

Relations between the hydrocarbon migration chimney and the electric self-potential field

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Abstract: Survey results for the distribution of self-potential field over the oil reservoirs in Albania are presented. Self-potential surveys have been performed in the framework of the integrated geophysical-geochemical experimental investigation for a direct oil and gas exploration. Relations between self-potential anomalies and hydrocarbon migration chimney are arguments in a particular paragraph. It is observed that hydrocarbon migration chimney has caused a multi-elements geochemical anomaly and integrated geophysical ones. 3D modeling results of the self-potential field distribution in oil reservoir located at different depths are analyzed also.

Key words: Direct Hydrocarbon Exploration, Hydrocarbon Migration Chimney, Self-potential Anomalies, Vertical SP gradient.

METHODS

Electric self-potential field distribution is observed over several oil and gas reservoirs in Albania. These carbonatic and sandstone oil reservoirs are located in different depths, from 900 up to 3500 meters. Geoelectrical observations have been carried out by the surface surveys of the electric self-potential and through analyses of the SP logs in the depth. Mathematical 3D modeling of distribution of electric current over oil reservoirs has been realized.

Migration of the hydrocarbons from their reservoir towards the Earth surface causes changes in the physical and chemical status of the covered reservoir rocks. The rocks of chimney become distinguished from the surrounding rocks located outside of the reservoir contour (Pirson, 1973). Such well-known phenomena have been studied in a number of hydrocarbon reservoirs in Albania (Frasheri *et al.*, 1982, Stambuli *et al.*, 1983). The main geochemical processes between rocks and hydrocarbon migration flow are the redox reactions. The epigenetic reduction facies of the covered rocks are observed over reservoirs. Consequently for a modeling of the self-potential field distribution, the oxidizing-reducing potential E_h has to be calculated:

$$E_h = E_0 + \frac{RT}{F} \cdot \ln \left(\frac{Fe^{+3}}{Fe^{+2}} \right) \quad (1)$$

where: E_0 - is the potential of a standard system, taken conventionally as $E_0 = 0$; R is the gas universal constant; F is Faraday's number, T is the solution temperature in Kelvin degrees. In parallel we have calculated the reducibility coefficient (Werner 1970):

$$K = \frac{C \cdot Fe_{HCl}^2 + Fe_{FeS_2}^2}{\Sigma Fe} \quad (2)$$

where: Fe_{HCl}^2 is the content of two valence iron ions abstracted by HCl; $Fe_{FeS_2}^2$ is the content of two-valence iron sulphide; $\Sigma Fe = Fe_{HCl}^{+2} + Fe_{HCl}^{+3} + Fe_{FeS_2}^{+2}$ is the total sum of content of iron ions, two and three valence, which have participated in the chemical reactions; $C = 0.236$ is a constant.

Figure 1 shows the stratigraphic column and the values of the coefficient K of the rocks over Ballshi oil and gas reservoir in Albania. Results from 130 analyzed samples show that the geochemical epigenetic facies changes from small reduction of the flysch formation in depth, towards the reduced neogenic molasses near the Earth surface. This status changes with an average gradient of $-0.021/100$ m. The surrounding chimney rocks represents negligible reduced facies, with a vertical gradient of $-0.00025/100$ m. The oxidizing-reducing potential E_h increases toward the depth with a gradient of $3.6 - 9.6$ mV/100 m in the rocks over the reservoir. These changes are determined by following equations:

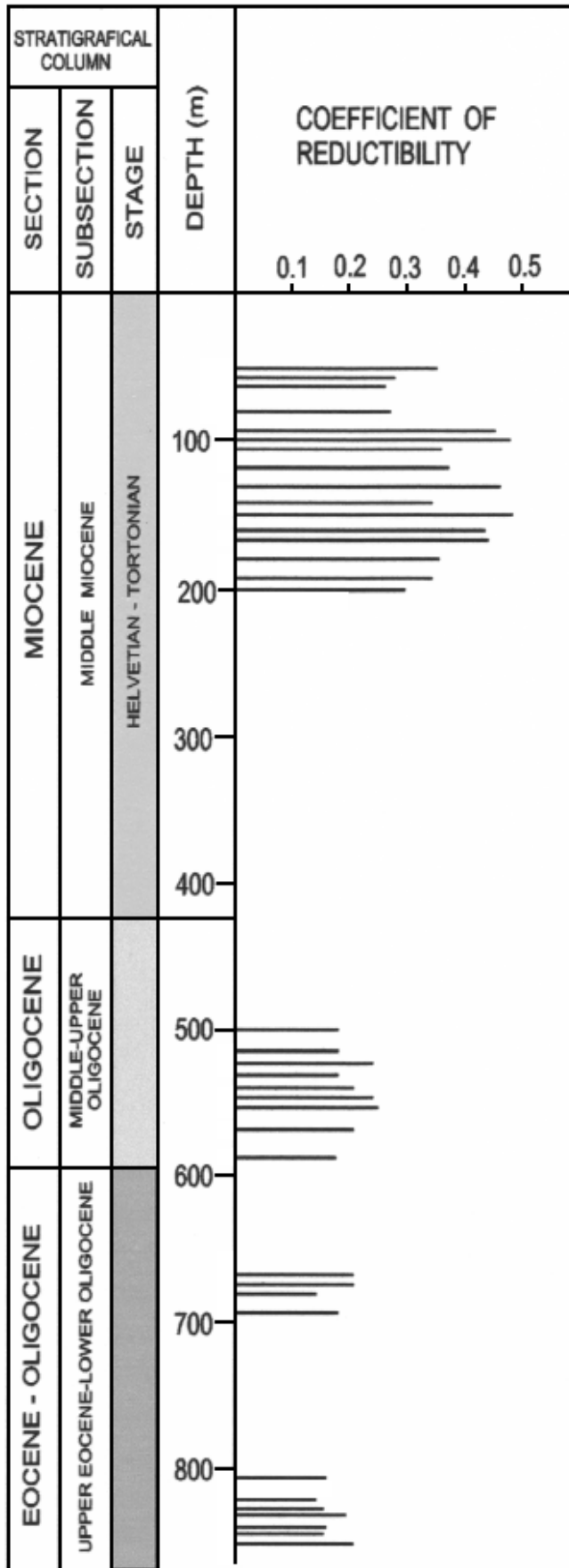


FIG. 1. Summary geochemical column of the reduction coefficient of Ballshi oil and gas reservoir. (After Stambuli Th. *et al.*, 1983).

