Bionatura – Jurnal Ilmu-ilmu Hayati dan Fisik Vol. 13, No. 2, Juli 2011 : 157 - 167
ISSN 1411 - 0903

ROCK DISCONTINUITY PATTERNS DEVELOPMENT ALONG CRUSHED ZONES SEPARATED BY FAULT MOVEMENT

Hendarmawan, Hirnawan, F., and Muslim, D.

Faculty of Geological Sciences and Engineering Padjadjaran University
E-mail: fhirnawan@bdg.centrin.net.id

ABSTRACT

Multivariate analysis was applied to rock-discontinuities taken from areas, in which folded and faulted sedimentary rocks occur. The purpose of the analysis is to verify the responses of these discontinuities to faults, from which the really existing fault can be delineated and mechanism and intensity of the deformation on Tertiary sediments underlying Quaternary sediments can be revealed that explain the intensity of neotectonism as the deformation continued on the Quaternary deposits. The sample parameters consist of strike and dip of both bedding planes and left also right diagonal joint sets respectively. From every site of two study areas two sample groups were taken from two rock-blocks separated by a fault. The analyses on the six parameters of the samples exhibit the contribution of each parameter to the rejection of the hypotheses of no effect of fault can be examined, which lead into a conclusion about how far does the parameter indicate the existing fault. The conclusion in Study Area 1 is that both right and left joint sets are significantly affected by reverse fault, suggesting that these two joint sets in uplifted rock-block were still affected by the folding process after reverse movement of the fault. Then, in Study Area 2, means of strike of bedding planes and right joint set significantly differ as a result of left lateral-slip fault certainly moving along a fractured zone.

Key words: Discontinuity responses to fault, mechanism of deformation, intensity of deformation, neotectonism

PERKEMBANGAN POLA DISKONTINUITAS BATUAN DI SEPANJANG ZONA HANCURAN YANG DIPISAHKAN PERGERAKAN SESAR

ABSTRAK

Analisis multivariat digunakan terhadap sampel-sampel diskontinutitas batuan yang diambil dari wilayah sebaran batuan sedimen terlipat dan tersesarkan. Maksud analisis ini adalah untuk memverifikasi respons pola diskontinuitas pada batuan atas sesar-sesar, sehingga keberadaan sesar-sesar itu dapat didelineasi dan mekanisme juga intensitas deformasi pada batuan Tersier ini di bawah sediment Kuarter dapat diungkapkan yang menjelaskan intensitas neotektonisme sebagaimana deformasi tersebut menerus pada sedimen Kuarter. Parameter sample-sampel meliputi jurus dan kemiringan baik bidang perlapisan maupun kelompok/kerabat kekar diagonal kiri dan kanan. Dari setiap tapak dari dua daerah studi masing-masing dua kelompok sampel diambil dari dua blok batuan yang masing-masing terpisah oleh sesar. Analisis terhadap enam parameter sampel-sampel itu menunjukan kontribusi tiap parameter terhadap penolakan hipotesis ketiadaan pengaruh sesar dapat diperiksa, yang mengarah kepada kesimpulan sampai sejauh mana keberadaan sesar-sesar terkait. Kesimpulan dari Daerah Studi 1 ialah bahwa baik kelompok kekar diagonal kiri maupun kanan secara nyata dipengaruhi oleh sesar naik, yang menunjukkan bahwa kedua kelompok kekar itu masih terlibat proses perlipatan setelah pergerakan sesar naik. Kemudian, di Daerah Studi 2 rata-rata jurus perlapisan dan rata-rata kekar diagonal kanan dari masing-masing blok batuan sangat berbeda sebagai akibat pergerakan sesar sinistral di sepanjang zona hancuran.

Kata kunci: Respons diskontinuitas atas sesar, mekanisme deformasi, intensitas deformasi, Neotektonisme

INTRODUCTION

Bedding-planes, joints and faults, known as rock discontinuities, are usually studied by mapping. Data of the discontinuities are plotted on a topographic base-map and reconstructed to become a structural geologic map. This map enables the geologists to interpret a phenomenon of a tectonic mechanism, in which the folded and faulted rock strata involved. Any kind of fault, its distribution and relation among the fault, joint sets and bedding- plane pattern can also be understood by conventionally applying stress analysis method and stereographic projection or Schmidt Net Diagram (De Sitter, 1956; Moody & Hill, 1956; Hills, 1972; Price & Cosgrove, 1990; etc.).

In this paper, in order to verify and measure the bedding-plane and joint patterns in an anticlinal structure generated in two separated rock-blocks as a results of reverse and/or strike-slip movement(s) in term of the effects of faults on bedding planes and joint sets, a multivariate analysis of differences between two means is employed. The objective of this analysis is to verify and measure the responses of joint sets and bedding planes to faults, which has not been able to be computed by using the above-mentioned diagram.

Geology

The Study Areas 1 and 2 are located in Sub-district of Ciniru, Regency of Kuningan, eastern West Java, Indonesia (Fig.1). Geology of the area and its vicinity is characterized by folded and faulted Tertiary turbidite sedimentary rock strata consisting of well stratified sandstone and claystone intercalation of Oligo-Miocene to Lower Pliocene age. This entire region is cut by two major reverse fault zones known as Baribis-Majenang Fault and Citanduy Fault. The trends of the fault zones and the anticlinal axes are WNW-ESE and NW-SE. The geology of each study area and the vicinity is discussed below.

