VARIATION OF VERTICAL STRESS IN THE HANOI TROUGH

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ABSTRACT

The rock-stress component caused by the Earth's gravity field is called vertical stress (S_v) and is governed by the weight of an overburden rock column. S_v can be determined from integration of density logs through petroleum industry. The magnitude of S_v is equivalent to integration of rock densities from the surface to the depth of interest. The Hanoi trough located in the mainland Vietnam is a northwestern part of the Red River basin. Twenty-seven wells across the Hanoi trough and off-shore used for the calculation of vertical stress magnitudes in this study. We show that there are some relations between vertical stress magnitudes and structural settings of the area.

1. INTRODUCTION

The Red River basin is the largest basin in Vietnam with a very complicated tectono-stratigraphic setting which varies from onshore to offshore, also from the northwest to the southeast. Hence, it can be divided into many sub-basins. The Hanoi trough is usually considered as a mainland-part of the Red River basin. The characteristics of this area are strong uplift and subsidence, inverted tectonism in Miocene, strong truncation and tilted fault blocks [Nguyen Manh Huyen et al. (2005)] (Figure 1).

State of tectonic stress is characterized by four components, including: the vertical stress (S_v), the maximum principal horizontal stress (S_{Hmax}), the minimum principal horizontal stress (S_{hmin}) and one stress orientation, usually taken to be the azimuth of the maximum horizontal compression. Initial studies of tectonic stress are estimations of S_{Hmax} orientations and relative stress magnitudes (stress ratio) at some specific areas around the world. In 1980s, magnitudes of stress components were estimated through hydraulic testings in deep wells [Zoback (2007)].

Cenozoic stress fields were clarified in the Northeastern and the Northwestern regions of Vietnam through analyzing of fault slip data sets [Phan Trong Trinh el al. (1993, 1994)]. In the Red River basin, it has been determined S_{Hmax} orientations from borehole data which were depicted on the World Stress Map [Tingay et al., 2010].

Among three components of stress magnitudes, vertical stress is the easiest one to be estimated which can be gotten through integration of density logs in wells. In southeastern Vietnam Sea, Nguyen T. T. Binh et al. (2007, 2011) and Nguyen Van Huong et al. (2011) estimated full stress tensor basing on well data in the Cuu Long and Nam Con Son basin. Tingay et al. (2003) and King et al. (2010) discussed about variations of vertical stress in the Northwest Borneo and the Southwest Australia.

This paper prensents the calculation of vertical stress magnitudes from density logs over 27 petroleum wells across the Hanoi trough and off-shore and discuss relations between vertical stress magnitudes and structural settings.

2. GEOLOGICAL SETTINGS

The Hanoi trough has a triangle shape with area of about 9000 km^2. One conner of the triangle locates near Việt Trì city. Its bottom edge runs more than 100 km long along the coast of provinces including Ninh Binh, Nam Dinh, Thai Binh and Hai Phong. The basin contains of Tertiary sediments aged Paleogene to Quaternary, mainly including coal-bearing terrigenous materials, with thicknesses varying from 3200 to over 7000 meters [Do Bat et al. (2005)].

