Collecting

In an effort to find pollen floras in association with mammal faunas, fiftyone mammal localities, of which faunal assemblages already studied and used in zonation of the continental Turkish Neogene, have been visited and hundredsixteen samples were collected for pollen analysis. Unfortunately, most of our samples proved to
be either barren, or to contain very few poorly preserved pollen grains. Only nineteen productive samples from nine different locations allow quantitative analyses. The pollen providing localities have a broad geographic coverage (Fig. 1). The stratigraphical position, relative to continental Turkish Neogene zonation (Ünay et al. 2003), and the sedimentary environment of these localities are given in Table 1. The localities without pollen is also listed in Table 2.

Although the informal zonation of the continental Turkish Neogene (Ünay et al. 2003), based on the evolutionary stages in the rodent families Muridae and Dipodidae, is incomplete and the correlation of its units A to P to the European MN “zones” is uncertain, we are confident that the sequence given is correct. Therefore we primarily correlate our pollen associations to this scheme. However, two of our samples (Çatakbağyaka and Eskihisar) come from levels that have so far yielded larger mammals only. Biostratigraphical correlation of these to the MN system is based on the assumption that the sequence of large mammals in Anatolia does not differ essentially from that in western Europe. It is clear, however, that the stratigraphical position of these associations is not well established. The sequence of these two localities allocated to the same MN zone is arbitrary.

Sample Preparation

Fifteen to twenty grams of each sample were treated with cold HCl (35%) and HF (70%) to remove carbonates and silica. Separation of the palynomorphs from the residue was carried out by using ZnCl₂. The residue was sieved on a 10mm nylon mesh, mixed with glycerine and mounted on a slide. A transmitting light microscope, using x400 and x1000 (oil immersion) magnifications, was used for the identification and the counting of the palynomorphs.

In this study, a botanical identification of the pollen grains was carried out. Classification was then performed comparing the fossil pollen grains with their living relatives from several pollen atlases, the photograph bank of the laboratory in Lyon as well as the keys in Faegri and Iversen (1989) and Moore et al. (1991). The palynological results are shown in detailed pollen

Figure 1. Geographic location of small mammal localities from which pollen were obtained. Localities: 1= Konya-Dursunlu; 2= Afyon-Akçaköy; 3= Afyon-Koçgazi; 4= Muğla-Askihisar; 5= Muğla-Yeni Eskihisar; 6= Muğla-Çatakbağyaka; 7= Sivas-Karaözü; 8= Çorum-Kagi; 9= Ankara-Keseköy.

Table 1. List giving the stratigraphical position of the localities yielded pollen floras relative to the MN scheme (de Bruijn et al., 1992) and the preliminary zonation of the Neogene of Anatolia (Ünay et al., 2003). Number of samples collected per locality in parantheses (* from Yavuz-Işık, 2008).

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*Ankara-Keseköy (16)
diagrams (Fig. 2-6) using the programmes TILIA and TILIA GRAPH (Grimm 2005).

MAMMAL DATA

In this study, previously identified mammal assemblages are used mainly for biostratigraphic purposes. Interpretation of small mammal assemblages in terms of biotope and paleoclimate is, in our opinion, a hazardous enterprise because: 1) The biotope requirements of most fossil species are not known. In contrast to plants most Neogene genera of mammals have become extinct. As a result there are only a few fossil groups, such as burrowing and aquatic talpids, dimylids, jerboas, flying and arboreal squirrels and beavers of which it may be assumed that they had similar life-styles as their extant counterparts. 2) Most concentrations of small mammal remains have accumulated through predation by birds of prey, which hunted over a larger area and probably had specific preferences and hunting techniques (diurnal/nocturnal). This circumstance results in an unknown degree of selection prior to fossilisation. 3) Other than in the case of plants, short periods of unfavourable circumstances (low temperature, drought) do not necessarily limit the range of small mammal species, because these may survive by acquiring special strategies (hoarding,
hibernating, burrowing etc.). 4) Associations of small mammals from bedded sediments originate almost invariably from paleosols in a lacustrine setting. Arboreal animals and those which were adapted to a desertic biotope may therefore be expected to be systematically underrepresented in collections. 5) The majority of the small mammal collections consists of water-transported isolated teeth. This means that there may have been an unknown degree of selection due to sorting.

These characteristics of small mammal assemblages, in combination with their, relative to plants, high rate of evolutionary change, make the mammal record very different from the pollen record. As a consequence it is less suitable for a quantitative analysis aiming at reconstructing the paleoclimate, but very useful for biostratigraphy.

RESULTS AND DISCUSSION

Many of the sampled mammal sites (42 out of 51) did not yield pollen. Various factors can cause sterility in palynological studies as recently discussed by Carrion et al. (2009). Carrion et al. (2009) reported failures with pollen analyses for the Quaternary of the Iberian Peninsula and stated that nature of depositional environment can be an important factor in case of palynological sterility and majority of the failed studies are open-air archaeological and palaeontological sites, and caves whereas lakes are often successfull sites. The pollen rich samples of our study, all being lacustrine,
supports this statement. The Kargi, Keseköy and Karaözü samples originate from paleosols in a lacustrine setting. The fossiliferous beds of Eskihisar, Çatakbağyaka, Koçgazi, Yenieski, Akçaköy and Dursunlu are lacustrine lignitic clays and deposit of Koçgazi is in a similar facies. However, most of barren samples are also lacustrine. The other main factor, reported by Carrion et al. (2009), causing palynological sterility was oxidation. It can occur pre-depositionally (e.g. soil inwash in lakes), syn-depositionally (e.g. high-energy sediment), post depositionally (e.g. fluctuation of lake levels) or after excavation, e.g. during field sampling. The identification of potential cause of oxidation needs further detailed investigations and it is beyond the scope of this study.

Despite the lack of pollen many samples, the obtained palynological information allows to get an idea of the vegetation during most of the Neogene in central and western Turkey. Additionally, these vegetational findings and their climatic implications are largely supported by mammal faunas already collected from the same localities.

Early Miocene

Nineteen samples from the Early Miocene localities Kargi-2 (1 sample), Keseköy (16 samples) and Eskihisar (2 samples), contain pollen (Fig. 2). The genus Engelhardia belonging to the mega-mesothermic family Juglandaceae, is common in the samples. Extant Engelhardia is characteristic for low altitude mixed broad-leaved and evergreen forests in subtropical SE China (Jimenez-Moreno 2006). Engelhardia and Oleaceae are common in the early Early Miocene assemblages from the eastern Mediterranean (Nagy, 1992). The decrease of Engelhardia (from Kargi-2 to Eskihisar) and the simultaneous increase of the cool temperate taxon Fagus may indicate that temperatures slightly decrease in the course of the Early Miocene. This temperature drop cannot have been high because mega-mesothermic floral elements such as Euphorbiaceae, Taxodiaceae, Myrica, Sapotaceae, Cyrillaceae-Clethraceae were still present during the early Middle Miocene. The fluctuations in percentages of evergreen Quercus and Ulmus in the samples of a sequence from Keseköy are probably due to minor differences in precipitation. The dominance of Alnus in the samples from Eskihisar indicates the presence of riparian environments. The constant presence of Pinus and undifferentiated Pinaceae indicates that uplands existed close to the depositional area.

The vegetation was dominated by elements of a mixed mesophytic forest which is similar to other Early Miocene data of pollen floras from Western Anatolia (Seyitömer Basin: Yavuz-Işık 2007; Burdur-Kavak area: Akgün et al. 2007). The flora identified in the current study reflects nearly subtropical conditions in the early and humid warm-temperate conditions in the late Early Miocene. Similarly, Akgün et al. (2007) reported warm subtropical climatic conditions during the Chattian and Aquitanian period in western Anatolia (mean annual temperatures between 16.5–21.3 °C) whereas it becomes cooler during the Burdigalian.

The Early Miocene pollen spectra from the Mesohellenic Trench, Greece (Ioakim et al. 2005) are, like the ones from Anatolia, rich in the mesothermic elements, Pinus and undifferentiated Pinaceae. However, the dominance of megathermic and mega-mesothermic elements in the spectra from Greece indicate higher temperatures and more humid conditions. Moreover, the predominance of herbaceous plants indicates more open vegetation for Mesohellenic Trench. The analysis of phytolith assemblages provides a proxy for habitat openness. The phytolith data of Strömberg et al. (2007) suggest that relatively open habitats had become common in Turkey and surrounding areas by the Early Miocene (~20 Ma). However, the low percentages of herbaceous pollen in Kargi-2 and Eskihisar suggests that open areas were not widespread around these areas during the early Early Miocene.

Although we don’t think that the correlation between climate and the diversity of rodent and insectivore species is straightforward, the presence in the assemblages from Kargi-2 and Keseköy of five species of Gliridae (dormice)
with cheek teeth with seven or more ridges per molar (De Bruijn et al. 1996) and of eight species of Muridae indicates humidity as well as the availability of diverse food sources. Although insectivores are in terms of specimens compared to rodents not numerous in these assemblages (max. 25 %) the group is quite diverse with the digging mole (Geotrypus), the water mole (Desmanodon) and a mollusc eater (Turkodimylus). The composition of the small mammal assemblage therefore strongly supports the pollen based reconstruction.

Middle Miocene

Four samples from three localities, Çatakbağyaka (2 samples), Koçgazi (1 sample) and Yeni Eskihisar (1 sample) provided pollen data (Fig. 3). The high percentage of trees in these pollen spectra seems to be characteristic for the Middle Miocene of Anatolia (see Akgün et al. 2007; Yavuz-Işık and Demirci 2009). Quercus, Parrotia persica, Ulmus, Zelkova, Carpinus orientalis and Alnus were the dominant trees in this forest. Conifers are represented by Cedrus and Pinus. Cedrus, a mid-altitude conifer which lives today between 2000-2500 m. in the Himalayas (Hoorn et al. 2000) is common. Cathaya, an altitudinal conifer living today in southern China (Fauquette et al. 2006), is represented by smaller percentages. The presence of high altitude elements in the spectra may suggest that Anatolia was uplifted after the Early Miocene.