Over the reservoir:

$$K = -0.079H + 0.54 \quad (3)$$

$$E_h = 9.6H - 6.0 \text{ (mV)} \quad (4)$$

In the same formation inside of the chimney:

$$K = 0.00025H + 0.22 \quad (5)$$

$$E_h = 0.01H - 5.88 \text{ (mV)} \quad (6)$$

where: H is the depth of the reservoir from the Earth surface.

The gradients of K and E_h are in dependence on the distance r from the epicenter of the reservoir. They have great values near this epicenter and decreases towards the contour of the reservoir. They are equal to zero outside the contour water/oil. These changes are determined by the equation:

Over the reservoir:

$$E_h = K(Z - H)(a - r) + C \quad (7)$$

Outside the reservoir:

$$E_h = C \quad (8)$$

where: H is the depth of the reservoir; Z is the depth of the survey point, where the potential is calculated, from the epicenter of the reservoir; r is the horizontal distance of this point to the epicenter of the reservoir; a is the radius of the reservoir; C is a constant.

These changes of the oxidizing-reducing status of the chimney and surrounding rocks are the source of the Electro-motor forces with a spatial distribution able to generate stationary electrical currents of the self-potential field in environment. The chimney of oxidizing-reducing system of the rocks over oil reservoir represents the "generator" of the electric currents.

For the theoretical modeling of the self-potential field I have used the following equation:

$$E_{Fem} = -\frac{RT}{F} \cdot \left(\frac{d}{dx} \ln C_{Fe^{+3}} - \frac{d}{dx} \ln C_{Fe^{+2}} \right) = -\frac{dE_h}{dx} \quad (9)$$

The distribution of self-potential voltage have been calculated using the equation of Poisson:

$$\Delta U = f(x, y, z) = \frac{d}{dx} (\gamma E_{Femx}) + \frac{d}{dy} (\gamma E_{Femy}) + \frac{d}{dz} (\gamma E_{Femz}) \quad (10)$$

where: $f(x, y, z)$ expresses the distribution of the Electro-motor force,

$$Fem = -\frac{RT}{F} \cdot \left(\frac{1}{C_{Fe^{+3}}} \cdot \frac{dC_{Fe^{+3}}}{dx} - \frac{1}{C_{Fe^{+2}}} \cdot \frac{dC_{Fe^{+2}}}{dx} \right) \quad (11)$$

where: $C_{Fe^{+2}}, C_{Fe^{+3}}$ are two and three valence iron ions concentration.

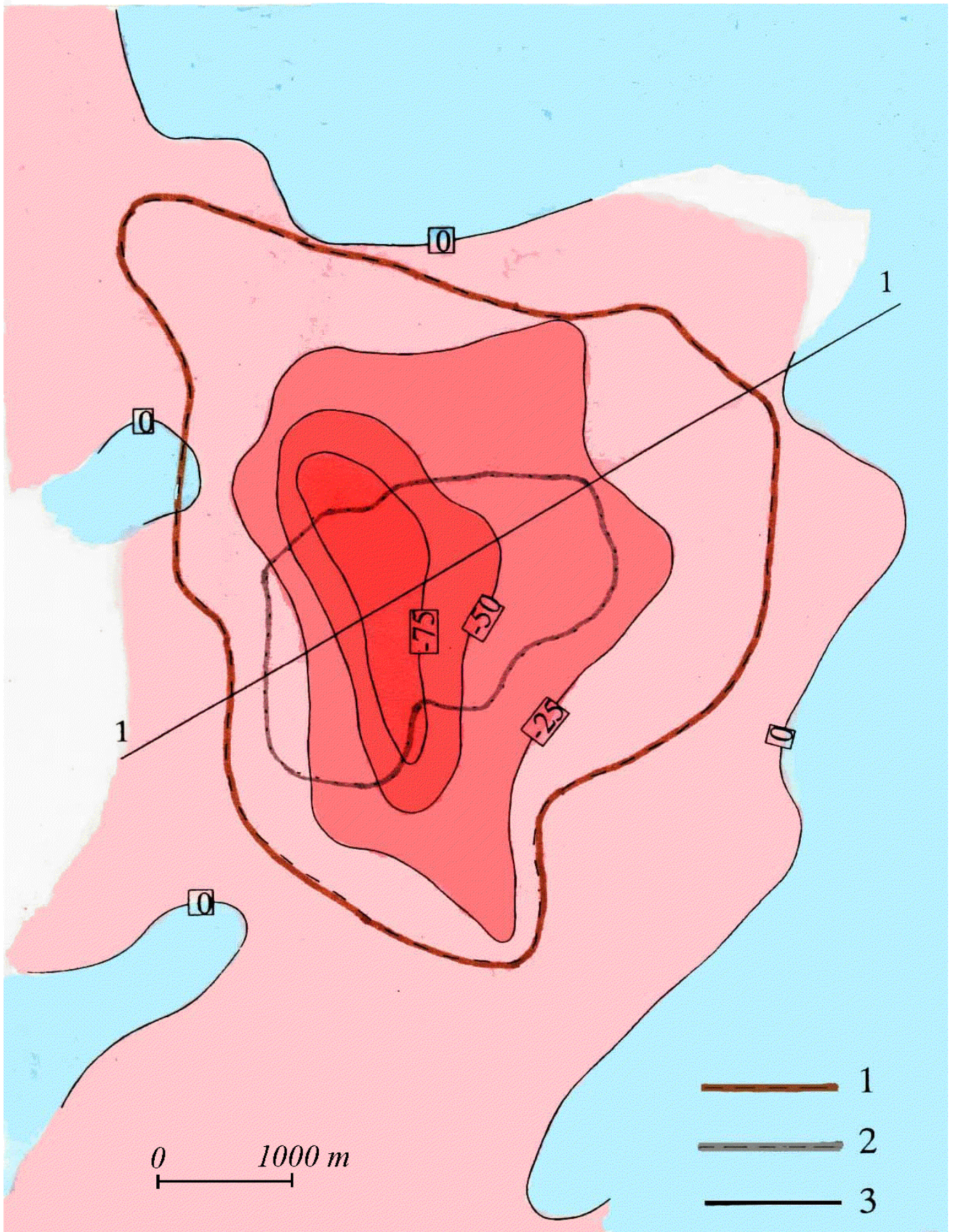


FIG. 2. Self-potential anomaly map, Ballshi oil and gas reservoir, Albania. 1 - The oil-water contour; 2- The oil-gas contour; 3- The potential contours (the contour values are in mV).