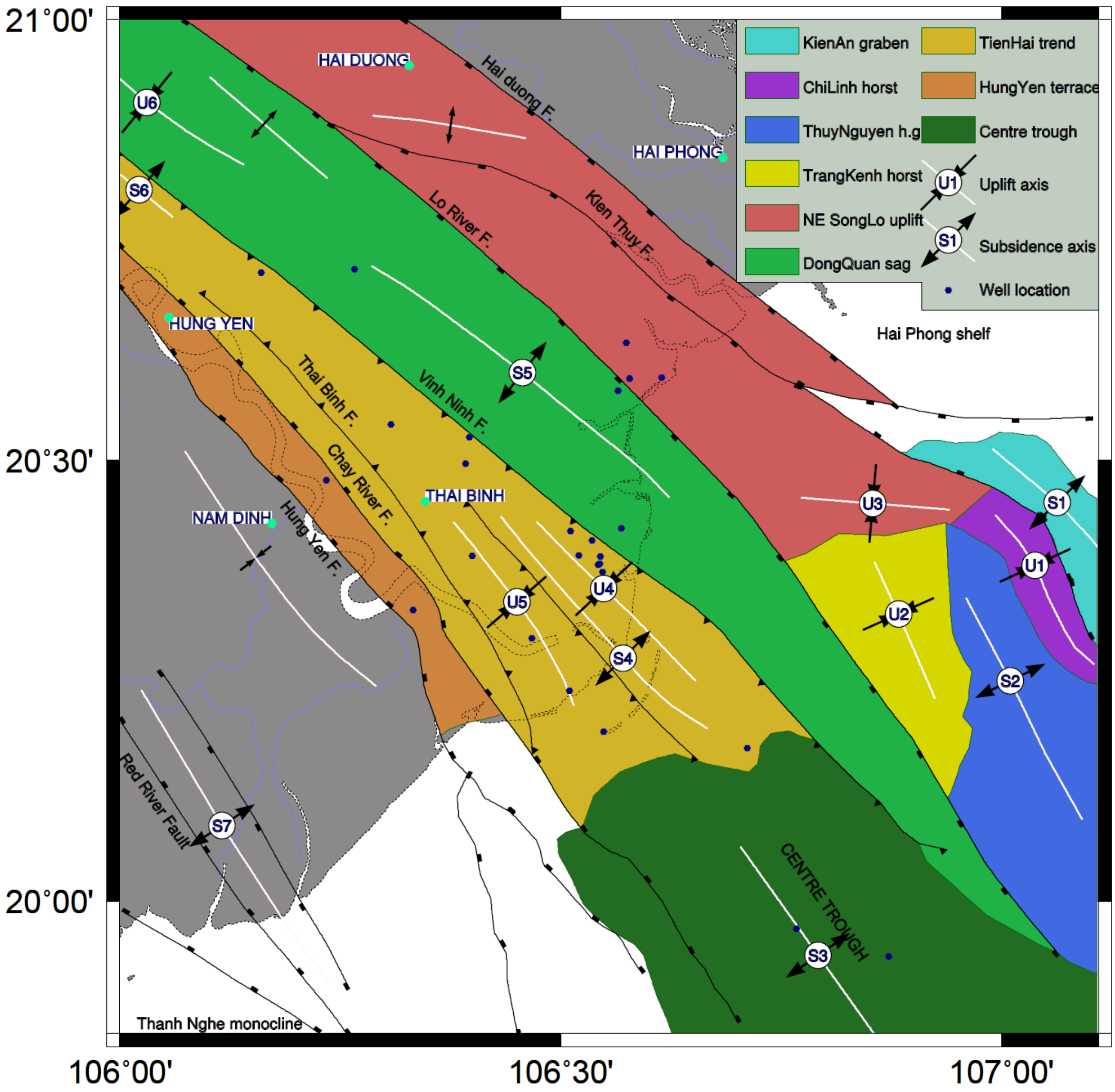

Figure 1: Structural map of the Hanoi trough. Adopted after Anzoil (1995), Phung Van Phach (1996), PVEP (2006), Do Bat and Ho Dac Hoai (2007).

Abbreviation of structural zones:

S1: Kien An graben; S2: Thuy Nguyen haft-graben; S3: Centre Trough; S4: Phuong Ngai sag; S5: Dong Quan sag; S6: Khoai Chau sag; S7: Ninh Binh graben; U1: Chi Linh horst; U2: Trang Kenh horst; U3: Tien Lang uplift block; U4: Tien Hai trend; U5: Kien Xuong trend;and U6: Van Giang trend.

The Hanoi trough is divided into three main trends: (1) the Central trend located between Chay river and Vinh Ninh faults; (2) the Northeast trend between Vinh Ninh and Lo River and faults; and (3) the Southwest trend between the Red River and Chay River faults. Among the three trends, the Central one underwent an inverted phase in late Miocene forming horst-type structures: Tien Hai horst at the northest and Kien Xuong horst at the souttwest. Phuong Ngai sag locates between the two horst. the Northeast trend also composes Van Giang and Dong Quan sags [Nguyen Manh Huyen & Ho Dac Hoai, (2007)] (Figure 1).

Table 1: Twenty-seven wells used for the calculation of vertical stress magnitudes in this study.

