Tectonic Stress-Strain Behavior in Several Sedimentary Basins

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EGU European Geosciences Union

2017-6222

INTRODUCTION

The stress-strain relationship affects many aspects during the entire life of petroleum reservoir. For this reason, the stress condition investigation job is routinely put into practice. While vertical principal stress (S_v) is reliably determined from density logs, minimum horizontal principal stress (S_{hmin}) is often calculated by employing poroelastic equation under the assumption of uniaxially strained basins such that they exhibit no lateral strains.

In this study, we compile data from published literature in 6 sedimentary basins (Fig.1) to calculate values of S_{hmin} using the poroelastic equation and compare them with directly measured values. The measured S_{hmin} is obtained via leak-off tests. In attempt to estimate prevailing tectonic strains, we improve the poroelastic equation by reassumming that unisotropically lateral strains do disturb the horizontal stress manner.

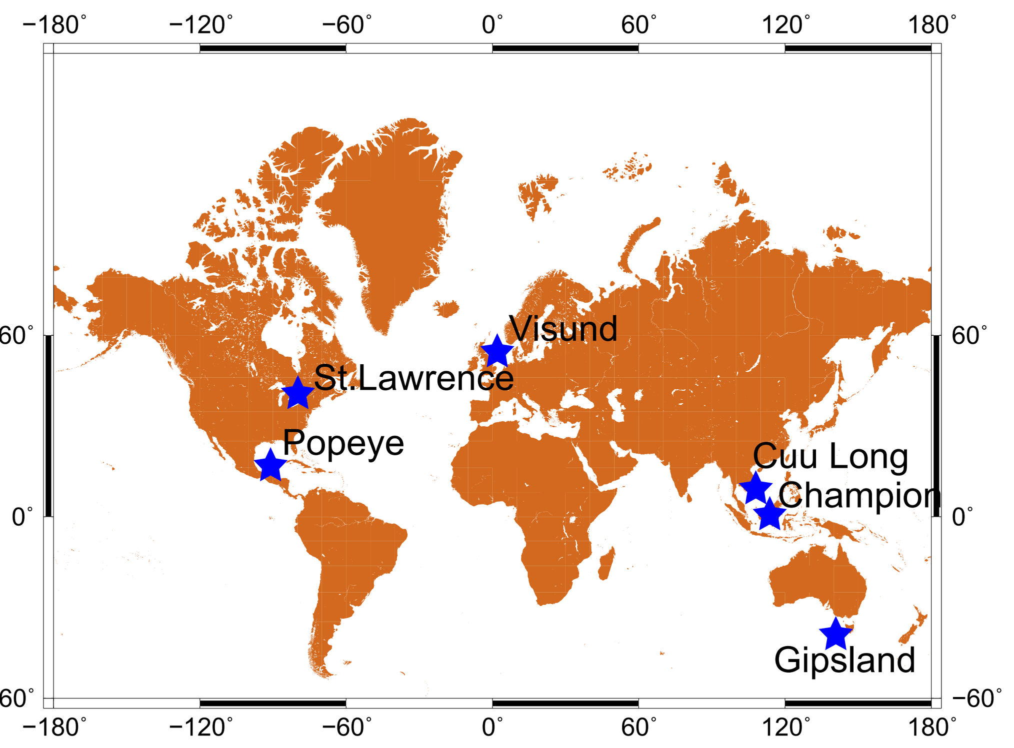

Fig. 1. Study locations

POROELASTIC-BASED CALCULATION

In petroleum industry, the conventional method of calculating minimum horizontal stresses is based on the following equation:

$$S_{hmin} = \frac{\nu}{1-\nu}(S_v - \alpha P_p) + \alpha P_p \qquad (1)$$

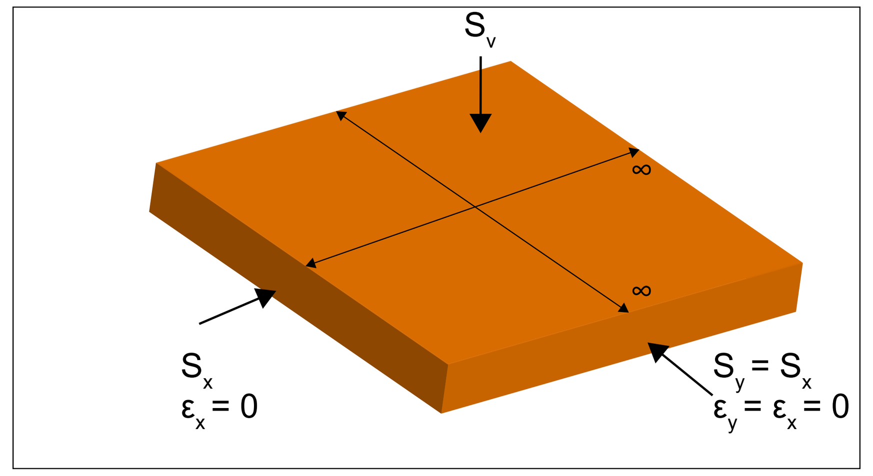

Fig. 2. Schematic describing uniaxial strain assumption

The equation is obtained by solving poroelasticity equation for horizontal stress with uniaxial strain asumption (Fig. 2) given that:

- Only vertical strain occurs during sediment burial (zero horizontal strains ($\varepsilon_x = \varepsilon_y = 0$).
- Two horizontal stresses (maximum and minimum) are equal in magnitude ($S_{Hmax} = S_{hmin}$).

In this study, for the calculation of S_h via the equation, we compile data of vertical stress S_v, pore pressure (P_p) and direct measurement of S_{hmin} (via leak-off tests). We assume Poisson's ratio (ν) of 0.25-0.3 and Biot's constant (α) of unity.

MEASUREMENT OF MINIMUM HORIZONTAL STRESS

During the leak-off tests, mud pressure is raised by pumping fluid into the wellbore. Once a fracture has been initiated in the wall of borehole, pumping is halted and the pressure declined curve is monitored. The pressure where major change in slope of the decline curve occurs is interpreted to be fracture closure pressure. Frature closure pressure is usually interpreted to be equal to the minimum horizontal stress.

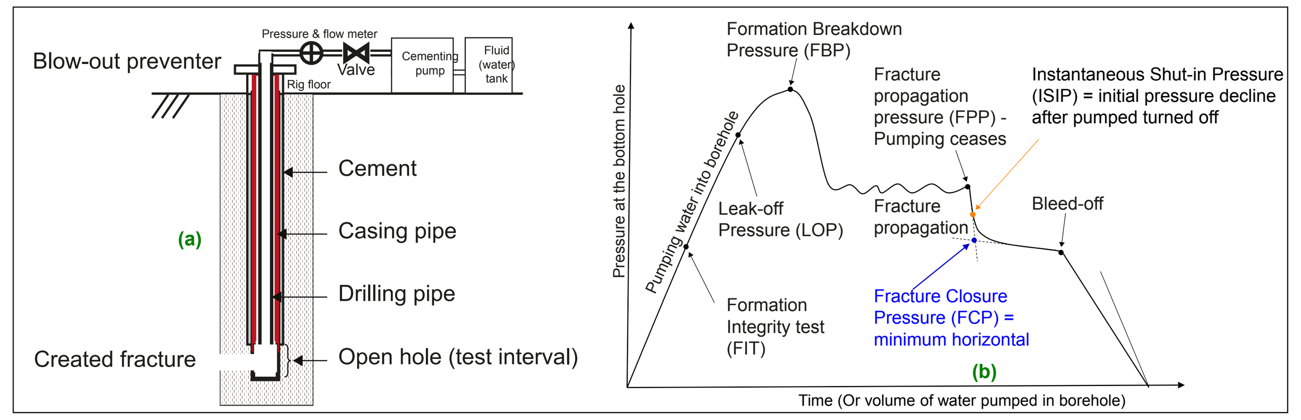

Fig. 3. Schematic of leak-off test (a) instrumentation (b) interpretation

GAP BETWEEN CALCULATION AND MEASUREMENT

We calculate values of S_{hmin} assuming no tectonic strains in the basins and compare them with directly measured values to obtain the difference (ΔS_{hmin}) between calculated and measured S_{hmin}. For the comparison, we analyzed LOT and pore pressure from exploration wells and ignored data from production well to prevent the influence of production-related pore presure drawdown.

The result indicates an underestimation, with no exception, by 4 to 29% if we use the simplistic poroelastic equation. This means that there is always some compressional tectonic strains in all the basins we analyzed and that the no horizontal strain assumption inherent to the equation is inadequate.