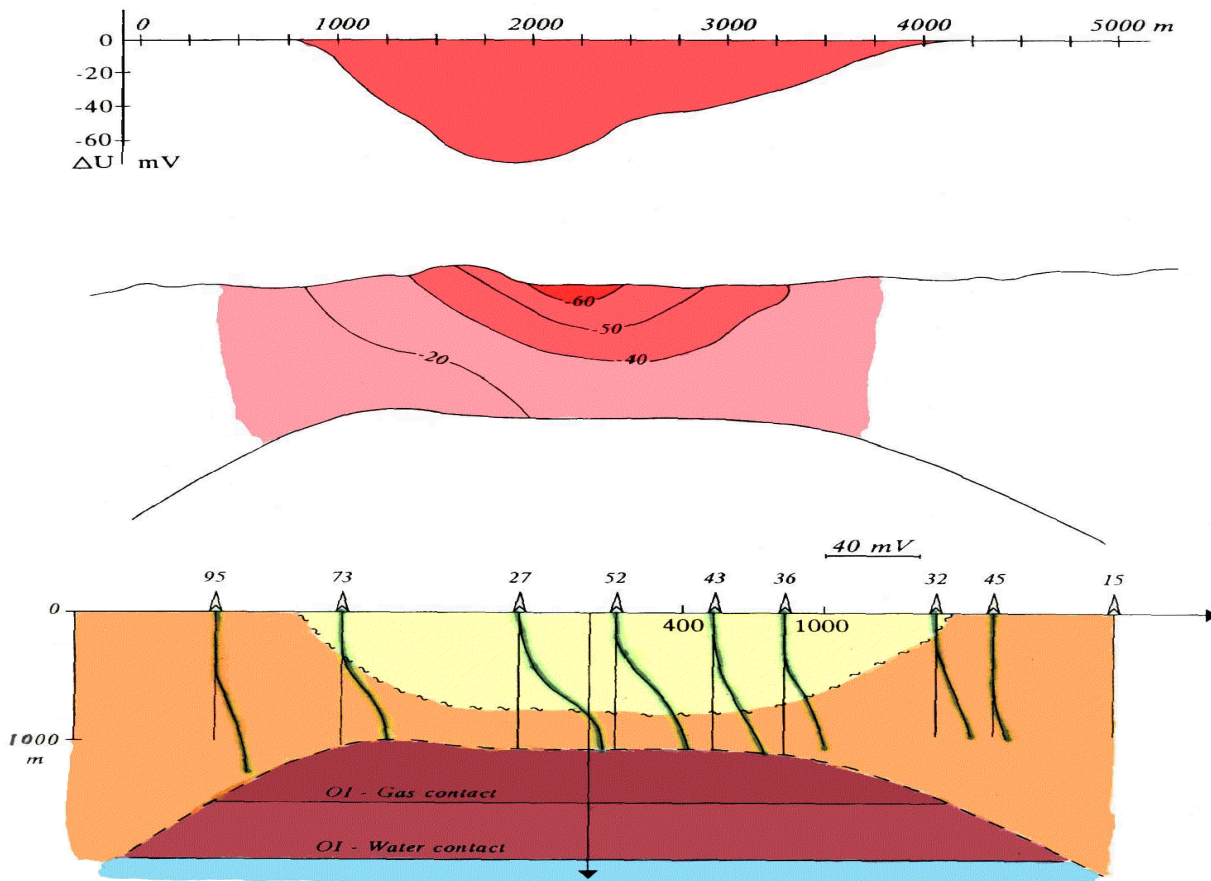


FIG. 3. Geoelectrical section 1-1, Ballshi oil and gas reservoir, Albania. a) Self-potential anomaly observed at Earth surface; b) Mathematical model of the distribution of self-potential in the vertical section; c) Vertical gradient of the “zero line” of SP logs in the wells in Ballshi oil and gas reservoir.