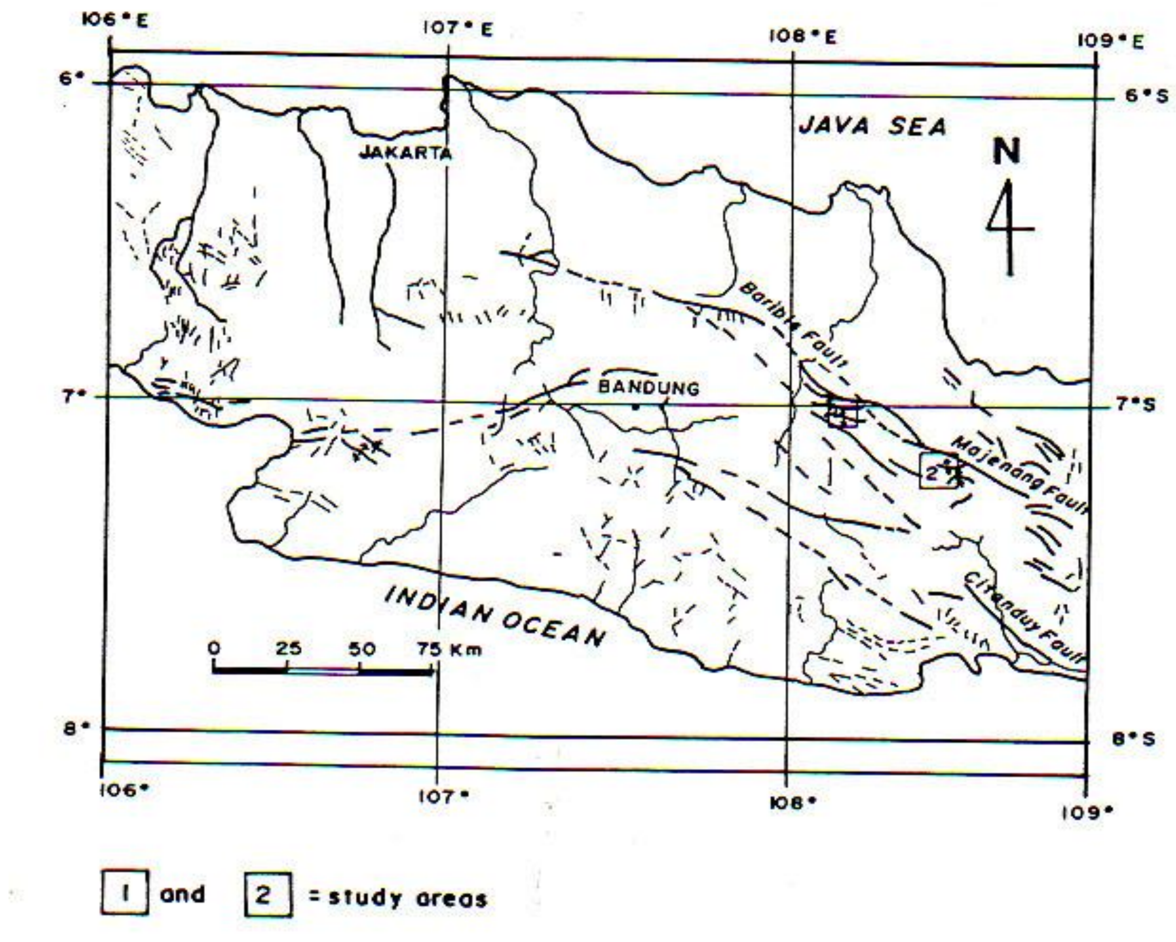

Figure 1. Locations of the study areas in Geological Structure Map of West Java, Indonesia (Soehaimi. 1990)

Study Area 1

Two litho-stratigraphic units comprising sandstone and claystone units are distributed in this study area and the surroundings (Fig. 2a). The units belong to the Cinambo Formation, known as the oldest exposures of Oligo-Miocene marine sediments. The sandstone unit consists of thick bedded sandstones (graywacke) with thin bedded claystones and limestones intercalation, whereas the claystone unit comprises thick bedded claystones with sandstones and limestones intercalation. The formation is folded generating anticlinal and synclinal axes in WNW-ESE direction. Two reverse faults dipping to the south cut the anticlinal flanks, of which one is occupied by the Cisuleuhan Stream with its alluvial deposits.

Data of bedding planes and joint sets being affected by strike-slip movements are collected from the study site on the above-mentioned stream and analyzed in order to test their patterns as the result of the significant faults. The verification enables us to conclude whether either left-lateral-(LL) or right-lateral-slip fault (RL) or both faults significantly affected the rock-discontinuity pattern in the study area.

Study Area 2

The geology of the study area and the vicinity reflects a similar configuration with that of the above-mentioned first study area. Here, in the Study Area 2, the folded and faulted sedimentary rock strata, known as Halang Formation of Upper Miocene to Lower Pliocene age occurs. The formation consisting of clay, sandstone and breccia units is cut by a reversed fault (Fig 2b). The trend of the fault is about W-E.

The clay unit is brownish grey to black, calcareous, intercalated with thin bedded siltstones and sandstones of 2 to 20 cm. thick. The sandstone unit is grey to brown, fine to very coarse grain, well stratified and intercalated with thin bedded marls and breccias. The sandstone beds show sedimentary structure of parallel lamination of 3 to 100 cm. thick. Finally, breccia unit consisting of lenses are distributed in the sandstone unit. Their color are grey to black comprising subangular fragments of andesitic rock of 8 to 10 cm. in diameter, set in a sandstone matrix. Here, rock-discontinuity data are also collected from the study site on the Citoal Stream in order to test the effect of significant strike-slip movement on their patterns.