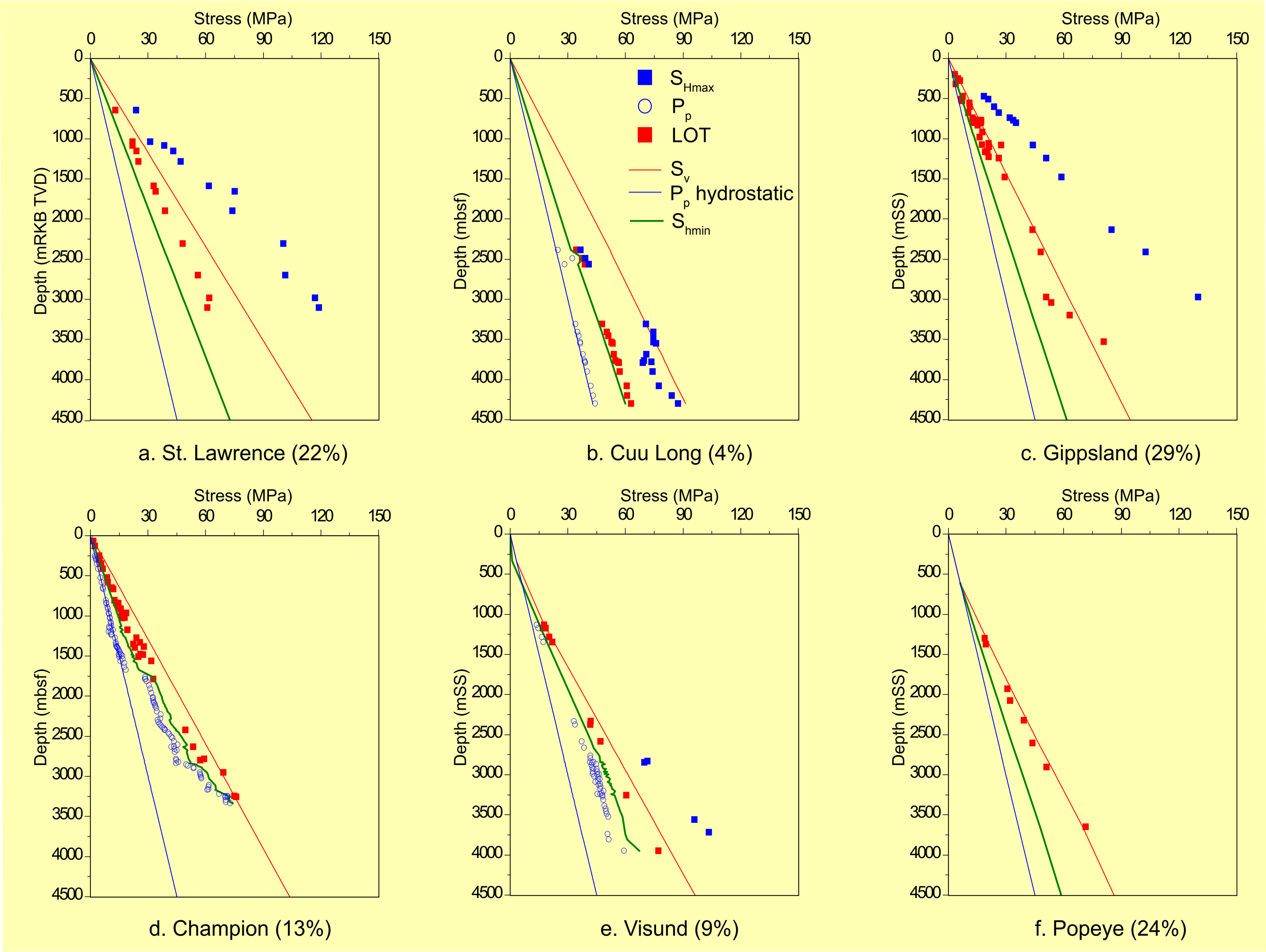

Fig. 4. Gap in minimum horizontal stress between LOT and calculation (the number next to location name is average difference

TECTONIC STRAIN CALCULATION

Due to the gap between measured and calculated values of horizontal stress magnitude (Fig. 4), by reassuming the laterally anisotropic strain behavior (that is, horizontal strains are now taken into account for the horizontal stresses), we apply the Hooke's law to derive the horizontal stress and strain effects. The equations derived to calculate the minimum and the maximum horizontal stresses with tectonic strain effect are in the form of

$$S_{hmin} = \frac{\nu}{1-\nu}(S_v - \alpha P_p) + \alpha P_p + \frac{\nu E}{1-\nu^2}\varepsilon_x + \frac{E}{1-\nu^2}\varepsilon_y \qquad (2)$$

$$S_{Hmax} = \frac{\nu}{1-\nu}(S_v - \alpha P_p) + \alpha P_p + \frac{E}{1-\nu^2}\varepsilon_y + \frac{E}{1-\nu^2}\varepsilon_x. \qquad (3)$$