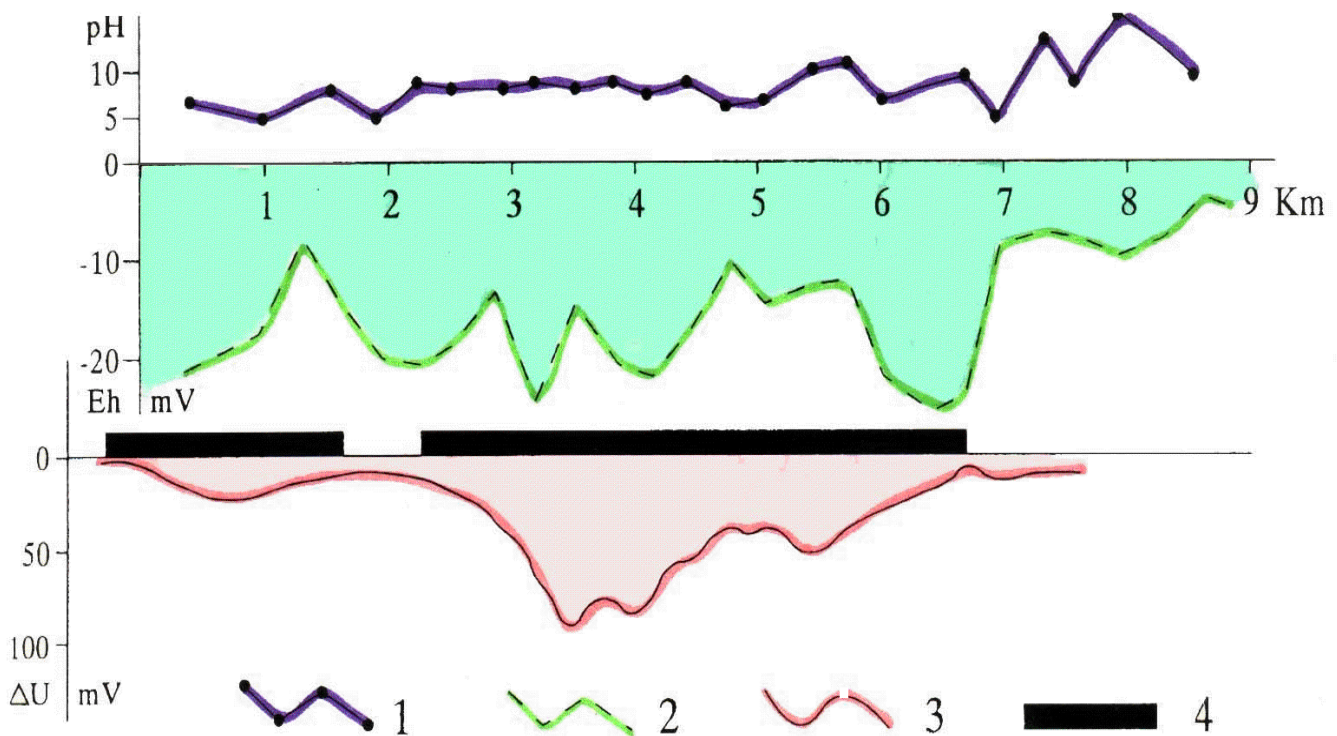


FIG. 4. pH anomaly (1), E_h anomaly (2) and self-potential anomaly (3) in the 1-1 Line, Ballshi oil and gas reservoir.

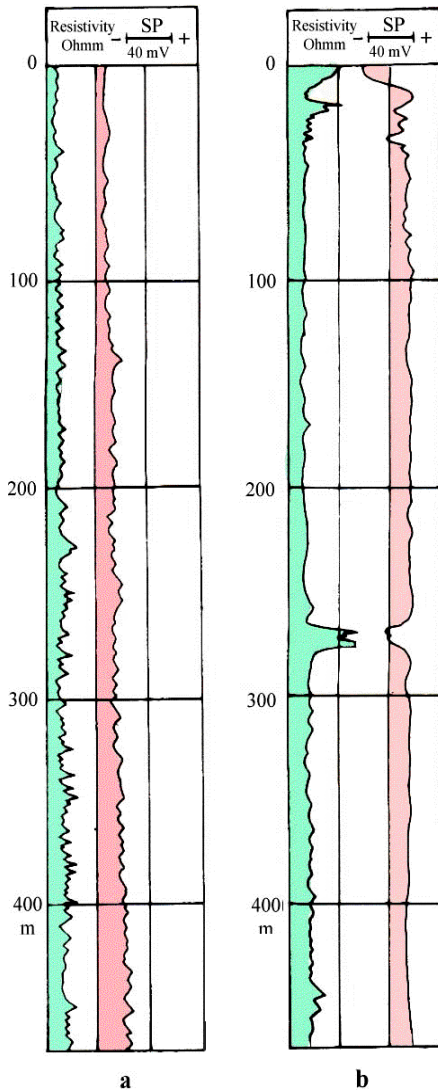


FIG. 5. Trend of the “zero line” of the spontaneous potential logs inside of the reservoir, with a positive vertical gradient from 2 to 15 mV/100 m (a) and outside of the oil-water contour, with a vertical gradient 0 mV/100 m (b)

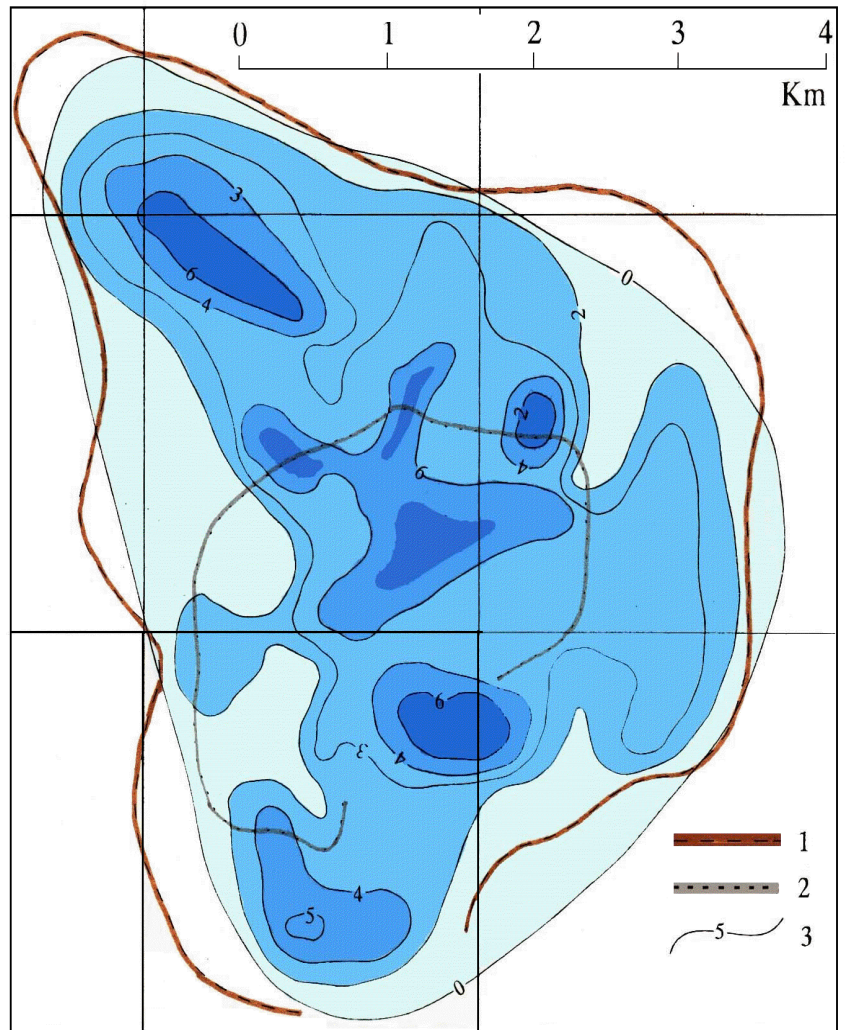


FIG. 6. Vertical gradient of the Spontaneous Potential (SP) logs in the wells in Ballshi oil and gas reservoir. (The numbers in the contours are average SP vertical gradients in mV/100 m).

