

**QUANTITATIVE ATTEMPT TO RECONSTRUCT
PALAEO PORE-PRESSURES BASED ON NEOGENE
SEDIMENTATION HISTORY IN THE PANNONIAN BASIN**

by

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Introduction. Young sedimentary basins are often characterized by the occurrence of anomalously high pressure both in the basin fill and in the basement. A number of mechanisms for the formation of high fluid pressures have been suggested and compaction of sediment is believed to be the main cause of overpressuring (DICKINSON, 1953; RUBEY and HUBBERT, 1959; BREDEHOEFT and HANSAW, 1968; SMITH, 1971; MAGARA, 1978; KEITH and RIMSTIDT, 1958). In an evolving sedimentary basin, burial is often so rapid that the pore fluid cannot escape quickly enough for fluid pressures to attain hydrostatic values, and for sediments to compact normally. This process may be augmented by aquathermal pressuring defined as pore-pressure created by thermal expansion of the pore fluid during the burial (BARKER, 1972; DAINES, 1982).

Some authors suggested that clay-mineral transformation also contributes to the formation of overpressure (HANSAW and BREDEHOEFT, 1968; BURST, 1969). MAGARA (1975) and CHAPMAN (1980) argue that this factor is of secondary importance and the numerical analysis of KEITH and RIMSTIDT (1985) confirms their opinion. Therefore, the compaction of sedimentary rocks may be taken to be the prime factor in overpressure generation.

The method

We have considered the one-dimensional problem and used that version of TERZAGHI's (1943) equation which is not restricted by the infinitesimal strain assumption. This is the assumption that the dimensions of a volume element do not change with time.

The infinitesimal strain equation is the following:

$$\partial/\partial x [K/\mu (\partial u/\partial x)] = a \partial u/\partial t,$$

where u = the excess pore-pressure, a = the coefficient of compressibility, K = the permeability, and μ = the viscosity. We basically use this equation, but, with a new vertical coordinate which is fixed to the material (rock matrix). The material coordinate is:

$$z = \int_0^x [i - \varphi(x)] dx.$$

The equation is solved numerically, and parameters are calculated step by step by means of a finite-difference method (Crank—Nicholson scheme). Moreover, the constant parameter a in the Terzaghi's equation is replaced by $\sigma(\varphi)$ which describes

the relationship between effective stress and porosity for sedimentary rocks. The definition of effective stress is given by the equation (HUBBERT and RUBBEY, 1959):

$$\sigma = S - p,$$

where S and p are the total and pore-fluid pressure, respectively. The effective stress gives the stress which is actually present in the rock matrix, therefore it is often called as rock-frame pressure. The porosity vs effective stress function is different for different rock types and can be obtained by using empirical porosity-depth curves (Fig. 1).

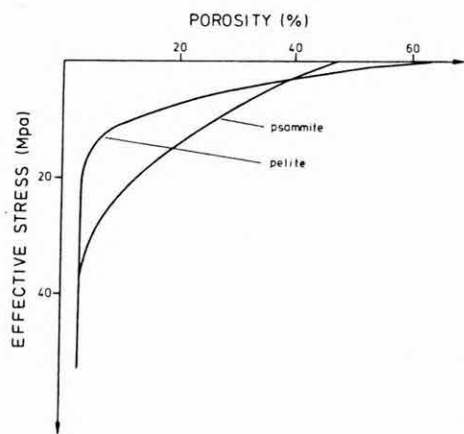


Fig. 1. Effective stress vs porosity relationships derived from SZALAY'S (1982) porosity vs depth relationships for normally compacted sediments in the Pannonian basin

The porosity vs depth function, measured at hydrostatic pressure, is called the normal porosity trend. In zones of overpressure the porosity is higher than the normal value depending on the rock-frame pressure.

A relationship to describe the dependence of the permeability on the porosity is also required. Unfortunately there is no general mathematical relationship expressing permeability in terms of porosity, that can be applied to all cases. It is because, there can be very high porosity with very low permeability if the pores are not connected, or the connecting channels are so fine that the surface tension is strong enough to prevent fluid movement between the pores. The controlling factor is, therefore, not the porosity itself, but the geometry of pores and the way they are connected.

In our modelling we used the following equation:

$$\log K = a\varphi + b,$$

where K is the permeability in mDarcy and φ is the porosity in percent (KEITH and RIMSTIDT 1985). The value of a and b parameters were taken from KEITH and RIMSTIDT (1985) for clays. For sandstone we assumed $a = 4$ and $b = 3.5$ and found that these parameters gave good results.

The sediments of the Pannonian basin can be divided into two broad rock types: pelites (clay, shale) and psammities (gravel, sandstone, conglomerate). These rocks are intermixed on a finer scale than the practical sizes of the blocks used in the finite differences method. In our case each block is divided into two volume fractions occupied by a pelite and a psammite component. This division allows a simple calculation of the bulk properties.