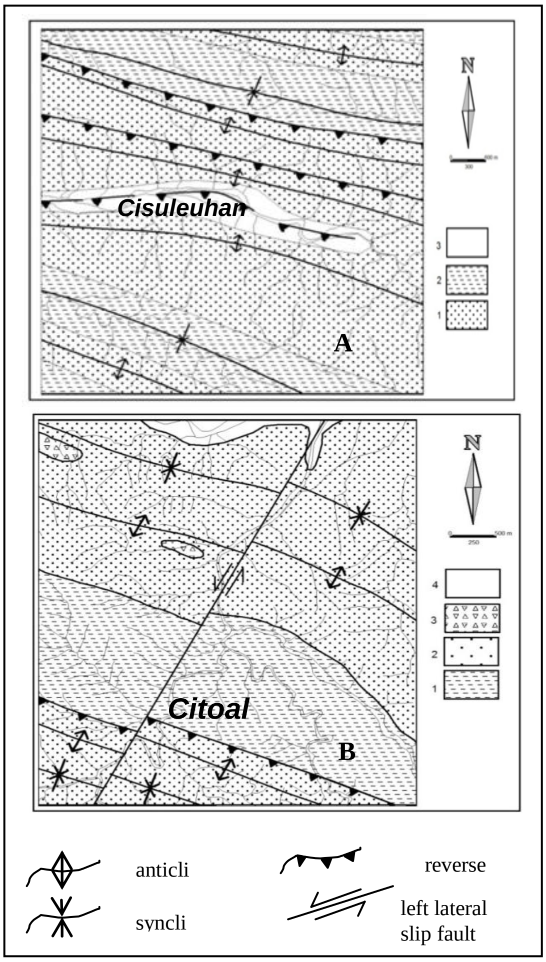

Figure 2. Simplified geologic map along Cisuleuhan, and Citoal Streams. [a] Study Area 1: 1) Sandstone and 2) Claystone units of Cinambo Formation; 3) Alluvial deposits. [b] Study Area 2: 1) Clay, 2) Sandstone, and 3) Breccia units of Halang Formation, and 4) Alluvial deposits. (Map modified from Djuri, 1973 and Rita, 1991 in Noorchoeron, 1996)

MATERIALS AND METHOD

Samples of rock discontinuities collected from two rock-blocks separated by a fault were measured in Study Areas 1 and 2 (Figure 1). The discontinuities generated in anticlinal flanks (Figure 3) comprise strike and dip of both bedding planes and left and right diagonal joints. In these study areas, in which the anticlinal flanks are cut by reverse faults strike-slip movements also maybe occur. They are either left- (LL) or right-lateral slip faults (RL) or both LL and RL. For the purpose of inferring which joint sets significantly differ each other and thus verify the occurrence of the existing fault that may be drawn in the geologic map, a multivariate analysis is employed.

Multivariate Test of Differences

In order to test the differences between two means of rock discontinuity and structural patterns, in term of strike and dip of joints and bedding planes, because of the effect of fault(s) on them, multivariate test by Rencher (1995) and Kramer (1972) were utilized.

In the case of p-variate observation, for example, from two multivariate populations, the above-mentioned rock discontinuety data may be arranged as in Table 1. In this table, the first subscript indicates the treatment or condition, the second subscript indicates the experimental element or number of observation that has been measured, and the superscript indicates the characteristic measured. These data may also be arranged as the p-dimensional vectors (Kramer, 1972)

Simultaneous Confidence Intervals

In the case of two treatments, involving unpaired data, when more than one measurement is made on each experimental unit, simultaneous confidence intervals may be constructed for the purpose of inferring which components of the mean vectors differ with treatments and thus contribute to the rejection of $H_o : \underline{\upsilon}_1 = \underline{\upsilon}_2$. This procedure is calculated later in Results and Discussion by using the sample evidence from study site in Study Area 1.

RESULTS AND DISCUSSION

Study Area 1

Discontinuity samples taken from two rock-blocks at study site in Study Area 1, which are plotted as poles in the Schmidt Net Diagram (Fig. 4), are arranged as in Table 1. The data comprises two groups of discontinuity. Group 1 and 2 consist of six characteristics, for examples, $y_1{}^{(1)}{}_j$, … , $y_1{}^{(6)}{}_j$, and $y_2{}^{(1)}{}_j$, … , $y_2{}^{(6)}{}_j$. The respective variables, such as given in the table, are strike and dip of bedding plane, angular distance of joint (left and right joint sets LJS and RJS; see Fig. 3) from strike of bedding plane as the acute angle, and dip of joint from vertical plane (see Fig. 5). These variables are calculated as the following examples (Hirnawan, 1987; see also Table 1): $y_1{}^{(1)}{}_1 = 285^o$ (strike of bedding plane N 285^oE); $y_1{}^{(2)}{}_1 = 66^o$ (dip of bedding plane 66^o); $y_1{}^{(3)}{}_1 = 75^o$ (strike of right joint RJ is 180^o; the acute angle from strike of bedding plane is 75^o); $y_1{}^{(4)}{}_1 = 19^o$ (dip of RJ is 71^o; angle from the vertical line is 19^o); $y_1{}^{(5)}{}_1 = 63^o$ (strike of left joint LJ is 222^o; the acute angle from strike of bedding plane is 63^o);$y_1{}^{(6)}{}_1 = 7^o$ (dip of RJ is 83^o; angle from the vertical line is 7^o).

The hypothesis is H_o: $\underline{\upsilon}_1 = \underline{\upsilon}_2$. The covariance matrices for group 1 and 2 being constructed are presented below.

The determinants are $|\underline{S}_1| = 2.8218 \times 10^9$, $|\underline{S}_2| = 7.6764 \times 10^8$, and $|\underline{S}| = 3.0870 \times 10^{10}$ respectively. Based on the determinants and data in Table 1 the hypothesis H_o: $\underline{\Sigma}_1 = \underline{\Sigma}_2$ can be tested as follow.