The solution of the equation (9) has been found using numerical methods.

DISCUSSION AND ANALYSIS

Self-potential anomalies at Earth surface have been observed in several oil reservoir areas in Albania. These anomalies have amplitudes between 20 up to 100 mV (Fig. 2, 3) (Fraseri, et al., 1981, 1982). Redox potentials E_h in the area of the reservoir have been observed too. These SP are analogues with the anomalies observed in oil reservoir areas in different countries (Czorgei and Lada, 1985; Pirson, 1973).

The presence of E_h anomaly shows that over oil deposits chimney of reduced rocks are located (Fig. 4).

Surrounding rocks outside of the reservoir area are oxidable (Fraseri, et al., 1981, Stambuli, et al., 1983). From 130 analyzed samples from geological section of the oil deposits shown in Figure 1, the conclusion is that the epigenetic geochemical facies changes from weakly reduced flysch rocks in depth towards reduced at the Earth surface, where neogenic molasses are located (Fig. 1). The coefficient of reductibility changes with an average vertical gradient of $-0.021/100$ m. The oxidizing-reducing potential E_h increases in depth with a vertical gradient of 3.6-9.6 mV/100 m in the rocks over the reservoir.

The self-potential anomalies are extended at depth, too. This fact has been proved through the positive drift at depth of the “zero line” or “clay line” of the Spontaneous

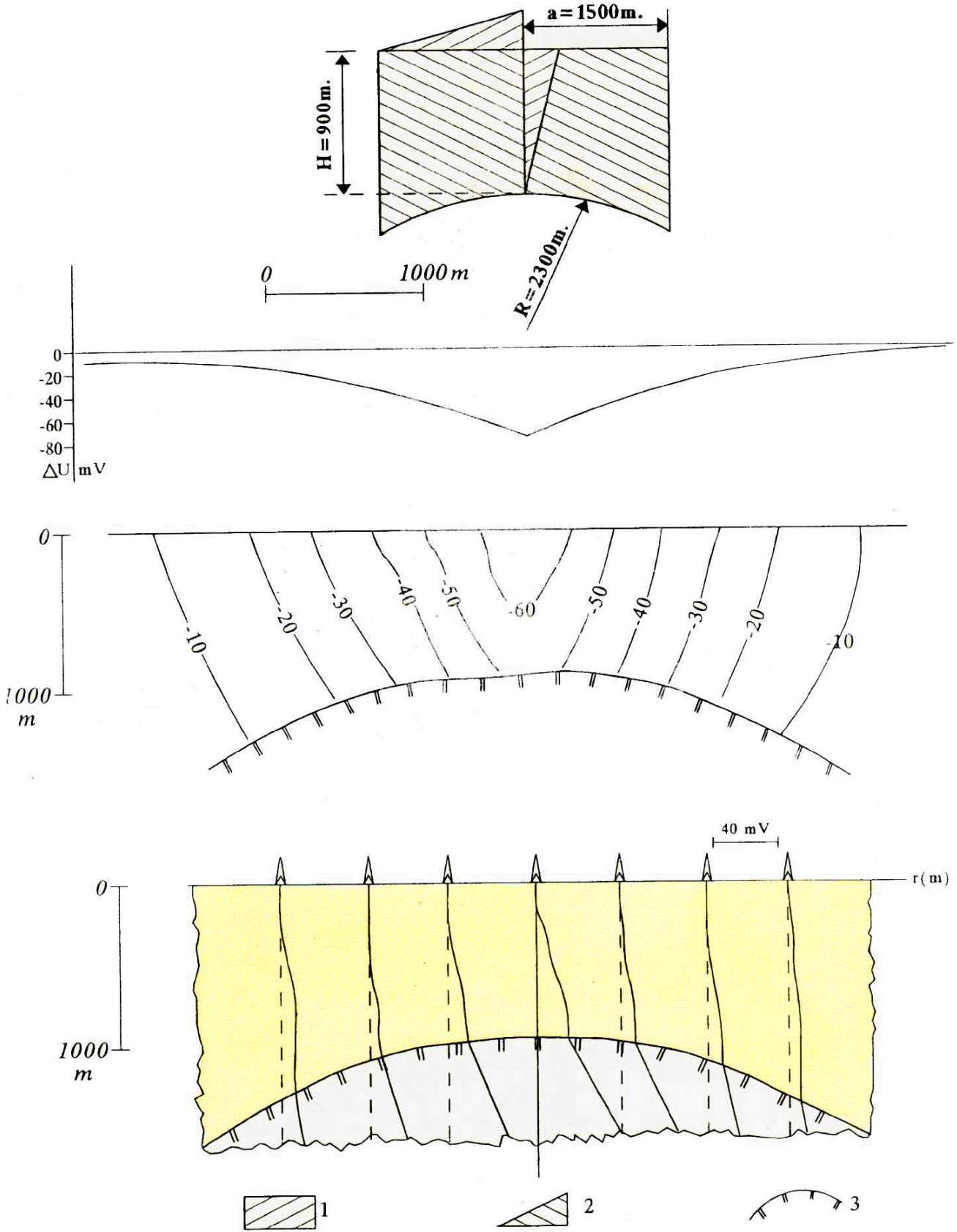


FIG. 7. Theoretical model of the self-potential field distribution in a shallow oil and gas reservoir area. 1- The reduction coefficient plot in the horizontal and vertical directions; 2- The reduced rocks zone over the reservoir; 3 - Top of the oil and gas reservoir.