Figure 3. Pollen diagram of the Middle Miocene samples. The groups are: other mega-mesothermic elements (Passifloraceae, Mimosa, Taxodiaceae, Anacardiaceae, Myrica, Alchornea, Polygalaceae, Palmae); other mesothermic elements (Castanaceae-Castanopsis type, Distylium, Loropetalum, Pterocarya, Juglans, Celtis Tilia, Carpinus betulus, Buxus, Betula, Ostrya); other herbs (Asteraceae Asteroideae, Asteraceae Cichorioideae, Campanulaceae, Rumex, Ephedra, Apiaceae, Caryophyllaceae, Rosaceae, Amaranthaceae/Chenopodiaceae, Valerianaceae). Ç:Çatakbağyaka, K:Koçgazi, Y:Yeni Eskihisar.

The impoverishment of the plant diversity towards the end of the Middle Miocene, especially the disappearance of megathermic and mega-mesothermic elements (Fig. 3) may indicate a climatic deterioration. The vegetation was almost subtropical in the early Middle Miocene while temperate conditions seem to have prevailed during the late Middle Miocene. The late Middle Miocene pollen assemblages then show a decrease in diversity, which possibly reflects a cooling event. A similar change of the vegetation has been recorded both in Turkey and Europe as discussed below.

The application of Coexistence Approach analysis to pollen data by Kayseri and Akgün (2010) shown that warm climatic conditions indicating Middle Miocene Climatic Optimum was existed in; Balikesir-Gönen and Çanakkale-Çan regions during latest Burdigalian-?Serrevalian, Samsun-Havza area during latest Burdigalian and Muğla-Milas region during late Burdigalian-Langhian period. Moreover Akkiraz et al. (2010) observed a decrease in precipitation during Middle Miocene in Turkey and stated that it could be related to a cooling.

Jimenez-Moreno et al. (2005) and Jimenez-Moreno (2006) shown that, in the Pannonian Basin-Hungary, a Burdigalian-Langian subtropical forest was replaced by a mesothermal one with deciduous Quercus, Fagus, Alnus, Carpinus, Ulmus, Zelkova etc. during the Serrevalian. Ivanov et al. (2002) observed a similar trend in palynofloras from the Carpathian forebasin (NW Bulgaria).

The Middle Miocene rodent faunas in Anatolia show the transition from Cricetodon to Byzantinia and from the small, low crowned, Eumyarion intercedens to the larger, and more hypsodont Anomalomys gaillardi. The first record of the jerboa Protallactaga and the last record of the ctenodactylid Sayimys are from the early Middle Miocene. The presence in Anatolia of a diverse forest during the early Middle Miocene as reconstructed on the basis of pollen flora, is corroborated by finds of the flying squirrels Forsythia and Albanensia in Çandır 2. The decline of the Gliridae with seven or more ridges per molar at the base of the Middle Miocene and the entry of the xerine sciurid Atlantoxerus in the upper part of the Middle Miocene are in line with the trend towards a cooler climate reconstructed on the basis of palynofloras.

Late Miocene

The only Late Miocene mammal locality that provided pollen data is Karaözü (Fig. 4). Despite low number of samples, the pollen spectra of Karaözü samples show a dramatic decrease in the diversity of vegetation probably indicating a deterioration of the climate. Trees are almost disappeared and herbs, with predominant Asteraceae, characterize the vegetation. It agrees with open vegetation characterized by dominance of Asteraceae, Apiaceae and Chenopodiaceae that was widespread in central Anatolia during the middle Tortonian period (Akgün et al. 2000; Akgün et al. 2007). A similar vegetation change with dominance of open landscapes with more xerophytic plants in Ukraine was correlated with the Late Miocene Cooling (Syabryaj et al. 2007) and it also reflected by Cenozoic megafloras from the Serbia (Utescher et al. 2007). Although Akgün et al. (2007) shown warm temperate climatic conditions during Late Miocene in Western and central Anatolia, also reported presence of dry seasons during the Tortonian (mean annual temperatures between 15.6- 20.8 °C).

The composition of the rodent faunas changes rapidly during this time-slice because of the arrival of the (quickly radiating) Murinae (true mice). The diversification within the genus Byzantinia, the arrival of the exotic hamster c.f. Rhinoceron, the gerbil Pseudomeriones and the porcupine Hystrix suggests that biotopes were dry.

Pliocene

Only one Pliocene locality, Akçaköy, provided pollen data (Fig. 5). Pinus and undifferentiated Pinaceae are dominant and occur associated with few deciduous trees. The small amount of Tsuga, Cedrus and Abies may point to the presence of a nearby mid-altitude forest. Herbs are abundant in the pollen spectra with dominant Asteraceae together with some Amaranthaceae/Chenopodiaceae, Dipsacaceae and Caryophyllaceae. The presence of Limonium among
Figure 4. Pollen diagram of the Late Miocene samples.

Figure 5. Pollen diagram of the Pliocene samples. Other herbs: Echinops, Artemisia, Ephedra, Apiaceae, Caryophyllaceae, Limonium, Knautia, Erodium, Valerianaceae.
with these families could point to alkaline soil conditions.

The pollen assemblage of Akçaköy reflects an open herb vegetation, with dominant Asteraceae, and tree associations composed mainly of undifferentiated Pinaceae. Development of open herbaceous vegetation is palynologically well-recorded during the early Pliocene from different regions of the Mediterranean area (Suc et al. 1999; Fauquette et al., 2006) as well as from a small surface section in the Central Anatolia (Yavuz-Işık and Toprak, 2010).

Popescu (2006) characterized the Pliocene, on the basis of palynofloras from the Black Sea region, by the competitive alternation between humid thermophilous forests and dry steppes. Suc et al. (1995), observed a similar vegetation pattern in the north-west Mediterranean region, but not in the southern Mediterranean region due to local aridity. Although the Akçaköy samples are rich in Asteraceae, a family very common in open and dry environments, aridity in Akçaköy area cannot have been intense during the Early Pliocene since conifers, in particular Tsuga, which is sensitive to summer drought (van Hoeve 2000), are present.

**Pleistocene**

Only one Pleistocene locality, Dursunlu provided pollen data (Fig. 6). The pollen assemblage of Dursunlu shows that the vegetation was dominated by herbs but had a significant arboreal component. Among the herbs, Asteraceae and Amaranthaceae/Chenopodiaceae are the most common elements, and together with Dipsacaceae and Artemisia they point out to an open vegetation. *Pinus* and undifferentiated Pinaceae are dominant among the trees. Altitudinal trees are represented only by few pollen grains. The abundance of Pteridophytes, high number of aquatics and algae points to presence of a lake. The high number of conifers present in the Akçaköy samples indicates that uplands were not far from the depositional site.

Overall, this vegetation indicates humid-temperate climatic conditions. This is conformable with the environmental reconstruction of Dursunlu on the basis of the avifauna (Louchart
et al. 1998). Louchart et al. (1998) described a rich, mainly aquatic avifauna, with a majority of extant forms from Dursunlu and interpreted these to indicate an open, steppic environment with a possible Mediterranean climate.

CONCLUSIONS

The palynological study on the lacustrine deposits associated with vertebrate assemblages of known ages from different parts of Turkey permitted the identification of a rich flora. Although mammal assemblages are used for biostratigraphic purposes in this study, they still support the palynologically inferred vegetation and climatic conditions.

The vegetation during the early Early Miocene was dominated by mega-mesothermic elements such as *Engelhardia*. This kind of vegetation points to a subtropical climate during the mentioned time-span. During the late Early Miocene changes in the vegetation are observed: thermophilous elements, especially *Engelhardia*, decreased and vegetation dominated by mesothermic plants such as *Quercus*, *Fagus*, *Alnus*, *Carpinus*, *Ulmus/Zelkova* etc. The early Middle Miocene vegetation is rich in mega-mesothermic trees such as *Hamamelidaceae* (Western Anatolia), *Engelhardia* and *Taxodiaceae*. However, the number of mega-mesothermic pollen and the diversity of the vegetation decrease considerably during the late Middle Miocene indicating a climatic deterioration. Late Miocene vegetation is dominated by Asteraceae representing open areas with almost no trees. The Pliocene vegetation is dominated by conifers and herbs in association with abundant freshwater algae. This flora represents temperate climatic conditions. The Pleistocene vegetation is dominated by herbs (Asteraceae, Amaranthaceae/Chenopodiaceae and Poaceae) characterising an open biotope. Conifers and Pteridophytes are also well represented in these spectra.

ACKNOWLEDGEMENT

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REFERENCES


Popescu, S-M., 2006. Late Miocene and early Pliocene environments in the southwestern Black Sea region from high-resolution palynology of DSDP Site 380A (Leg 42B). Palaeogeography Palaeoclimatology Palaeoecology, 238, 64-77.


Kargı Yelpaze Deltası’nın (Aksu Havzası, Antalya) Geç Miyosen Evrimi

Late Miocene Evolution of Kargı Fan Delta (Aksu Basin, Antalya)

*Serkan ÜNER¹, Kadir DİRİK², Attila ÇİNER²
¹Yüzüncü Yıl Üniversitesi, Jeoloji Mühendisliği Bölümü, 65080 Zeve Kampüsü, VAN
²Hacettepe Üniversitesi, Jeoloji Mühendisliği Bölümü, 06800 Beytepe, ANKARA

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ÖZ

Anahtar Kelimeler: Aksu Havzası, Kargı Yelpaze Deltası, Miyosen, yama resifi.