According to Kramer (1972) from equation $M = (n_1+n_2-2)\log|\underline{S}| - (n_1 1)\log|\underline{S}_1| - (n_2 -1)\log|\underline{S}_2|$ we find $M = (30)(10.48954) - (15)(9.45053)(15)(8.885158) = 39.65088$, and from equation $m = 1 - [1/(n_1-1) + 1/(n_2-1) - 1/(n_1+n_2-2)][(2p^2+3p-1)/6(p+1)]$ we find $m = 1 - [1/15 + 1/15 - 1/30][(2(6^2)+(3)(9)-1)/6(7)] = 0.788095$, then we find from equation 2.3026 mM = 71.953165, and since $\chi^2_{(21\,;\,.05)}$ that may be looked up as $T^2_{(21,\infty)\ .05} = 32.667$, there is sample evidence to reject the hypothesis H_o; so, the matrices group 1 and 2 are not equal.

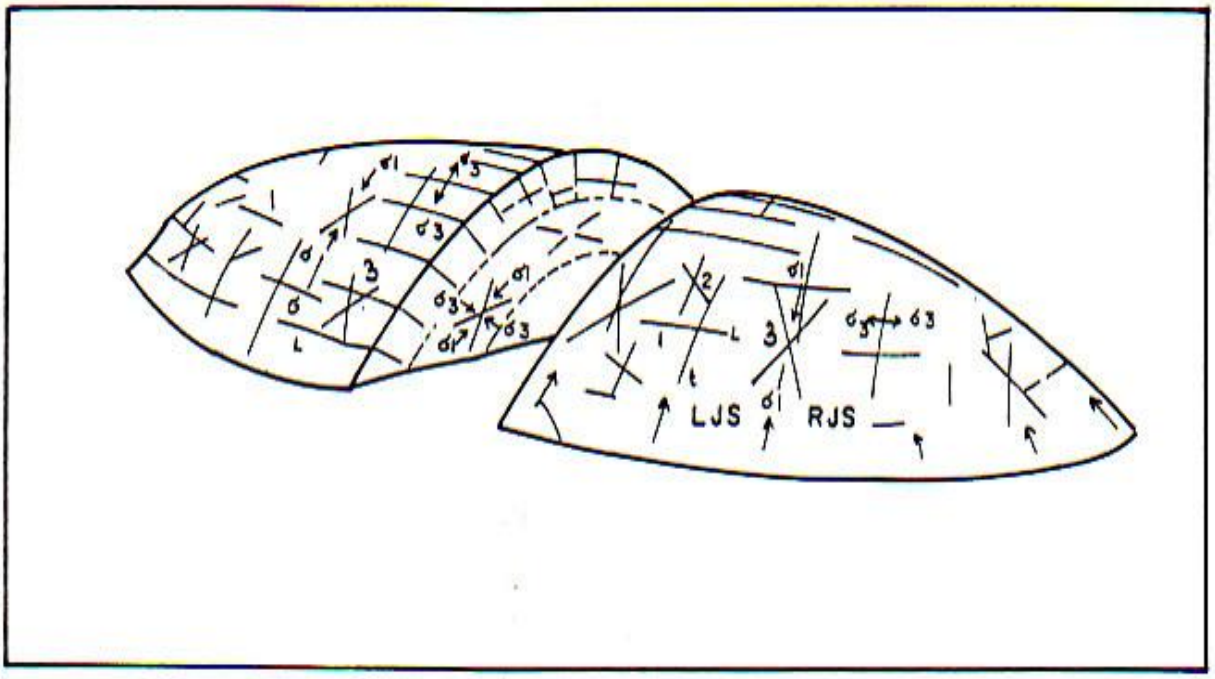

Figure 3. Joint pattern in anticline as a result of folding (after: Billing, 1986; Price & Cosgrove, 1991; McClay, 1995). 1) longitudinal joints; 2) transverse joints; 3) diagonal joints. Diagonal joints are of two trends known as left joint set (LJS) and as right joint set (RJS) which may develop into right lateral-slip fault (dextral) and left lateral-slip fault (sinistral) respectively (Hills, 1972). The respective σ_1 and σ_3 are maximum and minimum principle stresses.

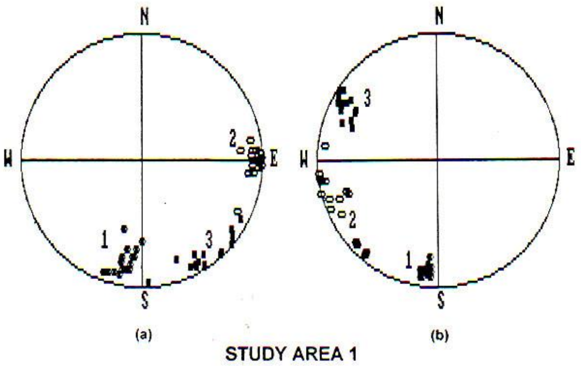

Figure 4. Plotted poles of discontinuity data from Study Area 1 in Schmidt Net Diagram illustrating fracture pattern of upward (a) and downward moving rock-blocks (b) separated by a reverse fault.

Now treating the randomly paired measurements in Table 1 by the method of paired observations we compute as $d_j^{(k)} = y_1{}^{(k)}{}_j - y_2{}^{(k)}{}_j$; $k = 1, 2; j = 1, 2, \ldots, n$ and they are listed for convenience in Table 2.