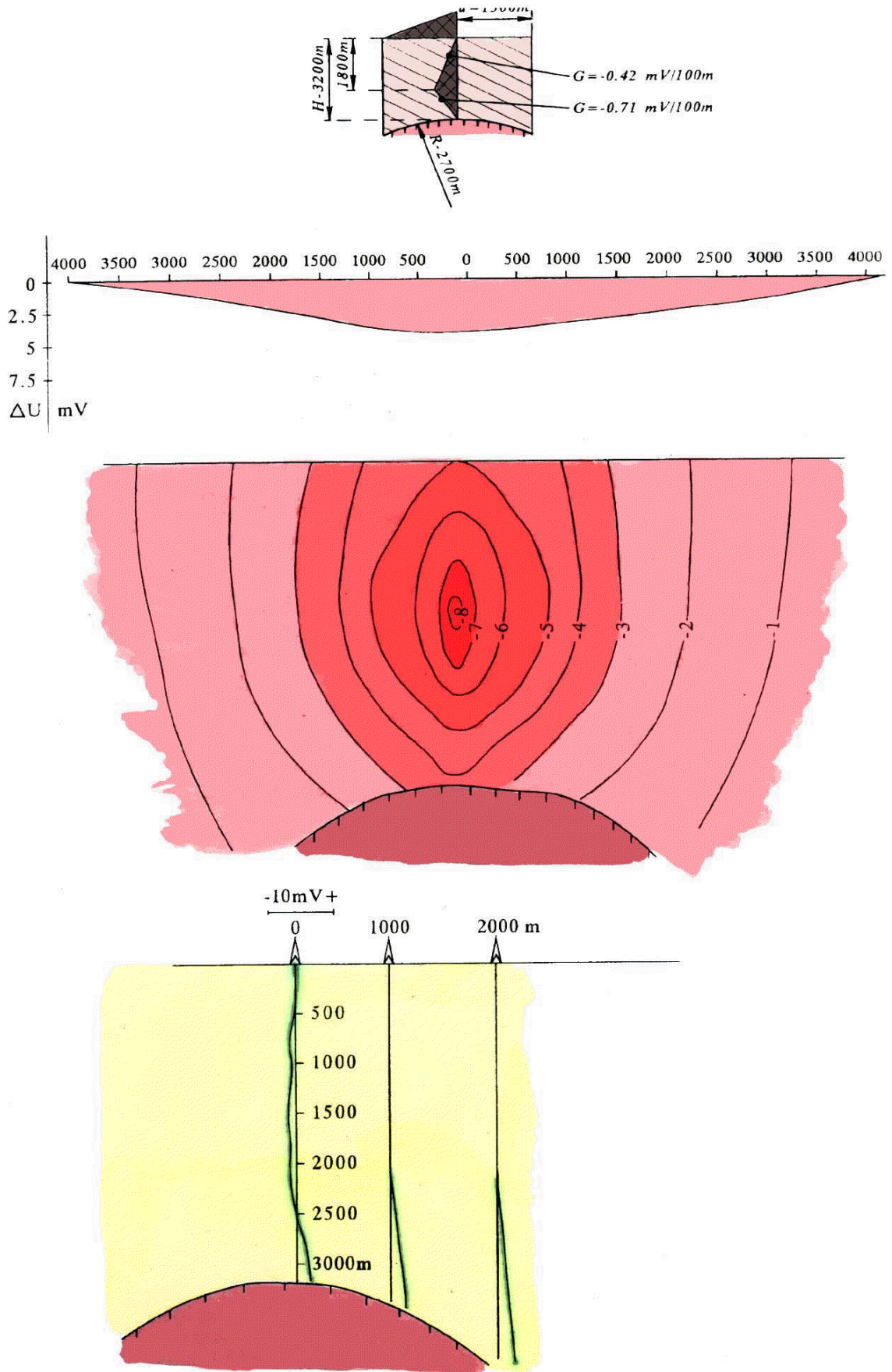


FIG. 8. Theoretical model of the self-potential field distribution in a depth oil and gas reservoir area. The legend as in Fig. 7.