ABSTRACT
Miocene Aksu Basin is a foreland basin, located on the southern part of the Anatolian peninsula in Africa-Eurasia subduction zone. The basin fill is composed of shallow marine clastics and carbonates and coarse grained fan delta deposits. In this study, structural and sedimentological evolution of Tortonian Kargı Fan Delta developed in the western part of the basin is examined in the context of tectonism and sea level changes. Facies, depositional processes and sub-environments (e.g. alluvial fan, lagoon, fan delta front) of this coarse grained fan delta sequence, indicate both regressive and transgressive periods. Alternations of continental red beds with shallow marine conglomerates containing patch reefs are very typical. Changes in the depositional characteristics of fan delta can be explained by regional tectonism and related sea level changes together with the amount of sediments carried into the basin. Kargı Fan Delta is a key sedimentary sequence in the understanding of the evolution of the Aksu Basin.

Key Words: Aksu Basin, Kargı Fan Delta, Miocene, patch reefs.

S. Üner
E-mail: suner@yyu.edu.tr
GİRİŞ


İsparta Açısı olarak isimlendirilen morfotektonik yapının merkezinde bulunan (Şekil 1a),
Miyosen Aksu Havzası’nın batı kenarında yer alan Kargı Yelpaze Deltası (Şekil 1b) kaba taneli deltalarla güzel bir örnektir. Tektonik deformasyonun yoğun olduğu bir bölgede (Şekil 1c) depolanan yelpaze deltası, genel olarak deniz kırıltılarını, resifal karbonatlar ve alüvyal çakıltıları arasında geçiş şeklinde göze lenen, tektrakıranlı transgresif-regresif bir istifie sahiptir. Yelpaze deltası istif içerisinde farklı sivi yelplerden oluşum ve resifikasyonu ile karakterize olan Porites ve Tarbellastraea egemen (Tuzcu ve Karabıyıkulu, 2001; Karabıyıkulu vd., 2005) koloniler mercanlar, sığ deniz ortamlarında küçük parçalar (yama) halinde gelişmiştir. Bu kolonilerin gelişmesi, karasal sediment getirimi ve deniz seviyesi olaylarına bağlı olarak zaman zaman kesintiye uğramıştır. Bu çalışmanın amacı; kaba taneli Kargı Yelpaze Deltası istfinin çökme süreçlerini ve çökme alt ortamlarını belirlemek, istfin içerisinde gözlenen yama resiflerinin oluşumu konusundan bahsedecek ve deniz seviyesi değişiminin delta evrimindeki rolünü belirlemektir.

BÖLGESEL JEOLÖJİ


YÖNTEM

Çalışma alanının jeoloji haritası hazırlanmış ve Kargı Yelpaze Deltası’na ait çökellerin yayılımı belirlenmiştir. Delta istifi, belirlenen en alt kesişmenden başlayarak yukarıya doğru litofasılere ayrılmış, bunlar arasındaki yanal ve düşey geçişler belirlenmiştir, tanımlamalar ilgili literatür ile karşılaştırılarak birimlerin oluştuğu ortamın ve ortam koşulları ortaya konulmuştur. Çalışma alanının yeşil, paleoakıntı yönlerinin belirlenmesi ve petrografik çalışmalar sonucunda, yelpaze deltasının belirlendiği kaynak kayaçlar belirlenmiştir. Yelpaze deltası çökelleri arasında bulunan resifal karbonatların, bu birimler arasındaki yerlerinin ve konumlarının değerlendirilmesi ile

Şekil 3. Kargı Yelpaze Deltası çökellerinde gözlenen sedimantasyon ile eş zamanlı gelişmiş normal fayların arazi görüntüsü (a), işlenmiş yakın plan görüntüsü (b).

Figure 3. (a) General and (b) close-up view of the synsedimentary normal faults developed within the Kargı Fan Delta.
deltanın gelişimini gösteren istif belirlenmiştir. Tüm bu veriler işığında, deniz seviyesi değişimleri ve tektonizmanın Kargı Yelpaze Deltası gelişimine zaman ve mekan içerisindeki etkisi görülmştir.

MİYOSEN HAVZA DOLGUSU


Kargı Yelpaze Deltası'nın Fasiyes Özellikleri


Kargı Yelpaze Deltası çıkıntıları; litolojisi, doku-sal özellikleri, tane boyu, tane şekli, bağlayıcı malzemeleri, sedimanter yapıları, fosil içerikleri gibi özelliklere göre 6 adet fasiyesi ayrılmıştır (Çizelge 1). Bu fasiyeslerin oluştuğu alt ortamlar ve oluşum süreçleri konu ile ilgili literatür incelenerek yorumlanmıştır.

Yama resifi (R)

Kargı Yelpaze Deltası çökül istifini oluşturan bu litofasiyesler konumu ve dizilimleri itibariyle üç ayrı fasiyes topluluğuna ayrılmıştır. Bu fasiyes topluluğunda, moloz akışı süreçleri temsil eden, matriks destekli kaba çakıl fasiyesi (F1) ile matriks destekli ince çakıl fasiyesinden (F3) ve flüvyal kana-dolgusu çökellere iki alt kısım, yelpace deltası suya girdiği bölümü temsil etmektedir. Matriks destekli kaba çakıl fasiyesi (F1) ve matriks destekli ince çakıl fasiyesinden (F3) oluşan bu kısım üzerinde zaman içerisinde yama resifleri gelişim göstermiştir.
<table>
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<td>Kumtaşı-çamurtaşı ardalanması ve yer yer çakılıh seviyeler</td>
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Figure 4. Generalised stratigraphic section of the Aksu Basin (modified from Poisson et al., 2003 and Karabıyıkolu et al., 2004).


| Fasiyes 2 | Düşük açı çapraz tabakalı kaba çakıl fasiyesi (F2) | Orta-iyi boylanma ve zayıf pekişme gösteren birim, 5-10º eğim açılı düzlemsel çapraz tabakalara sahiptir. Çakılların uzun eksenleri boyunca biniklenmeler (imbrications) gözlenmektedir. Çakıllarda gözlenen dizilim, yuvarlaklık ve iyi boylanma sedimanların dalga enerjisinin etkisinde sığ deniz (delta önüne) ortamındaki etkili ve boylanma eğilimi olan birimdir (Massari ve Parea, 1988; Karabıyıkoğlu, 2003).


| Fasiyes 5 | Fosilli silt-kil fasiyesi (F5) | Bej-koyu gri renkli, laminal silt-kil ardalanmasından oluşmaktadır. Fasiyeste bol miktarda gastropod (Conus) ve pelesipod (Pecten) fosili gözlenmektedir. Fosil içeriği üst katmanlara doğru artmaktadır. Sınırlı yanal devamlılığa sahip olan birimde siltli ve killi birimler içerisinde çeşitli boylarda çakıllar rastlanmaktadır (Şekil 7e). Kil çökelimi, laminal yapı ve yoğun pelesipod-gastropod fosilleri, durgun vida koşullarının etkisiyle sığ deniz (lagoon) ortamında gerçekleşen silt-kilardan oluşmaktadır (Reineck ve Singh, 1972; Reading, 1980).

| Fasiyes 6 | Tane destekli ince çakıl fasiyesi (F6) | Gri-bej renkli, kaba çakıl-kum fasiyesi (F3) sahip, 3-5 mm çaplı iyi boylanmış, yarı yuvarlak kireçtaşı ve ofiyolit kökenli çakıllardan oluşmaktadır. Pelesipod-gastropod fosilleri ve bol kavkı kırıntıları arkadaştırır. Katmanlarının gözden geçirilebilmesi 3 m yaşılmıştır (Şekil 7f). Yer yer boylanma eğilimi olan birime sahiptir (Sokolov, 1967). Tane destekli çakıl fasiyesi, çökelinin dalga enerjisinin etkisi ve deniz sularının etkisiyle (delta önüne) ortamındaki etkili ve boylanma eğiliminde birimdir (Sokolov, 1967; Steel vd. 1977).}
Figure 7. Field photographs of six facies encountered within Kargi Fan Delta sediments.

YELPAZE DELTASI GELÝŞİMİ

İster küresel, iстерse de bölgesel ölçekte olsun, deniz seviyesi değişimleri havza dolgusunun evriminde kritik bir öneme sahiptir (Muto, 1988).

Resif-yelpaze deltasi birlikteliği de, deniz seviyesi değişimlerine ait en güzel verilerinden birini oluşturur. Genel olarak siğ denizel alanlarda, yelpaze deltalarının ön kısımlarında oluşan
yama resifleri, çoğunlukla sediment getiriminin azaldığı transgresif dönemlerde ya da aktif delta lobunun yanal olarak yer değiştirildiği durumlarda gelişim göstermektedir (Sellwood, 1986; Dabrio ve Polo, 1988; Kazancı ve Varol, 1990).

Tortoniyen'de Aksu Havzası'nın batı kenarında depolanmaya başlayan Kargı Yelpaze Delta'si, Bey Dağları ve Antalya Napları'ndan aşınan sedimentler tarafından oluşturulmuştur (Şekil 10). Karasal ve sığ denizel çökellerin üzerinde alüvyon sedimentlerinden oluşan yelpaze deltası çökelleri, fasiyes özelliklerine göre çeşitli alt ortamlara ayrılmıştır (Şekil 11a). Alüvyon yelpaze deltası, delta önü ve kıyı-lagün çökellerinden oluşan stratigrafik istif incelendiğinde, regresif ve transgresif dizilimlerologically göz çarpmaktadır (Şekil 11b).

İstifin farklı seviyelerinde, sığ deniz çökellerin üzerinde alüvyon yelpazesine ait birimler bulunmaktadır. Delta önü çökelleri üzerine asındırmalı olarak depolanan, kiremit renkli, kaba taneli karasal çökeller, delta gelişiminin zaman içerisinde birçok kez duraksadığının göstergesidir. Bu karasal dönem kıyıda, sığ su koşullarında gelişim gösterebilen mercan resiflerinin gelişimine engel olmuştur.

Yelpaze deltası için regresif süreç, deniz seviyesindeki yükselme ile sona ermiştir. Alüvyon yelpaze deltası delta önü ve kıyı-lagün çökellerinden oluşan sığ denizel birimlerin üstüne depolanan sığ denizel birimler, yelpaze deltası için regresif gelişimi göstermektedir. Benzer olarak delta önü çökelleri üzerinde bulunan yama resifleri de, deniz seviyesindeki yükselmenin önemli bir göstergesidir.