No.	Well name	Top of density log (m)	Bottom of density log (m)
1	B10-STB2	644	1248
2	B26-STB-1X	296	1033
3	D24-1x	520	2748
4	PV-DQD-1X	1132	3443
5	PV-PC-1X	741	1970
6	PV-XT-1X	549	1864
7	THC_04	451	1235
8	W10	22	1957
9	W32	22	1696
10	W60	0	2169
11	W63	44	2392
12	W67	798	2400
13	W71	53	2370
14	W80	906	2484
15	W84	0	3110
16	W101	244	3193
17	W102	33	2950
18	W107	51	2585
19	W108	29	2876
20	W110	399	4208
21	W112	58	2190
22	W116	41	2763
23	W200	0	3710
24	W203	45	4077
25	102-CQ-1X	549	2957
26	102-HD-1X	553	3048
27	103T-H-1X	1707	3228

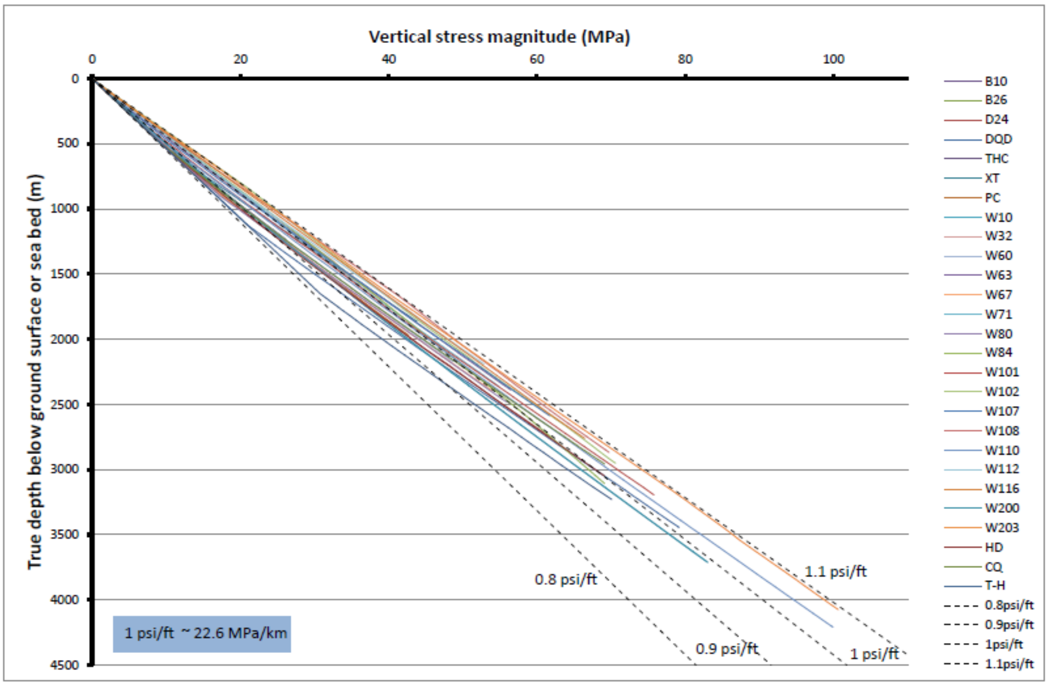

Figure 2: Calculated vertical stress magnitudes (MPa) versus depth of 27 wells across the Hanoi trough and off-shore. Note that 1 psi/ft ~ 22.6 MPa/km.