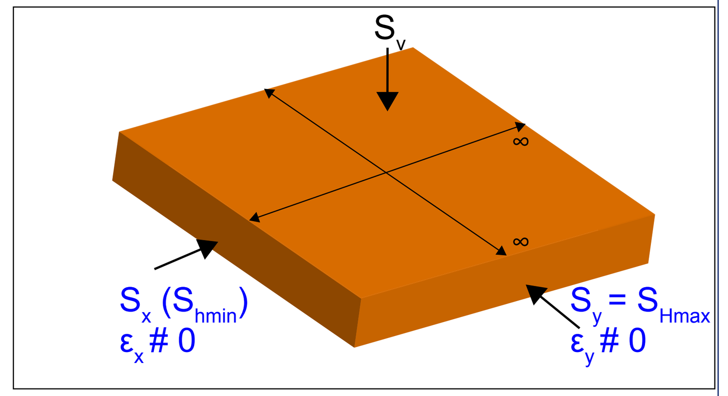

Fig. 5. Anisotropic stresses and strains assumption

For the calculation of tectonic strains, we also compile the values of maximum horizontal principal stress (S_{Hmax}) and elastic parameters (Young's modulus). The maximum and minimum horizontal strain in 4 locations are shown in Fig. 6. The result shows that the average value of tectonic strain varies from 0.61×10^{-3} to 22.7×10^{-3} in S_{Hmax} direction depending on regions, while that in S_{hmin} direction is nearly zero.

TECTONIC STRESS-STRAIN BEHAVIOR

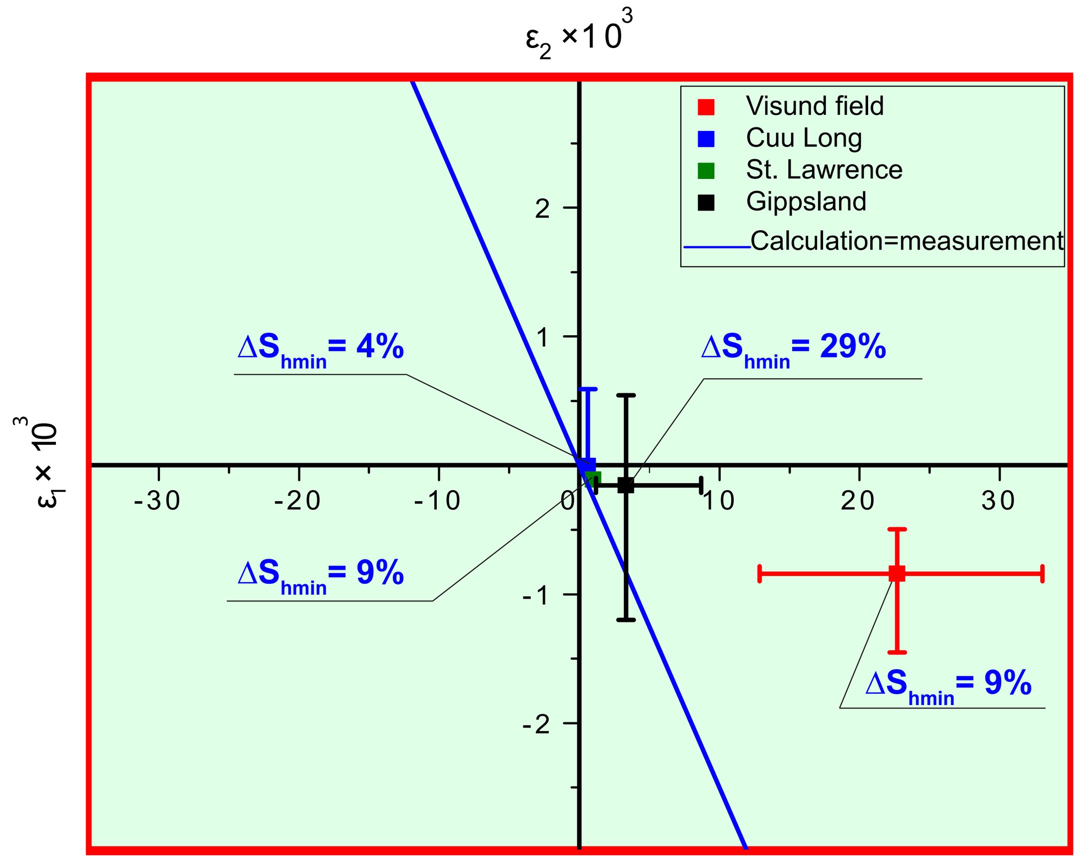

Fig. 6. Strains in 4 study locations

We attempt to investigate the relationship between tectonic stress and strain base on the obtained data. Since tectonic strain is discovered as the main factor that results in the addition of horizontal stresses, it is easy to misconceive that the region showing high ΔS_{hmin} would have high tectonic strain magnitude. However, the calculated tectonic strains that shown in Fig. 6 (with the values of ΔS_{hmin}) reveal that the stress-strain relationship is not consistent in different basins.