**TARTIŞMA ve SONUÇLAR**

Kargı Deltası, moloz akma ya da kütle akması baskın çökelleri, alüvyal besleyici sistemi, karasal ve sığ deniz fasiyesi arasındaki geçişler gösteren istif ve hemen yanındaki bulunan yüksek topografi ile tipik bir yelpaze deltası özelliği göstermektedir (Nemec ve Steel, 1988; Nemec, 1990).

Kargı Yelpaze Delta'sı istifinde gözlenen fasiyeserin yanal ve düşey yöndeki dizilimleri, yelpaze
deltasını oluşturan alt ortamların (alüvyon yelpazesi, kıyı-lagün, delta önü) belirlenebilmesini sağlamıştır. Tortoniyen’dedeki bölgede etkili olan genişleme tektoniği ve buna bağlı havza çökmesi yelpaze deltasının transgresif gelişimini göstermesine sebep olmuştur. İstifte gözlenen yama resifleri, sığ denizel çökeller (delta önü, kıyı-lagün) üzerinde yer almaktadır. Transgresif dönem için iyi bir göstere olan resifal kireçtaşlar, hızlı deniz seviyesi yükselmesi sebebiyle karasal kırıntı girdisinin azaldığı ya da durduğu, delta gelişiminin kesintiye uğradığı süreçte oluşmuş çökelme işaret etmektedir.

Yelpaze deltası istifindeki regresif dizilimler ise doğrudan bölgesel tektonizma ile açıklamak mümkün değildir. Genişleme tektoniğinde,
havzanın derinleştiği süreçte yelpaze deltası
nin regresif dizilim göstermesi, bu dönemde
tektonizmanın duraksadığı ya da karadan se
diman getiriminin ve sedimantasyon hızının art
tiği bir süreçle açıklanabilir. Delta çökellerin
de sıkça gözlenen, delta lobundaki yanal yer
değiştirmelerin transgresif veya regresif dizilim
lere sebep olduğu bilinmekle birlikte Kargı Yel
paze Deltası çökel istifinde bununla ilişkili sedi
mantolojik bir veriye rastlanmamıştır.

Mercan kolonilerine ait kalıntıların yelpaze del-
tası çökelleri arasında bulunması, delta geliş
minin bazı dönemlerinde hüküm süren iklim
ve ortam koşulları hakkında bilgiler sunmakta
dir. Aksu Havzası’nda gözlenen *Porites* ve *Tar-
bellastraea* egemen resifler, birlikte bulunduğu
yelpaze deltasının ilman/tropik-subtropik iklim
koşullarında, orta-yüksek dalga enerjisine sahip
bir kıyıda oluşturulunun göstergesidir.

Kargı Yelpaze Deltası’nın morfolojisi, yanal-
düşey fasyes değişimleri ve içerisinde bulunan
resifal karbonatların gelişimi, tektonizmaya
bağlı deniz seviyesi oynamaları ve olasılıkla ik
limsel nedenler tarafından kontrol edilmektedir.
Bölgesel genişleme rejiminin zaman içerisinde
duraksadığı dönemler, yelpaze deltası evrimin
de farklı süreçler gözlenmesinin temel sebebidir.

**KATKI BELİRTME**

Çalışma Hacettepe Üniversitesi, Bilimsel Araş-
tırımalar Birimi’nin 05D09602001 numaralı

*Şekil 10. Kargı Yelpaze Deltası’nın gelişimini ve içerisinde bulunan yama resiflerini gösteren üç boyutlu model.
Figure 10. 3D model showing the development of Kargı Fan Delta with patch reefs.*

KAYNAKLAR


Muto, T., 1988. Stratigraphic patterns of coastal-fan sedimentation adjacent to


Van Gölü Kuzey Havzasının Geç Holosen Paleoflorası

Late Holocene Paleoflora of Lake Van Northern Basin

*Güldem KAPLAN¹, Sefer ÖRÇEN²

¹Yüzüncü Yıl Üniversitesi, Mühendislik Mimarlık Fakültesi, Jeoloji Mühendisliği Bölümü, 65080 Van
²Yüzüncü Yıl Üniversitesi, Mühendislik Mimarlık Fakültesi, Jeoloji Mühendisliği Bölümü, 65080 Van

ÖZ

Anahtar Kelimeler: Holosen Palinolojisi, Paleoflora, Van Gölü Kuzey Havzası

ABSTRACT
Paleoflora reconstruction mainly based on pollen analysis of bottom sediments of Lake Van Northern Basin is the purpose of the study. The sediments were taken as 5 parts which covers totally 5 meters sequence by drilling method at water depth of 247 meters. To date the sequence, we compared the previous pollen diagrams of studies made in different basins of the bottom of Lake Van which have relative dating data. According to this, tentative time scale in the basis of varve chronology of the sequence covers about last 4000 years. Palynological results represent higher percentages of nonarboreal pollen (NAP) grains than arboreal pollen (AP) grains. Three pollen zones have been distinguished according to the onset and increase of several pollen curves such as Juglans and Cerealia-type. Palynological content indicates steppe for the Zone1 and Zone2 and anthropogenic steppe for the Zone3 around Lake Van Northern Basin for the last 4000 years.

Key Words: Holocene Palynology, Paleoflora, Lake Van Northern Basin
GİRİŞ


MATERIAL ve YÖNTEM


**SONUÇLAR ve TARTIŞMA**


Figure 2. Geological map of surrounding area of Lake Van (modified after Keskin, 2007)

Pollen zonu (van Zeist ve Voldring, 1978)
Pollen zonu (Wick vd., 2003)
Pollen zonu (Litt vd., 2009)

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<td>8250</td>
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<td>Gramineae baskı step vejetasyonu (Wick vd., 2003)</td>
</tr>
<tr>
<td>3400</td>
<td>10100</td>
<td>V-4</td>
<td>Chenopodiaceae ve Gramineae baskı çöl stebi (Wick vd., 2003)</td>
</tr>
<tr>
<td>5</td>
<td>10460</td>
<td>V-3</td>
<td>Artemisia ve Chenopodiaceae baskı çöl stebi (Wick vd., 2003)</td>
</tr>
<tr>
<td>4700</td>
<td>11450</td>
<td>V-2</td>
<td>Çöl benzeri koşullar, yüksek yüzde Éphedra distachya- tip (Wick vd., 2003)</td>
</tr>
<tr>
<td>4</td>
<td>11620</td>
<td>V-1</td>
<td>Yarı çöl periyot, Artemisia, Chenopodiaceae baskı (Litt vd., 2009)</td>
</tr>
<tr>
<td>9600</td>
<td>12700</td>
<td></td>
<td>Ağacaçı-çalılık polen yüzdesinde hafif bir artış (Litt vd., 2009)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1</td>
<td>Soğuk ve yarı çöl step vejetasyonu, Artemisia, Chenopodiaceae baskı (Litt vd., 2009)</td>
</tr>
</tbody>
</table>

Şekil 3. Tatvan Havzası ve Ahlat sırtı (Van Gölü) taban çökellerinin varv yaşlandırımları ve polen zonu karşıştırması.

Figure 3. Varve dating and pollen zones correlation of Tatvan Basin and Ahlat Ridge (Lake Van) bottom sediments.

Diyagramda belirgin olarak gözü çarpan diğer değişim *Cerealia* tip polenlerin % 2-3’lük bölukta % 20’lik değere ulaştığı 1000 mm seviyesidir. *Juglans* ve *Cerealia*-tip polenlerin yüzde değerlerindeki bu değişimler baz alınarak, polen diyagramının 5000-1760 mm arasında kalan kısmı Zon 1, 1760-1000 mm arasındaki kısım Zon 2 ve 1000 mm ile 0 mm arası Zon 3 olarak adlandırılmıştır.

Zon 1: 5000-1760 mm. Bu zon yüksek otsul polenler ile karakterize edilmektedir. Otsu polenler arasında Poaceae, Chenopodiaceae ve *Artemisia* polenleri en bol gözlenen polenlerdir.

**Şekil 4. Kuzey Havzası, Tatvan Havzası ve Ahlat Sırtı polen diyagramlarının karşılaştırılması ve yaşlandırılması.**

*Figure 4. Dating and correlating of Northern Basin, Tatvan Basin and Ahlat Ridge pollen diagrams.*


Zon 3: 1000-0 mm. Bu zonda da otsul polen yüzdesinin odunsu polen yüzdesine göre fazla
olduğu görülmektedir. Zon 2 ile Zon 3 sınırı Ce-
realia tip polen yüzdesindeki belirgin artışa göre
belirlenmiştir. Cerealıa tip polen yüzdesinin bu
zon içinde % 2-3’lerden % 20-25’lere kadar
çıktığı gözlemektedir. Yine bu zonda Cheno-
podiaceae, Poaceae ve Artemisia polenleri ot-
sullar arasında baskındır. Ancak Cerealıa tip po-
lenlerin artışı zoomonun içinde Quercus ve
Pinus en büyük yüzeye sahiptir. Diğer zon-
lardan farklı olarak Pinus polenleri zonun üst
kesimlerine doğru neredeyse % 20’lik bolluğa
ulaşmıştır. Juglans eğrisi bu zonda bir devam-
lılık arz etmektedir. Bu odunsulara daha düşük
yüzdelerle Pistacia, Betula, Olea gibi odunsu
polenlerin varlığına ve bolluğuna göre Zon 3 antropo-
jen step olarak tanımlanmıştır (Şekil 6).

Polen diyagramı boyunca tanımlanan tüm bu
polen bolulları göz önüne alındığında, Zon 1
ve Zon 2’de Poaceae, Chenopodiaceae ve
Artemisia baskın bir step vejetasyonu tanımla-
nmıştır (Şekil 4). Polen diyagramında alt se-
viyelerde tanımlanmayan ve/veya üst seviiyle-
re doğru artan ve bölgede geçmişten beri yetiş-
тирildiği bilinen ceviz (Juglans) ve ta-
hil polenleri (Cerealıa-tip) gibi bazı bitki polenle-
inin varlığına ve boluluğuna göre Zon 3 antropo-
jen step olarak tanımlanmıştır (Şekil 6).