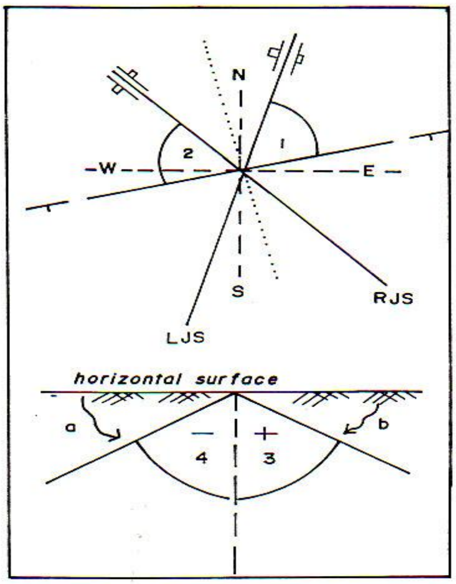

Figure 5. Illustration of the transforming of strike and dip of joints. (1) and (2) acute angle from strike of a joint to strike of a bedding plane, RJS= right joint set and LJS = left joint set; (3) and (4) transformed dip of a joint to vertical line.

Table 1. Transformed discontinuity data from two rock-blocks separated by reversed fault in Study Area 1 along Cisuleuhan Stream.

Upward moving rock-block							Downward moving rock-block						
No	$Y_1^{(1)}$	$Y_1^{(2)}$	$Y_1^{(3)}$	$Y_1^{(4)}$	$Y_1^{(5)}$	$Y_1^{(6)}$	No	$Y_2^{(1)}$	$Y_2^{(2)}$	$Y_2^{(3)}$	$Y_2^{(4)}$	$Y_2^{(5)}$	$Y1^{(6)}$
1	285	66	75	19	63	7	1	275	66	77	11	74	41
2	290	71	72	23	62	9	2	279	71	71	18	78	32
3	277	62	89	21	48	9	3	280	62	65	2	68	27
4	282	70	84	27	66	23	4	274	70	80	9	60	30
5	277	56	78	23	39	14	5	276	56	74	12	60	17
6	282	56	82	14	42	21	6	275	51	65	30	66	39
7	276	51	74	24	34	19	7	274	62	66	38	65	25
8	281	62	76	24	36	20	8	276	61	66	37	64	28
9	280	61	77	24	30	33	9	274	68	36	20	59	10
10	288	68	67	35	46	15	10	278	63	37	18	64	11
11	275	50	82	11	57	18	11	278	62	38	19	66	15
12	282	52	73	18	46	25	12	279	67	62	18	69	18
13	285	35	78	27	18	14	13	274	58	58	25	69	38
14	270	41	88	6	60	19	14	274	62	63	14	67	26
15	280	46	79	7	61	14	15	276	63	60	20	65	38
16	274	45	86	10	34	30	16	278	70	68	14	67	25

(Data source : Noorchoeron, 1996)

The covariance matrices for group 1 and 2 mentioned earlier being constructed are:

$$S_1 = \begin{bmatrix} 28.067 & 31.067 & -22.867 & 26.718 & 4.367 & -13.633 \\ 31.067 & 115.000 & -23.200 & 47.083 & 61.167 & -15.567 \\ -22.867 & -23.200 & 37.133 & -28.850 & 10.767 & 7.033 \\ 26.718 & 47.083 & -28.850 & 64.929 & -35.958 & -7.742 \\ 4.367 & 61.167 & 10.767 & -35.958 & 198.783 & -38.917 \\ -13.633 & -15.567 & 7.033 & -7.742 & -38.917 & 53.183 \end{bmatrix}$$

And

$$S_2 = \begin{bmatrix} 4.467 & 2.800 & -3.300 & -7.417 & 4.117 & -5.533 \\ 2.800 & 29.133 & 4.300 & -18.817 & 5.983 & -9.667 \\ -3.300 & 4.300 & 183.717 & -21.642 & 18.192 & 84.500 \\ -7.417 & -18.817 & -21.642 & 93.262 & -4.287 & 9.050 \\ 4.117 & 5.983 & 18.192 & -4.287 & 24.096 & 24.050 \\ -5.533 & -9.667 & 84.500 & 9.050 & 24.050 & 99.133 \end{bmatrix}$$

Then $\underline{S}$ is found to be

$$S = \begin{bmatrix} 16.267 & 16.933 & -13.088 & 9.650 & 4.242 & -9.583 \\ 16.934 & 72.067 & -9.450 & 14.133 & 33.575 & -12.617 \\ -13.083 & -9.450 & 110.425 & -25.246 & 14.479 & 45.767 \\ -9.650 & 14.133 & -25.246 & 79.096 & -20.123 & 0.654 \\ 4.242 & 33.575 & 14.479 & -20.123 & 111.440 & -7.433 \\ -9.583 & -12.617 & 45.767 & 0.654 & -7.433 & 76.158 \end{bmatrix}$$

Explanation :

$y_1^{(j)}$ and $y_2^{(j)}$ = variables representing upward and downward moving rock-blocks
$y_1^{(1)}$ and $y_2^{(1)}$ = strike of bedding planes
$y_1^{(2)}$ and $y_2^{(2)}$ = dip of bedding planes
$y_1^{(3)}$ and $y_2^{(3)}$ = acute angle from strike of right joint to strike of bedding plane
$y_1^{(4)}$ and $y_2^{(4)}$ = dip of right joint from vertical line
$y_1^{(5)}$ and $y_2^{(5)}$ = acute angle from strike of left joint to strike of bedding plane
$y_1^{(6)}$ and $y_2^{(6)}$ = dip of left joint from vertical line

Table 2. Differences $d_j^{(1)}$, … , and $d_j^{(6)}$ computed from data in Table 1.