For example, Visund field in North Sea, in which ΔS_{hmin} is quite low (9%) and thus expected tectonic strain should be low as well, turns out to be highly strained basin with an average strain magnitude of 22.7×10^{-3}. Gippsland basin, on the other hand, exhibits appreciable ΔS_{hmin} (average 29%) while the average tectonic strain magnitude is relatively small (3.3×10^{-3}).

According to equation 2 and 3, it should be noted that the relationship between additional stress and strain is scaled by Young's modulus (E).

In attempt to confirm this stress-strain behavior, we utilize finite element method (COMSOL commercial software) to carry out the borehole drilling deformation modeling in two boreholes (Fig. 7A &B). The model employs data of stresses and Young's modulus in Visund field and Gippsland basin. As can be seen in the figures, even though the stress applied in Visund is much lower than that in Gippsland, the deformation of the borehole is more severe. This is caused by the lower Young's modulus of Visund (0.71GPa) compare with 10 GPa of Young's modulus in Gippsland.

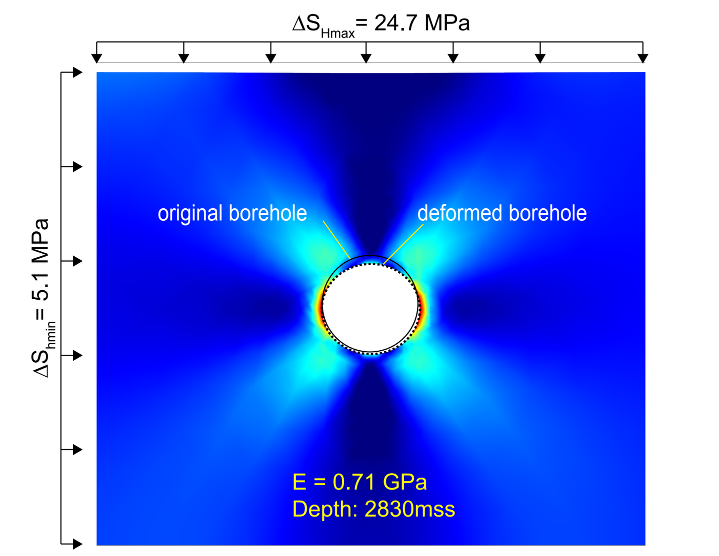

Fig. 7A. Visund field

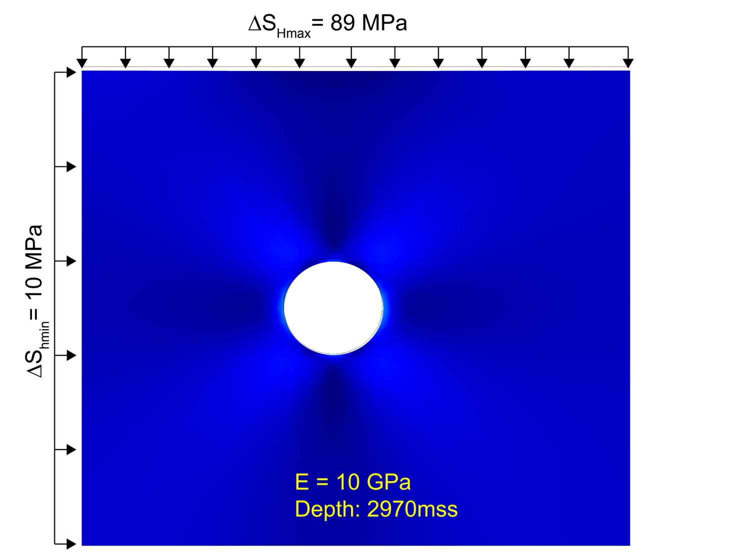

Fig. 7B. Gippsland

CONCLUSIONS

- The no horizontal assumption inherent to the simplistic poroelastic equation is inadequate and consequently can yield some erroneous results in determination of horizontal strees. It is vital to directly measure horizontal stresses than employing the poroelastic equation which is too simple comparing with the complicated state of stress in crust.
- Our attempt to investigate stress-strain behavior in different fields demonstrate that geomechanics of sedimentary bain is significantly afected by tectonic setup in the region and rock mechanical such as Young's modulus is a more dominant factor that controls tectonic stress.