Yapılan tüm bu tanımlamalar geçen 4000 yıl sü-
resince florada büyük değişimin olmadığını,
ancak günümüz florasinın esas şekli 2000 yı-
ldan bugüne kadarki süreçte kazandığığini göster-
mektedir.

Van Gölü’nün Kuzey Havzasına ait polen diyag-
ramı, Van Gölü’nün diğer havzalarında yapılan
çalışmalar, Anadolu’nun İran-Turan flora bö-
lgesine dahil kesimlerden elde edilmiş önce-
ki polen diyagramları, Iran, Ermenistan, Gür-
cistan, Irak, Suriye ve Lübnan’dan da daha önce-
den yapılmış olan polen diyagramları ile karşı-
laştırmıştır (Bottema, 1986; İnceoğlu ve Pehli-
van, 1987; van Zeist ve Bottema, 1991; Botte-
ma, 1995; Fajvus, 1995; Yasuda vd., 2000; Ste-
vens vd., 2001; Hunt vd., 2004; Hussein, 2006;
Hajar vd., 2008; Connor vd., 2007; Al-Ameri ve
Jassim, 2011; Roberts vd., 2011). Geç Holosen
paleoflora ve vejetasyonunun günümüzdeki
büyük oranda benzer olması dolayısıyla, po-
len diyagramı verileri dahil olduklarını flora alan-
lanıyla aynı karakterdedir. İran-Turan flora bö-
gesinde antropojenik etkilerle maruz kalın alan-
lardan elde edilmiş polen diyagramlarında otstul
polenler odunsulara oranla baskın olarak göz-
lenmektedir (van Zeist ve Bottema, 1991; Bot-
tema, 1995; İnceoğlu ve Pehlivan, 1987; Wick
vd., 2003; Hussein, 2006; Hajar vd., 2008; Litt
vd., 2009; Roberts vd., 2011). Akdeniz ve Avru-
pa Sibiryə flora bölgesinde dahil olan kesimlerde
Ostrya, Salix, Pinus, Quercus, Cedrus ve Olea
gibi odunsu polenler otsullardan bazılar olarak
tanımlanmıştır ve bu çalışma kapsamında olu-
suturan polen diyagramı ile büyük oranda fark-
lılık az etmektedir (Denefle vd., 2000; Yasuda
Connor vd., 2007;).

Büyük oranda step vejetasyonunun hakim oldu-
ğu alanlardan elde edilmiş polen diyagramları


Bu çalışmanın gerçekleştirilmesi için gerek-
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ve PALEOVAN proje ekibine teşekkürlerimizi
sunarız.
KAYNAKLAR


Şekil 6. Van Gölü Kuzey Havzası paleoflora zonları.
Figure 6. Paleoflora zones of Lake Van Northern Basin.


Erdtmann, G., 1943. An Introduction to Pollen Analysis. USA. Choronica Botanica Company. 238 s.


Geological Evolution of the Ulukışla Basin (Late Cretaceous-Eocene) Central Anatolia, Turkey

Ulukışla Havzasının (Geç Kretase-Eosen) Jeolojik Evrimi, Orta Anadolu, Türkiye

*Kemal ZORLU1, Selim İNAN2, Murat GÜL3, Nurdan İNAN2, Mehmet Ali KURT4, Musa ALPASLAN2

1Adıyaman University, Kahta Vocational School, Department of Architecture and City Planning, Kahta–Adıyaman/ TURKEY.
2Mersin University, Engineering Faculty, Department of Geological Engineering, 33343, Çiftlikköy–Mersin/ TURKEY
3Mugla University, Engineering Faculty, Department of Geological Engineering, 48000, Kotekli–Mugla/ TURKEY.
4Mersin University, Advanced Technology Education, Research and Application Center, 33343, Çiftlikköy–Mersin/ TURKEY

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ABSTRACT

The Ulukışla Basin (Central Anatolian, Turkey) developed between the Menderes-Taurides Platform and the Niğde-Kırşehir Metamorphic Massif. Evidence from the basin fill indicates that it evolved with asymmetric tectonics. An extensional phase (the Late Cretaceous-Late Paleocene) developed after subduction of the northern branch of Neotethyan Ocean. The narrow southern margin of Ulukışla Basin evolved over and in front of the Alihoca Ophiolites (remnant of the Neotethyan ocean floor) and it has been characterized with deposition of the agglomerates, limestone olistoliths, sandstones and mudstones in submarine slope to deep marine environment. At the same time, in the initially the relatively deep then shallow marine environment, broad northern part of the basin includes relatively fine-grained sandstones and mudstones overlying by reef limestone, which is interfingered with volcanic rocks. Depend on compressional phase (the Late Paleocene and Early Eocene), the basin evolved with the effect of regional tectonics; patch reefs formed over the volcanic highlands. In addition, volcanics interfingered with clastics that contain limestone and volcanic rock fragments. Basin evolution and inversion in this tectonic regime has been strongly influenced by deviations originated from overall northward motion of the African-Arabian plates. Other controls on the sedimentation and basin evolution are local tectonics, sea level changes and irregularity of basement topography.

Keywords: Basin inversion, compression, extension, intra-continental basin, Ulukışla basin.

ÖZ

Ulukışla Havzası (Orta Anadolu, Türkiye) Menderes-Toros Bloğu ve Niğde-Kırşehir Metamorfik Masifi arasında gelişmiştir. Havzaya ait dolguların sunduğu kanıtlar, havzanın asimetrik bir şekilde evrimleştiğini göstermektedir. Genişlemeli faz (Geç Kretase – Geç Paleosen) Neotetis Okyanusu kuzey kolu tabanının yırtımı uygaması sonrasında gelişmiştir. Ulukışla Havzası’nın dar güney kenarı, Alihoca Ofiyoliti (Neotetis Okyanus tabanı kalıntısı) üzerinde...
INTRODUCTION

In the context of the tectonic evolution of Turkey and its surrounding areas, suture zones and the microplates separating these suture zones have played an important role (Şengör and Yılmaz, 1981; Görür et al., 1984; Göncüoğlu, 1986; Guézou et al., 1996; Görür and Tüysüz, 2001; Fig. 1A). The suture zones have been evolved as a result of the closing of northern and southern branch of the Neotethyan Ocean during the Late Cretaceous-Miocene time. The tectonic development southern margin of Eurasian Plate, the Menderes-Taurides Platform and marine realm between these two plates were highly influenced by northward movement the African and Arabian Plates (northern margin of the Gondwana; Golonka, 2004). It has been suggested that changes in the direction and velocity of relative motion of the African and Arabian Plates due to development of the Atlantic and Indian Oceans (Guiraud and Bosworth, 1997) controls the characteristics of the volcanism and sedimentary basin evolution in and around the Menderes-Taurides Platform.

It is known that many sedimentary basins were developed on the Menderes-Taurides Platform during the Late Cretaceous-Tertiary (Okay et al., 2001; Gürer and Aldanmaz, 2002). Tuzgölü, Sivas, Çankırı-Çorum, Kırşehir, Haymana and Ulukışla Basins are the main basins (Fig. 1B). Earlier researches have improved numerous basin models. For example; the Haymana and Tuzgölü Basins are fore-arc basin (Görür et al., 1984) or remnant oceanic basin (Yilmaz et al., 1997; Görür et al., 1998); the Sivas Basin was interpreted as a piggy-back basin (Cater et al., 1991) or intra-continental basin (Poisson et al., 1996) and while the Çankırı-Çorum Basin is collision or piggy-back basin (Koçyiğit and Beyhan, 1998).

Similar to other Central Anatolian Basins, a range of models have been also suggested for the evolution of Ulukışla Basin. Some researchers offered as a fore-arc basin model (Görür et al., 1984, 1998), some of them suggested a back-arc basin model (Demirtaşlı et al., 1984), others proposed island arc model (Oktay et al., 1998), theMaastrichtian–Late Eocene Ulukışla Basin has carried a great importance for understanding the tectonic and sedimentary evolution of the Early Tertiary basins of Central Anatolia. There are also numerous studies on this basin, for example Oktay (1982), Özgül (1984), Robertson and Dixon (1984), Yetiş (1984), Yetiş and Demirkol (1984), İşler (1988), Nazik and Gökçen (1989), Göncüoğlu et al. (1991), Çevikbaş and Öztunalı (1992), Görür et al. (1998), Clark and Robertson (2002), Akgünül (2003) and Alpaslan et al. (2004, 2006).

Some of these studies clearly recognize that basin evolution and sedimentation were strongly controlled by...

tectonism and volcanism during the Late Cretaceous-Eocene. Aim of this study is to determine sedimentary features of the Ulukışla Basin controlled by extensional and compressional tectonic regime and to reveal the development of the basin within the global tectonic frame.

**GEOLOGICAL SETTING**

The stratigraphy of Ulukışla Basin has been assigned to in three major geologic units by Alpaslan et al. (2004) based on previous geologic studies. These are; 1) Pre-Upper Cretaceous geologic units: the Bolkar Carbonate Platform (the Permian to Late Cretaceous; Demirtaşlı et al., 1984), the Niğde-Kırşehir Metamorphic Massif (the Lower Paleozoic-Lower Cretaceous), the Alihoca Ophiolites (the Upper Cretaceous); 2) Upper Cretaceous-Eocene geologic units: the Ulukışla Formation, which has been detail examined in this study, includes deep sea sediment, volcano-sedimentary units and shallow marine carbonates; 3) Post Eocene geologic units: various type volcanites, evaporites and continental sedimentary rocks (Figs. 2 and 3).