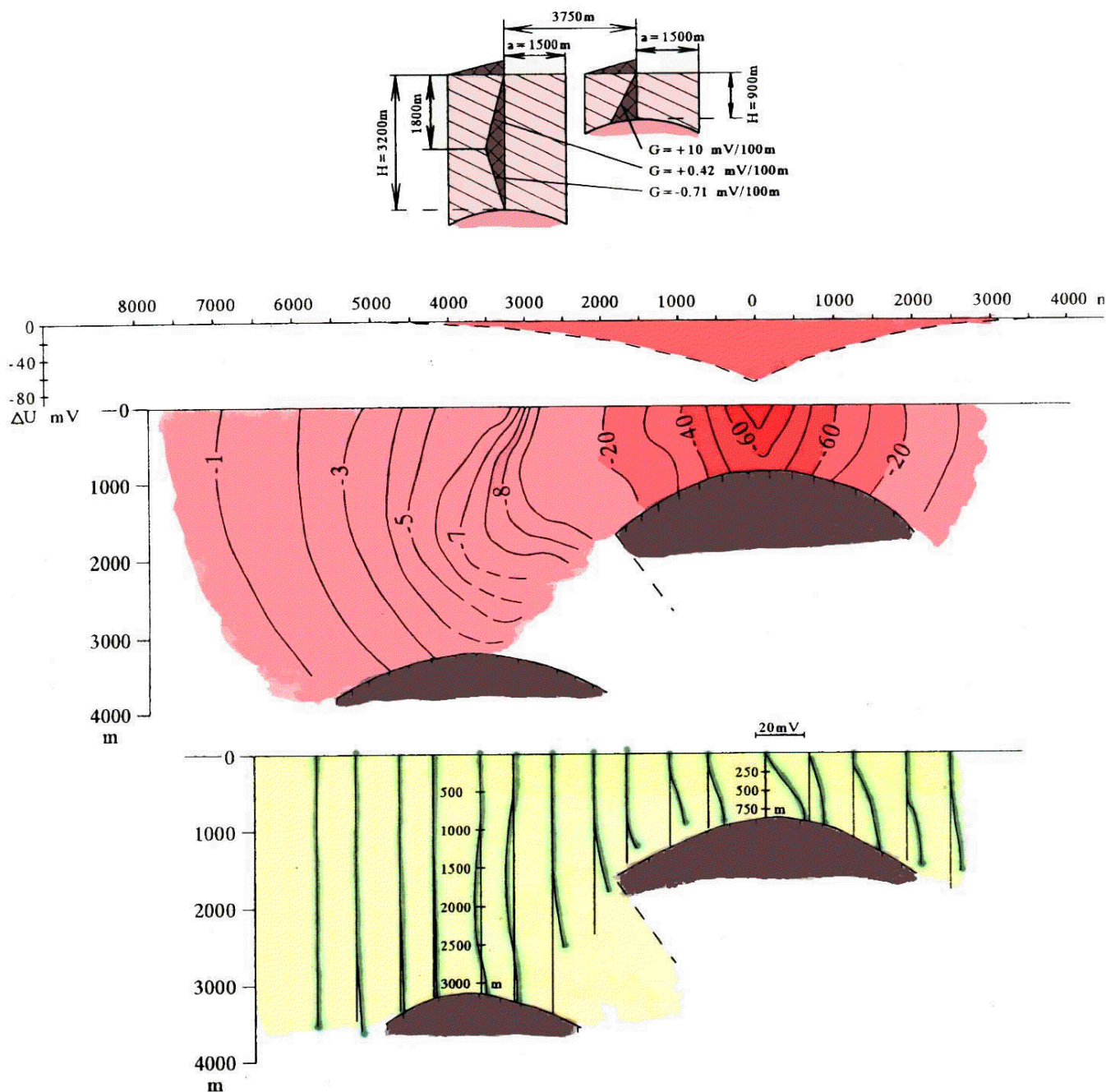


FIG. 9. Theoretical model of the self-potential field distribution in two oil and gas reservoirs, which are located at different depth. The legend as in Fig. 7.

Polarization logs (SP) (Fig. 5) (Frasheri, *et al.*, 1981). The vertical gradient of the SP reaches up to 10 mV/100m in the wells inside of the oil deposits area. It becomes zero in wells, which are located outside of the oil-water contour area. Several hearths with higher gradient values were observed in the map of the PS gradient (Fig. 6). This fact demonstrates that the reducing process of the rocks does not occur everywhere in the geological section. The same phenomena have been observed in the vertical plane, too. They depend on the geochemical conditions of the rocks in different depth over the oil reservoir. It is

necessary to be mentioned that the PS vertical gradient has been observed also in some wells with oil imprint only.

The field survey results have been verified by a mathematical modeling (Fig.7 and Fig. 8). In Figure 7 the reservoir is located at depth of 900 m and the intensively reduced rocks are located near of the Earth surface. In the model of the Figure 8 the reservoir is located at 3500 m depth, and the intensively reduced rocks occur in the middle of the geological section. Complicated anomaly shapes are observed in the case of two reservoirs, located close to each other (Fig. 9).

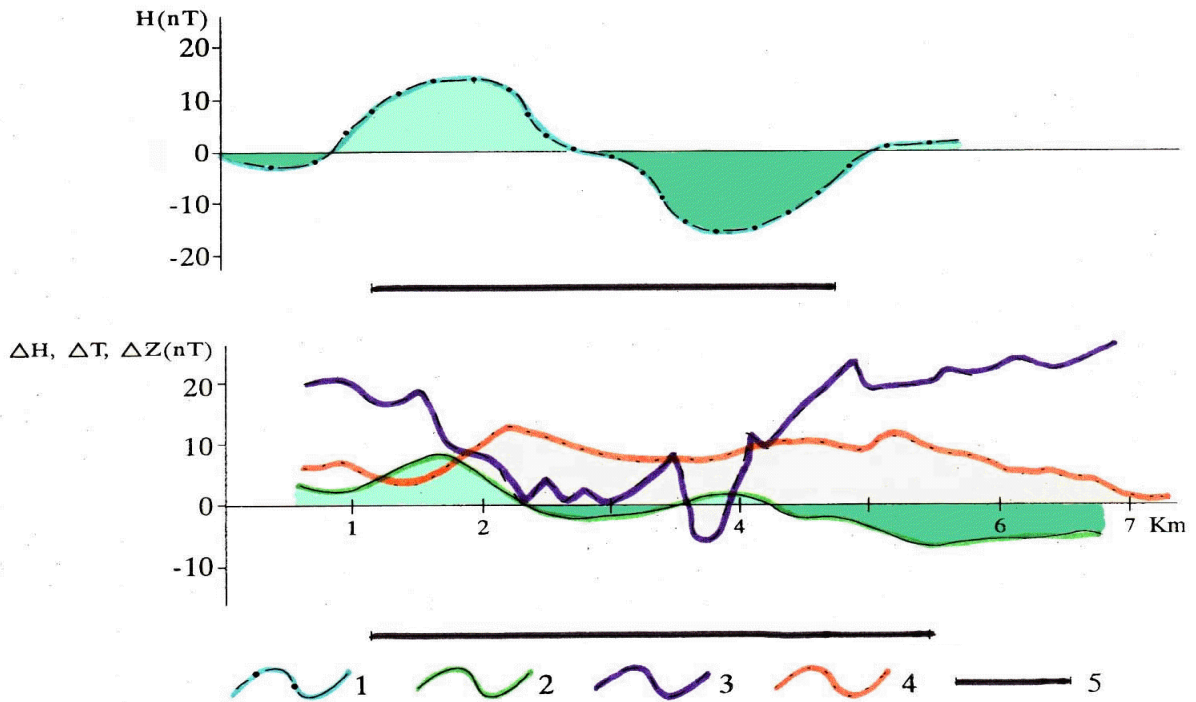


FIG. 10. Synthetic and observed magnetic anomalies in the 1-1 line, Ballshi oil and gas reservoir. 1 - Computed horizontal magnetic component H ; 2- Observed horizontal magnetic component H ; 3- Total magnetic anomaly ΔT ; 4-Computed vertical magnetic component Z ; 5- Projection of the oil-water contour at survey line.