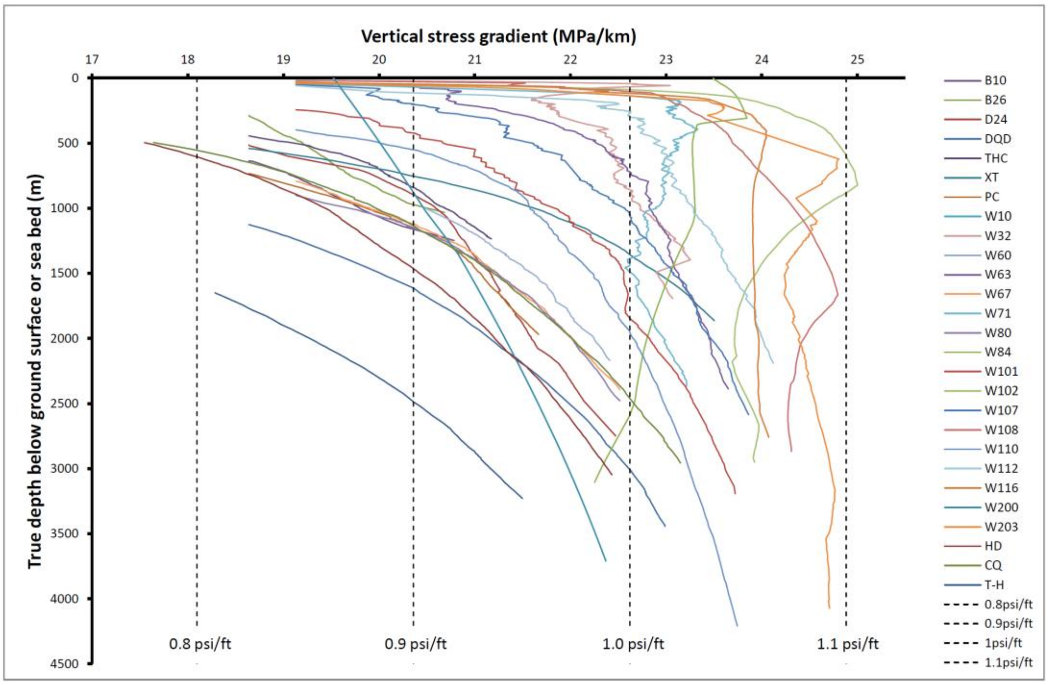

Figure 3: Calculated vertical stress gradients (Mpa/km) of 27 wells across the Hanoi trough and off-shore.

3. CALCULATION OF VERTICAL STRESS MAGNITUDES

The rock-stress component caused by the Earth's gravity field is called vertical stress, S_v and is governed by the weight of an overburden, ρgz. If the rock density is variable $\rho_{(z)}$, the vertical stress (S_v) is computed by [Zoback (2007)]:

$$S_V = g\int_0^z \rho_{(z)} dz \quad (1)$$

The vertical stress in offshore wells is equal to the pressure exerted by the weight of the water column from the surface to the seabed plus the weight of the sediment column at a specified depth. Hence, the vertical stress at any depth is easily calculated by integrating the density log from the surface (or seabed) [Tingay et al. (2003)]:

$$S_V = g\left(\int_0^{Z_B} \rho_{sea} dz + \int_{Z_B}^{Z} \rho_{(z)} dz\right) \qquad (2)$$

where *S_v is vertical stress magnitude, z_B is the depth of seabed, $\rho_{(z)}$ is the density as a function of depth, z, ρ_{sea} is the density of sea water, and g is gravitational acceleration. As density of water ~ 1 g/cm^3, water pressure (hydrostatic pressure) increase at rate of 10Mpa/km (0,44 psi/ft).*

S_v can be determined from integration of density logs through petroleum industry. The pressure exerted by the column of seawater can be calculated from an average density of 1,03g cm^{-3} for a known water depth [Bell (2003)].

Density logs are generally not run all the way to the surface (or seabed in offshore wells). In order to calculate the vertical stress it is necessary to first estimate an average density from the surface to the top of the density log. However, we use average value 1.95 g.cm^{-3} [c.f. Nguyen T.T. Binh et al. (2005)].