The Niğde-Kırşehir Metamorphic Massif, located in the northern boundary of the Ulukışla Basin, includes quartzite, gneiss, amphibolites, marble, mica schist, dolomitic marble, cherty limestones, granodiorite, monzonite and syenite intrusives (Çevikbaş and Öztunalı, 1992). Whitney and Hamilton (2004) showed that the high-grade basement rocks of massif are polymetamorphic character in metamorphism age of the Late Cretaceous. The southern part of Ulukışla Basin includes the Alihoca Ophiolite and the Bolkar Carbonate Platform. The Alihoca Ophiolite consists of serpentinized peridotite, pyroxenite, ultramafic cumulates, gabbro, microgabbro and dyke complex (Alpaslan et al., 2004). Some researchers have linked this body to the Pozanti-Karsanti Ophiolite that was derived from the Northern Neotethyan Ocean and was thrust onto northward edge of the Menderes-Taurides Platform (onto the Bolkar Carbonate Platform; Demirtaşlı et al., 1984; Çevikbaş and Öztunalı, 1992; Polat and Casey, 1995; White et al., 1996; Clark and Robertson, 2002, 2005). The Bolkar Carbonate Platform consists of crystallized limestones and marble intercalated with shale and dolomites (Demirtaşlı et al., 1984). The relations between the Niğde-Kırşehir Metamorphic Massif and the Alihoca Ophiolites or the Bolkar Carbonate Platform have not been observed in the study area.

The Upper Cretaceous-Eocene deposition in the Ulukışla Basin has been investigated under the different formations name by several previous researcher (e.g. Demirtaşlı et al., 1984; Çevikbaş and Öztunalı, 1992; Clark and Robertson, 2002, 2005). However it is thought that all of these formations deposited in the same marine environment, so all of them can be evaluated under same name, the Ulukışla Formation. This formation mainly contains fine to coarse-grained clastic rocks, volcano-sedimentary sequences and reef limestones. Akgünil (2003) identified the Shallow Benthic Zone (SBZ) 13-14-15 biozones in these sequences and implied that bottom part of the sequence deposited in restricted basin with normal salinity, sandy-clayey upper part was deposited in “inner shelf of open sea” environment. Calk-alkaline and shoshonitic dykes consisting of monzonite, trachyte and diorite intruded into this formation during and after the sedimentation (Alpaslan et al., 2004; Kurt, 2004; Alpaslan et al., 2006; Kalelioğlu et al., 2009; Figs. 2 and 3). Four logs were measured in this formation in order to determine the certain depositional settings (Fig. 2). Lithological properties of the logs are going to be explained following section in detail. The east-west trending thrust faults and symmetrical folding are commonly seen in the Ulukışla Formation (Fig. 2). Furthermore, the Ulukışla Formation is also cut by the northeast-southwest trending sinistral strike-slip faults related with the Ecemiş Fault Zone.

The first post-Eocene unit is the Oligocene Zeyvegediği Anhydrite including turbiditic sandstone (Nazik and Gökçen, 1989; Figs. 2 and 3). The Miocene continental deposits include limestone and marl alternations, conglomerates, siltstone and mudstone alternations (Nazik and Gökçen, 1989). These sediments mainly crop out along the Ecemiş Fault Zone (Ketin and Akarsu, 1965; Yetiş, 1984). The Pliocene polygenic conglomerates and reddish-greenish sandstones unconformable overlie the older
Figure 2. Geological map of the study area (Alpaslan et al., 2004).
Şekil 2. Çalışma alanının jeoloji haritası (Alpaslan vd., 2004).
### Sedimentology of the Ulukışla Formation

The Ulukışla Formation displays various sedimentary facies in different parts of the basin.

#### Units

(Çevikbaş and Öztunali, 1992). The Quaternary alluvial deposits cover the all older geologic units.

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**Figure 3. Generalized stratigraphy section of the study area (Alpaslan et al. 2004; Kurt, 2004).**

<table>
<thead>
<tr>
<th>System</th>
<th>Stage</th>
<th>Formation</th>
<th>Lithology</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
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<td>Quaternary</td>
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<td>Alluvial</td>
<td>Discordance</td>
<td></td>
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<tr>
<td>Cenozoic</td>
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<tr>
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<td>Anhydrite</td>
<td>Discordance</td>
<td></td>
</tr>
<tr>
<td>Palaeogene</td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Palaeocene</td>
<td></td>
<td>Discordance</td>
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<td></td>
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<tr>
<td>Cretaceous</td>
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<tr>
<td>Triassic</td>
<td>Bolkar Group</td>
<td>Tectonic</td>
<td></td>
<td></td>
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<tr>
<td>Palaeozoic</td>
<td>Nındde Kirşehir Massif</td>
<td>Crystallized limestone, marble, shale and dolomite</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Quartzite, gneiss, amphibolite, marble, mica schist, granodiorite, monzonite, syenite</td>
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</tr>
</tbody>
</table>

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**Şekil 3. Çalışma alanının genelleştirilmiş stratigrafi kesiti (Alpaslan vd., 2004; Kurt, 2004).**
The Imrahor log on the northwest margin (Figs. 2, 4 and 5); the Alihoca log on the southern margin (Figs. 2 and 6); the Kirkçeşit log (Figs. 2 and 7) and the Ardiçlı log in the central part of the basin (Figs. 2 and 8) were measured in this formation. The sandstone and limestone samples were collected for petrographical and paleontological purposes. The sandstones are named by using of Pettijohn et al. (1987), while the limestones are classified according to Dunham (1962) and Embry and Klovan (1972). The eight different facies have been separated according to lithology, geometry, sedimentary structures and fossil contents. These are; Distal Fan Turbidite (DFT), Middle Fan Turbidite (MFT), Proximal Fan Turbidite (PFT), Slope Facies (SF), Open Shelf Facies (OSF), Back Reef (BR), Reef Core (RC) and Volcano-sedimentary sequence (VS). The initial fourth facies are mainly including clastics with different size. The latter three are formed by carbonates. The last one includes volcanic material alternated with sedimentary rocks. The properties of the facies are evaluated in interpretation section of each log based on different researchers.

**Northern Margin: Imrahor Log**

**Description:** The basal part of the log (260 m) consists of alternations of yellow-grey (weathering color) sandstones and grey-green, laminated mudstones and unconformably overlies the basalt. The sandstone / mudstones ratio ranges from 1/8-9 to 1/2-3 (abundantly Te and lesser extent Td Bouma sequences; Bouma, 1962). The sandstones are mainly lithic arenite in composition. The quartz and muscovite grains are rich in near the bottom, while volcanic rock fragments and opaque minerals increase towards top of the section. Lamination is common sedimentary structures in the mudstone parts, while in addition to lamination, load cast, flow mark, groove mark and ripple mark were found in the sandstones. The muscovite, quartz and opaque minerals have been found in the sandstone in the lower part of section, while volcanic rock fragments were found in the upper part. The main palaeocurrents directions of clastic facies of the log were measured from the flute and groove marks, and vary between 80° and 128°. These initial sequences classified under the DFT facies. Five meters thick debris including sandstone, mudstones and limestone fragments, were observed in between 260 and 265 m of section. This possibly slumped section classified under the SF facies. Following fossil assemblages were found in the limestone thin section. **Benthic foraminifera:** Gyroidinella mangga LE CALVEZ; Planktic foraminifera: Acarinina cf. broedermanni (CUSHMAN & BERMUDEZ), Morozovella cf. subbotinae (MOROZOVA), Globigerina sp., Globigerinatheka sp., Catapsydrax sp. (Figs. 4 and 5). This section is overlain by the uniform beds of limestone and mudstone. Then, nearly 10 m thick wackestone-packstone type limestone (Back Reef Facies: BR) is observed. 3.5 m thick packstone-bindstone beds (Reef Core Facies: RC) are overlain by the 1 m thick basalt flow that starts with limestone fragments bearing basalt level. This level is followed by the 5 m thick wackestone (BR). Upper part of this level includes basalt pebble. These limestones contain; **Benthic foraminifera:** Idalina sinjarica GRIMSDALE, Anomalina sp., Daviesina sp., Discocylina sp., Pterodiscus sp., Planorbula sp., Miscellanea sp., Milliolidae, **Corals:** Litharaeopsis subepithecata (OPPENHEIM), Goniopora cf. elegans (LEYMERIE), **Algae:** Amphipora cf. propria (LEMOINE), Archaeolithothamnium cf. johnsoni ASTORILLI, Corallina cf. abundans LEMOINE, Distichoplax biseriatus (DIETRICH), Archaeolithothamnium sp. and echinoids. This thick limestone level is overlain by the 2.7 m thick basalt level that contains iddingsitized olivine, pyroxene, plagioclase, volcanic groundmass and calcite fillings in cracks. The upper part of the log contains 1.5 m thick sandy cream color, medium bedded wackestone and 6.5 m thick wackestone (BR). This level includes; **Benthic foraminifera:** Miscellanea sp., Pyrgo sp., Triloculina sp., Milliolidae; **Algae:** Amphiroa sp., Amphiroa cf. propria (LEMOINE), Distichoplax biseriatus (DIETRICH), Archaeolithothamnium sp., bryozoans and ostracods. **Interpretation:** Initial 260 m thick fine-grained clastics deposited in relatively deeper marine environment (comparing to uppermost part of the log). These finer-grained sediments covered vast areas in the northern part of the
Ulukışla Basin. The Bouma divisions and sedimentary structures of this part indicated that the distal turbiditic characters (Mutti, 1992). The mudstones were characterized the lower energetic environment that permit the deposition from suspension in pelagic and hemipelagic environment (Prothero and Schwab, 1996). The fine-grained sandstone levels were characterized the low-density turbidity current in this quiet environment (Prothero and Schwab, 1996). The high muscovite and quartz contents of the lower part are possible indicators of feeding from the Niğde-Kış şehir Metamorphic Massive. Then uplifting of the northern margin cut off this source and volcanic rocks became a subsequent source (Figs. 4 and 5). After this level, debris including possibly slumped mudstones and sandstones may indicate the slope environment. Then, limestones intercalated with volcanics. The fossil assemblages of the limestone and facies characteristics indicate reef environment. Initially planktic foraminifera bearing wackestone (BR) then depend on a shallowing of the environment coral and algae bearing bindstone (RC) deposited. Limestone facies evolved depending on energy level and sea level fluctuation (Fournier et al., 2004). Red algae and coral bearing bindstone deposits developed in the higher energetic environment of reef that is called as reef core (Hec kel, 1972; Gül and Eren, 2003). The wackestone and packstone around the bindstone reflect sedimentation in quieter water (Strasser and Strohmenger, 1997; Gü, 2007). Then, this environment become back reef, reef limestone deposition was ceased by volcanic rock developments. The fossil assemblage of reef limestone indicates the Upper Paleocene (Thanetian) age. Thus, the fine-grained clastic sediment in the lower part of the reef limestone section must be older this time.