For permeability we used the following formula:

$$K = K_{sh}(K_s/K_{sh})^{(1-R)},$$

where K_{sh} is the shale permeability, K_s is the sand permeability, and R is the pelite to psammite ratio.

In making the calculation, the time-span of sedimentation is divided into small Δt intervals and the sedimentation is modelled by addition of a thin layer in each Δt time interval. The load generated by a new thin layer is carried at the beginning totally by the pore-fluid and it is transferred progressively to the rock matrix. On the surface the pressure is always hydrostatic, the bottom can be permeable (hydrostatic pressure) or impermeable ($dp/dz = 0$).

Results

The results of the calculations are shown in Fig. 2 and 3 for boreholes Hód-I and Békés-1 respectively. In the case of borehole Hód-I it can be seen that a large overpressure has developed in the deeper strata and that it drops down to the hydrostatic pressure close to the basement. This pressure vs depth relationship is very important in controlling the migration of fluids. Namely, the peak of the overpressure constitutes a kind of "seal". Migration can occur upward in sedimentary rocks above the peak and downward in sedimentary rocks below the peak. The boundary conditions were defined at the surface and at the top of the basement. The excess of pressure

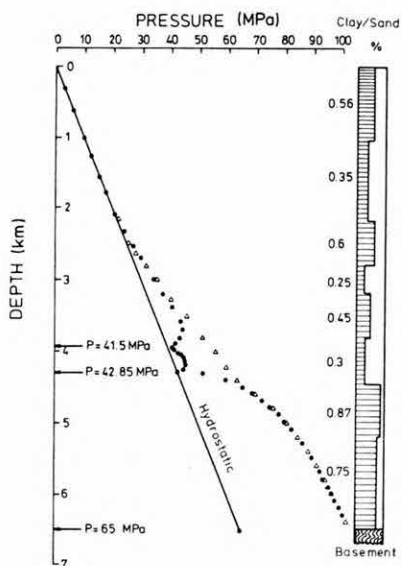


Fig. 2. The calculated pressure vs depth curve for the borehole Hód-I by supposing permeable basement (Δ), and, in addition, two nearly hydrostatic boundary conditions close to a depth of 4 km (\bullet)

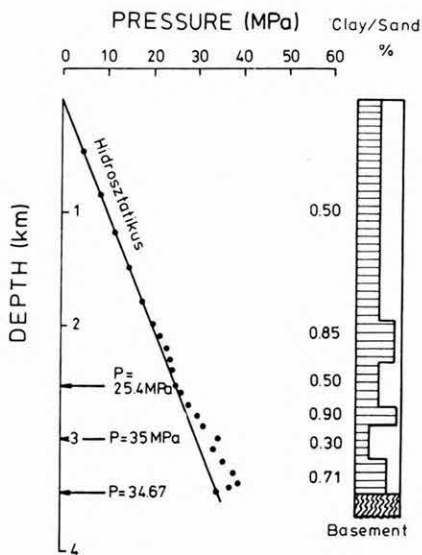


Fig. 3. The calculated pressure vs depth curve for borehole Békés-1 with permeable basement and two other boundary conditions

steadily increases with depth and the rate of increase changes according to the pelite—psammite ratio. The observed pressure seal can be modelled satisfactorily only by defining other boundary conditions. We assumed that the fluid pressure is close to hydrostatic at 3950 m and hydrostatic at 4285 m. Fig. 2 shows that the definition of these boundary conditions leads to good results. The pressure seals are not symmetric to the peak point of the pressure curve because of the downward decrease of the porosity. The depth position of the peak is not constant with time but moves downward.

In case of borehole Békés—I the calculated pressure vs depth curves shows overpressures smaller by one order of magnitude than in well Hód—I. This is mainly the consequence of the boundary conditions. At a depth of 2540 m hydrostatic pressure was measured, the basement was assumed to be permeable and therefore hydrostatic pressure was taken here, too. At a depth of 3020 m, 60 MPa pressure was measured in the pore fluid which is approximately equal to the lithostatic pressure. This high overpressure was unexpected, because:

- i the layer consists of sand of relatively great permeability,
- ii 30 MPa excess of pressure between two nearby hydrostatically pressured points, seems to be unrealistic.

We think therefore that either this was a wrong measurement or the result of a strong lateral effect which cannot be taken into consideration in a one-dimensional model.

Conclusions. According to our model calculation it can be understood that overpressures occur usually below 1200—1500 m only in the Pannonian basin. During sedimentation low overpressure in the near-surface layers can occur only for a short time because, as a result of the high porosity and permeability, the fluid could migrate away very rapidly.

To explain the evolution of pressure seals, lateral fluid migration has also to be taken into consideration. In one-dimensional calculation it can be modelled only by choosing suitable boundary conditions. Such boundary conditions can be defined if the position of highly permeable layers in a sedimentary basin are known. This can be obtained by interpretation of seismic sections and well-logs.

Two-dimensional models are more suitable to describe lateral migration. Their success, however, is also strongly dependent on the choice of adequate boundary conditions.

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