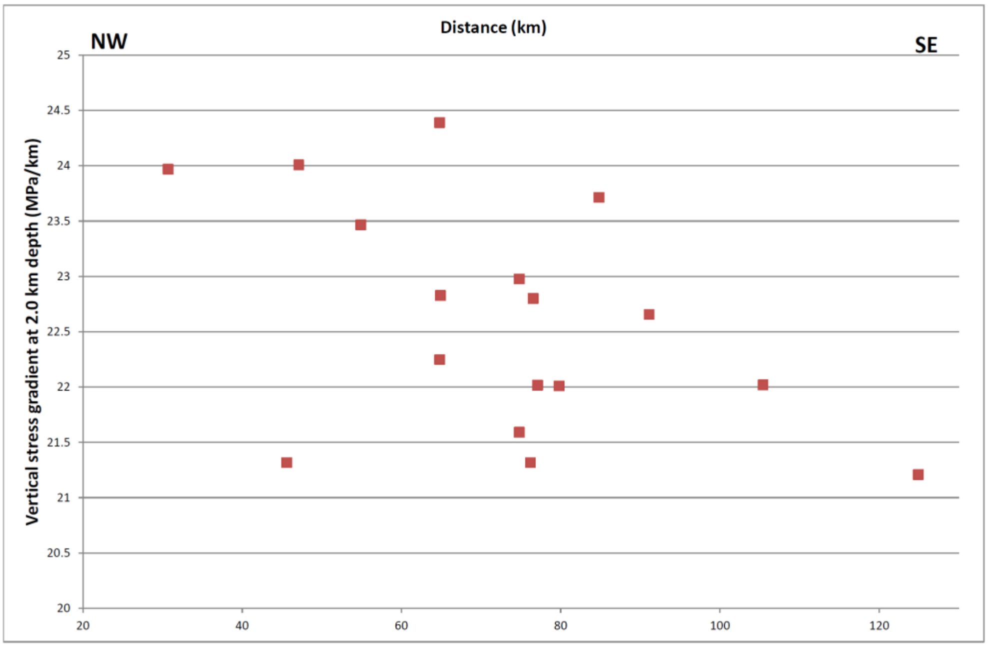

Figure 4: Vertical stress gradient (MPa/km) from NW-SE profile at 2.0 km depth along Vinh Ninh fault.

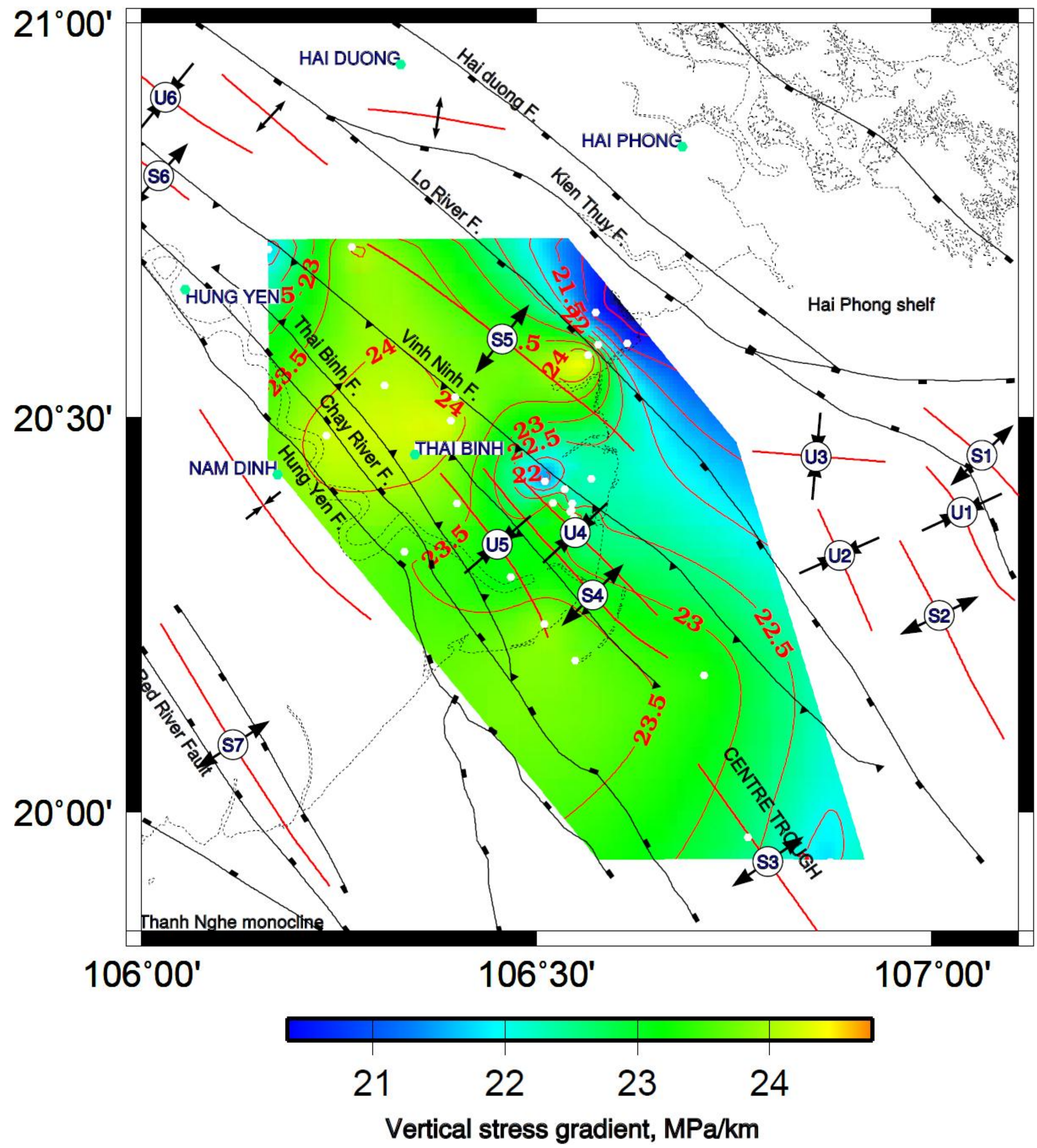

Figure. 5. Map of the vertical stress gradient across the Hanoi trough (below seabed for off-shore wells).