**Southern Margin: Alihoca Log**

**Description:** This log mainly composed of coarse-grained clastic rocks and overlies unconformable the Upper Cretaceous Alihoca Ophiolites (Fig. 6). It starts with nearly 40 m thick, red, brown and greenish colored agglomerates that include various grain sized basalt
and andesite pebbles (VS). Then wackestone overlies the irregular upper surface of the agglomerate. After this level 150 m thick cover including agglomerate and limestone fragments were observed. The last agglomerate level of this section is overlain by the lithicarenite including chert-slate-volcanic rock fragments. This normal graded sandstone is followed by slumped sandstone and mudstones (SF). Nearly ten meters thick erosive based pebble-granule bearing conglomerates and normal graded volcanic rock pebbles bearing conglomerates (MFT) overlie the thin to medium bedded cream colored limestones. This limestone classified as mudstone and wackestone that contain intraclast and planktic foraminifera (Globigerinidae). Then nearly hundred meter thick clastic deposits are observed. Laminated, green colored mudstones are alternated with yellow-grey colored medium and thin-bedded, medium and fine-grained lithicarenite and lithicwacke type sandstones (DFT). Those sandstones contain quartz, chert, radiolarite, limestone, volcanic and ophiolite rock fragments with varying
Load structure is common sedimentary structure, while ripple mark, burrow structure, erosive base, normal grading and flute mark are other sedimentary structures. The palaeo-current directions measured from imbricated clasts and groove and flute marks flow ranges between 50° and 95° (Fig. 2). Locally marl levels are found in between the mudstones. Then the section is ended with slumped mudstone and sandstone, erosive based sandstone and marl (SF). At the top of the section nearly 250 m thick basalt and 5-6 m thick red colored mudstones were observed.

Interpretation: the southern margin of the Ulukışla Basin is tectonically more active than the northern margin. The agglomerates and limestone alternations indicated that volcanic activity effect on shallow marine sedimentation. Intense volcanic activity with an excess volcanic rock fragments gave way to deposition of agglomerates, during the subsequent quiet period mudstone-wackestone deposited (Strasser and Strohmenger, 1997; Fournier et al., 2004; Gül, 2007). Intraclast content pointed out that the local high energy level of environment. The sandstones and mudstones may indicate the middle-distal submarine fan (MFT-DFT) deposition (Mutti, 1992). The Td and Te are abundant; this mudstone dominant part indicated the deposition in low energetic environment and suspension in pelagic and hemipelagic environment that evaluated under distal fan environment (Mutti and Ricci, 1972; Shanmugam, 2002). Normally graded Ta and Tb are locally found in the section that indicates the excess sediment input and high energetic environment than the Imrahö section and point out the middle fan turbiditic environment (Mutti and Ricci, 1972; Shanmugam, 2002). The grain composition of the sandstones indicates polymictic nature of source area. Previous researchers (Clark and Robertson, 2002; 2005) mentioned submarine volcanic activities in the Ulukışla basin. The agglomerate and slump deposits were developed depend on fragments supplied from those volcanic. The limestone deposited during the quiet environments.

Figure 6. Alihoca Log measured in the southern margin of the Ulukışla Basin.

Şekil 6. Ulukışla Havzası’nın güney kenarından ölçülmuş Alihoca kesiti.
Southern Part of Central: Kirkçeşit Log

Description: This log overlies the basalts and andesites (Fig.7). It starts with marl-quartzarenite-mudstone alternation that is cut by basalts (VS). After the 5 m thick covers, abundantly mudstone and siltstone, basalt and marl were observed. Before the nearly 35-40 m thick andesite and pillow lava-andesite, andesite and marl alternations, slumped mudstone and fine-grained sandstone (SF) were found. After the volcanics, grey-green colored, laminated, Morozovella sp. bearing, nearly 80 m thick mudstones (DFT) deposited. These mudstones are overlain by the Morozovella gracilis BOLLi bearing wackestones. Then a hundred seventy meter clastic sequence deposited. Several fining upward sequences were differentiated in this section. Each sequences starts with the pebble conglomerates and ends with the normal-graded sandstone (coarse to fine-grained sandstone) and coarse to medium-grained sandstones (MFT). Initial part sandstones are classified as a lithicwacke including slate, chert, andesite, basalt and limestone fragments with varying ratio. Those limestone fragments are the fragments derived from the Upper Paleocene (Thanetian) reef limestone. Reverse-graded clastic (PFT) is only found in between the 230 and 250 m of section. The general paleoflow pattern, measured from imbrications, varies between 183° and 250° (Fig. 2). Those clastic sequences are laterally pinching out inside the planktic foraminifera bearing mudstones and locally limestone. The laminated, green-grey colored mudstone deposited in between the 340 and 455 m (DFT). This mudstone level is cut by restricted conglomeratic bodies. The log ends with red colored thin bedded wackestone-grainstone then mudstone. The red limestone thrusting on clastic rocks include the Campanian-Maastrichtian fauna: Planktic foraminifera: Contusotruncana fornicata (PLUMMER), Globotruncana stuartiformis (DALBIEZ); Benthic foraminifera: Rotaliidae; red algae, pelecypod shell fragments. The whole section is overlain by the andesites.

After the volcanic and clastics alternations, andesites and pillow lava from the submarine volcanism ceased the sedimentation. Then depend on a lowering of energy level and relatively deep-quiet environment planktic foraminifera bearing 80 m thick mudstone deposited. The mudstones were characterized the lower energetic environment that permit the deposition from suspension in pelagic and hemipelagic environment evaluated as distal turbiditic environment (Mutti and Ricci, 1972; Mutti, 1992; Prothero and Schwab, 1996; Shanmugam, 2002). After this, restricted coarse-grained clastics evolved inside fine-grained clastic depend on a sediment input and proximity of source area. These coarser clastics are the products of sediment gravity flow in higher energetic shallow marine environment or reworked conglomerates in deep sea environment (Boggs, 1987; Cronin and Kidd, 1998). Fine-grained clastics that found in the lateral extension of the coarse clastics point out the deep sea environment. The high energy of environment cause to erosive base, depend on lowering of energy level, normally graded beds were deposited in middle fan turbiditic environment (Mutti and Ricci, 1972; Mutti, 1992; Shanmugam, 2002). Increasing of energy level and excess sediment input cause to reverse graded clastic deposition in proximal fan environment (Mutti and Ricci, 1972; Mutti, 1992; Shanmugam, 2002). These coarser clastics indicate the excess sediment input and high energetic environment than the Imrahor section. Upper Paleocene (Thanetian) reef limestone fragments of clastics probably derived from the patch reefs seen in the northern part of the log area. Then again quiet environment product laminated mudstones were observed. These younger deposits were thrust on by the red colored planktic foraminifera bearing Campanian-Maastrichtian limestone and mudstones. Narrow region in front of the southern margin of the Ulukışla Basin (the Alihoca and Kirkçeşit Logs) were filled by the coarser sediments, while asymmetrically vast areas in the northern part were filled by the finer-grained clastics (in the Imrahor Log) with a different age.

Northern part of Central: Ardiçi Log

Description: The lowermost part of this log comprises an alternation of agglomerate, andesite products of submarine volcanoes and planktic foraminifera bearing laminated mudstone, marl and limestone (VS; Fig. 8). The
Figure 7. Kırkgeçit Log measured in the south of the central part of the Ulukışla Basin.

Şekil 7. Ulukışla Havzası'nın orta kesiminin güneyinden ölçülmüş Kırkgeçit kesiti.
limestone levels are classified as a wackestone/packstone. The following fauna has been fixed from mudstones and limestones: Planktic foraminifera: Globigerina cf. linaperta FINLEY, Acarinina sp., Globigerinathea sp., Morozovella sp.; radiolarian, pelecypoda, ostracoda, rare echinoids and benthic foraminifer’s fragments. Paleontological data points out the Eocene age. The basal part of the detail log contains fifteen meter thick; fining upward channelized sequence including abundant volcanic rock fragments and opaque minerals derived from surrounding volcanic rocks. The sandier section of these bottom levels classified as lithicwacke that locally cuts by granule and pebble bearing channel conglomerates (MFT). The upper thirty meter of the log contains limestone (OSF). Initially medium-thick bedded, white colored, packstone with abundant benthic foraminifera (60-70 %) and lesser extent quartz (0-20 %) are found. Then thin to medium bedded wackestone, thickly bedded grainstone and medium-thick bedded wackestone with abundant quartz (0-40 %) and lesser extent benthic foraminifera (20-30 %) are observed. At the top of section, medium-thick bedded packstone with abundant benthic foraminifera (50-60 %) and lesser extent muscovite (0-20 %) were observed. These microfacies contain following fauna; Benthic foraminifera: Alveolina cf. corbarica HOTTINGER, Alveolina ellipsoidalis SCHWAGER, Assilina cf. prisca SCABAUB, Asterigerina cf. rotula KAUFMANN, Asterocyclina stella taramellii MUNIER CHALMAS, Discocyclina archiaci Bartholomei (SCHLUMBERGER), Discocyclina scalaris (SCHLUMBERGER), Gyroidinella magna LE CALVEZ, Lockhartia haimei (DAVIS), Nummulites cf. minvensis SCABAUB, Nummulites cf. atacicus LEYMERIE, Orbitoclypeus ramaraoi crimensis LESS, Orbitoclypeus ramaraoi ramaraoi (SAMANTA), Ronicothalia cf. couisensis (d’ARCHIC), Rotalia trochidiformis LAMARCK, Alveolina sp., Assilina sp., Asterocyclina sp., Chrysalidina sp., Opalthmidium sp., Orbitoclypeus sp., and Orbitolites sp. This fossil assemblage indicates the early to late Lower Eocene (the Ilerdian-Cuisian; Fig. 8). The section is nonconformably overlain by the andesites.
Interpretation: Intense submarine volcanic activity with an excess volcanic rock fragments gave way to deposition of andesite pebbles bearing agglomerates, during the subsequent quiet period mudstone and limestone developed depend on low sediment input and relatively deeper marine environmental condition (Strasser and Strohmenger, 1997; Fournier et al., 2004; Gül, 2007). High sediment input caused the lithic wacke and channelized coarser conglomerate evolutions. Normally graded clastics indicate the excess sediment input and high energy level in the middle fan turbiditic environment (Mutti and Ricci, 1972; Shanmugam, 2002). Then, sediment input was decreasing, and carbonates started to deposition. The types, abundance and size of the benthic foraminifera indicate suitable open shelf conditions. However, the high quantity extraclast (quartz + muscovite) and grainstone in the middle level of limestone indicates the higher energy environment (Fig. 8).