No.	$d_j^{(1)}$	$d_j^{(2)}$	$d_j^{(3)}$	$d_j^{(4)}$	$d_j^{(5)}$	$d_j^{(6)}$
1	10.000	0.000	-2.000	8.000	-11.000	-34.000
2	11.000	0.000	1.000	5.000	-16.000	-23.000
3	-3.000	0.000	24.000	19.000	-20.000	-18.000
4	8.000	0.000	4.000	18.000	6.000	-7.000
5	1.000	0.000	4.000	11.000	-21.000	-3.000
6	7.000	5.000	17.000	-16.000	-24.000	-18.000
7	2.000	-11.000	8.000	-14.000	-31.000	-6.000
8	5.000	1.000	10.000	-13.000	-28.000	-8.000
9	6.000	-7.000	41.000	4.000	-29.000	23.000
10	10.000	5.000	30.000	17.000	-18.000	4.000
11	-3.000	-12.000	44.000	-8.000	-9.000	3.000
12	3.000	-15.000	11.000	0.000	-23.000	7.000
13	11.000	-23.000	20.000	2.000	-51.000	-24.000
14	-4.000	-21.000	25.000	-8.000	-7.000	-7.000
15	4.000	-17.000	19.000	-13.000	-4.000	-24.000
16	-4.000	-25.000	18.000	-4.000	-33.000	5.000
Total	64.000	-120.000	274.000	8.000	-319.000	-130.000
Mean	4.000	-7.500	17.125	0.500	-19.937	-8.125

Other computation for finding the covariance matrix are performed as before by using these calculated differences, leading to the quantities.

$$\underline{S} = \begin{bmatrix} 29.333 & 24.000 & -25.667 & 15.467 & -7.067 & -27.867 \\ 24.000 & 104.933 & -35.067 & 47.800 & 36.633 & -20.467 \\ -25.667 & -35.067 & 181.450 & -16.467 & -16.675 & 107.750 \\ 15.467 & 47.800 & -16.467 & 142.267 & 30.567 & 5.933 \\ -7.067 & 38.633 & -16.675 & 30.567 & 182.996 & -23.325 \\ -27.867 & -20.467 & 107.750 & 5.933 & -23.325 & 217.583 \end{bmatrix}$$

and

$$\underline{S}^{-1} = \begin{bmatrix} 0.0535 & -0.0110 & 0.0025 & 0.0033 & 0.0058 & 0.0053 \\ -0.0110 & 0.0147 & 0.0013 & -0.0029 & -0.0030 & -0.0009 \\ 0.0025 & 0.0013 & 0.0084 & 0.0004 & 0.0001 & -0.0037 \\ -0.0033 & -0.0029 & 0.0004 & 0.0087 & -0.0011 & -0.0012 \\ 0.0058 & -0.0030 & 0.0001 & -0.0011 & 0.0067 & 0.0012 \\ 0.0053 & -0.0009 & -0.0037 & -0.0012 & 0.0012 & 0.0072 \end{bmatrix}$$

from which we compute, for the statistic $T^2_{(p,\, n-1)} = nD^2$, the value

$$T^2_{(6,15)} = 16(4.000, -7.500, 17.125, 0.500, -19.938, -8.125)\ \underline{S}^{-1} \begin{bmatrix} 4.000 \\ -7.500 \\ 17.125 \\ 0.500 \\ -19.938 \\ -8.125 \end{bmatrix} = 113.110.$$

Now $T^2_{(6,15)}(0.01) = 48.472$, so there is sample evidence for rejecting hypothesis H_o: $\underline{\upsilon}_1 = \underline{\upsilon}_2$, meaning that at least there is one variable which contributes to reject the hypothesis. So, simultaneous confidence intervals should be constructed for inferring which variable(s) of the mean vectors differ with treatments as a result of the effects of fault(s) movement. From the equation as

$$a = \underline{c}\ \underline{d}' - \sqrt{\underline{c}\ \underline{S}\ \underline{c}'}\ \sqrt{[(n_1+n_2)/n_1n_2)]T^2_{(p,n1+n2-2)}(\alpha)}$$
$$b = \underline{c}\ \underline{d}' + \sqrt{\underline{c}\ \underline{S}\ \underline{c}'}\ \sqrt{[(n_1+n_2)/n_1n_2)]T^2_{(p,n1+n2-2)}(\alpha)}$$

we compute for strike of bedding plane,

$$\underline{c}\,\underline{d}' = (1, 0, 0, 0, 0, 0)\begin{bmatrix} 4.000 \\ -7.500 \\ 17.125 \\ 0.500 \\ -19.938 \\ -8.125 \end{bmatrix} = 4{,}000,$$

$$\sqrt{\underline{c}\,\underline{S}\,\underline{c}'} = \sqrt{(1,0,0,0,0,0)\begin{bmatrix} 16.267 & 16.933 & \ldots & -9.583 \\ 16.933 & 72.067 & \ldots & . \\ . & . & \ldots & . \\ . & . & \ldots & . \\ . & . & \ldots & . \\ . & . & \ldots & . \\ -9.583 & & \ldots & 76.158 \end{bmatrix}\begin{bmatrix} 1 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \end{bmatrix}}$$

$$= \sqrt{16.267} = 4.0332$$

and

$$\sqrt{\frac{n_1+n_2}{n_1 n_2} T^2(p, n1+n2-2\ (0.05)} = \sqrt{\frac{16+16}{(16)(16)}(17.931)} = 1.497$$

Then we obtain from 4 ± (4.0332) (1.4971) the interval 4 ± 6.0381 or $-2.0381 \leq \upsilon_1^{(1)} - \upsilon_2^{(2)} \leq 10.0381$.