4. VARIATION OF VERTICAL STRESS MAGNITUDE

Density logs of 27 petroleum wells across the Hanoi trough and off-shore are collected at PetroVietnam (Table 1). To guarantee direct and original information about the stress field, exploration wells with well inclination of 20^o or less were sellected to investigate vertical stress magnitudes [Zoback (2007)]. Table 1 represents in datail the range of density data of 27 wells at depth which are used to calculated S_v magnitudes. Among the 27 wells, 17 wells have the top of density logs distributed at depth less than 500 m. Also among them, 20 wells have the bottom of density logs distributed at depth greater than 2000 m. There are 17 wells having data range greater than 2000 m.

Magnitudes and S_v gradients of 27 wells are represented in Figure 2 and Figure 3. The effect of the sea-water column are removed in calculating of S_v magnitudes in order to be convenient to compare between onshore and offshore wells. The result shows that S_v gradients range from 17.6 MPa/km to 25.0 MPa/km that are equivalent to gradient from 0.8 to 1.1 psi/ft, in which most of them varies at about 22.6MPa/km (equivalent to 1 psi/ft) (Figure 3).

The average value of S_v gradient is equivalent to commonly estimated values of Cenozoic basins all over the world (22.6 MPa/km or 1 psi/ft), consistent with the previous work of Nguyen T.T. Binh et al. (2011) in the Cuu Long and Nam Con Son basins, consistent with Tingay el al. (2003) at the Northwest Borneo which are belong to Sundaland block and also consistent with King et al. (2010) at the Southwest Australia. It is showed that there is a relatively-low differentiation of recent tectonism in the Sundaland block in paticular as well as the Eastern Vietnam sea region in general.

Theorically, variation in the magnitude of S_v must be due to lateral variations in the density of the subsurface. Variations in the density of sedimentary rock may be due to lateral facies variations, or may be attributed to secondary factors such as diagenesis, localized uplift and/or disequilibrium compaction overpressure. All of these factors may have an impact on the magnitude of vertical stress [King et al. (2010)].

Figure 4 dislays the northwest-southeast stress profile of S_v gradient at depth 2.0 km along the Vinh Ninh fault which shows that there is a decreasingly trend of S_v variation from the northwest to the southeast of the Hanoi trough. This is consistent with the structures as well as a general trend of the southeastward subsidence of the Red river delta.

The characteristics of the Hanoi trough are strong uplift and subsidence, inverted tectonism in Miocene, strong truncation and tilted fault blocks [Nguyen Manh Huyen et al. (2005)]. Lateral variation of S_v gradient across the Hanoi trough and off-shore (for off-shore wells, calculated depths are re-calibrated to sea-bed) is presented in Figure 5. Values in the figure is interpolated by Kriging method from calculated values of 27 mentioned wells. It can be said that, areas of high S_v gradient locate nearby reverse fault (Vinh Ninh fault), or coincide with uplift structures (Khoai Chau – Tien Hai trend). Areas of high S_v gradient usually depict the subsidences, for example, off-shore extension of of the Dong Quan sag and the northern end of the Centre trough of the Red River basin. It is showed that there are some relations between S_v gradient and geological structures of the studied area.

5. CONCLUSION

The paper presents a preliminary result on calculation of the vertical stress in the Hanoi trough. S_v gradients range from 17.6 MPa/km to 25.0 MPa/km. Average value of S_v gradients varies at about 22.6MPa/km which is equivalent to gradient of vertical stress component in the Cuu Long and Nam Con Son basins, off-shore southeastern Vietnam as well as other basins around the Southeast Asia region. It is showed that there is a relatively-low differentiation of recent tectonism in the Sundaland block in paticular as well as the Eastern Vietnam sea region in general.

6. ACKNOWLEDGMENTS

We thank PetroVietnam for data used in this study. We thank Institute of Geological Science – Vietnam Academy of Science and Technology for their partly financial support of this project.

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