Some small reefal mounds surrounded by relatively deeper marine mudstone crop out between the Ardıçlı and İmраhor logs. Bioclasts bearing wackestone and packstone around the bindstone bearing patch reef core reflect sedimentation in quieter water (Strasser and Strohmenger, 1997). These reefs include: Benthic foraminifera: Cuvillerina sireli İNAN, Gypsina linearis (HANZAWA), Miscellanea primitiva RAHAGHI, Rotalia trochidiformis LAMARCK, Discocyclina sp. Algae: Distichoplax biseriālis (DIETRICH), Corallina cf. abundans LEMOINE, Amphiroa cf. propria (LEMOINE). This fossil assemblage indicates the Upper Paleocene (Thanetian). These reefs show the existence of a shallow marine environment before the Eocene. The limestone in the Başmakçı Hill located in this area has been termed as the Başmakçı Limestone (Çevikbaş and Öztunalı, 1992) or the Başmakçı Member (Demirtaşlı et al., 1984; Clark and Robertson, 2002, 2005). Çevikbaş and Öztunalı (1992) suggested the Upper Paleocene age for this limestone, while Demirtaşlı et al., (1984) and Clark and Robertson (2002, 2005) consider it to be the Early Eocene.

LATE CRETACEOUS-Eocene GEOLOGIC EVOLUTION OF THE ULUKIŞLA BASIN

The lateral and vertical stratigraphy changings, facies distribution and asymmetrical depositional characteristics demonstrate the two-phased tectono-sedimentary evolution in the Ulukişla Basin: the Late Cretaceous-Late Paleocene Extensional phase and the Late Paleocene-Eocene Compressional phase.

Interpretation of the Late Cretaceous- Late Paleocene (Thanetian) Extensional Phase

Firstly, the Upper Cretaceous shallow marine environment limestone (unconformable resting on older rocks) was deposited in the narrow region in front of the southern margin of the basin (the Campanian-Maastrichtian limestone of Kırkgeçit Log). The narrow southern margin was tectonically more active than northern margin because of the earlier subduction of northern branch of the Neotethyan Ocean and related ophiolite emplacement. In addition to the agglomerates (VS), limestones, turbiditic clastic rocks (DFT) and slumped (SF) submarine slope deposits were deposited in this margin. The alkaline volcanism in form of pillow lavas and massive lava flows reflect post collision extension within the sedimentary sequence during this stage (Alpaslan et al., 2004).

The northern-northwestern margin, during the tectonic quiescence, was covered by large and relatively deeper water until the Late Paleocene (Thanetian). The fine grained sandstone and laminated mudstone (DFT) deposited during this time interval. The sandstones of the northern region (observed in the bottom part of İmраhor log) were initially fed from the Niğde-Kırşehir Metamorphic Massif, then from the younger volcanic rocks. Later, the red algae bearing patch reefs (RC; surrounded by fine-grained clastics and marl, BR) evolved in this area. The examples of the Paleocene patch reefs also occur in the area between the Başmakçı Village and the Ardıçlı Log. Such reefs need clear, well oxygenated, warm and high nutrient environment (Strasser and Strohmenger, 1997; Gül and Eren, 2003; Gül, 2007). Topographically higher areas (formed...
as a result of the volcanic activities or uplifting created the suitable environmental condition for the reef development. The reef limestone deposition interrupted time to time by syn-sedimentary volcanism (Fig. 9A). Because the materials erupted from the volcanoes deteriorated the environmental conditions.
Interpretation of the Late Paleocene-Eocene Compressional Phase

The regional uplifting caused breaking of northwest and southern margin of the basin and sea regressed asymmetrically towards the central part of the basin. On southern flank of the basin, shallow marine deposition represented with limestone-marlstone alternation (the Kırkgeçit log) changes into clastic dominated deposition as a result of the subsidence of basin with continuous regression. Despite the basal units composing of channelized coarse clastics (MFT, PFT), younger units contains sediments derived from the Paleocene reef limestone. Furthermore, the continuous basin margin uplifting and basin subsidence caused the deepening of environment and sandy/muddy turbidites deposition (DFT). These facies and/or environmental changings can be attributed to strong tectonic effect in the Ulukışla Basin. Intense tectonic activities caused to coarser clastics evolution (MFT, PFT).

Sedimentation on northern central margin of the basin started with the deep sea mudstone, limestone and submarine andesitic rock alternations (VS) synchronously with thrusting. The fossil content listed in the Ardıçlı Log section point out the relatively deeper marine environment. Possible sea level fallings and tectonic activities caused to deposition of coarser channelized deposits. Then open shelf environment (OSF) evolved presumably due to shallowing of the area, and extraclast-rich and abundant benthic foraminifera-bearing limestone (fossil contents listed in the Ardıçlı Log section) deposited. Thus the northern and southern flanks of this intracontinental basin reveal significantly different depositional features appear to have been separated by the local uplift may evolved due to tectonic and/or magmatic activity (Fig. 9B).

Final closure of the Ulukışla Basin was achieved by compressional deformation at the end of Eocene, orientated perpendicular to the E–W axis of the basin. The subsequent uplift and erosion resulted in the sub-Oligocene unconformity, as observed around the Ulukışla Basin (Clark and Robertson, 2005). The compressional regime has been characterized by the southward thrusting and E-W trending folds (Fig. 2). In the southern part of basin, the main E-W trending thrust zone allowed the emplacement of the calc-alkaline diorites (Kurt, 2004). The ongoing compression has also resulted with emplacement of the shoshonitic dykes (Kurt, 2004).

DISCUSSION AND CONCLUSIONS

Turner and Williams (2004) indicated that the sedimentary basin inversion is compressing of formerly extensional basins. The basin inversion caused that the basin exhumation and significant sedimentary deposits changes. Several inversion basins evolution reported by different researcher in different areas during the Late Cretaceous and the Early Tertiary time coeval with the Ulukışla Basin. The Ulukışla Basin evolved under the effect of Alpine Orogeny. The compressional region from Spain to Turkey was closely attributed to northern movement ratio of the Arabian and African Plates depend on the Alpine Orogeny (Boccaletti et al.,1988; Binks and Fairhead, 1992; Bosworth, 1992; Guiraud et al., 1992; Guiraud and Bosworth, 1997). Moreover, the sedimentary basin inversion in the some African Basin, for example SW and central part of the Somalia (from the Triassic to the Early Cretaceous extension, then continue with the compressive phase with folding and faulting), was attributed with changes of the Indian Ocean spreading (Boccaletti et al.,1988). The extensions of East and Central Africa during the Late Cretaceous, wrench faulting and basin inversion of it during the Early Tertiary time was evolved under the effects of both the Indian and Atlantic Ocean spreading ratios changes (Bosworth, 1992; Guiraud et al., 1992). Guiraud and Bosworth, (1997) emphasized that several basins along the Tethyan margin from the Morocco to the Syrian Arc were folded and inverted during the Early Tertiary time. Similar inversion basin evolution was also reported in front of the NW European Alpine Foreland basin (Ziegler, 1987a, 1987b). Ziegler et al. (1995) reported Cenozoic inversion effected basins some 1600 km from the Alpine front. Golonka (2004) schematically shows inversion affects over the southern margins of the Eurasian Plates; in and around the Turkey and the Central Europe.
Guiraud and Bosworth, (1997) shows the magnetic anomalies, tectonic events in Africa-Arabian Plates and related motion of the Africa against the Eurasian. The northern movement of African Plate during the Campanian depend on the Atlantic Ocean spreading caused closing of the Neotethyan Ocean and ophiolite emplacement. Rifting of the northern margin of the African and Arabian Plates during the Campanian-Maastrichtian time referred to an extensional regime in the Ulukışla Basin. Clark and Robertson (2002, 2005) consider the Ulukışla Basin to have formed in response to extensional, or transtensional processes in the Early Tertiary time. The extensional phase in the Ulukışla Basin is characterized by the finer-grained clastics deposition in wide, relatively deeper marine environment in northern margin, while coarser clastics are observed in narrow southern margin, which is tectonically more active. Subsequent northern movement of the African and Arabian Plates were not tolerated with the Neotethyan Ocean Crust due to subduction. Thus, the compressional regime developed in the study area. Depend on compressional phase; initially deeper marine environments, then shallow marine environment (host the Paleocene reefs) were observed. Those reefs are locally intercalated with the volcanic materials. The sedimentation shifting through the basin interior were evolved depends on regional uplifting, the Eocene sedimentation including reef limestone and clastics deposited. It is accompanied with calc-alkaline diorites and shoshonitic dykes (Kurt, 2004).

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REFERENCES