Since zero is included in the interval, we conclude at the 95% joint confidence level that the means for the strike of bedding plane in the two rock-blocks does not differ, suggesting that the reverse fault does not significantly affect them.

For dip of bedding plane, we compute as before and find $\underline{c}\,\underline{d}' = -7.500$ and $\sqrt{\underline{c}\,\underline{S}\,\underline{c}'} = \sqrt{72.067} = 8.4892$. Then from -7.500 ± (8.4892) (1.4971) we obtain interval -7.500 ±12.7134 or $-20.2134 \leq \upsilon_1^{(1)} - \upsilon_2^{(2)} \leq 5.2134$
(no significant difference). Then we obtain the following intervals.

- For strike of right joint set (RJS): $1.3929 \leq \upsilon_1^{(1)} - \upsilon_2^{(2)} \leq 32.8570$ *)
- For dip of RJS: $-9.8907 \leq \upsilon_1^{(1)} - \upsilon_2^{(2)} \leq 10.897$
- For strike of left joint set (LJS): $-9.9380 \leq \upsilon_1^{(1)} - \upsilon_2^{(2)} \leq -4.1339$ *) and
- For dip of LJS: $-21.900 \leq \upsilon_1^{(1)} - \upsilon_2^{(2)} \leq 4.9400$

*) significant

Study Area 2

From this study area two discontinuity samples, say group 1 and 2, each consisting of 21 numbers of observations are taken from two rock-blocks separated by a strike-slip fault (Fig. 2b). The data are plotted as poles in the Schmidt net diagram (Fig. 6), and arranged as in Table 3. The covariance matrices for group 1 and 2 are then constructed to test the hypothesis H_o: $\Sigma_1 = \Sigma_2$. The following result of the test shows that there is no evidence to reject the hypothesis as we find M = 7.581695 and m = 0.735119, and thus 2.3026 mM =12.833422 which is smaller than $T^2_{(21,\infty).05}$= 32.667. So, the matrices are equal. Then computation for the statistic $T^2_{(p,n1+n2-2)} = [n_1n_2/(n_1+n_2)]D^2$ and from equation given ealier we get the value T^2= 98.342254, and comparing this with the critical value $T^2_{(6,40)}.01$= 23.094 we have sample evidence to reject the hypothesis H_o:$\upsilon_1 = \upsilon_1$, from which we conclude that means of the discontinuity samples significantly differ between the two separated rock-blocks, suggesting that the fault really exists that gave different treatments.

Then, for the purpose of inferring which components of the mean vectors differ with treatments and thus contribute to the rejection of the above-mentioned hypothesis, the simultaneous confidence intervals are constructed and the given following intervals are listed as in Table 4.

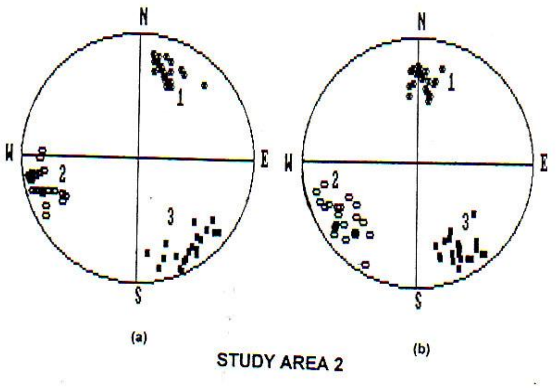

Figure 6. Plotted poles of discontinuity data from Study Area 2 in Schmidt Net Diagram illustrating fracture patterns of left (a) and right rock-blocks (b) looking down stream along the Citoal Stream separated by a left lateral slip fault

Table 3. Discontinuity data from two rock-blocks separated by strike-slip fault along Citoal Stream in Study Area 2

Upward moving rock-block							Downward moving rock-block						
No	$Y_1^{(1)}$	$Y_1^{(2)}$	$Y_1^{(3)}$	$Y_1^{(4)}$	$Y_1^{(5)}$	$Y_1^{(6)}$	No	$Y_2^{(1)}$	$Y_2^{(2)}$	$Y_2^{(3)}$	$Y_2^{(4)}$	$Y_2^{(5)}$	$Y_2^{(6)}$
1	108	44	338	51	235	64	1	82	33	320	43	241	48
2	103	48	330	48	250	47	2	103	43	305	45	220	40
3	106	47	335	45	221	62	3	102	41	312	53	240	63
4	114	40	342	66	239	61	4	98	42	313	51	238	59
5	104	50	339	61	220	68	5	94	45	331	50	233	64
6	102	51	328	68	242	66	6	83	39	328	54	231	55
7	115	41	351	67	226	45	7	97	36	324	60	248	58
8	101	58	333	62	230	59	8	93	44	323	63	255	50
9	110	42	341	64	236	58	9	100	31	332	52	241	51
10	111	49	351	58	221	63	10	85	48	321	68	232	68
11	113	43	350	63	236	51	11	86	40	315	61	242	39
12	109	56	358	57	254	57	12	91	51	335	62	245	42
13	133	55	352	55	247	60	13	90	52	321	55	247	69
14	112	39	332	44	224	56	14	89	47	298	69	231	71
15	116	54	350	72	236	67	15	99	35	344	65	256	44
16	107	45	340	54	231	55	16	95	49	314	42	243	54
17	99	53	349	71	217	54	17	87	50	327	39	244	60
18	98	60	343	70	224	69	18	96	37	335	41	249	43
19	105	59	341	60	247	87	19	92	46	339	64	241	49
20	100	46	348	69	258	65	20	105	53	348	56	255	53
21	119	52	363	56	247	74	21	101	34	336	57	247	52

(Data source: Noorchoeron, 1996) Explanation:

- $y_1^{(j)}$ and $y_2^{(j)}$= variables representing left and right rock-blocks looking down- stream
- $y_1^{(1)}$ and $y_2^{(1)}$ = strike of bedding planes
- $y_1^{(2)}$ and $y_2^{(2)}$ = dip of bedding planes
- $y_1^{(3)}$ and $y_2^{(3)}$ = strike of right joint (RJS)
- $y_1^{(4)}$ and $y_2^{(4)}$ = dip of right joint (RJS)
- $y_1^{(5)}$ and $y_2^{(5)}$ = strike of left joint (LJS)
- $y_1^{(6)}$ and $y_2^{(6)}$ = dip of left joint (LJS)

Table 4. Computed simultaneous confidence intervals for discontinuity samples from Study Area 2

No	Variable Means	Interval, $T^2_{(6,40)}.05$
1	Strike of bedding planes	$3.315 \leq d_1 \leq 26.878^*$
2	Dip of bedding planes	$-1.669 \leq d_1 \leq 14.621^{ns}$
3	Strike of right joint set (RJS)	$4.862 \leq d_1 \leq 32.566^*$
4	Dip of right joint set (RJS)	$-5.608 \leq d_1 \leq 16.180^{ns}$
5	Strike of left joint set (LJS)	$-18.444 \leq d_1 \leq 9.778^{ns}$
6	Dip of left joint set (LJS)	$-4.353 \leq d_1 \leq 19.209^{ns}$

*) significant; ^{ns}) not significant

CONCLUSION

The application of multivariate analysis of difference between two means to study the responses of rock-discontinuities to faults was examined, which leads to the delineation of the occurrence of the faults. This statistical test procedure was employed to discontinuity data taken from the sites at which a previous structural geologic study has been undertaken by many geologists.

The result of the statistical test for discontinuity samples taken from Study Area 1 showed that bedding plane is not affected by the reversed fault, otherwise strikes of both left and right joint sets (RJS and LJS) are significantly affected. This phenomenon suggests that both RJS and LJS in uplifted rock-block were still affected by the folding process after reversed movement of the fault.

Then, in Study Area 2, the respective intervals (Table 4) lead to the conclusion that means of strike of bedding planes and right joint set (RJS) significantly differ as a result of left lateral-slip fault (sinistral slip fault). This left lateral slip movement certainly moved along a fractured or jointed zone consisting of parallel left joint set (LJS). Therefore, the means of strike and dip of the LJS between the two moving rock-blocks do not differ.

Application of this kind of statistical test has also been successfully examined by the author to verify the active tectonic control on the development of morphometry of drainage basins in area of distribution of different lithology, but in a same domain of tectonic control (Hirnawan, 1997). Two groups of morphometry samples were taken from two areas in which Tertiary sedimentary rocks and the uncorformably overlying Quaternary volcanic products occur respectively. This test verifies how far did the active tectonics affect the frequency of rock discontinuity and thus contribute to the development of morphometry of the drainage systems in a different kind of lithology, of which this phenomenon exhibits the neotectonism.

As the areas of the present study are located at northern West Java, in which neotectonic activity is significant as well as at south-eastern West Java exhibited by the above-mentioned overlying Quaternary deformed volcanic deposits (Hirnawan, *et al.*, 2010), this study on the underlying Tertiary sedimentary rock formations at least has contributed to the explanation of the mechanism and the intensity of deformation of the formations by the active tectonics. This study has given the explanation how intensively did the deformation work on the underlying formations and it continued later on the overlying Quaternary rock formations in the vicinity after the origin of the unconformity in the next tectonic period.

ACKNOWLEDGEMENT

I wold like to thank to Mr. T. Noorchoeron and Mr. T. Widodo, alumni of the former Geology Department, University of Padjadjaran for their assistance.

REFERENCES

Billing, M. 1986. Structural geology. New Delhi: Prentice Hall of India Private Ltd.

De Sitter, L.U. 1956. Structural geology. London: McGraw-Hill Book Co. Inc.

Hill, E.S.. 1972. Elements of structural geology. London: Chapman & Hall Ltd. & Science Paperbacks.

Hirnawan, R.F. 1987. The effect of reversed fault on strike/dip of bedding planes and joints in Halang Formation in Bantarujeg, West Java. RISET – Geologi dan Pertamb. 8(2):31- 40.

Hirnawan, R.F. 1997. The characteristics of morphometry of drainage systems in area of distribution of different lithology in the same domain of active tectonic control. BPPT Analisis Sistem. IV(9): 66-67.

Hirnawan, F., Muslim, D., & Sukiyah, E. 2010. A measure of intense active tectonism through manifestation of river basin morphometry development on Quaternary volcanic deposits: Case study at Ciremai and Slamet Volcanoes. Proceeding of the XXIV FIG International Congress on geodetic survey, Sydney, Australia, April 11-16.

Kramer, C.Y. 1972. A first course in multivariate analysis. Virginia: Virginia Polytechnics Institute & State University.

McClay. 1995. The mapping of geological structures. Geological Society of London Handbook. New York: John Wiley & Sons.

Moody, J.D. & Hill, M.J. 1956. Wrench-fault tectonics. Bulletin of Geological Society of America, 67(9):1207-1246.

Noorchoeron, T. 1996. Strike and dip of bedding plane of rocks and joints, lineaments, and drainage pattern due to reverse fault in Cinangka area, Regency of Majalengka, Province of West Java University of Padjadjaran.

Price, N.J. & Cosgrove, J.W. 1990. Analysis of geological structures. Cambridge: Cambridge University Press.

Rencher, A.C. 1995. Methods of multivariate analysis. New York: Wiley Series in Probability and Mathematical Statistics.