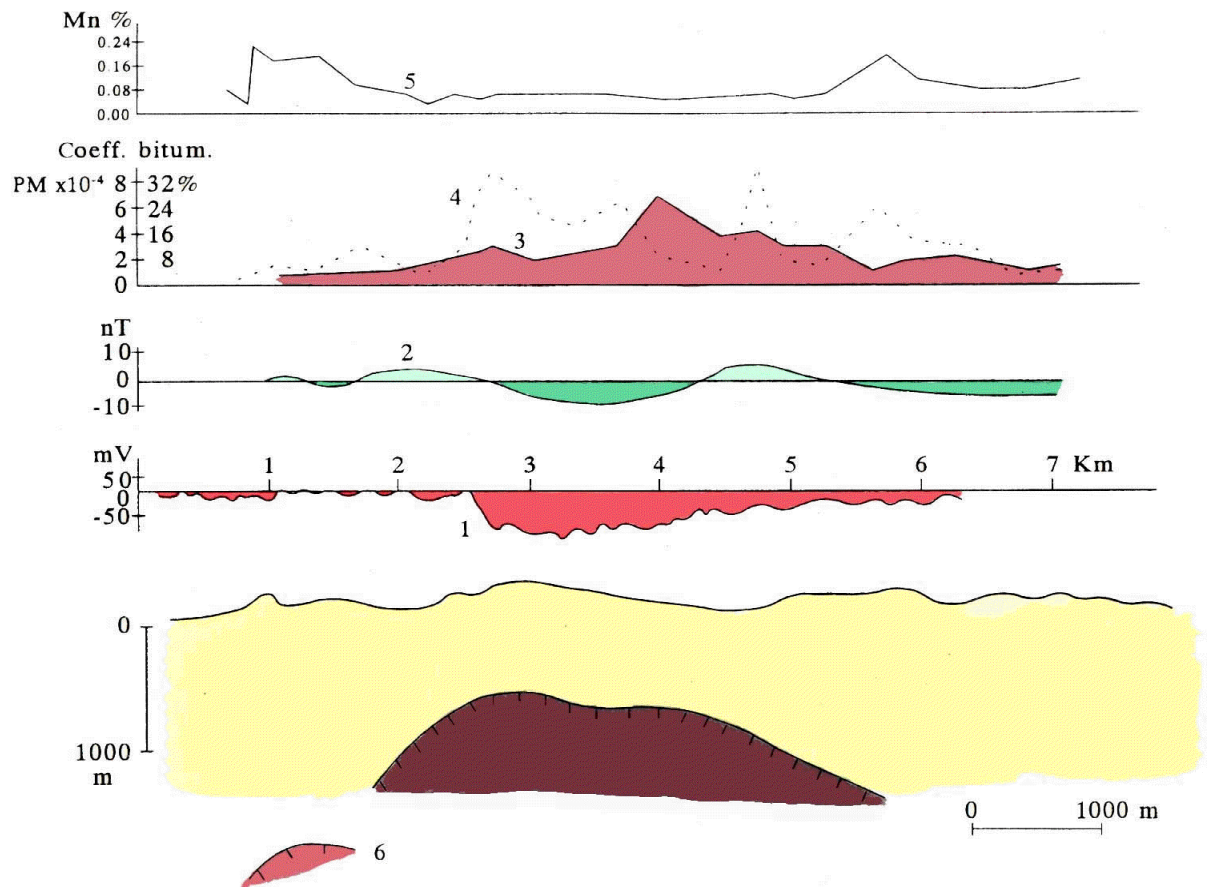


FIG. 11. Integrated geophysical-geochemical anomalies along 1-1 line, Ballshi oil and gas reservoir. 1 - Self-potential anomaly; 2 - Residual total magnetic anomaly of 4th order, recomputing at 250 m depth; 3 - Total gas anomaly; 4- Bituminous anomaly; 5- Manganese content anomaly; 6- Top of the oil and gas reservoir.

The electric field of natural currents is accompanied with magnetic anomaly, which can be observed in the reservoir area (Fig. 10). The total magnetic field anomaly has an amplitude about 5-8 nT (Frasheri, *et al.*, 1982). The magnetic field distribution over the oil reservoir is represented very "noisy". This fact could be explained by the heterogeneous distribution of the secondary magnetite in the subsurface ground, which is an element of the multielementary geochemical anomaly. Over the reservoir a weak pH anomaly is observed (Fig. 4).

SP anomalies on the Earth surface over syngenetic gas reservoirs are not observed, generally. In some anomaly cases, the amplitudes are very small, of the order -20 up to -30 mV, and potential contours represent a mosaic shape.

The studies of SP in various areas of Albania gave evidences for the existence of anomalies connected with the diffusion-adsorption or filtering processes. For the selection of anomalies that are linked with the presence of epigenetic reducing geochemical facies over the oil reservoirs it is necessary geoelectrical and magnetic surveys to be performed in complex with geochemical studies of the redox potential E_h , as well as gas, bitumen and microelements anomalies surveys.

The complex geophysical-geochemical anomalies along line I-I, over the Ballshi oil and gas reservoir are shown in Figure 11 (see also Fig. 2).

CONCLUSIONS

1. SP anomalies of magnitude up to -100 mV are observed on the ground surface over the oil reservoirs in Albania located at depths from 900-4000 meters.

2. SP anomalies are observed also in depth with a positive drift of the SP plot "zero line", which have the vertical gradient up to 10 mV/100 m.

3. SP anomalies are an inherent element of the complex, multi-element geophysical and geochemical anomaly over the oil reservoirs.

4. Complex geophysical-geochemical anomalies represent an indicator for the probability of the presence of commercial oil reservoir in depth.

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